89th Congress
2d Session

COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF WASHINGTON

REPORT

PREPARED BY

THE UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

THE WASHINGTON STATE DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

AND

THE UNITED STATES BUREAU OF RECLAMATION
AND OTHER AGENCIES

AT THE REQUEST OF

Senator HENRY M. JACKSON

CHAIRMAN OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

UNITED STATES SENATE

Printed for the use of the Committee on Interior and Insular Affairs

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1966

55-883 O

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MEMORANDUM OF THE CHAIRMAN

To Members of the Senate Committee on Interior and Insular Affairs:

I am transmitting for your information a report entitled "Mineral and Water Resources of Washington" prepared at my request by the U.S. Geological Survey with the assistance of other Federal and State agencies.

This detailed survey will be particularly helpful to government and business leaders in Washington. The compilation of data will also be of inestimable value to students of the State.

Members of the Congress and particularly the members of this committee, I am sure, will find this information of great value as we consider legislation regarding mineral and water development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

On August 21, 1964, I requested the Secretary of the Interior to determine if a comprehensive summary report on the mineral and water resources of Washington could be prepared for the use of citizens, professional personnel, and government, civic, and industrial leaders interested in mining, water, and industrial development.

This report, prepared in response to my request by members of the U.S. Geological Survey, the Bureau of Reclamation, the Washington State Department of Conservation Division of Mines and Geology with the cooperation of other agencies, is a thorough, detailed, and comprehensive work that I am sure will be of great value to all interested in the fields of mineral and water resources of the State of Washington.

I wish to express my thanks and appreciation to Secretary of the Interior Udall and to each and every one in the Department and in the State, and those with offices elsewhere, who contributed to making this very valuable and comprehensive report.

HENRY M. JACKSON,
U.S. Senator.

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AT THE REQUEST OF

SENATOR HENRY M. JACKSON

CHAIRMAN OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

UNITED STATES SENATE

LETTER OF TRANSMITTAL

DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., October 28, 1965.

Hon. HENRY M. JACKSON,
Chairman, Committee on Interior and Insular Affairs,
U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: In response to your request of August 21, 1964, we are pleased to transmit herewith a summary report on "Mineral and Water Resources of Washington."

The report is the joint effort of the U.S. Geological Survey, the Washington Division of Mines and Geology, and the U.S. Bureau of Reclamation, with important contributions from the Bonneville Power Administration and the Washington State Department of Highways.

The first part of the report describes the geology of the State and presents information on the known and potential mineral resources together with the outlook for future developments. All the mineral commodities known to occur in commercial or near commercial amounts are discussed.

A second part of the report deals with the State's very important resources of water. The quantity, quality, and distribution are outlined for both surface and ground water. The various uses for these vast resources are considered, together with suggested developments of their potential as municipal water supply, for generation of hydroelectric power, irrigation, and for the many additional requirements of a growing economy. Plans for projects intended to meet anticipated water requirements are summarized.

It is hoped that data in this report will be adequate to supply the information you desire.

Sincerely yours,

J. CORDELL MOORE,
Assistant Secretary of the Interior.

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INTRODUCTION AND SUMMARY

This report describes the mineral and water resources of Washington. Its purpose is to bring together in summary form authentic and up-to-date information on the State's resources of minerals and water. The report is based principally on published data on the geology and mineral and water resources of Washington but has been supplemented by information in the files of the United States Geological Survey and the Washington Division of Mines and Geology. It contains, in addition, information derived from the personal observations of many of the authors of individual sections of the report and, consequently, includes considerable information not previously available in published form. It is hoped that the material herein presented will be useful to the professional as well as to the nonprofessional who is, for one reason or another, interested in the State's resources.

In introductory chapters the geology of Washington is summarized, and a brief résumé is given of the mineral industry and its relative importance in the economy of the State. In succeeding chapters all the mineral resources known to occur in the State in commercial or near-commercial quantities are discussed. The use, manner of occurrence, distribution, and outlook for each of these resources are considered. Where available, production statistics are included.

A second part of the report deals with the State's very important resources of water. The quantity, quality, and distribution of surface and ground water resources and their use for municipal water supply are considered. In a separate chapter, developed and potential resources of hydroelectric power are discussed. A final chapter is concerned with water resource development exclusive of that dealing with hydroelectric power and municipal water supply.

This report is a joint effort of the United States Geological Survey, the Washington Division of Mines and Geology, and the United States Bureau of Reclamation, with important contributions from the Bonneville Power Administration and the Washington State Department of Highways. A. E. Weissenborn, United States Geological Survey, served as editor, assembled the various sections of the report, and coordinated the efforts of the many authors who contributed to the report. Marshall T. Huntting, Supervisor of the State Division of Mines and Geology, arranged for the participation of the various authors from State agencies. L. B. Laird, United States Geological Survey, coordinated the preparation of that part of the report concerned with water resources, and Gilbert V. Schirk, United States Bureau of Reclamation, was responsible for the preparation of the chapter on water resources development.

MINERAL AND WATER RESOURCES OF WASHINGTON

SECTION 1

GEOLOGY AND MINERAL RESOURCES

PREPARED BY

THE UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

THE WASHINGTON STATE DEPARTMENT OF CONSERVATION

DIVISION OF MINES AND GEOLOGY

WITH A CHAPTER ON SAND AND GRAVEL

BY THE

WASHINGTON STATE DEPARTMENT OF HIGHWAYS

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SECTION I

GEOLOGY AND MINERAL RESOURCES

GEOLOGY

INTRODUCTION

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Washington is familiarly known as the Evergreen State, but it might as aptly be termed the Land of Contrast. Within the State, rainfall varies from more than 200 inches annually in the Olympic Mountains to less than 10 inches in parts of eastern Washington. The lush forests of northern and western Washington contrast sharply with the barren, forbidding scablands of central Washington and the treeless wheat fields of the Palouse Hills; the towering, rugged Cascades contrast with the coulees and flat, basalt-covered mesas of central Washington and the level farmlands in the Puget Lowlands north of Seattle; the snow-capped volcanoes that crown the Cascades contrast with the magnificent beaches that stretch for miles along the Pacific Coast.

Washington's 68,192 square miles fall into seven distinct physiographic divisions. These are the Okanogan Highlands, the Columbia Basin, the Blue Mountains, the Cascade Mountains, the Puget Lowlands, the Olympic Mountains, and the Willapa Hills (fig. 1). Each of these areas differs from the others in climate, topography, and the natural resources that are available within it. These differences profoundly influence the economic life of the more than 2.8 million people who live within the boundaries of the State. These differences, in turn, are in very large part but a reflection of differences in the geology of each area. Natural resources and geology walk hand in hand. Therefore this volume, which discusses the mineral and water resources of Washington, begins with a summary of the geology of the State.

Our knowledge of the geology of Washington is derived from the findings of many geologists working over a period of many years, beginning back in the 1880's when Washington was still frontier country. Some of the early work of the U.S. Geological Survey was done in Washington, and geological mapping by this organization is still going on in many places in the State. The State of Washington Division of Mines and Geology—and its predecessor, the Washington Geological Survey—has actively been engaged in studying the geology and mineral resources of the State since the early 1900's and has produced a wealth of knowledge. Work done under the auspices of the University of Washington, Washington State University, and other universities has made important contributions to the knowledge of the geology, particularly in the Cascade Mountains.

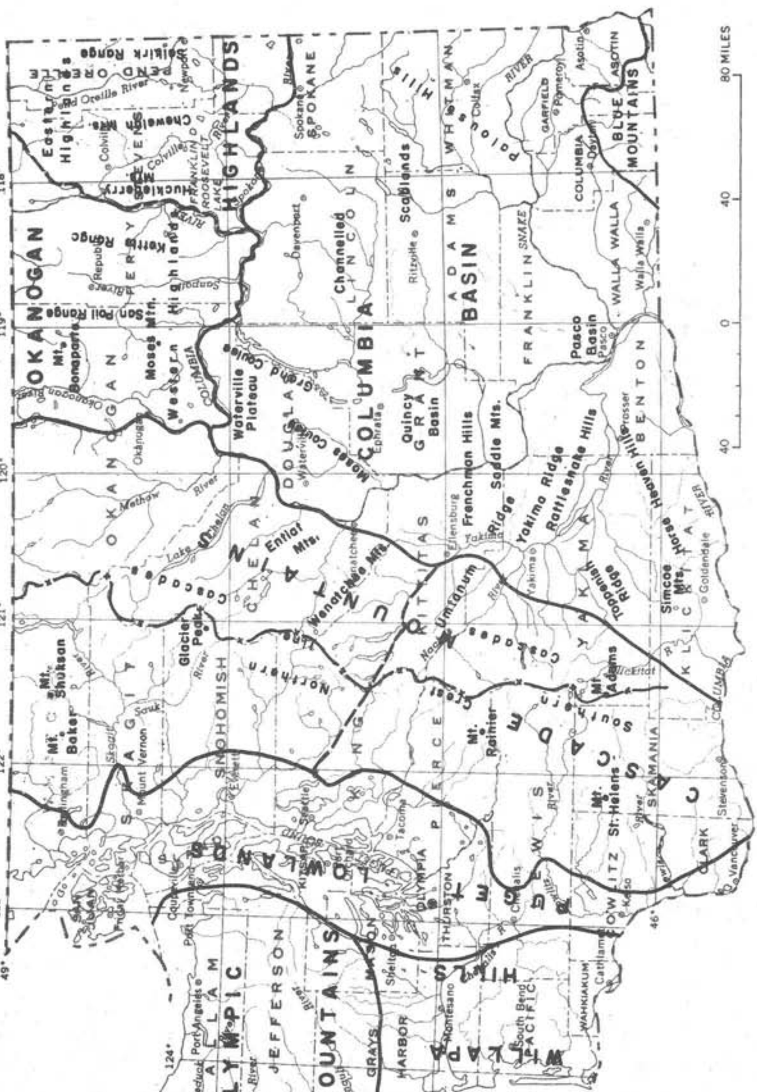

FIGURE 1.—Physiographic divisions of Washington.

Geologists from industry, searching for metallic and nonmetallic minerals as well as petroleum and natural gas, have likewise made many contributions to our knowledge of the geology of the State. Figure 2 shows the areas in the State covered by published geological maps from all sources. A number of other areas have been mapped geologically. Figure 2, however, includes only published geological mapping and does not include a considerable amount of work that has not yet been published.

Although there are a few critical areas where geological information is almost completely lacking, figure 2 indicates that the greater part of the State has been mapped geologically. However, published maps, on what by modern standards would be considered an adequate scale, are available only for the much smaller stippled areas of figure 2. Clearly, much remains to be done before it can be considered that the geology of the State is adequately known—or even as adequately known as that of its neighboring States.

Topographic maps are essential for many purposes such as recreational, industrial, and highway construction but are especially essential as bases on which to plot the geology and other data. Figure 3 shows the areas in the State which have been mapped topographically. Some critical areas from the standpoint of mineral and water resources still lack topographic maps, but because of intensive work during the past few years topographic map coverage for most parts of the State is well advanced—far ahead of the geologic mapping.

The following discussion of the geology of Washington is divided into four sections: northeastern Washington; the Columbia Basin, including the Blue Mountains; the Cascade Mountains; and western Washington. The geology of each of these sections is summarized with the intent of providing a background for the remainder of the report. As with other sections, bibliographic references are given for the benefit of those readers who wish more detailed information than can be included in these necessarily brief accounts. As an aid in following the geological discussion, the reader is referred to figure 4, a highly generalized map of the geology of Washington.

NORTHEASTERN WASHINGTON

(By R. G. Yates, U.S. Geological Survey, Menlo Park, Calif.)

Northeastern Washington, as defined here, includes Pend Oreille, Stevens, Ferry, eastern Okanogan, and northern Spokane Counties. It comprises less than 15 percent of the State's area, but from its mines comes over 90 percent of the State's metal production. It is, therefore, not surprising that the geologic setting of this part of the State is uniquely different from that of the remainder. Mountainous in character, it contrasts sharply with the smooth undulations of the Columbia Plateau to the south, but much less sharply with the higher and more rugged Cascade Mountains, which lie to the west. Likewise, its geology merges with the geology of the Cascades, but contrasts strongly with that of the Columbia Plateau.

This area, which lies east of the Okanogan River and north of the west-flowing stretch of the Columbia and its tributary, the Spokane,

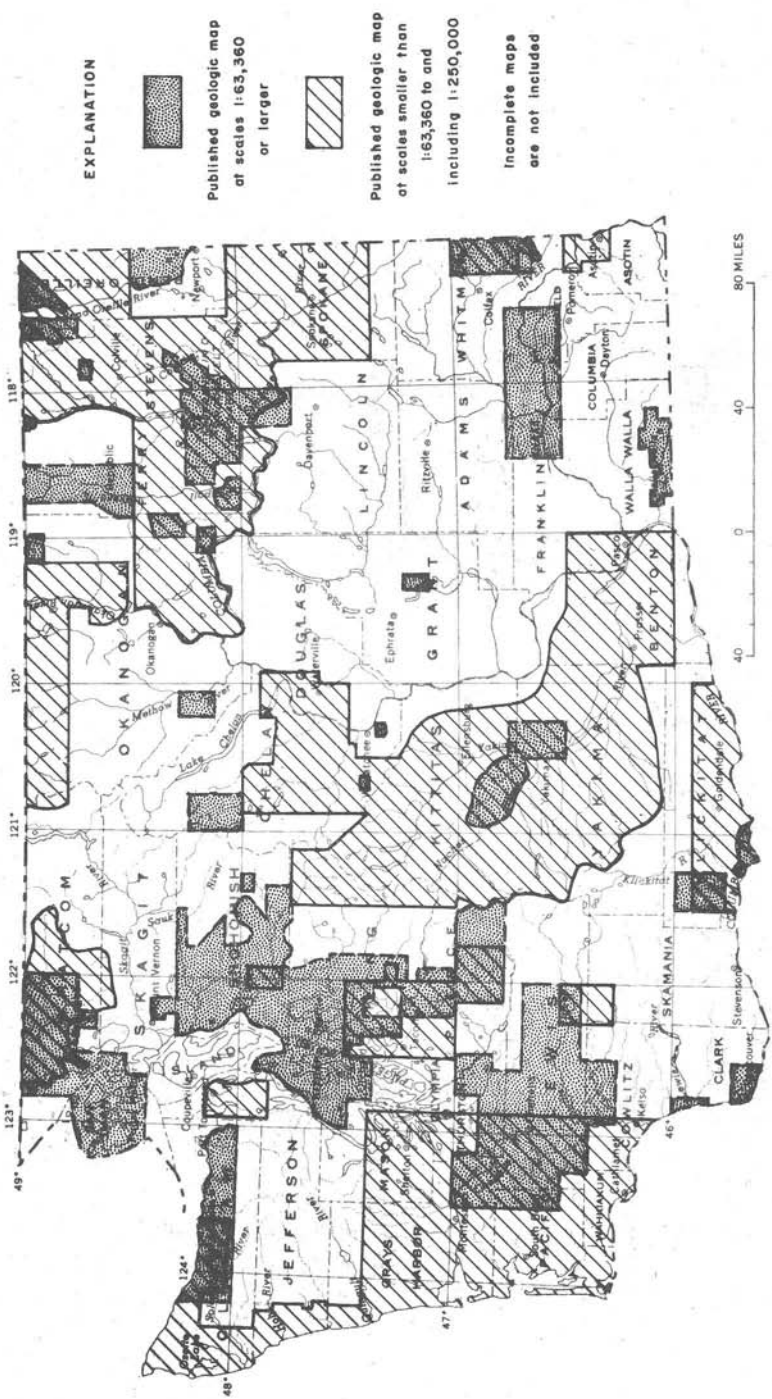

FIGURE 2.—Published geologic mapping in Washington.

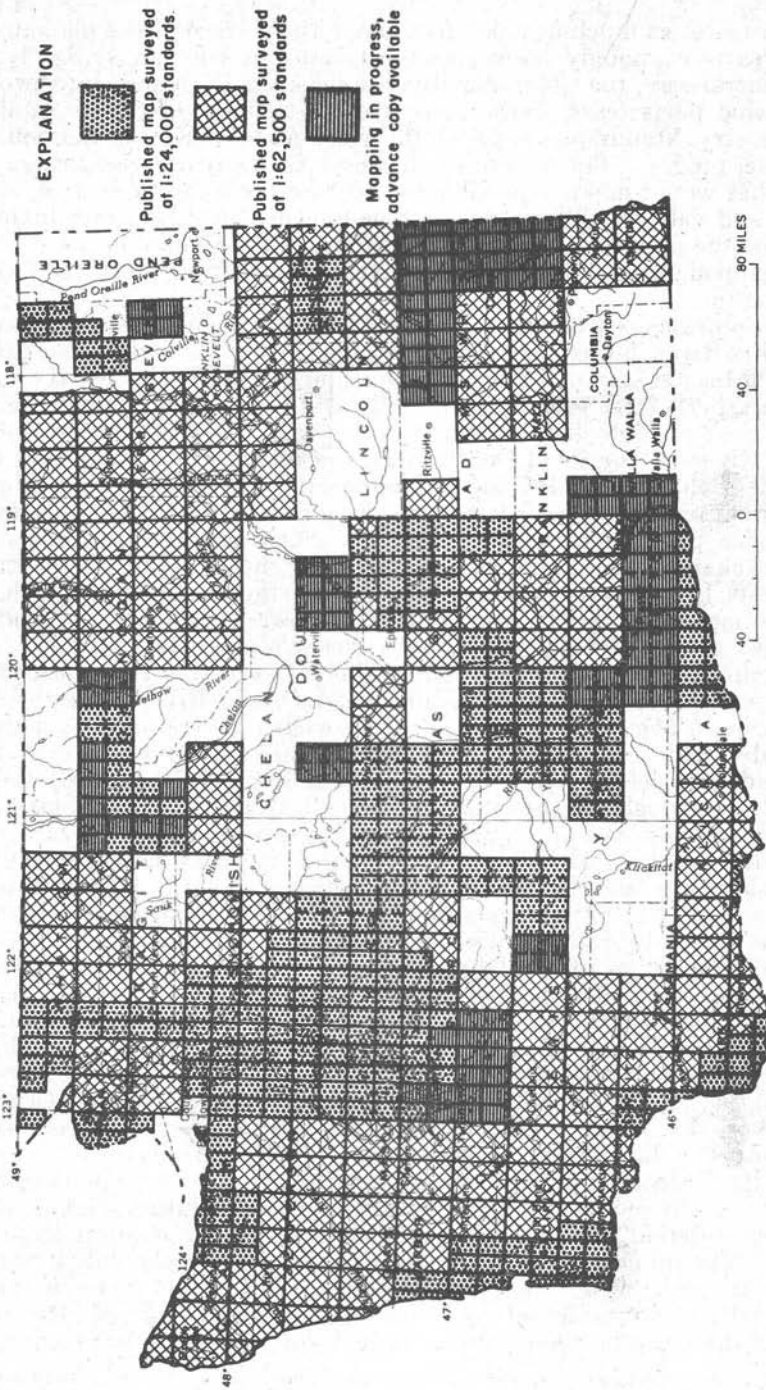

FIGURE 3.—Status of topographic mapping in Washington.

in places rises as much as 5,000 feet above the surface of the plateau. The area is commonly known as the Okanogan Highlands (fig. 1). In a general way, the Columbia River divides the Highlands into two geographic parts: east of the river are the Selkirk, Chewelah, and Huckleberry Mountains; west of the river are the Kettle, Sanpoil, and other ranges. The mountains, however, lack any orderly arrangement that would make it possible to separate them into a system of ranges and valleys. They appear to be crowded together, with little room for the narrow, south-trending valleys of the Columbia, Okanogan, Sanpoil, and Pend Oreille Rivers that drain northeastern Washington.

All the drainage from the area reaches the Pacific Ocean via the Columbia River, but some tributaries follow rather devious courses to reach the master stream. The Okanogan and Sanpoil Rivers behave as normal, orderly streams and flow directly south to join the Columbia in the shortest possible distance. But not so with the Pend Oreille and Kettle Rivers. The Pend Oreille swings northward in a wide arc to join the Columbia in British Columbia; the Kettle also selects a very circuitous route, as if it were making great—but futile—efforts to avoid a junction with the Columbia. Such irregularities reflect, in part, changes in the drainage pattern brought about by the great ice sheets that advanced southward during the Pleistocene epoch. The ice moved down the river valleys in great lobes that grew and coalesced to form a thick sheet that covered almost the entire area. As the climate warmed, the ice retreated northward, and lakes formed in the valleys of the Columbia and Pend Oreille Rivers and their tributaries. The melt waters of the swollen rivers, milky with suspended clay and fine silt, swept southward the sand and gravel that had been left by the ice, to deposit it and the suspended clay and silt in the slack waters of the lakes. Deposits of horizontal-layered silt, clay, and sand on the lower slopes of the valleys preserve the outlines of these ancient lakes. Near the International Boundary, terrace features indicate that the last high level of the lake in this valley was at an elevation of about 2,000 feet. The numerous steplike terraces along the valley walls of the Columbia River represent successive lower levels of the lake or lakelike river that succeeded the lake. The higher slopes and even the peaks near the Canadian border likewise were covered with the wastes of the glaciers; even today, deposits of gravel and sand, from a few to several hundred feet thick, and stray exotic boulders cover more than half the area of the mountain slopes. This extensive cover of ice-transported material greatly handicaps the interpretation of the bedrock geology, as well as increasing the difficulty of the discovery of mineral deposits.

Enough bedrock does extend through this mantle to demonstrate clearly that the sedimentary rocks in the eastern Okanogan Highlands record a different geologic history from those in the western Highlands.[1] The difference is not only in the age of the rocks, but in the conditions under which they accumulated. The oldest rocks in the State with well-established ages are east of the Columbia River. Most of these can be demonstrated to lie below the rocks that contain

[1] This division of two different groups of rocks, one in the eastern and the other in the western Okanogan Highlands, is only a broad generalization. The boundary between the two groups only approximates the course of the Columbia River. From the mouth of the Spokane River to Evans it is a few miles east of the river; from Evans to Northport it is west of the river; and from Northport to the International Boundary it is again east of the river.

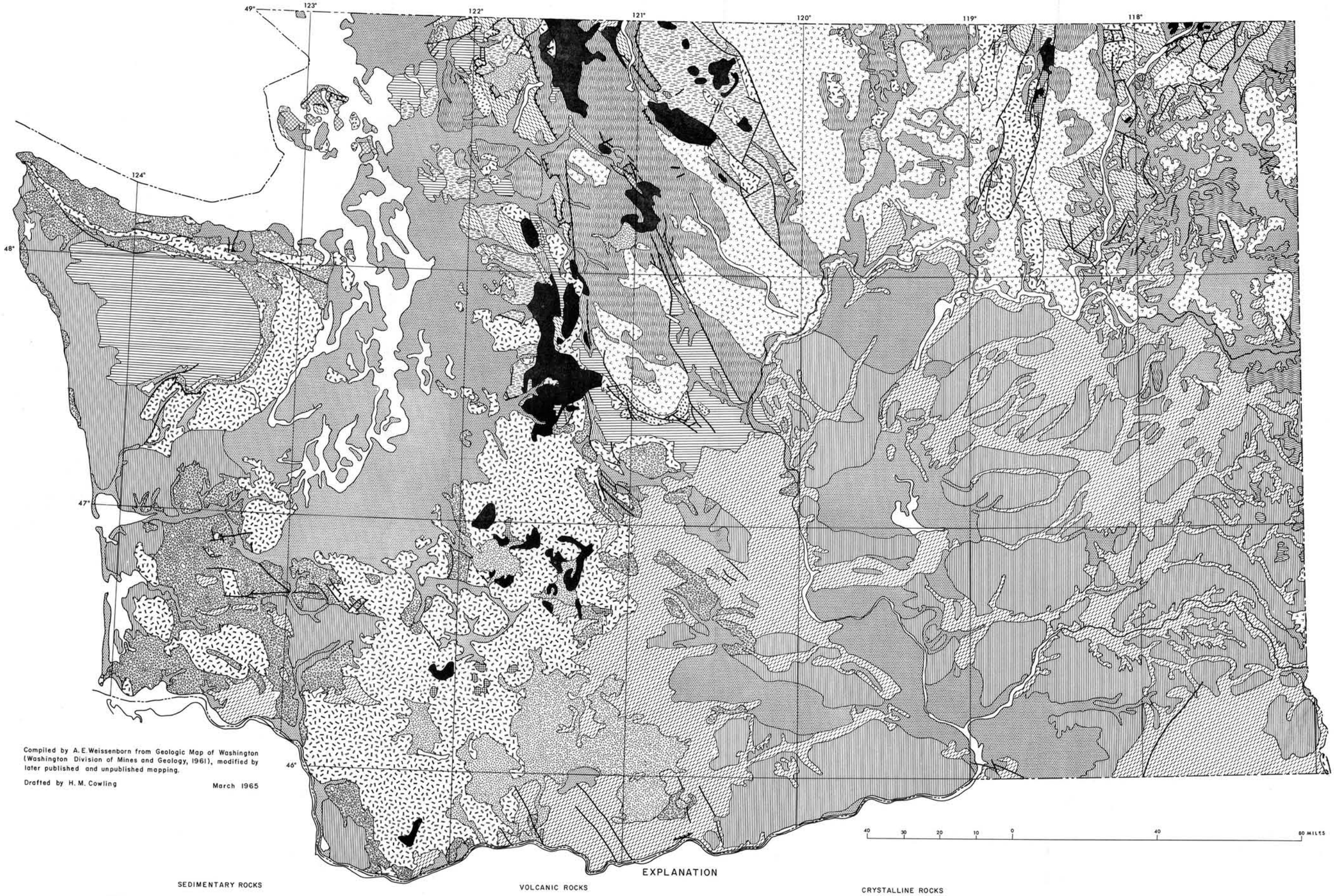

FIGURE 4.—Geologic map of Washington.

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fossils of Early Cambrian age. (The Cambrian is the earliest period of geologic time that can be identified by the kind of fossilized life preserved in the rocks.) These older rocks are of four categories: (1) Belt Series rocks, which are widespread in Idaho and Montana, (2) rocks similar to, but not identical with, the Belt Series, (3) rocks younger than the Belt Series, but older than Cambrian in age, and (4) gneisses of unknown Precambrian age. The Belt Series consists mainly of quartzite, argillite, and impure dolomite that were deposited in a slowly sinking basin whose western limit was probably somewhere in eastern Washington. They are not known to occur more than a few miles west of Pend Oreille County (Schroeder, 1952). Rocks that may be contemporaneous with the Belt Series occur in a south-southwest-trending belt near Chewelah and contain the famous magnesite deposits (Bennett, 1941; Campbell and Loofbourow, 1962; Campbell and Raup, 1964). The names of these formations are shown on figure 5. These are similar to Belt rocks in many respects but have more argillite and less quartzite; they may be representatives of an otherwise little-known part of the Belt depositional basin. Rocks of category 3 (Park and Cannon, 1943; Campbell and Raup, 1964), known in southern British Columbia as the Windermere Series, are a sequence of thick conglomerates and basaltic lavas that rest on the eroded edges of the older Precambrian rocks. Rocks of category 4 occur in the southeastern part of the area north of Spokane. Opinions differ on the age of these gneisses; some believe they are Belt rocks that were metamorphosed at depth under high temperature and pressure and have since been elevated to their present position by faulting; others believe they are very ancient rocks, much older than the Belt rocks, and form the basement upon which the Belt rocks were deposited.

In the eastern Highlands, all periods of the Paleozoic Era are represented by marine sedimentary rocks. The general sequence of Cambrian deposition began with sandstone (now quartzite), followed by shales (phyllites), limestones, and dolomites (Campbell and Raup, 1964; Campbell, 1947; Park and Cannon, 1943; Yates, 1964) (fig. 5). The Cambrian limestones and dolomites are hosts to the important lead-zinc deposits of Pend Oreille and Stevens Counties. By the beginning of the Ordovician Period, the carbonate deposition of the Cambrian had ended abruptly, and black muds, which were to become slates and argillites, were deposited over a wide area. The deposition of these black muds continued through the Ordovician, Silurian, and Devonian Periods, and very likely into the Mississippian (Dings and Whitebread, 1965). During Devonian time, conditions in the sea changed enough locally to permit the growth of reef-building organisms that resulted in the formation of lenses of limestone. These are found in northern Pend Oreille County in the Metaline area (fig. 5). Once again—probably during the Mississippian Period, and also in the Metaline area—the deposition of black muds was interrupted, and beds and lenses of coarse angular pebbles and cobbles were deposited. This change in sediments indicates a change in the character of the source area from which they were derived. In this case, a not-too-distant part of the sea floor was uplifted to a position where it could be eroded.

This is essentially the end of the record of Paleozoic deposition in the eastern Okanogan Highlands. For the record of the younger rocks

Republic area[1]		
Quaternary	Unconsolidated glaciofluvial deposits	
Miocene(?)	Klondike Mountain Formation	Basalt flows
		Volcanic conglomerate, breccia, and sandstone
Oligocene		Tom Thumb Member "lake beds"
Eocene	Sanpoil Volcanics	
	O'Brien Creek Formation--tuffs and conglomerate	
Permian	Greenstone, graywacke, argillite, and phyllite	
Pre-Permian	Phyllite, schist, and marble	

Northern Pend Oreille County (Metaline quadrangle)[2]	
Pleistocene	Glacial deposits
Tertiary	Tiger Formation (conglomerate and shale)
Devonian	Limestone and shale
Silurian	Slate
Ordovician	Ledbetter Slate
Cambrian	Metaline Limestone
	Maitlen Phyllite
	Gypsy Quartzite
	Monk Formation (phyllite)
?	
Precambrian	Leola Volcanics
	Shedroof Conglomerate
	Priest River Group (Belt Series?) (phyllite and quartzite)

Southern Stevens County (Hunters quadrangle)[3]	
Quaternary	Glacial deposits
Tertiary	Gerome Andesite
Early Mesozoic(?)	Covada Group (greenstone and graywacke)
?	
Paleozoic	Slate and siltite
	Chert
?	
Ordovician	Limestone and slate
	Chert
Cambrian	Old Dominion Limestone
	Addy Quartzite
Precambrian	Huckleberry Formation (greenstone and conglomerate)
	Buffalo Hump Formation (argillite and quartzite)
	Stensgar Dolomite
	McHale Slate
	Edna Dolomite
	Togo Formation (argillite)

1/ Generalized after S. Muessig (1959).

2/ Modified after Park and Cannon (1943).

3/ Campbell and Raup (1964).

FIGURE 5.—Stratigraphic names in common use in northeastern Washington.

(Becraft, 1964; Campbell and Raup, 1964; Mills and Davis, 1962; Muessig, 1959; Parker and Calkins, 1965, Staatz, 1964; Waters and Krauskopf, 1941), we must go to the western Highlands, where fossils identify rocks that range in age from Mississippian to Cretaceous (fig. 5). The rocks in this section were also deposited in marine waters but under quite different conditions. They accumulated in an area of active volcanism, where the earth's crust was unstable and depth of water and shapes of the basins of deposition were constantly changing. Such an environment is known as eugeosynclinal and is identified by the distinctive group of rocks that accumulate within it. These rocks are graywackes (dark-colored "dirty" sandstones), lenses of thin-layered chert, beds of conglomerate, small pods and reeflike bodies of limestone, and lava flows and tuffs (fragmental volcanic material) of basaltic and andesitic composition.

The boundary between this eugeosynclinal assemblage of rocks and the older nonvolcanic Paleozoic rocks to the east appears to be everywhere a fault boundary; consequently, the depositional relations between these two groups of rocks have not yet been observed. It is probable, however, that the rocks west of the Columbia River are also underlain by older Paleozoic rocks that are very likely quite different from those exposed east of the river.

The interval of time between the middle of the Jurassic and the middle of the Cretaceous Periods, about 65 million years, is without a sedimentary record in northeastern Washington. During this time the rocks of Jurassic and earlier age were folded and faulted, and were also invaded, thousands of feet below the surface, by great masses of molten rock that slowly crystallized to form the granitic batholiths. After the batholiths had congealed into masses of coarsely crystalline rock, all of northeastern Washington was elevated, and as it was elevated it was eroded. Erosion was vigorous enough to expose the batholiths before the end of the Cretaceous Period.

This elevation or uplift of northeastern Washington was doubtless far from uniform. In early stages of the uplift, the earth's outer crust was cracked and broken into fault blocks. Some blocks were elevated more rapidly than others; these became mountains, and other blocks that were elevated less rapidly became temporary storage basins for the waste that was being shed from the "mountain blocks." Some of this waste is as old as the Late Cretaceous and is largely pebbles, cobbles, and boulders of the rock types no longer occurring in the area. The differential movement of the basin blocks was accompanied by the migration of molten rock, or magma, which, moving upward along the faults, reached the surface and spread out as lava flows that accumulated on the floors of the basins.

One of these "collecting basins" is the Republic graben (Staatz, 1960), an elongated downfaulted block that extends from Nespelem to Danville. This graben, which began to be filled early in the Eocene, has a well-preserved record of early Tertiary events. One of the later Tertiary events was the formation of the gold deposits of the Republic and Orient districts. The first material added to the graben was coarse gravel and boulders derived from the highlands on either side of the graben. These were buried by great thicknesses of lavas of intermediate composition, which in turn were covered by fine-grained sediments deposited in temporary lakes within the graben and then by still more lava flows and fragmental volcanic rocks. All

in all, these lavas, tuffs, and lake sediments have a thickness in excess of 15,000 feet. Since it is extremely unlikely that these rocks accumulated in a gorge 15,000 feet deep, it can be confidently inferred that the graben floor subsided as they accumulated. Some magma, intruded during the late stages of graben growth, never reached the surface, but forced aside the early deposited lava flows and crystallized as granitic rock. The volcanic activity in the downdropped blocks appears to have ended before Miocene or late Pliocene times, when basalts of the Columbia Plateau lapped up on the south edge of the area.

The mountain-building and igneous activity that began in the Middle Jurassic and continued into the early Tertiary left a pattern firmly impressed in the rocks. In the eastern Okanogan Highlands, the layered rocks were tightly bent into folds whose axes trend northeasterly and extend into British Columbia, where they gradually change their trend to merge with the northwesterly continental trend. This belt of northeast-trending folds is called the Kootenay Arc. As these rocks were folded, they were also faulted along northwesterly directions as well as along the northeasterly trend of the folds. In the eastern part, the folding ceased before the Cretaceous granitic rocks were intruded, but farther west in the Okanogan Valley folding appears to have accompanied intrusion. By the end of the Cretaceous Period, the compressive stresses that produced the folds in northeastern Washington appear to have terminated, although they continued to the west in the Cascade Mountains. The folds in the western Okanogan Highlands are of northwesterly trends, conforming with those in the northern Cascades but contrasting with the northeasterly trends of the Kootenay Arc. Folds of both northeast and northwest trends, as well as intermediate north trends, occur in the valley of the Columbia River.

The information used in compiling this résumé of the geology of northeastern Washington was drawn largely from published reports on individual areas. The references cited are far from a complete bibliography, but were selected to give the interested reader an opportunity to expand his knowledge of the area from a fair sample of the more recent or more easily available published reports.

COLUMBIA BASIN

(By A. B. Griggs, U.S. Geological Survey, Menlo Park, Calif.)

In Washington the Columbia Basin occupies most of the area east of the Cascade Range to the Idaho border and south from the east-west course of the Columbia River and its tributary, the Spokane River, to the Oregon border. The Basin province encompasses all of this southeastern part of the State except for the southeast corner, where the Blue Mountains extend northeastward into Washington. Flows of basaltic lava flooded this entire area on a grand scale, forming a lava plain that has been modified by regional downwarping, so that it now has the general aspect of a structural basin centered in the Pasco area. On the west, north, and east the basin area is ringed by mountainous country; to the south it continues for many miles into Oregon. At the margins the top of the basalt lies between altitudes

of 2,500 and 3,000 feet, except where arched into ridges, and from these margins the terrain slopes toward the Pasco Basin, where the low point is about 400 feet above sea level and the top of the buried basalt is about 200 feet below sea level. Much of the drainage is controlled by these centripetal slopes. Marked exceptions are the two major streams, the Columbia and Snake Rivers, upon whose courses the surface configuration has had little or no effect. The western side has been significantly modified by the arching of the flows into a series of west- to northwest-trending anticlinal ridges. These attain heights of more than 1,500 feet above the adjacent valleys and are as much as 100 miles long. The more prominent of these are the Horse Heaven Hills, Rattlesnake Hills, Saddle Mountains, and Frenchman Hills.

The Blue Mountains are part of a mountainous complex making up a separate geomorphic province that lies mostly within northeastern Oregon. Within Washington the Blue Mountains are a broad northeast-trending, basalt-covered, anticlinal arch which attains altitudes over 6,000 feet. These mountains are now mostly a region of deep, rugged canyons which in places have cut through the basalt to the underlying rocks. The canyons are separated by narrow, flat-topped basalt ridges and are in considerable contrast to the lower rolling hill surface of the plateau area to the north and west. Because they occupy only a small area of Washington, the Blue Mountains are discussed here with the Columbia Basin.

The absence in the Columbia Basin of any exposures of prebasalt rocks, except around the periphery, is indicative that the early flows spread out over a terrain of only moderate relief. The flows slowly covered larger and larger areas encroaching on the surrounding mountains, and as they built up, numerous drainage channels were dammed and lake and stream sediments accumulated in an interfingering relation with the flows. As the accumulation of basalt flows became thicker, general subsidence of the area began and continued intermittently, probably even to the present. After the basalt eruptions ceased, the group of anticlinal ridges of northwest to west trend formed along the western side of the basalt plain. Starting before, and continuing as the ridges developed, volcanic debris was washed down from the Cascade Range to blanket the western margin and then partially fill the low areas between the ridges (Waters, 1955). At the same time, warping at other places formed local basins and broad arches. By Pleistocene time, several of these basins had subsided sufficiently that sediments began to accumulate in them. Contemporaneously and continuing to the present, prevailing southwesterly and westerly winds picked up the fine sediments exposed at the surface in these basins, as well as material from other sources, and transported them eastward to form the loess deposits that mantle much of the Columbia Basin. Late in the Pleistocene glacial period, an ice lobe advanced down the Okanogan Valley and onto the Basin to the south. This dammed the Columbia River and caused its water to flow southward across the Basin, first forming one channel, then another—the greatest of which is Grand Coulee. Toward the end of this glacial epoch, tremendous floods of water swept west and south across the region from near Spokane, and cut a maze of anastomosing channels through the loess and into the basalt and dumped great loads of debris in low areas (Bretz, 1959).

In the central part, the older rocks are completely covered; only around the periphery do they rise above the top of the lava surface as islands, or extend as partially buried ridges out from the edge of the mountains. These hills and ridges are most numerous in the northeast corner of the Basin and along the Washington-Idaho border. Those south and east of Spokane along the border are made up almost entirely of slightly metamorphosed sedimentary rocks of the Precambrian Belt Series, a group made up predominantly of argillite and quartzite. They are only the western outliers of this great series which forms the bedrock of much of northern Idaho and western Montana. Radiometric dating indicates an age of about 1,200 million years. Metamorphosed volcanic rocks, called greenstones, and some interlayered marine sedimentary rocks of Permian and Triassic age crop out within the Snake River canyon and in the canyon of the Tucannon River in the southeastern part of the State. Well-foliated gneiss and schist that are intruded by granitic rocks underlie the prominent ridges at the edge of the Columbia Basin east and north of Spokane. The gneiss and schist may be recrystallized parts of the Belt Series, or may be of even greater antiquity. Scattered low hills of prebasalt rock that rise above the basalt surface at intervals for almost 30 miles west from Spokane are made up mostly of Paleozoic sedimentary rocks. Granitic rocks that have intruded and metamorphosed the sedimentary group make up a smaller part of these hills. Westward beyond this, outliers of older rock are absent within the Basin, except within Grand Coulee. The basalt flows lap up on the north upon granite and a variety of metamorphic rocks on the west to the Cascade Range. Along most of the eastern border of the Cascade Range, the basalt flows lap over older volcanic rocks and continental sedimentary deposits.

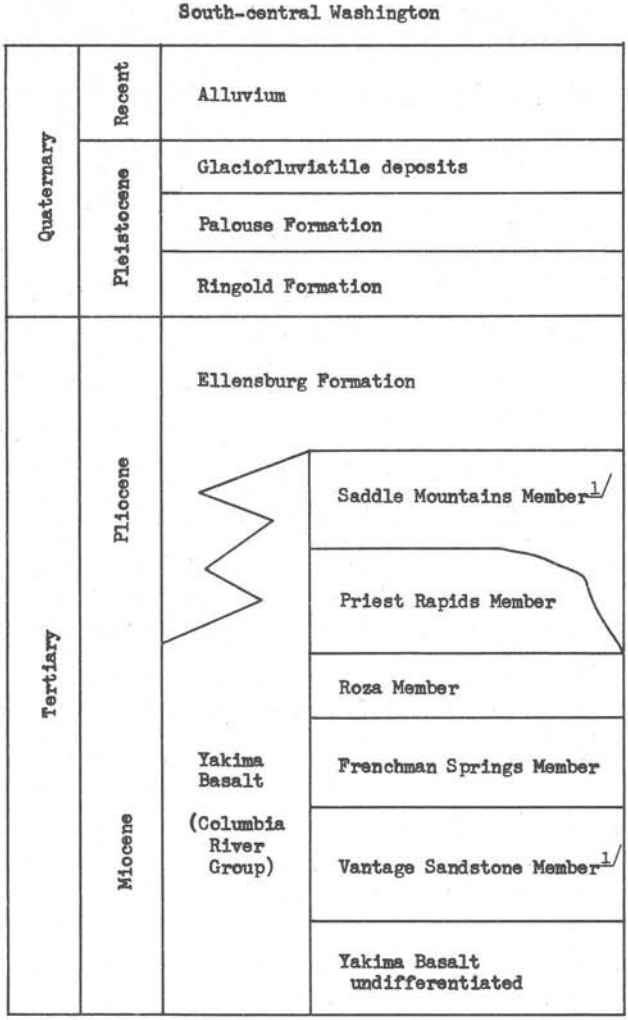
The basalt under the Columbia Basin collectively is called the Columbia River Group. It is a dense, black, hard rock, which is dominantly crystalline but may contain as much as 50 percent glass. Individual flows are usually from 50 to 150 feet thick and are of great lateral extent, commonly having spread out over tens of miles or more. J. W. Bingham and M. J. Grolier (1966, in press) state that one of the most widespread flows in the central part underlies an area of over 20,000 square miles. Maximum thicknesses for the greatest accumulations of flows are around 5,000 feet; these have been found in deep canyons or have been determined from the records of wells. An exploration well in southwestern Lincoln County penetrated through the basalts at 4,465 feet and passed through more than 200 feet of unconsolidated sand and clay before bottoming in quartz latite (A. E. Weissenborn, 1965, written communication). Another well in the Rattlesnake Hills was stopped after penetrating 10,665 feet of volcanic rocks. It is not known whether the entire thickness represents basalts of the Columbia River Group or whether part belongs to an older volcanic sequence. At the peripheries only a flow or so may represent the group, and here pillow lavas (piles of discrete, bulbous masses of lava with glassy selvages) and fragmental tuffaceous aggregates are more common. These were formed where lava flowed into bodies of water. Swarms of basalt dikes, containing rock identical to the flows, have been found at several localities around the eroded margins of the Basin. These dikes (and probably others still concealed in the central part), rather than volcanoes, are

considered to have been the conduits for the basalt. The total period of eruption spanned several million years, starting in the Miocene and continuing into the Pliocene Epoch. Fossil evidence, as well as numerous soil zones between flows, some of them very thick, point to this conclusion.

A division into two distinctive formations based upon stratigraphic position and chemical and mineralogic differences has been made of the Columbia River Group (Waters, 1961b). In Washington the older unit, the Picture Gorge Basalt, may underlie much of the Columbia Basin but is probably exposed only in the very southeast corner along the Grande Ronde or Snake Rivers; all the rest belongs to the younger sequence, the Yakima Basalt. Detailed maping at several localities has indicated the feasibility of delineating single flows or groups of flows, which can be traced over large areas (Mackin, 1961). Figure 6 shows the units delineated and mapped in the west-central part of the Basin in Washington.

Lake and stream deposits now consolidated to siltstone, sandstone, and conglomerate occur at many places around the margins. Most are interbedded with the basalt in layers usually from 10 to 50 feet thick, although locally they may be much thicker. They pinch out away from the margins in relatively short distances. In the vicinity of Spokane these rocks, which also accumulated to a thickness of many hundreds of feet beneath the basalt within the ancient Spokane River valley, are called the Latah Formation (Pardee and Bryan, 1926). At the western margin on the east-central flank of the Cascade Range, andesitic volcanic debris also accumulated on top of the basalt up to a maximum thickness of about 1,000 feet, and these rocks plus the interlayered sedimentary rocks are called the Ellensburg Formation (Smith, 1903b). Plant and animal fossils found in the Ellensburg and Latah Formations and other units of similar relations are from middle Miocene to Pliocene in age and bracket the span of time during which the basalts were extruded.

Beginning in the early part of the Pleistocene Epoch, gravel, sand, silt, and clay began to be deposited in lakes or by aggrading streams in the depressed basins. The largest of these, the Pasco Basin, had over 1,000 feet of material deposited on top of the basalt; most of this is sand and silt and is still relatively unconsolidated (Brown and McConiga, 1960). Other similar deposits accumulated west and north of Walla Walla; west of Lewiston, Idaho; in the Yakima Valley; and in the Quincy Basin (Lupher, 1944). Loess—wind-blown deposits of fine material, mostly silt—blankets much of the Columbia Basin; in places in the east-central part it is more than 200 feet thick. Overlapping, well-developed soil zones within the loess indicate that it has been accumulating through much of the Pleistocene Epoch (Washington State Univ., 1964). Glacial streams and the great floods denuded about a third of the northeastern part of the lava plain of its loess cover. The source of the floodwaters was glacial Lake Missoula, from which as much as 500 cubic miles of water was suddenly released with the failure of ice dams at the mouth of the Clark Fork Valley at Pend Oreille Lake (Pardee, 1942). These floodwaters are believed to have swept southwestward across the Columbia Basin in periods measured in days, denuding great tracts of their loess cover and cutting channels and rock basins in the basalt (Bretz, 1959). The floodwaters breached numerous divides, and the resulting



[1] Of Mackin, 1961.

FIGURE 6.—Stratigraphic column for Columbia Basin in south-central Washington (after Bingham and Grolier, 1966, in press)

denuded, anastomosing channel network is called the Channeled Scabland. (See fig. 7.) Constructional bars within the channels and accumulations of sand and gravel within the basins and at other places in the region were deposited by the floodwaters. These flood deposits have only a thin veneer of loess, which is indicative of their recentness.

The most valuable resource of the Columbia Basin is the loessial soils that make it one of the great grain-producing regions of the world. Clays, both residual and transported, which formed from the weathering of granitic rocks and basalt along the eastern margin of the State, are used for making refractory and common brick, and also

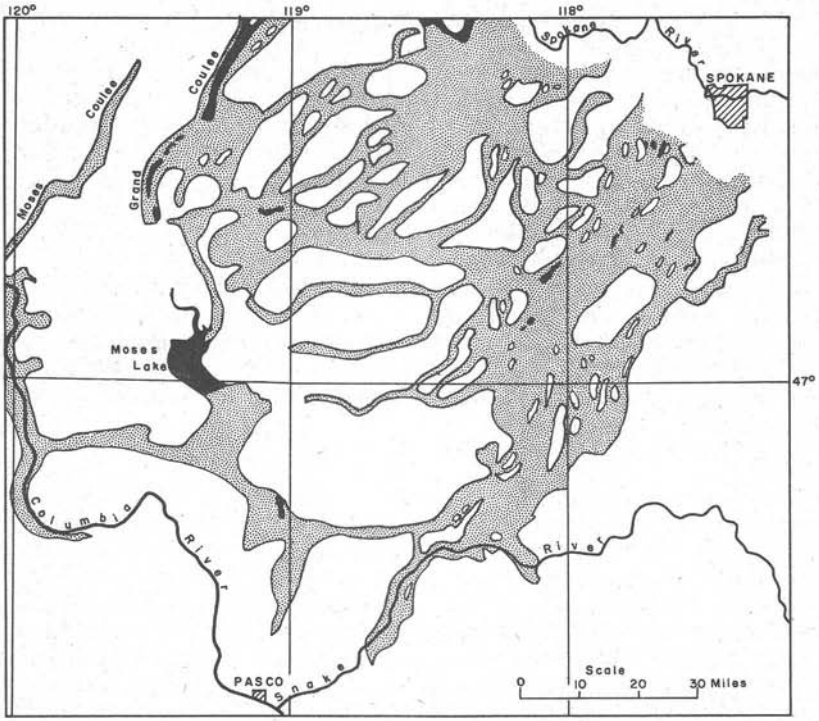


FIGURE 7.—Map of Channeled Scabland of eastern Washington (after Bretz 1959). Shaded areas are the channelways denuded down to or into the basalt, in which are scattered many deposits of gravel and sand. The islandlike areas between channels and to the east are loess mantled. Black areas are lakes.

are a potential source of alumina. The upper, more vesicular and fractured parts of some basalt flows, and some of the more sandy interbeds between flows, make good aquifers, which are the principal source of ground water in the Basin. With basalt outcrops only a short distance from any locality, good road metal is abundantly present all over the region, and sand and gravel deposits are scattered along many drainage channels. Diatomaceous earth occurs in thin deposits on top and interlayered with the basalt; a moderate production has come from some of these deposits.

THE CASCADE MOUNTAINS

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash., and F. W. Cater, U.S. Geological Survey, Denver, Colo.)

The Cascade Mountains of Washington are part of a vast mountain chain that extends nearly unbroken from Alaska through Canada and the United States to Mexico and beyond. In Washington, these mountains have profoundly affected the economic life of the State. Because of their ruggedness, the Cascades constitute a formidable

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barrier to east-west travel across the State. Only a few passes provide practicable routes across the mountains, and, except where the Columbia River breaks through the range, all are subject to heavy snows and dangerous snowslides during the winter months. The climate of the State is also profoundly affected by the mountains; rainfall is heavy on the western slopes, whereas much of eastern Washington is in the rain shadow of the Cascades and is arid or semiarid. Heavy precipitation in the mountains provides abundant resources of water and stimulates heavy forest growth at lower elevations. The crest of the range, however, is well above timber line.

Mineral deposits in the Cascades have been the source of a substantial part of the mineral wealth which the State has produced. The spectacular scenery is one of the great attractions of the State. The rugged Cascades form a recreational area of great variety and beauty, and tourism is an important factor in the economic life of the area.

Rock Units

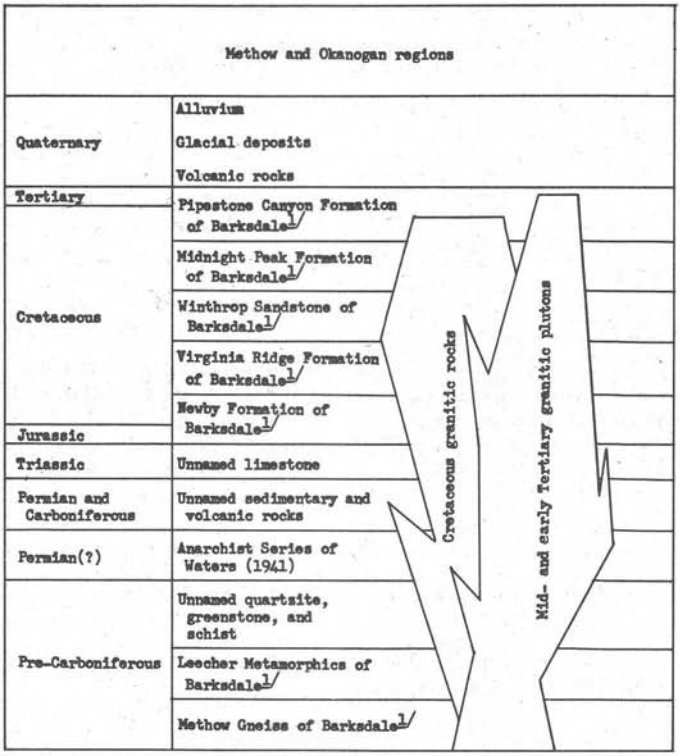
The Cascade Range in Washington consists of two geologically contrasting areas. South of Snoqualmie Pass, Tertiary volcanic rocks with relatively simple structures predominate. North of the pass, most of the exposed rocks are structurally complex pre-Tertiary igneous and metamorphic rocks. To some extent, the geologic differences are reflected in the topography, the area underlain by the pre-Tertiary rocks tending to greater ruggedness and topographic variety. Part of the ruggedness, however, is the result of Pleistocene and Recent glaciation, which has affected the northern part of the area more than the southern.

The northern part of the Cascade Mountains consists essentially of a core of crystalline rocks—mostly granitic rocks and metamorphosed ancient sedimentary and volcanic rocks—flanked by younger sedimentary and volcanic rocks. Superimposed on the rest of the range are five young volcanoes, which form the high peaks of Mount St. Helens, Mount Adams, Mount Rainier, Glacier Peak, and Mount Baker.

METAMORPHIC ROCKS

The oldest rocks in the Cascades are ancient sedimentary and volcanic rocks that have been intensely folded and metamorphosed into gneisses, schists, quartzites, and greenstones. These have been variously named, in different parts of the area, the Methow Gneiss, the Skagit Gneiss, the Swakane Gneiss, the Leecher Metamorphics, the Chilliwack Group, the Anarchist Series, and a host of other local names (fig. 8). Some are probably correlative, others are not.

The age of many of these rocks is not clear, but they represent a considerable interval of geologic time. Most are believed to be pre-Jurassic, but a few are younger. Various degrees of metamorphism are represented. In general, the less intensely metamorphosed rocks crop out along the west flank of the range, whereas moderately to strongly metamorphosed rocks occupy the core and the east flank. Course-grained gneisses underlie much of the more highly metamorphosed areas. Less abundant are biotite and hornblende schist, amphibolite, marble, and quartzite. In many places, these rocks are migmatized—that is, intricately mixed with or injected by granitic material, usually most intensely near pre-Tertiary intusive rocks.



1/ Huntting and others (1961); data source No. 2.

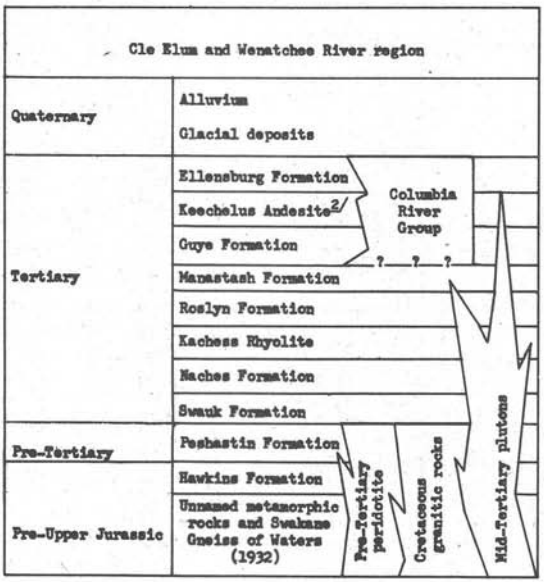
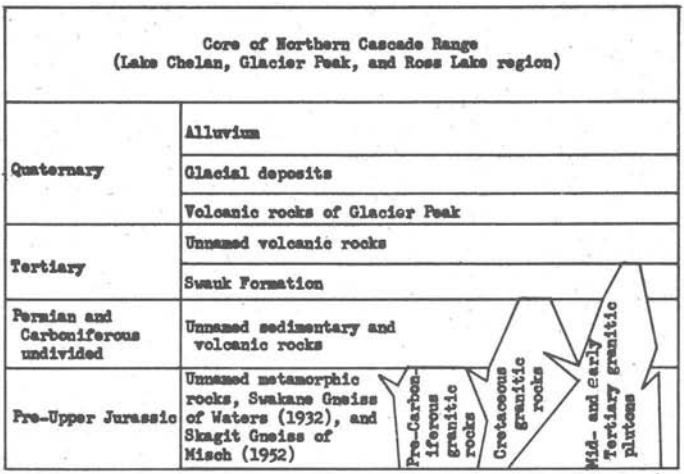
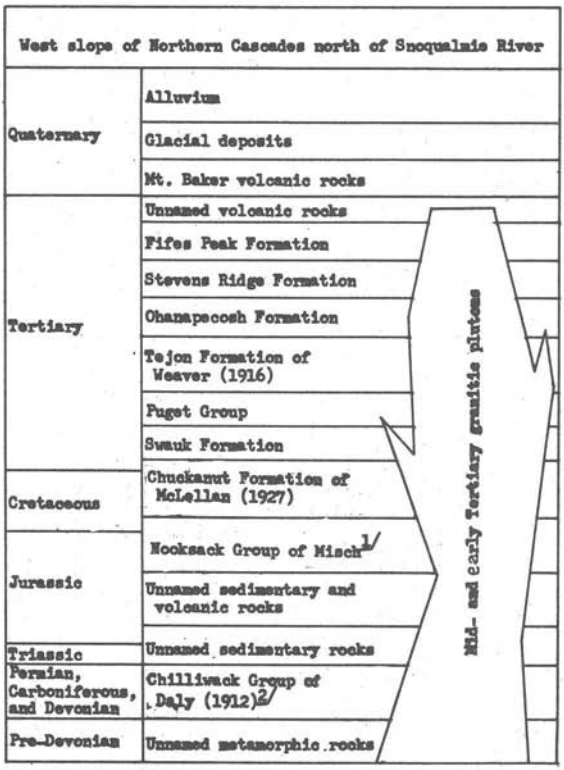


FIGURE 8.—Stratigraphic units commonly recognized in the Cascade Mountains of Washington.





1/ Huntting and others (1961), data source No. 70.

2/ Extended into Cascade area by Miller and Misch (1963).

FIGURE 8.—Stratigraphic units commonly recognized in the Cascade Mountains of Washington—Continued.

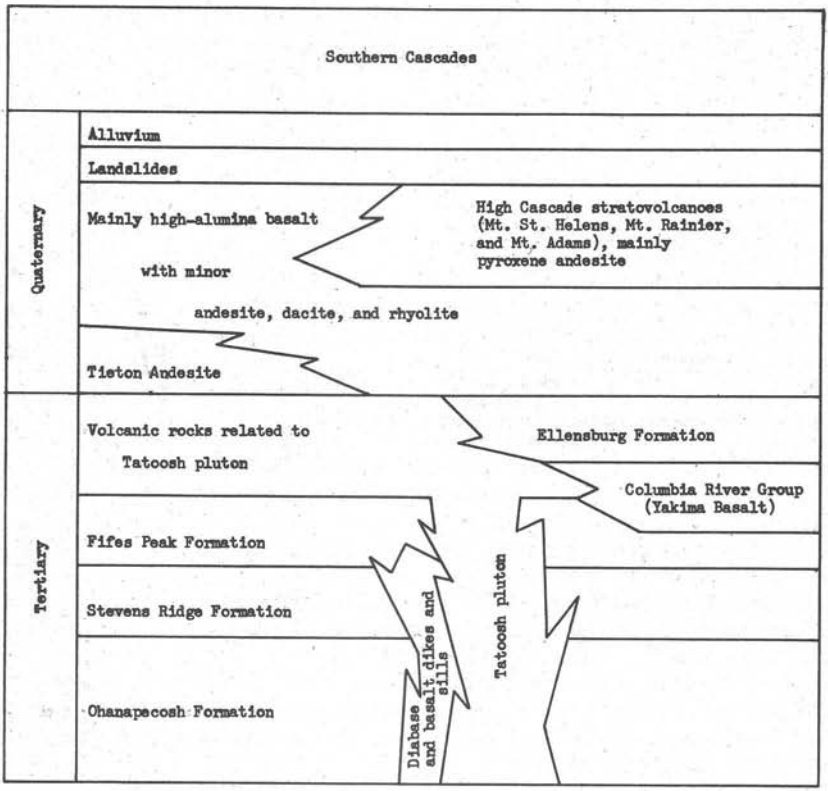


FIGURE 8.—Stratigraphic units commonly recognized in the Cascade Mountains of Washington—Continued.

Two units of biotite gneiss—the Skagit Gneiss as used by Misch (1952) that underlies much of the drainage basins of Lake Chelan and of the Skagit River in the Ross Dam-Newhalem area, and the Swakane Gneiss of Waters (1932) that crops out irregularly from the Columbia River above Wenatchee to the Suiattle River—are many thousands of feet thick. No positive stratigraphic correlation can be made between the two units because they are separated by masses of granitic rock and by structural complexities, but they are closely similar and may well be correlatives. Their composition suggests that they were formed from either acid volcanic rocks or from silicic sediments. Scattered limy and quartzitic layers in them are certainly of sedimentary origin.

Other units of the higher grade metamorphic rocks are thin but remarkably persistent along their strike. They serve as marker units in deciphering the geologic structures of the area. Remnants of conglomeratic textures and layers of marble and quartzite indicate that many of these rocks were derived from sedimentary rocks, but some of them may have been derived from volcanic rocks of basaltic composition.

Less metamorphosed rocks—slate, quartzite, marble, argillite, and metamorphosed volcanic rocks (greenstone)—crop out along the west flank of the range and in the upper Yakima River basin. Little is known concerning their ages; in all probability rocks of many ages are represented.

SEDIMENTARY ROCKS

Paleozoic sedimentary rocks.—Argillite, graywacke, sandstone, chert, limestone, and shale, all with interbedded volcanic rocks, crop out along the west flank of the Cascades. The sequence ranges in age from Devonian to Permian. Some units have been correlated by Misch (Miller and Misch, 1963) with the Chilliwack Group of Daly (1912); others are unnamed. Carboniferous and Permian rocks of much the same type are exposed on the shores of Ross Lake in the upper plate of a thrust fault. The Paleozoic sediments have been intricately and tightly folded but have not been greatly metamorphosed. Marine fossils are numerous in some of the rocks, and the probability is that most of these sediments are of marine origin.

Mesozoic sedimentary rocks.—Older Mesozoic rocks, mostly of Jurassic age, are exposed on both flanks of the Cascade ranges but are missing in the central part. They resemble the Paleozoic rocks but are less intricately folded and are still less metamorphosed.

Cretaceous beds crop out in a few scattered areas on the west slope of the mountains and extensively in down-faulted blocks in the drainage basins of the Pasayten and Methow Rivers. The rocks are mostly of marine origin and consist of shale, impure sandstone, graywacke, and conglomerate with only a few scattered lenses of limestone. The names by which they are known in the Methow-Pasayten area are shown in figure 8.

Continental sediments that span the time interval between the Cretaceous and the Tertiary are found in a great arc surrounding the Mount Stuart-Icicle Creek area, in the valleys of the Wenatchee, Swauk, and Cle Elum Rivers, and in scattered localities on the west side of the range. They consist of shale, shaly coal beds, arkosic sandstone, and coarse conglomerate derived from granitic and metamorphic rocks of local origin. In the Mount Stuart area, they include at the base laterite derived from underlying ultramafic rocks. The sequence was deposited on a surface of considerable relief. East of the mountains, and in the Mount Stuart area, these rocks are known as the Swauk Formation; west of the mountains they are assigned to the Chuckanut Formation of McLellan (1927). The two formations are probably correlatives (Miller and Misch, 1963, p. 170).

Tertiary sedimentary rocks.—Tertiary sedimentary rocks younger than the Swauk occur in an area near Cle Elum in the drainage basins of the Naches and Yakima Rivers. Like the Swauk, they are of continental origin and consist mostly of sandstones and shales interbedded with basalt. The formations into which they are divided are listed in figure 8. The Roslyn Formation contains workable beds of coal, and some coal beds are also known in the overlying Manatash Formation.

Quaternary deposits.—Glacial debris of various kinds is widely distributed throughout the Cascades. Thickest and covering the largest contiguous areas are the deposits along the lower parts of the western slope of the mountains. These deposits consist mostly of debris left by the ice lobe that occupied the Puget Sound area. The lower ends

of many of the valleys were dammed by this debris, forming lakes in which fine-grained sediment accumulated. Similar debris deposited by a lobe of the continental ice sheet coming down the Okanogan Valley blocked some of the valleys on the east slope of the mountains.

Most of the mountain areas have been deeply sculptured by alpine glaciers; indeed the magnificent scenery of the Cascades is due largely to the effects of this glaciation. Debris left by these glaciers forms till and moraines in most of the valley.

VOLCANIC ROCKS

Older volcanic rocks.—Volcanic rocks of probably Carboniferous and Permian ages have been mapped by Peter Misch (Huntting and others, 1961, data source No. 70) in the Northern Cascades near Ross Lake and at a few places to the south. In the drainage basis of the Methow River, J. D. Barksdale (Huntting and others, 1961, data source No. 2) has mapped a few areas of volcanic rock (the Midnight Peak Formation) interlayered with the Cretaceous sediments (fig. 8).

Tertiary volcanic rocks.—South of Snoqualmie Pass, the Cascades are almost everywhere underlain by a sequence of volcanic rocks of Eocene, Oligocene, and Miocene ages (fig. 8). In the vicinity of Mount Rainier, Eocene and Oligocene volcanic rocks reach a thickness of more than 10,000 feet (Waters, 1961). The sequence consists of flows, mudflows, and water-laid pryoclastic rocks. Local patches are found elsewhere in the Cascades but are not volumetrically important. Most of these rocks are of andesitic composition, but basalt, rhyolite, and dacite flows and breccia are intercalated with the andesite. The older of these rocks have been more folded and faulted and more intensely altered than the younger ones. Lapping over the Eocene, Oligocene, and Miocene volcanic rocks are basalt flows of the Columbia River Group of middle Miocene through early Pliocene age. Restricted mostly to the Mount Rainier-Snoqualmie Pass area are small patches of Miocene dacite or rhyodacite flows that are related to the intrusion of granodiorite plutons. These are glassy and have been only slightly altered.

Quarternary volcanic rocks.—The great cones of Mount Baker, Glacier Peak, Mount Rainier, Mount Adams, and Mount St. Helens were formed in comparatively recent times. The last major eruption from Glacier Peak has been dated by Carbon–14 as 12,000 years ago (Fryxell, 1965). John C. Fremont reported Mount Baker and Mount St. Helens in eruption in 1843 (Fenneman, 1931, p. 425). There are also reports of later eruptions of Mount Baker. Ash alone was ejected; none of these eruptions included lava flows (Coombs, 1939).

INTRUSIVE ROCKS

Granitic intrusive rocks

Rocks of granitic composition underlie large areas of the Cascades. They were emplaced during several periods and over a long interval of time.

Older granitic intrusive rocks.—The oldest of these rocks are dioritic masses that crop out in two small areas near Marblemont. Their age is uncertain, but they are believed to be pre-Carboniferous. They are shown on figure 4, but they are not quantitatively important.

Cretaceous and early Tertiary granitic rocks.—The main period of igneous intrusion in the Cascades began in the late Mesozioc and continued into the early part of the Tertiary. Intrusive masses of batholithic dimensions consisting largely of quartz diorite and granodiorite were formed. The batholithic masses underlie much of the extreme northeastern part of the Cascades and also crop out north of Lake Chelan and in the adjacent lower drainage basin of the Entiat River, as well as in the vicinity of Mount Stuart. These masses are known respectively as the Similkameen, Chelan, and Mount Stuart batholiths. Small plutons are found at the headwaters of the White River, on Chiwaukum Ridge, and in several other places.

The granitic masses are discordant or cut across the enclosing rocks in some places and are concordant or intruded parallel to the enclosing rocks in others. Borders are mostly gradational into the enclosing schists and gneisses, and foliation has been developed within the intrusions, particularly near their margins. Replacement, assimilation, and granitization of the host (or enclosing) rocks indicate that these masses were emplaced at intermediate or great depths.

Field evidence points to at least two main periods of intrusion, but on figure 4 all the granitic rocks of Cretaceous and Cretaceous and Tertiary age have been grouped together.

Radiometric age determinations indicate that most of the Cretaceous granitic rocks are from 100 to 120 million years old, but some age determinations as young as 40 million years have been obtained. These determinations, however, need confirmation.

Tertiary granitic intrusive rocks.—Several batholiths and smaller stocks and plugs of Miocene age crop out in the Cascades of Washington. The best known of these are the Tatoosh pluton near Mount Rainier (Fiske and others, 1963, p. 40), the Snoqualmie batholith between Snoqualmie Pass and Monte Cristo, the Cloudy Pass batholith on the crest of the Cascades northeast of Glacier Peak, the Golden Horn batholith in the Methow River drainage on the eastern slope of the mountains, and the Chilliwack batholith east of Mount Baker. These rocks, therefore, are among the youngest exposed batholithic rocks known. Recent radioactive age dating suggests that the age of some of these are as young as 14 to 20 million years.

The Miocene intrusive rocks range in composition from granite to quartz diorite but consist mostly of granodiorite. Some of them have chilled margins of porphyritic rocks and phases gradational into extrusive rocks (Smith and Calkins, 1906; Cater, 1960; Waters, 1961a). The Miocene batholiths are only now in the process of being exposed by erosion, and it is at least possible that the exposed masses are only cupolas rising from a very much larger batholith. All the bodies have features characteristic of intrusives emplaced at shallow depths in the earth's crust.

In addition to these larger intrusions of granitoid rocks, numerous dikes and irregular bodies cut the older rocks. Some are satellitic to the batholiths; others served as feeders to lava flows or pyroclastic deposits. In a few localities, as, for example, along Phelps Ridge south of Lyman Glacier, intrusive breccias are found that must have risen from an underlying batholith. Some of these breccias are mineralized.

Small intrusive bodies of andesite porphyry and diorite are locally abundant in the Cascades south of Snoqualmie Pass. South of

Mount Stuart, a swarm of basalt dikes cut the Swauk Formation but are not shown on figure 4.

Ultramafic intrusive rocks

Peridotites now mostly altered to serpentinite form lenticular masses distributed along a northwest-trending belt extending from Sumas Mountain, northwest of Bellingham, to Cle Elum. The Twin Sisters Mountains mass, the largest of these bodies, is elliptical and about 10 miles by 4 miles in area. Much of the mass is the high-olivine variety of peridotite known as dunite. Chromite deposits are found in the dunitic parts (Thayer and others, 1943; Ragan, 1963). The Twin Sisters mass is remarkably fresh except where sheared and serpentinized along its margins and thus differs from most of the other ultramafic masses, which are thoroughly serpentinized throughout.

In places, lateritic deposits, which developed on some of the masses by weathering, now form the base of the Swauk Formation and Chuckanut Formation of McLellan (1927) of Tertiary age. These bodies must therefore be pre-Tertiary in age, and, by analogy with similar rocks in British Columbia, they may be as old as Jurassic or Late Triassic. However, Ragan (1963) states that the Twin Sisters mass is intrusive into Paleocene rocks, and therefore it and several nearby similar but smaller bodies must be Tertiary in age. On figure 4, all of the ultramafic rocks are shown by a single pattern.

Structure

The rocks of the Cascades have been folded, faulted, overthrust, uplifted, and downwarped. Most strongly deformed are the metamorphic rocks in the core of the range, which have been tightly and intricately folded along north-northwesterly trending axes. Paleozoic and Mesozoic rocks are also tightly folded in places but less so than the metamorphic rocks. The Paleozoic rocks in particular have been involved in overthrusting. In general, Tertiary rocks have not been tightly folded, but they have been repeatedly folded, faulted, downwarped, and uplifted. Especially pronounced among the younger structures are the large grabens or downdropped blocks so prominent in the drainages of the Pasayten, Methow, Wenatchee, and Chiwawa Rivers. These also follow the prevailing north-northwesterly trend.

The north-northwesterly structural grain of the region developed early, as is indicated by the direction of foliation and folding in the metamorphic rocks. Subsequent dislocations followed the same trend until Miocene time, when the Miocene batholiths were intruded along a north-south line, a line followed by the trend of the present Cascade Range.

Geologic History

The earliest geologic record of the Cascade Mountains is preserved in the tightly folded metamorphic rocks that crop out in the core of the northern part of the range. These rocks record periods of sedimentation, volcanic outbursts, metamorphism, and mountain-building. Deformation associated with the building of this oldest ancestral Cascade Ranges established northwesterly structural trends that controlled all later deformation until well along in Tertiary time.

These old mountains were eventually planed off, and by late Paleozoic time the region was again submerged and receiving sediments. The later deformation of these rocks and, of course, of the older underlying rocks was not accompanied by strong metamorphism. Older Mesozoic rocks record renewed depression and sedimentation. By late Mesozoic (Cretaceous) time the rocks of the region were invaded by vast amounts of igneous material that cooled to form the older batholiths that crop out so widely in the northern part of the Cascades. The Swauk and Chuckanut Formations of latest Cretaceous and early Tertiary age record rapid denudation of adjacent parts of the region that were being vigorously uplifted to form still another chain of mountains. Uplift and erosion continued until many thousands of feet of rock was removed from these mountains and their cores were exposed.

The most complete record of Tertiary events is preserved in rocks of the southern part of the Washington Cascades. Here the vast piles of Eocene, Oligocene, and Miocene volcanic rocks bear witness to the magnitude of eruptions that accompanied growth of the latest of the ancestrial Cascades (Mackin and Cary, 1965, p. 15). Related to these volcanic rocks are the Tertiary granitic intrusions that underlie large areas in the northern part of the present Cascades. Concomitant with growth of the range and volcanic activity some areas were relatively depressed and received sediments that formed the Roslyn, Manatash, and other formations.

In Miocene time, vast floods of basaltic lava of the Columbia River Group lapped over the older volcanic rocks. These flows were deposited in flat sheets that once extended unbroken nearly to the present coast line, although in Washington only isolated remnants remain west of the mountains. The Eocene, Oligocene, and older Miocene volcanic rocks to the south were in part inundated by the basalt flood and in part formed islands in the basalt sea. The sedimentary, metamorphic, and intrusive rocks in the northern portion for the most part stood above the basalt flood.

By Pliocene time the ancestral Cascades of Mackin and Cary (1965) had been reduced to a plain, called by them the "Weaver Plain." Beginning about the middle of the Pliocene, this plain was uplifted to form the "Cascade Plateau" of Russell (1890). This plateau was eroded and dissected to form the present Cascade range; in fact the most striking feature of the Cascadian landscape, as seen from a distance, is the uniform altitude of the peaks and ridges which are the remnants of the old plateau. Throughout most of the range, the summits that delineate the old plateau surface vary in elevation from 6,000 to 8,000 feet; summits are highest in the center of the range and lower along the sides. This bowing-up of the Weaver Plain to form the Cascade Plateau is clearly visible in the Columbia gorges where the Columbia River basalts are strikingly arched. The Weaver Plain was not uplifted evenly, but was broken up into a series of blocks trending northwesterly parallel to the ancient structural trends. Individual blocks rose different amounts, so that now the uniformity of summits outlining the former Cascade Plateau is disrupted in places.

The relatively even skyline is broken here and there by isolated mountains that rise thousands of feet above it. Some of these, of

which Mount Stuart is an example, are monadnocks of granitic rocks, erosional remnants which, because they are formed of more resistant rock, rise above the general level of the dissected plateau. Others, such as Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams, are recent volcanic cones built on the platform of older rocks. These volcanic cones are independent structures not tectonically related to the uplifted surface on which they stand.

The rate of uplift was sufficiently slow so that the Columbia River maintained its course as the land rose. The rate of uplift was uneven, as shown by many Cascade valleys that consist of a broad "outer" valley into which a steep-walled, narrow "inner" valley has been incised, indicating a cessation of uplift followed by a renewal. This feature can be best seen on the slopes of the range and in the southern part; it has been destroyed by alpine glaciation in the higher mountains to the north. Some of these "inner" valleys have been cut in debris left by the continental ice sheets, indicating that uplift continued into the Pleistocene (Mackin and Cary, 1965, p. 23). Maximum uplift of the north-south trending range was about 8,500 feet.

The cones of the five Washington volcanoes are made of lava and volcanic ash, built up on a platform of the older rocks. They first appeared during the Pliocene, but volcanic activity has continued into very recent times; in fact, it may not yet have died out entirely.

The Cascade Range in Washington has been extensively glaciated, and nearly all the valleys have the typical U-shape of glaciated valleys. Glacial features, however, are more dominant in the northern part than they are in the southern part, where extreme glaciation was limited to the higher peaks. In the northern Cascades, cirques abound, and the details of the shapes of most of the peaks and ridges have been carved by glacial erosion. The rugged but spectacular and beautiful scenery of the northern Cascades is mostly the result of Pleistocene glaciation, which, in fact, is still going on. Severa hundred active glaciers still remain clustered around the higher peaks

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WESTERN WASHINGTON

(By H. C. Wagner and P. D. Snavely, Jr., U.S. Geological Survey, Menlo Park, Calif.)

Western Washington includes an area of approximately 20,000 square miles, a region of exceedingly variable physiography and greatly divergent rock types. Physiographically, the area runs the gamut from picturesque seashores to rugged glacier-studded peaks; the bedrock includes mudstones and limestones deposited in the sea as well as conglomerate and coal-bearing sandstones laid down on land; volcanic rocks were erupted in both environments. The part of western Washington between the foothills of the Cascade Range and the Pacific Ocean may be conveniently subdivided into three physiographic regions. The Olympic Mountains compose the northwestern segment; the Willapa Hills, an extension of the Oregon Coast Range, form the southwestern segment; and the Puget Lowland separates these higher areas from the Cascade Range (fig. 9).

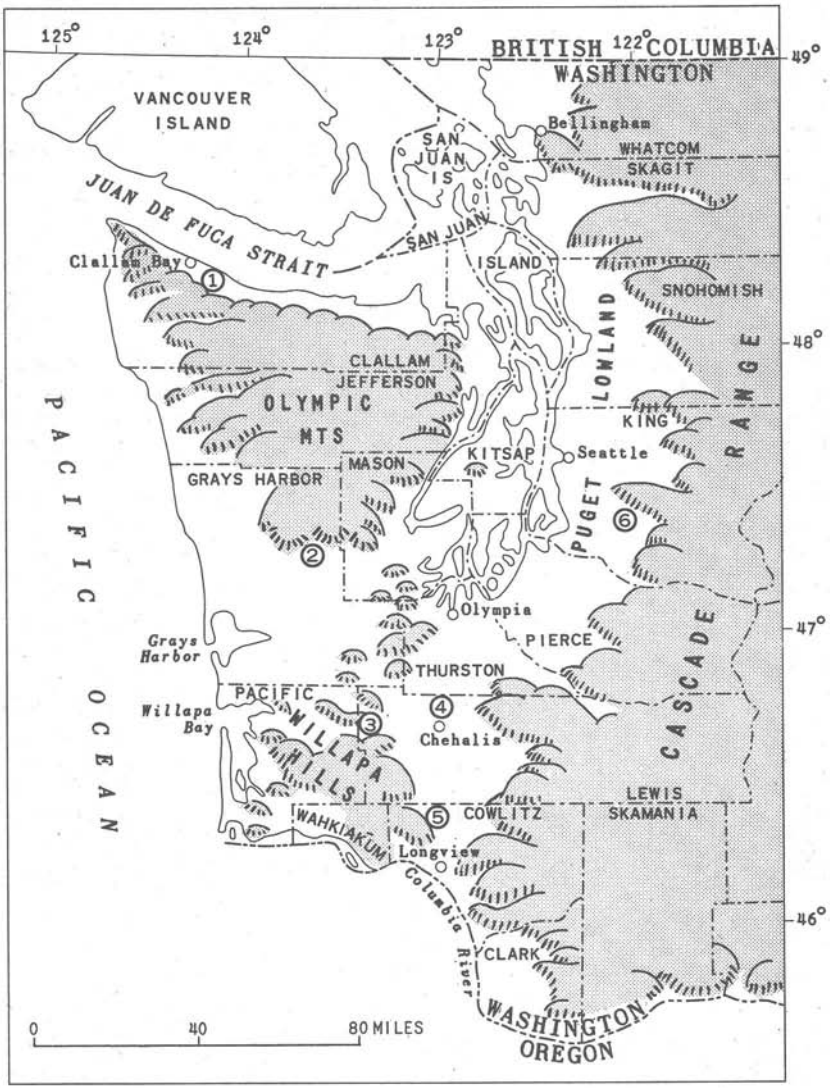


FIGURE 9.—Index map of western Washington, showing principal physiographic divisions and locations (circled numbers) of stratigraphic sections given in Figure 10.

The Olympic Mountains embrace an area of about 4,000 square miles and rise to heights of 7,965 feet at Mount Olympus. The Willapa Hills area includes the Black Hills, Doty Hills, and many lower hills in the southwestern part of the State. Approximately 3,000 square miles are encompassed in the Willapa Hills area, whose highest point, Boistfort Peak, reaches 3,110 feet above sea level. The broad downwarp of the Puget Lowland covers more than 6,000 square miles and contains most of the arable land in western Washington.

The lowland lies nearly at sea level, and much of the northern part is occupied by Puget Sound. The San Juan Islands separate the Puget Lowland from the Georgia Straits embayment of Canada, a small part of which extends into the United States. The foothills of the Cascade Range form a southern barrier in the vicinity of Longview, and separate the Puget Lowland from the northern extension of the Willamette Lowland of Oregon.

The foothills of the western Cascade Range, in particular those parts underlain by Tertiary rocks, are included in this description of western Washington geology.

The bedrock exposed in western Washington is chiefly of Tertiary age and is part of a eugeosynclinal [1] accumulation of sedimentary and volcanic rocks, predominantly of marine origin. Mesozoic marine sedimentary and volcanic rocks, although restricted in outcrop to the San Juan Islands and the northern foothills of the Cascade Range, may underlie most other parts of the area and represent deposition in a much more extensive eugeosyncline than that of Tertiary time. In this larger framework, the Tertiary eugeosyncline is a successor-basin whose axis of sedimentation migrated progressively westward as time passed and as the marine basin was reduced in size.

Pre-Tertiary Rocks

The bulk of the bedrock exposed in western Washington accumulated in Tertiary time, for in this area pre-Tertiary rocks are found only in the San Juan Islands, in the foothills of the northwestern part of the Cascade Range, and possibly in the core of the Olympic Mountains. The oldest rocks exposed in the San Juan Islands and the northwestern Cascades are a heterogeneous metamorphic and plutonic basement complex composed principally of gneissic amphibolites and quartz diorite (Danner, 1960a, 1960b; Misch, 1964). This complex is overlain by eugeosynclinal sedimentary and volcanic rocks that include conglomerate, graywacke, shale, chert, limestone, and basaltic lava flows, and such metamorphic rocks as quartzite, schistose graywacke, argillite, marble, phyllite, and greenstone. Poorly preserved fossil corals in the limestone indicate that rocks at least as old as Devonian are present (McLellan, 1927, p. 94; Miller and Misch, 1963, p. 166).

During late Paleozoic time (Mississippian, Pennsylvanian, and Permian Periods), a variety of predominantly marine sedimentary and volcanic material formed deposits of impure sandstone, shale, ribbon chert, limestone, submarine lava flows, and volcanic breccia. In Mesozoic time in the San Juan Islands, a thick unit composed of conglomerate, sandstone, shale, and silty limestone represents deposition near the strand line. Concurrently, in the northwestern Cascades marine shales and conglomeratic sandstones accumulated. In many parts of the San Juan Islands and the northwestern Cascades, metamorphism and associated deformation in Mesozoic time affected these pre-Tertiary rocks, and the shales were transformed locally into argillite and slate, sandstone into quartzite, limestone into marble, and volcanic rocks into greenstones. Accumulation of a thick sequence of marine siltstone and graywacke began in latest Mesozoic time

[1] A eugeosyncline is a linear downwarp of regional dimensions in which both sedimentary and volcanic rocks have accumulated to great thicknesses.

throughout much of western Washington, but these rocks are now exposed only in the core of the Olympic Mountains.

Tertiary Rocks

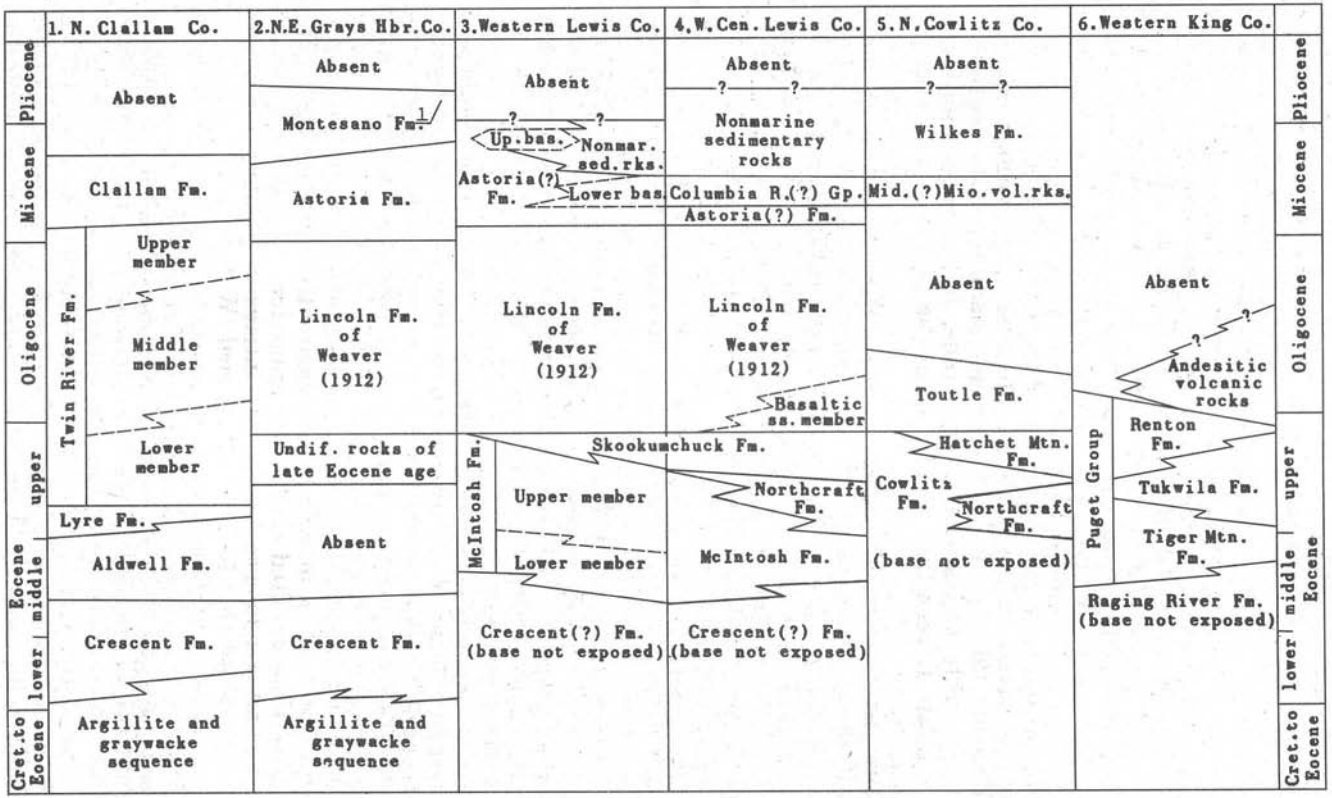
EOCENE DEPOSITS

At the beginning of Tertiary time, a north-trending depositional basin occupied the present area of the Olympic Mountains, the Willapa Hills, and the Puget Lowland in western Washington. The eastern margin of the basin is beneath the present site of the Cascade Range; the western margin was a submarine barrier or island chain and probably was some miles west of the present coast line. The depositional basin extended as a linear trough about 400 miles from Vancouver Island to the Klamath Mountains of Oregon (Snavely and Wagner, 1963, p. 1). This trough maintained its continuity throughout early and middle Eocene time, but regional uplift and folding in late Eocene time divided it into several separate basins of deposition.

The earliest Tertiary deposition in western Washington is a sequence of argillite and graywacke more than 30,000 feet thick that forms part of the core of the Olympic Mountains (fig. 10, cols. 1 and 2). Eocene fossils have been found about 15,000 feet below the top of the sequence, but the age of the lower part of these strata is unknown and may extend back to the Cretaceous.

The most widespread rock unit in western Washington is the Crescent Formation (fig. 10), a thick sequence of lower to middle Eocene volcanic rocks consisting of pillow lava flows, volcanic breccia, and water-laid fragmental debris that intertongues with thin units of tuffaceous marine sedimentary rocks. The lava in this predominantly volcanic sequence was erupted onto the sea floor, except in several places where the rate of extrusion exceeded the rate of downwarping of the basin, and islands were formed. Near centers of volcanism, thick prisms of basaltic flows and breccia accumulated to a thickness probably in excess of 20,000 feet; but only in the Olympic Mountains is the base of this volcanic sequence exposed. Away from volcanic centers, the basalt flows and breccia may exceed 10,000 feet in thickness; they form many of the structurally and topographically highest areas.

Along the northeast margin of the depositional basin, barrier-beach and coal-swamp conditions that had apparently persisted since Late Cretaceous time resulted in the accumulation of a thick series of sandstone and conglomerate beds with intercalated layers of concentrated plant debris that formed beds of coal (Weaver, 1937, p. 75–78). The coal-swamp conditions continued into middle Eocene time along the east margin of the basin where coal-bearing sandstones and carbonaceous siltstones are prominent in King and Pierce Counties (Tiger Mountain Formation of Puget Group, fig. 10). Westward these near-shore deposits intertongue with deeper-water siltstones in southwestern Washington (McIntosh Formation, fig. 10). Meanwhile in the Olympic Mountains, uplift in the Vancouver Island area resulted in a change from siltstone (Aldwell Formation, fig. 10) to sandstone and conglomerate (Lyre Formation, fig. 10) composed principally of metamorphic, granitic, and volcanic rock types. Locally, in extreme



[1] of Weaver, 1912.

FIGURE 10.—Correlation chart of Tertiary rocks in western Washington. (Data adapted from (1) Brown and others, 1960, and Gower, 1960; (2) W. W. Rau, unpublished data; (3) Pease and Hoover, 1957; (4) Snavely and others, 1958; (5) Roberts, 1958; (6) Vine, 1962, and Gower and Wanek, 1963.)

southwestern Washington, a middle Eocene sandstone-siltstone sequence was deposited by turbidity (density) currents that carried sand and silt, perhaps from the same Vancouver Island source, into the deeper parts of the basin.

In late Eocene time the depositional basin was divided by local uplift and volcanism (Northcraft Formation, fig. 10) into several separate basins of marine deposition. The northermost basin extended through the area of the present Juan de Fuca Strait and turned southward into the Puget basin; farther south a large embayment that projected into the present Grays Harbor area extended southeastward beyond Chehalis; the southernmost large basin occupied an area along the present lower part of the Columbia River. On the broad swampy coastal plains that bordered the late Eocene sea along the east margins of the embayments in the Puget and Grays Harbor basin areas, coal-forming plant debris accumulated into deposits of great lateral extent and uniform thickness. These deposits later became the economically important coal beds now found interbedded with arkosic sandstones and siltstones of late Eocene age in King, Pierce, Lewis, and Cowlitz Counties (Renton, Cowlitz, and Skookumchuck Formations, fig. 10). A locally thick sequence of basalt and andesite flows, breccia, and interbedded pebble conglomerates and sandstones (Hatchet Mountain Formation, fig. 10) in Cowlitz County locally intertongues with the coal-bearing nonmarine and near-shore marine sandstones and siltstones (Cowlitz Formation, fig. 10), and attests to the persistence of volcanic activity to latest Eocene time. Westward these near-shore coal-bearing deposits grade into deeper water marine tuffaceous (volcanic ash-bearing) sandstone and siltstone (upper member of McIntosh Formation, fig. 10). To the northeast in King and Pierce Counties, large quantities of andesitic volcanic sandstone, breccia, and conglomerate (Tukwila Formation, fig. 10) intertongue with and are overlain by thick nonmarine coal-bearing arkosic sandstone (Renton Formation, fig. 10) of late Eocene to possibly early Oligocene age, and indicate active subsidence of the land area adjacent to the Puget basin on the east.

In northwestern Washington, uplift in late Eocene time raised the area of the Olympic Mountains above sea level, and erosion locally cut through the middle to late Eocene siltstones, sandstones, and conglomerates (Aldwell and Lyre Formations, fig. 10) into the underlying volcanic rocks (Crescent Formation, fig. 10). Erosion of these uplifted volcanics furnished much basaltic debris to the marine strand and a thick sequence of lithic sandstone and siltstone with a few conglomerate lenses accumulated in the north coastal area of the Olympic Mountains (lower member of Twin River Formation, fig. 10).

OLIGOCENE DEPOSITS

In earliest Oligocene and latest Eocene time, very little detritus was furnished to the geosyncline from adjacent land areas, and basal Oligocene strata consist of basaltic sandstone and conglomerate (basaltic sandstone member of Lincoln Formation of Weaver (1912), and Toutle Formation, fig. 10) derived from erosion of islands composed of Eocene basalt. These deposits are widely distributed, are thickest near former volcanic centers or islands, and thin markedly or are absent in the central parts of the basins of deposition.

In early Oligocene time, regional subsidence took place, and most of western Washington was beneath the sea. Vigorous volcanism in the ancestral Cascade Range buried the coastal plain with andesitic debris and brought to an end the widespread coal-forming environment of late Eocene time. Debris-clogged streams carried great quantities of pyroclastic and detrital material to the near-shore marine environment where water-saturated volcanic detritus at steep delta fronts was periodically moved by submarine landsliding into the deeper parts of the basin. Meanwhile near the coast line, lagoonal swamps formed locally, and a thick deposit of basaltic conglomerate, sandstone, and pumice-rich lapilli tuff with local coal beds formed (Toutle Formation, fig. 10). The extensive accumulation of andesitic volcanic material along the Cascade Range blocked the streams that had carried arkosic detritus to the marine environment from northeastern Washington, and in most parts of the geosyncline ash, silt, and sand rapidly deposited throughout Oligocene time to form as much as 8,000 feet of marine tuffaceous siltstone and fine-grained sandstone with intercalated beds of pumiceous lapilli tuff (Lincoln Formation of Weaver, fig. 10). North of the ancestral Olympic Mountains, far removed from the volcanic vents of the Cascade Range, only a small amount of volcanic ash was furnished to a west-trending trough where more than 10,000 feet of siltstone and mudstone was deposited (middle and upper members of Twin River Formation, fig. 10). In late Oligocene time, continued subsidence resulted in burial of most of the Eocene volcanic highs, and in western Washington islands remained only in the area of the present Olympic Mountains.

MIOCENE DEPOSITS

In the deeper parts of the basin areas of western Washington, sedimentation continued uninterrupted from late Oligocene to early Miocene time. Volcanism in the low-lying ancestral Cascade Range waned and only silt-size material was supplied to the southwest-Washington part of the eugeosyncline. Late in early Miocene time, sand-size material from a northeastern Washington source was again transported by an ancestral Columbia River to the near-shore marine environment; and folding in southwestern Washington along generally northwest-trending structural axes developed many anticlinal and synclinal flexures that controlled in part the sites of deposition of Miocene marine and continental sedimentation. The maximum known eastward extent of the middle Miocene sea was near Centralia, where near-shore marine sandstones (Astoria Formation, fig. 10) overlie tuffaceous siltstones of Oligocene age. These near-shore sandstones grade eastward into continental basaltic sandstones and conglomerates derived from the western flank of the Cascade Range; westward they grade into fine-grained sediments deposited in the deeper parts of the Grays Harbor basin. Another broad embayment near the mouth of the Columbia River was the site of deposition of a thick sequence of fossiliferous sandstone and siltstone (Astoria Formation, fig. 10). Along the Strait of Juan de Fuca, an embayment may have extended as far as Puget Sound, but the only known middle Miocene rocks are the coal-bearing continental and near-shore marine strata exposed near Clallam Bay (Clallam Formation, fig. 10).

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Uplift in middle Miocene time shifted the strand line westward; and contemporaneously, a great volume of basalt was erupted from fissures east of the Cascade Range and supplied the basaltic lava that flowed down the Columbia River downwarp and spread northward into the Grays Harbor basin and westward to the sea ((Columbia River(?) Group and lower basalt of the Astoria Formation, fig. 10)). Where this lava reached the marine environment, thick accumulations of pillow basalt and breccia were interbedded with marine sandstones. Near the strand line in southwestern Washington, lava was extruded from local centers; in places, submarine and subaerial basalt flows and beds of basaltic fragmental debris from these vents are found intercalated with the micaceous fine- to coarse-grained sandstones of middle Miocene age.

In late Miocene time, additional uplift shifted the shore line westward nearly to Willapa Bay and subaerial basalt flows (upper basalt in Astoria Formation, fig. 10) were interbedded in coarse-grained sandstone in a nonmarine environment. In the Puget Lowland, large shallow lakes formed in local structural basins in late Miocene time. Sedimentation in these basins kept pace with downwarping, and as much as 1,000 feet of lacustrine clay, fluvial sand, and volcanic mudflow deposits accumulated (Wilkes Formation, fig. 10). These strata are in large part composed of pumice-rich pyroclastic debris derived from the venting of granodiorite plutons along the present site of the Washington Cascade Range.

Near the close of the Miocene, marked regional uplift of the Willapa Hills and intense deformation in the Olympic Mountains further reduced the area of marine deposition. The highlands thus formed furnished coarse debris to the near-shore environment, and a thick sequence of sandstones and conglomerates formed in the Grays Harbor basin near the present coast line (Montesano Formation of Weaver, 1912, fig. 10).

PLIOCENE DEPOSITS

Continued uplift shifted the shore line farther west in Pliocene time, and only the eastern fringe of marine deposits of Pliocene age is preserved near the present shore line. Sandy siltstones, sandstones, and pebble conglomerates (Montesano Formation of Weaver, 1912, fig. 10) as well as sandstones and siltstones of near-shore and deltaic origin (Quinault Formation, fig. 10) were deposited. Finer grained sediments undoubtedly accumulated offshore on the continental shelf. Downwarping and sedimentation that started in late Miocene time in the depression along the Puget Lowland continued into Pliocene time (Wilkes Formation, fig. 10), and in the southwestern part of the present Cascade Range remnants of andesitic lava of Pliocene and younger age are preserved in central Clark and western Skamania Counties. In westernmost Washington, the period of uplift that had started in late Miocene time continued, and the Willapa Hills and Olympic Mountains probably reached their maximum height by the end of the Pliocene Epoch.

Post-Tertiary Rocks

PLEISTOCENE AND RECENT DEPOSITS

During the Pleistocene Epoch the Puget Lowland and the flanks of the Olympic Mountains and Cascade Range underwent extensive and repeated glaciation, and many of the present land forms owe their origin to the ravages of ice scouring and the deposition of glacial debris. In the Puget Lowland are found the deposits of four major stages of glaciation (Crandell, 1963, p. 8); in the Olympic Mountains also are evidences of multiple glaciation (Brown and others, 1960: Crandell, 1964, pp. 135–138).

In early Pleistocene time a lobe of the great Cordilleran ice sheet of western Canada extended into the Puget Lowland to a point nearly 20 miles southwest of Olympia, and alpine glaciers and ice fields formed in the higher mountains of western Washington. Sheets of till formed by this lobe (Crandell, 1963, p. 13) are locally interbedded in thick deposits of glacial drift in the southern part of the Puget Lowland (Orting Drift, fig. 11). Piedmont alluvial fans of glaciofluvial origin were deposited along the western margin of the Cascade Range (Logan Hill Formation, fig. 11) and around the flanks of the Olympic Mountains (Taholah Formation of Glover, 1940 and Older drift, fig. 11). Debris derived mainly from the Cascade Range and the Olympic Mountains forms deeply weathered deposits preserved as broad benches that are as much as 1,200 feet above sea level in the western Cascade area (Logan Hill Formation, fig. 11) and nearly at sea level along the coast in the Grays Harbor area. When the climate ameliorated near the end of this cold period, the lobe retreated northward beyond the International Boundary, the climate became much as it is today, and northwestward-flowing streams, as well as mudflows formed of the products of contemporaneous volcanism, carried much debris from the Cascade Range into the Puget Lowland (Alderton Formation and lower part of Lily Creek Formation, fig. 11). At least twice more before the last period of extensive glaciation in the Puget Lowland the climate alternated between cold and warm for long periods of time, and Cordilleran glaciers invaded the area, leaving behind locally thick deposits of glacial drift and outwash gravels (Stuck Drift, Puyallup Formation, Salmon Springs Drift, Kitsap Formation, fig. 11). Concurrently, in the central Cascades, subaerial erosion, volcanism, and glaciation furnished large quantities of glacial drift and volcanic mudflow material to the western foothills (upper part of Lily Creek Formation, Wingate Hill Drift, and Evans Creek Drift, fig. 11). In the northern part of the Olympic Mountains, drift from alpine glaciers was deposited in many of the large valleys (Alpine Drift, fig. 11). Concurrently, and also later in Pleistocene time, broad piedmont ice lobes extended beyond the mountain front in the southwestern part of the Olympics and spread out upon the bordering lowland (Crandell, 1964, p. 137).

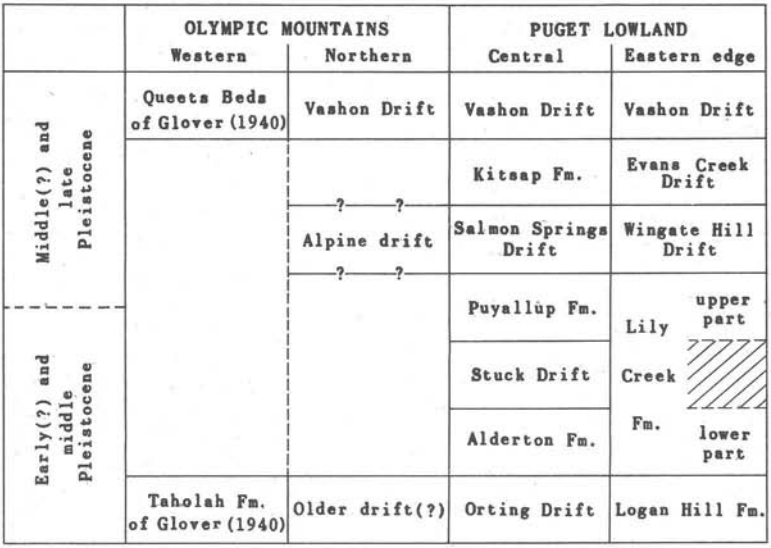

FIGURE 11.—Pleistocene stratigraphy of western Washington.

In late Pleistocene time, ice lobes from the Canadian ice sheet again extended southward beyond Olympia in the Puget Lowland and westward through the Juan de Fuca Strait to the Pacific Ocean. Streams flowing out of the mountains were dammed by these thick lobes, lakes formed, and lacustrine sediments many hundreds of feet thick accumulated before the climate again changed and the Ice Age came to a close. As the ice lobes retreated, thick deposits of glaciofluvial outwash and till remained in their wake along the north coastal area of the Olympic Mountains and in the Puget Lowland (Vashon Drift, fig. 11). Simultaneously, glaciofluvial deposits accumulated locally west of the Olympic Mountains (Queets Beds of Glover, 1940, fig. 11).

Marine sediments at Seattle provide evidence that, as Pleistocene time ended and the Recent Epoch began, waters from the Pacific Ocean flooded part of the Puget Lowland. The climate became somewhat warmer than at present (Crandell, 1963, p. 9), streams with headwaters in the higher mountains carried much silt and sand to the adjacent lowlands, and great mudflows swept masses of volcanic boulders and ashy silt into the southern part of the Puget Lowland. Worldwide melting of the continental ice sheets, and resultant rise in sea level, brought marine waters to their present position in the glacier-cut troughs of Puget Sound.

MINERAL RESOURCES

The Mineral Industry of Washington

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

In 1963 Washington's mineral production was $71.4 million, placing it 35th among the States with respect to the value of its mineral output. The State produced about 32 different mineral products. It led the United States in the production of olivine and was second in the production of magnesite, third in the production of diatomite, and sixth in the production of talc and soapstone, and sixth in the production of uranium. It ranked sixth among the States in the production of lead, twelfth in the production of zinc, and about sixth in the production of gold. In the Knob Hill mine at Republic and the Gold King mine at Wenatchee, it has two of the leading lode gold mines in the United States, and its Pend Oreille mine at Metaline in 1963 was the country's 12th ranking producer of both lead and zinc.

Washington's production of minerals compares favorably with that of her sister states of Idaho and Alaska, both probably in popular estimation better known as mining states. In 1963 Idaho's mineral production was $82.8 million, or 0.42 percent of the United States production; Alaska's was $67.8 million, or 0.35 percent of domestic production (D'Amico, 1964).

Only a relatively small percentage of the State's labor force is employed in mining. According to the Washington State Department of Employment Security, in 1963 approximately 224,000 were engaged in manufacturing, 76,500 in farming, 1,500 in commercial fishing, 11,100 in logging, and 1,900 in mining and quarrying. Manufacturing, which in 1963 had an annual payroll of $1.5 billion and produced $2.9 billion worth of goods, greatly overshadows mining, which in the same year had an annual payroll of $12.8 million and produced metals and nonmetallic minerals valued at $71.4 million. Cash received for farm products in 1963 amounted to nearly $600 million, about eight times the value of the raw minerals produced in the State. These figures, however, do not indicate the real importance of the mineral industry to the economy of Washington, for although only 1,900 persons were employed in mines and quarries, an additional 26,600 with an annual payroll of about $200 million were employed in processing the minerals, including smelting, refining, and casting of metals; manufacture of stone, clay, and glass products; petroleum refining, and the industrial chemical industry, including the Hanford atomic plant. Some of these processing plants treat principally raw materials that have been brought into the State, but nearly all draw on local sources for at least some of their raw materials. Some depend heavily on these local sources and could not operate without them; others use local materials exclusively. The State's resources of metallic and nonmetallic minerals contribute vital support to an important segment of its economy.

Coal and gold were the first minerals to be produced commercially in Washington. According to Glover (1954), coal was first discovered in 1833 in what was to become Washington Territory and was produced commercially for local use as early as 1853. Numerous other discoveries of coal soon followed, and by 1870 all the major coal fields in the State had been found. With the coming of the railroads and the rapid growth of the population, coal soon became the State's leading mineral product, a position it maintained for many years.

Gold also was discovered early in the history of Washington. In 1853 a party under Captain George B. McClellan searching for a railroad route across the Cascades is reported to have found placer gold in the Yakima Valley. Other placer gold localities were found in the same year between the Cascades and the Columbia River (Huntting, 1955). By 1855 placer gold was being mined along the Columbia and some of its tributaries in the vicinity of Fort Colville. Discovery of placers on the Similkameen River in 1859 brought a rush of miners to the area. Prospectors ranged through the country and others were found. Huntting (1955, p. 33) estimates that $9 million in placer gold was mined prior to 1866. The influx of miners to northeastern Washington was deeply resented by the Indian tribes and was one of the causes of the Indian wars that followed. The end result was the restriction of the Indian population to a few reservations and the opening of the State to settlement By 1900 most of the gold placers in Washington that had been found had been largely worked out.

The early history of lode mining has been described by Patty (1921). Lode mining did not begin until the early 1870's. The first known lode discovery was made near Mount Chopaka in Okanogan County in 1871 (Glover, 1954, p. 13). Locations were made on Silver Creek in the Index district in 1874. The Blewett area also was active in 1874, and the first stamp mill in the State was installed here in 1878. The first claims in the Monte Cristo district were located in 1889. The district was an important producer in the early days of mining in Washington, and a railroad was built into the district to serve the mines—the only railroad in the State constructed solely for mining purposes (Patty, 1921, p. 21).

The Lone Jack mine, the first important lode mine in the Mount Baker district, was discovered in 1897, but the district's placers were worked much earlier and occasioned a brief but lively gold rush when first discovered.

Lead-silver ore was found in Stevens County in 1893 near the present site of Colville, and rich ore from the Old Dominion mine was transported to Spokane by pack train. Impetus was given to mining by the building of a railroad into Stevens County, and numerous other discoveries of lode deposits were made in the Chewelah, Deer Trail, Northport, and other districts. The opening to prospecting of the north half of the Colville Indian Reservation in 1896 gave another impetus to mining in eastern Washington. Discovery of the important Republic district soon followed. Additional discoveries were made when the southern half of the reservation was opened to location in 1898. By 1900 most of the metal mining districts in the State were known, although it would be many years before some of them would be brought into production.

Figure 12 shows the growth of Washington's mineral production since 1900, when reliable records of production first became available. The lower curve gives the reported value in dollars. Because the value of the dollar has fluctuated widely, a more accurate measure of the magnitude of production is shown in the upper curve where the values are expressed in "constant dollars." In this curve the value of the dollar from 1957 to 1959, based on the wholesale price index, is taken as 100. The adjusted curve shows a steady increase in Washington's mineral production interrupted by some periods of low production, with the peak of production occurring at the start of World War II. If the current demand for the minerals Washington produces continues, the next few years should see production reach a new peak.

In contrast to some of the other western States, Washington is predominantly a producer of nonmetallic minerals. Of the estimated $1.8 billion worth of minerals mined or quarried from the State since 1866, 80.7 percent has come from nonmetallic minerals and only 19.3 percent was from metallic ores. This ratio still holds true; in 1963 81.6 percent of the value of the State's mineral production came from nonmetallic minerals and only 18.4 percent from metallic ores (fig. 13). In terms of total production and value of the product, coal, sand and gravel, and stone (including limestone for portland cement) are by far the most important mineral commodities produced in the State. Zinc, gold, lead, copper, uranium, and silver are the next most important commodities produced, but the total value of all these metals combined does not equal the value of the coal (fig. 13).

Coal production reached a peak about 1918. Since then it has declined drastically owing chiefly to the increased use of oil as a fuel, to the availability of cheap hydroelectric power throughout the Pacific Northwest, and to competition from Utah and Wyoming coal. Conversion of the railroads to diesel or electric power was a nearly fatal blow. The decline of coal as a factor in the mineral economy of the State is illustrated graphically in figure 13, which shows that, whereas coal has accounted for nearly 25 percent of the value of all minerals produced in Washington since the beginning of records, in 1963 it accounted for less than 2 percent of the mineral production. The efficiency of steam generating plants has increased markedly in recent years, and the more favorable hydroelectric power sites in the Northwest are rapidly being preempted. In addition, research may develop new uses for coal. Although no immediate improvement can be anticipated, Washington's substantial resources of coal should in the coming years once again become an important segment of the State's mineral industry.

The production of metallic minerals has shown a healthy growth in spite of low prices for lead and zinc which have been in effect from the early 1950's until recently, and despite the fact that some ore bodies have been mined out and are now abandoned. Among the outstanding events of the last 10 years or so have been the mechanization—and consequent increase in production—of the Metaline district, the development of the Gold King mine at Wenatchee into a major gold and silver producer, important developments in the Republic district, and the discovery of a highly profitable uranium mine on the Spokane Indian Reservation. The successful operation of the Van Stone mine and, more recently, the bringing in of the Calhoun mine

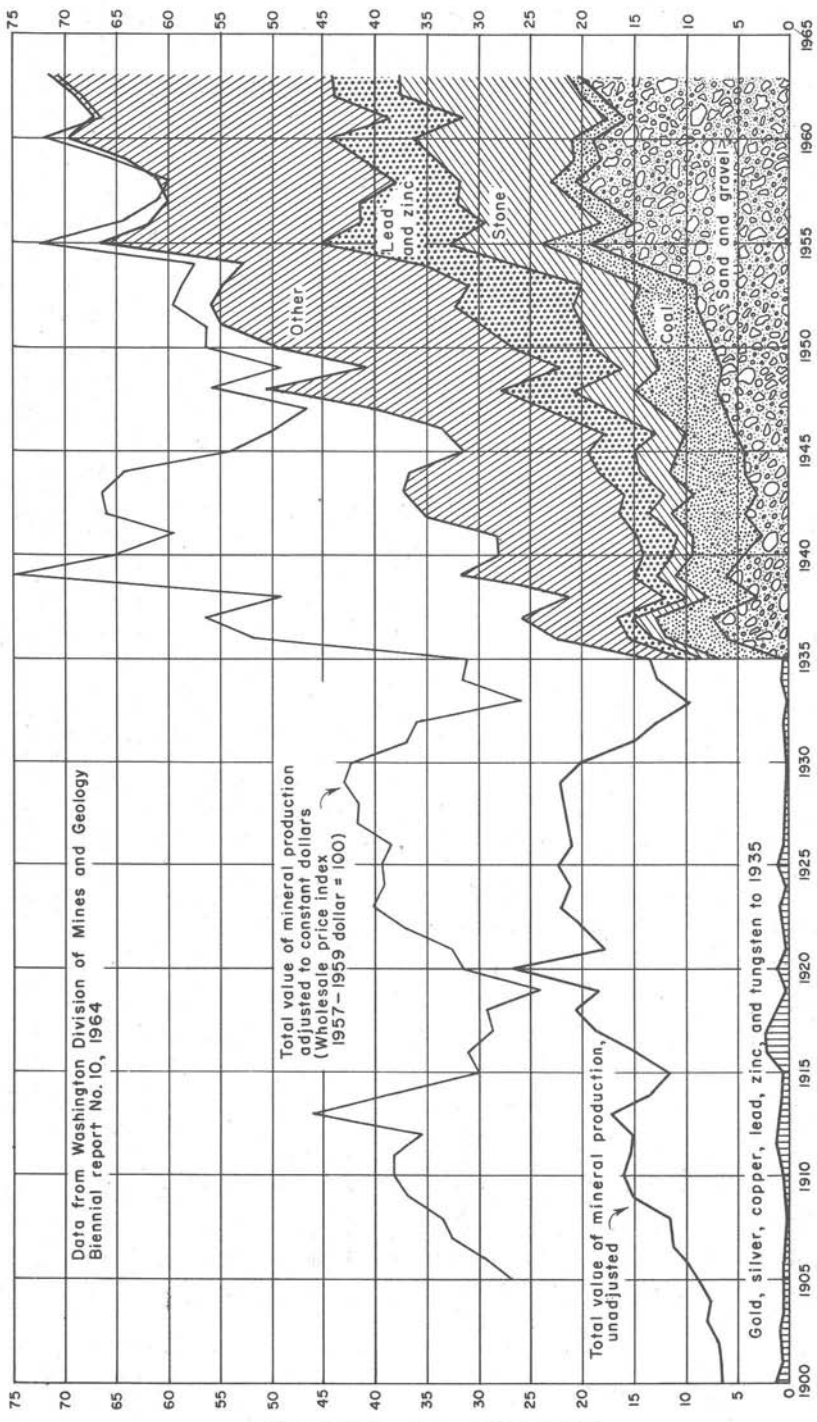

FIGURE 12.—Mineral production of Washington, 1900–63.

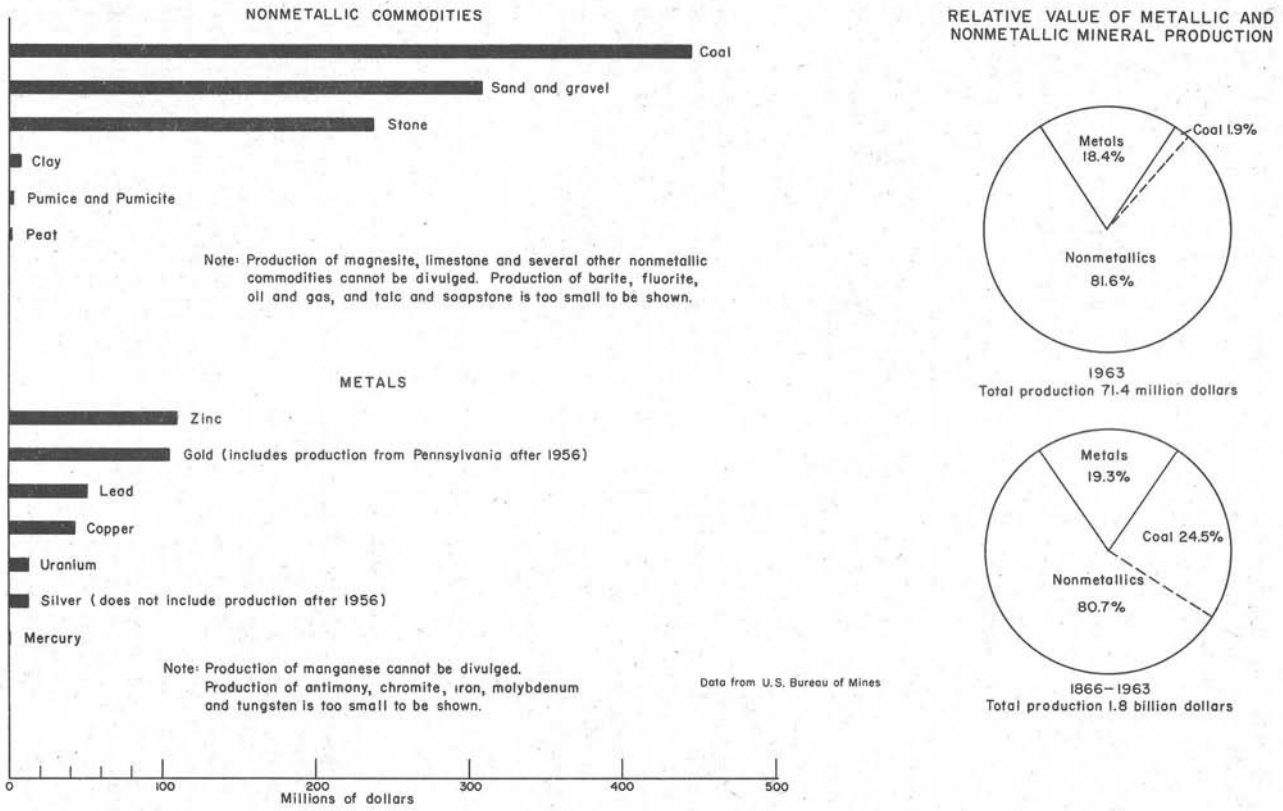

FIGURE 13.—Washington's mineral production by commodities.

have shown that mining in Stevens County need not be confined to the high-grade ore bodies from which most of the past production has come. These developments also show that even though most areas in northeastern Washington and in many parts of the Cascades have been thoroughly combed by prospectors during several periods of prospecting, application of new techniques of exploration, and mining and of new concepts of geology can discover new ore bodies. With price levels that will encourage exploration, discoveries should be made that will permit the continued growth of Washington's metal mining industry.

Nonmetallic mining has long been an important segment of Washington's mineral industry. With the continued growth of the State and its increasing industrialization, there will be an increased demand for nonmetallic minerals. Production of sand and gravel, cement, and other materials for the construction industry will increase. Production of olivine has increased rapidly in the last few years and should continue to grow. As the population increases, there will probably be a demand for other products which the State does not now produce or produces in small amounts.

Exploration in Washington for petroleum and natural gas has met with indifferent success up to now, although gas fields in Benton and Whatcom Counties and oil production in Grays Harbor and Jefferson Counties have proven that sources of petroleum and natural gas are present. Only about 100 wells have been located on sites selected as a result of sound geological investigations, and these provide inadequate coverage of the State's potential petroleum areas. Only further test drilling can determine whether oil and gas in commercial quantities occur in Washington.

Metallic Mineral Resources

ANTIMONY

(By D. R. MacLaren, U.S. Geological Survey Spokane, Wash.)

Antimony is a silvery white, soft, brittle metal chemically similar to arsenic and bismuth. It possesses three somewhat peculiar properties that strongly influence its uses; it expands on solidifying from a melt, it relatively strongly repells a magnetic field (a property called diamagnetism) and its electric conductivity varies markedly with changes in temperature. Antimony is most commonly used as an alloy, principally with lead for type metal, storage battery plates, sheeting and pipes used in the chemical industry, cable covering, castings, and ammunition. Other common alloys are with lead and tin for solder and machine bearings, and with copper and zinc for brass and brass products. Besides its use as an alloy, antimony is used in pharmaceuticals, laboratory chemicals, ceramics, and plastics.

There are many minerals that contain antimony, but the only important ore minerals are stibnite, Sb_2S_3, and to a lesser extent tetrahedrite ($Cu_{12}Sb_4S_{13}$), which is primarily an ore mineral of copper. Sometimes silver replaces part of the copper in tetrahedrite, which may then become an important ore mineral of silver. Whether it is a copper or silver ore mineral, the antimony is usually only a detriment to its value. A notable exception is the tetrahedrite silver ore of the

Sunshine mine in Idaho, from which the antimony is recovered by an electrolytic process.

The United States has been mostly dependent on foreign sources of antimony. In the past, Mexico, China, and Bolivia were the principal foreign sources (Purdy, 1951, p. 15), but during 1951 China ceased exporting antimony to the United States. In 1963, the principal imports of antimony were 4,337 short tons from Mexico, 4,010 short tons from the Republic of South Africa, and 988 short tons from Bolivia (Moulds, 1964, p. 241).

Nearly two-thirds of the antimony produced domestically is obtained from reclaiming antimonial scrap. Most of the rest is antimony or antimonial lead obtained at primary smelters as a by-product of treating imported antimonial ores. In 1963, only 645 tons of antimony was produced from domestic mines, nearly all of which was recovered from the treatment of the tetrahedrite ore by the Sunshine Mining Company at Kellogg, Idaho.

The total recorded production from Washington has been a little more than 3,300 tons of antimony ore, of which 2,300 tons was produced during World War I (Huntting, 1956). The last recorded production from the State was from the Bales property in 1952 (Huntting, 1956).

The first discovery of antimony in Washington was made in 1892 at the Great Republic mine in King County. Since that year, numerous occurrences of antimony have been reported. Huntting (1956) lists 275 mines and prospects where antimony minerals occur, but antimony production has been recorded from only 9 mines. Of these, only the Antimony Bell (fig. 14, No. 14), Antimony Queen (No. 13), Bales (No. 10), and Lucky Knock (No. 9) mines in Okanogan County were primarily producers of stibnite. Grand Central (No. 18) and Great Republic (No. 21) were primarily gold mines from which stibnite was recovered. The other mines from which antimony production has been reported and many of the reported occurrences of antimony contain tetrahedrite rather than stibnite, and their ores or potential ores are principally valuable for silver, gold, copper, or lead. Only those properties from which production of antimony has been reported and several of the reported occurrences containing stibnite are shown on figure 14.

Stibnite forms at relatively low temperature and pressure and is therefore usually deposited at or near the surface, with no apparent affinity for any particular rock type. In Washington, it is found in rocks of various types and ages, as a description of a few of its occurrences will illustrate.

At the Antimony Queen mine (fig. 14, No. 13) the rocks are irregularly interbedded argillite and graywacke of Triassic or Jurassic(?) age. Stibnite ore shoots, up to 2 feet wide and 40 feet long, occur in quartz veins and breccia zones in the argillite. From 1907 through 1941, the mine has produced more than 1,100 tons of ore (Huntting, 1956). Purdy (1951, p. 109) indicates that 1,000 tons of stibnite ore and several hundred tons of antimony oxide, prepared at a small plant near the mine, were shipped in 1916 and 33 tons of stibnite ore was shipped in 1941.

At the Lucky Knock mine (fig. 14, No. 9) irregular pockets of stibnite intermittently replace metamorphosed limestone of the Anarchist Series of Daly (1912) of late Paleozoic age. This is the

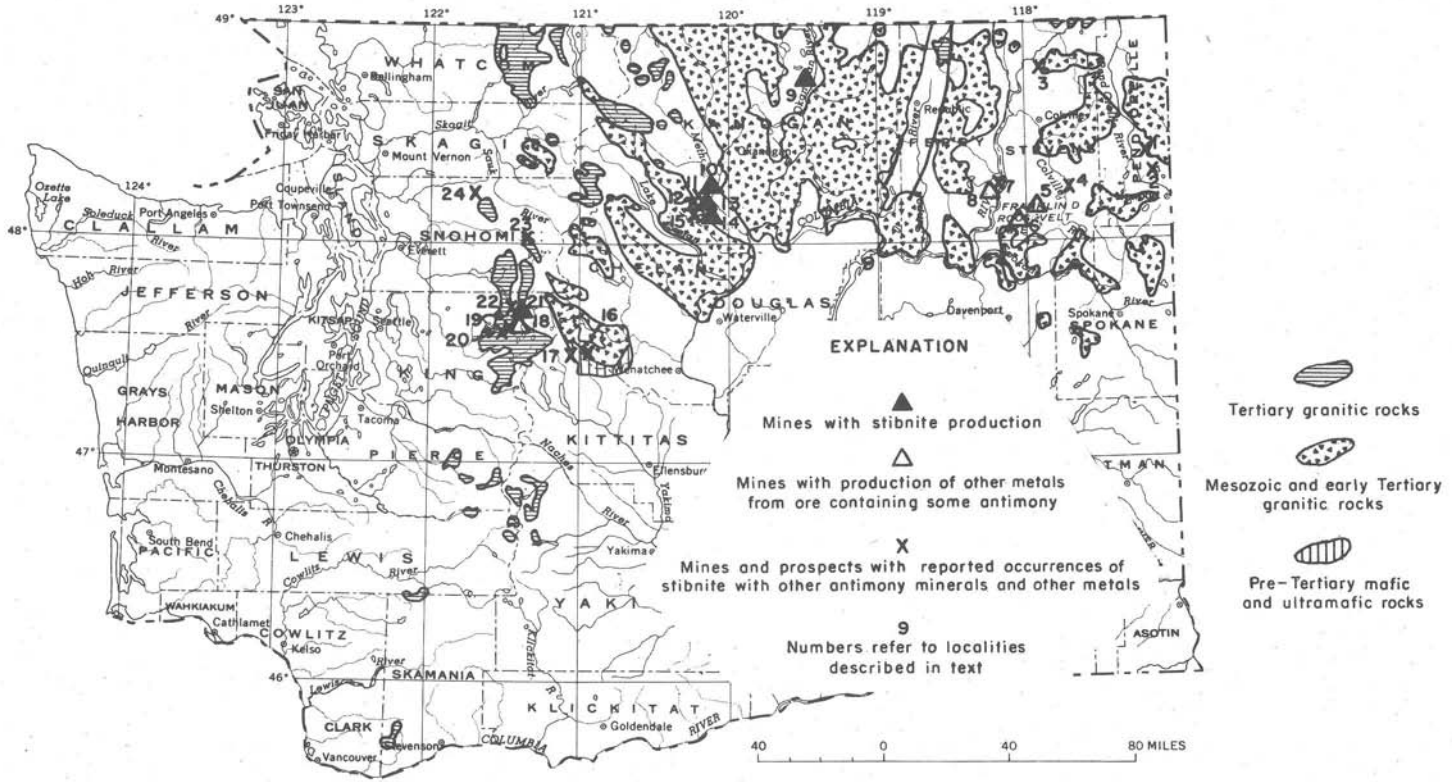

FIGURE 14.—Occurrences of antimony in Washington.

only known locality in the State where clusters of stibnite crystals have been found. Purdy (1951, p. 103) believes that the source of the stibnite is related to Tertiary andesite flows rather than to the nearby granitic intrusives of Mesozoic age. Production from this mine has been about 650 tons, all but 50 tons prior to 1949 (Huntting, 1956, Purdy, 1951, pp. 94–96).

The Bales mine (fig. 14, No. 10) is in an area of altered metamorphic rocks of the Leecher Metamorphics of Barksdale (1948). Three miles east of the property is an intrusive mass of quartz diorite, and 10 miles south is the Chelan granodiorite batholith. Lenses and stringers of stibnite and quartz occur along shear zones in thin-bedded limy hornblende schist. Shear zones containing stibnite lenses 2 to 12 inches thick have been traced by trenches for more than 600 feet horizontally and by drifts and crosscuts for more than 550 feet vertically. Huntting (1956) estimates that 100 tons of stibnite ore was produced from this property in 1951–52.

The Longstreet and adjacent Robert E. Lee mines (fig. 14, No. 8) are developed along an alaskite dike in a mass of Triassic or early Tertiary granodiorite. The granodiorite has been strongly altered and is mineralized along each side of the dike. On the hanging-wall side of the dike the only sulfide mineral is stibnite (Purdy, 1951, pp. 68–69). On the footwall side of the dike the altered zone, 10 to 15 feet wide, contains alternating bands of kaolinized and silicified material. Some of the silicified bands contain disseminated specks of pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, and galena, but no antimony mineral. In places, this assemblage constitutes ore containing up to 15 ounces of silver per ton and $6.00 per ton in gold.

At the Robert E. Lee, stibnite occurs along small discontinuous fractures but is not abundant. At the Longstreet, stibnite occurs in sparse amounts in a breccia composed of highly silicified fragments of granodiorite. According to Huntting (1956), 120 tons of ore was shipped, probably for the silver content.

The Great Republic mine (fig. 14, No. 21) is in Keechelus Andesite Series of former usage of Eocene to Miocene age. Stibnite occurs as small lenses up to 3 feet thick in quartz veins along a low-angle fault. The stibnite lenses appear to have an extremely erratic distribution, and exploration from one lens to the next might cost more than the value of the lenses discovered. Some stibnite ore was produced in 1938–1941 (Huntting, 1956), but the amount is not known.

Another mine in which stibnite has been reported is the Grand Central (fig. 14, No. 18). Here, the stibnite occurs in narrow veinlets of quartz, calcite, and pyrite in a 40-foot wide zone in the Keechelus Andesite Series. An unstated amount of ore was shipped in 1908, probably for its gold content (Huntting, 1956).

At the Antimony Bell mine (fig. 14, No. 14) a series of black argillites, graywackes, tuffs, breccias, and meta-lavas of andesitic and possibly basaltic composition of the Jurassic and Cretaceous(?) Newby Formation of Barksdale (1948) have been intruded by small stocks of hornblende quartz diorite. Small lenses of stibnite are found in shear fractures in greenstone, apparently an altered basalt (Purdy, 1951, p. 108). Purdy reports a shipment of 3 tons of stibnite ore from a lens 2 feet thick. Huntting (1956) reports a shipment of 1,300 pounds of stibnite ore in 1940, but whether this is included in the 3 tons mentioned by Purdy is not known.

The Wells Fargo mine (fig. 14, No. 5) is in an area of alternate beds of gray slate and thin beds of quartzite, Precambrian in age. Stibnite fills vugs in quartz veins and locally replaces sugary quartz. A small shipment of stibnite ore was made in 1937 (Purdy, 1951, p. 148).

At the Cleveland mine (fig. 14, No. 6) a series of Precambrian argillites, quartzites, slates, and dolomites is cut by diorite dikes and sills. Stibnite, tetrahedrite, and boulangerite occur as irregularly scattered bunches in quartz veins in the quartzite and slate and along shear zones in the dolomite near the diorite. Huntting (1956) reports production at 1,500 tons prior to 1897, and Purdy (1951, p. 137) reports several cars of boulangerite concentrates were shipped in 1946–47. This ore is primarily one of lead, and it is doubtful that much antimony was or will be recovered from this source.

Other properties shown on figure 14 contain small amounts of stibnite and are included principally to indicate the areas of distribution; they offer little promise of contributing to the antimony reserves of Washington. Most of them, however, have had very little development and small deposits of minable stibnite might be discovered by further work.

No. 1.—The Pinnel prospect, consisting of two small cuts in Precambrian quartzite, exposes lenses of intermixed quartz and stibnite ½-inch wide and 4 inches in diameter (Huntting, 1956). The prospect is about 100 feet west of a mass of Tertiary(?) granodiorite.

No. 2.—At the Lena Bell prospect a lens of massive stibnite 18 inches thick and 10 feet long occurs in Precambrian dolomite. Locally, the mineral fills short narrow stringers in fractures in Precambrian quartzite near a Tertiary grandodiorite mass (Huntting, 1956).

No. 3.—At the Tile Creek prospect stibnite occurs along fractures and vugs in a quartz lens along a limestone-argillite contact (Purdy, 1951, p. 145).

No. 4.—The Schrenberg prospect is in an area of Precambrian dolomite. Stibnite occurs as small lenses in the dolomite along the footwall of a 3-foot-wide quartz vein (Purdy, 1951, p. 144).

No. 7.—The Silver Lead is essentially a silver prospect. Small amounts of stibnite occur in small irregular segregations with calcite in silicified dolomite about 150 feet from a granodiorite stock (Purdy, 1951, p. 144).

No. 11.—At the Stibnite prospect a weak shear zone in altered quartz-hornblende diorite contains small pods of stibnite, possibly as much as 2 feet thick (Purdy, 1951, p. 125).

No. 12.—The geologic setting at the Jumbo prospect is similar to that at the Antimony Queen (No. 13). Sibnite occurs in a mineralized shear zone up to 2 feet wide in Mesozoic argillite and conglomerate.

No. 15.—At the Coyote prospect a small amount of stibnite occurs for about 10 feet along a 2-inch-wide brecciated shear zone in interbedded conglomerate, graywacke, and black argillite (Purdy, 1951, p. 123).

No. 16.—Rocks at the Snook and Ellen (Van Epps) prospect are diorite and serpentine. Small amounts of stibnite associated with arsenopyrite, chalcopyrite, and other sulfide minerals occur along a silicified and carbonatized contact. This zone ranges from 10 to 20 feet wide and has been followed along its strike for 220 feet (Purdy, 1951, p. 63; Huntting, 1956).

No. 17.—At the Denny (Goat Mountain) prospect stibnite occurs widely scattered in a 6-inch-wide quartz vein in sandstone of the Swauk Formation of Eocene age, and in a breccia along a fault contact between Swauk rocks and serpentine (Purdy, 1951, p. 88).

No. 19.—The Dawson prospect is in an area of granodiorite. An altered zone about 11 feet wide is mineralized mostly by pyrite and a little stibnite, which occurs in radiating clusters (Huntting, 1956).

No. 20.—The Bear Basin prospect is essentially a silver prospect. Some stibnite is found in a sericitized and mineralized fault zone that pinches and swells from thin seams to lenses 4 feet thick in granodiorite (Huntting, 1956).

No. 22.—Gold Mountain prospect is also essentially a silver prospect. Two well-defined veins containing pyrite, argentiferous stibnite, and some chalcopyrite reportedly occur in pyritized and kaolinized Keechelus Andesite (Huntting, 1956).

No. 23.—The Foggy mine is in an area of quartz diorite and schist. Purdy (1951, p. 135) believes the schist is the result of the metamorphism of andesite correlative with the Keechelus Andesite farther south. The Foggy vein and its numerous branch veins are developed along joints cutting both rocks. Stibnite in relatively large amounts, particularly at intersections of branch veins with the main vein, is associated with chalcopyrite, galena, sphalerite, and realgar. The average grade of many samples is 5.5 percent antimony, 0.2 ounce gold and 8.0 ounces silver per ton, 3 to 5 percent zinc, 3 to 4 percent lead, and 3.15 percent arsenic. If a large enough volume of the 5.5-percent antimony is stibnite, an economic concentrate might be made. There is no record of production, although some ore is believed to have been shipped (Huntting, 1956).

No. 24.—The John Feldt mine is in an area of andesite and quartz latite flows. Stibnite and bertheirite with tetrahedrite, chalcopyrite, and other metallic sulfide minerals fill open spaces between breccia fragments along a fault zone (Huntting, 1956).

Stibnite is known to occur at many localities in the State and in rocks ranging from Precambrian metamorphics to Tertiary lavas. The most promising areas in which significant amounts of stibnite might be found are the borders of mining areas in which well-fractured sedimentary or volcanic rocks are found and where mineralization took place during late Mesozoic or Tertiary times. Although the chance of Washington becoming a large producer of antimony is slight, additional exploration in at least three areas might result in worthwhile discoveries. In the order of their importance, the areas are: first, in Okanogan County on the east slope of the Cascade Mountains in the area that includes the Bales, Antimony Queen, Antimony Bell, Stibnite, Jumbo, and Coyote properties; second, in Okanogan County in the vicinity of the Lucky Knock mine; third, in King County west of the crest of the Cascade Mountains in the area that includes the Great Republic, Grand Central, Dawson, Bear Basin, and Gold Mountain properties. A fourth area that might deserve further investigation is the area that includes the Wells Fargo, Cleveland, Longstreet, Robert E. Lee, and Silver Leaf properties.

BAUXITE

(By V. E. Livingston, Jr., Washington Division of Mines and Geology, Olympia, Wash.)

Bauxite is the principal ore of aluminum. It is a mixture of varying proportions of three hydrous aluminum oxide minerals—gibbsite, boehmite, and diaspore. The impurities found in bauxite are clay minerals (kaolinite and halloysite), iron oxides, titanium oxides, and a number of minor accessory minerals. A more detailed discussion of the mineralogy of bauxite is given by Gordon and others (1958, pp. 71–75). In the Washington ferruginous bauxite deposits, gibbsite is the most abundant mineral. Boehmite occurs in small amounts; goethite and other iron oxides are plentiful.

Most of the bauxite deposits of the world are aluminous laterites that have been formed under tropical conditions. They are the result of leaching of silica and magnesia from the underlying bedrock. The principal requirements for the formation of laterite are abundant rainfall, good drainage, and a warm climate. The bedrock must have a moderate to high alumina content, but aside from this the bedrock type does not seem particularly important. In Europe and Jamaica, buaxite has formed in limestone sinkholes; South American bauxites have formed on schistose rocks; in Sarawak, bauxites have formed on gabbro, andesite, diorite, basalt, and amphibolite; and in Arkansas, bauxite is derived from nepheline syenite. The known bauxite deposits of Washington are the result of the weathering of Miocene basalt. They were formed in Pliocene time when a warmer climate prevailed than exists today. Because the mother rock—the basalt—was high in iron, bauxite derived from it is also high in iron.

More than 90 percent of the bauxite consumed in the United States is converted to alumina, and then to aluminum (Wilmot, 1960, p. 20). Bauxite is also used to manufacture abrasives and refractories and to make high-alumina cement and low-density insulating materials. It is also used in the chemical industry, as an absorbent or catalyst in the oil industry, and as a flux in making steel and alloys.

Bauxite is processed in two steps to make aluminum. The first step is the extraction of alumina from the bauxite; the second stage is the reduction of alumina to aluminum.

In the Bayer process, bauxite is put through a hot caustic leach under high pressure, yielding a sodium aluminate solution from which the alumina is precipitated and dried. Only high-grade bauxite can be used in the Bayer process. The Washington bauxite contains too much iron to be treated by this process.

In Norway, alumina is extracted by the Pederson process from high-iron bauxite similar to Washington bauxite. The bauxite is smelted in an electric furnace with limestone, iron ore, and coke to form pig iron and a calcium aluminate slag. Alumina is leached from the clay by a sodium carbonate solution and precipitated by the addition of carbon dioxide. Both pig iron and alumina are recovered by this process.

Acid-leach processes have been developed within the past few years using Northwest ores. However, by these processes the iron is not extracted from the ore in a usable form.

Regardless of how it was obtained, the alumina is reduced to aluminum by the Hall-Heroult process. In this process, alumina is introduced into a molten cryolite bath in an electric furnace lined with carbon, and reduced to the metallic form by electrolysis.

According to Patterson (1963) world bauxite reserves [1] are 5,760 million metric tons. World production of bauxite amounted to almost 30 million metric tons during 1963 (Williams and Stamper, 1964b, p. 289). The United States produced 1.4 million long tons, most of which came from Arkansas. Washington has no record of production. World resources and world production of bauxite are shown by continent in figure 15 (a and b).

The known bauxite deposits of Washington are located in Cowlitz and Wahkiakum Counties in the southwestern part of the State (fig. 16). Washington bauxites are ferruginous (rich in iron) and, in fact, could be considered as a source of iron in conjunction with the extraction of alumina. Average analysis for Washington bauxite is about 39 percent Al_2O_3, 7 percent SiO_2, 29 percent Fe_2O_3, 4 percent TiO_2, and 21 percent loss on ignition.

The bauxite deposits of southwest Washington were formed by the laterization of basalt flows some time during the Pliocene. The bauxite deposits across the Columbia River to the south in Oregon were formed at the same time and in the same way. According to Allen (1948), the basalt was first weathered and altered to clay, and then by leaching and removal of silica the clay was converted to bauxite.

Many of the flat-topped ridges between Kelso on the east and Cathlamet on the west are capped by bauxite, which, depending on the locality, may or may not be overlain by a bed of silt. The bauxite grades gradually downward into a kaolinitic clay, which in turn grades into basalt. Maximum thickness of the bauxite is probably between 15 and 20 feet, and it covers well over 2,000 acres. The maximum thickness of the silt overburden is about 30 feet.

The bauxite deposits of southwest Washington could easily be mined by inexpensive strip-pit methods and are adjacent to the cheap water transportation of the Columbia River. There are four alumina reduction plants along the lower Columbia River, located at Longview and Vancouver, Washington, and Troutdale and The Dalles, Oreg., that could utilize the alumina extracted from the bauxite. These and four other plants in the State are shown on figure 16). The U.S. Bureau of Mines has developed an acid-leach process (Holbrook and Yerkes, 1963) using Oregon bauxite, and an acid-leach process developed by T. R. Scott (1962, pp. 121–125) of the Commonwealth Scientific and Industrial Organization of Australia has been successfully used in extracting alumina from Washington ores in preliminary tests. Harvey Aluminum, Inc., is reported to have successfully run some preliminary tests on northwest Oregon bauxite using the Pederson process. Chittenden and Moulton (1951), McCarthy and others (1949), and Thompson and others (1949) have all reported on methods of extracting alumina from Oregon ores.

[1] Measured and indicated reserves that in some degree have been inventoried in terms of commercial enterprise and could be used under economic and technical conditions existing in 1963.

55-883 O—66——5

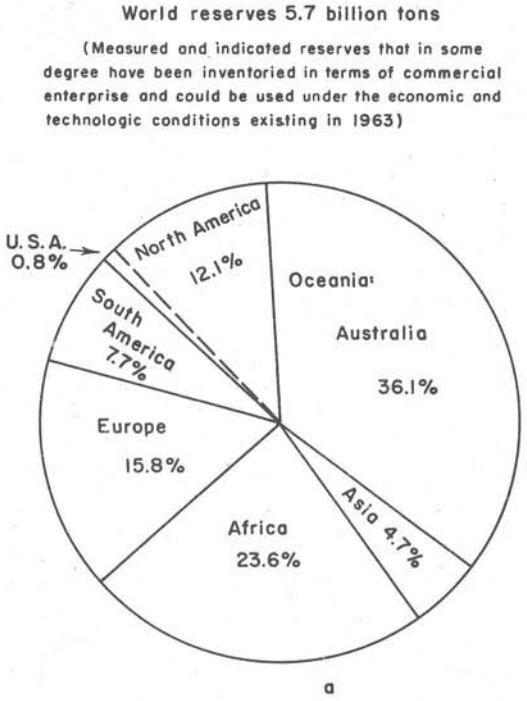

FIGURE 15a.—World bauxite reserves by continent. United States shown by dashed line in North America (after Patterson, 1963).

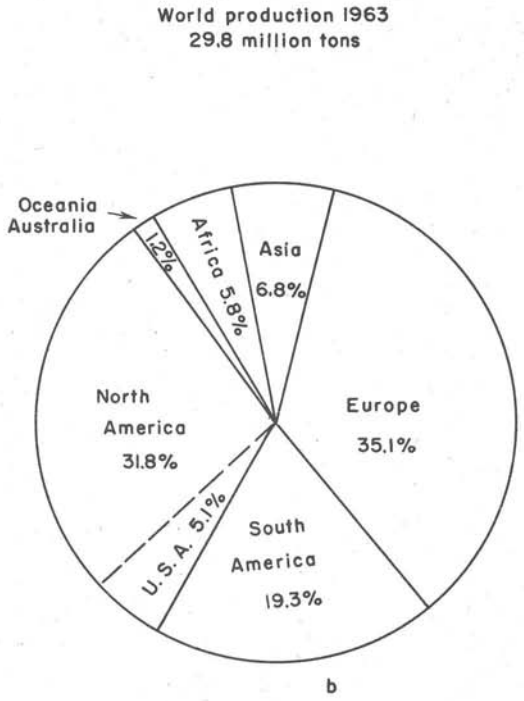

FIGURE 15b.—1963 world production of bauxite by continent. United States shown by dashed line in North America (after Williams and Stamper, 1964).

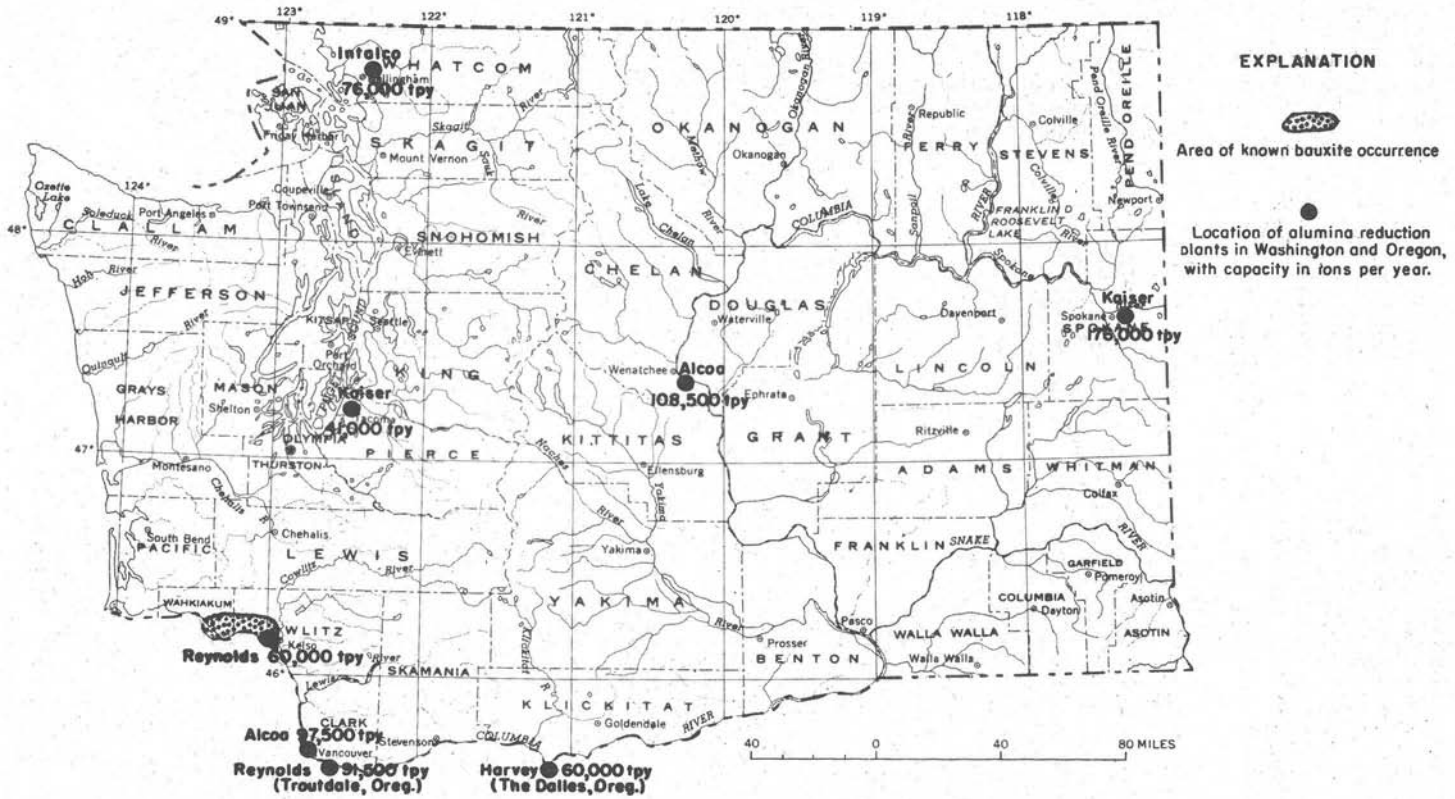

FIGURE 16.—Bauxite deposits in Washington and alumina reduction plants in Washington and Oregon.

The known bauxite deposits of Washington represent a resource of substantial size that has not yet been utilized. Combined with Oregon's similar deposits, they form a resource of large dimensions. The technical feasibility of producing alumina from these materials has been shown. With eight major aluminum plants close to the bauxite area, it is only a matter of time until the bauxite deposits of Washington will be mined. If the Pederson process, or some variant of it, is used, pig iron will be a valuable byproduct.

BERYLLIUM

(By F. G. Lesure, U.S. Geological Survey, Washington, D.C., and A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Beryllium is a light nonductile metal that is brittle at room temperatures. It has a number of uses both as pure and alloyed metal and in chemical compounds. The metal is used in special applications for aircraft, missiles, space exploration vehicles, and nuclear energy. Beryllium-copper alloys are used widely because of high strength, and high thermal and electrical conductivity. Alloys with aluminum, nickel, and magnesium are also used on a small scale. Beryllium compounds are used as a minor constituent in high-voltage electrical porcelain and glass.

Pegmatitic beryl is the principal source of beryllium in the world today, but recently discovered low-grade deposits of nonpegmatitic beryllium minerals will probably become important sources of beryllium in the future. Beryl is a beryllium aluminum silicate ($Be_3Al_2Si_6O_{18}$) commonly found as simple prismatic hexagonal crystals that range in diameter from less than an inch to a foot or more. Clear green crystals of gem quality are better known as emerald and the blue as aquamarine. The beryllium content of beryl can be as great as 14 percent BeO but is generally 12 percent or less because some of the beryllium is replaced by other elements. Beryl occurs disseminated throughout an unzoned pegmatite, but more generally is concentrated in certain beryl-rich zones in zoned pegmatites. Beryl is recovered by hand cobbing the material mined from beryl-rich zones. Crystals less than 1 inch in diameter cannot generally be recovered economically by hand sorting. Recovery of fine-grained beryl by milling and flotation methods has been successful in the laboratory but not on a commercial basis (Eilertsen, 1960, p. 98).

The United States depends largely on foreign imports of beryl as a source of beryllium. Domestic production amounts to less than 6 percent of consumption. The principal domestic production in 1962 was 218 tons of hand-cobbed beryl from South Dakota, New Mexico, Colorado, New Hampshire, Arizona, Connecticut, Maine, and Wyoming. Low-grade beryllium ores from Colorado supplied nearly as much total BeO as the hand-cobbed beryl did. In 1963, domestic production of hand-cobbed beryl had practically ceased. The price of beryl ore, based on BeO content, is $29 to $32 per short ton unit or ore containing 10 to 12 percent BeO. This means that a ton of relatively pure beryl is worth $290 to $320.

Pegmatitic beryl is reported from several counties in Washington (see table 16 and fig. 41 in chapter on feldspar, mica, and other pegmatite minerals), but in general all the occurrences are too fine

grained for economic recovery by hand sorting, and the known deposits are not large enough for milling. A few tons of beryl ore were mined from the Railway Dike deposit of Stevens County in 1952.

As far as is known, little or no prospecting has been done for nonpegmatite beryllium in Washington. Beryllium is present in trace amounts in unaltered silicic volcanic rocks in the central and northeastern parts of the State (Coats and others, 1962, p. 964), and the complex assemblage of granitic and metamorphic rocks, especially in the Cascade Range, might also offer a favorable environment in which to search for deposits of nonpegmatitic beryllium. Search for rocks similar to those of the beryllium deposits of the Seward Peninsula might be productive (Sainsbury, 1964).

The west slope of Mount Spokane is underlain by a biotite quartz monzonite within which are numerous irregular large and small masses of alaskite—a rock distinguished from the quartz monzonite by a nearly complete absence of biotite and other dark minerals, an abundance of muscovite, and the presence of garnet as a common accessory mineral. The alaskite and, to a much lesser extent, the quartz monzonite are cut by innumerable quartz-feldspar-biotite-muscovite pegmatite veinlets and stringers. Beryl crystals have been noted in the pegmatites at two localities on the south slope of Mount Spokane. In both instances, the country rock consisted of alaskite. Spectrographic analyses of the alaskite show trace amounts of beryllium. One specimen without visible beryl assayed 0.2 percent Be on spectrographic analysis and 0.5 percent Be when tested with a berylometer. These data are inconclusive, but the seemingly anomalous beryllium content of the alaskite is at least of scientific interest.

Samples of brine from saline lakes in eastern Washington and of salt deposits surrounding them are reported by the Washington State Division of Mines and Geology to contain small amounts of beryllium (Bennett, 1962, p. 129), as shown in the following tabulation:

County	Locality	Sample	BeO (percent)
Grant	Carbonate Lake	Salt from brine pool, north end	0.01
	do	Mixed salts	.036
Okanogan	Hauan Lake	Hole 4, 0 to 9 feet	.02
	Poison Lake	Epsomite crystal	.013
	Lenton Flat	Surface	.01
	do	Hole 1, at 1½ feet	.01
	do	Hole 1 at 4 feet	.02
	do	Hole 1 at 6 feet	.02
	do	Hole 1, 6 to 16 feet	.02
	Bentley Lake	Hole 1, 0 to 7 feet	.03

The beryllium content is far too low to be of commercial interest but suggests further investigation of the salt deposits and of the surrounding rocks from which the beryllium must have been derived.

BISMUTH

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

World production of bismuth, according to the U.S. Bureau of Mines, has averaged (1959–63) 5,720,000 pounds (Moulds, 1964). The major producers from primary sources are Bolivia, Canada, Korea,

Mexico, Peru, and Yugoslavia. Japan, The Netherlands, and Sweden produce the metal during refining of base metal concentrates, most of which are imported. The United States is an important producer from primary sources, from imported concentrates, and from recovery in secondary material (scrap). From 1959 to 1963, consumption in the United States has averaged about 1,738,000 pounds, of which about 43 percent was imported. In 1963, Peru supplied about 65 percent, Mexico 15 percent, Canada 14 percent, and Yugoslavia and The Netherlands the rest. All domestic bismuth is produced as a by-product during the refining of lead bullion; no ores are mined for bismuth alone. At present, bismuth is reported as being produced by American Smelting & Refining Co., The Anaconda Co., U.S. Smelting Lead Refinery, Inc., and United Refining & Smelting Co. (Moulds, 1964, p. 311).

Consumption of bismuth in the United States in 1963 was 2,175,038 pounds. Thirty-seven percent was used for pharmaceuticals and industrial and laboratory chemicals; 35 percent for fusible alloys (automatic firefighting devices, tool-tempering baths, pattern making, and dental uses); 26 percent for other alloys (in aluminum and iron products to improve machinability, for precise molds and precision duplication); and less than 2 percent for experimental and other uses (Moulds, 1964). The special properties of bismuth for specific uses give little chance for much substitution by other materials.

Research by various organizations on uses of bismuth includes: improvement of fusible alloys; thermoelectric conversion for both cooling and power generation; use of liquid bismuth as a carrier for U^{-235} in a thermal reactor for generating power; and acquiring data on energy-change characteristics of mineral substances, including bismuth (Callaway, 1960).

Bismuth is chemically grouped with arsenic and antimony, all three being relatively rare constituents of the earth's crust; arsenic is most abundant of the three, bismuth least abundant (Rankama and Sahama, 1952, p. 738), occurring as 0.2 ppm in the earth's crust (Mason, 1952, p. 41). In spite of its relative scarcity, bismuth occurs in many ore deposits formed under high or moderate temperature conditions. It is relatively abundant in the cobalt-nickel-silver deposits of Cobalt, Ontario, and in the tin deposits of Bolivia. Much of the bismuth produced in the United States is present in minor amounts in hypogene deposits mined principally for gold, silver, copper, lead, zinc, molybdenum, or tungsten, or various combinations of these metals.

Primary bismuth minerals are: native bismuth (Bi) and maldonite (Au_2Bi), the sulfides bismuthinite (Bi_2S_3), guanajuatite ($Bi_2(SeS)_3$), the tetradymite group ($Bi_2(TeS)_3$) which includes at least five minerals, and kallilite (Ni(Sb,Bi)S). At least 23 sulfosalts of bismuth have been described. These are various combinations with lead, copper, and silver. Cosalite and galenobismuthite are examples. A different association of bismuth is with niobium-tantalum oxides (i.e., bismutotantalite) in pegmatites.

Although no bismuth has been reported as being produced from ores of Washington, Kaiser reports (Kaiser and others, 1954) that lead concentrate from the Kaaba mine (Okanogan County) and the Sierra Zinc mine (Stevens County) both contain 0.4 percent Bi_2O_3. If the lead concentrate was shipped to one of the refineries that produce

bismuth during lead refining, then this bismuth must have reached the market.

Secondary bismuth minerals include the oxides bismite and sillenite (Bi_2O_3), russellite ($(Bi_2W)O_3$), and uranospherite ($Bi_2O_3 \cdot 2UO_3 \cdot 3H_2O$); the carbonates bismutite ($(BiO_2)CO_3$) and beyerite ($Ca(BiO)_2(CO_3)_2$); montanite ($(BiO)_2(TeO_4) \cdot 2H_2O$); there are several arsenates, a vanadate, and a molybdate of bismuth. A number of other minerals contain minor amounts of bismuth.

Deposits in Washington in which bismuth minerals have been identified or in which bismuth has been reported include: two pegmatites (one of which, however, may be a hydrothermal deposit in a sheared pegmatite); one contact metamorphic deposit; six probably high-temperature hydrothermal deposits, four of which are valued mostly for their tungsten content; and nine of moderate (or unstated) temperature hydrothermal deposits valued for their content of gold, silver, lead, or copper, or combinations of these metals. Of these last, seven are vein deposits and two are disseminated deposits. The names, locations, and brief descriptions are listed in table 1.

TABLE 1.—*Deposits in which bismuth minerals have been identified or in whose ore bismuth has been detected by analysis*

Property	Location	Geology
CHELAN COUNTY		
Holden mine	T. 31 N., R. 16 E.	Disseminated deposit of chalcopyrite and sphalerite in metamorphic rocks cut by granite dikes. Copper concentrate, 0.03 percent Bi_2O_3 (Kaiser and others, 1954).
Keefer Bros	T. 31 N., R. 15 E.	Narrow fissures in granodiorite cutting schist and gneiss carry high-temperature hydrothermal minerals. Values in Mo, Cu, Au, Ag, W, U. Gangue is quartz, tourmaline, and chlorite.
FERRY COUNTY		
Talisman mine	T. 40 N., R. 36 E.	Contact deposit. Chalcopyrite, sphalerite, galena, scheelite, pyrite, and magnetite with epidote, garnet, and zoisite in schist.
GRANT COUNTY		
Electric City	T. 28 N., R. 30 E.	Molybdenite, pyrite, and pyrolusite with quartz and fluorite in sheared pegmatite in granite.
OKANOGAN COUNTY		
Arlington mine	T. 34 N., R. 25 E.	Galena, chalcopyrite, tetrahedrite, sphalerite, pyrite, and pyrargyrite in quartz vein in granite.
Kaaba mine	T. 40 N., R. 25 E.	Galena, chalcopyrite, sphalerite, pyrite, molybdenite, and scheelite in quartz-calcite vein along a lamprophyre-granite contact. Pb concentrate carries 0.4 percent Bi_2O_3 (Culver, 1945; Kaiser and others, 1954).
Key mine	T. 36 N., R. 25 E.	Galena, pyrite, chalcopyrite, and sphalerite in vein in granite and schist.
Mountain Beaver	T. 38 N., R. 20 E.	Pyrite and chalcopyrite carrying gold and silver in andesite agglomerate.
Peacock	T. 35 N., R. 25 E.	Galena, tetrahedrite, chalcopyrite, sphalerite, pyrrhotite, and pyrite in quartz-sericite veins along contact of granodiorite and metamorphic rocks.
Wolframite	T. 40 N., R. 22 E.	Wolframite, scheelite, pyrite, sphalerite, and galenobismutite in quartz veins in granite (Culver, 1945).
SNOHOMISH COUNTY		
Lucky Strike	T. 30 N., R. 9 E.	Chalcopyrite, bismuthinite, pyrite, and pyrrhotite in metamorphic rocks near granodiorite.
Silver Coin	T. 30 N., R. 9 E.	Chalcopyrite, cosalite, sphalerite, pyrite, and pyrrhotite in quartz-sericite-chlorite gangue in fractures in granite.

Source: Data from Huntting (1956), Cooper (1962), and others as shown.

TABLE 1.—*Deposits in which bismuth minerals have been identified or in whose ore bismuth has been detected by analysis*—Continued

Property	Location	Geology
STEVENS COUNTY		
Railway Dike (Cannon)	T. 34 N., R. 42 E.	Pegmatite carrying columbite, uraninite, beryl, and a little bismutite.
Daisy-Tempest	T. 33 N., R. 38 E.	Galena, chalcopyrite, pyrite, sphalerite, marcasite, scheelite, tetrahedrite, and arsenopyrite in quartz-calcite veins in argillite and quartzite cut by diorite (Culver, 1945).
Germania	T. 29 N., R. 37 E.	Wolframite, pyrite, scheelite, molybdenite, galenobismutite, and arsenopyrite in quartz-tourmaline-fluorite veins cutting granite (Culver, 1945).
Melrose	T. 40 N., R. 41 E.	Tetrahedrite, galena, sphalerite, and pyrite in quartz vein in argillite. One 3-ton shipment contained 1.01 percent Bi.
Sierra Zinc	T. 38 N., R. 41 E.	Sphalerite, galena, chalcopyrite, pyrite, and molybdenite disseminated in limestone. Lead concentrates carried 0.4 percent Bi_2O_3 (Kaiser and others, 1954).
Tungsten King	T. 30 N., R. 42 E.	Huebnerite, pyrite, molybdenite, and cosalite in quartz-sericite vein in schistose argillite. Tungsten concentrate carried 0.8 percent Bi_2O_3 (Culver, 1945; Kaiser and others, 1954).

CHROMIUM

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Chromite, the only mineral used as a source of chromium, has three major types of uses, as determined by grade: metallurgical-grade ore, averaging about 49 percent Cr_2O_3; chemical-grade, averaging about 47 percent Cr_2O_3; and refractory-grade, averaging about 44 percent Cr_2O_3.

In 1963, 1,187,000 tons of chromite, containing about 335,000 tons of the metal chromium, was consumed in the United States. Of this, the metallurgical industry used 53 percent in corrosion resistant steel, ferroalloys, copper and aluminum alloys, and as pure metal. The chemical industry used 16 percent, largely for electroplating, for pigments and in tanning. The refractory industry used 31 percent, mostly for lining steel furnaces.

Deposits of chromite in the United States are either too low grade or too small to be workable except during exceptional periods of high price, as during wars, or when the Government has offered incentive prices above that offered for foreign ores, as under the Defense Production Act of 1950. No chrome ore is being produced at present in the United States. The last domestic production was in 1961. Of the nearly 1.2 million tons of imported ore consumed in the United States in 1963 (U.S. Bur. Mines Minerals Yearbook, v. 1), 45 percent came from the Republic of South Africa, 22 percent from Federated Rhodesia and Nyasaland, 15 percent from the U.S.S.R., 11 percent from the Philippines, 6 percent from Turkey, and minor amounts from other countries, mostly in Africa.

Primary deposits of chromite are found only in ultramafic rocks—those high in magnesium and iron—such as peridotite or dunite. Two main types of deposits occur—the layered type, as for example the Stillwater deposit in Montana; or as irregular pods and disseminations, the alpine type (Thayer, 1960). Only the alpine type occurs in Washington. Deep weathering of ultramafic rocks under humid

conditions forms laterite in which the chromite present in the rocks as an accessory mineral is somewhat concentrated, the chromite being resistant to weathering. Erosion of chromite-bearing rocks can form concentrations of chromite in placers.

Little chromite has been produced in Washington. The total is less than 300 tons for the period 1900–1955 (Huntting, 1956). In 1956, a small tonnage was produced at the Cypress Island mine, Skagit County (Baher and others 1958, p. 1203), and in 1959 the U.S. Bureau of Mines obtained 9 tons of chrome ore from the Twin Sisters area for mineral dressing research.

Deposits that have had at least some production are described in the first part of table 2. All other chromite deposits listed by Huntting (1956) are likewise included in the table except those deposits indicated as of little value and those deposits occurring in "fossil laterite." The locations of the chromite deposits are shown in figure 17.

Except for the Johnson Creek deposit (fig. 17 and table 2, No. 3) the deposits listed in the table are associated with the larger masses of ultramafic rocks. Of these, the Twin Sisters mass is by far the largest and has the most known deposits. The ultramafic masses in the area from the Cle Elum River to Peshastin Creek, on Cypress Island, and at Sumas Mountain have only one or two deposits each. Many more deposits, either relatively small or with only a little development are listed by Huntting (1956).

TABLE 2.—*Chromite deposits of Washington (laterites not included)*

DEPOSITS THAT HAVE PRODUCED

Index No. on fig. 17	County, district, and property	Location	Geology and production	References
	KITTITAS			
	Cle Elum:			
1	Boulder Creek	Sec. 35, T. 23 N., R. 14 E.	Chromite in serpentinized peridotite; part of carload (World War I).	Huntting, 1956.
2	Mount Hawkins	Sec. 33, T. 23 N., R. 15 E.	Chromite lens in serpentine; about 45 tons before 1943.	Do.
	OKANOGAN			
3	Conconully: Johnson Creek	Sec. 5, T. 34 N., R. 26 E.	Chromite in nearly solid, tabular body in ultramafic rock near contact with dolomite; 5.9 tons, 42 percent Cr_2O_3 (1955).	Do.
	SKAGIT			
	Cypress Island:			
4	Last Chance	Sec. 29, T. 36 N., R. 1 E.	Chromite in serpentine. Some production.	Do.
5	Ready Cash	Sec. 30, T. 36 N., R. 1 E.	Chromite in pods and veinlets in serpentine; 75 tons before 1919, 45.5 percent Cr_2O_3.	Do.
	WHATCOM			
	Sisters:			
6	Danny	Sec. 19, T. 37 N., R. 7 E.	Lenses of nearly solid chromite in dunite; 1.5 tons, 51.7 percent Cr_2O_3, Cr/Fe 3.13 (1934).	Thayer and others, 1943; Huntting, 1956.
7	Ribbon	Sec. 7, T. 37 N., R. 7 E.	Lenses of chromite in dunite. Crude ore 51.2 percent Cr_2O_3, Cr/Fe 3.06; 20 tons.	Do.

OTHER DEPOSITS

Index No. on Fig. 17	County, district, and property	Location	Geology	References
	KITTITAS			
8	Cle Elum: Denny	Sec. 36, T. 23 N., R. 14 E.	Chromite in small pods and disseminated in serpentine	Huntting, 1956.
	SKAGIT			
9	Cypress Island: Cypress Lake.	Sec. 29, T. 36 N., R. 1 E.	Chromite in a lens and disseminated in serpentine	Do.
	Sisters:			
	McMaster			
10	Three Lakes (including	Sec. 10, T. 36 N., R. 7 E.	Chromite in dunite; 56.4 percent Cr_2O_3, Cr/Fe 2.58	Thayer and others, 1943.
11	Leader and Meadow).	Secs. 3 and 4, T. 36 N., R. 7 E.	Chromite in bands, lenses and disseminated in dunite zones up to 145 feet wide. Cr/Fe 2.35 to 2.9. Large tonnage of low- to medium-grade material probably present.	Thayer and others, 1943; Huntting, 1956.
	WHATCOM			
	Sisters:			
12	Bumper	Sec. 13, T. 37 N., R. 6 E.	Chromite in lenses and pods in dunite	Huntting, 1956.
13	Galbraith	Sec. 8, T. 37 N., R. 7 E.	Lenses and stringers of chromite in dunite	Do.
14	Good Hope	Sec. 18, T. 37 N., R. 7 E.	Stringers of chromite in dunite	Do.
15	Lambert	Sec. 23, T. 37 N., R. 6 E.	Chromite in banded and disseminated zones up to 50 feet wide in dunite. Has several thousand tons of 50-percent chromite. Cr/Fe 2.65.	Do.
16	Opportunity	Sec. 18, T. 37 N., R. 7 E.	Chromite in schlieren with 60-percent chromite in dunite	Do.
17	Second Basin	Secs. 29 and 30, T. 37 N., R. 7 E.	Chromite in dunite	Do.
18	Thunder Mountain	Sec. 11, T. 37 N., R. 6 E.	Stringers and streaks of chromite in dunite in area 50 by by 50 feet.	Do.
19	Sumas Mountain: Sumas Mountain.	Sec. 30, T. 40 N., R. 5 E.	Chromite in bands ¼ to 2 inches wide, lenses up to 4 inches wide, and disseminations in serpentine.	Moen, 1962.

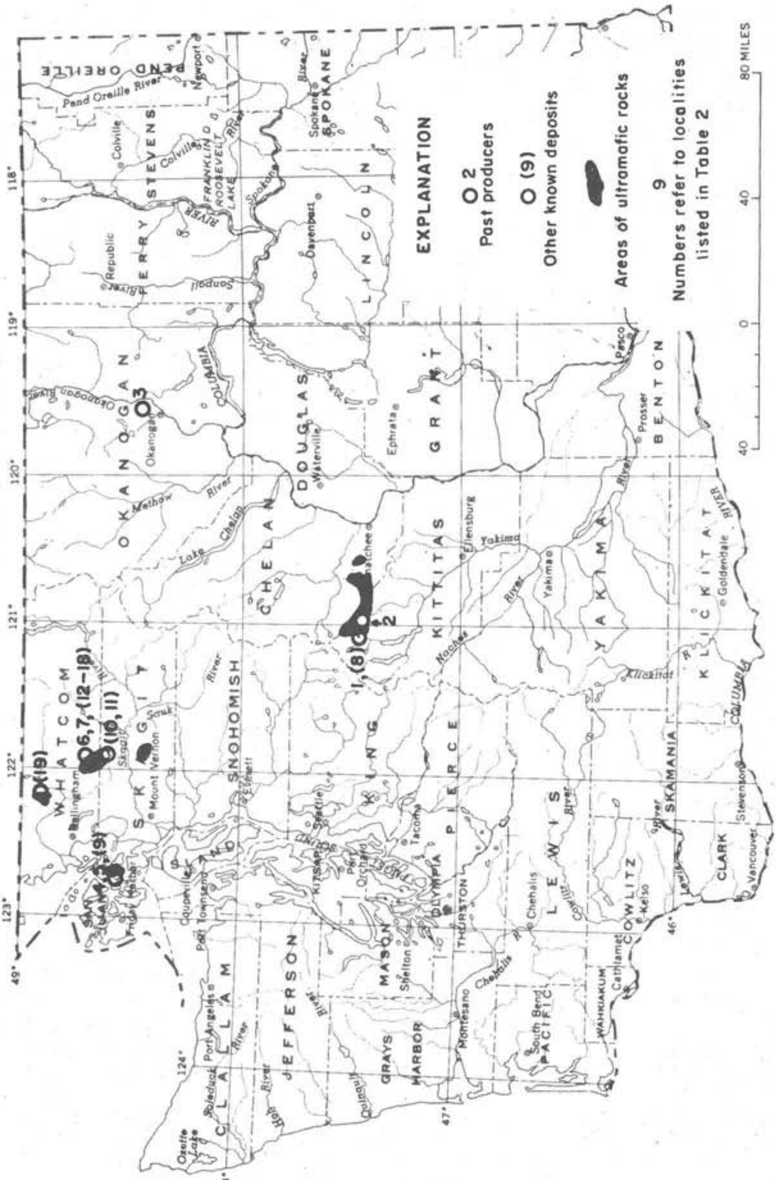

FIGURE 17.—Chromite deposits in Washington.

When ultramafic rocks of pre-Tertiary age in western Washington were exposed to weathering in early Tertiary time, warm humid climate prevailed. Deep laterite was formed, high in iron oxide, and with the chromium, nickel, and cobalt content of the ultramafic rock somewhat concentrated. Later, the laterite was covered by Tertiary continental sediments (the Swauk Formation and others of similar age to the west). Recent erosion has re-exposed this "fossil laterite" at several places in the State. Many deposits are at the basal contact of the Swauk Formation with the crescent-shaped band of ultramafic rock around the south side of the Mount Stuart batholith, between the Cle Elum River and Peshastin Creek. The large number of individual deposits lying along this contact are not listed in table 3, nor are the smaller deposits on Sumas Mountain and southeast of Silverton. Lamey and Hotz (1952) state that the average composition (percent) of the Cle Elum deposit is:

Fe	40.86	Al_2O_3	16.41
Ni	0.84	P	0.052
Cr_2O_3	2.40	S	0.111
SiO_2	8.96	Mn	0.46

They further state that in the Cle Elum part of this band of deposits there is available 6,250,000 tons of similar grade.

Only two areas appear to have possibilities as future sources of chromite in the State: the Twin Sisters area of primary chromite concentrations and the Cle Elum-Peshastin band of "fossil laterite." The latter is of interest only if a usable type of steel can be produced that contains chromium, nickel, and cobalt in about the same proportions as those in which these elements occur on the average in the deposits. A recent careful study of the use of similar material from the Philippines by Banning and others (1962) suggests that this may be economically feasible.

COPPER

(By J. S. Vhay and A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Copper is indispensible in the modern industrial economy, ranking after iron and aluminum in tonnage consumed. United States consumption in 1963 was 1,744,300 tons, of which 59 percent was used in wire mills, 39 percent in brass mills, and the remainder was used for a wide variety of purposes (Wideman, 1964, pp. 459–461). Copper's high thermal and electrical conductivity, malleability, ductility, and resistance to corrosion provide a unique combination of highly useful properties. The principal competitor to copper is aluminum, which can be substituted in many uses in electrical applications.

Copper, like certain other metals, can be effectively recovered from scrap, both as pure metal and from alloys, particularly brass. Secondary copper recovered in the United States in 1963 amounted to 974,000 tons. In the same period, mine production amounted to 1,213,166 tons; exports and stocks on hand account for the difference between the available copper and the United States consumption (Wideman, 1964, pp. 447–454).

Copper makes up only about 0.007 percent of the earth's crust (Mason, 1952, p. 43); thus a deposit with a grade of 0.7 percent copper, near the lower limit of workable ore, represents a concentration of

about 100 times. Chief ore minerals are chalcopyrite, bornite, chalcocite, tetrahedrite, enargite, tennantite, native copper, and many secondary carbonates, sulfates, oxides, and silicates. Copper is found in a great variety of geologic settings throughout the world, commonly associated with other metals, particularly gold, silver, lead, and zinc. However, most major deposits are in a few places: south-central Africa, the Andes Mountains of Chile and Peru, western United States, the upper peninsula of Michigan, and in Russia.

The first recorded copper production in Washington was in 1894. Production has been continuous since 1899, but highly variable, ranging from less than 3 tons in 1932 to 9,612 tons in 1940 (Huntting, 1956, p. 46) (fig. 18).

Washington's copper production has been small compared with the total for the United States. Total recorded production in the United States through 1963 was about 49,618,000 tons; total recorded production for Washington is about 121,850 tons, or a little less than one-fourth of 1 percent of the United States total (Gray and Hale, 1964, p. 1155). Nevertheless, some significant deposits exist in Washington, and at least one, the Holden mine in Chelan County, was an important producer. During its operation from 1938 to 1957, it produced more than 83 percent of the total copper mined in Washington. The Chewelah and Index districts together account for an additional 10 percent of the State's production, with the rest coming mostly from about 11 other districts (table 3). Forty-one of the better known occurrences are shown on figure 19, numerous others have been reported, but for the most part there is little information on their potential.

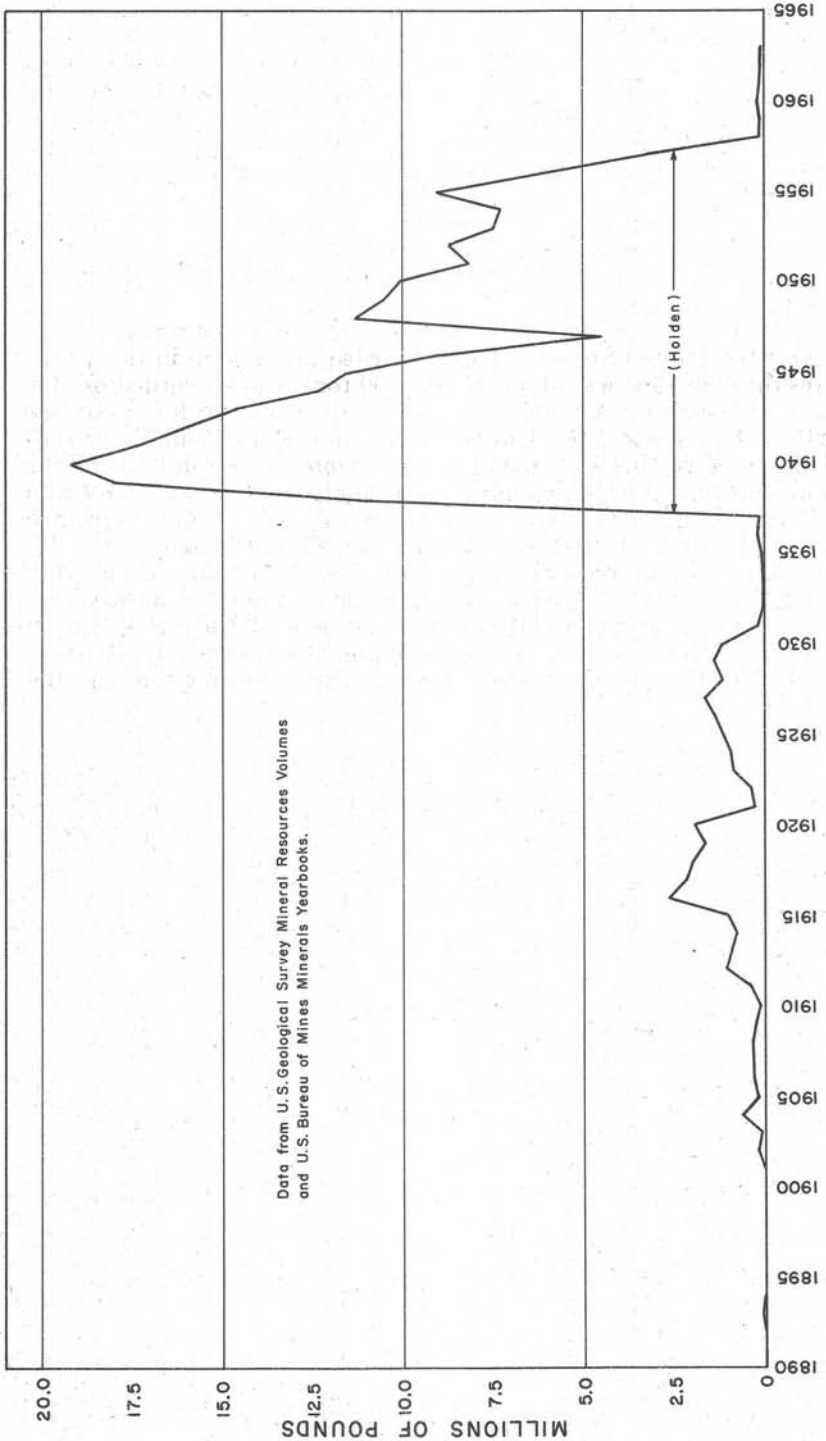

FIGURE 18.—Copper production in Washington, 1894–1963.

TABLE 3.—*Principal copper-producing districts of Washington*

Index No. on fig. 19	County, district, and principal mine(s)	Recorded production (pounds of copper)	Geology of principal mines	References
	PRODUCTION PLUS RESOURCES OVER 100,000,000 POUNDS OF COPPER			
1	Chelan: Railroad Creek (Holden)	212,000,000	Chalcopyrite, pyrrhotite, pyrite, sphalerite, galena, magnetite, molybdenite, and scheelite disseminated in silicified, brecciated gneiss in a septum between Tertiary and Cretaceous batholiths, near a Jurassic(?) stock.	Cater and Crowder, 1956; Youngberg and Wilson, 1952.
2	Snohomish: Miners Ridge (Glacier Peak)		Plug-shaped bodies of disseminations and veinlets of chalcopyrite, molybdenite, pyrite, pyrrhotite, and other sulfides with quartz, tourmaline, and carbonates in granodiorite near older gneiss.	Huntting, 1956.
	PRODUCTION PLUS RESOURCES 10,000,000 TO 100,000,000 POUNDS OF COPPER			
3	Ferry: Danville (Lone Star)	2,050,000	Chalcopyrite and pyrite disseminated and in veinlets on contact of silicified "dacite" and serpentinized "diabase," close to Tertiary pluton.	Parker and Calkins, 1964.
4	Snohomish: Index (Sunset)	14,000,000	Bornite, chalcopyrite, and pyrite in quartz-calcite veins in shear zones in granodiorite.	Huntting, 1956.
5	Stevens: Chewelah (Copper King) (United Copper) (Amazon).	11,130,000	Chalcopyrite, tetrahedrite, pyrite, and arsenopyrite with quartz and carbonates in mineralized fracture zones in argillite.	Do.
	PRODUCTION PLUS RESOURCES 1,000,000 TO 10,000,000 POUNDS OF COPPER			
6	Okanogan: Twisp-Methow (Alder)	1,220,000	Chalcopyrite, pyrite, sphalerite and pyrrhotite in silicified zone in meta-andesite near cupola of Cretaceous intrusive.	Huntting, 1956.
7	Stevens: Springdale (Loon Lake)	1,360,000	Chalcopyrite, bornite, tetrahedrite, and pyrite in quartz vein in argillite.	Huntting, 1956; Fulkerson and Kingston, 1958.
8	Chelan: Chiwawa (Red Mountain)	213,000	Pyrrhotite, chalcopyrite, sphalerite, pyrite, galena, and scheelite in breccia zone on gneiss-diorite contact.	Huntting, 1956.
9	Pend Oreille: Metaline (Pend Oreille) (Grandview).	850,000	Byproduct copper from lead-zinc deposits in dolomitic Metaline limestone.	Park and Cannon, 1943; Fulkerson and Kingston, 1958.

PRODUCTION PLUS RESOURCES 200,000 TO 1,000,000 POUNDS OF COPPER

10	Stevens: Orient (Napoleon)	608,000	Pyrrhotite, pyrite, magnetite, and chalcopyrite, with amphibole, garnet, and calcite in contact deposit; amphibolite cut by monzonite.	Huntting, 1956.
11	Okanogan: Palmer Mountain	526,000	Chalcopyrite-pyrite-arsenopyrite in quartz veins in gabbro or schist; also gold-quartz deposits in gabbro or greenstone.	Do.
12	Snohomish: Sultan (Florence Rae) (Kromona)	470,000	Chalcopyrite, pyrite, pyrrhotite, molybdenite, scheelite, and bornite with quartz and calcite in shear zone on quartz diorite contact.	Carithers and Guard, 1945; Huntting, 1956.
13	King: Taylor River (Rainy)	216,000	Chalcopyrite, pyrite, arsenopyrite, bornite, molybdenite, and scheelite disseminated in quartz diorite breccia pipe with quartz and tourmaline.	Huntting, 1956.
14	Ferry: Belcher	200,000	Production from several properties, mostly as byproduct of mining contact-metamorphic deposits for magnetite.	Do.
15	Chelan: Entiat (Winesap-Dick)	(1)	Pyrrhotite, pentlandite, chalcopyrite, and pyrite disseminated in badly faulted body of peridotite enclosed in quartz diorite.	Huntting, 1956; Patty and Kelly, 1946; Creasey and Storch, 1945.

[1] No production.

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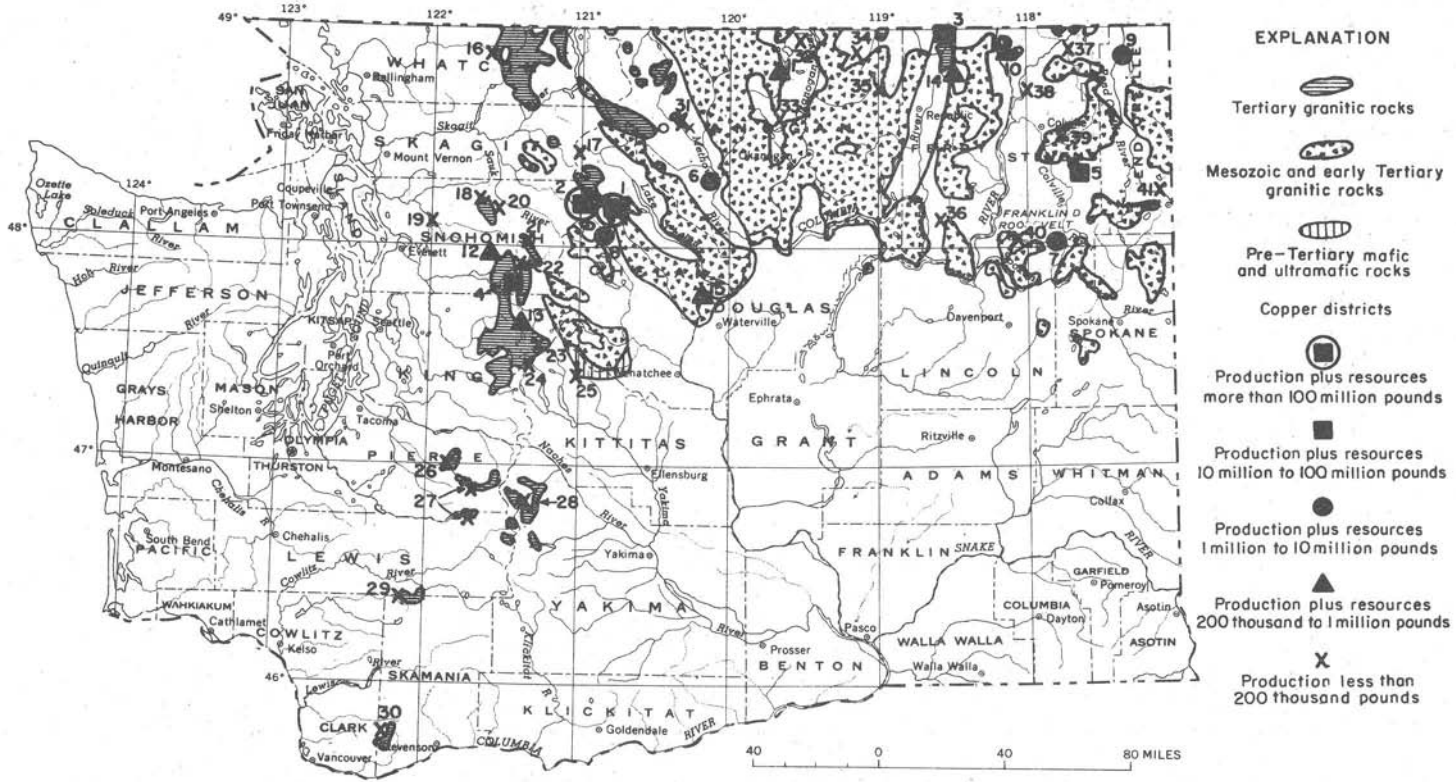

FIGURE 19.—Copper-producing districts of Washington.

Copper-producing districts

1 Railroad Creek
2 Miners Ridge
3 Danville
4 Index
5 Chewelah
6 Twisp-Methow
7 Springdale
8 Chiwawa
9 Metaline
10 Orient
11 Palmer Mountain
12 Sultan
13 Miller River
14 Belcher
15 Entiat
16 Mount Baker
17 Thunder Creek-Stehekin
18 Darrington
19 Granite Falls
20 Silverton
21 Monte Cristo
22 Silver Creek
23 Money Creek
24 Snoqualmie
25 Cle Elum
26 Carbon-Tahoma
27 Mount Rainier
28 Bumping Lake
29 St. Helens
30 Washougal
31 Mazama
32 Oroville-Nighthawk
33 Conconully
34 Myers Creek
35 Wauconda
36 Sanpoil
37 Northport
38 Bossburg
39 Colville
40 Deer Trail
41 Newport

Known occurrences of copper in Washington are restricted essentially to the Cascade Mountains and the Okanogan Highlands. The important deposits, like those in most western States, occur as veins or disseminated deposits in granitic intrusive rocks or as vein replacements or disseminations in the surrounding sedimentary or metamorphic rocks. This spatial relationship to the granitic intrusive rocks is clearly shown in figure 19. In the Cascade Mountains, most of the copper deposits are in or near Tertiary granitic rocks; few are associated with the Cretaceous granites. In the Okanogan Highlands, the association appears to be with the Cretaceous granites.

The most productive copper area in the State is in the Cascades near the junction of Skagit, Snohomish, and Chelan Counties. The Holden mine, in the Railroad Creek district, Chelan County (fig. 19, No. 1), was for nearly 20 years the State's leading producer. The mine was discovered in 1887 during the course of a railroad survey, and the first claims were staked in 1892. The mine did not come into production until 1938, after 10 years of exploration and development by Britannia Mining and Smelting Co., a subsidiary of the Howe Sound Co. From 1938 until it closed in 1957, about 10 million tons of ore was mined; from this 212 million pounds of copper, 40 million pounds of zinc, 2 million ounces of silver, and 600 thousand ounces of gold was recovered. The deposit has not only accounted for more than 83 percent of Washington's copper production, but ranks second only to the Republic district in gold production and was a major source of silver and zinc as well. The full impact of the Holden mine on the State's copper output is dramatically shown by the graph of annual production (fig. 18). Prior to 1957, Washington's average annual production of copper was more than 3,000 tons; since 1958, average production has been about 50 tons per year.

The Holden mine is in a cross fold in silicified and brecciated gneiss between the Cretaceous Chelan batholith and the late Tertiary Cloudy Pass batholith. The deposit consists of disseminated sulfides that replaced quartz-hornblende gneiss along a shear zone. The shearing parallels foliation and layering in the gneiss, which strikes generally northwesterly and dips steeply to the southwest. Several shear zones are known in the general area, and most contain disseminated pyrite in places, but the Holden mine is the only one known to contain significant amounts of valuable minerals. Most of the sulfide-bearing rocks also show more or less alteration of hornblende to sericite and chlorite.

The ore zone contains magnetite, quartz, pyrite, pyrrhotite, sphalerite, chalcopyrite, galena, gold, molybdenite, calcite, bournonite, and silver. Silver minerals have not been recognized in the ore, but the silver content apparently is greatest in at least some areas that are also rich in galena and sphalerite. Gold is most abundant in the pyrite-pyrrhotite-chalcopyrite-rich central part of the ore body. Molybdenite is too scarce to warrant recovery (Youngberg and Wilson, 1952).

The Holden ore body is cut by a variety of dikes, including some that are tentatively correlated with the nearby Chelan batholith of Cretaceous age and the Cloudy Pass Diorite of Youngberg and Wilson (1952) of Tertiary age. Youngberg and Wilson (1952, p. 11) believe that the ore is genetically related to quartz-hornblende intrusions that may be of Jurassic age. If that relationship is correct, the Holden

deposit apparently differs from other copper deposits in the Cascades and this may be an important point to keep in mind in future search for ore.

The Glacier Peak deposit on Miners Ridge (No. 2) is a few miles west and north of the Holden mine. The ore body consists of a stockwork of quartz-pyrite-chalcopyrite-molybdenite veins near the contact of granodiorite of the Cloudy Pass batholith with gneiss. Some of the ore is in gneiss but most is in the granodiorite (Cater and Crowder, 1956). The deposit has not been mined but has been explored extensively over a period of years. The property is currently held by Bear Creek Mining Co. Data on reserves have not been published, but a large tonnage of low grade copper-molybdenum is known to be present.

In the Chiwawa district (No. 8) a few miles south of the Holden and Glacier Peak deposits, the workings of the Red Mountain (or Trinity) mine explore an intrusive breccia in pre-Jurassic gneiss. The breccia contains fragments of gneissic rock in an igneous matrix and is believed to be a breccia pipe originating from an underlying part of the late Tertiary Cloudy Pass batholith. The shattered rocks of the mine area are impregnated with varying amounts of pyrite and pyrrhotite. Chalcopyrite and molybdenite are less common. Several other breccia pipes are known but have been but little explored. The locations of the breccia pipes may in part be controlled by a set of prominent northwest-trending faults.

The greatest number of copper occurrences in the State are in the western Cascades north of Snoqualmie Pass. The deposits are clustered along the margins of the Snoqualmie batholith, a granodiorite intrusion of Tertiary age, in a broad belt that includes the Miller River (No. 13), Index (No. 4), Sultan (No. 12), Silver Creek (No. 22), Monte Cristo (No. 21), Silverton (No. 20), and Darrington (No. 18) districts. The deposits are mostly in sedimentary and metamorphic rocks bordering the granodiorite, but some are in the intrusive rock. The chief producer in this area has been the Sunset mine in the Index district (No. 4). Total production was 263,500 tons averaging 2.45 percent copper (Huntting, 1956, p. 21). First production was in the early 1900's; the most productive period was from 1926 to 1929. There has been only small production since. The deposit consists of lenses of ore in shear zones in granodiorite. Ore minerals are bornite and chalcopyrite with pyrite, quartz, and calcite.

At least 25 other mines and prospects in this belt have produced some copper. These include the Florence Rae and Kromona mines in the Sultan district (No. 12), and the Rainy mine (also known as the Western State Copper mine) in the Miller River district (No. 13). The Rainy mine is in a breccia pipe in quartz diorite with chalcopyrite, pyrite, pyrrhotite, molybdenite, arsenopyrite, quartz, and tourmaline. Silver, gold, lead, and zinc accompany the copper in many of the deposits. Numerous other prospects are known, and there has been considerable exploration activity in this area in recent years.

South of Snoqualmie Pass the area is mostly underlain by volcanic rocks. Copper deposits are few, small, and scattered. They occur mostly as quartz-tourmaline veins containing chalcopyrite, magnetite, molybdenite, and in places gold. The veins are in Eocene or Oligocene volcanics surrounding the Tatoosh batholith in and near Mount

Rainier National Park (Nos. 26, 27, 28) and around other small Tertiary granitic plugs as far south as the Washougal district (No. 30) in Skamania and Clark Counties. Production from the deposits has been insignificant.

A group of copper deposits, none particularly productive, is found southwest of Mount Stuart in the Cle Elum district (No. 25). Most of them are in a band of serpentinized ultramafic rocks south of the Cretaceous Mount Stuart batholith.

Scattered along the eastern flank of the Cascade Mountains are a number of small mining districts, the best known of which are Twisp-Methow (No. 6), Entiat (No. 15), and Palmer Mountain (No. 11). The Twisp-Methow district lies between the Cretaceous Chelan and Similkameen batholiths. The Alder mine, the principal deposit, is in metamorphosed volcanic rock close to a plug of Cretaceous granite. The ore consists of sulfides of copper and zinc with considerable gold and silver. The property was an intermittent producer from 1937 to 1953. The grade of the ore is low, but the potential tonnage is said to be considerable.

The Winesap or Dick deposit in the Entiat district (No. 15) consists of pyrrhotite, pentlandite, chalcopyrite, and pyrite disseminations in a much faulted body of peridotite about 400 feet long by 100 feet wide. The peridotite is enclosed in quartz diorite and gneiss. Ore reserves are estimated at 30,000 tons. Metal content ranges between 0.6 and 1.7 percent nickel and from a trace to 0.7 percent copper (Creasey and Storch, 1945).

Some shipments of copper ore have come from the Palmer Mountain district (No. 11). The principal product has been gold from gold-quartz veins, but some copper ore has been mined from chalcopyrite-pyrite-arsenopyrite-quartz veins.

The bulk of the copper produced in the Okanogan Highlands has come from the Chewelah and Danville districts (Nos. 5 and 3). In the Chewelah area quartz-carbonate veins cut argillite and schist of probable Precambrian age in a belt west of the Cretaceous Loon Lake batholith. Gangue minerals are milky quartz and pyrite with siderite, ankerite, and calcite. Chalcopyrite and tetrahedrite are the ore minerals. The veins range in width from a few inches to as much as 19 feet, and average between 4 and 6 feet. The first claims were located in 1896, and significant production began about 1907. The principal period of production was from 1912 to 1919. During this period the United Copper mine was the largest producing metal mine in the State. Except for some leasing, the district was inactive from 1921 to 1954, when some exploration was done under a Defense Minerals Exploration Administration contract and about 2,000 tons of ore was shipped. There has been no activity since. Total production for the district is estimated about 11.1 million pounds of copper. Similar deposits in the nearby Springdale district (No. 7) have accounted for an additional 1.4 million pounds.

Production in the Danville district (No. 3) has come mostly from two mines, the Lone Star and the Morning Star. The Lone Star has been the more important. At this property, chalcopyrite and pyrite and small amounts of gold occur at the contact of a dark intrusive rock with sericitized and silicified greenstone. The ore zone follows the flat-dipping contact, which has an anticlinal form (Parker and Calkins, 1964, pp. 86–88). The property was first developed in 1897 and

produced until the end of World War I. The ore was transported by aerial tram to a nearby smelter in British Columbia. In 1955–56 the property was explored by the Granore Company with the aid of a Defense Minerals Exploration Administration contract.

The Morning Star ore body lies at the contact between Permian and Triassic greenstone and a large body of serpentine. Near the contact, shear zones in greenstone have been filled by serpentine. The ore is found in two sets of veins—gold-quartz-pyrite veins and pyrite-chalcopyrite-quartz veins. The gold-quartz-pyrite veins are restricted to the greenstone; the pyrite-chalcopyrite-quartz veins are found mostly at the contacts of the serpentine bodies or within them (Parker and Calkins, 1964, pp. 88–89). The mine is primarily a gold mine but has produced some copper. The property was active between 1903 and 1943.

At the Napoleon mine and at other properties in the Orient district (No. 10) in Stevens County and at several small properties in the Belcher district (No. 14) in Ferry County, copper and some gold occur with magnetite and iron sulfides in contact metamorphic deposits. Most of the ore has been mined for smelter flux because of its high-iron content.

Many other copper deposits and occurrences are reported in Washington. They are listed and described briefly in table 3. None can be considered highly productive, but they do indicate that copper is widespread in its occurrence, and may be found in minable amounts in the Cascade Mountains and the Okanogan Highlands. Numerous other occurrences are known, but they are not plotted on figure 19, either because they appear unpromising or because little information is available about them.

Although Washington is now producing almost no copper, numerous and widespread occurrences of the metal in the Cascade Mountains and the Okanogan Highlands, and the recent development of important copper properties in adjacent parts of British Columbia, indicate that the potential of this part of the State for producing copper should not be ignored. Because of the rugged terrain and the lack of transportation facilities, it is a difficult country in which to search for or operate mines. The area, however, is regarded by most geologists familiar with it as a favorable one for the discovery of copper deposits of potential value. The hoped-for discoveries are likely to range in size from relatively moderate size deposits like the Holden mine (10 million tons of ore) to considerably larger ones comparable to the Glacier Peak deposit, or to some of the deposits in Highland Valley, British Columbia. Most of them are likely to be near the margins of granitic rocks of late Tertiary age; in the Okanogan Highlands the association is more likely to be with Cretaceous granitic bodies. The metal content of the deposit will be that of the primary ore; because of climatic conditions and rapid erosion, little or no secondary enrichment can be expected.

GOLD

(By D. R. MacLaren, A. E. Weissenborn, and P. L. Weis, U.S. Geological Survey, Spokane, Wash., and Harold Kirkemo, U.S. Geological Survey, Washington, D.C.)

Man has prized gold as an ornamental metal, as a medium of exchange, and as a basis for monetary systems. Because of its beauty, resistance to corrosion, ductility, and malleability, it is widely used for jewelry, decorative lettering, plating, foil, and other arts.

About 80 percent of the gold consumed in the United States each year goes into jewelry, other artistic uses, and dentistry. The other 20 percent serves a wide variety of uses. Its great resistance to corrosion and oxidation makes gold a particularly effective protective coating in certain uses, despite its relative softness. Gold-plated electrical and electronic components are used in increasing quantities in military aircraft and in aerospace components. Gold is a very efficient reflector of infrared radiation, a property that has led to its use in both manned and unmanned satellites.

PRODUCTION

World production of gold has increased continuously over the past 10 years, reaching, in 1963, an all-time high estimated at 51.7 million troy ounces (Ryan, 1964, p. 549). This was largely due to expansion of production from South African mines. In contrast, United States production during the same period has declined steadily, and in 1963 it amounted to only 1,468,000 ounces, the lowest peacetime output since 1859. This continued decline is due largely to the rise in operating cost in domestic mines, without a commensurate increase in the fixed base price of $35.00 per ounce for gold. The result of this cost-price squeeze is shown clearly in the list of the 25 largest gold producers in the United States. These sources, which together account for 94 percent of domestic output, include 16 base metal mines, 5 placer mines, and only 4 lode gold mines. Under existing conditions a continuing trend toward an increasing percentage of United States gold production from copper and other metal mines that can recover gold as a by-product can be expected.

Washington is not among the major gold-producing States of the country. Total production figures are not known precisely, but probably amount to about 3,600,000 ounces through 1963, valued at about $105 million (Huntting, 1955, p. 32; Ryan, 1964, pp. 554–555). This amounts to approximately 1.2 percent of the total United States production. Yearly production figures for Washington are available for the years prior to 1959 (U.S. Bur. Mines Minerals Yearbooks), but since then separate production figures cannot be published, and the State total has been combined with that from Pennsylvania for reporting purposes. The total from Washington for the years 1959–63, is therefore estimated.

Although gold was first discovered in Washington in 1853, production has been greatest during the last 20 years, and since 1957 it has ranked from 5th to 7th among gold-producing States. During that time, annual production is estimated to have ranged from about 82,000 to 128,000 ounces. It is noteworthy that two mines presently operating in Washington, the Knob Hill-Gold Dollar mine at

Republic and the Golden King mine at Wenatchee, rank 4th and 10th, respectively, among United States gold producers, and are 2 of the 4 lode gold mines included in the first 25 (Ryan, 1964, p. 553).

Gold has come from 25 of the State's 39 counties (Huntting, 1955), but 6 counties have accounted for more than 99 percent of the production, and it is probable that just 2 counties, Chelan and Ferry, have produced more than 55 percent of all gold, and more than 75 percent of the lode gold mined in Washington. The leading counties producing lode gold are shown in table 4.

TABLE 4.—*Principal lode gold-producing counties in Washington*

County:	*Approximate value of gold produced through 1963*
Chelan	$35, 224, 000
Ferry	30, 503, 000
Snohomish	7, 200, 000
Whatcom	5, 101, 000
Okanogan	2, 131, 000
Stevens	1, 453, 000
Kittitas	882, 000
All others	161, 000
Total	82, 655, 000

Source: Data principally from Huntting, 1955, and U.S. Bureau of Mines Minerals Yearbooks, plus estimates of production for some counties.

The most significant lode gold-producing areas have been grouped into 26 districts that are plotted on figure 20. These in turn have have combined into 16 groups for which production figures are known or can be fairly closely estimated (table 5). It should be noted, however, that in some districts, records are incomplete, and production figures can only be considered as approximations. Although the total amount of placer gold recovered in Washington is believed to be about 0.9 million ounces, production data are too incomplete to permit a tabulation by county or district.

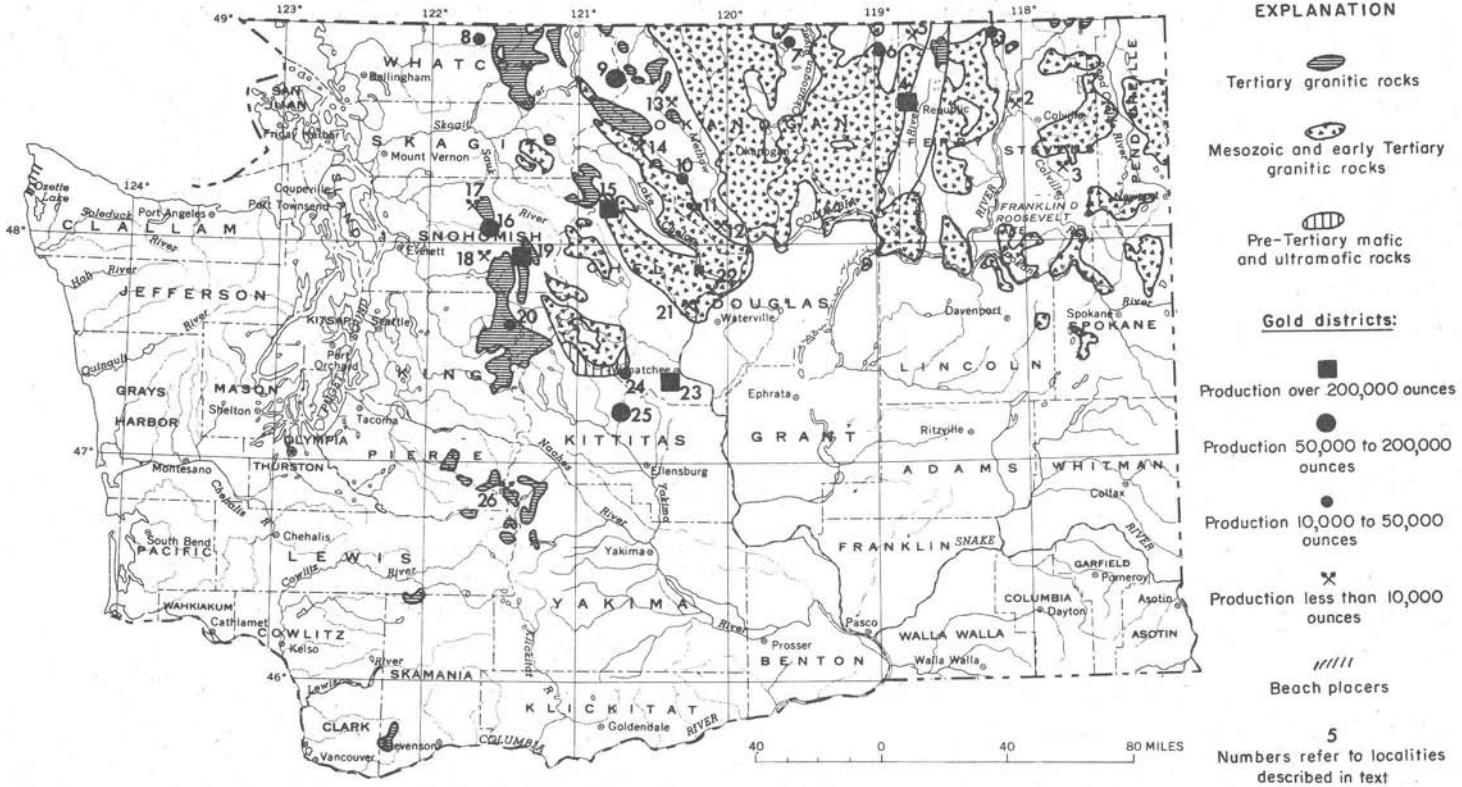

FIGURE 20.—Gold producing districts in Washington.

TABLE 5.—*Summary of Washington lode gold districts*

Index No. on fig. 20	County and district	Manner of occurrence	Remarks	Reference	Production through 1963	
					Ounces	Value
	Stevens:					
1	Orient (Pierre Lake).	Veins and replacements in latite near quartz monzonite and rhyolite porphyry intrusions. Gold associated with finely disseminated pyrite in quartz and calcite gangue.	Continuous lode production 1902–42. Placer production not known.	Bancroft, 1914, pp. 64–91; Fulkerson and Kingston, 1955.		
2	Kettle Falls (Myers Falls).	Fissure zones in argillite and limestone cut by granitic and dioritic masses; quartz veins. Pyrite, gold, silver, lead.	----------	Weaver, 1920, pp. 230–232	56,500	$1,453,000
3	Chewelah	Quartz veins with pyrite and chalcopyrite in metamorphosed Precambrian sediments.	Gold recovered as byproduct of copper mining. Production from placers not significant.	Weaver, 1920, pp. 92–109		
	Ferry:					
4	Republic	Veins and disseminated replacement deposits in structures in Republic Graben. Tertiary volcanic and sedimentary rocks cut by quartz-chalcedony veins; replacement deposits in andesitic breccia. Pyrite, gold, electrum, silver, arsenopyrite, tetrahedrite, stibnite, realgar, marcasite, polybasite, argentite, pyrargyrite, umangite, naumannite.	Discovered in 1898, continuous production thereafter; greatest production was 1910–28, 1937–65. More than 40 mines active at various times.	Bancroft, 1914, pp. 133–166; Muessig and Quinlan, 1959; Staatz, 1960, p. B304; Patty, 1921, pp. 165–188; Parker and Calkins, 1964, pp. 5–48; Umpleby, 1910.	962,600	30,503,000
5	Danville-Curlew	Gold-pyrite-quartz veins in greenstone near contact with serpentine. At Lone Star property chalcopyrite, pyrite, and minor gold occur in sheared serpentine along contact of dacite with alkalic intrusion.	----------	Parker and Calkins, 1964, pp. 84–90.		
	Okanogan:					
6	Myers Creek	Quartz and quartz-calcite veins in Paleozoic metamorphic rocks, younger granite; disseminated sulfide replacements in granite, breccia. Free gold, tetrahedrite, chalcopyrite, bornite, sphalerite, galena, molybdenite, pyrite, arsenopyrite, pyrrhotite, marcasite. Most gold from veins.	Placers discovered in 1888; production more than 2,000 ounces. Lode production from at least 12 mines. Greatest activity was after 1900.	Umpleby, 1911b, pp. 27–52. Huntting, 1956, pp. 135–147.	24,700	780,000
7	Oroville-Nighthawk.	Quartz veins and disseminated sulfide replacement deposits in Paleozoic metamorphic rocks and in Similkameen batholith. Veins contain free gold, pyrite, and copper and lead minerals; replacements are sulfides with principal value in copper.	Placer gold found along Similkameen River in 1859. District was made part of Indian reservation in 1860, reopened to prospecting 1898. Placer production was about 25,000 ounces; lode gold from at least 6 mines.	Umpleby, 1911a, pp. 64–68, 76. Patty, 1921, pp. 222–228.	32,300	655,000

TABLE 5.—*Summary of Washington lode gold districts*—Continued

Index No. on fig. 20	County and district	Manner of occurrence	Remarks	Reference	Production through 1963	
					Ounces	Value
	Whatcom:					
8	Mount Baker	Quartz veins with native gold, gold telluride and sulfides in diorite, greenstone, schist, slate west of Chilliwack batholith.	Placers discovered possibly as early as 1860's; production minor. Lodes discovered in 1897. Most production came from 3 mines.	Bethune, 1891, pp. 8–12, Huntting, 1956, pp. 175–180.	43,300	$876,000
9	Slate Creek-Azurite.	Quartz veins with native gold, tellurides, and sulfides in Cretaceous sediments near small Tertiary granitic plutons.	Discovered about 1893; production from at least 10 mines; most of production from 2.	Purdy, 1952	149,700	4,225,000
	Okanogan:					
10	Twisp	Quartz and calcite veins in Similkameen batholith and in schist, gneiss, on both sides. Pyrite, chalcopyrite, arsenopyrite, gold.	Gold discovered about 1887; 12 mines have produced. Placers insignificant.	Bethune, 1891, p. 69; Huntting, 1956 p. 147.		
11	Gold Hill	Quartz veins in sandstone and shale	Test shipments only	Patty, 1921, p. 259	22,500	696,000
12	Squaw Creek	Quartz veins and shear zones with pyrite, chalcopyrite, and scheelite in granite.	Most of production from 2 mines	Huntting, 1955		
13	Mazama	Quartz vein in diorite and andesite	Small shipments only	do		
14	Gilbert	Quartz veins in diorite	Small production only	do		
15	Chelan: Railroad Creek (Chelan Lake, Holden).	Sulfide replacement deposit in breccia zone in isoclinally folded schist and gneiss. Ore associated with offshoots from Tertiary Cloudy Pass batholith. Pyrite, chalcopyrite, pyrrhotite, galena, sphalerite, chalcocite.	Gold output was byproduct from copper mining. Entire production from Holden mine, which was operated from 1938 to 1957.	Youngberg and Wilson, 1952.	600,000	21,000,000
	Snohomish:					
16	Silverton	Arsenopyrite in quartz veins and shear zones in quartz diorite, serpentine, and metamorphic rocks.	Silver discovered about 1874; gold about 1891. Area essentially dormant since 1910. Production from 3 mines.	Patty, 1921, p. 282	113,900	2,300,000
17	Darrington	Chalcopyrite-pyrrhotite veins	Small production around 1940	Broughton, 1942		
18	Sultan Basin	Quartz veins in granitic rocks and in metamorphic rocks near borders of intrusion.	Production small	Broughton, 1942; Carithers and Guard, 1945.		
19	Monte Cristo-Silver Creek.	Calcite-quartz veins, replacements, contain sulfide minerals with gold and silver. Joints and bedding planes in metamorphic rocks, contacts with igneous rocks, joints in igneous rocks, replacements in shear zones in both igneous and metamorphic rocks. Both precious and base metal contents decrease below 300 feet; below this depth ore minerals are pyrite and arsenopyrite with gold and silver.	Activity began in 1897; started to decline in 1903; all but ceased by 1918. Production mostly from Monte Cristo and Justice (Golden Chord) mines; but at least 16 properties are reported to have produced some ore. Placers of Silverton-Monte Cristo area said to have produced more than $7,000,000 in gold.	Spurr, 1901; Broughton, 1942, pp. 19–38; Patty, 1921, p. 282.	227,700	4,600,000
20	Money Creek-Miller River-Buena Vista.	Quartz veins in granodiorite of Snoqualmie batholith, Arsenopyrite, pyrite, chalcopyrite, galena, gold.	Most production from one mine	Huntting, 1955	10,700	300,000

	Chelan:					
21	Entiat	Gold-bearing quartz veins in Swakane Gneiss of Waters (1932) and granodiorite of Chelan batholith.	Chief producer is Rex mine	Huntting, 1955; Waters, 1932.	9,200	$185,000
22	Chelan Butte	Gold quartz veins in granodiorite of Chelan batholith.	Very small production	Huntting, 1955.		
23	Wenatchee	Several altered zones in sandstone of the Eocene Swauk Formation are cut by quartz veins containing finely divided gold.	Entire production from Golden King mine. Mine discovered in 1885 and had sporadic production until 1949. Has operated continuously since.	Lovitt and McDowall, 1954; Lovitt and Skerl, 1958.	[1] 367,500	[1] 13,500,000
24	Blewett	Peridotite masses have invaded sediments of Peshastin Formation and pyroclastics of Hawkins Formation. Small masses and dikes of Mesozoic granodiorite intrude peridotite and have altered it to serpentine. Ore found in fissure veins in serpentine. Quartz, calcite, pryite, arsenopyrite, iron oxides, gold.	Placers first worked in 1860, lodes in 1874. District very active 1891–1907. Little production since 1910. Placer production estimated more than $1,000,000 through 1910. Lode production from at leat 10 mines.	Smith, 1903a, p. 79; Huntting, 1943, pp. 7–8; Huntting, 1955, p. 33.	26,600	539,000
25	Kittitas: Swauk-Peshastin.	Fissure veins in sandstone and shale of Eocene Swauk Formation, serpentine similar to Blewett district. Free gold in quartz-calcite gangue.	Placers discovered in 1860, lodes in 1873. Greatest activity between 1892 and 1895. Most of production from 4 mines. Most placer production was prior to 1910.	Smith, 1903a, pp. 76, 80; Huntting, 1955.	50,000	882,000
26	Pierce-Yakima: Summit.	Fissure veins in volcanic rock near granitic intrusions of Tatoosh pluton.	Unknown but very small production	Huntting, 1955		
		Other production not included in above			4,500	161,000
		Total			2,701,700	82,655,000

[1] Production through 1964.

HISTORY OF GOLD MINING IN WASHINGTON

The history of gold discoveries in Washington parallels that of many other western States. Survey parties seeking railroad routes reported the first discovery of placer gold at an unspecified location in the Yakima Valley in 1853, and subsequent prospecting identified placer gold in many places in the Okanogan Highlands and Cascade Mountains (Huntting, 1955, p. 28). In 1859 a party surveying along the United States-Canadian border found placer gold on the Similkameen River in Okanogan County. The report set off a short-lived rush, but it was not until the 1860's that appreciable production was reported. Many additional occurrences of placer gold were found between 1855 and about 1880. Early history of placer mining is obscure and contradictory, and discovery dates and production figures are not known with certainty (Huntting, 1955, pp. 28, 32–33).

The most productive placer districts in the State are believed to be those in the Similkameen, Oroville-Nighthawk, and Myers Creek areas of Okanogan County; the gravel bars along the Columbia River in Stevens and Ferry Counties; along Ruby Creek in Whatcom County; the Blewett, Peshastin, and Swauk Creek Valleys, Chelan County; the Monte Cristo-Silver Creek district, Snohomish County; and the Swauk district, Kittitas County. Beach placers were worked near Ozette, Clallam County, but production probably was not great. Many of the early placer workings, particularly those along the Columbia River, were worked by Chinese. No accurate production figures are available for the placer deposits of Washington, but the $20 million reported prior to 1903 is believed to have come largely from them. By 1900, most of the known placer deposits were largely worked out; total placer output since 1900 is estimated at no more than about 50,000 ounces, worth between $1,250,000 and $1,500,000 (Huntting, 1955, pp. 29, 32; U.S. Bur. Mines Minerals Yearbook, 1952–63).

An early discovery of lode gold was in 1871, at the base of Mount Chopaka, Okanogan County. C. P. Culver found gold-bearing veins in the Blewett district in 1878, where the first stamp mill was erected in what was then Washington Territory. The lodes at Monte Cristo, Snohomish County, were found in 1889, and the first vein deposits at Republic, Ferry County, were discovered in 1896. As with the placer deposits, most lode gold districts had been found by 1900, but in contrast, by far the greatest lode production has been after that time. It is interesting to note that the three most productive individual mines have a relatively recent history, although gold was known in all three districts prior to 1900. The Holden copper deposit in Chelan County was not worked until 1938 (Youngberg and Wilson, 1952, p. 1); the rich ore bodies at the Knob Hill mine, Republic district, were discovered in 1939 (Wright, 1948, p. 265); and the Golden King mine at Wenatchee did not become a major producer until 1949 (Huntting, 1955, p. 43). As of 1963, 4 mines were producing ore from which gold was recovered, and the Knob Hill mine, the Golden King mine and the Wind River mine were the only lode gold mines. At the Wind River mine in Skamania County, production in 1963 was 232 ounces of gold (Gray and Hale, 1964, p. 1155).

GEOLOGY, DISTRIBUTION, AND OCCURRENCE

Gold occurs as a native element, as a natural alloy with silver, copper, and platinum-group metals, and as tellurides and selenides. It is recovered as native gold or natural alloys in placer deposits, where its high specific gravity and chemical inertness causes it to become concentrated along with other heavy minerals as a result of repeated washing of detrital gravel and sand by streams. Gold in all its forms also occurs in veins and fracture fillings, stockworks, and replacement bodies, and as disseminations. It has been found alone in quartz or carbonate gangue, or together with other metals in sulfide ore bodies of many types. In Washington, as in many of the Western States, most gold occurrences are closely associated with batholiths, stocks, or smaller intrusive granitic bodies of Cretaceous or Tertiary age, as is clearly indicated on the map (fig. 20). Occurrences are widespread, and Huntting (1956) lists more than 800 mines and prospects. Most are in the Cascade Range and the Okanogan Highlands. Although many occurrences are known, 93 percent of the total production is from just seven districts—the Republic, Orient, Slate Creek-Azurite, Railroad Creek, Darrington, Monte Cristo-Silver Creek, and Wenatchee districts (fig. 20 and table 5). Three deposits, the Golden King and Holden mines (Chelan County) and the Knob Hill mine (Ferry County) have accounted for about $60 million, more than 75 percent of the lode gold mined in Washington. Of these, only two—the Golden King and the Knob Hill mines—were still in production in 1963; the Holden mine was closed in 1958.

Republic district

The Republic district (fig. 20, No. 4) in Ferry County is the most productive single district in the State, with more than $30 million worth of gold mined through 1963. Gold was found in the area in 1898, shortly after the north half of the Colville Indian Reservation was opened to prospecting, and gold has been mined continuously in the district since then. Between 1898 and 1901, small shipments of high-grade ore were made. In 1903, completion of a railroad line linking Republic with smelters on the Pacific Coast led to greater activity, and between 1909 and 1928, new discoveries resulted in a continuous increase in production. By the late 1920's, the higher grade ores were becoming depleted, and production began to decline (Huntting, 1955, pp. 30, 32, 34).

It was not until the completion of a new mill in 1937, designed to treat low-grade ores, and the discovery of new ore bodies in 1939, that production again increased (Wright, 1948, pp. 264–265). Production has been generally high since 1938, and for the period 1953–63 it is estimated to be about $10 million in gold (U.S. Bur. Mines Minerals Yearbooks, 1953–64). Since the closing of the Holden mine (Chelan County) in 1958, the Republic district has been the first-ranking gold district in Washington.

The Republic mining district lies in the Republic graben, a northeasterly-trending structural trench 4 to 10 miles wide, that extends for more than 50 miles from the mouth of the San Poil River to the Canadian border (Staatz, 1960, p. B304). The graben is bounded by one or more steeply dipping faults, which are known to have about 7,000 feet of vertical displacement. The oldest rocks in the area are

a group of sedimentary, igneous, and metamorphic rocks that range in age from late Paleozoic to early Tertiary (Parker and Calkins, 1964, pp. 5–48). Formation of the graben began in early Tertiary time, and continued intermittently until the Miocene (Parker and Calkins, pp. 83–84). During that time, much of the structural depression was filled by a variety of intrusive and volcanic igneous rocks, and intercalated pyroclastic and sedimentary detritus. Subsidiary breaks, which divided the subsiding graben into subblocks, in places provided zones of weakness that permitted the entrance of mineralizing solutions that produced the mineral deposits of the district.

The most important mineral deposits of the district are in a few north-trending veins, cross-veins, and associated breccia zones that lie in or near Eureka Gulch, just north of Republic. The veins are fissure fillings made up of wavy bands of light- and dark-colored quartz. The bands are roughly parallel to the vein walls, but in detail are highly irregular, and in places concentric around rock fragments or irregularities in the vein walls (Patty, 1921, pp. 171–172).

The ore minerals occur in dark, threadlike bands, and include free gold, electrum, tellurides, pyrite, arsenopyrite, chalcopyrite, stibnite, realgar, marcasite, tetrahedrite, polybasite, pyrargyrite, argentite, umangite, and naumannite. Umangite, a copper selenide, and naumannite, a silver-lead selenide, occur in few mining districts in the world. Because the ore minerals are find-grained, separation and identification of individual minerals is difficult. Gangue minerals are quartz, chalcedony, adularia, barite, calcite, and small amounts of sericite and graphite (Huntting, 1956).

Veins range from a few inches to more than 15 feet in width, but values are largely localized in lenses and ore shoots that make up only a part of the veins. Strike lengths of ore bodies range up to several hundred feet, and they typically persist through a considerable vertical range (Patty, 1921, pp. 171–172). Some veins have been mined to a depth of at least 1,200 feet.

More than 40 mines in the Republic district have been active at one time or another, and several have substantial production. Among the more productive are the Last Chance ($3 million by the end of 1923), the Quilp ($720,938 through 1920), the Republic (about $1,400,000 through 1910), and the Surprise (more than $1 million). A large part of the production came from one or more of the steeply dipping, north-trending quartz veins that characterize most of the productive parts of the district. However, at least one group of claims, now known collectively as the Knob Hill mine, has had extensive production from other types of ore.

The Knob Hill mine is the richest mine in the district and has probably produced more gold than any other mine in the State. Production began in 1910, and until about 1919 relatively high-grade ore was mined from its veins. Lower grade ore was mined until 1939 when production started from a previously unrecognized ore body. This new discovery was a breccia body consisting of flinty quartz and adularia replacing the fine-grained matrix of an andesitic intrusive breccia. Another ore body, the Stewart, is described as a stockwork of small quartz veins in a fine-grained pipe (Wright, 1948, pp. 264–275).

Detailed production figures for the Knob Hill mine are not available for publication, but Huntting (1956, p. 121) estimates total production

through 1951 of more than $10 million. The mine has continued active since that date, and in 1963 was ranked ahead of the Getchell mine in Nevada which produced $1.96 million in gold (Ryan, 1964, pp. 550, 553). Gold-silver ratios vary according to the type of ore, with vien ore averaging about 1:4, and disseminated and breccia ore about 1:7 (Wright, 1948, p. 275).

The Knob Hill mine is the only active deposit in the Republic district at present, but the relatively recent discovery of its most valuable ore, the extent of ground that is obscured by lake deposits, sand and gravel, and the difficulty in recognizing the brecciated and disseminated ores suggest that additional deposits may be found in the area.

Chelan County

Two major areas of gold production are in Chelan County, and in both the production is from a single mine. However, the geology of the two deposits is very different. The Golden King mine at Wenatchee (fig. 20, No. 23) is a lode gold deposit, whereas the Holden mine on Railroad Creek (No. 15) is a disseminated copper deposit, from which gold was recovered as a byproduct.

The Holden mine, about 11 miles west of Lake Chelan, was active from 1938 to 1958, during which time it produced about 212 million pounds of copper, 40 million pounds of zinc, 2 million ounces of silver, and 600,000 ounces of gold. The gold production, worth $21 million, made it the richest gold deposit in the State, although the continuing production from the Knob Hill mine near Republic either has or soon will surpass the output from Holden. The geology of the Holden mine is discussed under Copper.

The Golden King mine, also known as the Gold King mine, the Lovitt gold mine, and L–D mines, is about three miles southwest of Wenatchee, Chelan County. The mine is named for the Golden King lode claim, one of two located in 1885 on gold occurrences on the steep slopes northwest of Squilchuck Creek. In 1894 a five-stamp mill was built, and operated for several months. Recovery was poor because of the finely divided nature of the gold, and the dilution of ore with waste rock. Intermittent mining and milling operations were finally abandoned in 1911. From 1938 until 1949 about 40,000 tons of siliceous, low-grade gold- and silver-bearing material was quarried and shipped to the A.S. & R. Co. copper smelter in Tacoma, where it served as an excellent flux.

In 1949, E. H. Lovitt, a Canadian mining geologist, recognized possibilities for mining individual veins exposed in an adit on the Golden King claim. On behalf of the Wenatchee Mining Partnership, he organized the Lovitt Mining Co., Inc., and began operations which have since continued (Lovitt and McDowall, 1954; Lovitt and Skerl, 1958). In 1961, Wenatchee Mining Partnership, and Day Mines, Inc., Wallace, Idaho, formed L–D Mines. The new company constructed and began operating a 300-ton-per-day flotation concentrator in 1962. Since then, most of the mine output is milled, and the flotation concentrate and jig concentrate are shipped to the Bunker Hill Co. smelter at Kellogg, Idaho. A minor quantity of crude ore is shipped to the Tacoma smelter.

Total production through 1964 from the Golden King mine was about 833,000 tons of gold-silver ore, valued at nearly $13.5 million.

55–883 O—66——7

The precious metal content of the ore was about 367,500 ounces gold and 420,000 ounces silver, and the average grade was 0.44 ounce gold and 0.50 ounce silver per ton.

A unique belt of gold mineralization exists several miles west and southwest of Wenatchee. The area is underlain by several thousand feet of continental sandstone, shale, conglomerate, and coaly sediments of the early Eocene Swauk Formation. These beds are folded into broad synclines and anticlines trending in a northwesterly direction. One exception to the broad folds is the steeply folded Golden King anticline, which in places is overturned and cut by thrust faults. This structure extends about four miles northwestward from Squilchuck Creek, across Dry Gulch, and into the hills northwest of Squaw Saddle, the prominent landmark west of Wenatchee. Scattered along the anticline are "reefs" or elongate altered and mineralized zones in the Swauk Formation. These range in length from 200 feet to one-quarter mile and in width from 100 feet to about 600 feet. Exploration for gold has been conducted on six reefs, and mining performed on three of them.

Volcanic plugs and dikes, which intruded the Swauk Formation in middle Eocene time, form prominent ridges and knobs on both sides of the Golden King Anticline. These are porphyritic rocks of rhyolitic, dacitic, and andesitic composition. The spatial relationship of these barren rocks to the mineralized reefs suggests a genetic correlation.

The reefs exhibit various degrees of hydrothermal alteration and deformation. In the first, the feldspars in the arkosic sediments were altered to sericite, the bedding planes in some areas were obliterated, and superfically the rocks have the appearance of granite. More advanced alteration resulted in silicification and brecciation. In the most advanced alteration, the brecciated, silicified mass was resilicified.

Gold-silver mineralization in the reefs is typically epithermal, and is associated with porcelaneous quartz veins which range in thickness from a fraction of an inch to 6 feet. Native gold and electrum are the gold minerals present. Naumanite and aquilarite are the silver minerals; and pyrite, chalcopyrite, tetrahedrite, sphalerite, and stibnite are accessory minerals. The ore minerals are fine-grained, and never visible megascopically. In the southern portion of the Golden King claim, the veins were widely spaced and were mined individually. Farther north and on the adjoining MacBeth claim the ore bodies consist of innumerable closely-spaced veins in intensely silicified, brecciated masses. Minable ore has been found throughout a vertical range of about 1,000 feet. The Golden King and MacBeth claims have yielded most of the production to date.

IRON

(By V. E. Livingston, Jr., Washington Division of Mines and Geology, Olympia, Wash.)

Iron is one of the most fundamental commodities in our nation's industrial economy. The United States mined 143,303,000 long tons of iron ore during 1962 (Holliday and Lewis, 1963, pp. 660–661). Iron ore production accounts for more than 40 percent of the value of all metal mined in the United States (Reno, 1960, p. 403). United States production of iron ore in 1962 accounted for only 14 percent of the world total, but this country produced 23 percent of the world's pig

iron. Only about 15 percent of the ore mined in 1962 was shipped directly to reduction plants; the remaining 85 percent underwent some sort of beneficiation before shipment. Hematite has been the principal ore of the iron industry for many years; however, magnetite ores are becoming more and more valuable because of new beneficiation techniques that are being developed. Use of magnetite ore has increased from 13 percent of the total crude ore used in 1952 to 41 percent in 1962. Consequently, taconitic ores that were once considered useless have become a tremendous reserve of usable ore through newly developed concentration and agglomeration processes.

Most of the iron produced in the United States is converted to steel or used as cast iron, wrought iron, and various alloys with other metals. Other uses for iron ore are in making magnesite refractories, special portland cements, and mineral pigments such as ocher, umber, and sienna. It is also used for ship ballast, heavy concrete aggregate, and atomic reactor shielding. Ninety-four percent of the iron ore consumed domestically is reduced in blast furnaces (Reno, 1960, p. 41) and sold as cast iron or converted to steel.

Because of high construction and maintenance costs, and limitation on the type of ore and fuel that may be used, the blast furnace is best suited for treatment of large quantities of standard-grade iron ores. In recent years a trend has developed in the direction of smaller, less costly, and more flexible direct reduction furnaces for the treatment of smaller quantities of iron ore, particularly for the production of specialty steels.

Over three-quarters of the United States production of iron ore comes from the tremendous iron ore deposits of the Great Lakes region, which provide ore for the iron and steel industry of the eastern States. Smaller iron-producing centers in the West are at Provo, Utah; Pueblo, Colo.; and Fontana, Calif. (fig. 21). All of these centers are near sources of iron ore, limestone, and coking coal—the raw materials needed for the production of iron.

The principal ore minerals of iron are hematite (70 percent Fe) and magnetite (72.4 percent Fe). Less important, but still usable,

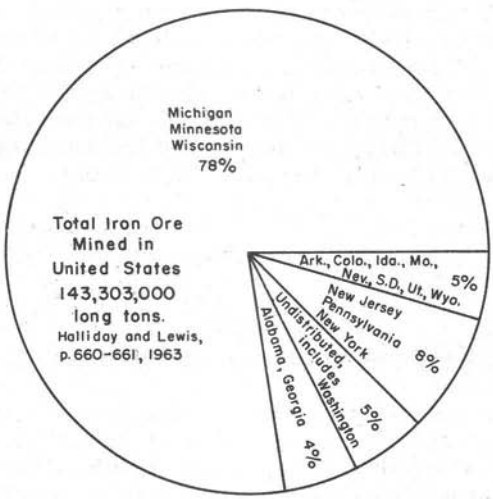

FIGURE 21.—Crude iron ore mined in the United States, 1962.

are limonite (59 to 63 percent Fe) and siderite (48.2 percent Fe). Under certain conditions, pyrite (46.6 percent Fe), and pyrrhotite (61.6 percent Fe) have been used as iron ores. The sulfur is removed by roasting, leaving an iron sinter, which in turn serves as the iron source.

Iron ore deposits have been formed by several different geologic processes. Some deposits have formed by the segregation of the iron minerals in an intrusive magma—a process known as magmatic segregation. Other deposits have formed where iron-bearing solutions or emanations from a hot magma have developed an iron-rich zone along the contact between an intrusive rock and the surrounding country rock. The solutions dissolve the host rock and deposit iron minerals in its place. Iron ore deposits may also be found as sedimentary beds where the iron was deposited by sedimentation. They also occur as laterites or residual deposits where the original iron-bearing minerals have been converted to oxides by weathering and the elements other than iron have been removed by ground water. Some iron deposits have developed by the oxidation of sulfide and carbonate ores, which leaves a gossan or capping of iron oxides. Finally, iron placer deposits are developed where iron minerals have been freed from an enclosing rock and concentrated in black sand deposits by stream or wave action. Washington has iron ore deposits that were formed by each of these geologic processes. The lateritic iron deposits in the Blewett-Cle Elum River area are of interest, not only because they are unusual but also because of the nickel content of the ore.

The iron industry in Washington had its beginning in 1880, when a blast furnace was erected at Irondale near the city of Port Townsend in Jefferson County. The furnace had a capacity of 10 tons of pig iron per day and used wood charcoal for fuel. After six months of operation, the furnace was found to be unsatisfactory and was abandoned. Later it was torn down and in its place a blast furnace with a capacity of 50 tons per day was constructed. Limonite or bog ore mined from the nearby Chimacum Valley proved unsuitable when used alone, so magnetite from Texada Island in British Columbia was mixed with it to produce an acceptable pig iron. The plant was closed from 1891 until 1901, when a new group of investors rebuilt the furnace and charcoal ovens. The plant operated for several years thereafter but was permanently abandoned in 1918. A few tons of iron ore have been used by iron manufacturers since, but, for the most part, the basic raw material for Washington's iron industry has been scrap iron.

Most of the iron ore produced in the State has been used for things other than making steel. It has been used to make ferromagnesite, heavy concrete aggregate, ferroalloys, and mineral pigments. It has also been used as an ingredient in special portland cement, for atomic reactor shielding, and for ship ballast. According to U.S. Bureau of Mines unpublished figures (1963), the total production of iron ore in the State for all uses is said to have been 165,847 tons having a value of $572,068.

Table 6 is a list of only the most widely known iron deposits in Washington or those that have had some production. These same deposits are plotted on figure 22. Huntting (1956, pp. 190–205) has listed 113 properties that are considered to be important because of their iron content.

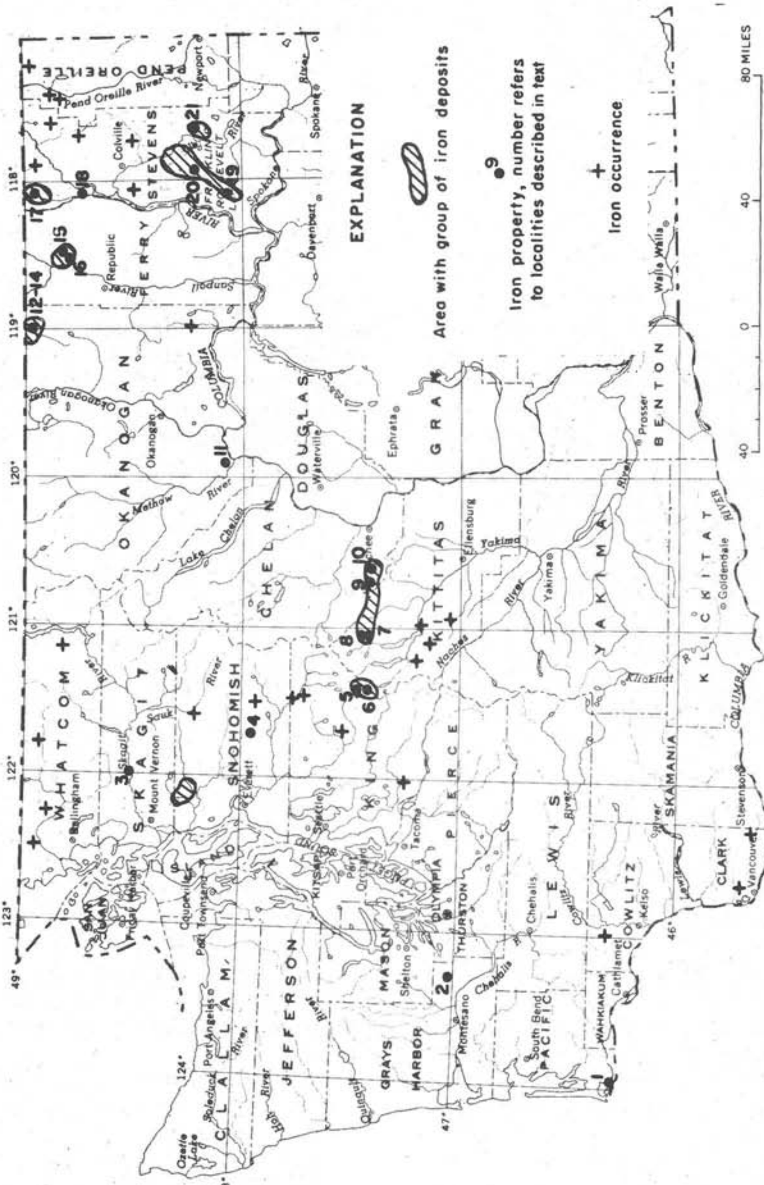

FIGURE 22.—Iron ore deposits in Washington.

TABLE 6.—*Iron deposits in Washington*

Index No. on fig 22	Property	Location	Geology	References
1	McGowan Placer	Pacific County, sec. 22, T. 9 N., R. 10 W., elevation, 6 to 11 feet.	Black sand deposit 1.5 to 8 feet thick covers a known area 2,400 by 400 feet. Deposit drilled by U.S. Bureau of Mines, 1944, showed 21.2 to 43.46 percent Fe; 3.04 to 14.01 percent TiO_2. High-grade sample showed 53 percent magnetite, 18 percent ilmenite, and 1 percent zircon.	Glover, 1942, pp. 14–15; Kelly, 1947; Zapffe, 1949, pp. 44–47.
2	Elma (Dennis)	Grays Harbor County, sec. 28, T. 18 N., R. 5 W., elevation 400 feet.	Sedimentary bed of magnetite-ilmenite sand cemented by hematite, 1 to 4 feet thick, covering at least 2 to 3 acres, under 3 to 8 feet of overburden. Assays 50.02 percent Fe, 0.8 percent SiO_2, 22.23 percent TiO_2, 0.18 percent P_2O_5, 0.062 percent S. Small shipments made for experimental purposes. Tonnage estimate: 5,000 tons known, 10,000 tons probable, 20,000 tons possible.	Glover, 1942, p. 7; Shedd and others, 1922, pp. 107–109.
3	Hamilton (Iron Mountain)	Skagit County, secs. 23 and 24, T. 35 N., R. 6 E., sec. 30, T. 35 N., R. 7 E., secs. 20 and 21, T. 35 N., R. 7 E., elevation, 100 to 900 feet.	Deposits are probably sedimentary in origin and occur as discontinuous beds or lenses in schist. The ore minerals are hematite with or without magnetite. The ore zone has been traced 6 miles in 1 direction and 22 in another. Assays of 15 samples show 37.79 percent Fe, 24.73 percent SiO_2, 6.01 percent Al_2O_3, 6.56 percent $CaCO_3$, 9.75 percent Mn_3O_4, 0.49 percent P, 0.16 percent S. About 5,000 tons has been produced. Estimated tonnage: 20,000 tons known, 100,000 tons probable, 500,000 tons possible.	Bethune, 1892, pp. 41; Glover, 1942, p. 15; Jenkins, 1924, p. 32; Northern Pacific Ry. Co., 1941, p. 7;[1] Patty and Glover, 1921, p. 70; Shedd, 1902, pp. 6, 9, 16, 19–25; Shedd, 1924, pp. 66–67; Shedd and others, 1922, pp. 95–102; Whittier, 1917, pp. 27–29; Zapffe, 1949, pp. 27–36.
4	Lockwood Pyrite	Snohomish County, sec. 36, T. 29 N., R. 8 E., elevation, 1,700 to 2,350 feet.	3 tabular ore bodies in metamorphosed sedimentary rocks. Ore minerals are sulfides—pyrite, pyrrhotite, and sphalerite. Assays of 150 samples showed 10 to 43 percent Fe, 9 to 46 percent S. Average of 75 assays shows 25 percent Fe, 25.6 percent S. Other values are 0.05 to 0.2 ounces Au.; 0.4 to 0.9 ounces Ag.	Broughton, 1942, p. 49; Carithers and Guard, 1945, pp. 79–86; Zapffe, 1949, pp. 37–41.
5	Williams-Smith	King County, secs. 35 and 36, T. 26 N., R. 10 E., elevation, 2,900 feet.	Ore bodies are contact metamorphic replacements of limestone. Magnetite crops out in 3 places, the largest being over 50 feet across. Assays show 66 to 67 percent Fe, 2.70 to 4.10 percent SiO_2, 0.0264 to 0.37 percent P.	Glover, 1942, p. 9; Shedd, 1924, p. 66; Shedd and others, 1922, pp. 93–94.

6	Denny and Guye (Mount Logan; Summit claims).	King County, sec. 6, T, 22 N., R. 11 E., secs. 31, 32, and 33, T. 23 N., R. 11 E., elevation, 3,500 to 4,600 feet.	Replacement deposit along contact of intrusive granodiorite and limestone. Ore occurs in discontinuous lenses, some of which are over 20 feet across. Ore mineral is magnetite. Assays run 55 to 68 percent Fe. Some lenses show significant values in gold, lead, silver, and zinc. Tonnage estimate: 15,000 tons known, 300,000 tons possible.	Bethune, 1892, pp. 42, 45; Glover, 1942, pp, 8–9; Northern Pacific Ry. Co., 1941, p. 7; [1] Patty and Glover, 1921, p. 70; Shedd, 1902, pp. 25–27; Shedd, 1924, p. 66; Shedd and others, 1922, pp. 86–92; Smith and Calkins, 1906, p, 13; Whittier, 1917; pp. 25–27; Zapffe, 1944c; 1949, pp. 22–24.
7	Cle Elum River south deposit (Balfour Guthrie).	Kittitas County, secs. 1, 2, and 3, T. 22 N., R. 14 E., elevation, 2,700 to 5,000 feet.	Lateritic iron deposits formed on serpentinized peridotite. Exposed between the Swauk Formation and older peridotite for a distance of 2 miles. Ore minerals are hematite and magnetite. Ore reserves are estimated at 3,370 tons exposed, 21,550 tons probable, and 191,360 tons possible.	Bethune, 1892, pp. 42–43; Broughton, 1944, pp. 36–39; Glover, 1942, pp. 10, 11; Julihn and Moon, 1945, pp. 29, 31; Lamey and Hotz, 1952; Lupher, 1944; Patty and Glover, 1921, p. 70; Ravitz, 1947; Shedd, 1902, pp. 27–36; 1924, p. 65; Shedd and others, 1922, pp. 73–79; Smith and Calkins. 1906, pp. 13–14; Whittier, 1917. pp. 22–25; Zapffe, 1949, pp. 67–76; Zoldok, 1948.
8	Cle Elum River north deposit (Balfour Guthrie).	Kittitas County, secs. 24, 34, and 35, T. 23 N., R. 14 E., elevation, 3,000 feet.	Lateritic iron deposits formed on serpentinized peridotite. Overlain by the Swauk Formation of Eocene age. Ore minerals are magnetite, hematite, millerite, and chrome spinel. Drilling indicates 6,250,000 tons of 40.86 percent Fe. Assays from 52 diamond drill holes averaged 40.82 percent Fe, 0.83 percent Ni, 2.40 percent Cr_2O_3, 8.83 percent SiO_2, 16.46 percent Al_2O_3, 0.051 percent P, 0.115 percent S, and 0.46 percent Mn.	Bethune, 1892, pp. 42–43; Broughton, 1944, pp. 40–41; Glover, 1942, pp. 10–11; Julihn and Moon, 1945, pp. 29, 31; Lamey and Hotz, 1952; Lupher, 1944; Patty and Glover, 1921, p. 70; Ravitz, 1947; Shedd, 1924, p. 65; Shedd and others, 1922, pp. 73–79; Smith and Calkins, 1906, pp. 13–14; Whittier, 1917, pp. 22–25; Zapffe, 1944; 1949, pp. 67–76; Zoldok, 1948.
9	Nigger Creek (Davenport)	Chelan County, secs. 7 and 8, T. 22 N., R. 17 E., sec. 12, T. 22 N., R. 16 E., elevation, 4,100 to 4,800 feet.	Sedimentary iron beds in 3 areas derived from laterized peridotite have 59,850 tons exposed, 45,720 tons probable, and 435,850 tons possible ore. Ore minerals are hematite and magnetite.	Broughton, 1944, pp. 16–20; Huntting, 1943, p. 15; Lupher, 1944.
10	Blewett (Washington Nickel).	Chelan County, secs. 13 and 14, T. 22 N., R. 17 E., elevation, 2,900 to 4,080 feet.	Iron-rich sediments derived from laterized peridotite carrying appreciable amounts of nickel and chrome, lying stratigraphically between Swauk Formation of Eocene age and older serpentinized peridotite. Ore minerals are hematite, magnetite, chromite, and nickel silicate. Tests and assays by U.S. Bureau of Mines show 46,000 tons assaying 32 percent Fe, 0.88 percent Ni, 2.5 percent Cr_2O_3. Investigations by the Washington Division of Mines and Geology indicate that total reserves probably do not exceed 2,000,000 tons.	Broughton, 1943b; 1944, pp. 15–16; Glover, 1942, pp. 3–5; Huntting, 1943, p. 19; Julihn and Moon, 1945, pp. 29, 31; Lamey, 1950; Lupher, 1944; Northern Pacific Ry. Co., 1941, p. 7; [1] Shedd and others, 1922, pp. 70–72; Weaver, 1911, p. 49; Zapffe, 1949, pp. 77–82.
11	Fuller (Pateros, Lone Pine)	Okanogan County, sec. 26, T. 30 N., R. 23 E., elevation, 2,300 feet.	Magnetite intergrown with hornblende and actinolite occurs in veins and thin lenses in syenite gneiss. Assays show 24.29 to 57.02 percent Fe, 3.10 to 4.19 percent TiO_2, and 1 percent S. Tonnage estimate: 2,000 tons known, 10,000 tons probable, 20,000 tons possible. Limited production during early 1940's.	Glover, 1942, p. 14; Northern Pacific Ry. Co., 1941, p. 7; [1] Shedd and others, 1922, pp. 68–69.

See footnote at end of table, p. 99.

TABLE 6.—*Iron deposits in Washington*—Continued

Index No. on fig 22	Property	Location	Geology	References
12	Aztec	Okanogan County, sec. 24, T. 40 N., R. 30 E., elevation, 5,100 feet.	Contact metamorphic replacement of limestone by magnetite, pyrrhotite, pyrite, and chalcopyrite. Assays show 18.6 to 50.6 percent Fe, 0.01 to 0.07 percent Cu, 0.2 to 8.7 percent S, 0.002 to 0.027 percent P, 11.8 to 25.6 percent SiO_2, 0.05 to 0.29 percent TiO_2, tr. to 0.005 ounce Au, 0.1 to 0.4 ounce Ag.	Broughton, 1943a; Shedd and others, 1922, p. 63; Umpleby, 1911, p. 48; Zoldok and others, 1947.
13	Magnetic (Buckhorn Neutral Aztec).	Okanogan County, sec. 24, T. 40 N., R. 30 E., elevation, 5,000 feet.	Irregularly shaped lenticular zones where limestone has been replaced by magnetite, pyrrotite, pyrite, chalcopyrite, and scheelite along a syenite contact. The ore is complex both mineralogically and chemically. A 1-ton mine run sample assayed 62.28 percent Fe, 6.75 percent SiO_2, 1.10 percent CaO, 7.60 percent Al_2O_3, 0.028 percent P, 0.012 percent S. Estimated 18,600,000 tons of reserves. Production reported in 1917–20, 1938, 1940, and 1941 in Mineral Resources of the United States and Minerals Yearbooks for those years.	Broughton, 1943a; Culver and Broughton, 1945, p. 28; Glover, 1942, pp. 12–13; Northern Pacific Ry. Co., 1941, p. 7; Patty and Glover, 1921, p. 71; Shedd, 1924, p. 69; Shedd and others, 1922, pp. 61–65; Umpleby, 1911a, pp. 47–48; Whitwell and Patty, 1921, pp. 92–93; Zapffe, 1949, pp. 12–17; Zoldok and others, 1947.
14	Roosevelt (Grant MacLean, Teddy Roosevelt).	Okanogan County, secs. 24 and 25, T. 40 N., R. 30 E., elevation, 4,600 feet.	Contact metamorphic deposit with magnetite, chalcopyrite, pyrite, and scheelite in limestone along a syenite intrusive contact. 12 carloads of ore shipped prior to 1912, 2,000 tons of magnetite shipped during 1919–20. Good values of Cu, Au, and Ag have been reported.	Broughton, 1943a; Culver and Broughton, 1945, pp. 28–29; Glover, 1942, pp. 13–14; Handy, 1916, p. 7; Northern Pacific Ry. Co., 1941, p. 7; Shedd and others, 1922, pp. 65–67; Umpleby, 1911a, pp. 44–46; Zapffe, 1949, pp. 17–18; Zoldok and others, 1947.
15	Belcher (Blue Bell-Belcher)	Ferry County, sec. 8, T. 37 N., R. 34 E., elevation, 4,050 to 4,500 feet.	2 or 3 replacement bodies of pyrite, magnetite, pyrrhotite, and chalcopyrite in a contact metamorphic zone where monzonite dikes intrude a limestone-shale series. Iron sulfides more abundant than magnetite. Production reported in U.S. Geological Survey Mineral Resources of the United States for 1909–11, 1913–17. Estimated reserves probably between 500,000 and 1,000,000 tons.	Bancroft, 1914, pp. 175–179; Glover, 1942, p. 6; McIntyre, 1907, p. 249; Shedd and others, 1922, pp. 59–61.
16	Oversight	Ferry County, sec. 18, T. 37 N., R. 34 E., elevation, 4,650 feet.	Lenticular ore body replacing limestone. Ore minerals are pyrite, pyrrhotite, magnetite, and chalcopyrite. 3 assays average 50.2 percent Fe, tr. Cu, 13.3 percent SiO_2, 14.2 percent S, 0.09 ounce Au. U.S. Bureau of Mines Minerals Yearbook reported production in 1934.	Bancroft, 1914, pp. 170–173; Glover, 1942, pp. 5–6; Huntting, 1956, p. 195; Shedd and others, 1922, p. 59.

17	Big Iron	Stevens County, sec. 24, T. 40 N., R. 37 E., elevation, 3,750 feet.	An elongate replacement zone in a limestone-quartzite series. The ore occurs as bands of magnetite, pyrite, pyrrhotite, chalcopyrite, scheelite, hematite, and limonite separated by quartzite beds. About 35,000 tons of ore was shipped from 1924 to 1937. The property produced during 1940–41. Iron assayed 56 percent in ore shipped.	Bancroft, 1914, pp. 82–83; Broughton, 1945, pp. 7–12; Culver and Broughton, 1945, p. 64; Glover, 1942, p 21;. Northern Pacific Ry. Co., 1941, p. 7; [1] Weaver, 1920, p. 276; Zapffe, 1949, pp. 19–20.
18	Napoleon	Stevens County, sec. 3, T. 37 N., R. 37 E., elevation, 2,350 feet.	Contact metasomatic deposit along the contact of amphibolite and monzonite porphyry. The amphibolite is the host rock and has been replaced by pyrrhotite, pyrite, magnetite, chalcopyrite, limonite, and some hematite. Assays of run-of-mine ore gave 33 percent Fe, 12 percent S, 10 percent CaO, 30 percent SiO_2, 0.3 percent Cu, 0.05 to 0.1 ounce Au, tr. Ag. Production reported for 1907–10, 1913–17; 1938–55.	Bancroft, 1914, pp. 89–91; Glover, 1942, p. 20; Shedd and others, 1922, pp. 55–56; Weaver, 1920, pp. 293–294; Zapffe, 1949, pp. 20–22.
19	Read	Stevens County, sec. 14, T. 30 N., R. 37 E., elevation, 2,700 feet.	Contact metamorphic replacement of limestone by magnetite, chalcopyrite, and scheelite. In some places magnetite makes up 80 percent of the ore. A few tons have been smelted. Tonnage estimates are 5,000 tons known, 100,000 tons probable, and 500,000 tons possible.	Broughton, 1945, pp. 12–16; Culver and Broughton, 1945, pp. 72–73; Glover, 1942, pp. 18–19; Shedd and others, 1922, pp. 43–46.
20	Hill (Iron Jack)	Stevens County, secs. 17 and 20, T. 31 N., R. 39 E., elevation, 3,050 feet.	Hematite, magnetite, and martite occur in fractured and metamorphosed dolomite, probably formed by replacements. Also, hematite interbeds in quartzite. Assays average 68.57 percent Fe, 1.69 percent SiO_2, 0.024 percent P, 0.006 percent S.	Glover, 1942, p. 18; Shedd, 1924, pp. 67–68; Shedd and others, 1922, pp. 40–43.
21	Kulzer (Capital, Vigilant)	Stevens County, secs. 20 and 21, T. 31 N., R. 41 E., elevation, 2,200 feet.	Irregular limonite-hematite metasomatic deposits in limestone against a granite contact. Ore also occurs in limestone at contact with overlying basalt. Property has had intermittent production since before 1914. Tonnage estimates in 1942 were 4,000 tons known, 15,000 tons probable, 50,000 tons possible. Assays show 53.56 percent Fe, 8.45 percent SiO_2, 0.14 percent P, 0.004 percent S.	Bethune, 1891, p. 80; 1892, p. 125; Glover, 1942, pp. 17–18; Northern Pacific Ry. Co., 1941, p. 7; [1] Patty and Glover, 1921, p. 71; Shedd, 1902, pp. 38–39; 1924, p. 67; Shedd and others, 1922, pp. 37–40; Weaver, 1920, pp. 186–187; Whittier, 1917, pp. 31–32.

[1] Informal publication of Northern Pacific Ry. Co., Land Department, Geological Division (tabulated summary, special geologic reconnaissance reports, Washington and northern Idaho), 19 sheets and index map supplement to tabulated summary.

According to the State of Washington, Department of Commerce and Economic Development, Washington's steel users consumed an estimated average of 540,000 tons of steel per year for the 5 years between 1954 and 1958. Currently (1965) there are two ferroalloy plants in operation in Washington—one at Rock Island near Wenatchee and the other at Tacoma. There are three producers of steel ingot, all in Seattle, and 154 iron and steel fabricators and foundries in the State.

Washington's industries offer a good year-round market for iron products. It probably is not large enough, however, to warrant blast-furnace facilities, especially in light of the fact that the State's known iron ore bodies are small and the cost of local coking coal is high.

Under present circumstances, Washington's most promising prospect for a steel industry using native ores is the direct reduction furnace. Direct reduction plants are small, and some processes are reportedly able to operate at a profit by producing only 150 to 200 tons of steel per day. Also, the fuel needed does not have to be metallurgical coke. Depending on the process, softwood char, lignite, and low-grade bituminous coal can be used as the reducing agent. Most of the potential iron ores in Washington are chemically complex and low grade and might cause problems in a blast furnace, but would present fewer problems in a direct reduction process. Other possible sources of iron that should be considered are the ferruginous bauxite ores of southwest Washington. Although these deposits are thought of primarily for their alumina content, if the ore were treated by the Pederson process or a modification of it, pig iron would be a by-product. The deposits are discussed in the Bauxite chapter of this report.

All things considered, it appears that Washington has a market that offers enough potential and has adequate resources for a direct reduction operation. The best location would be either near Cle Elum, where both iron ore and coal are available, or in the Seattle-Tacoma area, where coal is available and a good market exists.

A severe shortage of iron ore in their own country has encouraged Japanese industries to seek raw materials in other countries. At present (1965), they are buying ore from small high-grade deposits in British Columbia. With more development work, there is a good possibility that ore from some of the small but high-grade deposits in Washington could be exported.

MANGANESE

(By J. V. N. Dorr, II, U.S. Geological Survey, Washington, D.C.)

Manganese is one of the essential elements in the industrial civilization of this century. About 95 percent of the manganese consumed is in the manufacture of steel; the element has no economic substitute for desulfurizing and deoxidizing in the steelmaking process. It is also used as an alloying element in the production of steel in which properties of unusual toughness are needed, such as railroad switches and armor plate. Manganese bronzes are highly resistant to corrosion. Much smaller quantities are consumed in the chemical industry, the glass and ceramic industries, and the paint industry;

manganese dioxide of special properties is used in the manufacture of dry cells.

World production of manganese ore of all grades is about 14 million tons per year, of which the United State imports about 2 million tons, most of it containing more than 46 percent manganese. Manganese ores are irregularly distributed in the earth's surface, and some regions such as Europe and the United States, contain very little commercially useful ore, whereas other regions, such as Russia, Africa, India, and South America, contain large deposits. Thus, in 1963 the total United States production of manganese ore containing more than 35 percent Mn was about 10,000 tons. Washington produced no manganese ore in that year. The cumulative production from the State of Washington is about 47,000 long tons of manganese ore, some 46,000 tons of which came from a single mine, the Crescent mine (Magill, 1960). Thus the total production from the State amounts to slightly more than 2 percent of a single year's consumption of the country.

In December 1964, the price of metallurgical grade manganese ore containing more than 48 percent Mn was nominally about 78–80 cents per long ton unit (22.4 pounds) of contained manganese; that of ore containing between 45 and 48 percent Mn was quoted at 72 to 77 cents per long ton unit. Because the chemical composition of manganese ores varies widely from deposit to deposit, prices are subject to negotiation depending on the overall composition of the ore and its suitability for steelmaking or other uses, as well as other economic factors.

Manganese minerals which are of present economic importance are the oxides, particularly cryptomelane, psilomelane, pyrolusite, braunite, hausmannite, and others. Rhodochrosite, the manganese carbonate, has been used commercially on a small scale but may become more important, as it is easily manipulated and battery and metallurgical grade ore can be manufactured from it. A host of simple and complex manganese silicate minerals occur in significant deposits in the United States, but their manganese content cannot be extracted with profit at present prices for the metal. Extraction is technically feasible, but the energy input in refining is such that commercial production from the silicate minerals does not seem likely in the foreseeable future, for known world reserves of high-grade oxide manganese ore are very large. Furthermore, vast quantities of manganese oxide nodules that also contain cobalt and nickel are known to occur on the sea floor, and it may well prove more economic to harvest this material than to reduce the refractory manganese silicate minerals. Two pilot projects are now under way to establish costs and techniques for harvesting these nodules.

Manganese oxide ores occur as syngenetic managanese oxide bodies of sedimentary origin, as near-surface alteration products of syngenetic carbonate and metamorphic silicate bodies containing lower tenors of manganese, and as epigenetic hydrothermal vein and replacement deposits and supergene enrichments thereof. The first two categories have supplied and undoubtedly will continue to supply most of the commercial manganese ore of the world. The great high-grade or easily concentratable oxide ore deposits of Russia, Ghana, Gabon, South Africa, Brazil, and India are representative of these ore types, and known reserves are more than half a billion tons. Because

natural concentration of originally lower grade manganiferous rock to commercial grade ore by weathering processes is much more effective in tropical than in temperate or cold climates, much of the known reserve of such epigenetic ore is found in the tropic belt. It is reasonable to infer that more high-grade ore will be found in this relatively undeveloped part of the world.

Although some small syngenetic deposits that have been concentrated by natural processes to commercial grade ore have been worked in the United States, most deposits in this country from which manganese has been won are hydrothermal vein or replacement deposits, some enriched by weathering processes, or are classified as manganiferous iron ore, with a tenor in manganese too low to be worked for that element alone. The deposits in the State of Washington, with few unimportant exceptions, fall into the classification of replacement or vein deposits with very minor supergene enrichment.

Manganese was first discovered in Washington in Mason County, according to Green (1945) possibly in 1880, certainly by 1889. Other deposits were found in adjacent parts of the Olympic Peninsula and elsewhere in later years, but it was not until the accidental discovery by hunters in 1922 of the deposit that was to become the Crescent mine that an economic ore deposit was found.

Huntting (1956) locates 143 manganese deposits on the map accompanying his "Inventory of Washington Minerals," of which 118 are in counties comprising the Olympic Peninsula and 9 are in nearby Skagit and Snohomish Counties. Figure 23, generalized from this map, shows the distribution of manganiferous deposits. The occurrences in the central and eastern parts of the State are generally as gangue minerals in deposits of base or precious metals, as small and very low-grade vein deposits, or as low-grade deposits of manganese and iron oxides cementing disintegrated granite. These deposits have little possibility of significant manganese production and will not be further discussed. They are summarized in table 7.

TABLE 7.—*Manganese occurrences in Washington*

Index No. on fig. 23	Name of mine or claim	Mineral	Production (tons)	County
1	Smith	(?)	(?)	Whatcom.
2	Samish Bay	Bementite	(?)	Skagit.
3	Fidalgo	do	(?)	Do.
3	Mountain Home	Bementite, oxide	(?)	Do.
4	Belleville	Pyrolusite	(?)	Do.
5	Cicero	do	None	Snohomish.
6	Lake Riley	Rhodonite, rhodochrosite	(?)	Do.
7	French Creek	do	(?)	Do.
8	Chehalis River	Oxide	(?)	Lewis.
9	Ironstone Mountain	(?)	(?)	Yakima.
10	Denney	Oxide	(?)	Kittitas.
11	Dartford	do	(?)	Spokane.
12	Turtle Lake	do	(?)	Stevens.
13	Wellpinit	do	(?)	Do.
14	Marty	do	None	Do.
15	Moore	Rhodonite, pyrolusite	3.5	Okanogan.
16	Pogue Flat	Pyrolusite	[1] 750.0	Do.
17	Paramont	(?)	(?)	Grays Harbor.
17	Superior	(?)	(?)	Do.
17	Supreme	(?)	(?)	Do.
17	Excelsior	(?)	(?)	Do.
18	Crescent	Hausmannite, bementite	46,000.0	Clallam.
19	Zone of many deposits [2]	Bementite, neotocite, hausmannite.	1,000.0	Clallam, Mason, Jefferson, and Grays Harbor.

[1] Low-grade ore.
[2] For detailed listing and location of all deposits, see Huntting (1956).

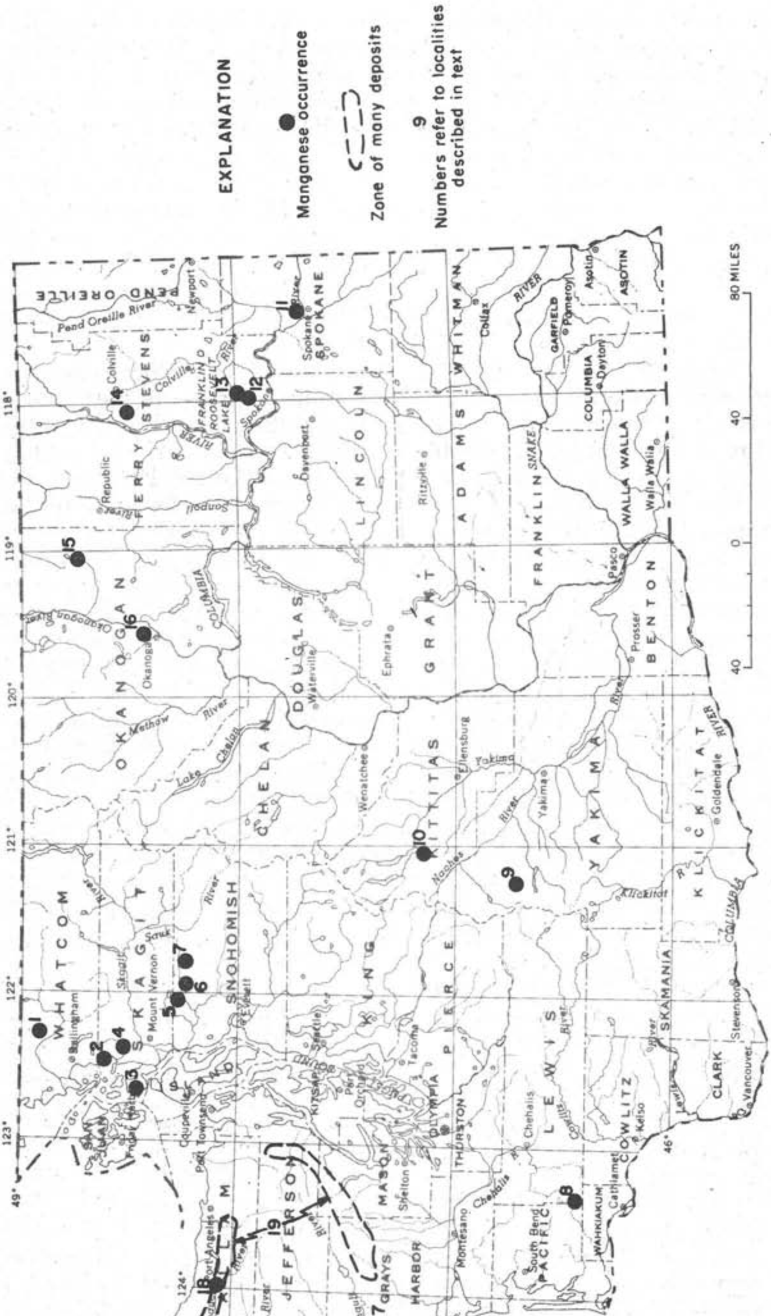

FIGURE 23.—Manganese in Washington.

The deposits on the Olympic Peninsula are all of one type and all occur in one of two stratigraphic formations, most in the Crescent Formation and some, stratigraphically below the Crescent, in a volcanic unit interbedded with the Soleduck Formation of Reagan (1909), both of Eocene age (Brown, written communication). These formations crop out in a roughly U-shaped zone on the north, east, and south sides of the peninsula. The host rocks are unusual rock types, being composed of spilitic pillow basalts of submarine origin, with associated pyroclastics and volcanic breccias and with highly lenticular argillaceous and siliceous limestones and calcareous and siliceous argillites. The manganiferous deposits commonly occur at or near the contact between the spilites and the sedimentary rocks and are largely in the sedimentary rocks.

Details of the genesis of these manganiferous deposits are warmly debated by various authorities, but most agree that the manganese was carried to the site of deposition by thermal fluids and was deposited in the present podlike or sheetlike bodies in part by replacing the host rocks and in part by filling voids and fissures in those host rocks. The deposition of much jasper accompanied the manganese. The manganese was derived from the volcanic rocks themselves, possibly at depth, possibly on the sea floor near the site of deposition. Park (1946) advocates that seawater in which the basalts solidified was important in the mineralization process, whereas Hewett (1956) delieves the fluids and possibly the manganese may have come from bepth. Magill (1960) states that none of the suggested theories explains all conditions found in the various deposits.

Following the discovery of the Crescent mine, an intense prospecting campaign was carried on in the Olympic Peninsula and, during the depression of the 1930's, WPA and CWA funds were made available for cleaning off and opening up many outcrops of manganiferous rock. As many as 75 men were thus engaged at one time. Shortly before and during World War II, the Geological Survey and the Bureau of Mines made rather intensive investigations of the most promising part of Washington, the Olympic Peninsula, studying the geology in some detail and drilling and trenching many manganiferous exposures. A deeper ore body in the Crescent mine was found, but no other significant production resulted from this work. State agencies, notably the Washington Geological Survey and the Division of Mines and Mining of the Department of Conservation and Development, did much work in the Olympic Peninsula, culminating in the excellent report by Green (1945). In 1960, Magill of the U.S. Bureau of Mines brought Green's report up to date in a useful summary of present information on the ore deposits of the peninsula.

Much has been written on the geology of these interesting manganese deposits, particularly by Pardee (1922, pp. 299–242; 1927), Park (1942, 1946), and Hewett (1956). Robert D. Brown, Jr., of the U.S. Geological Survey has studied in considerable detail the stratigraphy and composition of the host rocks of the manganiferous material in the Olympic Peninsula. Although his work is not yet published, he kindly made it available during the preparation of this report.

The Olympic Peninsula deposits are a very unusual type in that most of the oxide ore is hausmannite, Mn_3O_4, and most of the manganese silicate minerals are bementite or neotocite, hydrous manganese silicates of uncertain or variable composition. The only significant

ore mineral is hausmannite, known in many other parts of the world but the dominant ore mineral in very few deposits. The Crescent mine, now apparently exhausted, may well have been one of the larger concentrations of relatively pure hausmannite in the world. Bementite and neotocite are not rare minerals but in few places are found in such abundance as in the Washington manganese deposits. Thus the Washington occurrences have a scientific interest disproportionate to their economic importance.

Other manganese silicate minerals found in these deposits are rhodonite, piedmontite, inesite, and manganophyllite. Very minor rhodochrosite, the manganese carbonate, and manganoan calcite also occur. Hausmannite occurred in quantity only at one mine, the Crescent, but is present elsewhere. The silicate and carbonate minerals were subordinate in the Crescent mine. Elsewhere the silicates are dominant. Noncommercial native copper and cinnabar, an ore mineral of mercury, also occur in some deposits with the manganese minerals; in fact, the first manganese deposits were found in the search for copper ore.

The grade of the deposits varies widely. The average grade of the oxide ore shipped from the Crescent mine is said to have been over 51 percent. On the other hand, Green (1945) states that the average of 96 representative samples taken from other deposits, including a few with hausmannite in the ore, was 22.39 percent Mn and that the grade ranged from 5 to 32 percent Mn. Individual samples representing a few tons may be found which average much more than this, but Green's figure undoubtedly is typical of the run-of-mine grade in the silicate ores.

The lenticular deposits rarely exceed outcrop lengths of a few hundred feet, many are much less in visible extent. Because they are lenticular and are thought to have formed when the enclosing rocks were roughly horizontal, there is little reason to assume that their extension to depth should be radically different from their outcrop length.

In the present state of knowledge, no informed estimate of total reserves or the magnitude of the resource is possible; with present industrial techniques both may be considered small. The large number of individual deposits indicates a considerable aggregate tonnage of manganese minerals, but this tonnage is scattered in many small deposits, thus complicating extraction and adding to costs of access and development.

On the other hand, the Olympic Peninsula is an area of generally high rainfall, covered by rain forest. Because of the steepness of the topography, it has large talus deposits. Where the forest is virgin, bedrock is hidden by a deep mat of rotting vegetation and of moss, logs, and ferns. Pardee (1927) pointed out that most of the deposits then discovered were in burned and logged areas, and this is still true. It is not at all improbable that other oxide deposits lie hidden under the dense surface cover, for in a large area of intense manganese mineralization the Crescent oxide body should not be unique. So far, intense search has not revealed other bodies of any significant magnitude, although, according to Green (1945, p. 33), more than 1,000 tons of predominantly oxide ore was extracted from the Hurricane mine. Brown (written communication) points out that the manganese silicate occurrences are more common in siliceous country rock,

whereas the manganese oxide deposits are richer in the less siliceous limestones. Therefore, prospecting for the potentially economic oxide deposits should be guided by this observation.

Extraction of the manganese from low-grade silicate ores by various methods is technically possible (Green, 1945; Dean and others, 1934). In view of the ready availability to industry of high-grade oxide ores in normal times and the fact that an ample strategic stockpile of metallurgical-grade manganese ore has been accumulated by the Federal Government to provide for wartime emergencies, such silicate ores are not now attractive and the silicate deposits will probably not become an important factor in the economic life of the State.

MERCURY

(By E. H. Bailey, U.S. Geological Survey, Menlo Park, Calif.)

Mercury, or quicksilver as it is often called, is a metal that at ordinary temperatures is a liquid. Because of its liquidity, it is used in thermometers, and most people have at some time or another seen the shiny silver droplets that result from the breaking of a fever thermometer. Its liquidity also results in its being a key metal in the production of chlorine, which in turn is basic in the manufacture of plastics and detergents, and this has recently become the most important single use for mercury. It is also used for various kinds of electrical and scientific apparatus, dental preparations, fungicides and bactericides, medicines, and several thousand other minor uses. Despite its innumerable uses, the total quantity consumed in the United States in a single year is small, and in 1963, when consumption reached an all-time high, the quantity needed was only 3,000 tons. Within the mercury industry this quantity would be expressed as 78,000 flasks, because the liquid metal is always marketed in steel flasks about the size of a 2-quart bottle and containing a standard 76 pounds. Only a part of the mercury required by our industry comes from domestic mines; the rest is imported chiefly from mines in Spain and Italy. In 1963, domestic mines accounted for only about 19,000 flasks, or less than a quarter of the United States consumption. However, in time of need, domestic mines have produced a greater proportion of the Nation's requirements. In 1943, under wartime conditions, the United States production was nearly 32,000 flasks, or 95 percent of its consumption. Again in 1958, under the stimulus of a government support price, domestic mercury production was about 38,000 flasks, or 72 percent of consumption. Increasingly large amounts of secondary mercury are recovered each year, but still most mercury goes into products from which its recovery is not possible.

The value of a flask of mercury has fluctuated widely in the last 25 years—from less than $77 in 1948 to more than $630 in late 1965. The price is ultimately determined by the world market, which is controlled by the foreign low-cost producers. Their increasing production costs and decreasing reserves, when considered in conjunction with worldwide increasing consumption, predicate a long-term rise in price. However, the historic record also indicates that, unless the domestic market is artifically stabilized, one must also anticipate continuing wide fluctuations.

The only important mercury ore mineral is the red sulfide, cinnabar, but some ores contain the black sulfide, metacinnabar, or native mercury. All other mercury minerals are so rare as to be mineralogical curiosities. The mercury minerals are deposited in the rocks by warm mineralized waters rising from depth, and minable concentrations are formed only within the upper 1,000 to 2,000 feet of the earth's crust. The solutions rise through cracks or pore spaces, and deposits are generally found only where the rocks are fractured or unusually porous. Deposits formed near the surface are quickly eroded, geologically speaking, so the deposits still available for mining are those which are young enough to have escaped erosion, and they are generally late Tertiary or Quaternary in age. The heat required for the ore solutions may come from volcanic magma chambers, and many mercury deposits are in or near areas of young volcanic rocks. However, not all volcanic areas contain mercury; for example, in Washington the great expanse of Columbia River Group, occupying the southeastern third of the State, is not known to contain a single occurrence of any mercury mineral.

The recovery from the ore of the final product is more readily and cheaply done for this metal than for any other, except perhaps free gold. Consequently, the final product, which is 99.9 percent pure mercury, is nearly always recovered at the producing deposit, or at a nearby mine. The mercury is extracted by heating the ore hot enough to convert the mercury sulfide, or other mercury minerals, to mercury vapor, and by then moving the vapor to a place cool enough to condense it to the liquid metal. For this heating, two basic types of equipment are used—retorts and furnaces. In retorts, which are small stills, the gases from the fuel do not mix with the mercury vapor, whereas in furnaces they do. A second difference is that retorts generally process a batch and must be discharged and reloaded, but furnaces are operated continuously. Customarily retorts, being less expensive, are used to treat small amounts of rich ore, whereas furnaces are used to process large quantities of lower grade ore. Either can be made to extract efficiently more than 95 percent of the mercury in the ore.

Although mercury ores were discovered in Washington before 1896 in the Keystone mine in Kittitas County, the total production of the State has been less than 7,000 flasks, or 0.2 percent of the United States production (Bailey, 1962). Nearly all of the Washington mercury has come from the Morton district in Lewis County, about 80 miles south of Seattle. Here two adjacent properties, known as the Roy and Barnum-McDonnell mines, have yielded about 6,500 flasks since mercury was first noted in 1916 (fig. 24). Most of the production came between 1926 and 1935; since 1940 the mines have been largely inactive. At the Royal Reward mine in King County, several thousand dollars in mercury was recovered in 1957–58. A very small production has been reported from the Silver Tip and H-O-M-E mines in Kittitas County.

The mineral belt in the Morton district has a length of 2 miles, along which there are more than a dozen prospects in addition to the productive mines. The rocks are shale, tuffaceous sandstone, and coal of Eocene age, and basic sills and dikes that have intruded them (Mackin, 1944). The structure is complex, with the ores occurring in sediments near and beneath faults. Some rich ore consists of cinnabar in coal,

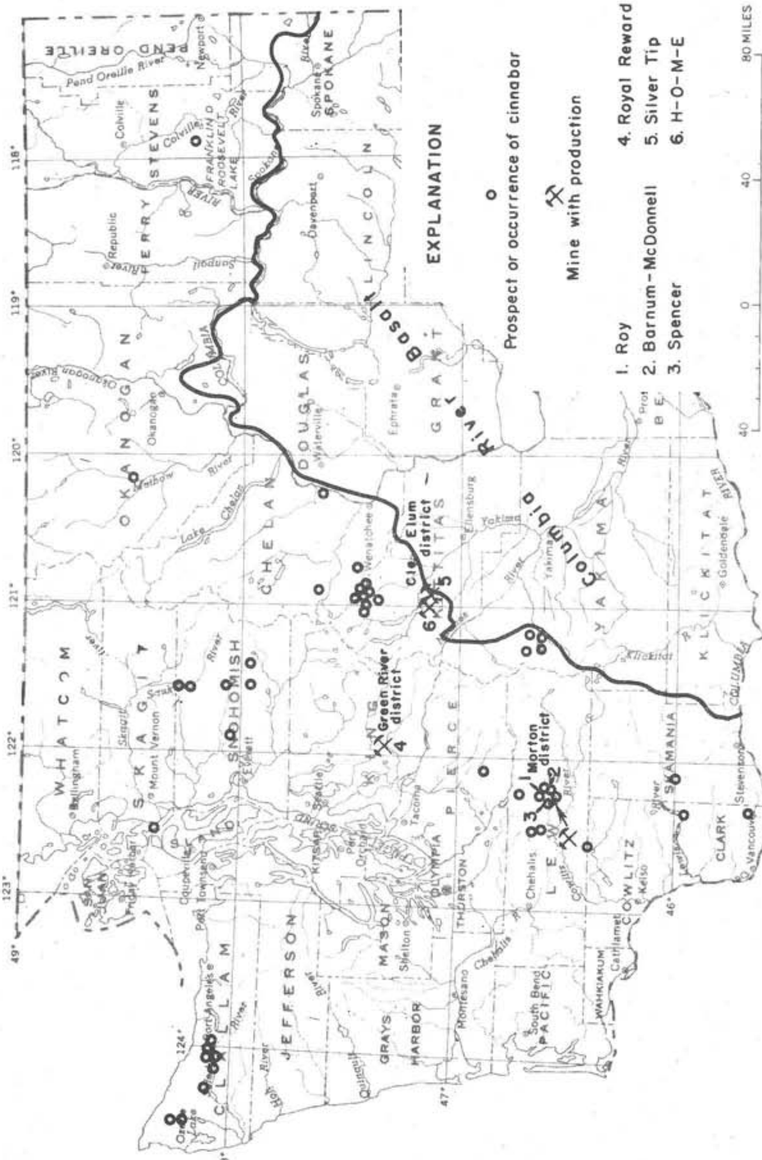

FIGURE 24.—Mercury in Washington.

which is unusual. Some sorted ore yielded over 100 pounds of mercury to the ton, but the average grade of furnace feed was probably about 5 pounds to the ton.

The Royal Reward and nearby Cardinal Reward mines in the Green River district 30 miles southeast of Seattle were developed in 1957–58. The geology is much like that in the Morton district, but here the ores contain, in addition to mercury minerals, also the antimony sulfide, stibnite, and arsenic sulfides.

The H-O-M-E and the Silver Tip properties in the Cle Elum district, Kittitas County (Huntting, 1956) are near the junction of Frosty and Taneum Creeks, about 25 miles from Ellensburg (fig. 24, Nos. 5 and 6). Cinnabar and free mercury are found in a shear zone at the contact of carbonaceous schist and highly altered calcareous sandstone.

Some of the concentrations of occurrences of mercury on figure 24 may be misleading in that they represent only a little cinnabar found in deposits of other kinds of ore. For example, the line of occurrences on the north side of the Olympic Peninsula represents minor occurrences of cinnabar in manganese deposits, and most of the cluster west of Wenatchee indicate occurrences of cinnabar in gold deposits. It does not seem likely that any of these will develop into mercury mines.

The widespread distribution of mercury in Washington, along with the record of production from a few mines, is sufficient to encourage the further search for new deposits and cautious exploitations of those now known. Because of a considerable cover of soil and vegetation in nearly all areas of known mercury occurrences, a realistic evaluation of Washington's mercury potential is impossible. In the Morton area, which has produced 99 percent of the State's mercury, less than 5 percent of the bedrock is exposed. It is probable that undiscovered deposits of mercury are present, but a considerable amount of exploration may be needed for the discovery of new deposits. The new geochemical methods of mercury detection should be considered in any exploration program. The known deposits in Washington have lacked large, rich ore bodies, but their ores can be profitably mined when the price of mercury is high enough. Late in 1964, the price of mercury began to rise, and by late 1965 was at levels of more than $600 a flask. If these prices are sustained it will be profitable to exploit mines containing ore that formerly was submarginal (Bailey and Smith, 1964).

MOLYBDENUM

(By R. U. King, U.S. Geological Survey, Denver, Colo.)

Molybdenum is a metal of considerable importance to our modern industrial economy, chiefly because of its versatility as an alloying element in the iron and steel industry. The metal is silvery white a little softer than steel, and has a melting point of 2610° C., the fifth highest of the metals. More than 85 percent of the molybdenum is used in the manufacture of high-temperature alloy steels, stainless steel, castings, and special alloys. Other uses include chemicals, pigments, catalysts, lubricants, and agricultural products. A continued rise in demand is foreseen for molybdenum for the remainder of this century.

Commercial production of molybdenum began in this country just prior to 1900 but was relatively small and intermittent until about 1914. Since that time, with few exceptions, domestic production has increased yearly to the current annual rate of over 60 million pounds. Molybdenum is our country's sole exportable ferroalloy metal, being produced in quantities sufficiently in excess of domestic consumption to supply a sizable portion of the free world demand. In 1964, United States consumption amounted to about 46 million pounds, whereas mine production was about 65 million pounds of molybdenum contained in concentrates. Since 1925, United States production has accounted for between two-thirds and nine-tenths of the world's molybdenum.

Molybdenum is marketed either in the form of molybdenite concentrate or as roasted concentrate (molybdenum trioxide). In April 1965, molybdenite concentrate was quoted at $1.55 per pound of contained molybdenum (95 percent MoS_2). Concentrates, however, are not readily marketable in small or individual lots, thus limiting somewhat the economic potential of small deposits.

In the United States, ore-grade material in large deposits mined primarily for the molybdenum content ranges from 0.2 to 0.5 percent MoS_2, but molybdenum may also be profitably extracted as a by-product from copper, uranium, and tungsten ores in which the molybdenum content is in the range of 0.01 to 0.1 percent.

Molybdenum is widely distributed in the rocks of the earth's crust, but deposits of commercial interest are found chiefly in igneous rocks of granitic composition or in sedimentary rocks closely related to granitic rocks. Trace amounts of this element, however, are found in ocean water and ground water; in soils; and in plant and animal tissue, where it apparently plays a vital role in many organic processes. It has not been found in its native or metallic state, but occurs in nature only in combination with other metallic or nonmetallic elements such as iron, calcium, tungsten, lead, sulfur, and oxygen. Some 12 minerals are known that contain molybdenum as an essential element, but of these only two, molybdenite (molybdenum disulfide) and wulfenite (lead molybdate), have been the source of most of the molybdenum produced to date. Other molybdenum minerals which are of more than passing interest, either for their molybdenum content or their geological significance as the demand for metal continues to rise, are ferrimolybdite (yellow, hydrous ferric molybdate), powellite (calcium molybdate, often with tungsten), jordisite (black, powdery molybdenum sulfide), and ilsemannite (blue, water soluble molybdenum oxysulfate).

Little molybdenum has been produced in the past in Washington, but a number of molybdenum deposits of potential economic importance are scattered across the Northern Cascade Mountains and across northeast Washington. Figure 25 shows the location of 59 deposits of molybdenum for which some reliable data are available and illustrates their distribution and mode of occurrence. Brief descriptions of the occurrences are given in table 8. Purdy (1954) has made a comprehensive study of the molybdenum deposits in the State of Washington.

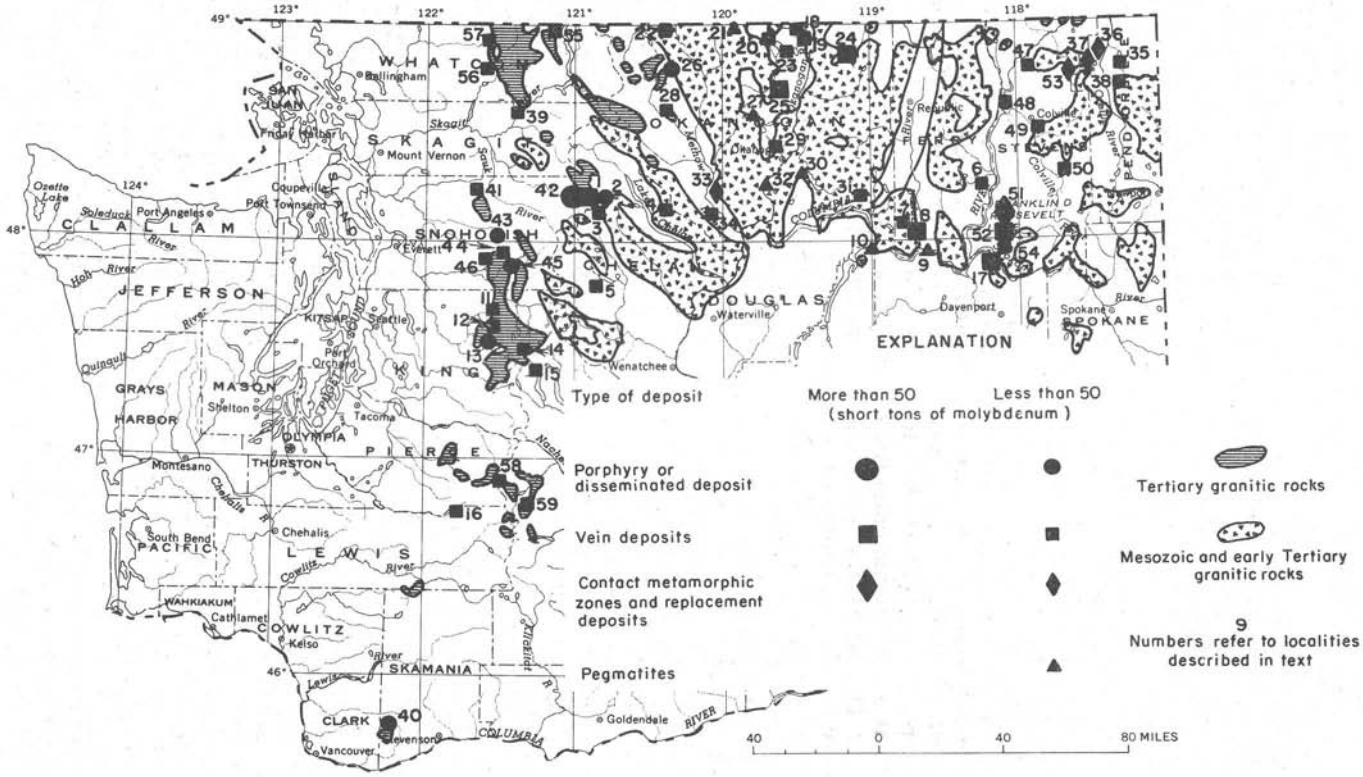

FIGURE 25.—Molybdenum occurrences in Washington.

TABLE 8.—*Molybdenum in Washington*

Index No. on fig. 25	County and name	Location	Manner of occurrence	Remarks	Reference
	CHELAN COUNTY				
1	Crown Point mine	Headwaters of Railroad Creek	Coarse molybdenite with pyrite and chalcopyrite in quartz vein in diorite.	Discovered 1897; produced small tonnages from 1902 to 1917.	Huntting, 1956; Crook, 1904; Purdy, 1954.
2	Holden mine (Howe Sound, Irene).	do	Zone of disseminated sulfide in metamorphic rocks. Small amounts of molybdenite, pitchblende, and scheelite.		Huntting, 1956.
3	Keefer Bros. mine	Red Mountain, near headwaters of Chiwawa River.	Molybdenite with chalcopyrite, bismuth, and uranium minerals in quartz veins in granodiorite.		Do.
4	Robischaud (Safety Harbor Creek, Copper King).	Headwaters of Safety Harbor Creek, east of Lake Chelan.	Molybdenite and chalcopyrite in quartz veins in granite.		Do.
5	Merritt (Smith)	At Merritt, Stevens Pass Highway.	Molybdenite and pyrrhotite in quartz lens in granite.		Do.
	FERRY COUNTY				
6	Cold Spring, Big Chief, Rosario.	Covada (Meteor) district	Small amounts of molybdenite, with copper, lead, and zinc sulfides in quartz veins in granodiorite and metamorphic rocks.		Purdy, 1954.
7	Abe Lincoln, Meadow Creek mine.	Keller district	Molybdenite with pyrite. Lead, zinc, and copper sulfides in quartz veins.		Pardee, 1918; Purdy, 1954.
8	Consolidated Mines & Smelting, Ltd. (California, Handspike, Iconoclast, Illinois, Pole Pick).	do	Molybdenite in quartz veins; fracture zones with copper sulfides in granite. Some powellite reported.	5 tons copper-molybdenum concentrates obtained from 2,000 tons of ore mined in the 1920's.	Purdy, 1954.
9	Schminski (Hellgate Rapids)	Sanpoil (Keller) district	Pegmatite in granite contains scattered patches of molybdenite.		Huntting, 1956.
	GRANT COUNTY				
10	Black-Rosauer (Electric City, Big Four).	Foot of east wall of Grand Coulee	Pegmatite lenses of quartz in granite contain molybdenite.		Purdy, 1954; Huntting, 1956.
	KING COUNTY				
11	Monte Carlo	Buena Vista district	Molybdenite with pyrite in quartz, tourmaline vein in shear zone in granite.		Huntting, 1956.
12	Goat Mountain, Devils Canyon (Cougar Creek) mines.	Miller River and Buena Vista districts.	Molybdenite with copper, lead, and zinc sulfides in quartz veins in granodiorite; some powellite and scheelite.	Narrow high-grade lenses contain up to 5 percent molybdenite.	Do.
13	Quartz Creek and Lost Lode prospects.	Snoqualmie and Taylor River districts.	Molybdenite in stockwork and sheeted zones in granodiorite.		Do.
14	Clipper prospect	On Middle Fork Snoqualmie River.	Molybdenite with copper sulfides in vein zone in granodiorite.		Purdy, 1954.

	KITTITIAS COUNTY				
15	Mineral Creek	Little Kachess Lake	Molybdenite with copper sulfides in breccia zone between rhyolite and basalt.	20 tons copper ore shipped prior to 1920.	Huntting, 1956.
	LEWIS COUNTY				
16	Eagle Peak	Near Longmire	Narrow high-grade copper veins in granite contain a little molybdenite.	Copper ore produced	Do.
	LINCOLN COUNTY				
17	Spokane Molybdenum	Pitney Butte	Molybdenite in quartz vein cutting granite	Potential resource of a few hundred thousand pounds of molybdenum. Small production in 1941.	Purdy, 1954; Huntting, 1956.
	OKANOGAN COUNTY				
18	49th Parallel, O.K. Copper, Golden Chariot.	Oroville district	Molybdenite with scheelite and copper sulfides in quartz veins in argillite.		Culver and Broughton, 1945; Huntting, 1956.
19	Moncosiglio (Adams)	do	Molybdenite with scheelite and copper sulfides in silicified bands in diorite.		Culver and Broughton, 1945.
20	Kaaba, Four Metals (Summit).	Nighthawk district	Quartz veins in granite contain base metal sulfides, molybdenite, and scheelite.		Huntting, 1956.
21	Horseshoe Basin (Arnold Peak, MacPhearson).	South of Arnold Peak	Pegmatite dikes in schist, contain a little molybdenite.	Small production of molybdenite in 1941.	Purdy, 1954; Huntting, 1956.
22	Sheep Mountain (Molly, Dodd, Boundary).	Near Internationa lMonument No. 11.	Quartz in veins and veinlets in granodiorite contain finely divided molybdenite.		Purdy, 1954.
23	American Rand, Triune	Wannacut Lake district	Quartz veins in argillite near contact with granite contain precious metals, sulfides, and a little molybdenite.		Umpleby, 1911a.
24	Bimetallic prospect	Near Havillah	High-grade bunches of molybdenite in flat-lying fault zone in altered granite porphyry.	Small production of high-grade molybdenite concentrate.	Purdy, 1954.
25	Starr (Silver Tip)	Aeneas Mountain, northwest of Tonasket.	Molybdenite with pyrite in breccia zone in granodiorite.	A few thousand tons high-grade ore shipped in 1939. Reserves of several hundred thousand tons of ore estimated.	Creasey, 1954.
26	Billy Goat, Carr, Hanks	On Eight Mile Creek near Winthrop.	Quartz-sulfide veinlets contain molybdenite scattered through large fractured and silicified zone in volcanic rocks.		Huntting, 1956.
27	Mineral Hill (Washington Consolidated Mines & Reduction Co., Seven Devils).	Mineral Hill, Conconully district	Pegmatite dike in granite contains coarse molybdenite aggregates.		Jones, 1917.
28	Molly (Luke)	Near Mazama	Molybdenite and copper sulfides in fractures in altered volcanic rock.		Huntting, 1956.
29	Green Lake	Near Green Lake	Quartz vein contains molybdenite		Do.
30	Corson	Omak Lake	Pegmatite in schist and gneiss contains a little molybdenite.		Do.
31	Sterling	6 miles northwest of Nespelem	Molybdenite with pyrite in quartz veins		Do.
32	Malott	Southeast of Malott	Molybdenite and copper sulfides in quartz pegmatite in granite.		Do.

TABLE 8.—*Molybdenum in Washington*—Continued

Index No. on fig. 25	County and name	Location	Manner of occurrence	Remarks	Reference
	OKANOGAN COUNTY—con.				
33	Dutch John, Sherwood, Lodge.	Near Carlton	Molybdenite, powellite, and scheelite in tactite.		Culver and Broughton, 1945; Purdy, 1954.
34	Holden-Campbell	On Squaw Creek west of Methow	Quartz-sulfide veins contain copper sulfides, molybdenite, and scheelite.		Huntting, 1956.
	PEND OREILLE COUNTY				
35	Little Noisy	East of Sullivan Lake, Metaline district.	Molybdenite and copper sulfides in quartz veins in granitic rock.		Park and Cannon, 1943.
36	Bella May, Polly Molly, Metaline Contact mines.	Metaline district	Wulfenite in oxidized lead zinc replacement ores in limestone.		Do.
37	Torelle (Coffin, Big Dike)	Near Ione, Metaline district	A little molybdenite with copper and lead sulfides in silicified marble.		Do.
38	Molybdenite Mountain	East of Tiger	Quartz vein contains small amounts of pyrite and molybdenite. Small amount of production prior to 1916.		Huntting, 1956.
	SKAGIT COUNTY				
39	Washington	5 miles north of Marblemount	Molybdenite in veins		Do.
	SKAMANIA COUNTY				
40	Miners Queen	Near Miners Creek, Washougal district.	Disseminated deposit of copper sulfides in altered diorite, contains a little molybdenite.		Do.
	SNOHOMISH COUNTY				
41	North Star (Sunrise)	Near Darrington	Copper, lead, zinc sulfides, and molybdenite in narrow quartz veins in granite.		Purdy, 1954.
42	Glacier Peak (Calumet)	Head of Miners Creek, Glacier Peak district.	Disseminated deposit of copper sulfides and molybdenite in brecciated granodiorite.	Several million ton orebody; potential reserve of byproduct molybdenum.	Do.
43	Sunrise Rustler, Copper Lake	Sultan Basin, Monte Cristo district.	Molybdenite and copper sulfides in quartz veinlets and disseminated in breccia zone in quartzite, hornfels, and quartz diorite.		Huntting, 1956; Purdy, 1954.
44	Sultan King, Iowa (Mint)	North Fork Sultan River, Sultan district.	Fracture zones in diorite and metamorphic rocks contain quartz-sulfide veins with molybdenite and scheelite.	Small tonnage of copper ore produced between 1930 and 1941.	Huntting, 1956.
45	Molly, Armament (Wayside)	Near Index, on North Fork Skykomish River.	Stockwork of quartz veinlets contains copper sulfides and molybdenite.		Broughton, 1942.

46	St. Theresa, Golden Eagle, Kromona.	Sultan Basin district	Molybdenite, copper sulfides, and scheelite in quartz veins in fracture zones in quartz diorite.		Caruthers and Guard, 1945; Huntting, 1956; Purdy, 1954.
	STEVENS COUNTY				
47	New Leadville, Lawrence American.	Bossburg district	Molybdenite and wulfenite in veins and replacement deposits in granite near contact with argillite and slate.		Huntting, 1956; Purdy, 1954.
48	Rightside, Columbia River	East side Roosevelt Lake, Kettle Falls district.	Quartz sulfide veins contain copper sulfides and a little molybdenite, in shale and argillite.	Small copper production	Huntting, 1956.
49	Rocky Lake	Colville district	Quartz-pyrite-molybdenite vein in granite.		Do.
50	Western Molybdenum mine (Juno Echo), Chewelah Standard.	Near Chewelah	Mineralized fault zones contain molybdenite, pyrite, chalcopyrite, and scheelite.		Cooper, 1956; Weaver, 1920.
51	Deer Trail Monitor	Near Fruitland, Deer Trail district.	Molybdenite in garnetized and silicified limestone near contact with granite.	Small molybdenum production 1936–41.	Purdy, 1954.
52	Germania mine	5 miles southeast of Fruitland	Molybdenite in quartz-tungsten veins in granite.	Produced considerable tungsten ore.	Culver and Broughton, 1945; Purdy, 1954.
53	Magma mine (Easy Money, Eldorado).	Northport district	Molybdenite and scheelite in contact metamorphosed limestone.		Culver and Broughton, 1945.
54	Midnite mine	6 miles northwest of Wellpinit, Spokane Indian Reservation.	Molybdenite associated with uranium ores in breccia zone in phyllite and quartz monzonite.		Weis and others, 1958.
	WHATCOM COUNTY				
55	Silver Creek prospect	West side Ross Lake near Canadian Border.	Molybdenite with copper sulfides in quartz veins and breccia zone in granodiorite and volcanic rocks.		Purdy, 1954.
56	Sulfide Creek (Shuksan)	East side of Mount Shuksan	Molybdenite in quartz veins in metamorphic rocks.		Huntting, 1956.
57	Midas	Mount Baker district	Small showing of molybdenite		Do.
	YAKIMA COUNTY				
58	Chinook	East side of Chinook Pass	Lens of high-grade copper sulfide in granodiorite contains a little molybdenite.	Small copper production in 1941.	Do.
59	Bird, Crosetti	Bumping Lake district	Molybdenite and scheelite in veins in granodiorite.	Small tungsten production, 1940.	Culver and Broughton, 1945; Huntting, 1956.

The molybdenum deposits of the United States are in a variety of geologic environments, of which the most important economically are the disseminated or porphyry type deposits, in which the mineral molybdenite is dispersed in hydrothermally altered and fractured bodies of granitic intrusive rocks either as the principal metallic mineral or as a minor constituent associated with copper sulfides. The deposits are commonly of relatively large size but have low metal content, and are therefore amenable only to large-scale, low-cost mining methods. They are by far the most productive of molybdenum today and have the greatest resource potential for the future. Ninety-five percent of the domestic reserves of molybdenum are in deposits of this type. At least six deposits of this type are known in Washington. These are the Starr (fig. 25 and table 8, No. 25), Billy Goat (No. 26), Miners Queen (No. 40), Glacier Peak (No. 42), Sunrise (No. 43), and Molly (No. 45) deposits. They are mostly restricted to the Northern Cascade Mountains and are associated with intrusive bodies of Tertiary granodioritic and adjacent metamorphic rocks.

Molybdenite in quartz veins is probably the most common mode of occurrence of molybdenum in the State. Numerous deposits of this type are found in the Northern Cascade Mountains and northeastern Washington (fig. 25). The vein deposits are in intrusive rocks of granitic and granodioritic composition and associated metamorphic rocks. Vein deposits are not likely to be profitably minable because of their limited size or tonnage, although, rarely, hand-sorted material may be produced from some deposits of exceptionally high grade.

A few contact metamorphic deposits of molybdenum are known in northeastern Washington (Nos. 33, 37, 51, 53). The molybdenum occurs as molybdenite or as powellite, commonly associated with the tungsten mineral scheelite in zones of silicated or garnetized limestone (tactite) close to contacts with granitic intrusive bodies. Contact deposits are generally not economically minable for molybdenum due chiefly to the low molybdenum content.

Pegmatite deposits in which molybdenite occurs commonly as coarse crystalline flakes and mineral aggregates associated with quartz, feldspar, and mica are known in the north central part of the State (Nos. 9, 10, 21, 27, 30, 32). Such deposits are found in granitic and metamorphic rocks, but only specimen mineral material has been obtained from these deposits.

Although more than 120 occurrences of molybdenum are reported in Washington (Purdy, 1954), probably only the disseminated or porphyry deposits and a few of the larger quartz vein deposits can be expected to have much potential for commercial sources of molybdenum. The widespread occurrence of deposits of these types in the northern Cascades suggests that this area is a favorable one for exploration for molybdenum.

NICKEL AND COBALT

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Nickel and cobalt are chemically closely related to iron and both are important as alloying elements with iron as well as other metals. According to the U.S. Bureau of Mines Minerals Yearbooks (v. 1), the average consumption of cobalt in the United States for the years 1961,

1962, and 1963 was 10,464,000 pounds. About 78 percent of this was for metallic uses—tool steels and other alloy steels of high strength at high temperatures and welding materials taking 43 percent; magnets, 24 percent; and cemented carbides, other alloys, and miscellaneous uses, 11 percent. The remaining 22 percent was for nonmetallic uses such as ground coat frit, pigments, salts, and driers. The average consumption of nickel in the United States for the same 3 years was 120,557 tons. The largest use was in ferrous alloys (steels and cast irons), 47 percent; nonferrous alloys and electrically resistant alloys, 33 percent; electroplating, 15 percent; and catalysts, ceramics, magnets, and miscellaneous uses, 5 percent.

Aside from a small amount of cobalt (about 7 percent of consumption) produced as a by-product from magnetite ores of Pennsylvania, and a little nickel (less than 8 percent of consumption) from the Riddle, Oreg., deposit, all the primary cobalt and nickel consumed in the United States is imported. Of the cobalt imported, over 60 percent is mined in Katanga, Republic of the Congo (some of this is refined in Belgium), about 13 percent is from West Germany, 16 percent is mined in Canada (10 percent of this is refined in Norway), and about 7 percent is from France (mostly mined in Morocco) and other countries. Of the nickel imported, about 98 percent is mined in Canada. Some of this is refined in Norway.

The important primary minerals of cobalt are cobaltite, safflorite, skutterudite, linnaeite, and glaucodot. In places considerable cobalt may be present in pyrite or arsenopyrite. Secondary minerals are erythrite and heterogenite. The major primary nickel mineral is pentlandite; of less importance are niccolite, maucherite, rammelsbergite, and a number of other sulfides and sulfarsenides. Some nickel may be present in pyrrhotite, and to a lesser extent in pyrite. The important secondary nickel mineral is the hydrated nickel silicate, garnierite. In the more mafic igneous rocks, some nickel is present in olivine and other magnesium silicates.

Nickel occurrences in Washington are of two general types—those occurring in, derived from, or closely associated with ultramafic bodies; and those where nickel is associated with sulfides of copper, lead, zinc, or other metals in veins or disseminated deposits in many different types of host rocks. (See table 9.) Cobalt occurs with copper and other metallic sulfides and sulfarsenides, in veins or disseminated deposits; a small amount is everywhere present with the nickel in ultramafic rocks.

TABLE 9.—*List of properties where nickel or cobalt occur (excepting those occurring in silica-carbonate rock, derived from serpentine, and those occurring in "fossil laterite")*

Index No. on fig. 26	County, district, and property	Location	Metal	Geology (grade or tonnage where known)	References
	CHELAN				
1	Chiwawa: Keefer Bros.	Sec. 20, T. 31, N., R. 16 E.	Nickel-cobalt	Molybdenite, chalcopyrite, arsenopyrite, pyrite, uraninite, scheelite, with quartz, tourmaline, and chlorite in fissures in altered granodiorite. Ni and Co reported.	Huntting, 1956.
2	Entiat: Dick (Winesap)	Sec. 9, T. 26 N., R. 21 E.	do	Disseminated pyrrhotite, pentlandite, pyrite, chalcopyrite in broken coarsely crystalline body of ultramafic rock enclosed in quartz diorite 30,000 tons—average 1.5 percent Ni, 0.68 percent Cu, 0.1 percent Co.	Patty & Kelly, 1946; Creasey & Storch, 1945.
	Meadow Creek:				
3	Blue Jay	Sec. 1, T. 31 N., R. 18 E.	Cobalt	Pyrrhotite, chalcopyrite, arsenopyrite in altered zone in gneiss.	Huntting, 1956.
4	King Solomon	Sec. 36, T. 32 N., R. 18 E.	do	Pyrrhotite, chalcopyrite, pyrite, sphalerite, arsenopyrite (with cobalt) in sulfide lenses in altered zones in gneiss.	Do.
5	Railraod Creek: Holden	Sec. 20, T. 31 N., R. 17 E.	Nickel	Samples from mafic dike with pyrrhotite southeast of ore zone, assayed 0.2 to 0.46 percent nickel.	Do.
	CLARK				
6	Washougal: Silver Star	Sec. 23, T. 3 N., R. 4 E.	do	Chalcopyrite, pyrite, sphalerite, galena, magnetite with quartz and siderite in altered volcanic rock near Tertiary pluton. Ni reported present.	Do.
	FERRY				
	San Poil:				
7	Congress	Sec. 35, T. 32 N., R. 33 E.	Nickel-cobalt.	Pyrite, chalcopyrite (Ni and Co present) in quartz vein on contact of schist and serpentine; quartz monzonite 1,000 feet east. Average 0.54 percent Ni, 0.03 percent Co.	Bancroft, 1914.
8	McJunkin	Sec. 27, T. 32 N., R. 33 E.	Nickel	Sphalerite, galena, pyrite (Ni present) with quartz in breccia zone at contact of limestone and serpentine.	Pardee, 1918; Huntting, 1956.
9	Shamrock	Sec. 35, T. 31 N., R. 33 E.	Nickel-cobalt.	Nickeliferous zone in brecciated limestone, parallel to granite contact (low grade Ni and Co).	Huntting, 1956.

	KITTITAS				
10	Cle Elum: Blue Bonnet	Sec. 25, T. 23 N., R. 14 E.	Nickel	Copper, nickel, gold, and silver; probably hydrothermal vein in serpentine.	Do.
	LEWIS				
11	Mount Rainier: Eagle Peak	Sec. 27, T. 15 N., R. 8 E.	Cobalt	Chalcopyrite, bornite, arsenopyrite, sphalerite, scheelite, molybdenite, linnaeite on mineralized joints in granite.	Patty, 1921; Huntting, 1956.
	MASON				
12	Olympic: Black and White	Sec. 17, T. 24 N., R. 5 W.	Nickel-cobalt	Manganese oxides and silicates with native copper, cuprite, etc., in lenses along altered basalt contact with phyllite-graywacke (Ni+Co, 0.12 percent).	Park, 1942.
	OKANOGAN				
	Conconully:				
13	Brown Lake	Sec. 6, T. 34 N., R. 26 E.	Nickel	Nickel-bearing sulfide in mass of ultramafic rock cut by granitic mass.	Huntting, 1956.
14	Johnson Creek	Sec. 5, T. 34 N., R. 26 E.	do	Nickel-bearing white sulfide in ultramafic rock.	Do.
15	Methow: Alta Lake	Sec. 22, T. 29 N., R. 23 E.	do	Chalcopyrite and pyrrhotite in shear zone in silicified schist and gneiss; up to 1.48 percent Ni reported.	Do.
	Nespelem:				
16	Lilman	Sec. 26, T. 32 N., R. 30 E.	do	Tetrahedrite, chalcopyrite, pyrite, pyrrhotite (Ni present) in replacement veins in granite.	Do.
17	Malott	Sec. 22, T. 32 N., R. 25 E.	do	Pyrite, pyrrhotite, chalocopyrite, sphalerite, molybdenite in quartz zone in pegmatite.	Do.
18	Stepstone	Sec. 5, T. 32 N., R. 31 E.	do	Chromite, pyrite, pyrrhotite, pentlandite, disseminated in serpentine and in quartz vein in limestone. Assays show 1.22 to 2.65 percent Ni.	Pardee, 1918; Huntting, 1956.
19	Twisp: Wolverine	Secs. 2, 11, T. 34 N., R. 18 E.	do	Pyrite, nickeliferous pyrrhotite, chalcopyrite, sylvanite(?) in quartz veins cutting granite.	Huntting, 1956.
	PEND OREILLE				
	Metaline:				
20	Grandview	Sec. 25, T. 40 N., R. 45 E.	do	Silver, copper, gold, nickel in quartz veins, in either Shedroof Conglomerate or Leola Greenstone.	Do.
21	LaSota	Secs. 3, 10, T. 37 N., R. 41 E.	Cobalt	Galena, sphalerite, tetrahedrite, bornite, chalcopyrite in quartz-tourmaline stringers and mineralized calcareous beds in phyllite. Co reported present.	Do.

TABLE 9.—*List of properties where nickel or cobalt occur (excepting those occurring in silica-carbonate rock, derived from serpentine, and those occurring in "fossil laterite")*—Continued

Index No. on fig. 26	County, district, and property	Location	Metal	Geology (grade or tonnage where known)	References
	SNOHOMISH				
	Darrington:				Huntting 1956:
22	Blue Bird	Sec. 19, T. 32 N., R. 10 E.	Nickel	Chalcopyrite, pyrrhotite in vein	Do.
23	Feldt	Sec. 30, T. 32 N., R. 9 E.	Cobalt	Stibnite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, tetrahedrite, cobaltite, with quartz and calcite in breccia zone in altered volcanic rocks.	Purdy, 1951.
24	Jumbo Mountain	Sec. 2, T. 31 N., R. 9 E.	Nickel-cobalt	Dunite intruding Tertiary sedimentary rocks carries some nickel in disseminated pyrrhotite. Higher concentrations of pyrrhotite, pentlandite, and chalcopyrite in shear zones in altered dunite at contact with quartzite. Up to 3 percent Ni reported.	Mills, 1960.
	Index:				
25	Hancock	Sec. 31, T. 29 N., R. 11 E.	do	Chalcopyrite and pyrite, in wide vein, probably in Tertiary granitic rock.	Huntting, 1956.
26	NonPareil	Sec. 6, T. 27 N., R. 11 E.	do	Chalcopyrite, bornite, chalcocite, pyrite with quartz in shear zones in altered granodiorite; 1.14 percent Co reported.	Weaver, 1912; Huntting, 1956.
27	Monte Cristo: Mackinaw	Sec. 19, T. 29 N., R. 11 E.	do	Niccolite, maucherite, pentlandite, chalcopyrite, cubanite, a little vallerite, sphalerite and gold, in lenses in ultramafic rock near fault contact with Eocene arkose. 80,000 tons average 1.7 percent Cu, 1.0 percent Ni, 0.05 percent Co, 0.15 ounce Au.	Milton and Milton, 1958; Huntting, 1956.
28	Silver Creek: Wild Rose	Sec. 32, T. 29 N., R. 11 E.	do	Cu, Hg, Co, As, Ni, Au, Ag, said to occur in the "pyrites" in zone along contact of peridotite and quartzite. May be similar to the Mackinaw deposit.	Spurr, 1901.
	Sultan:				
29	Big Copper	Sec. 4, T. 29 N., R. 10 E.	Cobalt	Copper, cobalt, gold and silver, probably in Tertiary granitic rocks.	Huntting, 1956.
30	Florence Rae	Sec. 27, T. 29 N., R. 10 E.	Nickel	Chalcopyrite, pyrite, pyrrhotite, sphalerite, magnetite, galena, hematite, scheelite, chromite in quartz-calcite viens in metamorphic rock, quartz diorite and peridotite. <0.25 percent Ni.	Carithers and Guard, 1945.

	STEVENS				
31	Chewelah: Windfall	Sec. 16, T. 32 N., R. 41 E.	do	Arsenopyrite, chalcopyrite, pyrite, galena, in quartz vein in silicified limestone cut by granitic rocks.	Huntting, 1956.
32	Kettle Falls: Daisy-Tempest	Sec. 7, T. 33 N., R. 33 E.	Nickel-cobalt	Arsenopyrite, nickeliferous pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and scheelite in quartz veins in argillite and quartzite cut by diorite. Co also reported present.	Culver and Broughton, 1945; Huntting, 1956.
	Northport:				
33	A. Anderson	Sec. 3, T. 39 N., R. 41 E.	do	Sphalerite and galena in replacement deposit in limestone near shale contact. Also, narrow vein shows 4 percent Ni (specimen?). (Also, a DDH had a 4-foot section with 0.42 percent Ni, 0.12 percent Co.)	Huntting, 1956.
34	Maki	Sec. 35, T. 39 N., R. 41 E.	Cobalt	Galena, sphalerite, pyrrhotite with calcite in bedding replacement in limestone near granite. Co reported.	Do.
35	New England	Sec. 26, T. 39 N., R. 40 E.	do	Sphalerite, galena with tremolite as limestone replacement near granite. Co reported present.	Do.
36	Wall Street	Sec. 35, T. 39 N., R. 39 E.	Nickel	Pyrite, pyrrhotite, tetrahedrite (?) sphalerite (?) in quartz vein in shear zone in limy argillite. Ni reported present.	Do.

All ultramafic rocks in Washington, whether fresh or serpentinized, carry from 0.1 to 0.2 percent nickel, as was pointed out as long ago as 1904 by G. O. Smith (1904, p. 4), and reemphasized by Purdy (1951, p. 89) when he said in discussing the nickel content of a silica-carbonate dike:

> Undoubtedly, the original source of the nickel is the serpentine, as it is characteristic of the serpentine in the western Cascade Mountains to carry approximately 0.2 percent nickel.

Both serpentinization and weathering set nickel free from the magnesium silicates to form garnierite as green stains or veinlets. The small amount of nickel in these rocks may be also somewhat concentrated during the formation of quartz veins by later hydrothermal solutions.

Further alteration of serpentine by hydrothermal solutions forms silica-carbonate rock—the so-called "nickel ledge." This may contain a little nickel, and any hydrothermal veins formed in this type of rock will also "inherit" this nickel. The best explored of this type of deposit is the nickel-gold deposit on Devils Mountain, near Mount Vernon in Skagit County. There the silica-carbonate rock consists of quartz, opal, chalcedony, carbonates, and a little pyrite and chromite (residual from the peridotite). In places this rock was brecciated, and quartz and sulfides (marcasite, pyrite, and bravoite) cemented the breccia; a small amount of gold was also deposited with the sulfides. The deposit presumably contains as much as 50,000 tons of sulfide-bearing breccia carrying 0.25 to 0.30 percent nickel and about 0.02 ounce gold per tons (Hobbs and Pecora, 1941).

Over 40 of the properties listed by Huntting (1956) under cobalt and nickel are either garnierite-serpentine deposits, nickel-gold-quartz veins, or the silica-carbonate-sulfide type of deposit, and none are believed important as possible sources of nickel or cobalt. Cobalt is present in most of the deposits but in much smaller quantities than the nickel.

Deep weathering of mafic and ultramafic rocks under tropical conditions forms a soil type called laterite that contains much iron oxide; this material has been mined as an iron ore in many places, as, for example, at Mayari, Cuba. Nickel and cobalt are also concentrated in laterite, as is chromite, which is resistant to weathering. In early Tertiary time, a tropical climate existed in Washington, and a laterite was formed on exposed ultramafic rocks. Later, this laterite was covered by Eocene sedimentary rocks. Removal of this sedimentary cover by recent erosion has exposed the "fossil laterite" in several places in the State. The chief occurrence is at the base of the Swauk Formation, where it is in contact with the band of ultramafic rocks lying in a crescent around the south side of the Mount Stuart batholith. Areas of high-iron laterite containing nickel, cobalt, and chromium are found at intervals along this contact from the Cle Elum River eastward to Peshastin Creek, Kittitas and Chelan Counties (Broughton, 1943b; Lamey and Hotz, 1952). Numerous mining claims have been located on these laterites. A similar "fossil laterite" above a small mass of ultramafic rock on the west side of Sumas Mountain, Whatcom County, is being re-exposed by the erosion of lower Teritary sedimentary rock similar to the Swauk Formation (Moen, 1962). The deposit on the Big Four property (Silverton

district, Snohomish County), as described by Huntting (1956), is similar to the Cle Elum ore.

In places, ultramafic rocks contain disseminations or segregated masses of sulfides. These generally consist of pyrrhotite, pentlandite, and chalcopyrite; cobalt is present in an amount equal to one-twentieth to one-thirtieth of the amount of nickel plus copper, and a very small amount of platinum is usually present. The Dick deposit (table 9 and fig. 26, No. 2) and the Jumbo Mountain deposit (No. 24) are examples of this type of deposit. At the Jumbo Mountain deposit, the sulfides also are concentrated on shear zones at the dunite-quartzite contact and may be the result of hydrothermal action.

Where hydrothermal solutions have been especially active in or along the contacts of ultramafic masses, considerable concentration and alteration of the sulfide minerals segregated in the igneous rock, as well as introduction of other metals, may take place. The Mackinaw deposit (No. 27) as well as possibly the Congress (No. 7), the McJunkin (No. 8), the Florence Rae (No. 30), the Stepstone (No. 18), and the Wild Rose (No. 28) deposits, at least in part, are of this type. At the Mackinaw (Milton and Milton, 1958), primary segregations of chalcopyrite, pentlandite, and probably pyrrhotite in a wide ultramafic dike have been extremely altered by hydrothermal solutions moving along a shear zone between the dike and Eocene arkose. The arsenides of nickel, niccolite, and then maucherite were formed, presumably, by replacing the pentlandite; cubanite is intergrown with the chalcopyrite, and some vallerite ($Cu_2Fe_5S_7$), sphalerite, and gold were deposited. There is now no pyrrhotite or pyrite in the deposit. As is to be expected, a small amount (approximately 0.05 percent) of cobalt is present.

With one exception, the rest of the deposits in the State reported to contain nickel or cobalt or both metals are all hydrothermal in origin and are not associated with ultramafic rocks. The exception is the Black and White deposit (No. 12), where a deposit of manganese oxides and silicates contains some native copper, cuprite, and up to 0.12 percent nickel plus cobalt. Most of the hydrothermal deposits either have not been studied carefully enough for the nickel or cobalt minerals to be detected or else the nickel and cobalt are present as impurities in other minerals such as arsenopyrite, pyrite, pyrrhotite, sphalerite, and to a lesser extent, chalcopyrite. Primary cobalt minerals are described in only two deposits listed in Washington Division of Mines and Geology Bulletin 37. The Eagle Peak deposit (No. 11) consists of chalcopyrite, bornite, arsenopyrite, sphalerite, scheelite, molybdenite, and linnaeite deposited on mineralized joints in granite. The Feldt property (No. 23) has two different types of veins on it—the one with cobalt has early pyrite and arsenopyrite enclosing occasional minute cubes of cobaltite; the other has tetrahedrite, chalcopyrite, sphalerite, and galena (Purdy, 1951, p. 129).

Most of the rest of the hydrothermal deposits contain chalcopyrite and some tetrahedrite or bornite, with one or more of the iron minerals pyrrhotite, arsenopyrite, or pyrite. About half of them also contain sphalerite, and galena is present in a few. The few in which copper minerals are not reported as being present are one associated with a basic dike near the Holden mine (No. 5) and three in the Northport district, Stevens County (Nos. 33, 34, 35), which are sphalerite-galena replacements in limestone.

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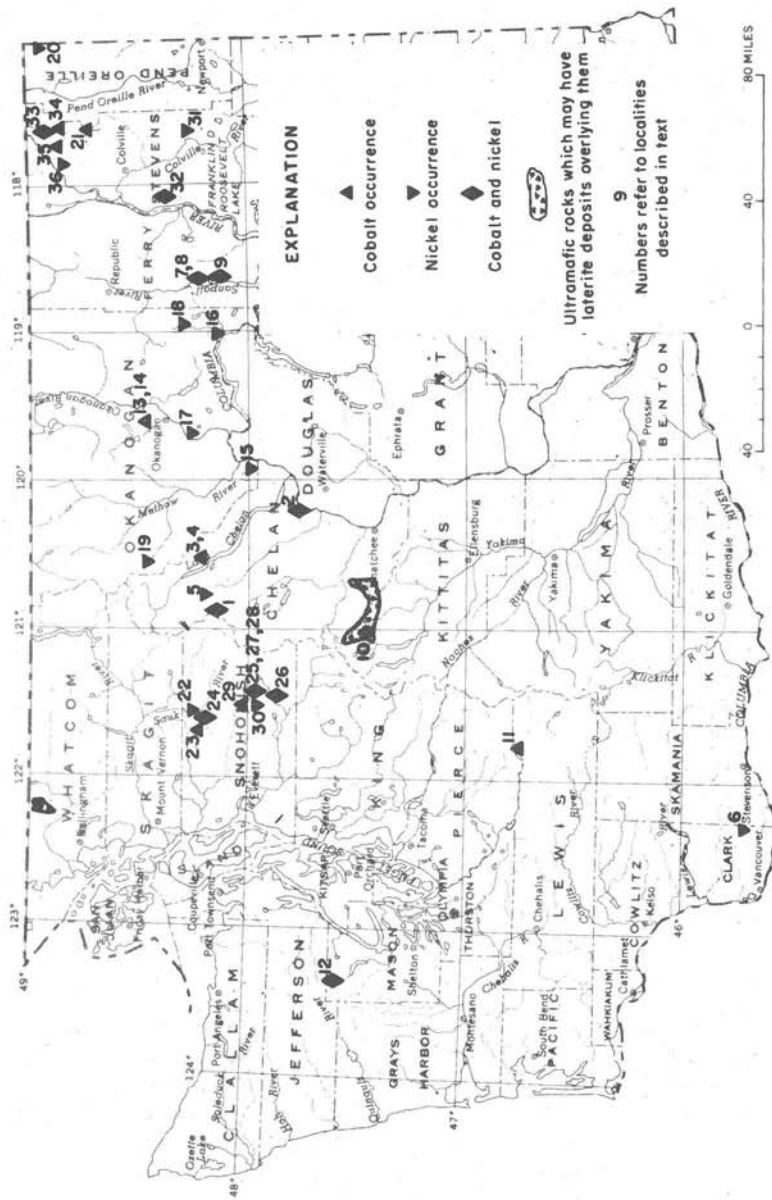

FIGURE 26.—Nickel and cobalt in Washington.

Almost no cobalt or nickel has been produced from deposits in Washington to date. A few deposits of possibly sufficient size and grade to interest mining companies are present in the State, such as the Mount Jumbo (No. 24) or the Mackinaw deposit (No. 27), but an additional problem, besides that of developing a large tonnage, is that of refining. Both cobalt and nickel ores require special and expensive types of refineries in order to produce usable metal. The nearest refinery that handles cobalt or nickel concentrates is that of Sherritt Gordon Mines, Ltd., at Port Saskatchewan, Alberta, Canada. The company has been treating custom concentrates on a toll basis. If sufficient tonnage of concentrates could be guaranteed and if a satisfactory arrangement could be made with this refinery, then there might be the possibility of appreciable nickel production, although transportation costs would obviously be high. Studies by the U.S. Bureau of Mines (Ravitz, 1947; Cremer, 1954) have shown that it is technically possible to make special steels by direct electric smelting of the Blewett-Cle Elum laterite ores. The Cle Elum-Blewett ores may perhaps be utilized at some future time for the manufacture of special alloy steels containing chromium, nickel, and cobalt in about the same proportions as these elements occur in the ores, but the economic feasibility of this has not yet been demonstrated.

SILVER, LEAD, AND ZINC

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Silver, lead, and zinc are discussed together in this report because in many deposits the three metals occur together. All three metals are widely used in our economy. Because industrial consumption of silver has for several years exceeded production of new silver, the price has risen and stocks of silver held by the United States Treasury have declined sharply. This situation has created problems that brought about a change in the use of silver in coinage. This will alleviate the current shortage, but with continuing increases in industrial use, silver is expected to remain in short supply.

Washington has produced substantial amounts of lead, silver, and zinc. Through 1963 the State has produced 227 thousand short tons of lead and 484 thousand short tons of zinc. Statistics on silver production are not available after 1956; to that year Washington's production was 16.4 million ounces. In the last 5 years, Washington usually has ranked about 6th or 7th among the States in the production of silver and 5th or 6th in the production of lead. During the same period, it has ranked 8th to 12th in the production of zinc. In 1963 the Pend Oreille mine in the Metaline district was the country's 12th leading producer of both lead and zinc, and the Republic district ranked 22d in the production of silver, although the district is more noted for the gold it provides.

Deposits of lead, silver, and zinc are distributed widely throughout the Okanogan Highlands and the Cascade Mountains. As is common throughout much of the western United States, many of these deposits in Washington are found in or close to masses of intrusive rocks of granitic composition. The most productive deposits in the State for lead and zinc are in carbonate rocks in Stevens and Pend Oreille

Counties. Some of these are a considerable distance from any surface exposure of granitic rocks, but viewed broadly even these deposits are seen to be in large roof pendants in a granitic terrain (fig. 27).

Much of the silver mined in Washington has come from deposits chiefly valuable for copper. The Holden mine in the Chelan Lake district, Chelan County (fig. 27 and table 10, No. 1), the United Copper and Copper King mines in the Chewelah district, Stevens County (No. 26), and the Sunset mine in the Index district, Snohomish County (No. 20), are the leading examples of this type. The Holden mine also produced zinc, and mines in the Chewelah area produced lead.

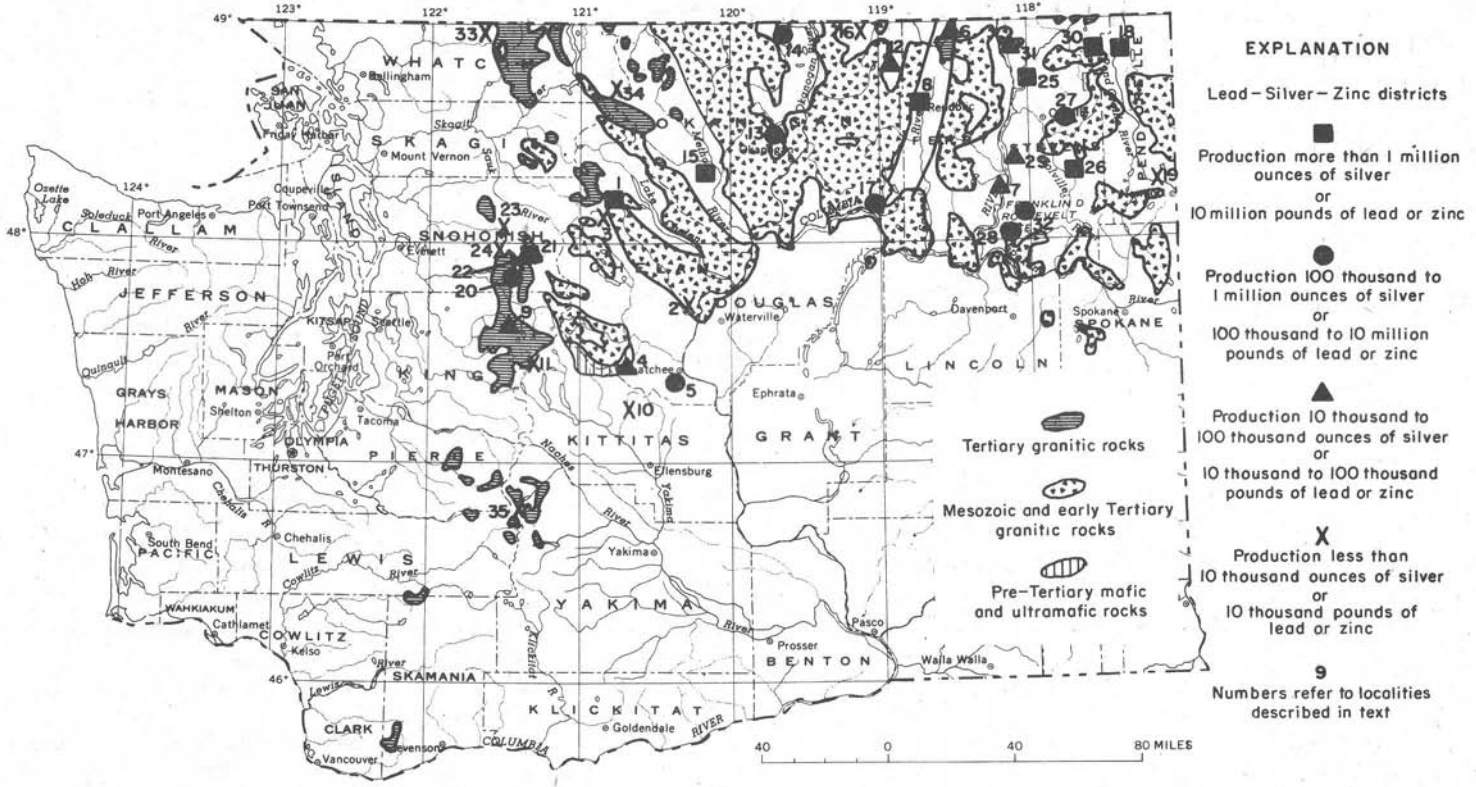

FIGURE 27.—Productive lead, silver, and zinc districts in Washington.

TABLE 10.—*Lead-silver-zinc districts in Washington*

Index No.	County, district, mine(s)	Magnitude of production [1]			Remarks	Reference
		Silver	Lead	Zinc		
	CHELAN					
1	Chelan Lake: Holden	A	------	A	Sulfide minerals disseminated in silicified, brecciated gneiss between Tertiary and Mesozoic granitic intrusions. Production 2,000,000 ounces of silver, 40,000,000 pounds of zinc.	Youngberg and Wilson, 1952.
2	Chiwawa: Red Mountain (Royal)	D	------	------	Disseminated sulfide mineral in breccia pipe. Said to have large resources of low-grade copper ore.	Huntting, 1943.
3	Entiat: Rex	D	------	------	Oxidized gold-quartz veins in gneiss. Minor silver as byproduct of gold mining.	Do.
4	Blewett	C	D	------	Quartz calcite veins in serpentine and in sedimentary rocks of Hawkins and Peshastin Formations. Silver and very minor lead as byproduct of gold mining.	Smith, 1903a; Huntting, 1955.
5	Wenatchee: Gold King	B	------	------	Quartz veins in silicified podlike bodies in Swauk Formation. Silver is byproduct of gold mining.	Lovitt and McDowell, 1954.
	FERRY					
6	Danville: Morning Star and Lancaster	C	D	------	Gold-pyrite-quartz veins in greenstone near contact with serpentine. Principal value is gold. Some silver from copper deposits and from the Lone Star mine.	Parker and Calkins, 1964.
7	Enterprise (Covada): Silver Bell	D	C	------	Small production from lead veins in "hornstone"	Pardee, 1918.
8	Republic: Knob Hill	A	------	------	Silver with quartz and calcite, adularia, native gold, electrum, telluride, and selenide in volcanic rocks and interbedded sediments. Chief value is gold, but for many years this has been the leading silver producer in the State.	Umpleby, 1910.
	KING					
9	Miller River: Cleopatra and Silver Dollar	C	------	------	Altered and mineralized zones with galena, chalcopyrite, tetrahedrite, and other sulfides along joints in granodiorite. Intermittent production to 1941.	Purdy, 1951.
	KITTITAS					
10	Swauk: Mountain Daisy	D	------	------	Fissure veins in sandstone and shale of Swauk Formation. Minor silver as byproduct of gold mining.	Smith, 1903a; Huntting, 1955.
11	Fish Lake: Esther and Louisa	D	D	------	Quartz veins in volcanic rock with ruby silver, galena, and sphalerite. First operated in 1890's.	Smith and Calkins, 1906.

	OKANOGAN					
12	Cascade: Bodie and Phil Sheridan	C	D		Quartz-calcite veins with gold and silver in tuff and andesite. Intermittent production 1907–16 and 1933–40.	Huntting, 1956; Patty, 1921.
13	Conconully: Arlington and Sonny Boy	B	C		Quartz veins with argentiferous galena, chalcopyrite, and other sulfides near contact of schist and granite. Disseminated deposits in north end of district have not been mined. Total production around $200,000; mostly in silver and mostly before 1916.	Jones, 1917.
14	Oroville - Nighthawk - Palmer Mountain: Kaaba, Four Metals, Premier, and Ruby.	B	B	C	Most of production from Kaaba mine from quartz vein in granodiorite near roof pendent. Produced intermittently 1915–29 and 1943–50. Ore very low grade. Original activity in district was gold mining. In Palmer Mountain portion of district, gold-quartz veins with pyrite, chalcopyrite, and galena in diorite and greenstone.	Patty, 1921; Umpleby, 1911b; Lander and others, 1902.
15	Methow: Alder, Hunter, and Independence	B	D	(A)	Low-grade disseminated copper-gold-zinc ore body in altered andesite near cupola of Cretaceous granite. Produced intermittently 1937–53. Zinc resources possibly in excess of 2,000,000 pounds, but zinc was not recovered in previous operation.	Huntting, 1956.
16	Meyers Creek and Mary Ann Creek: Poland China, Mother Lode, and Morning Glory.	D	D		Contact metamorphic deposits in metamorphosed sediments, and quartz veins with pyrite, marcasite and galena in argillite. Worked intermittently 1907–40. Silver and lead mostly byproduct of gold mining. Copper predominant in contact metamorphic deposits.	Umpleby, 1911a.
17	Nespelem: Apache and Little Chief	B	D		Narrow seams of rich silver ore in sheared zones in granite. Worked intermittently 1911–40.	Patty, 1921.
	PEND OREILLE					
18	Metaline: Pend Oreille and Grandview	B	A	A	Zinc-lead replacement deposits in Cambrian Metaline Limestone. Silver content of ore low but production substantial because of large tonnage treated. Leading metal producer of State. Production through 1963: 590,124 ounces of silver, 368,010 short tons of zinc, 168,896 short tons of lead, 420 short tons of copper, and 254 ounces of gold from 14,546,966 short tons of ore. Value of production $121,173,086. Potential ore reserves very large.	Park and Cannon, 1943; Dings and Whitebread, 1965.
19	Newport: Comstock and Bead Lake	D	D		Irregular quartz veins with galena, chalcopyrite, and sphalerite in quartzite intruded by diorite. Small intermittent shipments, 1917–37.	Jenkins, 1924.
	SNOHOMISH					
20	Index: Sunset	B			Ore bodies occupy shear zones in Tertiary granodiorite. Copper mine with substantial production of silver. Not operated since 1943 except for exploration. Total production 1,500 ounces gold, 156,000 ounces silver, and 12,912,000 pounds copper from 263,500 tons of ore. Substantial amounts of submarginal ore remains.	Huntting, 1956; Weaver, 1912; Patty, 1921; Toepfer, 1953.

See footnotes at end of table, p. 131.

TABLE 10.—*Lead-silver-zinc districts in Washington*—Continued

Index No.	County, district, mine(s)	Magnitude of production[1]			Remarks	Reference
		Silver	Lead	Zinc		
	SNOHOMISH—continued					
21	Monte Christo: Pride, Mystery, Golden Chord, and Foggy.	A	A(?)	----------	Pyrite, pyrrhotite, arsenopyrite, sphalerite, galena, and chalcopyrite with quartz and calcite deposited in joints, along bedding planes, and along contacts. Ore mostly in granodiorite intrusive and in andesite. Near-surface ores richest. Gold, silver, lead, and zinc content decreases with depth, although veins continue, 300,000 tons of ore reported mined from Mystery and Pride claims. Mining began about 1889; district active until about 1905. Accurate data on production lacking Chief value in gold and silver with some copper and lead. Zinc content of ore not recovered.	Spurr, 1901; Lander and others, 1902.
22	Silver Creek: New York-Seattle and Silver Creek.	D(?)	D(?)	----------	Ore deposits similar to those of Index district. Production probably minor, but details not known. Numerous prospects with no recorded production.	Huntting, 1956; Broughton, 1942.
23	Silverton: Copper Independent and Bonanza Queen.	D	D	----------	Gold-silver-copper replacements with minor lead along shear zones in Tertiary granitic and older metamorphic rocks. Numerous prospects but only small production.	Do.
24	Sultan: Rudebeck-Florence Rae and Forty-five.	D(?)	----------	----------	Complex sulfides in shear and fracture zones in granodiorite and in intruded rock. Only small production.	Do.
	STEVENS					
25	Bossburg (Clugston Creek): Bonanza, Young America, and Van Stone.	B	A	B	At Bonanza mine, ore occurs as irregular stringers of galena, pyrite, and sphalerite in lenticular deposit in schist. Mine closed in 1952. At Young America mine, ore is in irregular stringers and disseminations in dolomite. At Van Stone mine, ore is in silicated carbonate rock near Spirit pluton.	Jenkins, 1924; Weaver, 1920; Hundhausen, 1949.
26	Chewelah: United Copper, Copper King, and Amazon.	A	B	D	Chalcopyrite veins in Precambrian argillite. Silver important byproduct of copper mining. Some lead and a little zinc. Most productive period, 1907–23. No production since 1956.	Bancroft, 1914; Weaver, 1920.
27	Colville: Old Dominion----------	B	B	B	Most of production from Old Dominion mine (located in 1883) from irregular lenticular bodies in limestone near granitic intrusive. Ore from upper workings reported to average 100 to 400 ounces of silver per ton. Ore contains trace of gallium. It is reported that $2,000,000 was produced prior to 1897, but accurate information is lacking. Production since 1902 valued at $373,000. Last production in 1953 from reworking old tailings.	Bancroft, 1914; Jenkins, 1924; Weaver, 1920.

28	Deer Trail: Queen, Providence, and Deer Trail.	B	B	B	Quartz lenses with silver-lead minerals in limestone and argillite. Near-surface ore said to have averaged 150 to 200 ounces of silver per ton.	Weaver, 1920; Jenkins, 1924.
29	Kettle Falls: Daisy and Benvenue	C	C	D	Quartz veins in quartzite and argillite near dioritic intrusion. Intermittent production to 1953.	Weaver, 1920; Patty, 1921.
30	Northport (Aladdin): Deep Creek, Electric Point, Lead Point, Anderson (Calhoun), Gladstone, and Lead Trust.	B	A	A	Tabular ore bodies with few gangue minerals in faulted and folded carbonate rocks bordering Spirit pluton. Location of ore bodies usually structurally controlled. Ore bodies range from small, high-grade, steep chimneys, as at Gladstone mine, to large, low-grade, flat, cylindrical bodies, as at the Calhoun mine. The district has the greatest number of productive mines of any in the State.	Yates, 1964; Jenkins, 1924; Patty, 1921; Weaver, 1920.
31	Orient: Napoleon, First Thought, and Galena Hill.	C	C	----	Gold, silver, and copper from contact metamorphic deposits in amphibolite and argillite; oxidized material mined for smelter flux. Gold and silver from quartz lenses in schist and gneiss. Some lead from veins in schist near contact with diorite. First Thought mine in Tertiary Volcanics.	Weaver, 1920; Bancroft, 1914.
32	Springdale: Cleveland	B	B	B	Parallel ore lenses of complex sulfides and sulfarsenates of lead, silver, and zinc in brecciated dolomite. First located in 1892.	Jenkins, 1924; Weaver, 1920.
	WHATCOM					
33	Mount Baker: Boundary Red Mountain and Lone Jack.	D	D	----	Quartz viens in diorite with free gold, pyrite, chalcopyrite and pyrrhotite. Silver recovered as byproduct of gold mining.	Patty, 1921.
34	Slate Creek: Azurite and New Light	D	D	----	Small production of silver and lead from gold veins in argillite.	Huntting, 1956.
	YAKIMA					
35	Bumping Lake: New Find	D	----	----	Narrow chalcopyrite quartz viens with tungsten in fracture zone in granite. Some silver recovered from small shipment of copper ore.	Culver and Broughton, 1945.

[1] Symbols are as follows:
A—Production more than 1,000,000 ounces of silver or 10,000,000 pounds of lead or zinc.
B—Production 100,000 to 1,000,000 ounces of silver or 100,000 to 10,000,000 pounds of lead or zinc.
C—Production 10,000 to 100,000 ounces of silver, or 10,000 to 100,000 pounds of lead or zinc.
D—Production less than 10,000 ounces of silver or 10,000 pounds of lead or zinc.

Mines valuable chiefly for gold have also been an important source of silver in the State. The outstanding example is the Republic district in Ferry County (No. 8) which, since the early days of mining, has been and continues to be a leading source of silver within the State. The Gold King mine in the Wenatchee district (No. 5) and the Morning Star mine in the Danville district in Ferry County (No. 6) are others; there are more that could be cited. The Monte Cristo district in Snohomish County (No. 21) might be placed in this class, although it also produced copper and some lead. Some of the Monte Cristo ore was said to be high in zinc, but no payment was made for any of the zinc mined in the district in the early days of mining.

Quartz veins with varying proportions of lead, silver, and zinc have accounted for a considerable amount of silver and lead and some of the zinc. Deposits in the Conconully district (No. 13), Nespelem district (No. 17), and the Meyers Creek district (No. 16) are examples of this type of deposit.

Contact metamorphic deposits such as the Napoleon deposit in the Orient (No. 31) district have accounted for some silver and lead and a little zinc.

Lenticular deposits in schist at the Bonanza mine in the Bossburg district, Stevens County (No. 25,) have been the source of important amounts of lead and some silver and zinc.

The greater part of the lead and zinc and much of the silver mined in the State have come from deposits in carbonate rocks in Pend Oreille and Stevens Counties. These deposits are found in the Metaline (No. 18), Northport (No. 30), Bossburg-Clugston Creek (No. 25) and Colville (No. 27) districts.

Silver, along with gold, was one of the first metals to be mined in the State; production records go back to 1882 (fig. 28). The curve of silver production in the State shows three prominent periods of activity. The first, during which the State attained its greatest recorded yearly production to date (approximately 520,000 ounces), ended with the panic of 1906; the second lasted until the depression of the 1930's; and the third is still continuing. The source of the silver mined in the first period is not precisely known because records of production prior to 1905 are incomplete or lacking. Presumably most of the silver came from the Old Dominion and other silver-lead mines in Stevens County; from gold-silver mines in the Republic district, Ferry County; and from gold-copper mines in the Monte Cristo and other districts in the western Cascades. These districts were among the first to be discovered in the State. In the second period, much of the production was obtained as a byproduct of copper mining in the Chewelah district in Stevens County and at the Sunset mine in the Index district, Snohomish County. The Old Dominion and other silver-lead mines in Stevens County continued to produce, as did the gold-silver mines of the Republic district. A host of small silver-lead mines in Okanogan and Ferry Counties also made substantial contributions to the total.

In the last period, the Republic district continued as one of the State's leading silver producers, but its position was challenged by production of silver from the Holden Mine in Chelan County, where the silver was obtained as a byproduct of copper mining. The Kaaba mine in the Oroville-Nighthawk district in Okanogan County produced a considerable amount from low-grade complex ore between 1943 and

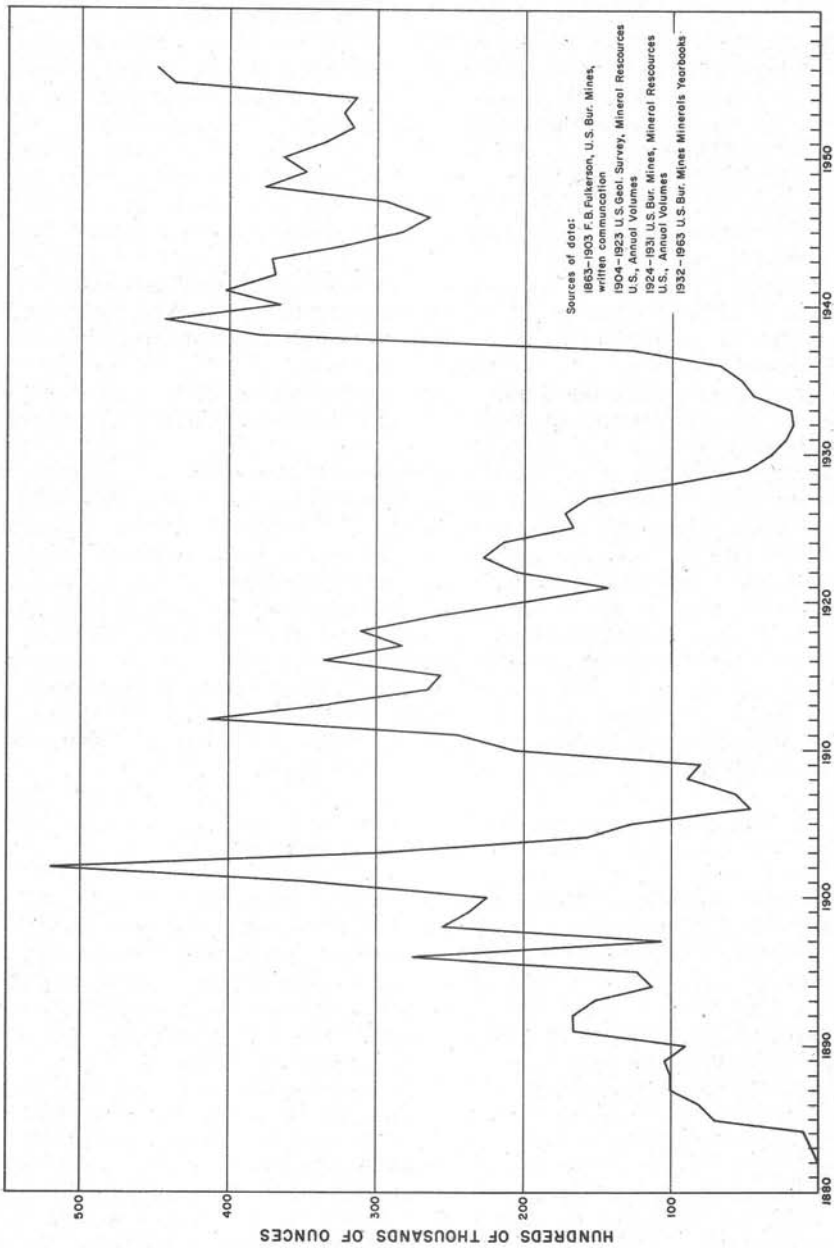

FIGURE 28.—Production of silver in Washington 1882–1956.

1947, as did the Alder copper-gold mine in the Methow district. The Bonanza mine in Stevens County contributed a very substantial amount of silver from 1948 to 1952. The Gold King gold mine in the Wenatchee district, Chelan County, has produced considerable amounts of silver since the early 1950's as a byproduct of gold mining. Since the closing of the Holden mine, almost the entire production of silver has come from the Republic district, the Metaline district in Pend Oreille County, and the Wenatchee district. The ores of the Metaline district are very low in silver, but because of the large tonnage treated, production of silver amounts to around 30,000 ounces annually. Since 1957, the amount of the State's annual silver production has not been published.

The production curves for lead and zinc follow an entirely different pattern (fig. 29). Lead mining has been carried on in the State for many years, and lead has been derived from numerous sources, mostly in Stevens, Okanogan, and Ferry Counties. Production of lead, however, was small. No production of zinc was recorded until 1911, when a small shipment was made from the Oriole mine in the Metaline district. It was not until 1922 that uninterrupted production of significant amounts of zinc got under way at the Metaline district. Production of both lead and zinc continued at low levels until the late 1930's, when full development of the Metaline district began. Metaline rapidly became a leading producer of both zinc and lead. Except for the Holden mine, which, until it closed, produced zinc along with copper, silver, and gold, the zinc and lead produced in the State since about 1946 has come almost entirely from Metaline and from the Bossburg and Northport districts in Stevens County. From 1956 through 1962 almost all the production of both metals came from the Metaline area. With the opening of the Calhoun mine (formerly the Anderson pit) in the Northport district, Stevens County will again become an important producer.

LEAD-ZINC-SILVER DEPOSITS OF NORTHERN PEND OREILLE AND NORTHEASTERN STEVENS COUNTIES

Because of their importance as a resource both to the State and nationally, the lead-zinc-silver deposits in northern Pend Oreille and northeastern Stevens Counties are discussed more fully in the ensuing paragraphs. Much of the information, particularly concerning the mines of Stevens County, has been contributed by R. G. Yates, who has studied the mineral deposits of northeastern Washington over a period of many years.

The deposits are found in a belt of northeast-trending structures that contains all the Cambrian limestone in Washington. The belt extends from the Salmo area of British Columbia southwestward to the mouth of the Spokane River. In Washington, the lead-zinc deposits are in an elongate area lying northwest of the Kaniksu batholith and southeast of the Columbia River (fig. 30). This area, which does not extend south of Colville, is divided into four mining districts; the Metaline district in Pend Oreille County; and the Northport, Bossburg-Clugston Creek, and Colville districts in Stevens County (fig. 30). The Metaline district is separated from the other three by a high mountain range which is composed of phyllite and quartzite and is almost barren of ore deposits (fig. 30). The Spirit pluton, an east-west

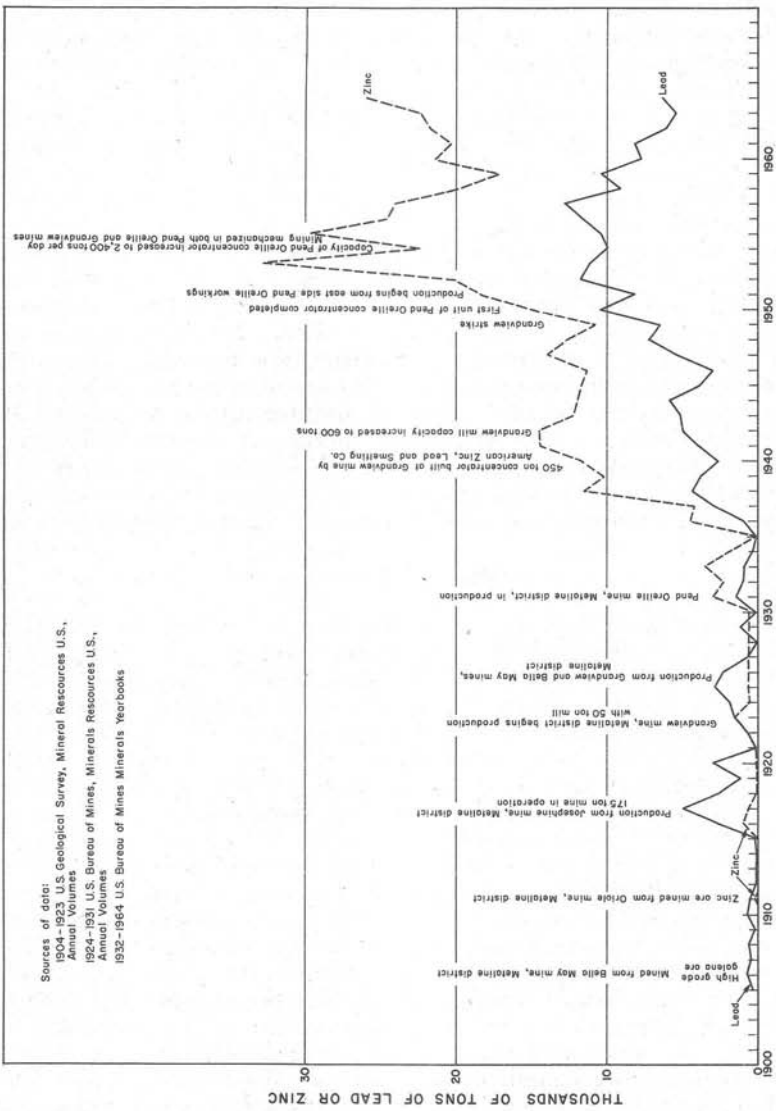

FIGURE 29.—Production of lead and zinc in Washington, 1905–64.

trending body of granodiorite, extends across eastern Stevens County, separating the Northport district on the north from the Bossburg-Clugston Creek district on the south. The Colville district is still farther to the south in the vicinity of the town of Colville. These four districts, together with the Salmo district in British Columbia, form a geologic entity that is one of the great lead-zinc producing areas of the world.

Most of the mines are in the upper or middle parts of the Cambrian Metaline Limestone, but some are in the underlying Maitlen Phyllite (fig. 31). Some may be in argillaceous rocks younger than the Metaline Limestone and at least one deposit is in the Gypsy Quartzite.

Mines in the carbonate rocks and near the Spirit pluton generally are low in silver, whereas those in argillaceous rocks and farther away from the Spirit pluton tend to be higher in silver. An empirical but quite well-defined line can be drawn between the two types of deposits (fig. 30). However, the distribution of silver with respect to base metals is complex, and the simple relationships described above do not always hold. The ratio of silver to base metals may be affected by other less obvious factors. Not all the deposits were necessarily formed at the same time, or structural conditions may have influenced deposition of metals, to mention just two. Zoning of metals in the deposits of northeastern Washington has been little studied and presents an interesting problem on which more work might profitably be done.

METALINE DISTRICT

In the Metaline district the productive ore bodies are mainly restricted to a wedge-shaped, structurally depressed block or graben between the Flume Creek and Slate Creek faults. The Oriole mine, an exception to this, is west of the graben in Gypsy Quartzite and has been a minor producer. The graben is about 16 miles long and about 9 miles wide at its maximum width just below the International Boundary (fig. 30). The ore bodies are in a broad, faulted anticline within the graben, where they occur as large, irregular replacement deposits in the Middle Cambrian Metaline Limestone. Sphalerite and galena are essentially the only ore minerals; gangue minerals are jasperoid, dolomite, and coarse calcite. Pyrite is locally abundant but generally rare. The ore is commonly associated with dolomitization and with zones of striking brecciation. Cavities and caverns are locally abundant within the ore zones. Mineralized replacement bodies are known throughout the length of the graben, but the presently productive mines are all in the southern part.

Small, irregular replacement bodies and scattered grains of sphalerite and galena are found throughout the entire stratigraphic thickness of the Metaline Limestone except the very basal part, but practically all the lead and zinc mined so far has come from an irregular zone 35 to 200 feet stratigraphically below the overlying Ledbetter Slate. This zone is known locally as the "Josephine horizon" (fig. 31). A small tonnage of more pyritic ore was mined some years ago from a second zone—known locally as the "Yellowhead horizon"—1,100 to 1,200 feet stratigraphically below the Ledbetter Slate. This zone is exposed in only a few places and has been but little explored. In the Metaline district, no ore bodies have been found in the Maitlen

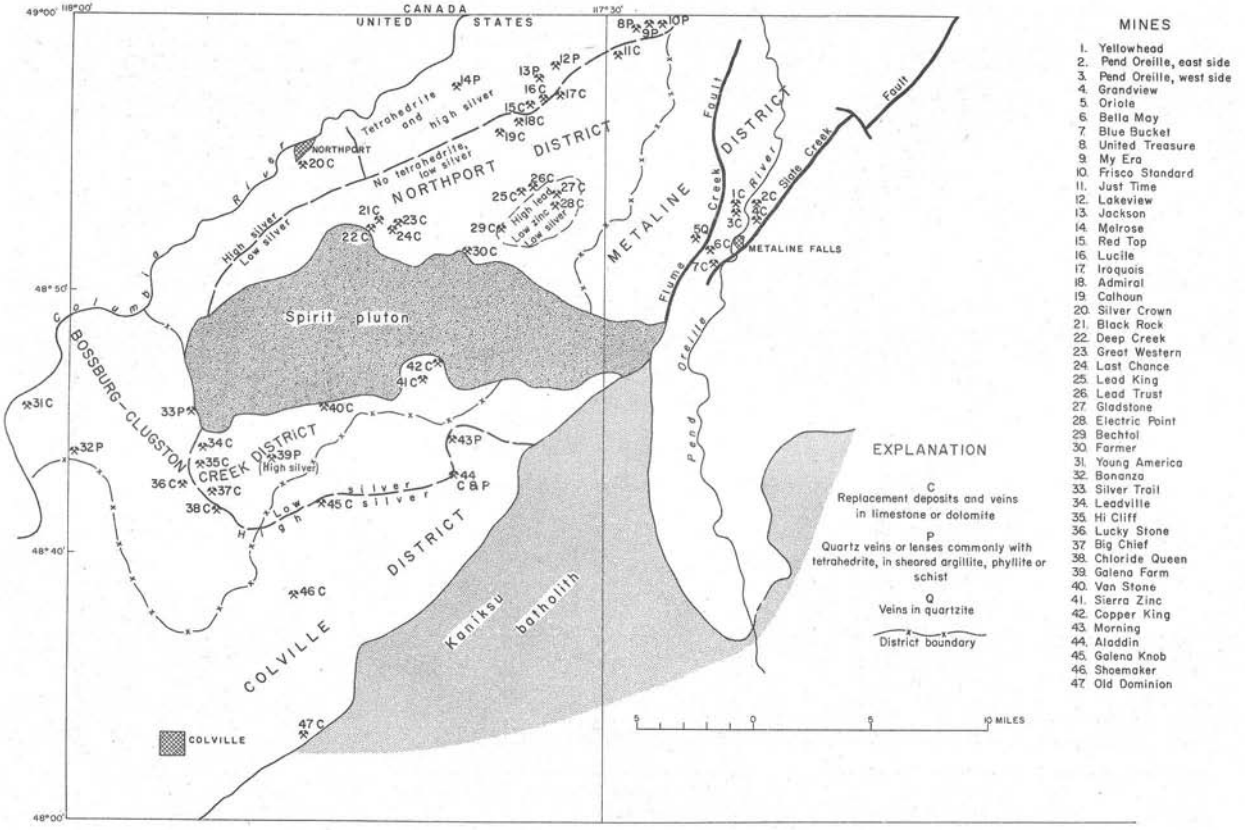

FIGURE 30.—Distribution of lead-zinc deposits in northeastern Washington according to mining districts, batholithic rocks, and silver content (after R. G. Yates).

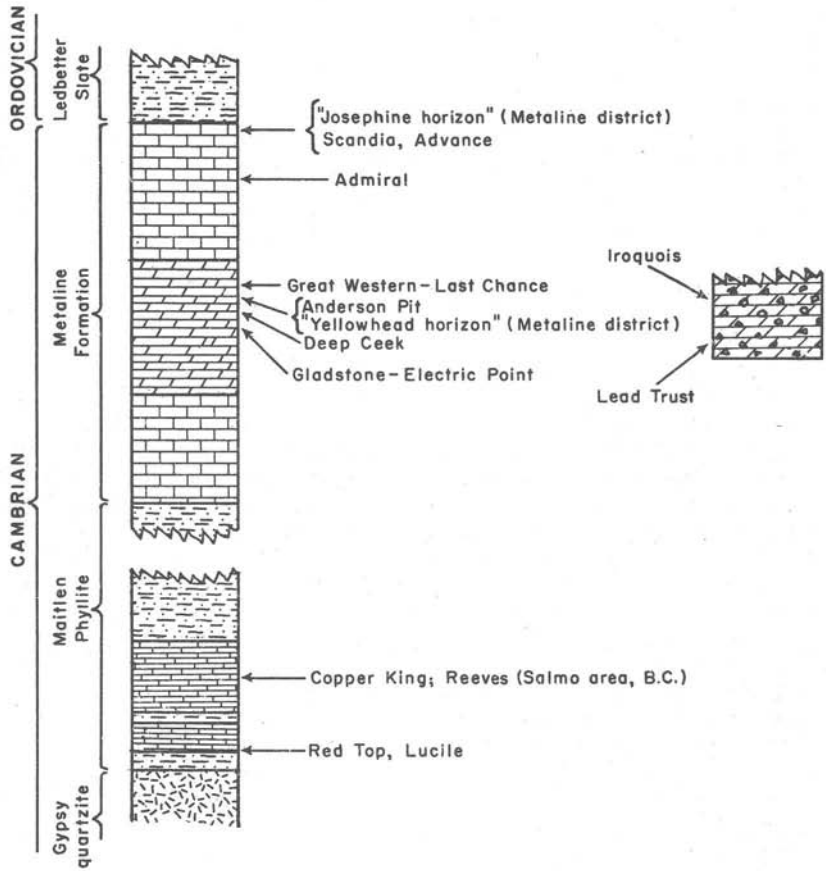

FIGURE 31.—Stratigraphic positions of some ore bodies in northeastern Washington (after R. G. Yates).

Phyllite, which underlies the Metaline Limestone, although important ore deposits are found in carbonate rocks in the Maitlen or its equivalent in adjoining parts of British Columbia and Stevens County.

Lead and zinc minerals are said to have been discovered in the Metaline district as early as 1896. The earliest recorded production was in 1906, but until 1929 production was small and erratic. Substantial production was not achieved until 1938, when nearly a quarter of a million tons of ore was produced. Production increased sharply in 1950, when the mines became highly mechanized, and in 1957 reached a high of nearly 1 million tons of ore.

Exploitation of the Metaline district was delayed because of its remoteness from transportation, but even after rail transport became available development was slow. The district is an excellent example of how diverse and changing factors can influence mining. Full development of the district depended on four factors: (1) the need for zinc, (2) an understanding of the geology of the district and the stratigraphic control of the ore zone, (3) an economic method of separating the lead from the zine, and (4) the development of low

cost mining methods. Increased consumption of zinc and the decline of zinc production from zinc deposits in the Central States established the need for zinc. Study of the geology of the district by mining company geologists and in 1936 and 1937 by Park and Cannon of the U.S. Geological Survey demonstrated the stratigraphic control of the ore. Differential flotation solved the problem of separating the lead and the zinc. Development of the district was aided by a drilling project carried out jointly by the U.S. Bureau of Mines and the Geological Survey during World War II, which indicated the presence of very large quantities of low grade ore. Development of a highly mechanized system of mining has permitted the mining of low grade ore in the face of rising costs. An additional factor was the persistence of two men, Jens Jensen, president of the Pend Oreille Mines & Metals Co., and L. P. Larsen, now deceased, president of the company for many years, which in large part is responsible for the present development of Metaline into the State's most important mining district.

From 1906 through 1963 the district has produced 590,124 ounces of silver, 168,986 tons of lead, and 368,010 tons of zinc from 14,546,966 tons of ore. The value of the metal produced was $121,173,086. The effect of the mechanization on the grade of the ore is striking. Up to 1950, when the mechanization of the mines became effective, the average grade of all ore mined was 0.043 ounces of silver per ton, 1.38 percent lead, and 3.60 percent zinc. In the 5-year period 1960–64, the silver averaged 0.036 ounce per ton, the lead 0.84 percent, and the zinc 2.31 percent. The present ore averaged 3.15 percent combined lead and zinc, whereas before mechanization the ore extracted averaged nearly 5 percent combined lead and zinc.

Only that part of the Metaline district in the vicinity of the producing mines has been explored except by widely scattered drill holes. This amounts to only a small part of the area within the Metaline graben that is potentially favorable for ore. Data on which to base ore reserve estimates are lacking, but the potential of the district is obviously large. In testimony given in 1959 before the Federal Power Commission in a hearing on Boundary Dam, the writer made the following statement regarding potential ore reserves of the Metaline district:

> It is likely that the Josephine horizon will produce 36 million tons of ore, and it is not impossible that the ultimate production will exceed 146 million tons. The grade will average between 3 and 4 percent combined lead and zinc, and the amount of zinc in the ore will be approximately twice the lead.

Estimates of ore reserves given at the same hearing by other witnesses were greatly in excess of these tonnage figures. With adequate price levels for lead and zinc, it seems likely that the Metaline district will continue to be an important producer of these metals for many years.

NORTHPORT DISTRICT

The Northport district has produced about 40,000 tons of lead, 82,500 tons of zinc, and over 180,000 ounces of silver from a total of 48 mines. Production of lead and silver ores began about the turn of the century, but the presence of these metals was known at a much earlier date. Zinc was not recovered until 1916, when the Great Western mine began shipping zinc ores; although the ores mined prior to this contained zinc, there apparently was no attempt to recover

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this metal. Most early production was from high-grade ore bodies of fairly limited extent; it was not until after World War II that mining began on the lower grade but larger deposits. In the last few years there has been but little mining, but much effort has gone into exploration. As one result of this, mining of a large low-grade zinc deposit, the Calhoun mine (formerly Anderson Pit), is expected to begin in the fall of 1965.

In the Northport area there are three general types of ore bodies: (1) dolomite or limestone replacement deposits; (2) nodules of galena in chimneys in dolomite; and (3) pockets of high-silver tetrahedrite in quartz veins in shear zones in argillite. The highest silver content is in ore deposits of the third class, and the lowest is in the second class; silver values in the first class are intermediate but have produced the most silver because of the greater tonnage of ore mined from the deposits.

The dolomite or limestone replacement deposits occur in the dolomite of the Cambrian Metaline Limestone and to a lesser extent in the basal limestone member of the Maitlen Phyllite (Reeves Limestone of British Columbia). Deposits in the Metaline Limestone occur in the middle and upper members. (See fig. 31.) Hydrothermal dolomite is not as widespread as it is in the Metaline district but does occur in association with some deposits. There is also some silicification. The ore bodies are controlled by both bedding and faults. Ore minerals are galena, sphalerite, and pyrite, which is associated with pyrrhotite in ores near the Spirit pluton.

The larger ore bodies of the limestone-dolomite replacement deposits are the Deep Creek, Black Rock, Northwestern, Calhoun, and Iroquois. The ore minerals are very spottily distributed through the ore bodies, with high-grade shoots separated by low-grade or nearly barren rock. When considered as a unit, these ore bodies become large-tonnage, low-grade deposits that can be mined by low-cost methods.

Closely related but mineralogically different are the deposits in the lower Maitlen Limestone unit on Red Top Mountain (Red Top and Lucille). Due to the presence of tetrahedrite, these ores are anomalously high in silver. Unfortunately, the high-grade shoots that have been found to date were small.

The ore chimneys are best represented by the Gladstone and Electric Point mines on Gladstone Mountain. The ore, massive galena, forms in "nodules" from a few inches to many feet in diameter. The nodules are usually in a matrix of iron oxide and talc, and the galena in the upper part of the ore bodies is largely oxidized to secondary minerals. The chimneys are nearly vertical with walls that vary from sharp contacts between hard dolomite and soft matrix to those that grade out through loose dolomite sand to solid dolomite. The chimneys have been explored to as much as 800 feet below the surface. Some reached the present surface; others did not. All that have been discovered are very low in silver and contain almost no zinc.

The high-silver tetrahedrite in quartz veins is economically not important. Because of the discontinuity of the veins, which have been sheared into small, discontinuous lenses by thrust and reverse faults, mining is difficult and requires considerable exploration to keep in ore. The Melrose, Jackson, Lakeview, and Frisco Standard are examples of this type of deposit.

The Northport district has large areas of unexplored, geologically favorable ground. Because exposures of bed rock are sparse in many places, geochemical prospecting has been helpful in outlining exploration targets. The replacement deposits are the most attractive because of their potentially large tonnage, but the grade is low so that development has been slow.

BOSSBURG-CLUGSTON CREEK DISTRICT

The Bossburg-Clugston Creek district has a recorded production of over 12,500 tons of lead, almost 500 tons of zinc, and over 300,000 ounces of silver; in addition, there has been a large, undisclosed production of all these metals from the Van Stone mine. The district's production comes from 18 mines, although three, Van Stone, Bonanza, and Young America produced the major part. The district contains deposits having both high and low silver content, and the average ratio of silver to lead is considerably higher than in the Northport and Metaline districts. Much of the silver comes from mines along the fringe of the district, in particular from the Bonanza and Young America mines.

The deposits are largely replacement deposits in Cambrian dolomite. One notable exception is the Bonanza mine, where the ore occurs in a breccia zone in phyllite and schist of probable late Paleozoic age. Two other mines, the Van Stone and Blue Ledge, are in carbonate rocks that have been partly converted to silicate minerals during the emplacement of the Spirit pluton, which lies immediately to the north. In other respects, most deposits are similar to the limestone-dolomite replacement deposits of the Northport district. Galena and sphalerite are the ore minerals.

COLVILLE DISTRICT

The Colville district, which lies between Colville and Aladdin, contains 15 mines that have collectively produced almost 500 tons of lead, 150 tons of zinc, and over 360,000 ounces of silver. The district's one large mine, the Old Dominion, which accounts for most of the production, is the oldest mine in Stevens County, having been located in 1883. All mines in this district lie in or near the fringe of the high-silver area as shown in figure 30. The deposits are in dolomite of Cambrian age and in limestone of possibly Precambrian age.

THORIUM AND THE RARE EARTHS

(By M. H. Staatz, U.S. Geological Survey, Denver, Colo.)

Thorium and the rare-earth metals are treated together in this report, as they are commonly associated in nature and are closely interrelated economically.

Thorium, like uranium, is the parent of a series of radioactive decay products ending in a stable isotope of lead. Thorium differs from uranium in that its minerals tend to be dispersed rather than concentrated in significant deposits; also, its minerals are relatively stable during weathering.

Thorium has a number of industrial nonenergy uses and considerable energy potential as an atomic fuel. Over 90 percent of the thorium consumed industrially in the United States is used in thorium-

magnesium alloys and gas mantles. Minor amounts are used in refractories, polishing compounds, chemicals, drugs, and electronic products. A new thorium nickel compound, which has great strength at elevated temperatures, has recently been introduced (Baroch, 1964, pp. 1106 and 1110). Thorium also has a major potential use in atomic reactors. It cannot, however, be used directly in a nuclear reaction, but must first be converted to a fissionable uranium isotope by neutron capture. The use of thorium for nuclear energy is still in the experimental stage, and is in competition with relatively cheap, abundant uranium (Kelly, 1962, p. 25). In 1963 three power plant prototype reactors using thorium were in operation or in an advanced stage of construction in the United States (Baroch, 1964, pp. 1106–1107).

The rare-earth metals comprise the 15 elements having atomic numbers 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy) holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Yttrium (Y), with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so called because cerium is their most abundant member. The remaining eight elements (Gd through Lu) together with yttrium are called the yttrium group. The two groups are also referred to respectively as the "light" and "heavy" rare earths. The properties of the members of the two groups of rare earths are sufficiently distinct to cause one group to predominate over the other in most minerals, even though all or nearly all are ordinarily present (Olson and Adams, 1962).

The rare earths have many industrial applications. The glass industry is the principal consumer, with rare-earth oxides being used for rapid polishing. Lesser quantities of compounds are used to color, decolor, and opacify glass. Rare earths are also used in the steel industry, nonferrous alloys, arc light carbons, catalysts, promoters, phosphors, and activators (Parker, 1964, pp. 944–945; Mandle and Mandle, 1964). The rare-earth industry is developed almost entirely on the cerium group elements, primarily cerium, lanthanum, praseodymium, and neodymium. Although considerable research is being directed to find use for the yttrium group elements, the current demand is small.

Thorium and rare earths are found in a large number of minerals, but only a few of these minerals have been found in large enough concentrations to be used as ores. The most important source of thorium and the rare earths is monazite, a phosphate of the cerium group rare earths. The thorium content of this mineral is variable and may range from 0 to 33 percent but commonly contains from 3 to 10 percent thorium oxide and 55 to 60 percent combined rare-earth oxides. Monazite is found in pegmatites, granites, syenites, carbonatites, veins, metamorphic rocks, and both modern and fossil placers. Other important minerals containing thorium and rare earths are the multiple oxide minerals, samarskite, euxenite, and brannerite. Important thorium minerals that contain only minor amounts of rare earths are thorite and thorianite. These two minerals are found principally in veins. An important rare earth mineral that does not contain

thorium is the rare-earth fluocarbonate, bastnaesite. This mineral is currently being mined from a large carbonatite body at Mountain Pass, Calif.

Present thorium and rare-earth requirements are relatively small compared to many other metals, and industrial consumption in the United States in 1963 was about 50 tons of thorium oxide (Baroch, 1964, p. 1106) and 2,337 tons of rare-earth oxides (Parker, 1964, p. 944). Imported monazite has been the principal source of most of the thorium and rare earths consumed in the United States. In recent years, however, much of the rare earths have been obtained from the bastnaesite deposit at Mountain Pass, Calif.

In the past, domestic supplies of monazite have come from placers in Florida, North Carolina, and Idaho. However, in 1963, a Florida beach sand deposit was the only domestic producer. The marketing of ores of thorium and rare earths is difficult, as there is no established market comparable to those of the more widely used metals, and prices of their ores are generally determined by negotiation. Detailed information on the economic factors of thorium and rare earths is given by Kelly (1962).

Washington has never been a producer of either thorium or the rare earths. Small amounts of these elements are known, however, from several types of deposits in the State, as shown on figure 32.

Thorium and rare-earth minerals are found in pegmatites in five areas. A few scattered crystals, tentatively identified as samarskite, occur in a pegmatite on the AA No. 2 claim in the Orient district (fig. 32, No. 1) (Weis, Armstrong, and Rosenblum, 1958, p. 33). Small crystals of this mineral have also been identified in a pegmatite on the Sanpoil property (No. 3) (Huntting, 1956, p. 353). Monazite was found associated with biotite pods in a pegmatite on the Rosalie claims east of Sherman Creek Pass (No. 2) (Weis, Armstrong, and Rosenblum, 1958, p. 32), and this mineral has also been found at Happy Hill northwest of Okanogan (No. 4) (Huntting, 1956, p. 353). A number of thorium- and rare-earth-bearing minerals, euxenite, allanite, brannerite, and cyrtolite, are reported from a pegmatite on the Peterson property near Grand Coulee dam (No. 5) (Huntting, 1956, p. 352).

Monazite has been reported in at least seven places in stream and beach placers, but in four of these it is present only in trace amounts. The highest grade material is a beach sand from Moclips near Grays Harbor (No. 6), where Day and Richards (1906, pp. 1218–1219) reported 71.5 pounds of monazite per ton of beach sand. Placers along the Columbia River in Douglas County (No. 7) and at the Wilmont bar (No. 8) in Ferry County were reported to contain 30 and 6 pounds per ton of gravel, respectively (Day and Richards, 1906, pp. 1218–1219). The placers from which these two samples were obtained, however, are now covered by the Rufus Woods and Franklin D. Roosevelt Lakes.

Brannerite occurs in a vein deposit at the Western States Copper Co. mine, 13 miles east of Snoqualmie (No. 9). Here a brecciated granodiorite has been cemented with quartz, pyrite, and chalcopyrite; the brannerite is found in the quartz in a few places (Weis, Armstrong, and Rosenblum, 1958, p. 31).

Monazite-bearing residual clay, derived from granitic rocks, metamorphic rocks, and a clayey sand bed in the Latah Formation, occurs

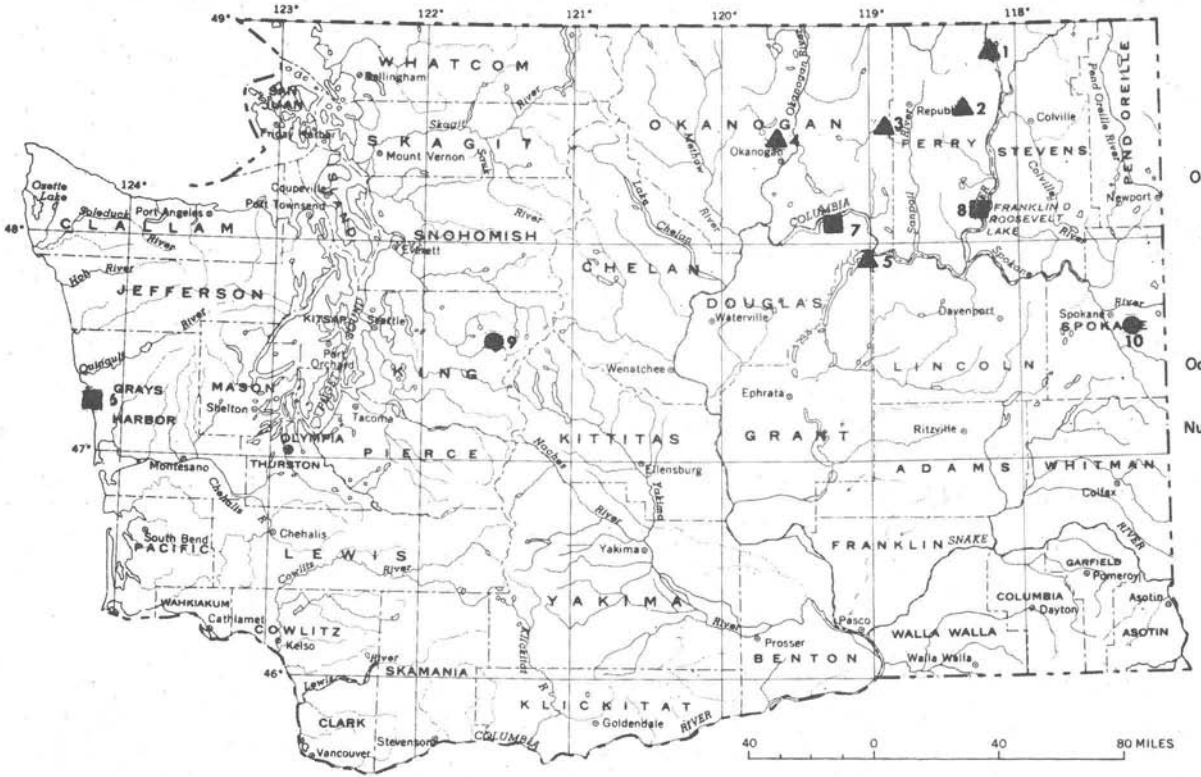


FIGURE 32.—Thorium and rare-earth localities in Washington.

5 to 10 miles east and southeast of Spokane (No. 10). Although spread over a wide area, the monazite concentration is low and was estimated to make up only 0.01 percent by weight of the clay in one area (Hosterman, Overstreet, and Warr, 1964). Furthermore, the thorium oxide content of the monazite is low, and three samples from three areas had an average content of only 3.6 percent thorium oxide.

The general small size and low grade of the known thorium and rare-earth deposits in Washington, together with much larger resources and higher grade unworked deposits in Idaho, Montana, Colorado, North Carolina, South Carolina, and Florida, suggest that little if any will be produced in the near future unless larger and higher grade deposits are discovered.

TIN

(By C. L. Sainsbury, U.S. Geological Survey, Denver, Colo.)

Tin has been used at least since the late Bronze age (3500–3200 B.C.), and today it remains a strategic commodity, of which the United States has little. The metal has 2 modifications; "white" tin of tetragonal symmetry and specific gravity of 7.31, and "gray" tin of cubic symmetry and specific gravity of 5.75 (Lange, 1961). At low temperatures (below 13.2 C.), the white tin changes to gray tin, which crumbles to a powdery mass. If alloyed with any other metal, the change from white to gray tin is prevented. Toward air, water, and weak acids and bases tin is chemically resistant because of the formation of a thin oxide coating. This inertness, along with its extremely low surface tension in the molten state, which allows it to build very thin coatings on other metals, leads to its main use as tin plate. Other major uses are as alloys in bearing metal and in solder, bronze, and brass.

Although the United States consumes more than 54,000 long tons of primary tin metal yearly (1962), it produces only a few tons, most of which comes from small tin deposits in Alaska and as a byproduct from molybdenum mining in Colorado. Of even greater significance is the fact that the total U.S. resources of possible economic grade are but a small percentage of 1 year's consumption. Hence, every domestic tin deposit is of great interest, although this interest is tempered by the fact that tin has been easy to obtain on a worldwide basis and, in fact, has often been in excess supply. The major tin-producing countries are Malaysia, Indonesia, Bolivia, Republic of the Congo, and Nigeria, listed in decreasing importance.

Most of the commercial lode tin deposits of the world are associated with biotite granite, biotite-muscovite granite, or, as in Bolivia, with near-surface intrusive rocks of granitic composition. The minerals cassiterite (SnO_2) and stannite ($Cu_2S{\cdot}FeS{\cdot}SnS_2$) are the only commercially important tin minerals; of these, cassiterite accounts for the major part of the world's tin production, mostly from placer deposits derived from eroded lodes or granites that contain cassiterite as an accessory mineral. Throughout the world, other elements are consistently associated with tin deposits; of these elements arsenic, antimony, bismuth, molybdenum, tungsten, copper, lead, zinc, and, to a lesser extent, silver are most common. In fact, several tin mines of the world were initially mined for silver, and several mines that

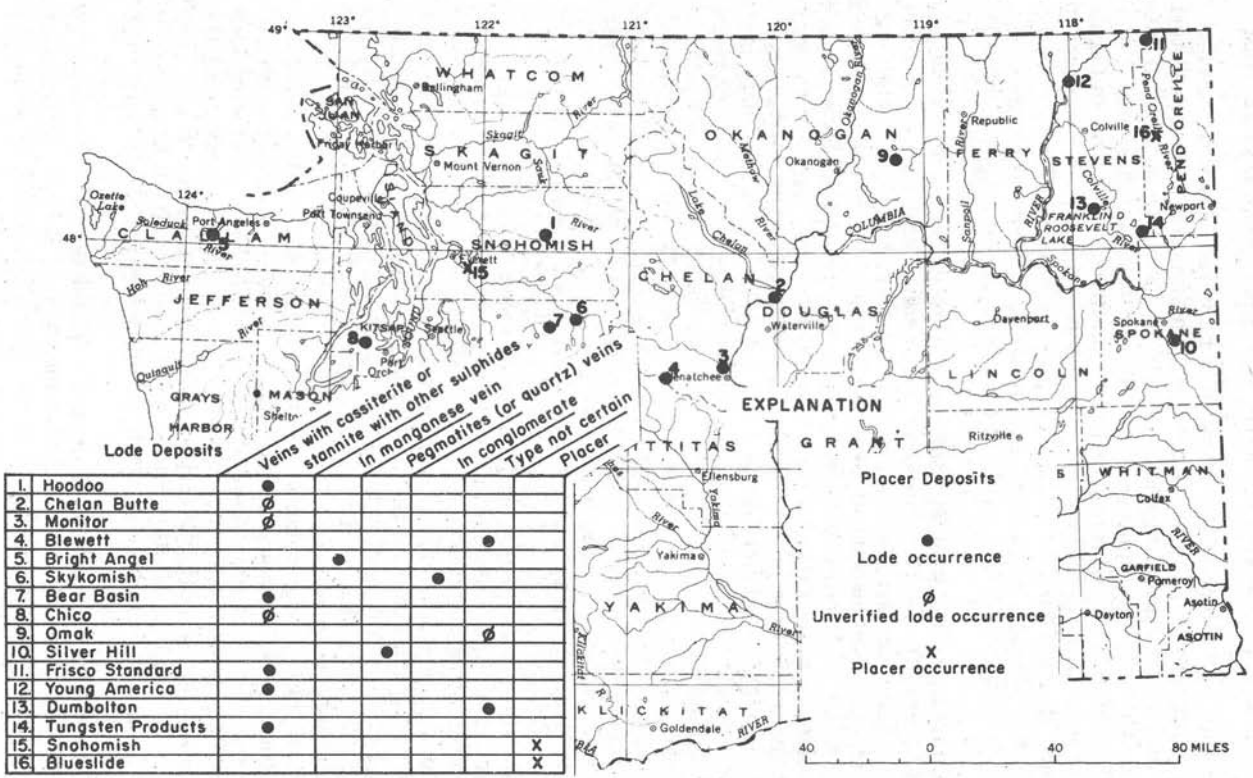
initially produced tin became silver mines. Hence, in evaluating the potential tin resources of an area, the geochemical associations outlined above are of some importance. Of importance, too, is the fact that most of the major tin deposits of the world lie in orogenic belts, many of which parallel the continental margins as, for instance, the Malayan tin belt and that in Bolivia.

In Washington the tin minerals stannite and cassiterite are reported to occur in lodes at 14 places (fig. 33), of which 4 localities are not confirmed by examination by a competent geologist (Huntting, 1956). Placer tin is reported from two localities. The deposits fall into several distinct categories, most of which represent types common in larger tin districts. None of the deposits in Washington can be considered presently as minable, although only a little exploration has been done on most. The commonest type contains the tin-sulfide mineral stannite associated with other sulfide minerals in veins in granite, granodiorite, or sedimentary or metamorphic rocks. In several of these deposits, as at Bear Basin, Frisco Standard, and Young America, the mineral assemblages are very similar to those in the stannite zone of tin deposits elsewhere in the world (Twelvetrees and Ward, 1910). At the Loon Lake deposit, tin and tungsten occur in a quartz vein in greisenized granite, an association common elsewhere in tin deposits.

At an unverified occurrence at the Bright Angel prospect in Clallam County, antimony and tin were reported to occur in manganese ore. Hewett (1964, p. 1488) shows that some hypogene manganese veins contain notable tin. The reported tin at the Bright Angel prospect may not be either geochemically unusual or economically significant.

Of the known tin deposits, only those at Silver Hill, in Spokane County, have been explored sufficiently to determine ore reserves. The deposits consist of pegmatite and quartz veins up to a few hundred feet long, a few feet wide, and average about 40 feet in depth. Cassiterite, the main tin mineral, is restricted to the pegmatites, some of which contain up to 3 percent of tin locally. Total reserves are small, however (Page, 1942, pp. 177–203). Near Skykomish, in King County, cassiterite occurs in conglomerate of the Swauk Formation, and it is perhaps significant that the placer cassiterite near Snohomish in Snohomish County is in the drainage basin of the streams that locally erode the Swauk Formation.

The extent of known tin-bearing deposits in Washington does not lead one to suppose that major deposits will be found. On the other hand, the geochemical and mineralogical associations are similar to other areas where tin-silver deposits have been mined. As tin-silver deposits containing stannite often grade downward into cassiterite deposits, it is not unlikely that such may be the case in some deposits in Washington. The search for commercial tin deposits might best be directed toward evaluation of deposits in the Swauk Formation and to deep drilling of stannite-bearing sulfide veins. However, it should be remembered that enrichment of tin at depth in such deposits will probably be accompanied by impoverishment of silver, which has made other tin-sulfide lodes minable.



1.	Hoodoo	●					
2.	Chelan Butte	ø					
3.	Monitor	ø					
4.	Blewett					●	
5.	Bright Angel			●			
6.	Skykomish				●		
7.	Bear Basin	●					
8.	Chico	ø					
9.	Omak					ø	
10.	Silver Hill				●		
11.	Frisco Standard	●					
12.	Young America	●					
13.	Dumbolton					●	
14.	Tungsten Products	●					
15.	Snohomish						X
16.	Blueslide						X

FIGURE 33.—Reported tin occurrences in Washington (after Huntting, 1956).

TITANIUM

(By G. W. Thorsen, Washington Division of Mines and Geology, Olympia, Wash.)

Titanium is a silver-white metal noted for its lightness, strength, and resistance to corrosion. It is roughly half as heavy as most steel alloys and at temperatures below 1,000° F. has a strength-to-weight ratio exceeding both aluminum and stainless steel (Stamper, 1960, p. 885). Almost all titanium metal is produced from the minerals ilmenite and rutile. Ilmenite, when pure, contains 31.6 percent titanium, 36.8 percent iron, and 31.6 percent oxygen. Theoretically, rutile is composed of 60 percent titanium and 40 percent oxygen. In nature, both ilmenite and rutile contain varying amounts of impurities.

Titanium metal is currently used in applications where high strength and light weight are of paramount importance and cost is of little object. Thus, an estimated 93 percent of 1963 titanium metal consumption was used in space and aeronautical applications (Stamper, 1963, p. 1138). Use of titanium metal in the chemical industries for its excellent corrosion resistance is just developing. The outstanding performance of the metal in salt water environments offers a vast potential market that has barely been touched. The relatively high price ($3.80 to $4.00 per pound for plate, December 1963) of semifabricated products is probably the basic obstacle to more widespread use. This price will inevitably drop as costs are brought down by technological developments and volume production. The price of titanium concentrates (January 1965) depends on the form and metal content of the ore, varying from about $21 per long ton for ilmenite (with 54 percent TiO_2) to $104 per short ton for rutile (96 percent rutile). The great bulk of titanium is used in the oxide form. The extreme whiteness, opacity, and chemical inertness of titanium oxide pigments make then unequaled for use in paint, paper, floor coverings, and many other applications. Most titanium oxide comes from ilmenite and titanium-rich slag produced as a coproduct with iron. Some ilmenite goes into the production of titanium metal and titanium alloys. The main uses of rutile are for pigments and for welding rod coatings, but it is also used for the production of titanium metal and for other applications.

Most of the world's ilmenite is obtained from lode mines and other concentrations in igneous rocks. Rutile concentrates are derived mostly from beach sand placers, but some rutile is obtained from lode mines. The United States is the chief producer of ilmenite and the chief consumer of both ilmenite and rutile. Australia is the chief producer of rutile. United States production in 1963 consisted of 888,000 tons of ilmenite and 11,900 tons of rutile (Stamper, 1964, p. 1134).

Both ilmenite and rutile are commonly found as finely disseminated constituents of igneous and metamorphic rocks. Where the titanium minerals have been weathered out and concentrated by stream and wave action, important placer deposits may be formed.

Nearly all known commercially important rock deposits of titanium minerals are associated with anorthositic or gabbroic rocks (Lynd, 1960, p. 852). The titanium mineral deposits occur as segregations and dikes, usually associated with magnetite or hematite.

Titanium occurs in varying amounts in the beach sands, both present and ancient, of southwestern Washington. In these sands, it is present largely in the form of fine-grained (80 to 200 mesh) titaniferous magnetite and hematite, ilmenite, and intergrowths of these minerals (Thorsen, 1964). Proportions of these and other mineral constituents (possibly recoverable as byproducts) vary from place to place, depending on the source areas and degree of placer concentration. A small amount of titaniferous placer sand from Washington has been shipped for test purposes, but there has been no production.

Titanium concentrates assaying over 40 percent TiO_2 (and 40 percent Fe) can be produced from both Grays Harbor and Columbia River sands. It might be more practical, however, to make a concentrate containing all the magnetic Fe-Ti oxides. From this concentrate, a Ti-rich slag could be obtained as a by-product. The concentrate would assay approximately 15 percent TiO_2 and 55 to 60 percent Fe for sand from the mouth of the Columbia River. A similar concentrate of Grays Harbor magnetic black sand contains approximately 40 percent TiO_2 and 40 percent Fe.

This difference between the two occurrences is probably indicative that a higher proportion of Grays Harbor sand came from the weathering of volcanic lavas and ash falls than did the Columbia River sand, which is derived mostly from crystalline rocks. Placer concentrates in Willapa Bay are probably a mixture of these sources and, hence, intermediate in compositon. Preliminary drilling by various individuals, companies, and the U.S. Bureau of Mines has indicated placer concentrations within tidal elevations at Point Brown, Grays Harbor, and at McGowan along the lower Columbia River estuary (Kelly, 1947).

Partially cemented Tertiary placer sands up to 4 feet thick occur near Elma. Titanium in this deposit appears to be largely in the form of ilmenite and titaniferous magnetite and is quite similar to that found in present beaches at Grays Harbor.

Residual deposits containing significant amounts of titanium have been found in Spokane, Cowlitz, and Wahkiakum Counties. These deposits are considered to be derived by the chemical decomposition of basalt rock and have been investigated as possible sources of aluminum. The titanium content is in the form of very fine-grained ilmenite or titaniferous magnetite and is too low to be mined for the titanium alone. However, as a by-product of aluminum production, the deposits might be considered a potential reserve. The Excelsior clay deposit 11 miles southeast of Spokane has been found to contain 12,533,000 tons of clay (Scheid, 1945, p. 2). It averages 17.4 feet thick and contains 7.1 percent TiO_2 and 28.7 percent available Al_2O_3. If all the titania could be recovered, it would amount to 890,000 tons. Tonnage figures are not available for the Cowlitz-Wahkiakum County iron-rich bauxites; however, it is known that they occur over extensive areas and are more than 20 feet thick in places. Their average analyses are 4.2 percent TiO_2 and 38.8 percent Al_2O_3 (Washington Div. Mines, unpublished). Bedrock occurrences of ilmenite in Washington are known but are not of commercial significance.

TUNGSTEN

(By S. W. Hobbs, U.S. Geological Survey, Denver, Colo.)

Tungsten owes its strategic importance in the National economy to the very special and, in some cases, unique physical properties of the metal, its alloys, and its compounds. It is one of the heaviest of all metals, extremely hard, strong, and with a high tensile strength. Only carbon, of all the elements, has a higher melting point. Furthermore, tungsten maintains its strength at temperatures far above the softening point for most materials and imparts this property to alloys and compounds of which it is a component. Its principal use is in high-speed tool steels, dies, cutting and grinding materials, and electric light filaments. These uses devolve directly from the hardness and high temperature properties of the metal and its alloys. Minor amounts of tungsten are used for contact points in electrical apparatus and as a catalyst in certain chemical reactions. Some of its compounds are used in flameproofing and waterproofing fabrics, in dyes, and other applications.

Approximately 16 minerals have been discovered that contain tungsten as an essential component, but of these only 4 account for practically all commercial production—scheelite ($CaWO_4$), ferberite ($FeWO_4$), wolframite ($Fe,MnWO_4$), and huebnerite ($MnWO_4$). The last three of the four form a group with a continuous range in composition from one end member (ferberite) to the other (huebnerite), and are usually lumped under the name wolframite. Although tungsten minerals occur in a wide variety of environments and modes of occurrence, the two most common are in quartz veins associated with granitic rocks and in contact metamorphic zones (tactite) at or near the margins of granitic rocks, especially where the granitic rocks have intruded calcareous sedimentary beds. Both scheelite and wolframite occur in the quartz veins, but usually only scheelite is found in the contact zones. In addition some tungsten is recovered from low-grade disseminated deposits in fractured zones in granitic bodies—usually as a byproduct of the recovery of other minerals. Tungsten is also recovered in a few places from placers. Tungsten has been mined from one hot spring deposit in Nevada.

Lemmon and Tweto (1962, p. 1) have pointed out that most of the important deposits in the northwestern United States are related spatially and in time to the widespread intrusive granitic bodies of Cretaceous and early Tertiary age. This relationship is especially true in northeastern and north-central Washington, where the wide distribution of tungsten minerals related to such intrusives labels the area as a tungsten province in which the likelihood for discovery of economic ore bodies is greater than elsewhere. However, a word of caution is necessary. Tungsten minerals tend to occur in deposits with high grade but small and widely separated pockets of ore that are seldom economic to mine. A small high-grade pocket of ore may be a momentary economic windfall, but the difficulty and cost of locating others often more than offsets the initial gain. Major production has always come from those rarely discovered deposits of good size and grade or from very large deposits of lower grade that prove economic because of their large tonnage and optimum conditions for cheap mining.

Although the United States tungsten mining industry has operated continuously (except for 1921 and 1922) for over 60 years, the yearly production has ranged widely and to meet requirements the country has imported tungsten in amounts that generally exceed domestic mine output. Only a very few domestic producers have been able to compete consistently on the open market with foreign producers (Holliday, 1960, p. 914). However, in time of emergency and under Government incentive price programs, a large domestic productive capacity has been demonstrated twice during the last two decades, and these examples illustrate the fact that the United States does have a substantial supply of tungsten to be found and produced if the need warrants the cost to extract it.

Washington has never been a major source of tungsten in spite of its rather long history of production. The total output amounts to less than 1 percent of the Nation's total through 1962. As of 1964, the State ranks in eighth place among all the tungsten-producing States in the country [1] in the total amount shipped since 1900.

First production of tungsten in the State was from the Germania mine in Stevens County in 1904. Production from this mine together with lesser production from other nearby properties has accounted for a large part of the nearly 4,000 tons of 60-percent WO_3 concentrates in the State through 1962. Tungsten occurrences are reported from 14 counties in the State, but aside from Stevens County the only other localities that have yielded noteworthy amounts are in Ferry and Okanogan Counties.

The tungsten deposits of Washington have been described and catalogued in considerable detail by Culver and Broughton (1945) and by Huntting (1956). Table 11 summarizes the available information on most of the localities in the State that are more than mere mineral occurrences. Many of these, however, are of no current economic significance. The locations of the deposits listed on table 11 are shown by corresponding numbers on figure 34.

[1] Production data from U.S. Bureau of Mines Minerals Yearbooks.

TABLE 11.—*Tungsten mines and prospects in Washington*

Index No. on fig. 34	County	District and localities	Description	Selected references
1	Okanogan	Chewack district: Wolframite Mountain (Hatfield, Cathedral Peak, Tungsten Peak, Zellweger, and others).	Wolframite with some scheelite and pyrite in gently dipping (15°) relatively narrow quartz veins in coarse-grained biotite granite. Vein widths range from 1 inch to 24 inches but commonly 5 to 10 inches. Vein exposed at 4 principal localities along a projected surface trace of 2¼ miles, but heavy talus and glacial debris cover most of country and continuity and correlation of the vein cannot be proved. Strike length equals about 1½ miles. About 6 cars of handpicked tungsten ore shipped prior to 1920; smaller amount, including 1 ton of concentrate, in later years. Inaccessibility of area, narrow vein width, flat dip, and pockety nature of wolframite distribution militate against significant future production.	Culver and Broughton, 1945.
2	do	Nighthawk district: Four Metals and Kaaba-Texas.	Base metal-bearing quartz veins in granodiorite, limestone, argillite, and quartzite. Scheelite occurs as scattered crystals in the veins and locally as streaks and pods of greater concentration near vein walls. Small pods in Four Metals vein reported to contain as much as 2 percent WO_3. No reported tungsten production.	Culver and Broughton, 1945; Umpleby, 1911b.
3	do	Oroville district: 49th Parallel, OK Copper, and Golden Chariot.	Very minor amounts of scheelite in narrow quartz veins and stringers that cut a series of metamorphic rocks and intrusive diorite, granite, and related igneous rocks. Associated with molybdenite, chalcopyrite, and pyrite. No production.	Do.
4	do	Oroville district: Moncosilgo	Occasional scheelite in very thin fractures in diorite that also contain cuprite, chalcopyrite, molybdenite, pyrite, and native copper. No production of tungsten reported.	Do.
5	do	Conconully district: Starr	Very minor scheelite associated with pyrite and molybdenite along fractures and disseminated in granitic rocks. No tungsten production.	Culver and Broughton, 1945; Creasey, 1954.
6	do	Conconully district: Silver King, Lady of the Lake, and Gubser	Scheelite in scattered small amounts associated with pyrite, molybdenite, galena, sphalerite, chalcopyrite, in irregular quartz veins that follow shear zones in argillite, granitic rocks, and fine-grained dike rocks.	Culver and Broughton, 1945.
7	do	Crawfish Lake (Windiate-Auberton)	Scheelite and chalcopyrite in tactite at contact of quartz monzonite and 3-foot-thick limestone layer in metamorphic series. Scheelite sparsely scattered for most part. One 3-inch-thick lens of higher grade scheelite-bearing tactite. No recorded tungsten production.	Huntting, 1956.
8	do	Myers Creek district: Strawberry Lake.	A group of contact metamorphic deposits containing notable amounts of magnetite, pyrite, and pyrrhotite, Some chalcopyrite and small amounts of disseminated scheelite in places. No reported production of scheelite.	Culver and Broughton, 1945; Broughton, 1945.
9	do	Magnetic and Roosevelt		
10	do	Crystal Butte		
11	Ferry	Republic district: Kelly Camp	Scheelite as disseminated small grains and some few coarsely crystalline aggregates in tactite at contact of diorite and limestone in a small roof pendent. No recorded production.	Culver and Broughton, 1945.
12	Stevens	Orient district: Big Iron	Scheelite in scattered crystals and clusters of crystals in contact metamorphic magnetite deposit. Some pyrite, pyrrhotite, and chalcopyrite occur in association with magnetite. Scheelite too sparse and irregularly distributed to be recovered. Possible economic concentrations in area, but probably always secondary to magnetite.	Culver and Broughton, 1945; Broughton, 1945.

13	-----do-----	Northport district: Red Top mine and Lucille.	Small lead-zinc deposits with local concentrations of scheelite crystals in shear zones, quartz veins, and quartz stringers in marble and argillite. Scheelite associated with galena, sphalerite, chalcopyrite, and pyrite, but also in separate streaks, pods, and scattered crystals. Tungsten secondary to lead and zinc in importance. Few local pods of ore estimated to contain 1–2 percent WO_3, but most too widely spread for profitable recovery. No production of tungsten reported.	Culver and Broughton, 1945; Huntting, 1956.
14	-----do-----	Magma-----	Small amount of scheelite scattered in contact metamorphic zone. No production.	Culver and Broughton, 1945.
15	Pend Oreille---	Metaline district: Little Noisey-----	Small amount of scheelite with galena and sphalerite in a quartz vein cutting phyllite and granitic rock. No production.	Do.
16	Chelan-----	Chiwawa district: Royal (Red Mountain).	Scheelite in minor amounts in pyrrhotite-chalcopyrite ore bodies localized by brecciated zone at contact of gneiss and diorite. Not abundant enough to mine as tungsten ore but possibly by-product production should other minerals warrant operation.	Do.
17	-----do-----	Railroad Creek district: Holden mine.	Minor amount of scheelite in parts of the mined-out Holden mine ore body. No tungsten saved during mining.	Do.
18	Okanogan-----	Squaw Creek district: New Deal-----	A series of quartz veins ranging from a few inches to 15 feet wide cutting granitic and metamorphic rocks. In many places the veins are closely associated with and parallel to basic dikes. Scheelite scattered through many of these in minor amounts, usually too small for mining. Small local pockets may contain as much as 2 percent WO_3. Dutch John deposit comprises small amount of scheelite in tactite at contact of granite and limestone layers in metamorphic rock. No production of tungsten from any of these properties.	Do.
19	-----do-----	Squaw Creek district: Minnie-----		
20	-----do-----	Squaw Creek district: Dutch John----		
21	-----do-----	Squaw Creek district: Holden-Campbell, Highland, Methow, Chelan, Golden Eagle, and Washington.		
22	Ferry-----	Keller District: Pacific Mutual and Silver Lead (Addison).	Small amount of wolframite and a little scheelite together with galena, sphalerite, pyrite, chalcopyrite, chalcocite, malachite, and azurite in a 4- to 6-foot quartz vein in biotite-quartz-muscovite schist and gneiss. One pocket of possible commercial grade tungsten ore known, but no recorded production.	Do.
23	-----do-----	Covada district: Guin mine-----	Wolframite and scheelite with pyrite and tetrahedrite in quartz vein in Covada Group metasedimentary rocks. Small production reported.	Do.
24	-----do-----	Covada district: Silver Leaf-----	Scheelite in lenticular quartz veins in shear zone in Covada Group. Mineralized zone about 50 feet wide contains minor amounts of pyrite, chalcopyrite, sphalerite, stibnite, and tetrahedrite in addition to scheelite that is restricted to several narrow quartz veins in the shear zone.	Do.
25	Stevens-----	Summit district: Daisey-----	Scheelite in quartz veins in diorite and argillite associated with arsenopyrite, pyrite, tetrahedrite, galena, and sphalerite. Tungsten-bearing veins generally in diorite and are between a few inches and a foot thick. Scheelite occurs in veins as lenses and stringers parallel to walls.	Do.
26	do-----	Summit district: Washington Metals..	Gray vitreous quartz veins in porphyritic granite. Veins usually narrow (2 to 12 inches) and pinch and swell along strike and down dip. Main tungsten mineral is wolframite scattered irregularly through quartz vein. Tourmaline and feldspar in veins at places. Small production reported from Washington Metals.	Do.
27	do-----	Summit district: Columbia tungsten (Black Horse and Stockwell).		

TABLE 11.—*Tungsten mines and prospects in Washington*—Continued

Index No. on fig. 34	County	District and localities	Description	Selected references
28	Stevens	Germania area: Germania mine	Wolframite and minor scheelite, pyrite, and molybdenite in nearly vertical quartz veins in granitic rock. Main vein ranges from a few inches to 3 feet thick and was mined from 3 levels that are 200 feet, 375 feet, and 500 feet below the highest outcrops. Ore was stoped for a maximum length of 1,700 feet on the intermediate (main haulage) level. Tungsten values decreased drastically on the lowest (500) level where the wolframite was largely succeeded by molybdenite. One main vein, but a few minor veins parallel the main structure and are mostly too narrow to mine. Germania mine produced in excess of 1,250 tons of 60 percent WO_3 concentrates before main ore shoot was depleted. Some production made from eluvial material and from reworking of tailings.	Culver and Broughton, 1945; Huntting, 1956.
		Germania Consolidated mine	Wolframite and scheelite with associated pyrite and molybdenite in glassy quartz veins that are part of the southwestward extension of the vein zone at the Germania mine. There are at least 3 veins from a few inches to a foot thick. Wolframite occurs as widely scattered crystals and erratically distributed small pods and shoots of ore-grade material. Production has been erratic and data incomplete but is said to approximate $100,000 in value.	Do.
29	do	Chewelah district: June-Echo (Western Molybdenum).	Scheelite in zone of narrow quartz veins at or near contact of diorite intrusive and limestone. Other minerals are chalcopyrite, pyrite, and molybdenite. Some parts of vein estimated to contain 1 percent WO_3.	Culver and Broughton, 1945.
30	do	Springdale district: Blue Grouse Mountain, Harrison, and Tungsten King.	Huebnerite in 2 types of occurrence: (1) Small crystals disseminated in greisenized (altered) granite at contact with Deer Lake argillite, and (2) large, well-formed bladed crystals up to 3 inches long in quartz veins that angle into the argillite from the contact and for the most part follow the bedding in the sedimentary layers. Pyrite, molybdenite, and manganese oxides accompany some of the occurrences. Small production has been made from various properties at intervals since before World War I to the present.	Do.
31	Snohomish	Sultan district: Kromona	Small amounts of scheelite and powellite in a few quartz veins that cut quartz diorite.	Do.
32	do	Sultan district: Mint		
33	Chelan	Blewett district: Blewett Tungsten (Culver Gulch).	Scattered crystals of scheelite in narrow quartz vein	Do.
34	Yakima	Bumping Lake district: Copper Mining Co.	Series of mineralized shear zones in granodiorite. Sulfide minerals and scheelite found in several zones but only Bird vein (Clara), that is opened by 3 adits and series of pits and trenches for nearly 2,000 feet, contains significant amounts. Scheelite scattered erratically in streaks, small pods, or single crystals in narrow quartz veins or silicified zones and usually associated with chalcopyrite, arsenopyrite, pyrite, and a little molybdenite. Although scheelite is fairly persistent along the length of the shear zone, the average content of WO_3 is low and the higher grade streaks and pockets are too widely spaced and erratic for large scale mining. Small production might be possible from very localized concentrations.	Do.

35	Spokane	Silver Hill	Scheelite and wolframite associated with cassiterite in a series of pegmatites and quartz veins in high-grade metamorphosed sediments that are cut by granitic intrusive rocks. Pegmatites and veins are discontinuous and ore minerals are erratically distributed. Several veins considered wide enough for possible commercial production, but their irregularity and discontinuity militate against large scale operations. Small amount of tungsten concentrate shipped in 1962.	Culver and Broughton, 1945; Page, 1945.

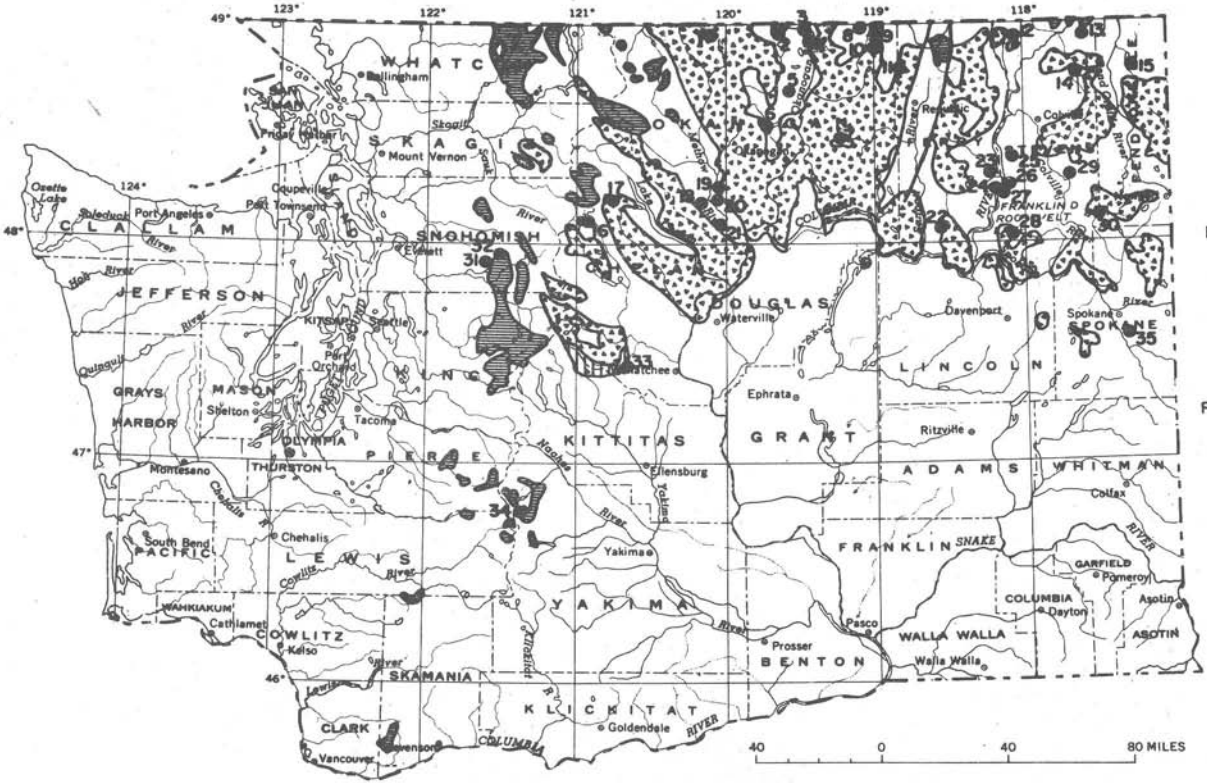


FIGURE 34.—Tungsten in Washington.

Occurrences of tungsten in Washington are restricted for the most part to the north-central and northeastern part of the State and to areas in which granitic, metamorphic, or sedimentary rocks are exposed. They are usually closely associated with the granitic intrusive bodies or the contacts of granite with sedimentary rocks—especially those containing some limestone layers. No deposits have been found, nor should any be expected, in the wide areas covered by the Columbia River basalt in south-central or southeastern Washington, nor have any been discovered in the andesitic rocks that comprise much of the southern part of the Cascade Range. Also, there are no verified occurrences in the Puget Sound Lowland nor westward to the coast.

By far the most important deposits on the basis of past production are the wolframite-bearing veins of southern Stevens County. These veins, all apparently associated with the Loon Lake granitic rock, include the Germania area (No. 28, fig. 34) that has accounted for the great bulk of output from the State. Unfortunately, the main ore shoot at the Germania mine has been essentially depleted and the mine closed. However, on the basis of past history, widely scattered small deposits, and the favorable geologic environment, it would be surprising if additional moderate to small production from this area did not recur at times of higher metal prices.

Washington has never been a major tungsten-producing State, and at the present time there are no mines in production. With the depletion of ore resources at several of its formerly active mines, its future is not particularly bright. However, a large part of the State is marked as a tungsten province by virtue of widely scattered occurrences and small deposits of the minerals of this metal, and should metal prices rise the possibilities for new discoveries are reasonably good—many times greater than in areas without these occurrences.

URANIUM

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Uranium, the heaviest common element, is a mixture of three semistable radioactive isotopes, U^{234}, U^{237}, and U^{238}. U^{238} can be converted to plutonium (Pu^{239}). When U^{234} or Pu^{239} are bombarded with neutrons, they fission, energy is released, and a chain reaction can be started. Uncontrolled chain reactions provide the terrible power of the atom bomb; controlled chain reactions in nuclear reactors produce heat which can be converted to power, and also provide radioactive isotopes for research and for industrial and military uses.

Uranium occurs in nearly all geologic environments except those typified by ultramafic rocks, the plateau basalts, and some marine sediments (Stocking and Page, 1956, p. 5). The principal source of uranium in the United States is from deposits in sandstone beds of continental origin, where uranium minerals occur as impregnations between grains. The most important of these deposits are on the Colorado Plateau. Uranium is also found in lacustrine limestones and in some coal beds. It is also found in small concentrations in black shales of marine origin and in deposits of phosphorite. Important deposits occur in veins. Uranium is found in small amounts in many

igneous rocks, and uranium minerals are common but minor constituents of many pegmatites.

Uranium is moderately soluble in water and may be carried long distances by the underground circulation. It is chemically reactive and thus may be a constituent of a large number of minerals. It can be removed from solution by adsorption on many different substances, including carbon, and commonly is found concentrated in carbonaceous sediments. These same characteristics account for the presence in many small deposits of little or no economic value.

There are more than 90 minerals that contain uranium (Frondel and Fleischer, 1955). Of these, the only ones that occur in significant quantities in Washington deposits are uraninite, an oxide (and pitchblende, a variety of uraninite); coffinite and uranophane, silicates; and autunite, meta-autunite, phosphuranylite, and torbernite, all of which are phosphates.

Until 1954, despite persistent search, no uranium occurrences of significance had been found in Washington. In the summer of 1954, uranium minerals were discovered by the LeBret brothers on the Spokane Indian Reservation in Stevens County. The discovery was made while prospecting for tungsten at night with an ultraviolet lamp. This find became the Midnite mine (fig. 35, No. 1) and touched off a uranium boom in the State. Shortly thereafter uranium was discovered on the Dahl farm on the west slope of Mount Spokane (No. 2), some 40 miles east of the Midnite mine and about 30 miles northeast of Spokane. This became the Daybreak mine and marked the discovery of a second uranium area in the State. Other discoveries were made, but none so far have proved to be of the importance of the original two. As a result of these discoveries, a mill was built in 1957 at Ford in Stevens County to treat the ores and Washington became an important producer of uranium. Total uranium produced from the State to February 28, 1965, is 4.7 million pounds of U_3O_8 from 1.2 million tons of ore.

MIDNITE MINE AREA

The Midnite mine has exposed a number of ore bodies along the western contact of a tongue of schist, phyllite, and quartzite of the Precambrian Togo Formation, which projects southward into porphyritic quartz monzonite of the Cretaceous Loon Lake batholith (Becraft and Weis, 1963, p. 59). Five of these bodies have been mined. Individual ore bodies are as much as 700 feet long, 200 feet wide, and more than 150 feet deep (Sheldon, 1959).

Near the surface, the uranium ore is thoroughly oxidized and consists of a mixture of secondary uranium minerals intimately associated with iron oxide films and coatings. Individual crystals are generally less than 0.5 mm in diameter. Meta-autunite is by far the most abundant mineral, occurring as thin films on fractures or as discrete crystals on iron oxide. Uranophane and phosphuranylite are common, and a few other oxidized uranium minerals have been identified (Becraft and Weis, 1963, pp. 58–62).

In 1957, Becraft and Weis identified sooty uraninite and coffinite together with pyrite and marcasite in a few specimens of unoxidized ore. In 1965, specimens of sooty uraninite were relatively plentiful in the Midnite open pit and veins of dense, shiny pitchblende were

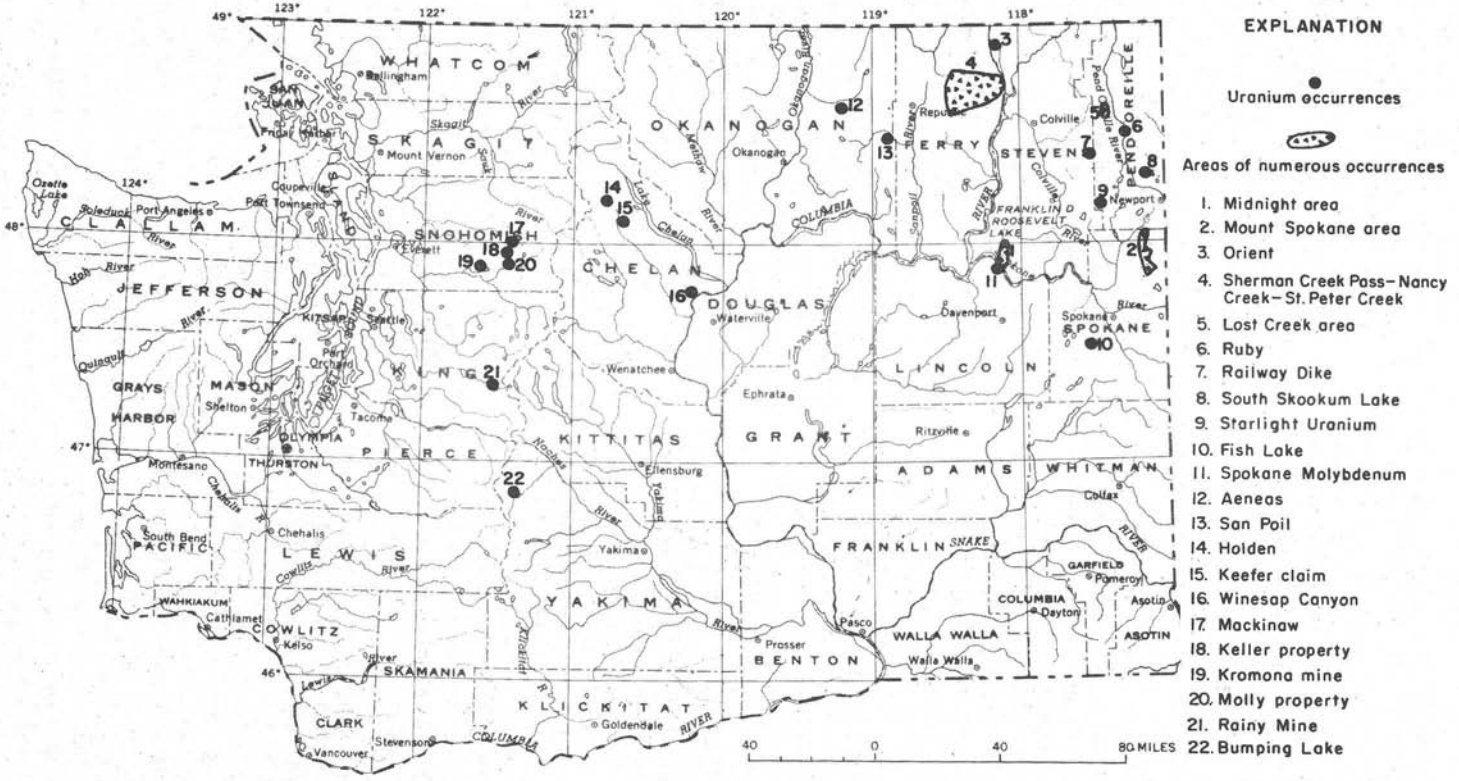


FIGURE 35.—Uranium in Washington.

quite abundant in some of the faces of the open pit. According to Shoichiro Hayashi (written communication, 1964), the pitchblende is an intergrowth of uraninite and a niobium-bearing mineral or minerals.

Almost all the uranium minerals are in the metamorphosed sedimentary rock; only locally are secondary minerals abundant enough in the underlying quartz monzonite to constitute ore. There is some evidence to suggest that the uranium is associated with small, steep faults which cut the Togo Formation near its contact. Some of these fractures may be older than the quartz monzonite. Redistribution of uranium occurred as a result of oxidation of the primary uranium minerals by ground water.

Production from the Midnite mine began in 1955 and ceased in 1962. The Ford mill continued operating on stockpiled ore until July 1, 1965, when the company's contract to deliver uranium concentrate to the Atomic Energy Commission was fulfilled. During the 6½ years of the operation, the mine produced 1,125,637 tons of ore, all of which was treated at the Ford mill. In addition, some ore was shipped to Salt Lake City previous to August 1957, when the Ford mill went on stream. Ore reserves remaining at the Midnite mine are estimated at 847,500 tons averaging 0.240 percent U_3O_8 (Gray and Hale, 1964 p. 1156).

Following the discovery of the Midnite mine, several other discoveries were made in the same general area. At the Lowley lease on the Spokane River about 7½ miles south of the Midnite mine, uranium minerals were found in an intensely shattered zone at the contact of impure quartzite and granodiorite. About 285 tons of ore was shipped in 1956 (Becraft and Weis, 1963, p. 66); there has been no production since. In 1958 some diamond drilling was done with the aid of a Defense Minerals Exploration Administration contract. Results were inconclusive.

Small, sparse flakes of secondary uranium minerals were found on the west side of Deer Mountain in sheared rock. The occurrence is at the contact of the Togo Formation and quartz monzonite of the Loon Lake batholith and is about 5 miles northeast of the Midnite mine. No ore-grade material is exposed (Becraft and Weis, 1963, p. 67).

At the Big Smoke lease about a mile north of the Lowley lease, uranium minerals occur along a faulted contact between granodiorite and pyroclastic and sedimentary rocks of the Gerome Andesite. Metatorbernite is found as sparse, small crystals in carbonaceous shale and sandstone. The occurrence has been explored by several shallow percussion holes and by extensive bulldozing. Only minor amounts of uranium have been discovered (Becraft and Weis, 1963, pp. 66–67).

Uranium ore in an entirely different geologic setting was discovered in 1955 at the Peters lease as the result of an airborne scintillation survey. The Peters lease—also known as the Northwest Uranium mine—is about 4½ miles southeast of the Midnite mine. At this locality, uranium is found in the basal member of the Gerome Andesite of Oligocene age. In the mine area the Gerome Andesite consists of interbedded tuffaceous sandstone, arkose, and carbonaceous shale overlying a poorly sorted conglomerate about 100 feet thick. The formation rests on quartz monzonite of the Loon Lake batholith. The conglomerate, which is poorly cemented, contains many cobbles and boulders as much as a foot in diameter and some that are much larger. The ore zone, which is about 30 feet thick, is near the base of the

conglomerate. It contains much carbonaceous material in thin arkosic lenses and in irregular, sporadically distributed masses. No recognizable uranium minerals are visible at the deposit except for some green stainings at a few places near the surface. The conglomerate above the ore zone contains practically no carbonaceous matter, but carbonaceous material is abundant in some of the beds above the conglomerate. In the mine area the ore zone lies from a few feet to as much as 80 feet below the surface. It is bounded on the west by a north-trending fault and on the south by an east-trending fault. Drill holes show that the ore zone continues west of the north-trending fault but has been down-dropped 285 to 345 feet. The uranium almost certainly was brought in by circulating water and was deposited in the carbonaceous parts of the basal conglomerate. The source of the uranium, however, is uncertain (Becraft and Weis, 1963, pp. 62–66). An interesting feature of the deposit is the very meager surface showings to indicate its existence. The original discovery was made in carbonaceous layers above the conglomerate and was not especially promising. Not until the full thickness of the basal conglomerate had been tested by drill holes did the potential of the deposit become evident.

The deposit was explored with the assistance of a Defense Minerals Exploration Administration contract from 1956 through 1958. It was operated first by the Silver Buckle Mining Co. and later by Dawn Mining Co. Although the ore is low grade, the relatively shallow depth of cover over most of the deposit and the unconsolidated nature of the overburden made possible low cost mining by open-pit methods. Little or no blasting was required in either the ore zone or the overburden. Total production to the time the mine was closed in March 1962 was 87,300 tons of ore containing 305,700 pounds of uranium. Considerable ore remains, but the more easily recovered or higher grade ore has probably been removed.

MOUNT SPOKANE AREA

The first discovery in the Mount Spokane area (fig. 35, No. 2) was made when green crystals of autunite were found in a hole dug for a fence post on the Dahl farm. The discovery was reported in 1955 but is said to have been actually been made some years earlier, although the uranium was not identified at the time. Mr. Dahl is said to have seen a specimen of autunite and recognized it as similar to the green crystals he had found on his farm some years previously. This discovery became the Daybreak mine. Since 1955, at least 28 other occurrences have been found in a belt 1 to 1½ miles wide on the west and south slopes of Mount Spokane, extending from the south fork of Deadman Creek (about sec. 7, T. 27 N., R. 45 E.) northwesterly for about 14 miles to the boundary of Spokane and Pend Oreille Counties in sec. 1, T. 29 N., R. 44 E.

The east side of Mount Spokane is underlain by highly metamorphosed rocks of probable Precambrian age. The Precambrian gneisses and schists have been intruded by biotite quartz monzonite of Cretaceous age—part of a large intrusive mass known as the Loon Lake batholith. The quartz monzonite is similar to other granitic rocks of the Loon Lake batholith except that the only dark mineral present is biotite. Hornblende, which is common elsewhere in the

Loon Lake batholith, is completely absent. The intrusive contact trends northeasterly nearly through the summit of Mount Spokane. Within a belt a few miles wide bordering the contact, there are irregular patches and masses of rock in which the dark biotite gives way almost completely to white muscovite. This rock, which appears to be largely a metasomatic replacement of the biotite quartz monzonite, has a characteristic dazzling white appearance. Its texture varies from aplitic (a fine-grained sugary texture) to graphic (a texture in which the component minerals form a pattern resembling cuneiform characters). In field mapping, this rock has been termed an alaskite—a name for a type of light-colored granitic rock. Quartz-feldspar-mica pegmatites cut the biotite quartz monzonite, as well as some of the gneisses, but become more abundant as the alaskite masses are approached. In the alaskite, the pegmatites are very abundant and in places may make up as much as 25 percent of the rock.

The uranium deposits are closely similar. In all of them, coarsely crystalline autunite [1] (hydrous calcium uranyl phosphate) is the only uranium mineral except for exceedingly finely dispersed uraninite, which is found in some of the autunite crystals (Leo, 1960, p. 110; Ross, 1963, p. 1392). In all the deposits the autunite occurs as fracture fillings and in open spaces in the host rock. Autunite alone fills the voids; there are no gangue minerals. The fracture fillings range in thickness from mere coatings on fracture walls to solid masses of crystals 15 inches or more across. The Daybreak mine in particular has been the source of spectacular specimens of autunite which now grace museums (Weis and others, 1958, p. 26). At all the deposits the country rock has been bleached and altered, but hydrothermal alteration is not intense (Leo, 1960, p. 103). The fractures trend at all angles, but at several of the occurrences—most notably at the Daybreak mine—autunite is particularly abundant in flat-dipping open fractures. The autunite appears to be restricted to the near surface; none has been found at depths greater than about 150 feet. Mapping of the Mount Spokane quadrangle by the author of this chapter has shown that without exception all of the 29 uranium occurrences known to date are in or immediately adjacent to masses of alaskite. This is significant, as it can serve as a guide to future prospecting.

The origin of the deposits is something of an enigma. The deposition of the autunite in open fractures, the absence of any gangue minerals, the restriction to the near surface, and the abundance of radioactive springs in the uranium areas strongly point to deposition from circulating ground water. Pegmatites are abundant in the uranium areas but are equally abundant elsewhere. Leo (1960) has shown that the phosphate in the autunite could have been obtained from the leaching of the apatite in the quartz monzonite (or alaskite). Some of the pegmatites also contain apatite. The source of the uranium is more obscure. An analysis cited by Leo (1960, p. 124) does not indicate that the quartz monzonite contains unusual amounts of uranium. No analyses are available of the alaskite, but numerous scintillator traverses fail to indicate that this rock is notably more radioactive than the quartz monzonite.

Mapping of the Mount Spokane quadrangle has shown that the rocks have been subjected to deep weathering. The weathered zone

[1] Includes meta-autunite I and II, which are less hydrated varieties of autunite.

has been partly stripped off by subsequent erosion but still remains in many places. Scheid (Hosterman and others, 1960), in his work on the clays of northern Idaho and northeastern Washington, recognized a period of deep weathering in Tertiary time, which he termed the "Excelsior period of weathering." He attributed the formation of the clay deposits to this period of weathering. The deep weathering on Mount Spokane probably corresponds to this same period of Tertiary weathering. It is possible that the Mount Spokane uranium deposits were formed during the same period of Tertiary weathering when the clays were formed. Uranium may have been leached from the weathering alaskite and deposited at favorable places above the then existent water table. To at least a minor extent, solution and deposition of uranium may be still going on.

Most of the uranium mined from the Mount Spokane area has come from the Daybreak mine, but eight different properties have contributed to the total. The total amount shipped to the Ford mill from the Mount Spokane area is 12,361 tons of ore containing 53,809 pounds of U_3O_8. In addition to this, about 6,300 tons of ore was shipped to Salt Lake City before the Ford mill was in operation. In 1964, the only activity in the area was at the Daybreak mine, which produced a few hundred tons of ore. The area is essentially one for the small producer, but given the proper incentive more ore could be mined from known deposits and it is probable that other similar deposits could be discovered.

OTHER DEPOSITS

Deposits somewhat similar to those of the Mount Spokane area are known in the Lost Creek area (fig. 35, No. 5) in Pend Oreille County. Like the Mount Spokane deposits, they occupy open fractures in a light-colored granitic rock. Small shipments have come from the Lost Creek claim (Triple H and J. Mining Co., Inc.) and Quartz Ridge claims (Hi Noon Uranium, Inc.). In addition, one small shipment was made by the Green Nugget Mining Co. from the H.P.S. group of claims in the Priest Lake area of Pend Oreille County (not shown on figure 35 because its location is uncertain).

There is no record of any other production of uranium in the State, but there are numerous localities where uranium minerals have been noted or anomalous radioactivity has been reported. Many of these are associated with small pegmatite lenses in gneiss, as in the Sherman Creek Pass-Nancy Creek-St. Peters Creek area (fig. 35, No. 4). Many claims have been staked on occurrences of this type, but they are unlikely to have much potential value. Numerous other occurrences have been reported, but little information is available on most of them. The better authenticated ones, together with all localities from which there has been production of uranium ore, are listed in table 12.

TABLE 12.—*Uranium occurrences in Washington*

Index No. on fig. 35	Area or property, location	Type of occurrence	Remarks	Reference
	CHELAN COUNTY			
14	Holden mine: Secs. 18–19, T. 31 N., R. 17 E.	Abnormal radioactivity associated with ore on 2,500 level in western part of mine.	No uranium mineral identified	Weis and others, 1958, p. 30.
15	Keefer claims: On west slope of Red Mountain.	Uraninite reported associated with tourmaline, chalcopyrite, and other sulfides in intrusive breccia.		Do.
16	Winesap Canyon: Sec. 5, T. 28 N., R. 21 E.; near head of Winesap Canyon.	Quartz-feldspar-muscovite pegmatite with minor uraninite.		Huntting, 1956.
	FERRY COUNTY			
4	Sherman Creek Pass-Nancy Creek-St. Peter Creek area between Kettle Falls and Republic.	Numerous radioactive anomalies in pegmatite lenses in gneiss.	Numerous claims staked. No production.	Do.
	LINCOLN COUNTY			
11	Spokane Molybdenum mine: Sec. 32, T. 28 N., R. 37 E.	Pitchblende in stringer which cuts quartz vein with molybdenite and other sulfides.	Country rock is quartz monzonite of Loon Lake batholith.	Becraft and Weis, 1963, pp. 67–68.
	OKANOGAN COUNTY			
12	Aeneas: Sec. 15, T. 36 N., R. 29 E.	Slight radioactivity along pegmatite veins in gneiss.		Huntting, 1956.
13	Sanpoil: Sec. 25, T. 35 N., R. 31 E.; on Sanpoil River.	Pegmatite with samarskite and radioactive fluorite.		Do.
	PEND OREILLE COUNTY			
5	Lost Creek area: T. 36 N., R. 43 E.; west of Blueslide.	Autunite veins in granite. Somewhat similar to deposits in Mount Spokane area.	Small production from two properties.	Do.
6	Ruby: Sec. 6, T. 34 N., R. 44 E.; near Ruby.	Pegmatite with few scattered grains of autunite and uraninite.		Do.
8	South Skookum Lake: Sec. 6, T. 33 N., R. 45 E.; half a mile east of South Skookum Lake.	Autunite in shear zone in granite	Prospected by Silver Dollar Mining Co.	Do.
9	Starlight Uranium: Sec. 10, T. 32 N., R. 42 E.; near Calispell Creek.	Autunite in weathered granite		Do.

	SNOHOMISH COUNTY			
17	Mackinaw: Sec. 19, T. 29 N., R. 11 E	Copper-nickel property on contact of serpentine and arkose.	Some samples slightly radioactive.	Broughton, 1942.
18	Keller property: Sec. 6, T. 28 N., R. 11 E. near Mineral City.	Uraninite in quartz veinlets		Huntting, 1956.
19	Kromona mine: Sec. 13, T. 28 N., R. 9 E	Shear zone with copper minerals. Ore slightly radioactive.		Do.
20	Molly: Sec. 30, T. 28 N., R. 11 E	Uraninite reported with molybdenum and copper.		Do.
21	Rainy mine (Western States Copper): Sec. 16, T. 24 N., R. 10 E.	Minor brannerite with quartz, pyrite, and chalcopyrite in breccia pipe in granodiorite.		Weis and others, 1958, p. 31.
	SPOKANE COUNTY			
2	Mount Spokane area: Forms belt 1 to 1½ miles wide and 14 miles long on west side of Mount Spokane.	Autunite filling fractures and open spaces in pegmatitic alaskite.	Autunite found in at least 29 localities. Production from 8 properties.	Weis and others, 1958, pp. 23, 31; Leo, 1959; Ross, 1963; Huntting, 1956.
10	Fish Lake: Secs. 32-33, T. 24 N., R. 42 E.; just north of Fish Lake.	Slight radioactivity in irregular masses of pegmatite in metamorphic rocks.		Huntting, 1956.
	STEVENS COUNTY			
1	Midnite mine area: West of Wellpinit	At Midnite mine, series of ore bodies along contact of porphyritic quartz monzonite and schist and phyllite of Togo Formation. At Peters lease, ore body is in conglomerate at base of Gerome Andesite.	Principal uranium-producing area of Washington. Large reserves remain.	Becraft and Weis, 1963, pp. 58-67.
3	Orient: Sec. 26, T. 40 N., R. 36 E	Autunite in pegmatitic gneiss		Huntting, 1956.
7	Railway Dike (Merikay): Sec. 33, T. 34 N., R. 42 E.; on Chewelah Creek.	Large pegmatite which locally shows intense radioactivity. One specimen contained uranium-bearing columbite.	Has produced a few tons of beryl	Weis and others; 1958, p. 33; Huntting, 1956.
	YAKIMA COUNTY			
22	Bumping Lake: T. 15 N., R. 12 E.; 5 miles south of Bumping Lake Dam.	Strong radioactivity in soil and gravel around radioactive spring.	Over 80 claims staked in rush following discovery.	Huntting, 1956; Weis and others, 1958, p. 81.

FUTURE OF URANIUM MINING IN WASHINGTON

The uranium industry in Washington is at a standstill because the Dawn Mining Co., owner of the Midnite mine, has fulfilled its quota of uranium with the Atomic Energy Commission and the Commission is not making any new contracts. Although the Midnite mine is not operating, substantial reserves of good grade ore remain, but cannot be mined until there is once again a market for the ore. Some ore also remains in the Mount Spokane area, although developed resources are small.

With the closing of the Ford mill, the uranium industry in the State has become quiescent and will remain so until a market develops for uranium. When this occurs, prospecting, exploration, and development of uranium mines will be reactivated. Intensive prospecting following the discovery of the Midnite mine resulted in other discoveries in the Midnite and Mount Spokane areas and elsewhere in the State. Discoveries made to date are more than sufficient to prove that the geological environment in eastern Washington is favorable for uranium deposits, and the chances for further discoveries in eastern Washington must be considered good. Given the incentive to prospect, discoveries similar to the Midnite might be made along the margin of the Loon Lake batholith. Other deposits similar to the Peters lease ore body could occur in the conglomerates interbedded in the Gerome Andesite. In both of these environments sizable ore bodies are known to occur, but poor exposures make them hard to find. Additional discoveries of ore bodies of the Mount Spokane type are almost certain to be made in the Mount Spokane area if further search is made, and discoveries are possible elsewhere in Washington where rocks similar to Mount Spokane alaskite are known to occur. These ore bodies are likely to be small, but some may be large enough for a successful small operation.

Uranium occurrences found to date in the Cascade Mountains appear to have little or no potential value. This area, however, has been prospected very inadequately for uranium. Enough anomalies have been found to suggest that the area has possibilities (fig. 35). It is pertinent to remember that the two original discoveries in northeastern Washington—the Midnite and the Daybreak mines—were quite fortuitous. Further search seems definitely warranted at the appropriate time.

Nonmetallic Mineral Resources Other Than Fuels

ALUNITE

(By M. T. Huntting, Washington Division of Mines and Geology, Olympia, Wash.)

Alunite is a hydrous sulfate of potassium and aluminum, $KAl_3(SO_4)_2OH_6$, in which sodium commonly substitutes for part of the potassium. It is pink or white and inconspicuous in outcrops. It commonly occurs as compact earthy masses that resemble clay; rarely it is coarsely granular.

Although alunite is not now being used commercially in the United States, it is used abroad as a source of potash alum and has attracted attention in this country as a potential source of potassium, sulfur, and aluminum. The interest in alunite as a source of potassium was spurred by the blockade of Germany by Great Britain during World War I, which cut off the normal supplies of potash to this country. By 1918 at least 128 plants in the United States were producing potash from alunite, kelp, wood ashes, lake brines, cement dust, beet-sugar waste, blast-furnace dust, and other sources. During World War II attention was again focused on alunite, this time as one of several alternate raw materials for the production of aluminum. During this war it was the effectiveness of German submarines in cutting off normal offshore supplies of bauxite and causing a critical shortage of this strategic material that forced our attention to alunite. A process for the recovery of alumina and potassium sulfate from alunite was patented by Kalunite, Inc. (Fleischer, 1944), and a plant utilizing this process was constructed at Salt Lake City to process alunite from Marysvale, Utah. The plant was never operated on a commercial basis.

About 1934 alunite was discovered 8 miles east of Enumclaw, Wash., and in 1939 Kalunite, Inc., became interested in the deposits and began an exploration program. More than 4,400 feet of diamond drilling was done by the company in four localities along White River in King and Pierce Counties in T. 20 N., R. 7 and 8 E., and in T. 19 N., R. 7 E. At the same time WPA crews directed by the Washington Division of Mines and Mining did more than 3,600 feet of trenching on State-owned land in the area. Although the results of this work did not live up to expectations, and the planned aluminum plant to use this material in Tacoma was never built, the exploration did show an area of about 16 square miles in which alunite was sporadically distributed.

The alunite is considered to occur as replacements of Tertiary andesitic flows and tuffs and as fillings of open spaces in these rocks. Apparently, silicification and kaolinization accompanied the alunitization of the rock. The diamond-drill records and outcrops indicated that the higher grade masses of alunite occurred as irregularly shaped bodies without definite continuity in any direction. The largest body was about 57 feet by 40 feet by 37 feet in size. In most of the mineralized areas the alunite content was quite low.

A total of 1,140,000 tons of alunite-bearing rock is reported (Kelly, Strandberg, and Mueller, 1956, p. 32) in the area. Some 600,000 tons of 30-percent alunite is in the SE¼ sec. 4, T. 19 N., R. 8 E.; an estimated 240,000 tons of 21.4 percent alunite is 1¼ miles to the southeast; and 300,000 tons is in the NE¼ sec. 7 and in secs. 5 and 6. Sohn (1952a) reports approximately 2 million tons of alunite containing 20.5 to 32.9 percent Al_2O_3.

Most of the alunite so far found is just beneath thick layers of silicified rock. The wide distribution of silicified rock and clay mineralization strongly suggests that more alunite-rich rock could be found by further exploration.

BARITE

(By W. S. Moen, Washington Division of Mines and Geology, Olympia, Wash.)

Barite, the sulfate of barium, has the chemical formula $BaSO_4$. It contains about 66 percent barium oxide (BaO) and 34 percent sulfur trioxide (SO_3). It is a heavy white crystalline mineral (specific gravity about 4.5) that is relatively soft. Barium is the 15th most abundant element in the earth's crust, and according to Clarke and Washington (1924, p. 20) the average igneous rock contains 0.05 percent barium. Commercial deposits of barite occur as veins, beds, and as residual masses in clay overlying limestone. Barite is also a common gangue mineral of many ore deposits, mainly with the ores of lead, zinc, copper, silver, antimony, and manganese. However, as a gangue mineral it is seldom of economic importance.

The uses of barite are based on its relatively high specific gravity, its color, inertness, or barium content. The major uses of barite in the United States are in well-drilling muds, glass, paint, rubber additives, and in chemical compounds. Washington barite has been used mainly in oil-well-drilling muds, in sugar and metal refining, and by the paint industry. (See fig. 36.)

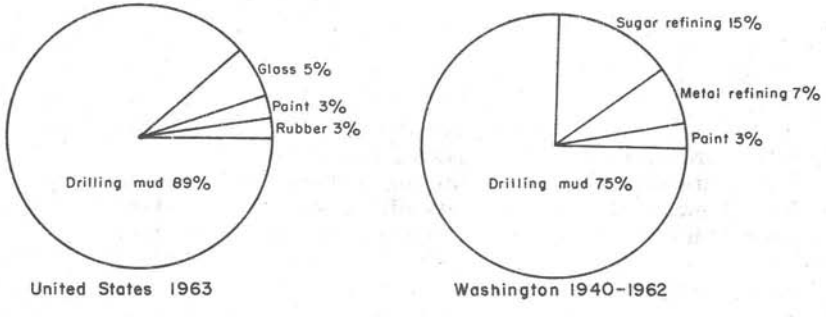


FIGURE 36.—Major uses of barite in the United States and Washington.

For well-drilling muds the barite is ground to minus 325 mesh and should have a specific gravity of at least 4.2. It is generally mixed with bentonite mud that gels when the drill stops rotating. The barite-weighted mud assists in controlling liquid and gas pressures, helps prevent "blowouts," and floats the drill cuttings. In glass making, barite acts as a flux and makes glass more brilliant and

workable. An intimate mixture of barium sulfate and zinc sulfide is used in the manufacture of lithopone, a substance used as a white pigment in paints and also as a filler or pigment in the manufacture of rubber, linoleum, and plastics. Many barium chemicals are consumed in the United States, the main ones being barium hydrates, oxides, carbonates, chlorides, chlorates, titanates, and nitrates; and blanc fixe (artificially precipitated pure barium sulfate).

Since 1955 the annual domestic consumption of barite and its derivative materials has been from 1.2 to 2 million tons, of which about one-third is imported. The total estimated production of barite for Washington from 1940 through 1962 was about 16,000 tons. Annual production is given below.

Washington barite production, 1940–61 [1]

Year:	Short tons	Year—Continued	Short tons
1940	153	1958	2,200
1942	1,068	1959	250
1951	250	1960	5,499
1953	97	1961	5,700
1955	50	1962	(2)
1957	100		

[1] Moen, 1964, p. 15.
[2] Cannot be cited.

The entire 1960 and 1961 production was shipped to Alaska for use in drilling mud. No barite mines were producing in the State in 1963 or 1964.

The general overall price for crude barite is about $16 to $18 per ton f.o.b. mines. According to Engineering & Mine Journal Metal and Mineral Markets of January 11, 1965, water ground, floated, and bleached barite sells for about $45 to $49 per ton f.o.b. mine or mill. These prices apply to barite that contains at least 95 percent barium sulfate and less than 1 percent iron.

The productive barite deposits of Washington are confined to the northeastern part of the State, mainly within Stevens and Pend Oreille Counties. (See fig. 37.) The host rocks for these deposits consist principally of argillaceous and calcareous sedimentary rocks of Precambrian and early Paleozoic age. Early Cretaceous granitic rocks, which were intruded after the development of the major folds and faults of the region, appear to be the source of the barite. Barite-rich hydrothermal solutions escaping from the granitic rocks deposited barites in fractures and also replaced preexisting rocks.

The barite deposits of Washington include both veins and replacements. Commonly, the veins are filled fissures along shear zones and range in thickness from thin stringers to massive deposits as much as 12 feet wide; veins average about 200 feet in length but may be as much as 1,300 feet long, and several extend to at least 200 feet in depth. Where viens cut favorable rock types, such as limestone, dolomite, and calcareous siltstones, replacement deposits have developed, both as veinlike bodies and as uniform replacement of selected sedimentary beds. Individual replacement veins are up to 10 feet in width and as much as several hundred feet long. Several parallel veins may form a mineralized zone up to 20 feet wide. Where there has been a uniform replacement of a sedimentary bed, the barite is fairly uniform

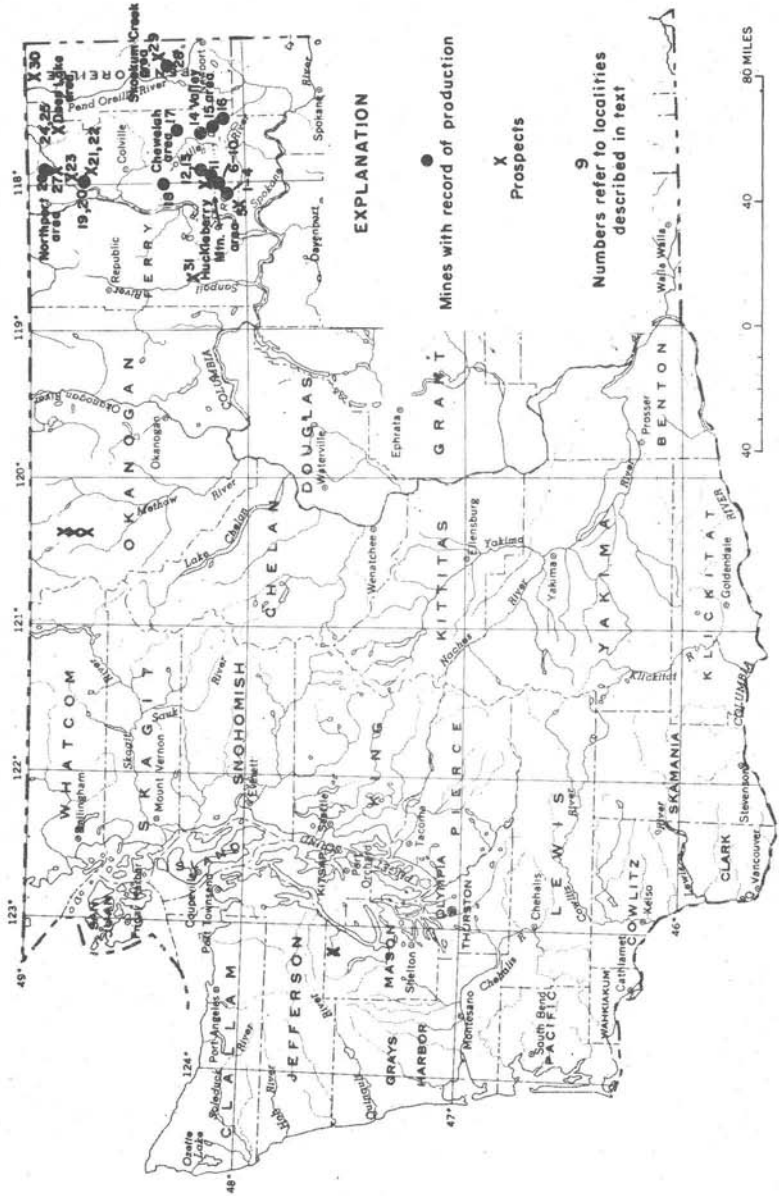


FIGURE 37.—Barite deposits in Washington.

in thickness and does not pinch and swell. Bedded barite deposits occur interbedded with argillaceous and calcareous sedimentary rocks. Barite may occur as a replacement of a single bed or several beds that are separated by thin beds of sedimentary rocks. Individual beds of barite are as much as 10 feet in thickness, and several beds may form a mineralized zone as much as 50 feet thick. Several of the bedded barite deposits are at least 300 feet long.

Several of Washington's barite deposits are remarkably pure and assay as much as 97.03 percent $BaSO_4$. Others are high in calcite and/or quartz and contain as little as 40 percent $BaSO_4$. Twelve deposits contain material that assays 94 percent or more barium sulfate, which is suitable for use in the chemical industries. Fourteen deposits have material that contains 90 to 94 percent barium sulfate, which meets the specifications for well-drilling mud. In addition to calcite and quartz, minor amounts of manganese, alumina, iron, lead, zinc, and strontium are present in several of the barite veins.

Of the 35 reported occurrences of barite in the State, 26 are in Stevens County, 4 in Pend Oreille County, 3 in Okanogan County, and 1 each in Ferry and Mason Counties (fig. 37). Only the deposits in Stevens and Pend Oreille Counties have produced barite. Barite deposits in other parts of the State occur mainly as gangue in metalliferous and nonmetalliferous veins. As such, they have not been of commercial value; however, it is possible that some barite might be recovered as a byproduct in the milling of the ores. Pertinent information about barite deposits of Stevens and Pend Oreille Counties is given in table 13.

55-883 O—66——12

TABLE 13.—*Barite deposits of Stevens and Pend Oreille Counties*

Index No. on fig. 37	Property	Section, township, range	Host rocks	Specific gravity of barite	Estimated reserves (tons)		Remarks [1]	
					Measured and indicated ore	Inferred ore		
	STEVENS COUNTY							
	Huckleberry Mountain area:							
1	Allan prospect No. 1	21-30-38E	Argillite, quartzite	4.42	300	12,850	B — —	
2	Allan prospect No. 2	20-30-38E	Quartzite, greenstone	4.37	400	1,000	A, B —	Abundant iron oxide on fracture surfaces.
3	Allan prospect No. 3	28-30-38E	Argillite, quartzite	4.30			B — —	Minor copper mineralization accompanies barite.
4	Allan Barite (Four A) mine	21-30-38E	Argillite, greenstone	4.00–4.40	1,400	2,750	A, B, D	Minor copper mineralization accompanies barite.
5	Cedar Canyon prospect	1-29-37E	Argillite, quartzite	4.35–4.45			A, B —	
6	Shallenberger mine	10-30-38E	Argillite	4.38	8,000	10,000	A, B, D	
7	Deer Park Barite No. 1 mine	10-30-38E	do	4.38			A, B, D	Outcrop of barite vein in Shallenberger mine.
8	Deer Park Barite No. 2 mine	15-30-38E	Argillite, siltstone	4.29	50	1,000	A, B, D	
9	Chamokane prospect	15-30-38E	Argillite, quartzite	4.39			B — —	Barite occurs as waste on old mine dumps; vein not exposed.
10	Hillside (Copper Butte) mine	11-30-38E	Argillite		5,000		C, — —	
11	Wells Fargo mine	36-31-38E	Argillite, quartzite	4.42	175	1,800	A, B, D	
12	Cardinal mine	30-31-39E	do	4.35–4.38	1,100	6,800	B, D —	
	Cardinal prospect	30-31-39E	Argillite, dolomite	4.35	100	1,850	A, B —	6 to 12 inch copper vein along footwall of barite vein.
13	Yellow Jacket mine	29-31-39E	Argillite, quartzite	4.45–4.48	425	2,250	A, B, D	
	Valley area:							
14	Smith (Inklers Point) mine	14-31-40E	Argillite, limestone	3.80–4.40	400	750	C, D —	Minor copper staining in barite.
15	Bakie mine	24-31-40E	Argillite	4.42–4.48	1,000	6,000	A, B, D	Barite occurs in scattered lenses.
16	Pease (Loon Lake) mine	33-31-41E	Argillite, quartzite	4.42	900	15,000	B, C, D	Much iron oxide present.
	Eagle Mountain area:							
17	Eagle Mountain (Lynx Cat) mine	33-33-41E	Argillite, siltstone	4.30–4.38	1,100	3,000	A, B, D	
18	Madsen mine	26-34-38E	Dolomite	4.32–4.50	450	1,450	A, B, D	Minor sphalerite present in barite.
	Clugston Creek area:							
19	Uribe (Bruce Creek) mine	5-37-39E	Argillite, siltstone	3.91–4.40	10,000	200,000	B, C, D	
20	Ohman prospect	5-37-39E	do	3.91–4.40	150	2,500	B, C —	
21	Jacobson mine	16-37-39E	Argillite	3.82–4.25	800	2,000	B, D —	
22	Rose prospect	9-37-39E	do	4.26	250	3,500	B — —	
23	Williams Lake prospect	36-38-38E	Argillite, quartzite	4.00–4.35			B, C —	
	Deep Lake area:							
24	Deep Lake prospect	27-39-41E	Argillite, slate	3.87–3.92	60	280	C — —	
25	Lotze prospect	26-39-41E	Slate, argillite	2.64–4.25	1,600	2,000	B, C —	

	Northport area:							
26	Flagstaff Mountain mine	9-39-39E	Limestone, argillite, quartzite.	3.81–4.27	8,000	24,000	B, D	—
27	O'Toole Mountain (Riverview and Ellingwood) prospect.	9-38-39E	Argillite, shale	3.76	17,000	150,000	B, C	—
	PEND OREILLE COUNTY							
28	Skookum Creek area: Bobcat mine	14-33-44E	Argillite, quartzite	4.00	5,000	7,000	B, D	— Barite stained by iron oxide.

[1] A—suitable for chemical purposes; B—suitable for use in heavy media well-drilling mud; C—milling required to upgrade much of the barite; D—record of past production.

Source: Data from Moen, Wayne S., 1964, "Barite in Washington," Washington Div. Mines and Geology Bull. 51.

The more productive areas of Stevens County include the Huckleberry Mountain area in southwestern Stevens County, Eagle Mountain east of Chewelah, the Clugston Creek area north of Colville, and Flagstaff Mountain southwest of Northport. The Huckleberry Mountain area contains 13 deposits of barite, 7 of which have a record of production. Deposits from which barite has been mined are the Allan mine (No. 4), Shallenberger mine (No. 6), Deer Park Barite (Nos. 7 and 8), Wells Fargo mine (No. 11), Cardinal mine (No. 12), and the Yellow Jacket mine (No. 13) (fig. 37 and table 13). The deposits in general occur as fissure and replacement veins in argillite, siltstone, and quartzite. Most of the veins are steeply dipping and parallel to the regional faults and folds, which trend in a northeast direction. Several veins are as much as 10 feet wide and may be traced for several hundred feet.

The Eagle Mountain barite deposit (No. 17) contains fissure and replacement veins in argillite and siltstone. The barite occurs in moderately to steeply dipping veins that are 3 to 4 feet wide. Several thousand tons of barite, which contained about 95 percent barium sulfate, have been mined from this deposit.

The Clugston Creek area contains barite deposits of the bedded type. The host rocks of these barite deposits are thin-bedded siliceous siltstones and argillites that contain minor beds of massive limestone. The deposits range in thickness from beds less than a sixteenth of an inch thick to massive beds almost 10 feet thick. At the Uribe mine (No. 19), a series of replaced beds make up a mineralized zone that ranges from 10 to 80 feet in thickness. The deposit is concealed by a thick cover of glacial debris, but the deposit has been exposed by past mining operations for a length of 250 feet. Production records show that the ore contains from 80 to 90 percent barium sulfate and that its main outlet has been the oil well drilling industry. Although several thousand tons of barite have been mined from the Uribe deposit, substantial reserves remain which possibly could be upgraded to at least 95 percent barium sulfate by milling.

On Flagstaff Mountain, southwest of Northport, several hundred tons of barite have been mined for use in oil well drilling muds. Past shipments of the barite have averaged 4.2 in specific gravity. At the Flagstaff Mountain barite mine (No. 26), a vein of barite 6 to 8 feet in width occurs as fissure fillings and replacements in sheared limestone, argillite, and slate. Outcrops of the vein suggest a possible length of 1,300 feet, but mining has been confined to the northeastern end, where the vein is horizontal. Elsewhere the vein appears to be nearly vertical.

The Bobcat mine (No. 28) north of Newport is the only barite mine in Pend Oreille County that has a record of production. About 1,000 tons of barite, having an average specific gravity of 4.1, were mined in 1962 for use in oil well drilling muds. The barite occurs as lenticular bodies up to 25 feet wide and 50 feet long in sheared argillites and fine-grained quartzites. A barite mineralized zone about 60 feet wide and 360 feet long has been exposed by mining operations. Although over 10,000 tons of ore probably remain at the Bobcat deposit, the lenticular nature of the barite presents problems in mining.

In addition to the deposits listed in table 13, barite is present as a gangue mineral at the Hardrock Thomas prospect (No. 29) and the Lead Hill mine (No. 30), both in Pend Oreille County, and at the

Congress mine (No. 31) in Ferry County. It is also reported as a gangue mineral at a few other localities in eastern Washington.

The total barite reserves of Washington are estimated to be about 500,000 tons of barite ore that contains 60 to 97 percent barium sulfate. About 59,000 tons of this is in measured or indicated ore; the remainder is inferred (Moen, 1964, p. 31). Much of the barite is suitable only for use in oil well drilling muds, but several of the higher grade deposits could supply barite to the paint and chemical industries. Inasmuch as almost 90 percent of the barite is consumed by the oil well drilling companies, the State is in a favorable position to supply any future demand of the oil industry along the west coast of Washington, Oregon, and in Alaska.

CARBON DIOXIDE (CO_2)

(By W. H. Reichert, Washington Division of Mines and Geology, Olympia, Wash.)

Carbon dioxide (CO_2) is a colorless gas at ordinary temperatures. It is not flammable and does not support combustion, although it is a common product of combustion of all carbon compounds. It is the chief constituent of the breath exhaled by animals and also is the source of the carbon used by plants in the process of photosynthesis. In relation to air, its specific gravity is 1.5290, and it is soluble in water. The gas will liquefy at 32° F. under a pressure of 35 atmospheres. The liquid in turn will freeze and turn to "snow" (dry ice) when the pressure is dropped to ordinary atmospheric pressure, thus lowering the temperature to −109° F., at which temperature the "snow" will evaporate without first becoming a liquid. The "snow" is pressed into cakes for commercial use, a cake in the form of a 10-inch cube weighing about 45 pounds.

Carbon dioxide is used in the manufacture of soda by the Solvay process; in the sugar industry; in the manufacture of carbonated beverages; in the manufacture of dry ice; in the treatment (dry ice method) of warts; as a quick coolant in various industries; in fire extinguishers; as an inflatant for tires, rafts, life belts; and for many other purposes.

Carbon dioxide is released into the atmosphere from several sources: the combustion of fuels, the respiration of animals, the decay of organic matter, and liberation from the earth by mineral springs and volcanoes (Clarke, 1924, p. 50; White and others, 1963, pp. 3–4; White and Waring, 1963). Mineral springs and volcanic emanations are natural sources of carbon dioxide for commercial use. Manufactured sources of CO_2 include: byproduct from ammonia plants using natural gas as raw material; byproduct of fermentation in the manufacture of alcohol; and byproducts of cement mills, lime kilns, and iron blast furnaces.

Springs that produce water containing carbon dioxide in Washington are in the following counties: Chelan, Cowlitz, King, Klickitat, Lewis, Pierce, Skamania, Snohomish, and Yakima (Valentine, 1960). Commercial utilization of the CO_2, however, has been successful only at the Klickitat Mineral Springs in the NE¼ sec. 23, the NW¼ sec. 24, T. 4 N., R. 13 E., and in the NW¼ sec. 19, T. 4 N., R. 14 E., near Klickitat in Klickitat County. At this last locality, some of

the wells drilled have produced only CO_2 and others have produced water containing CO_2.

The area in which the Klickitat Mineral Springs are located is underlain by a thick series of basalt flows of the Columbia River Group of middle Miocene through early Pliocene age. The basalt is estimated to extend to a depth of at least 1,000 feet below the bottom of Klickitat Canyon. Repeated Quaternary volcanism in the Cascade Mountains forced new lavas into these lava flows through preexisting faults. The 1961 Geologic Map of Washington (Huntting and others, 1961) shows two major faults extending northwest from the Columbia River through this area, and minor faults probably occur there also. Canyons have been cut into both the older and younger flows, and later deposition of gravels and silts resulted in the superficial deposits found in the Klickitat Canyon. Steam and air are usually the dominant gases emanating from volcanoes, but CO_2 is the dominant "active" gas (White and Waring, 1963, p. 2). At the Klickitat Mineral Springs, it is believed that a slowly cooling buried lava, younger than the Columbia River basalts, is the source of the gas and possibly the mineral waters that make their way through the faults and fissures in the Columbia River basalts and openings in the superficial deposits, finally emerging at the surface, both in the canyon bottom and in the canyon wall.

Commercial development of the Klickitat Mineral Springs began when the Gas-Ice Corp., of Seattle, Wash., was organized in 1931 to explore the possibilities of developing the springs. It was decided that, although there was no future in the sale of mineral water, the CO_2 could be used in the manufacture of dry ice. The Gas-Ice Corp. completed its first dry-ice plant in 1932, at which time the output of 3 tons per day was more than the market could absorb. The demand for dry ice increased, however, and more wells were drilled to supply the CO_2. Available production figures for the Klickitat operation are as follows:

Washington carbon dioxide and dry ice production

Year	Carbon dioxide (pounds)	Dry ice (tons per day)
1932 (May to December)	199,867	3
1933	414,282	3
1934	630,391	3
1935	(1)	3
1936	1,085,551	5
1937	1,200,000	(1)
1938	1,644,000	(1)
1939	2,149,195	6
1940	2,559,638	10

[1] No figures available.

Source: U.S. Bureau of Mines Minerals Yearbooks 1936, review of 1940.

Production eventually reached 18 tons per day. A total of 45 wells have been drilled, of which about 20 are producing at the present time (1965). To date, 1.8 billion cubic feet of gas has been taken out.

Rank of Washington carbon dioxide production in the United States

Year:	Rank	Year—Continued	Rank
1949	7th	1957	4th
1950	7th	1958	4th
1951	8th	1959	4th
1952	8th	1960	4th
1953	4th	1961	5th
1954	4th	1962	5th
1955	[1]	1963	5th
1956	4th		

[1] No value given.

Source: U.S. Bureau of Mines Minerals Yearbooks 1949–63.

Future production, of course, will depend on supply and demand as well as costs of production and marketing. At the present time, Gas-Ice Corp. is able to meet the market needs with production from the wells at Klickitat and by recovery from a waste product from a plant at Finley in Benton County, where ammonia is produced from pipeline natural gas. Increased demand probably could be met by deeper drilling of the existing wells, thus providing greater pressure and consequent increased output of the wells. The drilling of new wells would also materially add to the output. It is believed that, because of the probable depth and consequent slow cooling of the intrusive mass, the supply of CO_2 should continue for a great many years.

The potential resources of carbon dioxide in the State have been but little investigated. Mount Adams, Mount Baker, Mount Rainier, Mount St. Helens, Glacier Peak, and Tumac Mountain—a postglacial cinder cone about 22 miles south of Mount Rainier (Abbott, 1951, p. 1495)—are all centers of Tertiary volcanism. Buried intrusives similar to the one responsible for the CO_2 at Klickitat Mineral Springs could occur almost anywhere in the large area affected by the late Quaternary volcanism. These intrusives could give rise to comparable amounts of CO_2.

Existing wells drilled for oil and other products might also be a source of carbon dioxide. For example, the Simcoe Oil Co.'s Simcoe No. 1 well in the NW¼NW¼ sec. 24, T. 11 N., R. 17 E., near Wapato in Yakima County, abandoned after drilling to 2,760 feet in the fall of 1930, was sampled for helium-bearing gas on February 17, 1957, by members of the U.S. Bureau of Mines, Division of Helium Resources. The mole-percent analysis of this gas shows a carbon dioxide content of 98.8 percent (Munnerlyn and Miller, 1963, pp. 74–75).

CLAYS

(By J. W. Hosterman, U.S. Geological Survey, Beltsville, Md., and V. E. Livingston, Jr., Washington Division of Mines and Geology, Olympia, Wash.)

Clays are natural earthy materials composed of very fine grained particles (clay minerals) that are particularly hydrous aluminum silicates but may contain small amounts of iron, magnesium, potassium, sodium, calcium, and other less important ions. A clay deposit consists of one or more of the clay minerals, such as kaolinite, endellite, montmorillonite, nontronite, and illite. It may also contain nonclay minerals in varying quantities; the most common of these are

quartz, feldspar, mica, and minerals composed of iron, manganese, and titanium oxides. Variations in mineral and chemical content, particle size and shape, impurities, and other characteristics of the clay result in a wide range of physical properties that determine the economic usefulness of the deposits.

Physical properties of the clays include plasticity, color, refractoriness, specific gravity, porosity, deformation with drying and firing, green and fired strength, viscosity, and gel strength. The purity of the clay enhances the economic value of most clay deposits, but for some uses, particularly in making common brick and tile, certain nonclay minerals are desired for color and to control shrinkage.

A prime use of clays is in the manufacture of ceramic products. In this category are the structural clay products such as building brick, drain tile, sewer pipe, terra cotta, and similar items. Also in this category are refractory products, which are made from clays that have a high fusion point (pyrometric cone 19 or above). Whiteware and porcelainware are ceramic products usually made by blending feldspar and flint clay with relatively pure kaolin clays that burn to an almost white color. Pottery and stoneware are made from a variety of clays that are semirefractory and fire to a dense product. The manufacture of portland cement consumes a large tonnage of clay, but much of this material is more nearly a shale than a clay. Lightweight aggregate for concrete is made by firing clays that will expand on sintering. The composition, mineral structure, method of identification, and testing of the various clays for different uses have been summarized by Murray (1960), Klinefelter and Hamlin (1957), and Grim (1953 and 1962).

Clays mined in Washington have a variety of actual or potential uses, but probably two-thirds of all clays consumed in the State are used for the manufacture of ceramic products. Production of clay, exclusive of fire clay, in Washington in 1963 was 134,000 short tons valued at $123,000. Fire-clay production figures for Washington in 1963 cannot be revealed. In 1963, Washington ranked as the 37th State in tonnage and 38th in value of clay produced. Table 14 shows the amount in short tons and the value of clay produced (exclusive of fire clay) from 1944 through 1963 in the State of Washington. For 14 years (1944 to 1957) the value of clay production steadily increased, and in 1957 Washington ranked 29th in tonnage and 28th in value of clay produced. The business recession of 1957–58 caused a sharp decline in the production of heavy clay and refractory products. Table 14 shows that clay production as of 1963 has not yet fully recovered from that recession.

TABLE 14.—*Clay production (exclusive of fire clay) 1944–63 in Washington*

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1963	134,000	$123,000	1953	259,000	$312,000
1962	103,000	100,000	1952	291,000	353,000
1961	145,000	138,000	1951	286,000	366,000
1960	169,000	162,000	1950	267,000	217,000
1959	180,000	171,000	1949	220,000	267,000
1958	196,000	183,000	1948	234,000	262,000
1957	298,000	488,000	1947	192,000	216,000
1956	320,000	440,000	1946	235,000	227,000
1955	365,000	412,000	1945	183,000	204,000
1954	261,000	318,000	1944	54,000	97,000

Source: Data from U.S. Bureau of Mines Minerals Yearbooks.

There are several nonceramic uses for which the clay of Washington might be suitable. One of these is as a filler and coater in the manufacture of paper. The specifications for coater clay are more rigid than for filler clay, but in both cases a pure kaolin clay with a high degree of whiteness and brightness is demanded. Other applications in which clay may be used as a filler or extender include rubber products, fertilizers, pesticides, insecticides, adhesives, linoleum, and textile sizing. Kaolin clays (kaolinite and endellite) have been investigated as a possible source of alumina (Al_2O_3), the material from which aluminum is made. Montmorillonite is the main constituent of bentonite, which forms a gel and expands to several times its normal volume when immersed in water. It is used as a sealer for earth-lined canals and reservoirs and as a forest fire retardant.

Yellowish green nontronite is a clay mineral closely related to montmorillonite; in fact, it is often referred to as an "iron montmorillonite" because of its high iron content. Nontronite has no economic importance, nor does it make a useful clay product. On the other hand, it is a rare clay mineral found only in a few areas of the world. It occurs in Spokane and Whitman Counties as a weathering product of the basalts in the Columbia River Group of Tertiary age, and is found filling cracks, crevices, and vesicles in the basalt.

Occurrences of various type clays in Washington are shown on figure 38.

REFRACTORY CLAY

There are two principal areas producing refractory clay products in the State (fig. 38). One area is in the vicinity of Seattle, where intermediate- to high-heat-duty refractories are made by the International Pipe & Ceramics Co. (formerly Gladding, McBean & Co.). The other area is in eastern Washington in the vicinity of Spokane, where intermediate-heat-duty refractory products are made by the International Pipe & Ceramics Co., which bought the property of Washington Brick & Lime Co. In King County, refractory clay beds occur in the Puget Group of Eocene and Oligocene age. The Hammer Bluff Formation of Glover of post-Miocene age that overlies the Puget Group was formerly a minor source of refractory clay. In Spokane, Stevens, and Whitman Counties, clay beds in the Latah Formation of Miocene age are currently used for making refractory clay products. However, in the past, residual clay derived from granitic rocks was the main source of raw clay for refractories.

Refractory-grade clay deposits occur in other parts of the State, but currently none of them are mined for use in refractory products. In northern Whatcom County the Sumas shales of Glover (1941) of Eocene age locally contain several beds that would make intermediate-heat-duty refractories (Moen, 1962). The refractory properties of the residual clay derived from andesite in Pierce County are high enough to make low- to intermediate-heat-duty refractory products. Ceramic tests of the semiflint and semiplastic clays of the Cowlitz Formation of Eocene age in southwestern Washington indicate that these clays would make excellent high-heat-duty refractory products. Shales of refractory grade are also known to occur in the Swauk Formation of Eocene age in Chelan and Douglas Counties.

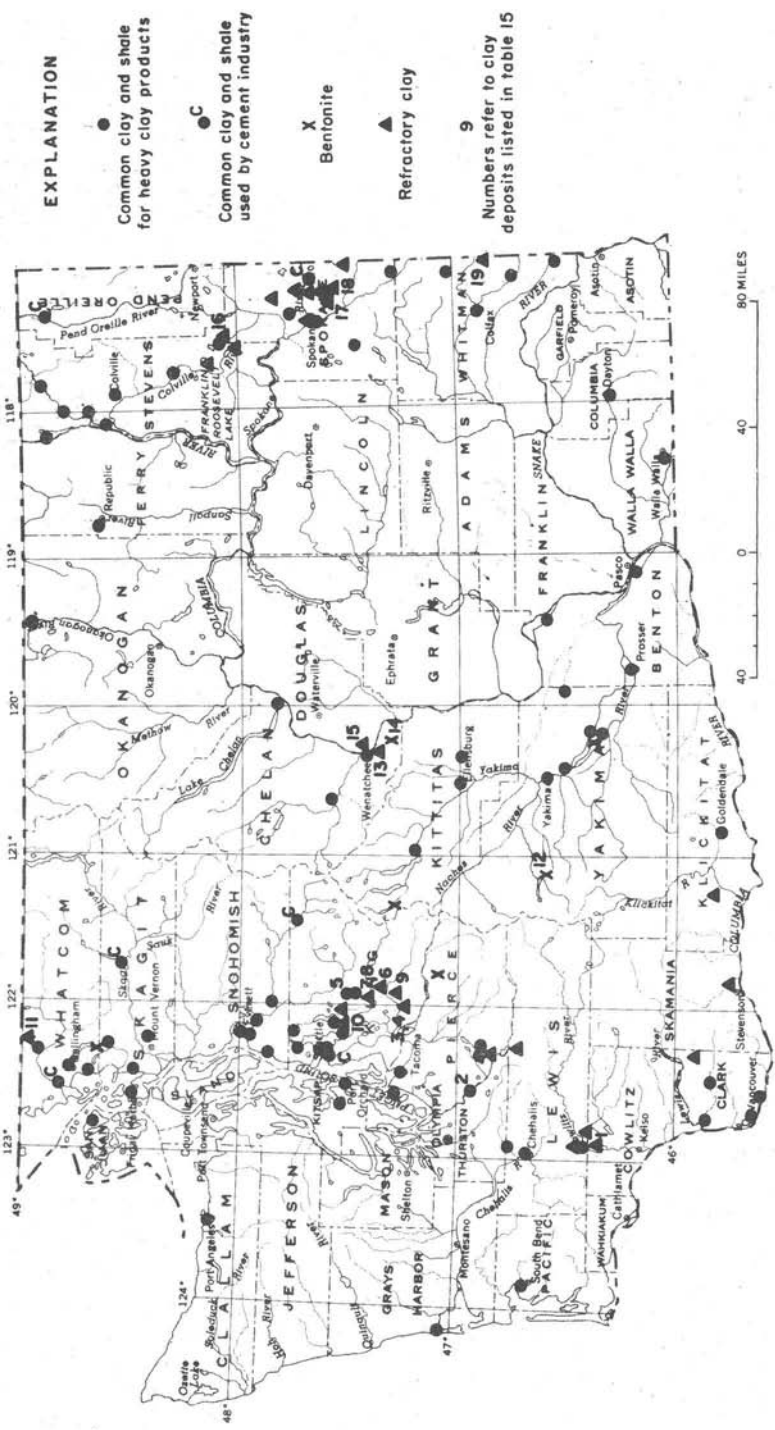


FIGURE 38.—Clay occurrences in Washington.

COMMON CLAY AND SHALE

Common clay and shale include the material used in making such products as building brick, tile, and flowerpots, known as heavy clay products, and the clay or shale that is mixed with limestone to make cement. Because the cost involved in shipping heavy clay products is high, only local clay deposits can be used economically. In many instances, these deposits may be any material that is cohesive, plastic, and can be dried and fired without distortion. The clay usually consists of a mixture of kaolinite and illite, a high percentage of impurities, and may be any color. Deposits of common clay and shale are shown on figure 38. Clay-processing plants currently producing products from common clay and shale are listed on figure 39. The cement companies using clay or shale are listed in the chapter on limestone.

The clay deposits used for making heavy clay products in the State are found in glacial, residual, eolian, and alluvial materials (Sohn, 1952b). Glacial clays are found predominently in the Puget Sound area but also occur in the northernmost counties of the State. Alluvial clays are found throughout the State but are not used abundantly in the Puget Sound area. Residual clay derived from andesite in Pierce County and residual clays derived from basalt and pre-Tertiary igneous and metamorphic rocks in Spokane County have been used for making building brick and tile. Clay and shale from beds of the Puget Group are used for making building brick and tile in King County. The Skookumchuck Formation of Eocene age is used in Lewis County. The Latah Formation of Miocene age, the Ellensburg Formation of Miocene and Pliocene age, and the Palouse Formation of Pleistocene age have been used extensively for making brick and tile in the Columbia Basin.

FILLER CLAY

The only clay that has been used as a filler in the State was from the Ringold Formation of Pleistocene age. The clay was mined in Yakima County (NW¼ sec. 35, T. 12 N., R. 23 E.) and processed by the Corliss-Kaiser Co., Inc., as a filler in asphalt floor covering. The Ringold Formation is predominantly a sandy clay with kaolinite, illite, and montmorillonite in approximately equal amounts.

The residual clays derived from granitic and gneissic rocks in Spokane County may be suitable for use as a paper filler. The clay would require beneficiation, which would produce byproducts such as high-silica sand for the glass industry and fine-grained mica that can be used as an insulating material or lubricant. Kaolinite is the predominant clay mineral present, and illite occurs in very minor amounts. Clay of this type is currently being processed in Latah County, Idaho.

BENTONITE

Bentonite is composed of the clay mineral montmorillonite and formed by the alteration of volcanic ash. In Washington a small amount has been used for sealing irrigation canals and reservoirs and as a forest fire retardant. Bentonite is currently mined in small quantities by the West Bros. Construction Co. of Naches, from a pit

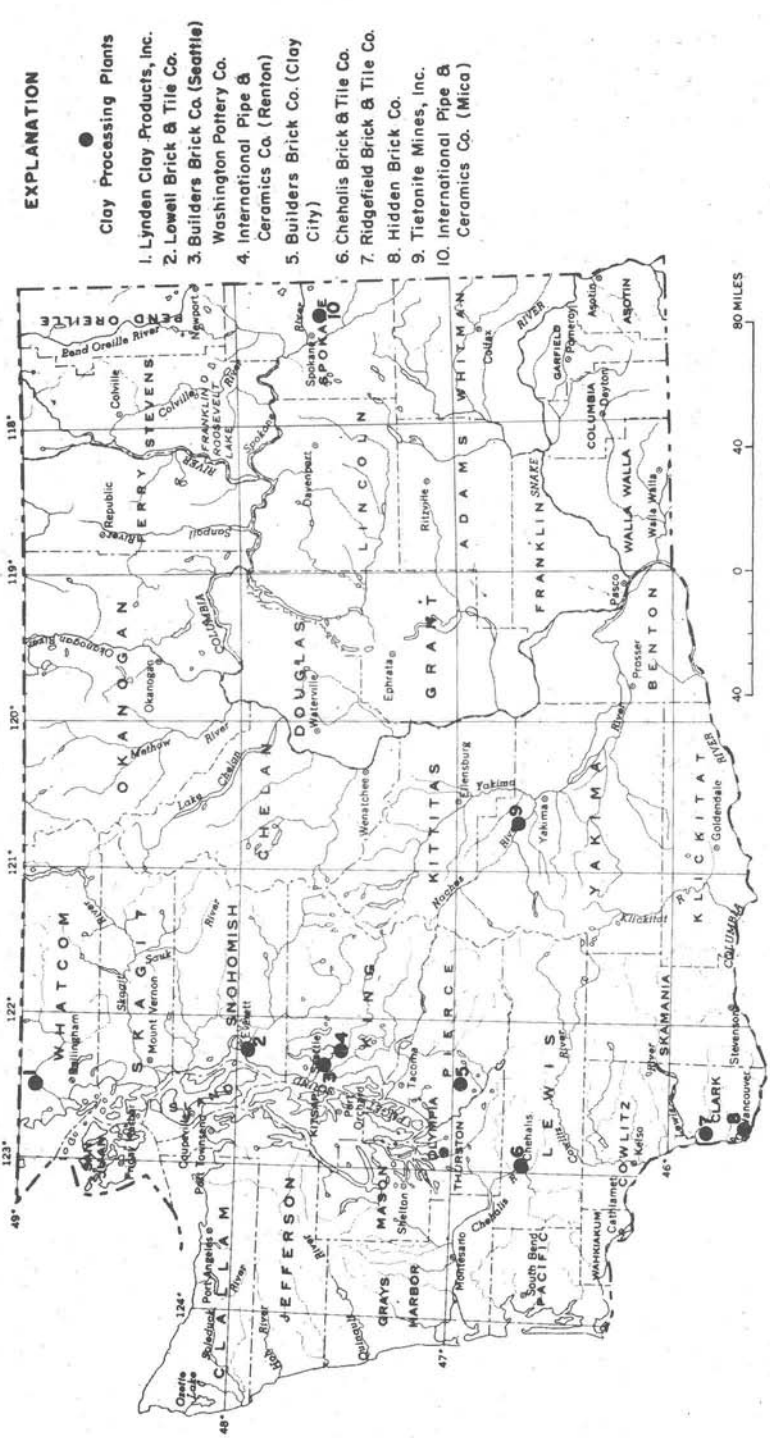


FIGURE 39.—Plants currently producing clay products in Washington.

near Tieton Reservoir (E½ sec. 7, T. 13 N., R. 14 E.) in Yakima County. Other deposits occur in Whatcom, Chelan, Pierce, and Kittitas Counties (fig. 38). These occurrences should be investigated for future economic possibilities.

EXPANDABLE CLAY AND SHALE

Lightweight aggregate is made from any material that is suitable for producing a concrete that is significantly lighter in weight than concrete made with sand and gravel. The lightweight aggregate material can be classified either as natural or as manufactured. Natural aggregates include volcanic cinders, pumice, diatomite, and volcanic ash; manufactured aggregates are made from vermiculite, perlite, clay, shale, and slate. Byproducts of other industries, such as blast furnace slag, are also marketed as lightweight aggregate. This section discusses clay and shale as a potential source of lightweight aggregate. Other sources of lightweight aggregate are discussed elsewhere in this report.

At the present time there are no plants in the State of Washington producing lightweight expandable clay or shale aggregate. A plant at Mead, near Spokane, was built in 1958, operated for a year, and closed in 1959. A small plant near Tenino was operating on a test basis in 1962 but to date has not produced any expandable clay or shale aggregate. A plant was constructed at Woodinville in King County in the late 1940's to make expandable aggregate from glacial clays but operated only briefly, mostly on an experimental basis, before it was closed.

The U.S. Bureau of Mines tested many samples of clay and shale from western Washington (Harris and others, 1962) and one sample of clay from the Latah Formation (Miocene age) in Spokane County (written communication). Previous testing showed that glacial materials were unsuitable for expandable aggregates; therefore, none were sampled by the Bureau. The one sample from Spokane County also proved to be unsuitable for making expandable aggregate, although other samples tested by private interests are reported to have given good results. However, 36 samples of clay and shale from western Washington showed good to fair expanding or bloating properties. Harris and others (1962) reported that in western Whatcom County the expandable clay and shale samples were from the Chuckanut Formation of McLellan of early Eocene age, and one sample was from the pre-Tertiary metamorphic rocks. In western Skagit County the expandable shales were found in the pre-Tertiary Leech River Group of McLellan. In western Snohomish County clay of the Chuckanut of McLellan was found to be expandable. The expandable clay found in King and Pierce Counties occurs in the Puget Group of middle Eocene through early Oligocene age, and all localities are relatively close to the Seattle-Tacoma market. At Roslyn, Kittitas County, expandable clay was found in the Roslyn Formation of Eocene age. The best expandable clay was found in Thurston County in the Skookumchuck Formation of late Eocene age, and other expandable clay was found in the McIntosh Formation.

HIGH-ALUMINA CLAY

During World War II the U.S. Geological Survey and the U.S. Bureau of Mines investigated the high-alumina clay deposits in Washington. Results of this work have been published (Hosterman and others, 1960; Nichols, 1945 and 1946; Popoff, 1955; and Sohn, 1952a). High-alumina clay deposits are found in Spokane, King, and Cowlitz Counties. In Spokane County the high-alumina clay deposits mainly occur on the south and west sides of Mica Peak in the Latah Formation and as saprolite of basalt and pre-Tertiary igneous and metamorphic rocks. The predominant clay minerals are endellite and kaolinite, and alumina contents as high as 35 percent have been reported. A conservative estimate of the amount of high-alumina clay, averaging 20 percent or more Al_2O_3, present is about 12 million tons. In King County, the high-alumina clay deposits occur in the Cedar Lake and Snohomish 15-minute quadrangles. The minerals are kaolinite with some boehmite and gibbsite in flint and semiflint clay beds of Eocene age. An estimated 20 million tons of high-alumina clay is present that averages 30 percent or more alumina. In Cowlitz County, the high-alumina clay deposits are 7 miles northeast of Castle Rock. The clay deposits occur as flint clay beds of Eocene age and as saprolite of Tertiary(?) basalt and andesite flows. The principal clay minerals are kaolinite, gibbsite, and montmorillonite. About 17 million tons of clay averaging 29 percent or more alumina has been estimated to be present.

ECONOMIC CONSIDERATION AND RESOURCE POTENTIAL

The clay products of Washington fall into two categories. The first and largest group includes the clay and shale processed into heavy low-cost products. For these products, the clay and shale must be cheap to mine, close to the processing plant, and close to the consumer. This economic control results in a concentration of plants and clay pits in the more densely populated parts of the State (figs. 38 and 39). The second and minor group comprises the clay products capable of competing for distant markets. The economic value of these clays is dependent on a specific property or on a certain quality of the finished product, and transportation and mining costs are less significant. The better grade refractory products made in King and Spokane Counties fall into this category.

The supply of raw clay for heavy clay products (pottery, cement, brick, tile, and so forth) is more than adequate for the needs of the immediate future. Resources of common clay are virtually inexhaustible, although depletion of local pits and changing of consumer requirements will result in adjustments in the raw materials used in the heavy clay products. Present sources of clay used for intermediate- and high-heat-duty refractories and particularly super-heat-duty refractories are not nearly so abundant as the common clay, but there is enough available to continue to meet current demands. Thorough prospecting and testing would probably reveal other resources as good or better in quality than much of what is being used at the present time. Bentonite resources for local uses are probably adequate for many years, and deposits are known at several localities other than where it is now mined.

TABLE 15.—*Data of selected refractory and special clays*

Index No. on fig. 38	Location	Type	Mineralogy	Color	Thickness (feet)	SiO_2 (percent)	Al_2O_3 (percent)	Fe_2O_3 (percent)	Loss on ignition (percent)	PCE	Fired color	Use	Reference [1]
	KING COUNTY												
3	Blum property, Cumberland area, 20 miles southeast of Seattle	Hard claystone		Light gray to reddish brown	Bed "A" 8 to 20 Bed "B" 6 to 12		32.6	9.6	5.1	29 18–23	Buff Red	Refractory, common brick	Nichols, 1946.
4	Kummer area, 20 miles southeast of Seattle	Flint clay	Kaolinite; boehmite	Dark gray to reddish brown	8	39.66	40.85	3.80	15.46	28–32+	Buff	Refractory	Glover, 1941.
5	Harris property, Issaquah area, 10 miles east of Seattle	Flint to semiflint clay	Kaolinite; siderite	Gray	50 to 70					29–32	Off white	do	Nichols, 1946.
6	Durham area, 15 miles southeast of Seattle	Flint clay	Kaolinite; boehmite	Dark blue to gray	15 to 40	61.2	46.1	2.7				Refractory, 2,450,000 tons	Do.
7	Taylor area, 15 miles southeast of Seattle	Altered volcanics, semiflint clay	Kaolinite		22±	73.6	19.8	8.4	3.1	28 23+	White Buff	Refractory do	Wilson, 1923.
	WHATCOM COUNTY												
11	Sumas area, 25 miles northeast of Bellingham	Shale		Bluish gray	11±	51	33	4		26–31	Light buff	Refractory, structural wares	Moen, 1962.
	PIERCE COUNTY												
2	LaGrand area, 25 miles south of Tacoma	Altered volcanics				66	22	2		16–31	do	Refractory	Shedd, 1910; Valentine, 1960.
	COWLITZ COUNTY												
1	Castle Rock area, 6 miles northeast of Castle Rock	Clay	Kaolinite	Light brown to black			30	3	17	30+	Buff to gray	Refractory, 11,000,000 tons	Popoff, 1955.
12	Tieton area, 30 miles west of Yakima	do	Montmorillonite	Light green to buff		68	12.9	1				Ditch liner, fire retardant	Kelly and others, 1956.
	CHELAN COUNTY												
13	Wenatchee area, 3 miles south of Wenatchee	Shale		Dark gray to brown		51.26	32.6	0.61	14.22	34–35	Light buff	Refractory	Glover, 1941; Hodges, 1938b.
14	Wenatchee area, 2 miles south of Wenatchee	Clay	Montmorillonite	Light gray			3.31	17.54	12.25			Ditch liner	Glover, 1941; Valentine, 1960.
	DOUGLAS COUNTY												
15	Wenatchee area, 2 miles north of Wenatchee	Gritty shale		Blue-gray		55.6	37.41	3.4	11.29	26+	Off white	Refractory	Huntting, 1943; Glover, 1941.
	WHITMAN COUNTY												
19	Cox property, Palouse area, 1 mile south of Palouse	Sandy clay		Light gray		58.77	30.28	1.6	8.44	30	Light buff	do	Glover, 1941; Wilson 1923.
	SPOKANE COUNTY												
16	Clayton area, 20 miles north of Spokane	Clay		Blue-gray to yellow	10+	51.56	32.46	1.90	10.51	30+	do	do	Wilson, 1923.
17	Mica area, 10 miles southeast of Spokane	do	Kaolinite	Light gray	50±	54.80	31.10	1.68	9.40	30+	Light gray	do	Hosterman and others, 1960.
18	Freeman area, 12 miles southeast of Spokane	Residual gneiss	do	White	45±	77.0	13.8	1.7	4.4	30–31	Cream	Refractory whiteware	Goodspeed and Weymouth, 1928; Wilson, 1923.

Index No. on fig. 38	Location	Type	Mineralogy	Color	Bulk density (pound per cubic foot)	Moisture (percent)	Ignition loss	Processing temperature °C	Bulk density (pound per cubic foot)	Compressive strength (psi)	Absorption (percent)	Use	Reference [1]
	KING COUNTY												
8	Cedar Mountain, Hobart area, 10 miles southeast of Renton	Shale		Gray to tan	73	3.5	5.8	1,195–1,210	50.0–59.0	1,970	9.8	Lightweight aggregate	Wilson, 1923.
9	Franklin Coal Mine, Black Diamond area, 10 miles southeast of Seattle	do		Brown	80	.9	10.1	1,150–1,160	46.0–61.0	1,720	10.5	do	Chew and Boyd, 1960.[2]
10	Newcastle area, 5 miles east of Seattle	do		Gray to brown	78	2.2	5.4	1,125–1,130	52.2–61.8	2,250	10.7	do	Do.[2]

Source: By V. E. Livingston, Washington Division of Mines and Geology.

[1] For a more complete list of references see Valentine (1960).

[2] A preliminary investigation of clay deposits in Minnesota, North Dakota, Montana, northern Idaho, and Washington (Northern Pacific Ry. Co., Properties and Indus. Devel. Dept., Geol. Div.). The report by Chew and Boyd also gives information on many of the other deposits listed in the table.

Washington contains large resources of undeveloped clay deposits that will serve future industries. The present resources of clay and shale suitable for expandable aggregate are more than adequate. Increasing demands for this clay product will undoubtedly stimulate production within the State. Other potential uses include ceramic whiteware and paper-filler clay. Beneficiation of the residual clay derived from granitic rocks in Spokane and Whitman Counties would produce a paper-coating clay along with such by-products as sand for the glass industry and mica for insulation and lubrication. The high-alumina clays have not yet been used as a source of alumina for the aluminum industry, except experimentally. Recent developments in mineral technology may make high-alumina clays competitive with bauxite as a source of alumina (Mining World, July 1963). Should this development take place, Washington's large resources of high-alumina clay would be in a favorable position to supply local aluminum plants. Table 15 lists many of the clay deposits of the State and summarizes the physical, chemical, and ceramic properties of the clay. Other pertinent data also are given, including reference to reports in which the deposits have been described.

DIATOMITE

(By V. E. Livingston, Jr., Washington Division of Mines and Geology, Olympia, Wash.)

Diatomite is an earthy white chalklike material that is composed of the siliceous (opaline) exoskeletons or frustules of microscopic one-celled aquatic plants called diatoms. The diatom skeletons are composed of two overlapping halves, or valves. The frustule is perforated by many pores, so the valves consist mostly of open space.

Diatoms live in almost every body of water. Occasionally they flourish in great profusion in lakes and in some areas of the ocean, and as they complete their life cycle and die, their skeletal remains accumulate in thick beds as bottom deposits. If there is a minimum influx of silt, sand, or other impurities, very thick and pure deposits will accumulate. Such deposits are known at Lompoc, Calif., where the diatomite has accumulated to a thickness of more than 1,000 feet. Diatomite deposits are located in widely scattered areas where the earth's surface was once covered by the sea or lakes. Rapid decay of the organic matter and leaching or flushing out of the soluble materials has left only the tiny, insoluble, and delicate yet almost industructible siliceous frustules as sedimentary deposits. Although the quality of diatomite can be affected by uplift and folding of the deposits, only under severe cases is the industrial value affected. When the quality is affected it is because the diatom shells are crushed and broken.

Diatomite is known by many names, some of which are diatomaceous earth, silica, diatomaceous silica, kieselguhr, chalk rock, and moler. It is sometimes incorrectly called infusorial earth (infusoria are protozoans and thus are animals rather than plants) and fuller's earth (which is a bleaching clay). Pure diatomite is white, but it is darkened by the presence of organic matter, iron oxide, or other foreign material. It is very light weight, having a lump density, as it occurs in the

ground, between 20 to 40 pounds per cubic foot. Because of the various contaminants, such as water, sedimentary detritus, and organic matter that are usually present in diatomite deposits, the raw product is generally cleaned and calcined to prepare it for industrial use. Its weight then may be reduced to as little as 5 pounds per cubic foot. The specific gravity is about 2 and its fusion point is between 1400° and 1750° C. depending on kind and amount of impurities present. Unprocessed diatomite has a hardness between 4 and 6 on the Moh's scale. It is softer than window glass and just slightly harder than brass. It is insoluble in all solutions except hydrofluoric acid and strong caustics. Diatomite is easily confused in the field with beds of pure volcanic ash, because they are both white, very fine grained, and have similar texture. However, the two materials are easily distinguished by microscopic examination.

The uses of diatomite have increased steadily during the past few years, mostly because some of the larger firms that mine diatomite are actively engaged in research to find new uses for that product. Practically all the uses of diatomite are dependent upon the natural cellular and porous structure of the diatom's frustule, its low apparent density, high strength, elasticity, low thermal conductivity, chemical inertness, light color, high melting point, and large surface area per unit weight. Its principal uses in decreasing order of volume used domestically are as a filter aid, mineral filler or extender, insulating agent, lightweight concrete aggregate and pozzolan, abrasive, and absorbent. About 48 percent of the diatomite consumed in the United States is used as a filter aid (Hartwell and Schreck, 1963, p. 532). Manufacturers of beer, liquors, antibiotics, serums, soap, petroleum products, cooking oils, paints, lacquers, soft drinks, sugar, and fruit juices are a few of the many industries that utilize diatomite as a filtering agent. About 23 percent of the diatomite produced in the United States is used as a filler, carrier, or extender in products that need additional bulk such as paints, paper, plastic, and insecticides (Hartwell and Schreck, 1963, p. 532). About 6 percent is used as an insulator for both heat and sound (Hartwell and Schreck, 1963, p. 532). The remaining 23 percent is used for miscellaneous purposes. From 1960 through 1962 the United States had an average annual production of 482,202 tons of diatomite, which was about 33 percent of the world production. Average value per ton has increased from about $15.70 in 1932 to $50.72 in 1963. Prices per ton in 1963 were $62.26 for filtration, $49.91 for insulation, $137.00 per ton for abrasives, and $50.07 for filler (Petkof, 1964, p. 490). Presumably this was the price for unprocessed pit-run material. Average price per ton of processed bagged diatomite for the following uses in less than carlots during 1958 was as follows: filter aid, $139; paint and polish fillers, $150; paper fillers, $105; insecticide carriers, $95; and matches and acetylene tanks, $115. Diatomite sold for $43.50 per ton in carlots for insulation, $230 per ton for catalyst support aggregate, and $175 per ton for dehumidifiers (Otis, 1960, p. 280).

In 1963 California was the leading diatomite producer in the United States, followed in order by Nevada, Washington, Maryland, Arizona, and Oregon.

Diatomite deposits form in both marine and fresh water and there is no difference in the commercial application of diatomite from the two types of deposits. All the deposits in Washington accumulated

in fresh water. They range in age from Miocene to Recent. In the western part of the State the deposits are mostly associated with peat bogs (Skinner and others, 1944, p. 20). East of the Cascade Mountains diatomite accumulated in lakes and ponds that existed at various places on the basalt plains of the Columbia Basin during the outpouring of the Yakima Basalt. Many of the diatomite occurrences in Washington are similar to those found at many other places in that the diatoms apparently fluorished in areas of volcanic activity. The silica that the diatoms used to make their shells probably came from water that dissolved it from nearby volcanic rocks.

Diatomite deposts are known in 18 of Washington's 39 counties (fig. 40). Three of these counties—Kittitas, Grant, and Adams Counties—have had production. The U.S. Geological Survey (Katz, 1914, p. 448) reported the first diatomite production from Washington in 1914. No statistics were given at that time and very few have been published since. Production has been almost continuous since 1914, and most of it has come from Kittitas and Grant Counties.

The largest diatomite area in the State is in the Squaw Creek drainage basin in south-central Kittitas County, mostly in Tps. 15 and 16 N., and Rs. 19, 20, and 21 E. (fig. 40, Nos. 10–15). The diatomite was deposited in a fresh-water lake that was formed when lava flows of the Yakima Basalt dammed a stream valley (Mackin, 1961, p. 21). This diatomite bed is generally 5 to 17 feet thick, is poorly stratified, and is irregularly jointed. The joints and fractures were formed by movements of the earth's crust after the diatomite was deposited. Yellow iron staining is common as an impurity along the joint planes in the upper part of the deposit, where groundwater has transported iron from the overlying basalt flows and deposited it in the diatomite. Nodular masses of yellowish-green to black opal are present in the diatomite, but they are considered by J. H. Mackin to be insignificant so far as contamination is concerned (p. 9 of unpublished report "Diatomite Deposits of East-Central Washington," prepared in 1946 for the Land Department of the Northern Pacific Railway Co.). Moisture content varies but is generally around 20 percent.

Several companies have produced diatomite from this area, the last one being the Dicalite Division of Great Lakes Carbon Corp. Other companies that have been active are the Kittitas Diatomite Co., Majestic Diatomaceous Earth Co., American-Japanese Silica Co., and Great Western Silica Co. Production in the area was terminated in the late 1950's when the United States Army included the deposits in the area of the Yakima Firing Range. An estimate made for the purpose of determining the value of the diatomite taken in the Army condemnation suit indicated that there are well over 3 million dry tons of strippable reserves with a possible 75 million tons of total reserves in the Kittitas County diatomite deposits.

The Quincy diatomite deposits in Grant County (fig. 40, Nos. 2–8) are similar in composition and origin to the Squaw Creek deposits. They have been mined since about 1945 by Dia-cousti-lite Products Co., Inc., and the Quincy Corp. (known since 1953 as the Kenite Corp.). These deposits are located in Tps. 17 and 18 N., Rs. 23 and 24 E. The deposits in T. 18 N., R. 23 E. were flooded by a rising water table brought about by the irrigation of surrounding land through the development of the Columbia Basin irrigation project.

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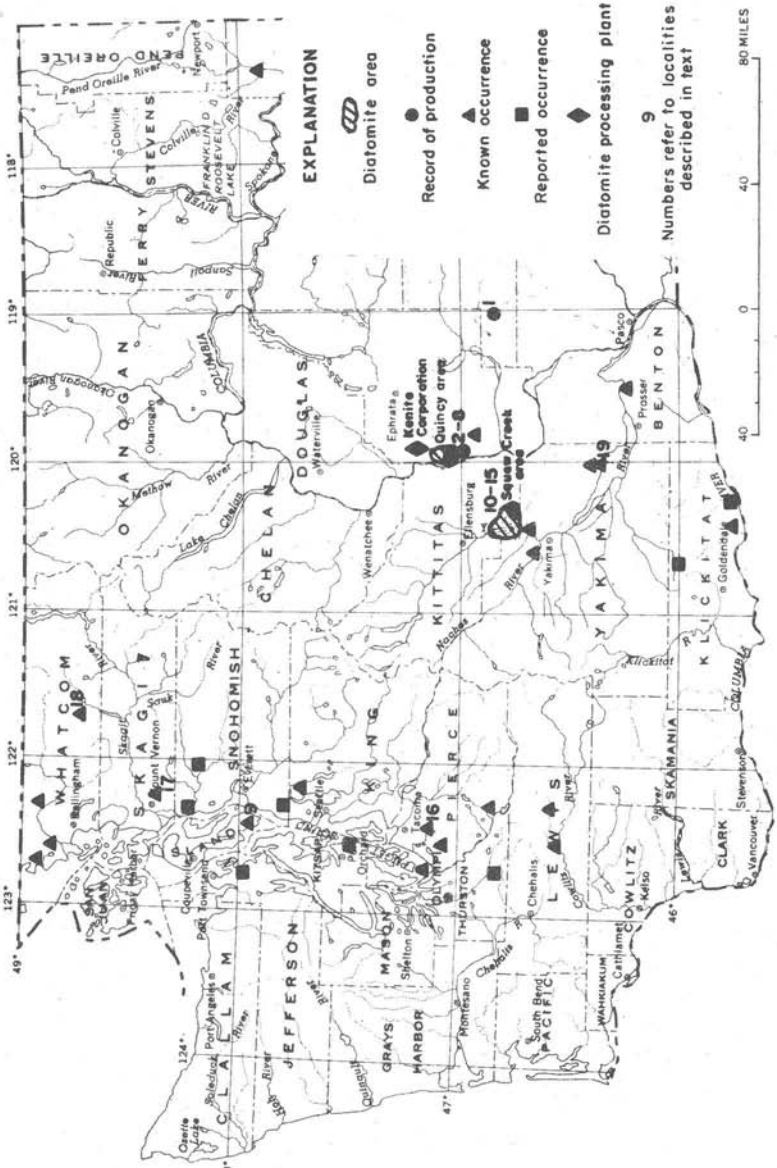

FIGURE 40.—Diatomite in Washington.

An estimated 1.5 million tons of diatomite owned by the Kenite Corp. became waterlogged and thus unusable (U.S. Court of Claims, 1964). This forced Kenite to seek new reserves, which they found on the south slope of the Frenchman Hills anticline in sec. 8, T. 17 N., R. 24 E. No estimate is available of reserves at Kenite's new property on the Frenchman Hills anticline.

Most of Washington's production has come from the deposits mentioned above. These are the only ones on which data on reserves are available. Many other diatomite deposits are known in the State. Among these are a deposit in Adams County, 10 miles east of Othello (fig. 40, No. 1); one in Island County, near Maxwelton (No. 9); one in Pierce County, 2 miles west of Parkland (No. 16); one in Skagit County on Nookachcamp Creek (No. 17); one in Whatcom County, 2 miles west of Baker Lake (No. 18); and one in Yakima County, near Sunnyside (No. 19). Other lesser known occurrences are shown on figure 40. Analyses and filter-aid tests made on material from 19 deposits in Washington are given in a publication by Skinner and others (1944), to which the reader is referred. Additional data on the diatomite deposits of the State are available in reports by Valentine (1960) and Mackin (1961); also in an unpublished report by J. H. Mackin.[1]

Although Washington has substantial resources of diatomite there are some serious problems that face the diatomite industry in the State. Diatomite deposits occur in several localities in the State, but Washington's principal known resources are in the Squaw Creek and Quincy areas.

In the Quincy Basin a rise in the water table as a result of irrigation has caused the abandonment of one deposit. Extension of irrigation to other areas could similarly affect other deposits. The Squaw Creek deposits cannot be worked at present because they are within the Yakima Firing Range. Inasmuch as they are on the extreme edge of the range there is a possibility that sometime in the future these deposits may be made available for exploitation.

Looking into the future, Washington's diatomite resources could become a very important export item. According to Otis (1960, p. 280) there are no diatomite producing countries in the Far East. If locks are installed at all of the dams below the Wanapum Dam on the Columbia River, the principal diatomite deposits of the State would be easily accessible to tidewater transportation and overseas export.

FELDSPAR, MICA, AND OTHER PEGMATITE MINERALS

(Including Some Nonpegmatite Sources of Feldspar and Mica)

(By F. G. Lesure, U.S. Geological Survey, Washington, D.C.)

Feldspar, mica, and quartz are the chief pegmatite minerals that have potential economic importance in Washington. Beryl, columbite-tantalite, and lepidolite have been found up to now only in small and generally noncommercial amounts in a few pegmatites. Other minerals such as apatite, garnet, tourmaline, various phosphates, and uranium minerals are only of mineralogical interest. Sporadic

[1] Diatomite deposits of east-central Washington. (Prepared for Land Department, Northern Pacific Railway Co., 1946.)

prospecting and a little mining have been done on the pegmatite deposits in the State. Total production, valued at a few thousand dollars, includes 700 pounds of sheet mica from Chelan County, a few tons of scrap mica from Skagit County, and a few thousand pounds of beryl from Stevens County. Resources of feldspar and scrap mica may be large, but known resources of sheet mica, beryl, columbite-tantalite, and lithium minerals are small or none.

PEGMATITES

Pegmatites are coarsely crystalline igneous rocks generally found as lenticular or tabular bodies in metamorphic rocks or associated with large granitic intrusions. Individual mineral grains range in length from an inch or less to many feet, and a large variation in grain size within a single pegmatite body is common. Pegmatites are composed mostly of feldspar, quartz, and mica. The most common accessory minerals are garnet, tourmaline, apatite, and beryl; many other less common pegmatite minerals are rich in cesium, lithium, molybdenum, niobium, rubidium, scandium, tantalum, thorium, tin, tungsten, uranium, yttrium, zirconium, and the rare earths. The many rare and unusual minerals found in some pegmatites make them favorite collecting sites for mineralogists and rockhounds.

In many pegmatites the minerals are more or less evenly distributed throughout, but in others the minerals are segregated into certain layers or parts of the body called zones. These zones can sometimes be mined selectively to recover the desired minerals by hand sorting and are, therefore, important economically.

In general, zones are successive shells, complete or incomplete, that commonly reflect the shape or structure of the whole pegmatite body. Where best developed, the zones are concentric about an innermost zone or core (Cameron and others, 1949, p. 14). According to accepted practice, the zones from the outermost inward to the core are called border zone, wall zone, and intermediate zones.

The structure of some zoned pegmatites is complicated by the presence of two other types of pegmatite units: fracture fillings, which are generally tabular masses of later minerals that cut previously formed zones, and replacement bodies, which are masses of later minerals that have taken the place of earlier formed minerals.

Recent studies have increased the general knowledge of the occurrence, origin, and economic importance of pegmatite deposits (Cameron and others, 1949; Jahns, 1955), and studies made during World War II have helped improve techniques of prospecting and exploration (Stoll, 1950; Page and others, 1953; Norton and Page,1956).

FELDSPAR

Feldspar is the general name for a group of aluminum silicate minerals that contain varying amounts of potassium, sodium, or calcium. The feldspars are important rock-forming minerals and constitute nearly 60 percent of many igneous rocks. The principal potassium feldspars are orthoclase and microcline, which have the same chemical composition ($KAlSi_3O_8$) but different crystal form. The sodium-calcium feldspars, called plagioclase, form a complete series of minerals that range in all proportions from pure $NaAlSi_3O_8$

(albite) to pure $CaAl_2Si_2O_8$ (anorthite). Natural orthoclase and microcline generally contain 10–25 percent $NaAlSi_3O_8$ and plagioclase generally contains 5–15 percent $KAlSi_3O_8$. Intergrowths of orthoclase or microcline with albite are called perthite, which is common in pegmatites.

The potassium feldspars and the more soda-rich forms of plagioclase are the types generally mined. Until recently much of the feldspar produced was perthite, which is commonly concentrated as very large crystals in certain zones in pegmatite bodies. Today finer grained pegmatite and granite are mined in bulk, and a mixture of potassium and sodium feldspar is recovered by milling and flotation. In 1963 about 67 percent of the feldspar used was from flotation concentrates, 17 percent was from handsorting, and 16 percent was from feldspar-rich sand (Cooper, 1964a, p. 496). In 1957 these figures were 42, 46, and 12 percent, respectively.

The average price of crude feldspar was $10.06 per long ton in 1963 and $9.51 in 1960 (Cooper, 1964, p. 495). The average price of ground feldspar was $12.28 per short ton in 1963 and $13.40 in 1960. From 1956 to 1963 about 55 percent of the feldspar sold in the United States was used in glass, 30 percent in pottery, 5 percent in enamel and 10 percent in other ceramic uses, scouring soaps, and abrasives. The United States is self-sufficient in feldspar production capacity. There is an increasing shortage of high-grade potassium feldspar, but there is also an increase in use of lower grade and finer grained materials through milling and flotation. The largest production comes from North Carolina, California, and Connecticut. Other important producing States include Colorado, Georgia, Maine, New Hampshire, South Dakota, and Virginia. There is no recorded production of feldspar from Washington, but material from several deposits has been used in ceramic tests. Resources of feldspar may be large but have not been investigated thoroughly because of the lack of a local market. Until a local demand develops, the long distance to potential buyers makes feldspar mining unlikely.

In recent years, various materials have been used in the glass and ceramic industries as substitutes for feldspar. Chief among these are nepheline syenite, aplite, talc, pyrophyllite, and blast furnace slag (de Polo, 1960, p. 286). Most nepheline syenites contain too much iron oxide for use in glass, but a deposit in Ontario, Canada, that is low in iron is mined extensively. The syenite bodies in northern Okanogan County contain more iron-rich minerals than the Ontario deposits, but beneficiation might produce an acceptable product.

MICA

The principal mica minerals are muscovite (white mica), biotite (black mica), and phlogopite (amber mica). All have a perfect basal cleavage and form crystals that can be split into thin sheets having various degrees of transparency, toughness, flexibility, and elasticity. The micas are common minerals, but only muscovite is mined extensively in the United States.

Two types of mica are sold: sheet mica, which must be relatively flat, free from most defects, and large enough to be cut into pieces 1 square inch or larger; and scrap mica, which is all mica that does not meet sheet mica specifications and is generally ground to a powder.

Small sheets of untrimmed mica of poorer quality that can be punched or trimmed into disks 1 inch or larger in diameter are classified as punch mica and are also included in the general term sheet mica. Sheet muscovite is an important insulating material in the electronic and electrical industries. Built-up mica made from very thin sheets and reconstituted mica made from scrap can be substituted for larger sheet mica for some uses. The principal uses of scrap mica are in the roofing, wallpaper, rubber, paint, and other industries.

Sheet-quality muscovite is obtained from the large crystals scattered throughout unzoned pegmatites or concentrated in certain units of zoned pegmatites. The value of sheet mica depends on the color, size, structure, and quality of the natural crystals. Reddish brown or ruby mica brings a higher price than green mica. Mica that is clear and flat is more valuable than mica that is stained (contains inclusions of foreign matter between the sheets) or is bent and cracked. The manner in which the crystals are obtained by mining and the care and skill of preparation are also important factors affecting the value.

Details of the preparation and classification of mica and trade practices of the industry are too elaborate to discuss here. The best published reference is by Rajgarhia (1951), whose knowledge of the subject was based on a lifetime of experience in the sheet mica business in India, which supplies most of the world's mica. Excellent references written in the United States are by Skow (1962), Montague (1960), and Jahns and Lancaster (1950).

The discontinuous nature of most mica concentrations, the great range of quality of material, the expense of mining, and the large amount of hand labor needed for preparation generally limit domestic sheet mica mining to periods of very high prices. Since the end of the Government purchasing program in June 1962, little sheet mica has been mined in the United States. Most of the recent production of sheet mica has been from North Carolina, New Hampshire, and South Dakota. Only a few hundred pounds of sheet mica has been produced in Washington.

Many pegmatite deposits contain only scrap mica, and a large amount of scrap is produced during the mining, trimming, and fabricating of sheet mica. Scrap mica is also recovered from mica schists and as a byproduct from the mining of feldspar and clay. Most of the mica mined in the United States is scrap mica. Resources of scrap mica in mica schists and in residual clay deposits may be extensive in Washington. Production of scrap mica in Washington has come largely from biotite schists in Skagit County, but other deposits of mica schist probably could be used.

The selling price of mica can range from only a few cents per pound for punch or scrap to many dollars a pound for large sheets of the best quality. In 1958 the price schedule under the U.S. Government purchase program for sheet mica of superior quality (termed "good, stained, or better") ranged from $17.70 per pound for the smallest size to $70 per pound for the largest size. Prices in 1958 for India mica of similar grade ranged from $2.50 to $37 per pound (Montague, 1960, table 8). Prices for sheet mica in 1964, as quoted in the Engineering & Mining Journal Metal and Mineral Markets, ranged from $0.07 a pound for sheets 1½ inches across to $8.00 a pound for sheets 8 inches or more across. Scrap mica is valued at the mine at $20 to

$30 per short ton. Most of the buyers of mica are in the eastern United States.

QUARTZ

Quartz is the most common mineral found in nature and is the principal source of silica (SiO_2) and silicon (Si). It is an important constituent of pegmatite, forming nearly pure cores of many zoned deposits. Deposits described as pegmatitic quartz have been mined in Washington (Valentine, 1960, pp. 91–93; Carter and others, 1962, pp. 33–57). These and other quartz deposits are described in the chapter on silica.

BERYL

Pegmatitic beryl is the principal source of beryllium in the world today, but recently discovered low-grade deposits of nonpegmatitic beryllium minerals will probably become important sources of beryllium in the future. Beryllium is discussed in a separate chapter, but the pegmatitic occurrences of beryl in Washington are given in table 16, and the localities are shown on figure 41.

COLUMBITE-TANTALITE

The mineral series columbite-tantalite is found generally in small amounts in granite and pegmatites. Columbite is composed of niobium (columbium) oxide and various amounts of tantalum, iron, and manganese; tantalite is principally tantalum oxide and various amounts of niobium, iron, and manganese. The only known occurrence of columbite-tantalite in Washington is in the Calispell Peak area, Stevens County, where a few pounds were recovered from the Railway Dike.

Niobium and tantalum are closely related elements that tend to occur together. Besides columbite-tantalite, other mineral series containing these elements include tapiolite-mossite, pyrochlore-microlite, fergusonite-formanite, and euxenite-polycrase (Parker, 1963; Barton, 1962, pp. 16–21). Concentrations of these minerals are rare and largely restricted to pegmatites, alkalic rocks, carbonatites, granites, and placer accumulations. Both metals have certain physical properties that make them useful in high temperature metallurgy, electronics, and other applications (Barton, 1962, pp. 3–13). The United States is the largest consumer of these metals but is only a minor producer. Placer deposits in Idaho have been an important source in recent years (Parker, 1963; 1964).

LITHIUM MINERALS

The chief lithium minerals produced from pegmatites in the United States are spodumene, a lithium aluminum silicate that is used mainly as a source of lithium compounds; lepidolite, a lithium mica that is used in glass and ceramics; and amblygonite, a lithium aluminum phosphate, for which there is only a sporadic market.

Today most of the lithium minerals used come from large deposits that have been developed in North Carolina, Quebec, and Southern Rhodesia. Lepidolite has been reported near Riverside, Okanogan County, Washington. Another reported occurrence in the Trinity

Tunnel in Chelan County (MacPhee, 1926) is probably an error (Valentine, 1960, p. 62).

Prices of lithium minerals are based on quantity of lithia (Li_2O) in the ore and are determined by direct negotiation between buyer and seller. Prices quoted per unit of Li_2O (a unit being 1 percent of 1 short ton or 20 pounds) ranged from $11 to $12 for spodumene and lepidolite ores in 1955 (Schreck, 1961, pp. 56, 59).

PEGMATITES IN WASHINGTON

Pegmatite occurrences have been reported in 11 counties in Washington, but few detailed descriptions of individual deposits are available. Such information as is known is summarized in table 16. The localities are shown in figure 41. The pegmatites are associated with large granitic intrusions and areas of metamorphic rock. In Chelan County, bodies of alaskite, granodiorite, and granophyric pegmatite are found in the border phases of the Chelan batholith south of Lake Chelan (Waters, 1935, pp. 772, 781), and dikes of quartz-oligoclase pegmatite cut mica gneiss in the Trinity Tunnel in the Cascade Range (Richarz, 1933, pp. 759–761).

Pegmatite dikes are also widely distributed through the Kaniksu batholith and adjacent metamorphic rocks in the Metaline quadrangle of Pend Oreille County (Park and Cannon, 1943, p. 27). Pegmatite dikes and veinlets are also found in great abundance in the granitic rocks on Mount Spokane in Spokane County. They are particularly abundant in an alaskitic rock which occurs as masses of varying size within the main granitic body.

TABLE 16.—*Reported pegmatite and other occurrences of mica and feldspar in Washington*

[Number of deposit refers to locality on fig. 41]

Deposit	Location	Minerals	Description	Reference
CHELAN COUNTY				
Chelan Falls (34)	1½ miles from Chelan Falls	Mica	700 pounds "gold" mica in sheets as large as 2 by 3 inches produced from "kidney" in a ledge 3,000 feet long, before 1897.	Colles, 1905, p. 332; Sterrett, 1923, p. 330; Glover, 1936, p. 66; Valentine, 1960.
Chelan Tunnel (32)	Near highway tunnel, sec. 20, T. 27 N., R. 21 E.	Feldspar	Rather pure segregations and dikes in Swakane Gneiss.	Valentine, 1960.
Goman (33)	SW¼NW¼ sec. 5, T. 26 N., R. 21 E., in Winesap Canyon.	Muscovite	Sheets as large as 3 inches but averaging 2 inches in diameter. Pegmatite exposed in cut 4 by 6 feet.	Huntting, 1943, p. 53; Valentine, 1960.
Indian Creek (31)	NW¼ sec. 22, T. 26 N., R. 19 E	Mica	Unknown quantity of practically pure mica schist.	Valentine, 1960.
Lake Creek (26)	NW¼SE¼ sec. 5, T. 27 N., R. 15 E	Beryl	Pegmatite exposed in road cut	Do.
Mad River (29)	Mad River north of Leavenworth	Mica	Reported deposit, no details	Do.
Trinity Tunnel (Royal Development Co.) (27).	SE¼SE¼ sec. 21, T. 30 N., R. 16 E	Feldspar	Quartz-oligoclase pegmatite dikes cut mica gneiss.	Richarz, 1933, pp. 759–761; see also Valentine, 1960.
Tumwater Canyon (30)	Sec. 21, T. 25 N., R. 17 E	Mica	Large mass of friable schist about 90 percent muscovite. May be the best commercial possibility of scrap mica in Washington.	Valentine, 1960.
Wenatchee Lake (28)	Sec. 20, T. 27 R., R. 17 E., on south side of road on north shore of lake.	Feldspar	Pegmatite containing 70 percent feldspar reported to occur in quantity.	Do.
Winesap (33)	Secs. 1, 2, and 11, T. 26 N., R. 21 E	do	Pegmatite dikes containing pink feldspar	Do.
FERRY COUNTY				
Belcher mine (12)	Sec. 6, T. 37 N., R. 34 E	do	Dike 20 to 60 feet thick; chunks of pure feldspar as much as 1 foot in diameter on dump.	Kelly and others, 1956, p. 29; Valentine, 1960.
Gemini (13)	11.7 miles northeast of Nespelem, at Cache Creek Summit.	Beryl(?)	No details available	Valentine, 1960.
Kettle Falls (10)	Vicinity of Kettle Falls	Beryl	Small crystals in pegmatite; now under water.	Do.
Sherman Creek (11)	Sec. 17, T. 36 N., R. 36 E., north valley wall of Sherman Creek.	Muscovite	Small pegmatite exposed in cut 25 feet long, 8 feet wide, and 8 feet deep. Mica bent, ruled, stained, "A" structure. Scrap quality. Other pegmatite bodies reported in the area.	Valentine, 1960; W. C. Stoll, 1943, written communication.
KING COUNTY				
Tunnel Creek (25)	2 miles up Hope Lake trail from old road at Scenic.	Mica	Trail cut through pegmatite containing books of mica 1 inch or more in diameter.	Valentine, 1960.

TABLE 16.—*Reported pegmatite and other occurrences of mica and feldspar in Washington*—Continued

[Number of deposit refers to locality on fig. 41]

Deposit	Location	Minerals	Description	Reference
OKANOGAN COUNTY				
Kruger-Elleneham Mountains (17)	Secs. 3, 9 and 16, T. 40 N., R. 26 E.	Microcline, nepheline.	Small intrusions of nepheline syenite; usable product might be obtained by milling and flotation.	Campbell, 1939; Valentine, 1960.
Mazama (18)	On property of Sidney Walter near Mazama.	Mica	Large sheets of muscovite reported	Valentine, 1960.
Nespelem (14)	On property of R. F. Hudnutt near Nespelem.	Beryl	No description available	Do.
Riverside (16)	A few miles west of Riverside	Lepidolite	Pegmatite(?) dike containing lepidolite reported.	Do.
Tunk Creek (15)	SW¼SE¼ sec. 8, E½NW¼ sec. 17, T. 35 N., R. 27 E.	Mica, feldspar.	Pegmatites containing orthoclase and muscovite.	Do.
PEND OREILLE COUNTY				
Blueslide (4)	Sec. 10, T. 35 N., R. 43 E., near Blueslide.	Beryl	Small beryl crystals in pegmatite	Do.
Blueslide (3)	5 to 10 miles from Blueslide	Mica	Reported occurrence of large sheet muscovite.	Do.
Coffin (1)	Sec. 16, T. 38 N., R. 42 E.	Feldspar	Pink feldspar makes up 70 percent of the granite county rock. Commercial product might be obtained by flotation.	Do.
Cusick (5)	Sec. 35, T. 35 N., R. 45 E., 8 miles east of Ruby.	do	White microcline in lens 30 feet long and 1 to 3 feet thick.	Shedd, 1924, p. 127; Wilson, 1927, p. 10; Glover, 1936a, p. 44; Valentine, 1960.
Lost Creek (2)	Sec. 20, T. 36 N., R. 43 E., on southeast side of Granite Peak, on Lost Creek.	Beryl	1 crystal in pegmatite	Valentine, 1960.
SAN JUAN COUNTY				
Deer Harbor (21)	West shore of Deer Harbor on Orcas Island.	Albite (sodic feldspar).	4 pegmatite dikes, 25 to 60 feet thick. Tests show material suitable for porcelain ware.	McLellan, 1927, pp. 172–174; Wilson, 1927, pp. 2–8.
SKAGIT COUNTY				
Nooksack (20)	In bed of tributary to Nooksack River, NW¼ sec. 10, T. 36 N., R. 7 E.	Plagioclase feldspar.	2 or more dikes, 1 foot thick	Valentine, 1960.
Skagit talc products (19)	Secs. 11 and 14, T. 36 N., R. 11 E.	Mica	Biotite schist associated with talc deposits. Small tonnage shipped in 1947 and 1948 to roofing concern for scrap mica. Similar deposit in sec. 15 near Alvard talc body.	Do.
SNOHOMISH COUNTY				
Barclay Creek (24)	Ridge between Barclay and Lewis Creeks, elevation 3,000 feet.	Muscovite	Books 8 inches across in contact zone between schist and granodiorite.	Weaver, 1912, p. 42.

Del Campo Peak (22)	4 miles west of Monte Cristo near Del Campo Peak.	Beryl	Reported large deposit from which 2 crystals were sold.	Glover, 1936, p. 119; Valentine, 1960.
Jones prospect (23)	North side of stream near north center sec. 11, T. 28 N., R. 10 E.	do	Reported occurrence; no details	Valentine, 1960.
SPOKANE COUNTY				
Fish Lake (39)	SW¼ sec. 33, T. 24 N., R. 42 E., in Spokane, Portland and Seattle Ry. cut.	Beryl, feldspar.	Pegmatite dike 5 feet thick	Do.
Freeman-Mica area (37, 38)	Southeast of Spokane in T. 23, 24, 25 N., R. 44, 45 E.	Scrap mica, clay.	Muscovite in residual kaolin deposit could be recovered as byproduct of clay beneficiation. Similar deposits are being worked in Idaho.	Glover, 1936, p. 66; Kelly and others, 1956, pp. 40–42; Valentine, 1960.
Mica Peak (36)	Center T. 24 N., R. 45 E	Feldspar, mica.	Pegmatite dikes containing considerable feldspar and scrap mica.	Glover, 1936, p. 44; Valentine, 1960.
Mount Spokane (35)	East slope of Mount Spokane	Mica	Mica locally abundant in schist east of contact with quartz monzonite.	Valentine, 1960; Weissenborn, 1965, oral communication.
Mount Spokane (41)	South and west slopes of Mount Spokane.	Beryl	Myriad of small pegmatitic quartz-feldspar veinlets cut alaskite bodies in quartz monzonite on south and west slopes of Mount Spokane; some pegmatites in quartz monzonite. Beryl crystals found in pegmatites in alaskite in two areas on south slope. (See also chapter on nonpegmatitic resources of beryllium.)	Weissenborn, 1964, written communication.
STEVENS COUNTY				
Calispell Peak area (6)	Secs. 28, 29, 32, T. 34 N., R. 42 E	Beryl, feldspar.	Several pegmatite dikes and stringers contain beryl.	Valentine, 1960; Wright, 1952, written communication.
Kettle Falls (8)	SW¼ sec. 11, T. 36 N., R. 38 E	Beryl	Small ¼-inch crystals in 5-inch pegmatite sill in quartzite; now under water.	Valentine, 1960.
Marcus (7)	Near Marcus, 5 miles from Colville River.	Mica	Reported deposit; no details	Do.
Railway Dike (6)	NW¼ sec. 33, T. 34 N., R. 42 E., on ridge 1 mile south of Calispell Peak.	Beryl, feldspar, mica, columbite-tantalite.	Concordant zoned pegmatite, 25 to 50 feet thick, 1,050 feet long, beryl and rare columbite-tantalite concentrated in quartz-muscovite wall zone; coarse-grained perthite intermediate zone contains rare beryl. Workings include 8 trenches and a 350-foot adit.	Valentine, 1960, Huntting, 1956, p. 356; Puffett, 1954, written communication.
Waitts Lake Granite (9)	T. 31. N., R. 39, 40 E	Feldspar	Porphyritic granite containing feldspar phenocrysts 3 inches long. Feldspar might be recovered by flotation.	Valentine, 1960.
WHITMAN COUNTY				
Bald Butte (40)	Secs. 1, 2, 11, 12, T. 13 N., R. 45 E	do	Medium-grained dikes of quartz-orthoclase-microcline-muscovite pegmatite, 5 to 10 feet thick and as much as ½ mile long cut quartz diorite.	Hoffman, 1932, pp. 646–647; Valentine, 1960.

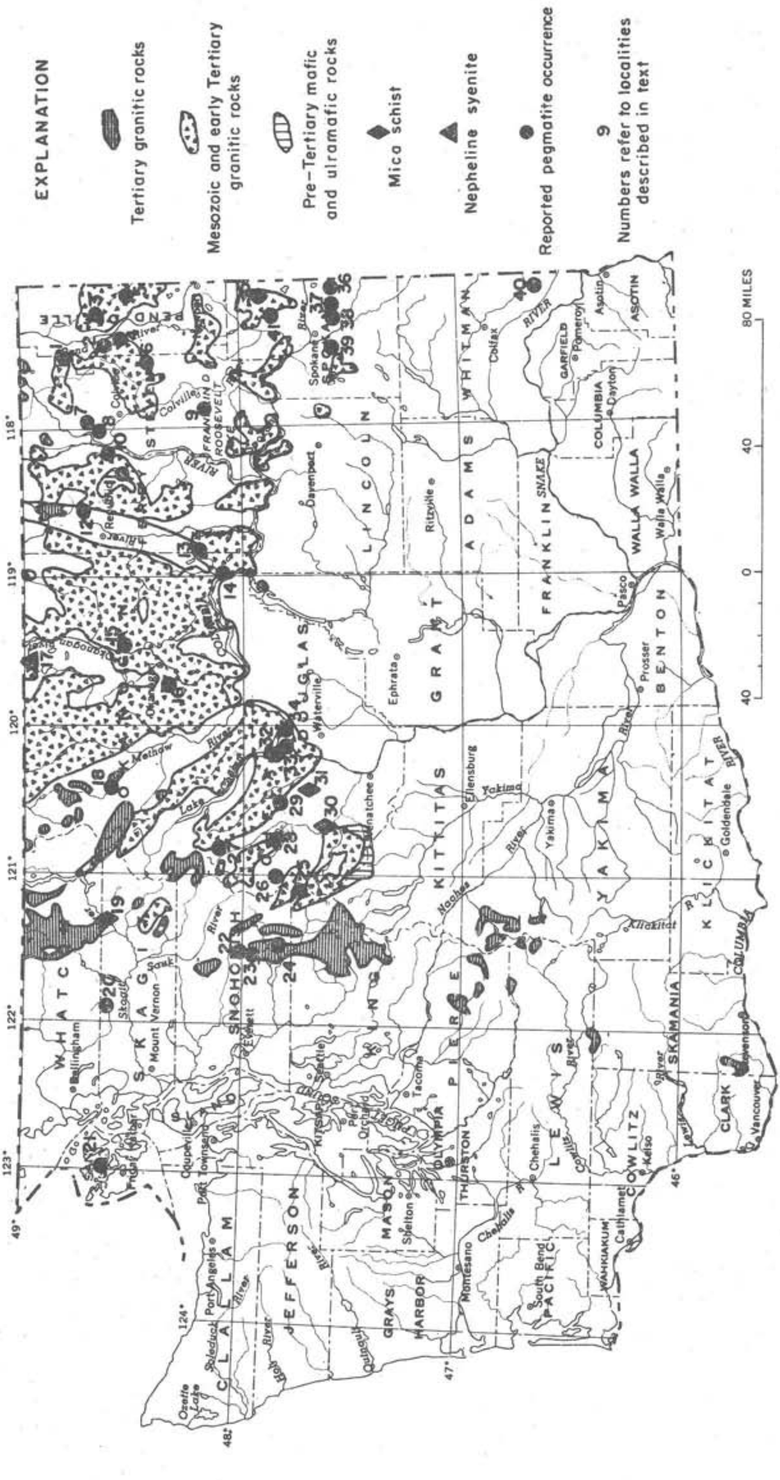

FIGURE 41.—Pegmatite minerals in Washington.

FLUORSPAR

(By R. E. Van Alstine, U.S. Geological Survey, Washington, D.C.)

Fluorspar is a mineral aggregate or mass containing enough fluorite (CaF_2) to be of commercial interest; certain grades are essential to the chemical, aluminum, steel, and ceramic industries. Hydrofluoric acid made from fluorspar is the basis for increasingly important fluorine chemicals. For the aluminum industry the fluorspar is converted to aluminum fluoride and synthetic cryolite, used as the electrolyte in the reduction of alumina to aluminum metal. In the steel industry fluorspar serves as a flux in basic open-hearth, basic-oxygen, and electric furnaces. Fluorspar is invaluable in the manufacture of opal container glass and enamels for coating steel or cast iron.

Fluorspar is marketed as acid, ceramic, and metallurgical grades; domestic prices for these grades range from about $45 to $30 per short ton. Acid-grade fluorspar, used for making hydrofluoric acid, contains at least 97 percent CaF_2. Specifications for ceramic-grade fluorspar depend partly on the buyer's requirements; generally acceptable material contains at least 93 to 95 percent CaF_2. Metallurgical-grade fluorspar must contain more than 60 percent effective CaF_2, which is determined by subtracting from the total CaF_2 2.5 percent for each percent of SiO_2. Of the record 736,000 short tons of fluorspar consumed in the United States in 1963, about 58 percent was acid grade, 37 percent was metallurgical grade, and 5 percent was ceramic grade (Ambrose, 1964, p. 523). The higher priced, higher grade products generally are concentrates from flotation mills.

The United States is the world's leading consumer of fluorspar and was for many years the largest producer. Since 1952, however, imports have exceeded production and, in 1963, amounted to about 555,000 tons—approximately 2¼ times the domestic production (Ambrose, 1964, pp. 519, 526, 527). About 80 percent of the 1963 imports came from Mexico, which since 1956 has been the leading fluorspar producer; Spain and Italy supplied almost all of our other fluorspar imports.

Although fluorite has been found in many different types of rocks and mineral deposits, most commercial deposits are in limestone, silicic volcanic rocks, or granitic rocks. The deposits are principally veins or replacement bodies formed at low temperatures and pressures near the earth's surface. The fluorspar occurs in banded cryptocrystalline form resembling chalcedony, in crusts, in globular aggregates with radial fibrous texture, and in granular and massive forms. More than 80 percent of the fluorspar produced in the United States has come from the Illinois-Kentucky district, where fluorite-calcite veins and bedding-replacement deposits are localized along and next to faults in limestones, shales, and sandstones. In the replacement deposits, sphalerite is associated with the fluorite and constitutes an important source of zinc, cadmium, and germanium.

Eighteen fluorite localities in Washington, including mineralogic occurrences that represent types of deposits productive in other States, are shown on figure 42 and described briefly in table 17. They are restricted to north-central and northeastern Washington, in the Cascade Mountains, Okanogan Highlands, and Selkirk Mountains (Culver, 1936, pp. 17–18). The fluorite occurs mainly in Paleozoic

limestone and argillite, in Mesozoic and Tertiary granitic intrusives, and in Tertiary volcanic rocks. It is found in veins at most of the localities; in pegmatite at the Electric City (No. 6), Sanpoil (No. 9), and Spokane deposits (No. 13); in lenses at the Riverside deposit (No. 5); in a replacement body at the Read deposit (No. 15); and possibly in a pipelike body in the Sheridan area (No. 11).

Only 382 tons of fluorspar has been shipped from Washington deposits (McDougall and Roberts, 1958, p. 502), all from a vein in granite at the Mitchem deposit (No. 12) in Ferry County. This production, made during war periods of strong demand and high prices, was as follows: 60 tons in 1918, 152 tons in 1940–42, and 170 tons in 1945–46. The 1918 production was hand-picked acid-grade material, and the rest was of metallurgical grade. In 1945, Western Minerals Co. operated a small heavy-media process plant at the Mitchem deposit and shipped the product to steel plants (Davis and Greenspoon, 1947, p. 1438).

The five fluorite occurrences (Nos. 2, 3, 4, 5, and 12) that lack base-metal sulfides and precious metals, three of which are in granite and are associated with chalcedony, appear to be epithermal deposits. This type of deposit formed at relatively low temperatures and pressures and has been the source of most of the fluorspar production in western United States.

Fluorite occurs at 13 of the 18 localities as a minor mineral in deposits worked or explored for metals, but has not been recovered as a by-product. The Sheridan area (No. 11) appears to be the most promising source of fluorspar from metalliferous deposits. The volcanic rocks here contain as much as 30 percent fluorite in certain zones at the American Flag deposit (Glover, 1936, p. 44). They are also host rocks for an incompletely explored pipelike body of purplish fluorite, cockscomb quartz, and muscovite, with some pyrite and chalcopyrite, at the Silver Bell deposit (Pearson, R. C., 1965, oral communication). The Sheridan area is about 35 miles southwest of the Rock Candy fluorspar mine, near Grand Forks, British Columbia. It is the fluorite locality in Washington closest to this former center of production. A vein zone at the Canadian locality yielded more than 42,000 tons of fluorspar concentrates intermittently between 1918 and 1942 and contains large fluorspar resources (Bartley, 1961).

The consumption of fluorspar is growing steadily in the United States, and when prices of imported fluorspar increase as the foreign demand and costs of production and shipping rise, new sources of domestic fluorspar will be sought. Search for additional fluorspar deposits in Washington may well be directed to a belt extending north-northeast from Grand Coulee Dam. In this belt, seven of the fluorite localities (Nos. 6–12), including the only productive deposit, are along or within 8 miles of the Republic graben or its southward projection to the Columbia River (Staatz, 1960; 1964, pp. 54–59). This down-dropped structure is characterized by relatively young intrusive and extrusive rocks and by faulting that occurred from early Tertiary until at least Miocene time. The graben has been mapped for 52 miles in Washington and its eastern margin extends north for another 45 miles in British Columbia (Little, 1957). In Washington, fluorite is found in Tertiary volcanic rocks at two of the above-mentioned localities. It is found in granitic rocks, presumably of the Colville batholith, at the five other localities. (See table 17.) However, some

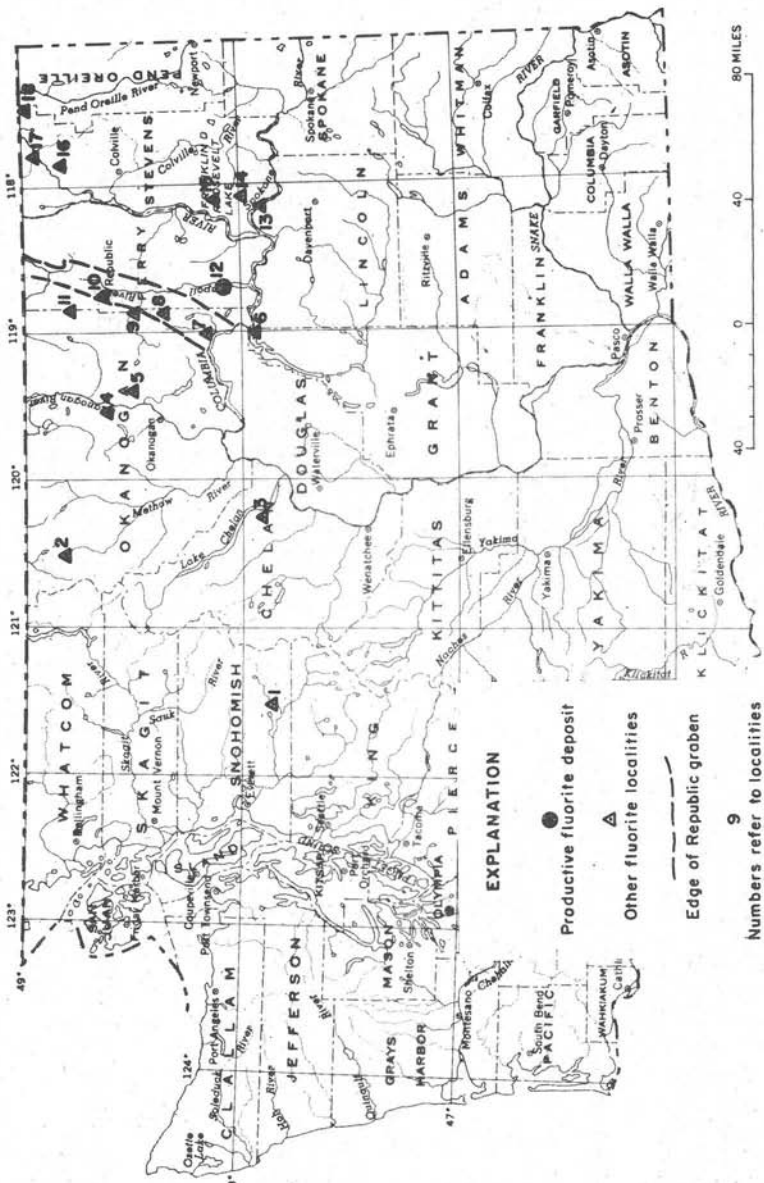

FIGURE 42.—Fluorspar deposits in Washington.

TABLE 17.—*Fluorite localities in Washington*

Index No. on fig. 42	Name	Location	Description	References
1	Index district (Ethel Consolidated Mining Co. copper deposit).	Secs. 34 and 35, T. 28 N., R. 10 E.	Quartz-calcite-bornite vein with minor fluorite, in granodiorite.	Weaver, 1912, pp. 65, 76.
2	Three Pinnacles-Lost River deposits.	Sec. 25, T. 38 N., R. 19 E.	Veins of fluorite and chalcedony 2 to 12 inches thick in granite.	Valentine, 1960, p. 42.
3	Slide deposit	E½SW¼ sec. 17, T. 28 N., R. 21 E.	Seven veins of fluorite and chalcedony, each less than 6 inches thick, in a zone about 300 feet thick; in granite.	Valentine, 1960, pp. 41–42.
4	Montgomery deposits	Sec. 14(?), T. 36 N., R. 26 E.	Thin veinlets of flourite in limy argillite	Valentine, 1960, p. 42.
5	Riverside deposit	About 5 miles east of Riverside, in T. 35 N., R. 27 E.	Small lenses of fluorite in gneiss and schist	Do.
6	Electric City molybdenum-silver-gold deposit.	Sec. 14, T. 28 N., R. 30 E.	Pegmatite lenses with quartz, fluorite, molybdenite, and pyrite; in granite of the Colville batholith.	Huntting, 1956, p. 269.
7	Apache silver deposit	Sec. 27, T. 31 N., R. 30 E.	Quartz-pyrite-galena veins with minor fluorite, in granite of the Colville batholith.	Pardee, 1918, pp. 65, 69, 79.
8	Park City district (Ramore, Gladore, and Wasco lead-silver-zinc-copper deposits).	Secs. 14 and 10, T. 33 N., R. 31 E.	Veins and shear zones with quartz, sulfide minerals, and minor fluorite, calcite, and sericite in quartz monzonite of Colville batholith.	Pardee, 1918, p. 99; Staatz, 1964, pp. 67–69.
9	Sanpoil uranium deposit	Sec. 25, T. 35 N., R. 31 E.	Pegmatite with radioactive violet fluorite and samarskite, in granite of the Colville batholith.	Huntting, 1956, p. 353.
10	Republic district (Republic gold-silver-selenium deposit).	NE¼ sec. 12, T. 36 N., R. 32 E.	Chalcedony-calcite vein with sulfide minerals in Tertiary flows, breccias, and tuffs; fluorite abundant in some specimens.	Thomson, 1913, p. 676; Bancroft, 1914, pp. 146, 147; Huntting, 1956, p. 124.
11	Sheridan area (Zalla M, American Flag, and Silver Bell silver-gold-copper deposits).	SW cor. T. 38 N., R. 32 E. and SE cor. T. 38 N., R. 31 E.	Quartz-calcite-chalcopyrite veins with minor fluorite in Tertiary volcanics; as much as 30 percent fluorite in some zones; possibly pipelike body at Silver Bell deposit.	Patty, 1921, p. 199; Glover, 1936a, p. 44; Valentine, 1960, p. 42.
12	Mitchem deposit	NE¼ sec. 24, T. 30 N., R. 32 E.	Steep northwest-trending vein in granite of the Colville batholith, consisting of green, purple, and colorless fluorite with calcite, chalcedony, and rare pyrite; high-grade lenses, but about 50 percent CaF_2 across mining widths; clay along walls. Deposit is small; less than 2 feet thick.	Pardee, 1918, p. 127; Burchard, 1933, pp. 21–23; Davis and Greenspoon, 1947, p. 1438.
13	Spokane molybdenum deposit	NE¼SE¼ sec. 32, T. 28 N., R. 37 E.	Quartz vein and small pegmatites with molybdenite, pyrite, pitchblende, gold, muscovite, and fluorite; in Cretaceous quartz monzonite.	King, Moore, and Hinrichs, 1952, p. 8; Purdy, 1954, pp. 31–34; Becraft and Weis, 1963, pp. 67–69.
14	Germania tungsten deposit	Sec. 13, T. 29 N., R. 37 E.	Quartz veins in Cretaceous quartz monzonite, generally less than 3 feet thick, with ferberite, scheelite, pyrite, molybdenite, chlorite, and minor fluorite.	Weaver, 1920, p. 128; Culver and Broughton, 1945, pp. 77–79; Becraft and Weis, 1963, pp. 70–71.
15	Read iron deposit	NW¼ sec. 14, T. 30 N., R. 37 E.	Replacement deposit in Paleozoic limestone next to granite of Cretaceous batholith; minor fluorite with magnetite, chalcopyrite, wollastonite, tremolite, quartz, garnet, and rare scheelite.	Shedd, Jenkins, and Cooper, 1922, p. 45; Broughton, 1945, p. 14.

16	Phalen Lake molybdenum deposit.	Near center T. 38 N., R. 39 E.	Quartz veins and lenses in granite and argillite, with molybdenite, pyrite, and minor fluorite; accessory fluorite in granite near contacts with schist and quartzite.	Weaver, 1920, p. 128; Huntting, 1956, p. 273.
17	Northport district (Coyote and Mountain View silver-lead-zinc deposits).	Secs. 26 and 35, T. 40 N., R. 39 E.	Quartz veins with sulfide minerals and minor fluorite in argillite and limestone cut by granite.	Weaver, 1920, pp. 313-314; Huntting, 1956, pp. 239, 330; Valentine, 1960, p. 42.
18	Northport district (Frisco Standard lead-zinc-silver-gold deposit).	SW¼NW¼ sec. 12, T. 40 N., R. 42 E.	Quartz veins with sulfide minerals and rare fluorite in Paleozoic black slate, locally schist.	Park and Cannon, 1943, pp. 61-62; Huntting, 1956, p. 326; Valentine, 1960, p. 42.

granitic rocks previously regarded as part of the Mesozoic Colville batholith are actually Tertiary in age (Staatz, 1964, pp. 25, 58). In British Columbia the productive Rock Candy fluorspar mine is in Tertiary syenite about 4 miles west of the northward extension of the fault zone bordering the graben (Dolmage, 1929; Little, 1957). The fluorite and geologically young structural and igneous features apparently are at least spatially related throughout this belt.

Search for fluorspar might also be successful near other areas in north-central and northeastern Washington where fluorite occurrences are shown. Areas near upper Mesozoic or Tertiary granitic intrusive bodies and structures near the margins of uplifts and depressions might be examined, because such geologic features are related to most of the productive fluorspar deposits of western United States. As fluorite in some of the western deposits is very fine grained and resembles chalcedony, with which it is commonly associated, deposits of this type of fluorite may have been overlooked in Washington and elsewhere in the western United States. The color of the fluorite is highly variable, and the characteristic purplish or greenish colors, glassy luster, octahedral cleavage, and crystal forms may be lacking. This fine-grained fluorite generally can be distinguished readily from associated chalcedony because the fluorite is softer and noticeably heavier.

GEM MATERIALS

(By M. D. Dasch, U.S. Geological Survey, New Haven, Conn.)

Gem materials are minerals and closely allied naturally occurring substances that are used as gem stones and ornamental stones. Gem stones are used for personal adornment; ornamental stones are used for objects such as vases and statuettes, and for other decorative purposes.

Gem materials generally possess one or more of three major qualities: beauty, determined by personal taste; durability, determined by hardness and toughness; and rarity. Portability, fashion, and the degree to which workmanship has enhanced the natural attributes of the raw material are, likewise, important qualities. "Precious" gem materials, by definition, exhibit all three major qualities of beauty, durability, and rarity, whereas "semiprecious" materials possess only one or two of these attributes. Diamond, emerald, ruby, and sapphire have long been esteemed as the precious gems. ("Precious opal," a variety of opal, must be considered semiprecious, for it lacks durability.) Although precious gem stones have been reported from two Washington localities, semiprecious gem materials account for all the recorded production.

Gem materials are sought by both amateur and professional collectors in Washington. The gem industry is operated almost entirely by individuals and small lapidary firms, rather than by large companies. Production is sporadic and production data, recorded in annual volumes of Mineral Resources of the United States (U.S. Geological Survey, 1885–1923; U.S. Bureau of Mines, 1924–31) and the Minerals Yearbook (U.S. Bureau of Mines, 1932–62), are incomplete. The available statistics are summarized in the following paragraph.

The discovery of precious opal in Whitman County led to the first significant recovery of gem materials in Washington. Production from this locality in 1891 totaled more than $5,000. The area was worked during 1892 and 1893, but reliable production figures were not recorded. Annual gem stone production in Washington between 1906 and 1921 probably never exceeded $1,000; the few figures available indicate that it fluctuated considerably, ranging from $50 to $850 a year. Although gem materials were mined in Washington during the 1920's and 1930's, the Federal Government did not record production from individual States. H. C. Dake estimated that the State produced about $85,000 of agate and other quartz minerals in 1938, about $90,000 in 1939 and about $140,000 in 1940. These figures were published in the U.S. Bureau of Mines Minerals Yearbooks for those years but are not official government statistics. From the early 1940's through the middle 1950's, Washington generally ranked third or fourth in the Nation in the production of gem materials; the value of production was not published during this period. Since 1955, Washington has ranked sixth, seventh, or eighth in the country. Annual production from 1956 through 1960 was estimated at $75,000 a year. In 1961, the most recent year for which gem stone statistics are available, Washington ranked fifth in the Nation in agate production and seventh in total gem production.

Opalized wood and quartz varieties, such as agate, chalcedony, jasper, and silicified wood, account for nearly all the gem stone production in Washington since the early part of the century. Production has risen markedly in the State during the last 30 years, due to the increased interest in lapidary work. Some of the good gem stone localities, such as the opalized wood areas of Saddle Mountain, the Rattlesnake Hills, and the Roosevelt area, are on private land. Many owners, however, have opened their properties to collectors for a small fee.

Gem materials of Washington have been discussed by many authors, among them: Dake, Fleener, and Wilson, 1938; Glover, 1949; Valentine, 1949 and 1960; Kauffman, 1952; Schlegel, 1956 and; Sinkankas, 1959. These references have been used as a basis for the locality descriptions that follow. Additional references to both old and new Washington localities occur in semitechnical gem and mineral journals, such as The Mineralogist.

Washington gem materials are discussed alphabetically in the following summary, which includes the better known collecting localities. For a given commodity, the localities are described in physiographic sequence, beginning with the Coast Ranges (the Olympic Mountains and the Willapa Hills) and ending with the Columbia Plateau in southeastern Washington. The physiographic subdivisions and the approximate locations of deposits numbered in the text are shown on figure 43.

ANTHOPHYLLITE

Anthophyllite is a rather soft, magnesium-iron silicate that occurs in crystalline schists. Fibrous specimens of this characteristically clove-brown, less commonly dark green, mineral may furnish material suitable for cat's-eyes, a type of cabochon exhibiting an opalescent effect. In Skagit County, somewhat serpentinized ferrous anthophyllite is exposed on the James Stephens property (fig. 43, No. 42)

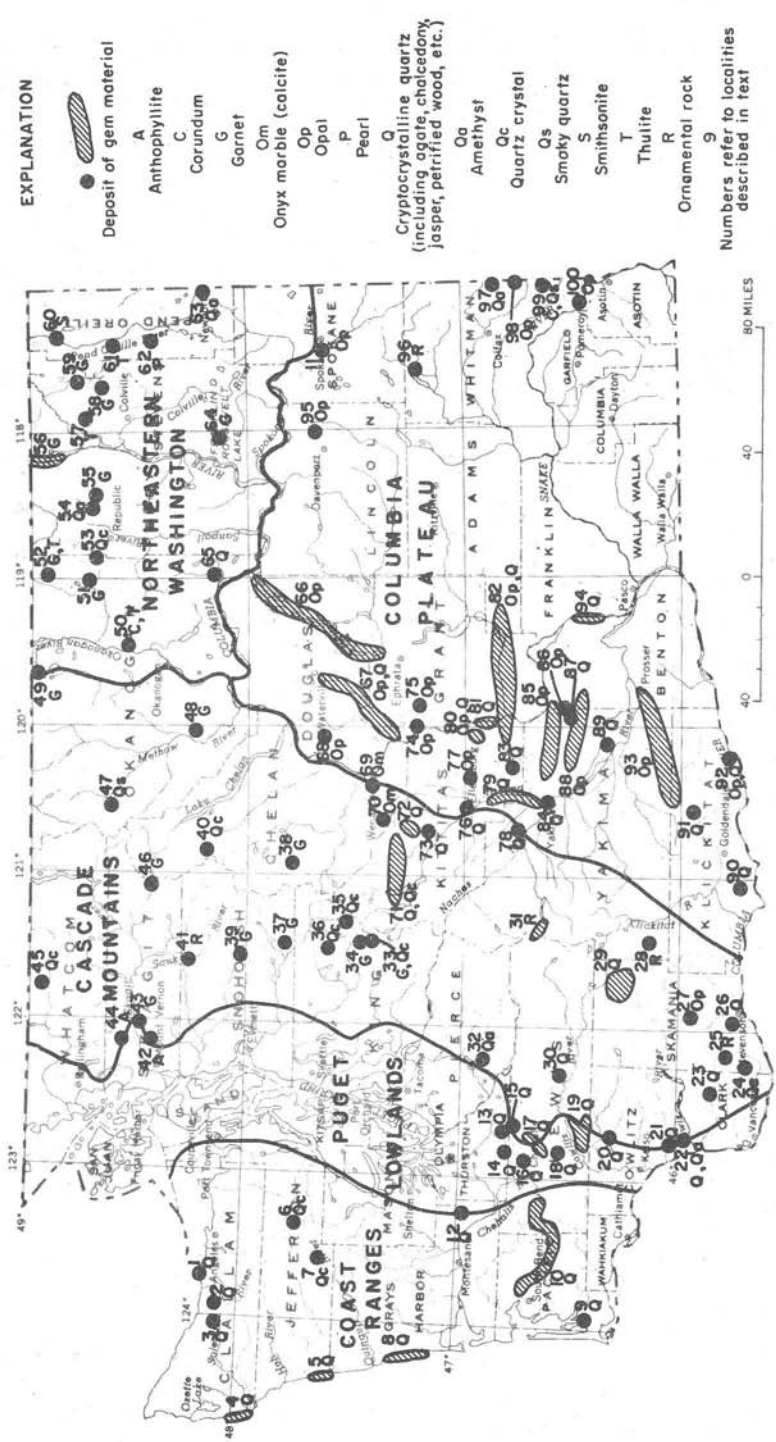

FIGURE 43.—Gem materials of Washington.

and on the Scott property (No. 44). The dark green material has been called "nephrite jade" and "jadeite." Anthophyllite on the James Stephens property has been mined by the Northwest Talc and Magneisum Co.; a few pounds of it was sold under the name of jade by the original owner (Valentine, 1960, p. 44).

CORUNDUM

Corundum, aluminum oxide, has a hardness exceeded only by diamond. The mineral is a common constituent of metamorphic rocks, some igneous rocks, and the gravels derived from them. Transparent precious gem varieties of corundum have been reported in the State: *ruby*, colored deep red by chromium, and *sapphire*, commonly colored blue by titanium and iron. Small crystals of sapphire and ruby occur near a thulite deposit on Tunk Creek (No. 50), Okanogan County (Valentine, 1960, p. 45). On Bald Butte (No. 99), Whitman County, corundum crystals as much as an inch in diameter are found in the soil; some of them are of gem quality (Valentine, 1960, p. 132).

GARNET

Six silicate minerals with similar physical properties, crystal forms, and a basic chemical formula, in which certain elements replace one another to form a series, are collectively called garnet. Clear, flawless garnet of attractive color may be faceted as a semiprecious gem. Well crystallized, relatively pure garnet is mined from bedrock or dredged from placer deposits for use as an abrasive. The factors of hardness and availability create a demand for this relatively inexpensive abrasive material. Many Washington occurrences are described in the literature simply as massive garnet; that is, the type of garnet is not specified. Three specific minerals, however, have been reported in the State. *Almandite*, a deep red or brownish red iron aluminum silicate, occurs in a variety of igneous and metamorphic rocks, especially mica schist. It is the garnet mineral most commonly used as an abrasive. Good specimens can be faceted as a transparent red gem. *Grossularite*, calcium-aluminum silicate, has a wide range of color—green, red, yellow, or cinnamon brown. This garnet, which generally occurs in metamorphosed crystalline limestone, may also be of gem quality. *Pyrope*, a magnesium aluminum silicate that ranges in color from ruby red to nearly black, is the most popular of the gem garnets. It occurs in igneous and metamorphic rocks such as peridotite and serpentine.

Washington garnet localities are scattered through the Cascade Mountains and the northeastern part of the State. Production of gem garnet was reported in 1939, but no information is available concerning its source. The occurrences listed below warrant further investigation before their potentials as producers of gem or abrasive garnet can be determined.

Cascade Mountains

Skagit County.—Garnetiferous schist forms the country rock at the Last Chance mine (No. 43). Pyrope crystals, up to three-fourths inch in diameter, are disseminated through a schist south of Cascade Pass (No. 46).

Snohomish County.—On Vesper Peak (No. 39), a lens composed primarily of grossularite measures 50 by 70 feet; some of the garnet is of gem quality. Garnet crystals, as much as an inch in diameter, are associated with epidote and hornblende on the north side of Barclay Creek (No. 37).

King County.—Two potential sources of abrasive garnet are the Guye Peak locality (No. 34), where a zone of massive garnet occurs along a contact between granodiorite and metamorphic rock, and the Denny Mountain locality (No. 33), where a massive garnet zone is as much as 10 feet in thickness.

Chelan County.—Small garnet crystals are abundant in mica schist near Gaynor (No. 38).

Okanogan County (western part).—At the Four Metals mine (No. 49) garnet occurs in a 2- to 7-foot quartz vein, but probably is not present in sufficient quantity to be of commercial importance. Garnetiferous beds, some over 10 feet in thickness, are exposed along a contact zone at Texas Creek (No. 48) (Valentine, 1960, pp. 42, 43).

Northeastern Washington

Okanogan County (eastern part).—At Buckhorn Mountain (No. 52), massive grossularite comprises much of the tactite associated with a magnetite ore body; the garnet has potential use as an abrasive. Muscovite schist at the Moore prospect (No. 51) contains almandite.

Ferry County.—Evidence from test pits shows that massive garnet occurs near a limestone-intrusive rock contact at the Midnight Mountain locality (No. 55).

Stevens County.—Reddish brown garnet crystals are common in outcrops of the Orient Gneiss along the Kettle River (No. 56). In some zones abrasive garnet may be present in commercial quantity. A 4-foot zone of massive grossularite is exposed along a limestone-granite contact at the Magma mine (No. 59). Massive red garnet is reported at the Bon Air School locality (No. 58), and massive red-brown garnet is found along a limestone-granite contact at the Deer Trail Monitor mine (No. 64) (Valentine, 1960, p. 43).

ONYX MARBLE

True onyx is a form of chalcedony, a variety of quartz. Unfortunately, the term "onyx" is often used to denote a special kind of limestone deposited by cold springs; popularly it is called onyx marble or Mexican onyx. Limestone is composed primarily of the mineral calcite, a calcium carbonate. In contrast with quartz, which is hard and relatively durable, calcite is a soft mineral, generally unsuitable for use as a gem stone. Onyx marble, however, is composed of fine-grained calcite that may be fairly tough. It is used for table tops, book ends, and for other decorative purposes. Onyx marble has been reported from two localities in Chelan County: White translucent material is abundant in Number One Canyon (No. 69) west of Wenatchee (Sinkankas, 1959, p. 557). Blue, black, and buff onyx marble crops out near Blewett Pass (No. 70) (Glover, 1949, p. 18). True onyx localities in the State are described in a later section on cryptocrystalline quartz.

OPAL

Opal is a rather soft amorphous mineral; that is, it has no definite crystalline structure. It occurs in igneous, metamorphic, and sedimentary rocks. Opal is deposited in cavities and cracks as gelatinous silica, and, in many places, its formation is associated with volcanic activity. *Precious opal* has an internal play of delicate to brilliant colors called opalescence. *Common opal,* which may be white or one of many colors, does not exhibit opalescence. Precious opal, common opal, and extensive fields of opalized wood (wood replaced by opal) are found throughout the Columbia Plateau. Precious opal from Washington has been cut into cabochons, whereas common opal and opalized wood have been cut and polished for use as book ends and other decorative objects.

Fire opal, a transparent yellow, orange, or red variety of precious opal, has been reported as cavity fillings in volcanic rocks along Moses Coulee (No. 67), Douglas County (Valentine, 1960, p. 45). Excellent quality fire opal has also been reported from two localities within a mile of Mondovi (No. 95), Lincoln County (Valentine, 1960, p. 46). In Whitman County, precious opal reportedly occurs on the Snake River at the Moses locality (No. 100) (Valentine, 1960, p. 46). The most famous precious opal field in the State is the Whelan locality (No. 98); it is located on the Washington-Idaho border in Whitman County. Opal was discovered here in 1890 during the excavation of a 22-foot well on the Odonnell farm. Opals occurred in a decomposed basalt and were described as ranging in size from half a pea to a hen's egg. The find generated a miniature rush, and in the summer and fall of 1891 more than $5,000 of fine material was produced. The opal was ranked at that time with the best Hungarian specimens, some of the finest in the world. The Whelan locality was worked intensively from 1891 to 1893 and for a short time in 1904; the workings were abandoned when hard rock was encountered (Glover, 1949, pp. 30–31; Sinkankas, 1959, pp. 111–112).

Common opal of green color occurs near Waterville (No. 68) in Douglas County (Sinkankas, 1959, p. 115). In Grant County, large brownish nodules of common opal are embedded in diatomaceous earth in the Quincy area (No. 75) (Sinkankas, 1959, p. 115). Massive greenish yellow common opal occurs as nodules and veinlike bodies in diatomite beds of the Kittitas region (No. 77), Kittitas County (Glover, 1949, p. 25). Opal of undetermined variety occurs as amygdales in lava buttes along the Wind River (No. 27), Skamania County (Valentine, 1960, p. 44). Common green opal is also found in basalt flows in a road cut on Highway 95 just south of Spokane (No. 11) and in an abandoned quarry near Fort Wright just northwest of the city.

Some of the most remarkable occurrences of opalized wood in the United States are found on the semiarid Columbia Plateau of Washington. The wood has been replaced by common opal, as in the well known Petrified Forest of Arizona. The opalized wood is predominantly coniferous, although replaced wood of other trees, such as elm and oak, also is common. Opalized wood observed at a single locality may represent species from both high and low elevations, indicating that the trees were transported from their original growing sites. During Miocene time, wood in swamp areas and driftwood along the

shore lines of shallow lakes were buried by normal sedimentation and by repeated falls of volcanic ash. In some places these wood-bearing beds were covered by lava flows. During or after burial, the wood was replaced by silica in the form of common opal.

Douglas County.—Logs of opalized wood are associated with basalt along the east side of Moses Coulee (No. 67) (Sinkankas, 1959, p. 115).

Grant County.—Opalized wood occurs in volcanic rock of Grand Coulee (No. 66), now inundated, and at Trinidad (No. 74) (Sinkankas, 1959, p. 115). Large, beautifully colored logs have been collected along the summit of the Saddle Mountains (No. 82) between Othello and Beverly. Exceptional specimens from this field are suitable for ring stones and brooches (Valentine, 1960, p. 45).

Kittitas County.—A large quantity of opalized and silicified wood, concentrated within an area of 6 square miles, is preserved by the State in Ginkgo Petrified Forest State Park (No. 80). Much of the wood, which ranges in size from flakes to nearly whole logs, is encased in basalt and in ash beds. The wood-bearing strata, which are about 800 feet thick, contain specimens belonging to many species, including the ginkgo tree (Sinkankas, 1959, p. 378).

Yakima County.—Opalized wood from the Barrel Springs locality (No. 86), once fashioned into arrowheads by the Indians, is suitable for cutting and polishing (Valentine, 1960, p. 45). Excellent quality wood opal occurs on Yakima Ridge (No. 85), especially near Cairn Hope Peak and on the eastern extension of the ridge in Benton County (Sinkankas, 1959, p. 115). Fine specimens also have been collected from the Rattlesnake Hills (No. 88), Yakima and Benton Counties (Sinkankas, 1959, p. 115). The Horse Heaven Hills (No. 93), which extend from Klickitat County through Yakima County into Benton County, have been described as the most productive wood opal locality in the State; collecting is exceptionally good north of Bickleton and near Mabton and Prosser (Sinkankas, 1959, pp. 114–115).

Klickitat County.—Opalized wood is concentrated between basalt layers at the Roosevelt locality (No. 92) (Valentine, 1960, p. 45).

PEARL

Pearl, an organic gem stone composed of calcium carbonate, is formed within the shells of certain mollusks (shellfish). Mollusks withdraw calcium carbon and oxygen from fresh or salt water to build their shells. If a foreign object, such as a parasitic organism or a grain of sand, becomes entrapped in the soft tissues of the animal, the mollusk deposits concentric layers of calcium carbonate around the object to prevent irritation. Continued deposition results in the formation of a pearl. Although pearl is very soft, it is highly prized as a gem stone. Generally it is white, although some specimens are faintly colored or even brown or black. Fresh-water mollusks, called mussels, live in Tacoma Creek (No. 62), Pend Oreille County. They have yielded 27 well-formed pearls of a lavender shade (Sinkankas, 1959, p. 595).

QUARTZ

Quartz, an oxide of silicon, is the most common of minerals; it occurs in nearly every rock type. It is hard and may be transparent, translucent, or opaque. Commonly it is colorless or white but may be of

any color, depending on various impurities. Quartz occurs either as coarsely crystalline varieties or as cryptocrystalline varieties. The individual crystals of coarsely crystalline quartz have the luster of broken glass. Cryptocrystalline quartz is massive; individual crystals are so fine that they cannot be resolved with a microscope. Coarsely crystalline quartz commonly is faceted as gems, whereas the numerous varieties of cryptocrystalline quartz are cut into cabochons, or cut and polished for ornamental purposes.

Three coarsely crystalline varieties of quartz found in Washington as suitable gem materials are quartz crystal or "rock crystal," amethyst, and smoky quartz. *Quartz crystal*, if relatively pure, is transparent and water-clear. Owing to its great abundance, it is the least valued of the quartz gem stones. Quartz crystal is cut into vases, crystal balls, beads, and faceted into shapes that resemble diamonds, sometimes called rhinestones. Exceptionally pure quartz crystal is used by the electronics industry; most Washington localities, however, yield quartz crystal that is presently of value only to the gem collector. *Amethyst*, a violet or purple coarsely crystalline quartz, is the most prized variety of quartz. *Smoky quartz* ranges from shades of smoky yellow and brown to nearly black; it is more common and consequently less valued than amethyst as a gem stone. Crystalline quartz occurs throughout Washington but is most common in the Cascade Mountains.

Coast Ranges

Jefferson County.—Numerous clear quartz crystals, as much as 2 inches in length, occur on Mount Anderson (No. 6) and in parts of a quartz vein on Rustler Creek (No. 7) (Valentine, 1960, p. 46).

Cascade Mountains

Whatcom County.—At Yellow Aster Butte (No. 45), quartz crystals, as long as 4 inches, fill vugs, or pockets, in quartz veins (Valentine, 1960, p. 46).

Chelan County.—Clusters of quartz crystals at the Crown Point mine (No. 40) occur in a vuggy zone in diorite (Valentine, 1960, p. 46).

King County.—Clear quartz crystals in a vuggy zone on the Clipper property (No. 35) may be pure enough to be used by the electronics industry (Valentine, 1960, p. 46). Quartz crystals line vugs and joint planes at the Denny Iron prospect (No. 33) (Valentine, 1960, p. 46). In Devil's Canyon (No. 36) clear quartz crystals up to 2 inches long are clustered in a wide vuggy zone (Valentine, 1960, p. 46).

Kittitas County.—Quartz crystals fill geodes found on the west shore of Lake Cle Elum (No. 71) (Valentine, 1960, p. 46).

Pierce County.—A quartz vein on the Siegmund ranch (No. 32) contains crystals with amethystine tips (Valentine, 1960, p. 44).

Skamania County.—Amethyst occurs on the Rainbow prospect (No. 24) (Valentine, 1960, p. 45).

Cowlitz County.—Amethyst-lined geodes, some measuring as much as 8 by 14 inches, are found east of Cloverdale (No. 22) (Sinkankas, 1959, p. 379).

Okanogan County (western part).—Large, slightly smoky quartz crystals have been reported from Early Winters Creek (No. 47) (Valentine, 1960, p. 46).

Northeastern Washington

Okanogan County (eastern part).—Large quartz crystals are exposed in workings in the Sheridan district (No. 53).

Ferry County.—Amethyst has been reported northeast of Republic (No. 54).

Pend Oreille County.—A quartz vein at the Ries locality (No. 63) contains amethyst crystals (Valentine, 1960, p. 45, 46).

Columbia Plateau

Whitman County.—Amethyst occurs in quartz zones at the Ringo locality (No. 97). Smoky quartz crystals are numerous in a sand pit at the Colton locality on Bald Butte (No. 99) (Valentine, 1960, p. 46).

Cryptocrystalline quartz varieties, especially chalcedony, jasper, and silicified wood, occur in great quantity in Washington. *Chalcedony,* which is deposited from aqueous solutions, lines or fills rock cavities. Common chalcedony is a translucent, dull gray, blue, brown, or white material. It has a waxy luster and commonly is botryoidal or mamillary in shape. Excepting the blue variety, common chalcedony is not an unusually handsome gem stone. Naturally stained varieties of chalcedony, however, are extremely popular gem materials. They are cut into cabochons or carved as ornamental objects.

Agate is a variegated chalcedony that has been colored by inclusions. The contrasting colors may be banded or irregularly distributed. Distinctive agate patterns have been given popular names: *moss agate,* for example, is typified by mosslike patterns, caused by visible impurities such as manganese oxide; *fortification agate* is characterized by distinct angular bands.

Green chalcedony, speckled with red jasper, is called *bloodstone. Plasma,* another green chalcedony, contains irregularly distributed white or yellowish spots. Reddish brown to yellowish red chalcedony is called *carnelian,* and yellow-brown chalcedony is known as *sard. Onyx* is a layered chalcedony in which straight bands of contrasting color parallel one another.

Jasper, a variety of impure and opaque cryptocrystalline quartz, is colored red by iron inclusions, but also may be yellow, blue, or green. *Jasp-agate* is light colored agate containing irregular particles of jasper. The term *petrified wood* is loosely applied to wood that has been replaced by mineral matter, commonly some form of silica. Wood that has been mineralized by a variety of quartz, such as agate or jasper, properly should be termed silicified wood. It is cut and polished for use as decorative objects, such as book ends and table tops; occasionally it is used as a unique building stone.

Varieties of cryptocrystalline quartz are found throughout the State. Chalcedony and jasper have been carried westward by rivers that drain the Coast Range and the Cascade Mountains. They have been concentrated by wave action on islands and coastal beaches of Juan de Fuca Strait, and along the Pacific Coast from the northern end of the Olympic Peninsula southward to the Oregon border. Agate, jasper, and other types of cryptocrystalline quartz are common in many stream gravels, especially those in the southern half of the State. Silicified wood is abundant on the Columbia Plateau. Cryptocrystalline quartz varieties are less common in the northeastern part of the State.

Juan de Fuca Strait and Pacific Coast

Clallam County.—Agate Beach (No. 1) on Juan de Fuca Strait is misnamed; jasper, not agate, is the common variety of cryptocrystalline quartz found here. The red jasper, distinguished in part by handsome orbicular markings, has been weathered from glacial drift and possibly from nearby basalt (Sinkankas, 1959, p. 379). Cobbles and pebbles of spherulitic jasper occur in abundance on ocean beaches of the Olympic Peninsula, especially near the mouth of the Quillayute River (No. 4). Before it was transported to the coast, the jasper was associated with manganese deposits of the Peninsula (Valentine, 1960, p. 44).

Jefferson County.—Jasper is found in beach gravels near Kalaloch and north of Queets (No. 5) (Glover, 1949, p. 19; Sinkankas, 1959, p. 379).

Grays Harbor County.—Excellent red jasper used to be common on the beaches from Point Grenville south to Copalis (No. 8) (Glover, 1949, p. 21).

Coast ranges and Puget lowland

Clallam County.—Spherulitic jasper has filled spaces between basalt pillows on the Ed. B. manganese claims (No. 3) (Valentine, 1960).

Grays Harbor County.—Pelecypod (clam and oyster) shells replaced by chalcedony weather from road banks about 10 miles north of Oakville (No. 12) (Sinkankas, 1959, p. 379).

Pacific County.—Agate-bearing gravels occur at the base of Pleistocene sands and clays near the mouth of Bear River (No. 9) (Valentine, 1960). Carnelian, agate, and common chalcedony, derived from basalts in mountains to the east, occur in almost every stream and gravel bed along State Highway 12 (No. 10) between Raymond (Pacific County) and Adna (Lewis County). This 40-mile stretch of road includes two collecting localities of special interest. One is in the vicinity of Willapa, where chalcedonic casts of pelecypod shells contain trapped water. (Masses of chalcedony with entrapped water are popularly called "enhydros" or "water agates.") In the second locality, chalcedony tinged with carnelian has replaced pelecypod and gastropod (snail) shells found near Lebam (Glover, 1949, p. 28; Sinkankas, 1959, p. 379).

Thurston County.—Agate and chalcedony occur in the Tono coal mining district (No. 14) (Valentine, 1960). Chalcedony with finely banded green chert is found in the Skookumchuck River canyon (No. 13) south of Vail (Valentine, 1960).

Lewis County (western half).—At the Fall River locality (No. 15), bloodstone and plasma fill cavities in basalt (Valentine, 1960). Cryptocrystalline quartz varieties occur over a wide area in the vicinity of Centralia and Chehalis. Agate, weathered from basalt in mountains to the east, is abundant east of Centralia (No. 16) (Valentine, 1960, p. 44). Agate, carnelian, chalcedonic nodules, and petrified wood occur in stream gravels of the Newaukum River north of Forest (No. 17) (Sinkankas, 1959, p. 379). Chalcedony and carnelian are common in gravels near Mary's Corner (No. 18), south of Chehalis (Sinkankas, 1959, p. 379), and the best known sard and carnelian deposits in Washington occur in gravels of Cedar Creek and the Salmon River near Toledo (No. 19) (Dake and others, 1938, pp. 183–184).

Cascade Mountains

Kittitas County (western half).—Agates, blue chalcedonic nodules, and geodes have been collected from extensive exposures of the Teanaway Basalt (No. 71) between Redtop Mountain and the west side of Cle Elum Lake. Of particular interest in the central part of this belt is the Cumby locality, where jasp-agate occurs as veinlets in basalt. Several hundred pounds of the material was mined and sold in 1955 (Valentine, 1960, p. 45). Agate-filled geodes and blue chalcedony have been collected at several localities in the vicinity of Liberty (No. 72) (Sinkankas, 1959, p. 378). Blue chalcedony also has been collected in Horse Canyon (No. 73) (Valentine, 1960, p. 45).

Lewis County (eastern half).—Mercury mines near Morton (No. 30) yield specimens of clear chalcedony speckled with cinnabar, the red mercury mineral (Sinkankas, 1959, p. 379).

Cowlitz County.—Agate, jasper, and brilliantly colored petrified wood are abundant at the Silver Lake locality (No. 20) (Valentine, 1960, p. 44). Enhydros occur in lava beds east of Kalama (No. 21) (Dake and others, 1938, p. 235). Chalcedony, carnelian, and fortification agate are found east of Cloverdale (No. 22) (Sinkankas, 1959, p. 379).

Clark County.—Gem-quality green plasma, some mixed with small veins of red jasper, has been produced from the Bells Mountain mine (No. 23) (Dake and others, 1938, p. 143).

Skamania County.—Cavity fillings of buff-gray chalcedony are found at the Stevenson locality (No. 26) (Valentine, 1960, p. 45). Agate, jasper, and carnelian occur over a wide area which centers around Table Mountain (No. 29) and is underlain by volcanic rocks. Similar material occurs over most of Skamania County north of a line between Mount St. Helens and Mount Adams (Sinkankas, 1959, pp. 379–380).

Northeastern Washington

Okanogan County.—Moss agate and chalcedony are found in gravels of the Nespelem River just north of Nespelem (No. 65) (Sinkankas, 1959, p. 378).

Columbia Plateau

Grant County.—A petrified forest has been reported near Palisades in Moses Coulee (No. 67) (Sinkankas, 1959, p. 378). Petrified forests also are exposed near Corfu and Smyrna in the Saddle Mountain area (No. 82) (Sinkankas, 1959, p. 378).

Kittitas County (eastern half).—Agate pebbles are found in gravels of the Columbia River for many miles downstream from Vantage (No. 81) (Sinkankas, 1959, p. 378). Silicified wood, as well as the opalized wood previously described, is preserved in Ginkgo Petrified Forest State Park (No. 80) (Sinkankas, 1959, p. 378). Lavender-blue chalcedony has been reported from near Ellensburg (No. 76) (Glover, 1949, p. 24). Onyx occurs as massive fillings in basalt of the Squaw Creek area (No. 83); earlier in the century some of it was sold to a lapidary in California (Glover, 1949, p. 24). Petrified wood is abundant in many places along the west bank of the Yakima River (No. 79) between Yakima Canyon and Roza Creek, Kittitas and Yakima Counties (Sinkankas, 1959, p. 378)

Yakima County.—A foot-thick bed of red and maroon jasper and yellow opal is interlayered with basalt flows north of Yakima (No. 84); the material is suitable for small ornaments (Valentine, 1960). Black- and brown-layered onyx was reported from the vicinity of Naches (No. 78) in 1891 (Glover, 1949, p. 32). A bed composed almost entirely of petrified wood fragments is exposed along the Sunnyside-White Bluffs road (No. 87); the wood is suitable for cutting and polishing (Valentine, 1960).

Franklin County.—Agate and jasper are common constituents of gravels that form the White Bluffs (No. 94) on the Columbia River between Ringold and Byers Landing (Glover, 1949, pp. 20–21).

Klickitat County.—Agate, carnelian, jasper, and petrified wood are abundant in an area 20 miles northeast of Goldendale (No. 91), and in another locality about 2 miles west of Warwick (No. 90) (Sinkankas, 1959, p. 378). One of the two greatest agate-producing areas in the United States during 1955 centered about Roosevelt (No. 92) (Hartwell and Blankenbaker, 1958, p. 479).

SMITHSONITE

Smithsonite is a soft brown zinc carbonate, usually associated with zinc deposits in limestone. The rather rare specimens used as gem stones have delicate yellow, green, or blue hues. They are cut as cabochons, occasionally faceted, or used for other ornamental purposes. Fine quality smithsonite occurs in the Josephine mine (No. 60) near Metaline Falls, Pend Oreille County (Sinkankas, 1959, p. 531).

THULITE

Thulite is the rose red gem variety of zoisite, a hydrous calcium aluminum silicate. This moderately hard gem stone is colored by manganese impurities. Thulite is cut into cabochons or used for ornamental objects. The four thulite occurrences in Washington are restricted to the northeastern part of the State. Two deposits occur in Okanogan County: Gem quality zoisite is associated with epidote, green garnet, and other contact metamorphic minerals at the Roosevelt mine (No. 52) on Buckhorn Mountain (Valentine, 1960); thulite occurs in lenses in hornblende schists on Tunk Creek (No. 50), and has been used for brooches and fireplace facing (Valentine, 1960). In Stevens County, a small vein of thulite has been reported from the Smoky Bullion property (No. 57), and in Pend Oreille County, small thulite crystals are found in a pegmatite at the Timber Mountain locality (No. 61) (Valentine, 1960).

ORNAMENTAL STONE

Ornamental stone with attractive patterns and colors has been produced in Washington for decorative purposes. Although not properly classed with gem materials, for convenience a few occurrences are described here. Black igneous rock, probably gabbro, crops out at Darrington (No. 41), Snohomish County. The feldspar crystals have a silky sheen that gives the rock a handsome appearance when it is polished (Valentine, 1960). Andesite, a light colored, fine-grained igneous rock in which feldspar is the predominant mineral, has been

quarried for ornamental purposes from two localities in Yakima County. At Dog Lake (No. 31), a light gray andesite, that breaks into long flat tablets of varying sizes, has been used as flagstones and patio blocks (Valentine, 1960). On Mount Adams (No. 28), a light pinkish gray andesite that splits into sheets has been used for flagstones, stone benches, and for other decorative purposes (Valentine, 1960). In Skamania County, at the head of the north fork of the Washougal River (No. 25), small blue spherulites of dumortierite, an aluminum borosilicate mineral, comprise about 2 percent of a quartz-muscovite-andalusite rock. Owing to the bright patches of blue dumortierite, the rock has possibilities as an attractive lapidary material (Valentine, 1960). Sheeted metamorphic rock in various shades of purple, red, and brown, is quarried occasionally at the Hole in the Ground locality (No. 96), Whitman County, for use as flagstones, patio paving, table tops, and benches (Valentine, 1960). Decorative stone composed of a marble-serpentine mixture was produced from several quarries (not plotted) in Stevens County about 1900.

Other gem materials, such as turquoise, chrysocolla, and diamond have been reported from Washington, but the locality information is vague and the authenticity of these occurrences has not been established.

The nature and incompleteness of the data make estimates of gem material resources impracticable. Agate, jasper, chalcedony, and silicified and opalized wood are found in Washington each year, however, and the possibility of locating abundant materials in unexploited areas of the State is excellent.

GRAPHITE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Graphite is pure crystalline carbon. It is characterized by black color and complete opacity, even on thin edges, and by its great resistance to chemical decomposition under all conditions. It is insoluble in all common chemical reagents, including boiling aqua regia, but converts slowly to carbon dioxide when heated in an oxygen atmosphere at temperatures of 600° to 700° C.

Graphite is a common and widespread constituent in many metamorphic rocks, where it generally occurs as disseminated flakes. It also is found in veins and in thermally metamorphosed coal seams. Vein deposits are rare. Most vein graphite comes from Ceylon. Lump and chip graphite from Ceylon veins is used extensively in brushes for electric motors.

Flake graphite from disseminated deposits in schists and gneisses is known in many places. Few deposits equal those of the Malagasy Republic (formerly Madagascar) in size, grade, flake size, and quality. Malagasy flake graphite is used in many parts of the world for high-quality crucibles and lubricants. "Amorphous" graphite, actually very fine-grained crystalline carbon, is mined extensively from large "baked" coal seams, particularly in Korea and Mexico. It is used in large quantities for foundry facings, in rubber manufacture, for corrosion-resistant paints, dry-cell batteries, and pencil leads, and a host of other uses that do not require extremely high purity or certain

physical characteristics such as density or particle size and shape (Lamb and Irving, 1956, pp.328–330).

Although graphite is required in a variety of uses and products, total United States consumption in peacetime has never exceeded 50,000 tons per year, and a large proportion of that is low-cost amorphous graphite. For example, in 1963, 47,000 tons were consumed; 77 percent was Mexican amorphous graphite (Drake, 1963, p. 1). In 1963, as in most years, most of the graphite consumed in the United States was imported, and most of the highest grades, and highest cost raw material, came from Ceylon and the Malagasy Republic. Between 1952 and 1963, United States producers dwindled from three to one despite extensive known resources of graphite in several States. Domestic producers have thus far been unable to compete with the quality and cost of imported graphite, and long-established habits among domestic consumers appear to preclude extensive domestic production in the foreseeable future (Cameron and Weis, 1960, pp. 226–234).

Graphite occurs in a variety of metamorphic rocks in Washington and is probably even more widespread than is presently known. However, so far as is known, graphitic rock has been sold from only one property in the State, and that was more than 70 years ago. Valentine (1960) lists 33 occurrences, which are shown in figure 44. All localities shown and descriptions provided are from Valentine (1960). Many appear to be either mineralogical curiosities or so low grade and fine grained as to be unsuited for any commercial purposes. Others are difficult to evaluate because of inadequate data regarding size, grade, and commercial type. Some probably warrant limited investigation, although the history of domestic production, the current status of the domestic industry, and the distance to major markets do not appear to favor graphite mining in Washington either at present or for many years to come.

Two flake graphite deposits in Washington may contain graphite of sufficient grade and quality to be classified as commercial types, although reserves are unknown. No. 1, in NW¼NE¼NW¼ sec. 27, T. 34 N., R. 29 E., Okanogan County, contains flake graphite in schist and gneiss. (The numbers refer to the deposits shown on figure 44.) American Graphite and Metal Corp. has mined some of this graphite and milled it at their mill in sec. 29, T. 34 N., R. 27 E. As of 1965, no graphite has been sold. No. 2, in NE¼ sec. 2, T. 38 N., R. 36 E., on the north side of Boulder Creek, Ferry County, is reported to consist of coarse-grained marble containing up to 10 percent flake graphite. The average grade of the deposit and the size of the flake graphite are unknown, but should a market develop, the deposit may warrant investigation.

A number of flake graphite occurrences may warrant further investigation if a demand develops. No. 3, in the center of sec. 16, T. 38 N., R. 4 E., Whatcom County, is reported to contain sericitic graphite schist. No. 4, on the west slope of Cultus Mountain near the center line of sec. 22, T. 34 N., R. 5 E., Skagit County, reportedly consists of both graphitic schist and massive graphite in a small fault. No. 5, in sec. 2, T. 34 N., R. 10 E., Skagit County, is described as graphite schist. No. 6, in sec. 20, T. 27 N., R. 18 E., near Wenatchee Lake, Chelan County, and Nos. 7 and 8, in secs. 17 and 20, T. 27 N., R. 20 E., on the North Fork of Potato Creek, Chelan County, are

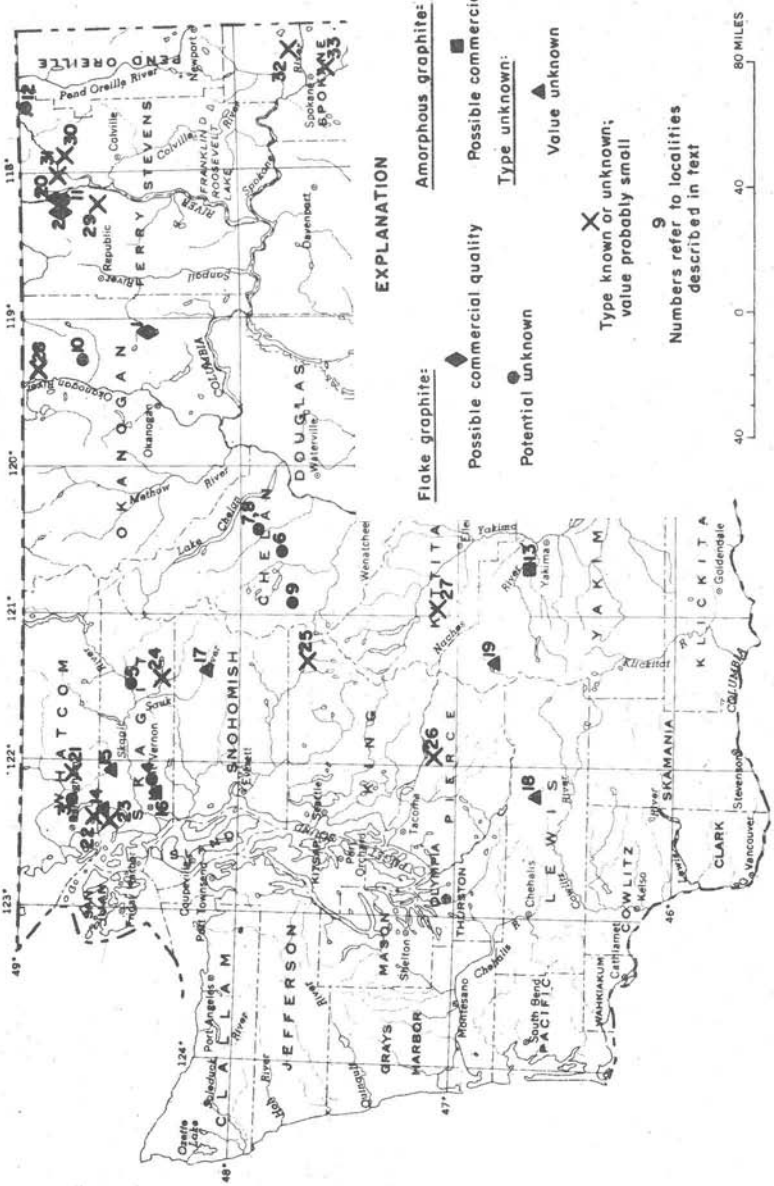

FIGURE 44.—Graphite occurrences in Washington.

also reported to consist of graphitic schists. No. 9, in Chelan County near the confluence of Nason Creek and White Pine Creek, reportedly exposes "lenses and veins" in graphitic schists. Locality 10, east of Tonasket, Okanogan County, is reportedly graphitic schist, but may be too fine grained to be of much value. No. 11, in the NE¼ NW¼ sec. 24, T. 38 N., R. 36 E., Ferry County, contains disseminated flake graphite in limestone and other rocks. A sample is reported to have assayed 7.57 percent graphite. Graphitic schist near Boundary in Stevens County (No. 12) is not precisely located, but additional information might be worthwhile.

One occurrence of amorphous graphite is reported "somewhere on Naches River west of Yakima" in Yakima County (No. 13). A sample of high-grade amorphous graphite is said to have come from there. The report appears to justify investigation.

Another occurrence (No. 14) is reportedly near Lake Samish in Skagit County. Its type is unknown but it is said that some graphite from this locality was shipped to a paint company in Tacoma, Wash., in 1890. If this is true, it is the only producer in the State.

Additional reported occurrences of unknown type are shown at several localities (Nos. 15–20). Others that are probably too small, too low grade, or otherwise unsuited for development are shown at other localities (Nos. 21–33).

HIGH-ALUMINA REFRACTORY MATERIALS

(By G. W. Thorsen, Washington Division of Mines and Geology, Olympia, Wash.)

High-alumina refractories are special-purpose refractory materials capable of withstanding high temperatures, corrosive atmosphere, and mechanical shock. They are composed largely of mullite—an artificial product formed by heating the natural high-alumina minerals kyanite, sillimanite, andalusite, dumortierite, or topaz to about 1500° C. Kyanite, sillimanite, and andalusite, which are the most widely used, have identical compositions ($Al_2O_3 \cdot SiO_2$) but different crystal structure. Dumortierite and topaz are alumina silicates with chemically-bound water and other volatile constituents. Mullite is also found as a natural mineral but is of rare occurrence.

The different mullite-forming minerals exhibit different physical properties and thus have specific applications where one performs better than another. Kyanite expands on conversion to mullite, and this expansion is used to compensate for shrinkage of other ingredients in mortar and ramming mixtures. Mullite can also be produced synthetically by calcining various mixtures of bauxite, kaolin, alumina, and silica.

Recent figures on the production and consumption of mullite-forming minerals have not been published. According to Foster (1960, p. 782), domestic consumption in 1955, including synthetic mullite, was 46,000 tons. In 1963 domestic output of kyanite materials and synthetic mullite was reported to be at an alltime high (Cooper, 1964b, p. 695). Foster (1960, p. 781) states that about half of United States consumption is met from domestic sources. Nearly all domestic production comes from deposits in the southern Appalachians.

55–883 O—66——15

Except for small quantities consumed in the glass and enamel industries or used to increase the alumina content of some fire clays, all kyanite and related minerals are used to make mullite refractories. About 90 percent of mullite refractories are used as lining in metallurgical and glass furnaces. Most of the remainder is used by the ceramic industry for kilns, kiln furniture, and saggers (containers).

According to the Engineering & Mining Journal Metal and Mineral Markets for February 8, 1965, prices for bagged kyanite on the Atlantic Coast ranged from $50 per ton for 35-mesh material to $58 per ton for 200-mesh material. Imported kyanite of 60-percent grade brought from $76 to $81 per short ton.

The high-alumina refractory minerals occur almost exclusively in metamorphic rocks. They result from the metamorphism of argillaceous sediments, particularly clay-rich quartzites (Wright, 1957 p. 275). The common mode of occurrence is as disseminated crystals or crystal aggregates in a quartzitic or schistose matrix. The particular mineral that forms depends principally on physical conditions during the metamorphic process. Kyanite is considered to be generally a result of regional metamorphism. Andalusite is more commonly associated with contact metamorphism. Sillimanite may develop from either form of metamorphism. Generally only one of the minerals is found in a given deposit, but it is not uncommon for two of them to occur together and all three are found in a few deposits (Espenshade and Potter, 1960, p. 6). Dumortierite and topaz appear to be formed largely by pneumatolytic or pegmatitic solutions derived from granitic magmas. They are not as common as the other mullite-forming minerals.

There has been no production from Washington of any of the five high-alumina refractory minerals. They are known to occur in numerous localities in northeastern Washington and in a few places in the eastern Cascades. Little information is available on other possible occurrences in the extensive metamorphic terrain of the Cascade Mountains. The known occurrences of possible commercial interest are listed below.

Stevens County.—Andalusite occurrences are common in northern Stevens County in many places near granitic contacts with argillaceous sedimentary rocks. The main andalusite-rich mica schists, however, occur intermittently for about 30 miles along a northeasterly trending belt near Colville. These rocks are considered to be either Precambrian or Cambrian in age. In only one instance (Parody Peak) has a bed been found that is substantially thicker than 100 feet. All andalusite-bearing beds follow the general northeasterly trend of the area and dip about 50 degrees to the northwest. In most places, the andalusite grains appear to make up from one-fourth to one-third of the rock and are evenly distributed within a particular bed. In most of the strata the andalusite grains appear fairly well defined but are still intergrown enough with the micaceous matrix so that they do not break free when crushed. Inclusions are abundant, generally in the form of mica and quartz; and they commonly make up an estimated 10 to 30 percent or more of a given metacryst (grain). Staurolite is also present in some areas. In places the andalusite metacrysts have apparently been replaced by sericite. In these instances, what may in the field look like a good grade of partially altered andalusite schist may be seen to contain little or no andalusite when examined

microscopically. The Stevens County deposits described, as well as the Huckleberry Mountain deposit in Pend Oreille County, were examined by the writer in the summer of 1964.

The Aladdin Mountain deposit (fig. 45, No. 3), mostly in sec. 33, T. 38 N., R. 41 E., consists of several parallel andalusite-mica schist beds that crop out on the west end of the mountain. Two of the beds are over 100 feet thick but are poorly exposed because of heavy soil and forest cover and could not be traced more than 400 feet. The andalusite metacrysts appear to be fairly typical of Stevens County deposits in both quantity and quality, containing abundant inclusions of other minerals.

Andalusite-mica schist has been found in sec. 18, T. 36 N., R. 41 E., in the vicinity of the Longshot mine (No. 2) and extending along the ridge in both directions for a total distance of over 3,000 feet. The same stratum continues on to the northeast for a total distance of almost 2 miles, averaging between 125 and 150 feet thick. This continuation contains abundant "crystallike" forms scattered throughout in the same manner as the andalusite-rich zone. Recent work, however, indicates that there is little if any andalusite in this material and that the "metacrysts" are actually extremely fine mixtures of minerals, the most abundant of which is quartz. Considerable work remains to be done in determining just how much of the Longshot deposit actually contains andalusite and the overall andalusite content.

The Meadow Creek occurrence (No. 4) probably contains the best-developed crystals of all the Stevens County andalusite deposits examined. These are as much as 2 inches long and appear to be freer of inclusions than those in the other deposits. The bed appears to be about 60 feet thick and is exposed as a low ridge for about 330 feet. It is located between Aladdin and Huckleberry Mountain in sec. 35, T. 38 N., R. 41 E., adjacent to a small granitic mass. Two minor occurrences of andalusite in schist near granitic contacts are in sec. 35, T. 37 N., R. 40 E., near Mill Creek and sec. 4, T. 35 N., R. 40 E., on Old Dominion Mountain (Valentine, 1960, p. 6).

The bulk of the Parody Peak andalusite-mica schist (No. 1) is located in sec. 22, T. 35 N., R. 38 E., about 5 miles southwest of Colville. This unit is thought to be within the Addy Quartzite of Cambrian age (J. W. Mills, written communication, 1963). This rock can be found intermittently along a distance of more than 9,000 feet; however, in much of this length the beds are less than 50 feet thick and contain calcareous interbeds. The andalusite grains are up to 2 inches long in places but more commonly are about one-third of an inch long. The grains are quite evenly distributed throughout the zones in which they are found and in many places seem to make up as much as one-third of the rock. Fine inclusions are present in variable amounts in the andalusite metacrysts and may comprise as much as 25 percent of the grains. The main andalusite-rich mass is slightly over 400 feet thick in places, wedging out against a granitic mass on one end and becoming sericitized on the other. This richest zone is quite erosion-resistant and stands out in a series of cliffs for a distance of roughly 1,200 feet.

Pend Oreille County.—Three well defined beds of andalusite-bearing schists in secs. 29 to 32, T. 38 N., R. 42 E., that range from 80 to 120 feet in thickness are on Huckleberry Mountain (No. 5). Numerous thinner beds from a few inches to 10 feet or more thick are also present

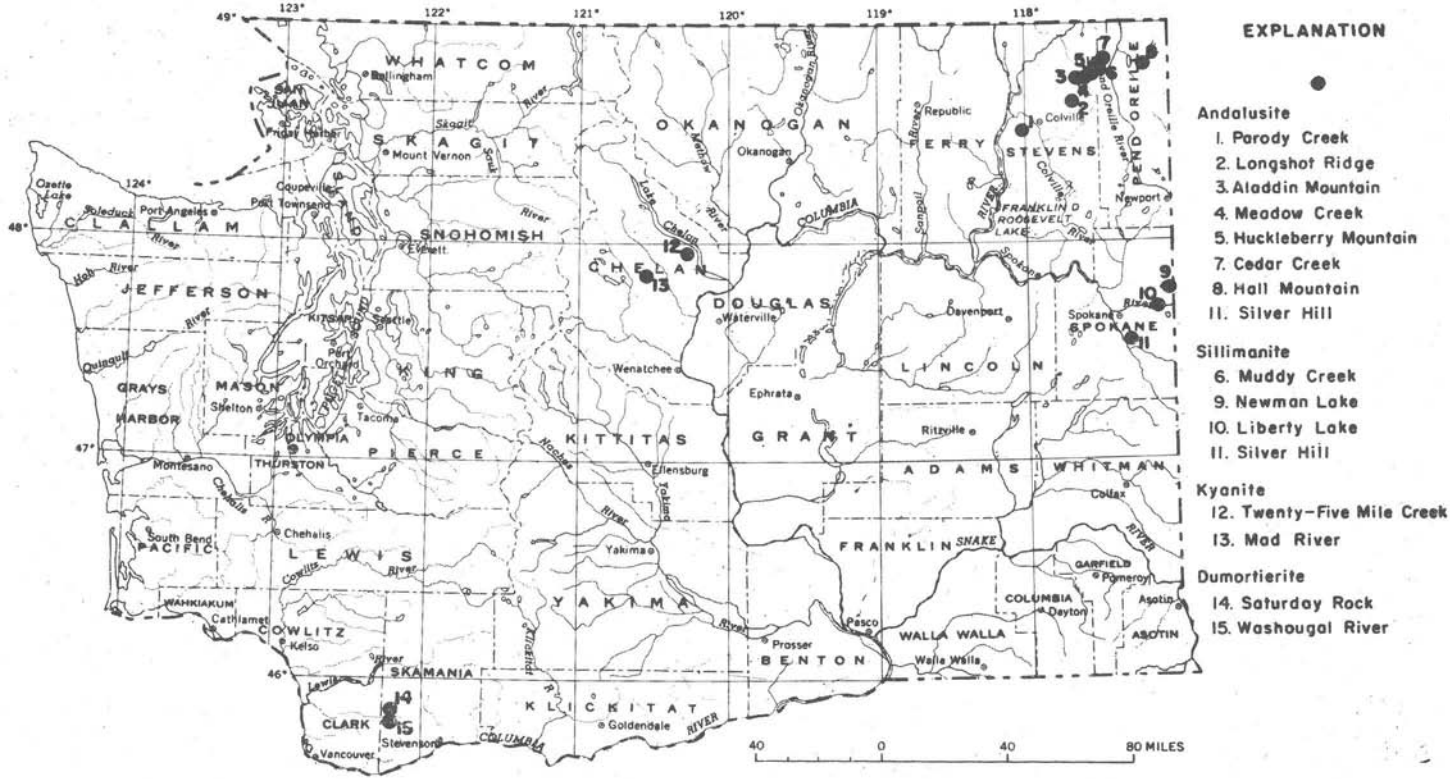

FIGURE 45.—Occurrences of high-alumina refractory materials in Washington.

across a section of many thousand feet. The three major beds are best exposed where they cross the mountain near the summit at an elevation of over 5,000 feet. The thickest of these beds is exposed fairly continuously for about 3,500 feet along strike, and the others are sporadically exposed in heavy forest cover for lesser distances. Biotite is so abundant in much of the Huckleberry Mountain material that wet, freshly broken rock appears almost black, and the andalusite metacrysts show only as vague shadowy outlines. It would be impossible to estimate the proportion of andalusite present without extensive analytical work.

Other aluminum silicate mineral occurrences are reported in several places in Pend Oreille County (Park and Cannon, 1942), and these are probably quire similar geologically to those in Stevens County. They have not been systematically examined, so their extent and overall grade are unknown. Sillimanite is found over a wide area, but the richest occurrence is reported to be in sec. 27, T. 38 N., R. 42 E., near Little Muddy Creek (No. 6) west of Ione. Here, sillimanite in the form of fine needles is considered to make up 50 percent or more of the hornfels country rock. Andalusite crystals exceeding three-fourths of an inch long are reported in the phyllite near Cedar Creek (No. 7) northwest of Ione probably in the SW¼ sec. 2. Both of these occurrences are in the Maitlen Phyllite of Cambrian age. Another andalusite occurrence is reported near a granitic contact in the NE corner sec. 15, T. 38 N., R. 44 E., on Hall Mountain (No. 8) (Park and Cannon 1943, p. 41).

Kittitas County.—Andalusite along an intrusive contact is also reported in a slate member of the Carboniferous(?) Peshastin Formation of Mount Stuart (Smith and Calkins, 1906, p. 4) in the Cascade Mountains.

Spokane County.—Both sillimanite and andalusite are present in poorly exposed Precambrian schists over an area of about one-fourth square mile on Silver Hill (No. 11), south of Spokane, Wash. (Page, 1942, pp. 180, 181). The geology of the area is very complex, and aluminum silicates of at least two separate generations are present. The sillimanite occurs as thin bands alternating with bands of biotite, quartz, and feldspar. The andalusite is associated with graphite in bands as much as several feet thick interbedded with quartzite. In the case of both the sillimanite and andalusite, there are wide variations not only in the mineral content of a given bed but also in the thickness and spacing of beds.

Sillimanite is found in the Spokane Valley sparsely disseminated in outcrops of gneiss in sec. 6, T. 25 N., R. 45 E., just west of the intersection of Trent and Parker Roads. It occurs abundantly in secs. 2 and 11, T. 26 N., R. 45 E., just east of Newman Lake (No. 9). It probably occurs in other places in the belt of Precambrian gneisses on the east slope of Mount Spokane and in the extension of this belt to the north (A. E. Weissenborn, written communication, 1965). Sillimanite is also present in gneiss and schist west of Liberty Lake (No. 10), in secs. 15, 16, 21, 22, and 26, T. 25 N., R. 45 E. (P. L. Weis, written communications, 1965).

Chelan County.—The Twenty-five Mile Creek kyanite deposit (No. 12) is largely in sec. 1, T. 28 N., R. 20 E., a few miles from Lake Chelan. The kyanite muscovite schist crops out intermittently for several hundred feet, but the actual extent is difficult to determine because of soil cover. The kyanite makes up as much as an estimated 90 percent of the rock in thin seams, but other portions are practically

barren. The kyanite crystals are as much as 2 inches long in pegmatitic zones, but the average length is probably less than half an inch (Wash. Div. Mines and Geology field notes).

An occurrence of "massive crystalline kyanite" has been reported in NW¼ sec. 16, T. 27 N., R. 18 E., Chelan County. It is stated to be in Mad River canyon (No. 13) on the east side of Maverick Peak (Valentine, 1960).

Skamania County.—Although the two Washington occurrences of dumortierite are apparently small, their proximity to each other might be indicative of a "province" worth further exploration. Both are associated with small Tertiary granodiorite masses. The occurrence mentioned at the head of the North Fork of the Washougal River (No. 15) (Schaller, 1905, p. 102) is probably on what is now known as the West Fork. In this deposit, dumortierite crystals are reported to occur as radiating clusters up to 3 mm in diameter. Specimens contain about 2 percent dumortierite and 35 percent andalusite, but the extent and overall grade of the deposit is unknown.

The Saturday Rock dumortierite deposit (No. 14) is in the SE¼ sec. 2, T. 4 N., R. 5 E., probably 5 or 6 miles north of the deposit mentioned above. In the Saturday Rock occurrence, dumortierite has apparently formed by hydrothermal alteration of disseminated tourmaline along joints. The dumortierite is erratically exposed for about a hundred yards along a road cut and may locally constitute up to an estimated 5 percent of the rock.

The andalusite deposits of Stevens and Pend Oreille Counties are probably the only known mullite-forming mineral deposits in Washington that might be considered a potential resource. While they are fairly extensive, their relative low grade and the impurity-intergrown character of the crystals would necessitate extensive beneficiation. In addition, the limited thickness and steep dip of most deposits would make large-scale mining difficult and expensive, and their distance from major users would necessitate relatively high transportation costs.

MAGNESITE

(By W. A. G. Bennett, Washington Division of Mines and Geology, Olympia, Wash.; P. L. Weis and A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Magnesium carbonate ($MgCO_3$) occurs in relatively pure form in nature as the mineral magnesite. Its theoretical composition is 47.8 percent MgO and 52.9 percent CO_2, but iron can substitute for magnesium in any amount, and most natural magnesite mined contains a small amount of iron.

Two varieties of magnesite are known. A cryptocrystalline type, sometimes known as "bone magnesite," has an earthy luster and conchoidal fracture. It is formed by alteration of magnesium silicate rocks such as serpentinite or dunite. Crystalline magnesite, with vitreous luster and perfect cleavage on individual mineral grains, is usually found associated with dolomite, although a few deposits are in limestone. The deposits were formed by alteration of dolomite or limestone, or were laid down as original sedimentary beds (Ladoo and Myers, 1951, p. 298; Comstock, 1963, p. 27). Although the cryptocrystalline deposits occur in more places, the crystalline variety generally forms the larger deposits. Both types have a specific gravity from 3.0 to about 3.1, depending on the percentage of iron, and both types

have a hardness of 3.5 to 4.5. Colors are generally white, light shades of off-white, gray, red, or brown, but magnesite has been found with a wide range of colors.

Magnesite is used chiefly as a source of magnesium oxide, or magnesia (MgO). Magnesite and, to a lesser extent, brucite ($Mg(OH)_2$) formerly were nearly the only sources of the world's magnesia, but since about 1937 they have shared this distinction with dolomite and natural and artificial brines, including sea water. Properly speaking, the term "magnesite" should be restricted to the mineral, but in the trade magnesium oxide, properly termed "magnesia," is commonly referred to as "magnesite." Two major types of magnesia are marketed. Dead-burned magnesite of commerce is the product obtained by heating magnesite or other substances convertible to magnesia to temperatures higher than 1,450° C. for a long enough time to form weather-stable granules suitable for use in refractories. Caustic calcined magnesite of commerce is the product obtained by heating magnesite or other substances convertible to magnesia to such a degree that less than 10 percent ignition loss remains and the magnesia displays absorptive capacity or activity (Wicken, 1960, p. 534).

Caustic calcined magnesite is used in the manufacture of oxychloride cements, rayon, fertilizer, insulation, rubber, and a variety of chemical compounds that contain magnesium. It is also one of several possible sources of magnesium metal (Comstock, 1963, p. 4). A little more than 10 percent of the annual consumption of magnesium oxide is in the form of dead-burned magnesite mostly for refractory use (Comstock, 1960, p. 487). Most of the magnesite mined in Washington is used to make dead-burned magnesite, principally to make refractory brick used as liners in steel-making furnaces and kilns.

World production of crude magnesite in 1963 was 9,050,000 short tons. The three largest producers were the U.S.S.R., Austria, and China, with 32 percent, 16 percent, and 11 percent of the world total, respectively. The United States produced about 528,000 short tons of crude magnesite in 1963; all of it came from two States, Nevada and Washington. Domestic production of refractory magnesia in 1963 was 713,000 short tons. About 21 percent, or 149,730 tons, was made from ores; the rest was from well brines and sea water (Williams and Stamper, 1964a, pp. 767–775). Production of magnesia and other magnesium compounds from brines has increased rapidly in the last 10 years, and as technology improves and treatment cost are lowered, production from brines can be expected to continue to grow and become increasingly competitive with crude magnesite ore.

Magnesite production in Washington began about 1916. By the end of 1932, the total production, partly estimated, amounted to 1,362,629 tons valued at $9,421,970 (Glover, 1936a, p. 63). Subsequent production figures cannot be disclosed, but the U.S. Bureau of Mines Minerals Yearbook reports that in 1962, output of magnesite from the Red Marble quarry supplied the largest part of the $3,938,000 of nonmetallic minerals produced in Stevens County. Since World War II, Washington, Nevada, and California have produced most of the crude magnesite mined in the United States, and for the past several years, Washington has been the largest producer.

Magnesite was first recognized in Stevens County, Washington, by Shedd in 1902 in the course of a survey of building stone quarries

(Shedd, 1903, p. 91). Attention was also called to the occurrence by Darton (1909, p. 23) and again by Shedd (1913, p. 126). The Finch and Allen-Moss quarries, the former worked first for limestone, were the first to produce magnesite. Because of the demand for magnesite during World War I, the Northwest Magnesite Co. and the American Mineral Production Co. were organized to quarry the deposits. The latter company through a subsidiary built a railroad from Valley to the Allen-Moss deposit. As World War I came to a close, the demand for magnesite declined, and the American Mineral Production Co. eventually went out of business. The Northwest Magnesite Co. continued operations as conditions improved and eventually gained control of the larger and more important deposits of the area (Whitwell and Patty, 1921, pp. 16–23).

The Stevens County magnesite is found as massive lenses in the Precambrian Stensgar Dolomite. Distribution within the Stensgar Dolomite is variable both in place and amount. The deposits are entirely restricted to this formation. Although there has been some controversy about the origin of the deposits, most geologists believe that they are the result of hydrothermal replacement of the dolomite by magnesium-rich solutions which may possibly have originated in nearby granitic intrusives and have obtained their magnesium from leaching of dolomite beds at depth (Campbell and Loofbourow, 1962, p. 38).

About 15 occurrences of magnesite have been found in the belt of outcrops of the Stensgar Dolomite in Stevens County (fig. 46). This has a length of about 27 miles, extending from the Colville Valley on the northeast to the Spokane Valley on the southwest. The Stensgar Dolomite has a maximum thickness of 730 feet on the northeast but averages 300 to 400 feet. Only 5 percent is exposed in outcrops (Campbell and Loofbourow, 1962, p. F–17). Stratigraphically, it lies near the top of the Deer Trail Group, which is overlain by the Huckleberry Formation, also of Precambrian age. This in turn is overlain by the Addy Quartzite of Cambrian age. Underlying units in descending order are the McHale Slate, the units of dolomite, slate, and quartzite of the Edna Dolomite, and the Togo Formation. The Precambrian formations have been compressed into many small folds and some large ones, and these have been cut by several longitudinal or strike faults. The effect has been to repeat the Stensgar Dolomite three times in the north central part of the belt and to fault it out in several places along the strike in the southwestern half of the belt (Campbell and Raup, 1962). The westernmost fault segment of the Stensgar Dolomite, 4 miles long, contains the Black Bear (No. 12), Davis (No. 11), and Midnight (No. 8) deposits (fig. 46), which are undeveloped and probably relatively small. The Red Marble segment, about 3 miles long, includes the Red Marble deposit (No. 13) and the small, early-worked Crosby deposit (No. 10) on the north. The easternmost segment of the Stensgar Dolomite begins half a mile east of the Red Marble quarry and continues for 4 miles. It includes the Double Eagle and Keystone deposits (Nos. 7 and 9), the former on the axis of a northward-plunging anticline and the latter on the west limb of a syncline. These folds and the folded fault plane that brought up the Red Marble segment presumably account for the repetition of the small isolated occurrence of the Stensgar at the Nogue deposit (No. 6).

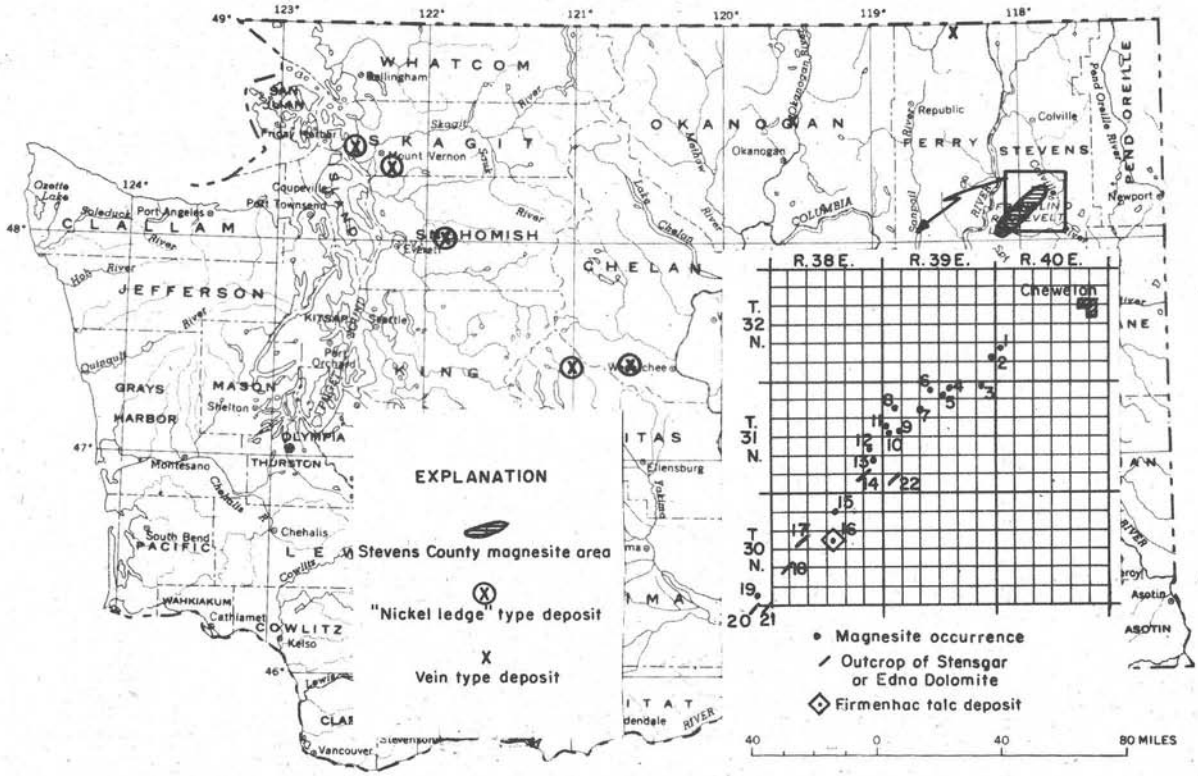

FIGURE 46.—Magnesite deposits of Washington.

Between the Red Marble (No. 13) and the Turk (Nos. 19 and 20), the last important deposit on the southwest, there are no known magnesite occurrences except for the early-worked U.S. Magnesite deposit (No. 15), although there are occurrences of magnesitic dolomite.

The Finch deposit (No. 1), now probably nearly worked out, originally extended to the overlying slate on the west and ended against siliceous dolomite on the east. The dimensions of the deposit were about 700 feet east to west by about 500 feet north to south. It contained blocks of dolomite or low-grade magnesite in places and dipped moderately steeply to the west. The vertical dimension was 330 feet, or 70 feet below the level of operation (Hodge, 1938c). Hodge reports that CaO averaged 2.3 percent across the ore body and SiO_2 averaged 4.82 percent.

The northern part of the Allen-Moss deposit (No. 2) had a low dip to the west. It was about 300 feet wide and had a vertical dimension of 160 feet. It averaged 3.0 percent CaO and 3.9 percent SiO_2. The southern part had relatively thin high-grade layers alternating with high CaO and siliceous layers. Its overall vertical dimension was about 200 feet.

The Woodbury deposit (No. 3) was worked on a small scale during the early part of World War I. Analyses taken across a 30-foot face indicate low grade, mostly because the rather coarsely crystalline magnesite lies along bedding planes as irregular replacements in the dolomite.

The Phoenix deposit (No. 5) shows a small body of coarsely crystalline magnesite at the southwestern end of a Stensgar outcrop about 1,000 feet long and 300 feet wide. The Nogue (No. 6) shows only patches of magnesite.

The Keystone (No. 7) has been extensively worked, and the amount of ore that remains is not known. Presumably, operations reached a point where impure ore and waste caused the transfer of operations to the Red Marble deposit. As has been mentioned, before magnesite was recognized here this quarry was worked for building stone. The width of outcrop before the more recent operations was 1,100 feet between the overlying lower slate member of the Buffalo Hump Formation and mafic intrusive bodies on the southeast. The Stensgar Dolomite here was replaced by magnesite, mostly in the upper part next to the overlying Buffalo Hump Formation. Much of the rock on the southeast is brucite. What is probably the largest hydromagnesite body in the United States (Eugene Callaghan, 1942, personal communication) occurs in a shear zone mentioned by Shedd (1903) that cuts across the magnesite.

The Double Eagle deposit (No. 9) includes two outcrops, of which the larger is 1,500 feet east and 100 feet above the other. The area between outcrops is not well exposed but probably is dolomite. The old quarry, 60 feet wide, extends 100 feet north into the hillside, where the face shows magnesite and magnesitic dolomite. The west deposit is an opening 70 by 50 feet with a 20-foot face at the back, which shows massive magnesite for half the width.

The Crosby deposit (No. 10) crops out in an area 400 feet by 125 feet. Development consists of several trenches opened in pink to red finely crystalline magnesite that analysed 43.6 percent MgO.

The Red Marble deposit (No. 13) has a total length of about 4,000 feet and a width of 450 feet. It crops out at an altitude of 3,500 feet on the north, rises to 4,000 feet at the old quarry, then descends into a shallow ravine on the south. Much of the deposit is coarsely to finely crystalline, reddish to pinkish, and white magnesite. Banding is indicated in places by color differences as well as grain size. Samples taken before present operations began (table 18, Nos. 2, 3, and 4) average 45.6 percent magnesium oxide and range from 0 to 1.4 percent calcium oxide. The depth of the ore body is not known.

The easternmost segment of the Stensgar Dolomite, half a mile east of the Red Marble quarry, is a potential source of magnesite. Shedd (1913, App. A, No. 66) reports that a sample from there contained 45.76 percent MgO.

TABLE 18.—*Analyses of carbonate rocks from Stevens County magnesite belt* [1]

No.		Ignition loss	SiO_2	Al_2O_3, Fe_2O_3	CaO	Experimental MgO	Calculated MgO
1	Woodbury deposit; NE¼ sec. 1, T. 31 N., R. 39 E.; magnesite	47.9	2.6	1.9	3.6	41.4	43.9
2	Woodbury deposit, average of 4 analyses	46.6	1.9	1.7	24.2	24.8	25.4
3	Red Marble quarry; SE¼ sec. 24, NE¼ sec. 25, T. 31 N., R. 38 E., average of 9 analyses	50.1	2.8	.9	.5	44.5	45.8
4	Red Marble quarry, magnesitic dolomite	45.3	.9	.8	20.9	--------	24.7
5	Red Marble quarry, dolomite	45.1	3.9	.9	29.3	22.0	20.8
6	Stensgar Dolomite; NE¼ sec. 35, T. 31 N., R. 38 E.; average of 6 analyses	46.0	4.4	1.5	28.6	--------	21.3
7	Stensgar Dolomite; magnesitic dolomite	45.4	3.3	1.4	25.5	--------	24.4
8	U. S. Magnesite quarry; N½ cor. sec. 10, T. 30 N., R. 38 E.; average of 6 analyses	49.4	3.8	1.1	1.2	43.4	44.3
9	U. S. Magnesite quarry; average of 13 analyses	40.6	11.0	2.2	15.2	26.9	27.7
10	Stensgar Dolomite; SE¼ sec. 17, T. 30 N., R. 38 E.; probably magnesitic	45.9	2.5	1.0	26.2	23.8	24.4
11	Stensgar Dolomite; secs. 19, 20, and 30, T. 30 N., R. 38 E; probably magnesitic	47.5	.5	1.2	25.7	24.7	25.1
12	Stensgar Dolomite; probably magnesitic	47.6	2.0	1.1	14.9	33.2	35.0
13	-----do	46.5	1.4	1.4	21.9	25.3	28.8
14	-----do	45.2	3.6	.4	21.9	20.2	21.7
15	Turk deposit, North end; SW¼ sec. 36, T. 30 N., R. 37 E.; average of 4 analyses	44.3	6.5	2.1	1.4	45.1	45.5
16	Turk deposit, South end; NW¼ sec. 1, T. 29 N., R. 37 E., magnesite, average of 2 analyses	46.4	4.8	.9	.7	45.8	47.1
17	"Nickel ledge," siliceous "dolomitic rock"	31.04	32.12	6.37	1.81	26.73	--------
18	Magnesite, collected by Stone, Red Marble quarry(?) 17 miles west of Valley, Wash.	[3] 49.51	4.27	[2] 8	1.07	45.02	--------
19	Magnesite, collected by Stone, U.S. Magnesite quarry(?)	[3] 47.81	8.83	[2] 85	7.39	38.41	--------
20	-----do	[3] 46.03	5.60	[2] 88	6.88	40.90	--------
21	Magnesite, collected by Stone, Allen quarry	[3] 50.32	.46	[2] 1.01	.31	46.23	--------
22	Brucite(?), collected by Stone, Allen quarry	[3] 5.23	1.20	[4] 2.36	.92	90.59	--------
23	Edna Dolomite, sec. 31, T. 31 N., R. 39 E	29.9	31.2	3.7	14.6	--------	20.6
24	Firmenhac talc, SW¼ sec. 15, T. 30 N., R. 38 E	47.7	1.5	1.2	18.8	29.4	30.8
25	Edna Dolomite, NW¼NE¼ sec. 1, T. 29 N., R. 37 E	39.3	8.1	1.6	17.5	--------	33.5
26	-----do	43.5	6.3	2.2	1.4	45.1	46.6
27	-----do	32.5	21.1	2.5	41.7	.6	22.2

[1] Source: Bennett (1941, pp. 23–25) for analyses Nos. 1 to 16 and 23 to 27; Wells (1937, p. 62) for analyses Nos. 18 to 22; Smith (1904, p. 4) for analyses No. 17.

[2] FeO.

[3] CO_2.

[4] Fe_2O_3.

The U.S. Magnesite deposit (fig. 46, No. 15), worked during World War I, includes an area 125 by 100 feet near the base of the Stensgar. Yale and Stone (1921, p. 151) report 38.41 percent MgO in the upper 40 feet and 40.90 percent in the middle 18 feet of the quarry. Other analyses are shown in table 18, Nos. 8 and 9. Some good grade

magnesite occurs here, but much of it is intimately intermixed with dolomite, and quartz veins cut across the rock in places. The deposit is at the northeast end of a 2-mile long faulted segment of the Stensgar Dolomite (Campbell and Loofbourow, 1962).

The north half of the Turk deposit (fig. 46, No. 19) consists of two masses that were outlined by drilling in 1942. Each part is roughly 200 feet square and extends to a depth of about 220 feet (Bennett, 1941, pp. 21–23; 1943, 22 pages). The outcrop of the north part lies between valley level and 100 feet above on the west, and the south part lies between 100 and 200 feet above. On the basis of the drilling and about 450 analyses of most of the cores from 19 drill holes, as well as adit and surface samples, reserves of a little more than 2 million tons of magnesite have been calculated for the north part of the Turk deposit.

Analyses made by the U.S. Bureau of Mines (Bennett, 1941, p. 23–25) show magnesitic dolomite in the Stensgar Dolomite southwest of the Red Marble deposit as follows: NW¼ sec. 36, NE¼ sec. 35, T. 31 N., R. 38 E. (fig. 46, No. 14; table 18, No. 7), and secs. 19, 20, and 30, T. 30 N., R. 38 E. (fig. 46, No. 18; table 18, Nos. 11–14). The Edna Dolomite, which is unusually siliceous in secs. 30 and 31, T. 31 N., R. 39 E. (fig. 46, No. 22; table 18, No. 23), appears to be magnesitic at the Firmenhac talc deposit in the SW¼ sec. 15, T. 30 N., R. 38 E. (fig. 46, No. 16; table 18, No. 24). In the vicinity of the Turk magnesite deposit, the formation grades from limestone through limey magnesite to high-grade magnesite (fig. 46, No. 21; table 18, Nos. 25–27)

The operations of the Northwest Magnesite Co. have been carried on almost continuously for nearly half a century. The Finch deposit was the first to be explored and was worked later in conjunction with the Allen-Moss. It seems probable that these deposits are essentially worked out. Hodge (1938, p. 41) reported 387,000 tons reserves in the Finch and 201,250 in the Allen-Moss quarries, and 100,000 tons "of fair grade" in the south Turk deposit in the NW¼ sec. 1, T. 29 N., R. 37 E. (fig. 46, No. 20; table 18, No. 16). Operations were started in 1944 at the Keystone deposit, which was connected with the Finch quarry by a tramline. Another tramline completed in 1954 extended from the Finch to the Red Marble quarry. Beneficiation of magnesite by flotation was started in 1942 or 1943 and by sink-float process in 1945.

Other occurrences of magnesite are known in Washington, two in Skagit County and one each in Ferry, Okanogan, Snohomish, Kittitas, and Chelan Counties (Gildersleeve, 1962, and fig. 46). None offer much promise. The deposits in Skagit, Snohomish, Kittitas, and Chelan Counties are large but low grade. They are the so-called "nickel ledges" and are intimate mixtures of silica and carbonate minerals, including magnesite (Smith, 1904, pp. 3–4; Hobbs and Pecora, 1941). The Okanogan deposit is a narrow vein of magnesite in serpentine. At the Ferry County deposit, one-fourth inch veinlets of hydromagnesite are found cutting serpentine (Valentine, 1949).

The production of magnesite in Stevens County probably will continue for some years, but it would seem unlikely that operations would continue beyond the resources at the Red Marble deposit unless other deposits that do not crop out are found. The competition of magnesia produced from sea water and bitterns as well as from other materials such as dolomite is strong and has been increasing

for the past 10 years. The prospects do not appear to be very bright for the discovery of economic deposits of magnesite in areas outside Stevens County.

OLIVINE, SERPENTINE, AND ASBESTOS

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Olivine, serpentine, and asbestos are considered together in this report because all three occur principally in ultramafic rocks. Exceptions to this are the olivine in basalt, the serpentine in silicated dolomite, and some types of amphibole asbestos. The first two are of geologic interest only; the last constitutes only 5 percent of the world's supply of asbestos. In a few places—Arizona, for example—minable chrysotile asbestos does occur in dolomite metamporhosed by diabase sills.

Olivine consists of magnesium and iron silicate ($(Mg, Fe)_2SiO_4$), and the olivine in dunite is close to the magnesium end of the series. An olivine from the Twin Sisters mass shows 50.1 percent MgO and 8.28 percent FeO (Ross and others, 1954). Serpentine is a hydrous silicate of magnesium ($H_4Mg_3Si_2O_9$), which contains about 44 percent MgO. Both olivine and serpentine are used mainly as refractories. They have also been used as sources of magnesium metal and salts, but at present, sea water and brines are used as the sources for the metal and salts of magnesium. The greatest use of olivine is as a molding sand by foundries and glass plants. This is because of olivine's refractoriness (forsterite, the pure magnesium type of olivine, has a melting point of 3461° F.), its strength at high temperatures, and its resistance to corrosion by most compounds except acid slags (Clark and McDowell, 1960, pp. 704, 707). Refractory forsterite bricks are made by adding magnesia to olivine and bonding them either chemically or by firing. Its use as a blasting sand has developed recently. For this use, as well as for use as foundry sand, olivine has the advantage that it does not cause silicosis, as silica sand may. It has been used also as an ingredient in the manufacture of fertilizers. Additional uses of serpentine are as a base for some special paints, in insecticides, and, especially formerly, as a decorative stone—"verde antique."

In recent years, Washington and North Carolina have produced most of the olivine consumed in the United States. The mining and use of olivine in Washington have increased spectacularly in recent years; the following percentage increases of production took place: from 1957 to 1958, 110 percent; 1958 to 1959, 44 percent; 1959 to 1960, 44 percent; 1960 to 1961, 50 percent; and 1961 to 1962, 34 percent. The present annual production in the State is approximately 25,000 tons. Nearly all this production has been from the Twin Sisters dunite mass, Skagit and Whatcom Counties; some has been from a mass on Cypress Island, Skagit County. The Twin Sisters dunite mass is the largest known in the United States and is unusual, and valuable, in that the olivine in it is almost completely unaltered. Only around its edges is the olivine serpentinized (Ragan, 1963). This is true of most of the younger (middle Tertiary(?)) masses of dunite in the State. The older ultramafic rocks, on the other hand, are now mostly serpentine. Figure 47 shows the locations of the larger masses of ultramafic rocks. They are also shown on figure 4, the geologic map of Washington.

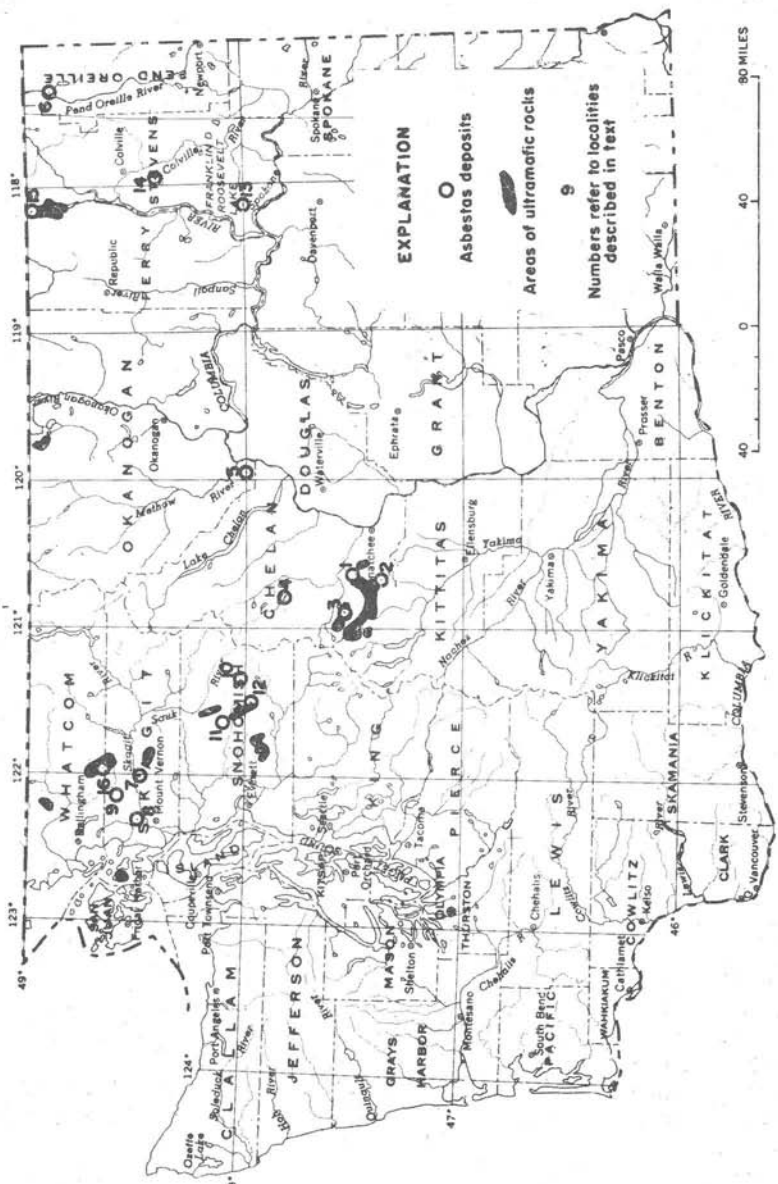

FIGURE 47.—Ultramafic rocks and asbestos occurrences in Washington.

Table 19 lists past and present producers. Any mass of ultramafic rocks can be considered as a possible source of serpentine, but only the Twin Sisters mass is known to contain large amounts of unaltered olivine.

TABLE 19.—*Producers of olivine and serpentine*

OLIVINE

County	Name	Location of deposit
Skagit	Manganese Products Co	Olivine Hill on Cypress Island.
	Northwest Olivine Co	Twin Sisters Mountain.
	Omega Mining Co	Do.
	Pacific Olivine Co	Do.
	Scheel quarry	Do.
Whatcom	Olivine Corp	Do.

SERPENTINE

Stevens	Green Mountain Marble Co	Sec. 13, T. 31 N., R. 40 E.
	Keystone quarry	Secs. 8 and 9, T. 31 N., R. 39 E.
	Keystone Supplement quarry	Sec. 13, T. 31. N., R. 40 E.
	McGrath quarry	Sec. 12, T. 31 N., R. 39 E.
	North American quarry	Secs. 12 and 19, T. 31 N., R. 39 E.
	Pacific Coast Marble, Tiling & Manufacturing Co	Sec. 18, T. 31 N., R. 41 E.
	Peach quarry	Sec. 12, T. 31N., R. 39 E.
	Regal quarry	Sec. 7, T. 32 N., R. 41 E.
	Royal quarry	Sec. 9, T. 32 N., R. 41 E.
	Sage quarry	Sec. 18, T. 31 N., R. 41 E.
	U.S. Marble Co	Secs. 8 and 9, T. 31 N., R. 39 E.

The uses of olivine as a molding sand, in forsterite bricks, and as a blasting sand are relatively new and are increasing rapidly. With the Twin Sisters mass less than 25 miles (airline) from the port of Bellingham, the west coast industrial areas from Los Angeles north to Vancouver, British Columbia, are available as possible markets, so the use of olivine should continue to increase.

Asbestos is the term used in commerce to describe minerals of fibrous habit in the serpentine and amphibole groups of minerals. Chrysotile, of the serpentine group, is silky, flexible, fire resistant, and is a nonconductor of electricity. It constitutes about 95 percent of the world supply of asbestos. The long-fiber (three-quarters of an inch or longer) material is woven into fabrics that have many uses. Examples are brake and clutch linings and fireproof cloth; a low-iron variety of long-fiber chrysotile is used in asbestos-cement products such as shingles and for making asbestos paper. The shortest fibers find use in boiler and roofing cements and as fillers in a great variety of products.

Various minerals of the amphibole group that are fibrous in habit have been similar to those of chrysotile. Although somewhat less flexible than chrysotile, they are, on the other hand more resistant to acids. They include amosite, used mostly for high-temperature insulation and for fire-resistant marine partitions; crocidolite, long-fiber types of which have fire- and acid-resistant uses, and the short-fiber type is used in asbestos-cement piping; tremolite, actinolite, and anthophyllite are used in chemically resistant filters, welding rod coatings, and as fillers. Paligorskite ("mountain leather"), which occurs as flexible sheets of matted fibers, has not been reportedly used commercially yet, but has some properties similar to short-fiber asbestos.

TABLE 20.—*Asbestos deposits in Washington*

Index No. on fig. 47	County-district-deposit	Location	Geology (production)	Reference
	CHELAN			
	Blewett:			
1	Mill Creek	Sec. 30, T. 24 N., R. 18 E.	Anthophyllite in serpentine	Valentine, 1960.
2	Peshastin Creek	Sec. 14, T. 22 N., R. 17 E.	Networks of small veinlets of short-fiber asbestos in serpentine.	Do.
3	Trout Lake	Sec. 19, T. 24 N., R. 16 E.	Anthophyllite in serpentine. Chrysotile reported nearby.	Do.
4	Chiwawa: Goose Creek	Sec. 18, T. 27 N., R. 17 E.	Anthophyllite in felty masses and veins	Do.
	OKANOGAN			
5	Methow: Alta Lake	Near center T. 29 N., R. 23 E.	Lenses of short-fiber amphibole asbestos (mined and used in paint).	Do.
	PEND OREILLE			
6	Metaline Area		Considerable paligorskite is associated with the lead-zinc ore.	Park and Cannon, 1943.
	SKAGIT			
	Hamilton:			
7	Lyman	Sec. 34, T. 35 N., R. 6 E.	Long fibered amphibole asbestos. (A small amount has been shipped.)	Valentine, 1960.
8	Burlington	Sec. 32, T. 35 N., R. 4 E.	Fibrous soapstone-actinolite mixture in shear zone cutting greenstone (has been mined for use in special cements).	Do.
9	Scott	Sec. 27, T. 36 N., R. 5 E.	Long-fibered amphibole asbestos	Do.
	SNOHOMISH			
	Silverton:			
10	Bedal Creek	Sec. 35, T. 30 N., R. 11 E.	Slip-fiber asbestos in narrow veinlets	Do.
11	Clear Creek	Sec. 3, T. 30 N., R. 9 E.	Talcose asbestos in serpentine dike	Do.
12	Sultan: Florence Rae	Sec. 27, T. 29 N., R. 10 E.	Cross-fiber asbestos in narrow veinlets in peridotite	Do.
	STEVENS			
13	Cedar Creek: Boundary Butte	Sec. 21, T. 29 N., R. 37 E.	Fibrous tremolite in altered dolomite	Do.
14	Colville: Stranger	Sec. 35, T. 34 N., R. 38 E.	Fibrous tremolite interbedded with dolomite	Do.
15	Orient: Laurier	Secs. 5, 6, 7, T. 40. N., R. 37 E.	Thin masses of short-fiber asbestos in fractures in serpentine	Do.
	WHATCOM			
16	Sisters: Twin Sisters	Sec. 36, T. 37 N., R. 6 E.	Thin veinlets cross-fiber asbestos in serpentinized peridotite	Do.

The average consumption of asbestos in the United States for the years 1961, 1962, and 1963, according to the U.S. Bureau of Mines Minerals Yearbooks (vol. 1), was 705,387 tons; of this, domestic production amounted to only about 8 percent. About 23 percent of the world's production (average for the same 3 years, 3,008,333 tons) is consumed by the United States, the largest user. Most of the imported asbestos comes from Canada, which produces over 40 percent of the world supply, but a small amount, mostly special kinds and grades, comes from southern Africa (U.S. Bur. Mines Bull, 585, 1960, and Minerals Yearbook, vol. 1, 1963).

Washington has produced no chrysotile asbestos and only a small amount of amphibole-type asbestos. The last mention of any production reports was for 1935 when according to Bowles and Stoddard (1936), material prodced near Burlington was a mixture of talc and (amphibole) asbestos. Any production of asbestos in later years from this deposit is presumably included with the talc and soapstone chapters of the U.S. Bureau of Mines Minerals Yearbooks.

Known occurrences of asbestos are shown on table 20 and plotted on figure 47, which also shows the large areas of ultramafic rocks. The few past producers are also indicated on table 20.

Although more than half of those deposits listed contain amphibole rather than chrysotile asbestos, most of the deposits are in serpentine or peridotite. Two are deposits of tremolite in dolomite; one is in greenstone.

Until a deposit of large size is developed and a market secured for the product, there is little chance of much production of asbestos in the State because of the economics of the asbestos industry.

PEAT

(By M. T. Huntting, Washington Division of Mines and Geology, Olympia, Wash.)

Peat consists of partially decomposed plant tissue that has accumulated in water or in wet places. It represents an early stage in the conversion of vegetable matter to coal. Peat is classified in accordance with its major plant constituents. Moss (sphagnum) peat is made up of the remains of moss of the genus *Sphagnum* but rarely *Hypnum* is the dominant genus. Reed-sedge (fibrous) peat is composed mainly of the remains of sedges (*Carex*), but also may contain the remains of other plants such as reeds, tules, pondweeds, water lilies, and scouring rushes. Wood peat is made up of particles of partially decomposed wood ranging in size from fragments of twigs to complete large logs. Humus is peat that is so decomposed that the plant material is not identifiable. Muck is peat that contains 40 percent or more of mineral matter (Sheridan and DeCarlo, 1957, pp. 3–4).

Moss peat is preferred for many uses, but the 1963 production in the United States was as follows: Reed-sedge, 53 percent; humus, 27 percent; and moss, 20 percent. In 1963, approximately 96 percent of all peat sold in the United States was used for general soil improvement. It is used to improve the tilth of sandy soils and of clayey soils in lawns, gardens, and golf courses. It also is used, either alone or in mixes with sand and soil, for house plants and as a planting medium in greenhouses and nurseries. Smaller amounts

55-883 O—66——16

are used as poultry and stable litter, as packaging material, and in mixed fertilizers. Most peat is acid (pH 3.5) to neutral (pH 7.0); sphagnum moss peat ordinarily is the most acid variety. This acid quality is utilized to condition soil for such acid-loving plants as rhododendrons and azaleas. For some uses, peat acts as a deodorizer; for other uses, such as packing material for fruits and vegetables, its reported antiseptic property is valuable. Although peat is used extensively for fuel in Ireland, Russia, and other countries, the ready availability of better fuels has precluded its use as fuel in the United States. Large areas of peat lands are utilized in Washington for the growing of cranberries, blueberries, and truck garden crops. Cranberry culture is restricted to sphagnum peat lands exclusively, and probably 90 percent of the blueberries grown in Washington are on land underlain by fibrous peat.

World production of peat in 1963 was 169.5 million short tons, of which 578,530 tons was produced in the United States. Of this, 37,248 came from Washington deposits (Sheridan, 1964, pp. 308, 314–315). The United States production in 1963 had a value of $5,422,877, a 4.6-percent increase over the previous year. Washington production in 1963 was valued at $187,549, 35 percent less than in 1962. Total recorded Washington production from 1935 to 1963 was 516,386 tons, having a value of $2,121,440. No production data are available for the years prior to 1935 or for the years 1944, 1946, 1948–1950.

The average unit value of peat sold in the United States increased from $9.15 a ton in 1962 to $9.92 a ton in 1963. Prices varied greatly, however, depending chiefly upon whether the peat was sold in bulk or in packages. Bulk peat averaged $6.88 a ton, and packaged peat $12.87 a ton. Prices ranged from less than $2.00 a ton (unprepared peat sold in bulk) to $75.00 a ton (packaged peat sold for special uses). By far, the highest unit values were obtained for peat sold in small packages—the smaller the package the higher the price per unit volume. Peat sold in Washington in 1963 had a unit value of $5.04, the lowest of any State.

The leading peat-producing country in 1963 was the U.S.S.R., with about 95 percent of the world output. The United States ranked fourth in world production. In recent years, Washington has ranked among the top three of four States in peat production. From 1951 through 1954, Washington outranked all other States. In 1963, the State ranked fourth behind Michigan, Indiana, and California in tons sold. However, because of higher unit values for peat sold in other States, the value of peat sold in seven States exceeded that in Washington. Washington production in 1947 was 2,425 short tons, having a value of $10,125. This had increased by 1951 to 45,304 tons, having a value of $99,000, but production declined steadily to 27,770 tons valued at $121,000 in 1960. It then increased to 37,248 tons valued at $187,549 in 1964. Inasmuch as large reserves of peat in the State remain to be exploited and the demand for peat can be expected to grow, increased production of peat in Washington is very probable.

Many peat operations in the United States are small and employ less than three men each, but some operations are large and are completely mechanized. About 31 percent of the peat consumed in this country is imported from Canada and West Germany. Imports in 1963 totaled 261,331 short tons and had a value of $12,357,557—well

over twice the value of U.S. production. In Washington and elsewhere in the Northwest and the Pacific Coast States, sphagnum peat imported from British Columbia dominates the market. Almost a third of the total value of peat imports into the United States enters through the Washington Customs District. Imports into Washington have been increasing rapidly since 1952. Details on the market for moss peat in the northwestern States are given in a report prepared by the State of Washington (Washington Dept. Commerce and Econ. Devel., Div. of Business and Econ. Research, 1961).

Conditions that favor the accumulation of peat are a climate that is conducive to rapid plant growth and topography in which large areas of land are poorly drained. Poor drainage is essential so that water can accumulate to a depth sufficient to inhibit the decay of plant material that accumulates but not to a depth so great that plants cannot thrive in it.

A large percentage of the peat reserves in the United States are in the northern part of the country, which was covered by massive continental glaciers during Pleistocene time (the "Ice Age"). Glaciation produced many shallow basins and large flat-to-gently-sloping areas underlain by a relatively impermeable till (a mixture of gravel, sand, and clay that is sometimes called "hardpan") that impedes water from seeping into the ground.

Peat accumulates in two general types of environment: (*a*) lakes and (*b*) marshes, swamps, or bogs. A peat deposit in a lake may consist of a thin ring around the margin of the lake; a more extensive area with only a small lake or pond remaining near the center; a deposit in which the lake has been completely filled with peat, and thus obliterated; or a deposit bordering only a part of the lake shore. Numerous examples of each of these types are found in Washington. Peat accumulates in lakes through the growth of plants around the shallow margins and by extension of this marginal growth outward to form floating mats on the surface of the water. This is supplemented by the growth of microscopic floating plants that die and sink to the bottom of the lake, building up the layer of jellylike sedimentary peat that commonly underlies the fibrous (reed-sedge) or sphagnum (moss) peat in most Washington peat deposits. This sedimentary peat has no market value because it becomes hard and dense when it is dried.

Peat that was deposited in marshes, swamps, or bogs may contain layers of wood peat, fibrous peat, or sphagnum peat. These layers represent successive plant communities that thrived during the several thousand years that were required for the peat deposit to accumulate. The average rate of accumulation in 151 deposits in the Puget Sound lowlands of Washington as computed by Rigg and Gould (1957, p. 361) was 1 inch of peat in 41 years. The oldest peat tested by radiocarbon dating in those experiments was $13{,}650 \pm 550$ years.

Peat deposits are found in Washington in each of the following types of undrained or poorly drained areas: Irregular surfaces on glacial outwash deposits; irregular surfaces on piedmont fluvial deposits; valleys or stream channels dammed by glacial deposits; valleys of tributary streams dammed by materials deposited by the aggrading of the main stream; valleys dammed by alluvial fans from tributary streams; locally overdeepened (now abandoned) stream channels; depressions in flood plains; isolated lagoons or dammed mouths of valleys resulting from deposition of sediments by sea waves and cur-

rents; irregular morainic surfaces on glacial till; depressions or undrained flats between adjacent sand dunes or in places where drainage is obstructed by dunes; landslide depressions; volcanic craters; and beaver ponds.

G.B. Rigg (1958, p. 1), in a report on his detailed examination of the peat deposits of Washington stated:

> Peat deposits are widespread in all but the southeastern quarter of Washington, occurring in 28 of the 39 counties. Most of the deposits are in areas affected by continental glaciation and 64 percent of the total peat land, including most of the large deposits, was examined. Individual peat deposits vary in size from an acre or less to as much as 3,500 acres, and they vary in depth from a foot or so to as much as 63 feet. There is no consistent relation between large size and great depth. Ten peat areas contain more than 1,000 acres each. Sphagnum bogs are numerous in western Washington, but only a few are found in the eastern part of of the State. The largest sphagnum bog is 57 acres in area.
>
> Most of the peat in the state is of the fibrous variety. * * * Other materials associated with the peat are muck, marl, diatomite, and pumicite. More than half of the peat deposits contain a layer of pumicite, which in most deposits is one-fourth to one-half inch thick but in a few is more than 3 feet thick. Most of this pumicite came from an eruption of Glacier Peak about 6,700 years ago. A few bogs have two layers of pumicite, and two bogs, the Deer Lake No. 2, in Stevens County, and the Fargher Lake deposit, in Clark County, have four layers.
>
> Analyses of 46 samples of peat from 28 different deposits in 14 counties show most of the peat to contain 86 to 95 percent water, 1.5 to 7.5 percent ash, 0.81 to 2.45 percent nitrogen, 0.05 to 0.35 percent P_2O_5, 0.12 to 0.28 percent K_2O, 0.001 to 0.025 percent chlorine, and 0.006 to 0.020 percent sulfur. Acidity varies between pH 3.5 and 7.7, sphagnum peat being the most acid. Most of the peat varies between pH 4.6 and 5.0. Total replaceable bases, expressed as milliequivalents per 100 grams of oven-dry peat, ranges from 1.5 to 116.

The total of 50,000 acres mentioned above does not include all the deposits known in the State. In Snohomish County alone, 21 large deposits, whose areas range from 10 to 500 acres each and total more than 2,300 acres, are known. Soil maps of Snohomish County (Anderson and others, 1947), King County (Poulsen and others, 1952), and Kitsap County (Wildermuth and others, 1939) show a total of 25,740 acres of peat land but only 10,387 acres of peat was examined by Rigg (1958, p. 19). Thus it is probable that there may be as much as 100,000 or more acres of peat land in Washington. The deposits examined by Rigg are distributed among the State's physiographic provinces as shown in the table below.

Province	Deposits		Areas	
	Number	Percent of total	Acres	Percent of total
Puget Sound	235	72	32,248	64
Okanogan Highlands and Selkirk Mountains	44	14	7,656	15
Cascade Mountains	21	6	1,535	3
Olympic Mountains	17	5	2,514	5
Columbia Lava Plateau	6	2	1,533	3
Willapa Hills	4	1	5,073	10
Blue Mountains	0	0	0	0
Total	327	100	50,559	100

W. S. Moen and G. W. Thorsen (1965) report that in 1964 peat was being produced from 32 deposits in Washington. Sphagnum peat was produced from at least 3 deposits (fig. 48, Nos. 2, 5, and 63).

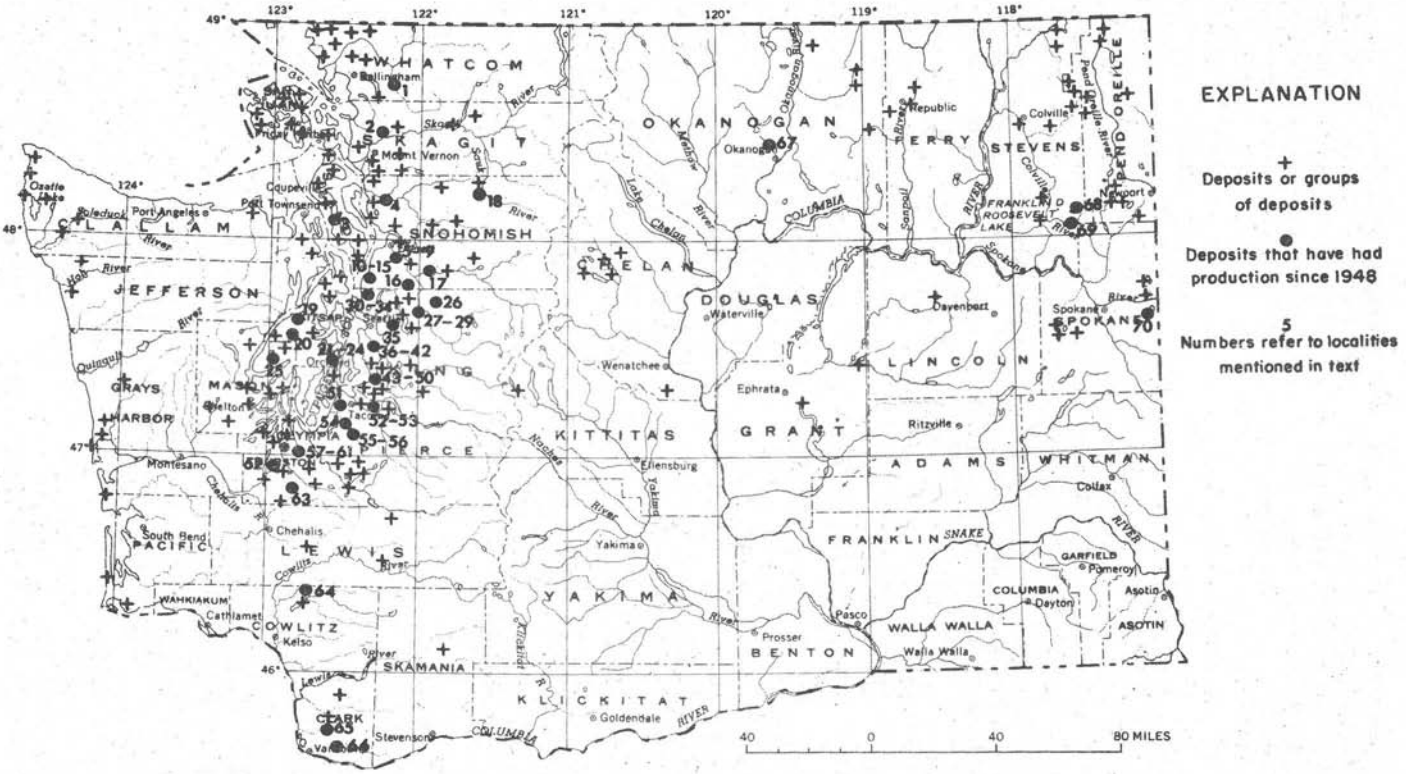

FIGURE 48.—Peat in Washington.

In contrast with almost all other mineral resources, the ultimate reserves of peat in Washington are well known or can be estimated with fair accuracy. If all the peat land that is known in the State is managed in such a way that all the peat can be excavated and sold at some time in the future, there will be an adequate reserve for a very long time in the future. However, very serious problems are arising in land management practices that, through restrictive zoning, are making it increasingly difficult to operate many peat deposits in the highly urbanized areas in the State—the areas where the peat is in greatest demand. Serious consideration should be given to proposals such as that of the Open Space Study of the Puget Sound Governmental Conference, which would establish "green belts" of land in which housing and commercial developments would be prohibited, and peat lands would be classified or zoned for this "green belt" use. Under this classification, the peat could be excavated and then the land could be developed for recreational or other public use.

PUMICE, PUMICITE, VOLCANIC CINDERS, AND PERLITE

(By M. T. Huntting, Washington Division of Mines and Geology, Olympia, Wash.)

Pumice is a fragmental, highly cellular, light-weight volcanic rock that forms in the craters of active volcanoes by the expansion of abundant water vapors and other gases as the molten material is ejected during eruptions. The rock is commonly rhyolitic, less commonly andesitic, in composition. Pumicite, sometimes called volcanic ash, is the fine-grained dustlike equivalent of pumice; its grain size is less than 4 mm. It is thrown into the air as a cloud of dust during explosive volcanic activity. Volcanic cinders are heavier volcanic material somewhat like pumice, but less frothy and usually darker colored. Perlite is a volcanic glass having a concentric, shelly structure and usually a notable percentage of water.

Because of its hardness and the angularity of crushed particles, pumice is an excellent abrasive, and until only a few years ago most of the pumice consumed in the United States was used for this purpose. Its light weight and heat-insulating value have in recent years stimulated its use in the building industry for loose-fill insulation, as plaster sand, and as concrete aggregate, both in massive concrete structures and in concrete building blocks. Pumicite also is commonly used as an abrasive, but the use of pumicite as well as pumice in abrasive products has been declining in recent years. Pumicite is also used as an insecticide carrier and as a filler in paints and rubber goods. Its largest volume use in Washington has been as a pozzolan in portland-cement concrete, notably in the Priest Rapids and Wanapum Dams on the Columbia River. Klemgaard (1958) reported in detail on this and other pozzolanic uses of pumicite in Washington. Volcanic cinders are used as road surfacing material, as aggregate for concrete blocks and monolithic concrete structures, as roofing granules and ground cover, and as drainfield rock where a porous permeable medium is required. Perlite is not used in its natural form, but when heated rapidly to about 1,700° F. (930° C.) it "pops," or suddenly expands to a cellular glass that is equivalent to naturally produced pumice. Expanded perlite is usually much

lighter in weight than pumice, weighing from 2 to 20 pounds per cubic foot. Expanded perlite is used as aggregate for building plaster, where its light weight is a distinct advantage over ordinary plaster sand, and its ease of application is an advantage over exfoliated vermiculite, which is similarly used. Of the perlite used domestically in 1963, 39 percent was used for aggregate in light-weight building plaster, 24 percent for insulation, 15 percent for filter aids, 12 percent for concrete aggregate, 4 percent as an admix in oil-well cement, 2 percent for soil conditioning, 2 percent for miscellaneous uses, 1 percent for filler, and 1 percent for wallboard (May 1964, p. 874). Some of the miscellaneous uses are as a rooting medium for cuttings and young plants in nurseries, as a cleaning agent for oily floors, as chicken-house litter, and as an abrasive and polishing agent.

The bulk of the pumice consumed in the United States is produced domestically; about 147,000 short tons was imported in 1963, approximately double the imports of the previous year. United States production was 2,618,000 tons, 15 percent greater than in 1962 (May 1964, pp. 930–931). Washington production in 1963 could not be revealed, but 1962 production was 10,000 tons, having a value of $130,000 (Gray and Hale, 1964, p. 1146).

The first commercial production of pumice for the manufacture of lightweight building blocks in Washington was in 1940. The demand for pumice for this use and for loose-fill insulation expanded very rapidly during the 1940's, and several dozen Washington deposits were opened and operated at that time. The number of operators has decreased markedly in recent years, and only three deposits were in production in 1964 (Moen and Thorsen, 1965, pp. 23, 29). These were the pits of Ewer Lumber Co. (Westone) (fig. 49, No. 32), Dura-Blox, Inc. (No. 44), and Lee C. Swartz (Soap Lake) (No. 38). Total recorded production in the State from 1943 to 1963 [1] has been 246,309 short tons, having a value of $1,686,421. Although small amounts of pumicite had been mined in Washington previously, the first large-scale production was in 1957, when material was mined from the Army deposit (No. 8) and was processed for use as a pozzolan in the Priest Rapids Dam on the Columbia River. Approximately 79,000 tons of pumicite was used in this and the nearby Wanapum Dam by the time the latter dam was completed in 1963. Volcanic cinders have been produced on a small scale from four deposits (Nos. 19–22) in south-central Washington, but no quantitative record is available. Although several perlite deposits are known in the State, none of these has had any production.

Pumice and pumicite occur as beds that were deposited by airfall on land surfaces or in bodies of water, and as unstratified deposits around volcanic vents. Pumice also occurs in some places as frothy or vesicular coverings on rhyolite flows and extrusive domes, but no deposits of this type are known in Washington. Like pumice, volcanic cinders are a product of volcanic eruptions, and they are commonly the principal rock that makes up small to large volcanic cinder cones. The pumice of Washington is from two volcanoes: Mount St. Helens, in the southern part of the State, and Glacier Peak just north of the center of the State. Both volcanic peaks are in the Cascade Mountains and are Pleistocene to Recent in age. The pumice from Glacier

[1] No production data are available for 1951.

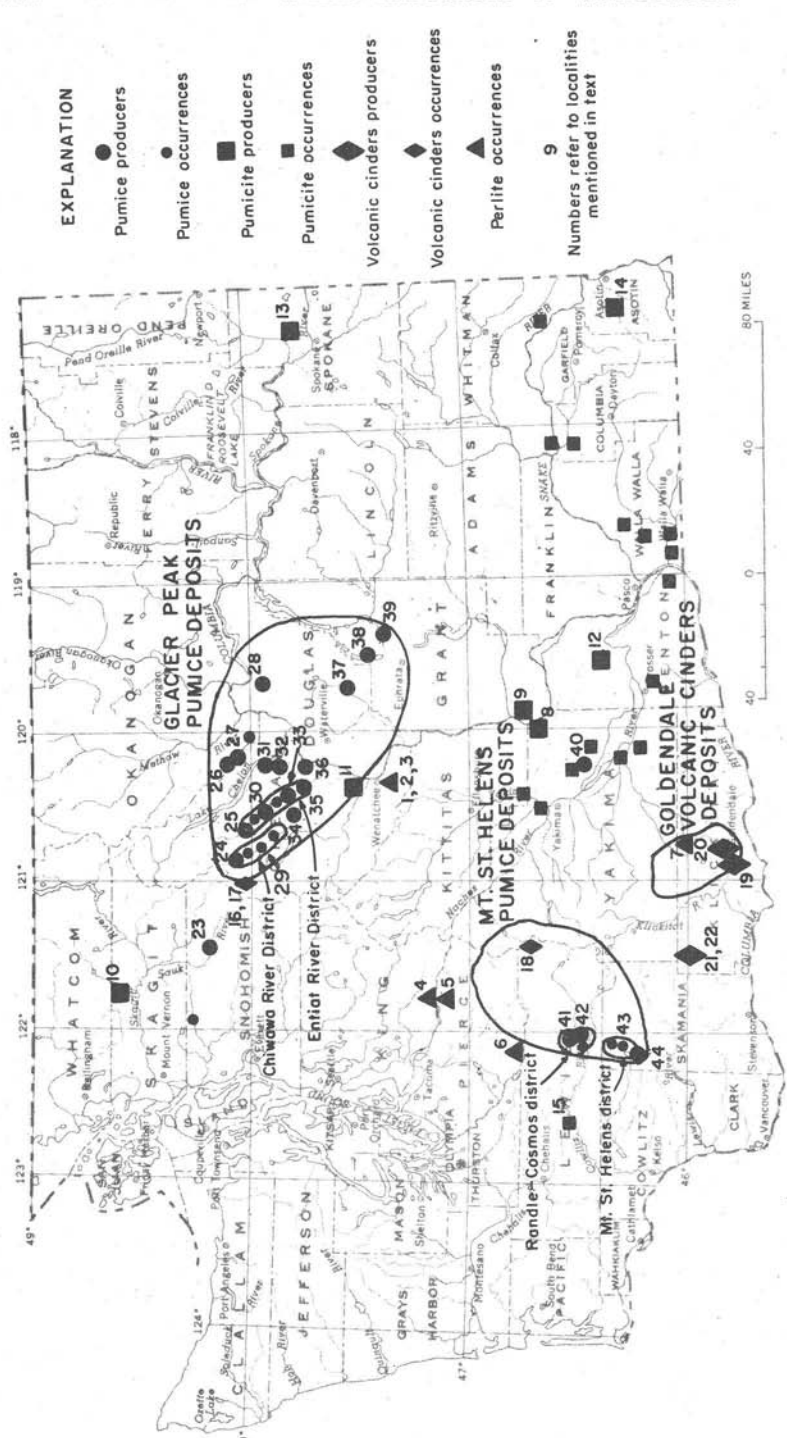

FIGURE 49.—Pumice, pumicite, volcanic cinders, and perlite deposits in Washington.

Peak lies in a fan-shaped area that extends about 85 miles southeastward from the peak. The St. Helens pumice is in a fan-shaped area extending about 50 miles northeastward from that mountain (Carithers, 1946, p. 9). Pumicite deposits in Washington are mostly in the eastern part of the State. They range in age from late Miocene or Pliocene to Recent. The older deposits are of semiconsolidated material in beds interstratified with other sedimentary rocks and basalt flows. The younger deposits are of unconsolidated loose, powdery material that occurs at or near the surface. Although a few of the younger deposits may have resulted from the erosion and redeposition of consolidated pumicite beds, most of them are thought to have originated from volcanic eruptions in Washington and Oregon during late Pleistocene and Recent time, and were distributed over wide areas of the State by wind action. Volcanic cinders occur as volcanic cinder cones of late Pleistocene or Recent age in the southern Cascade Mountains near Goldendale and in the central Cascades southeast of Mount Rainier. Perlite forms where siliceous water-bearing magmas cool rapidly under pressure. The most favorable geologic environments for perlite to form are in near-surface volcanic necks, feeder dikes, and sills, especially where they are in contact with sediments that were water-saturated at the time of intrusion. Perlite deposits in Washington are in volcanic rocks ranging in age from Eocene to Recent and having acidic to intermediate composition. They are mostly in the Cascade Mountains and their foothills.

Pumice and pumicite deposits in Washington were described in detail by Carithers (1946), who said of the Mount St. Helens deposits:

> The pumice deposits of Mount St. Helens are in Skamania and Lewis Counties, and occur as erosional remnants of two beds, or sheets, of different ages that were deposited throughout a fan-shaped area extending from north to east from the volcano. These sheets extend as far as 50 miles from the peak, but not all of this wide area contains pumice to a depth that is economically important. The thickest parts of the beds are confined to a belt 1 to 6 miles wide that extends north to northeast from the volcano for a distance of about 30 miles. The direction of the major part of the showers was probably controlled by south and southwest winds which prevailed at the times of eruptions, as they do at present. This belt extends from the northeast slope of Mount St. Helens across the Spirit Lake area at the head of the North Fork of the Toutle River, across the upper valley of the Green River, and across the Cowlitz River Valley near the confluence of the Cowlitz and Cispus Rivers.

The thickest reported pumice bed is at the Swift Creek deposit (No. 43). It is 20 feet thick. The largest production in this area came from the Popcorn pit (No. 42) originally operated by the Kosmos Timber Company as a source of ballast for logging railroad construction and later operated by Western Sales and Manufacturing Co., Seattle, as a source of aggregate for light-weight concrete building blocks. Three other producers in the area have been the Hunt and Gaines pit (No. 41) in Lewis County and the Draughn and Dura-Blox pits (No. 44) in Skamania County.

In the Glacier Peak area, as in the St. Helens area, the thickest pumice deposits and the largest pumice fragments are closest to the mountain; the average size of the fragments and the thickness of the deposits diminish with distance from the volcano. In the upper Chiwawa Valley, about 12 miles east of Glacier Peak, the fragments average about one-half inch or more in diameter and many are as much as 3 or 4 inches. In the Entiat Valley, the fragments average about one-third inch; in the Columbia River area, less than one-fourth

inch; and farther east, on the Columbia Plateau, less than one-tenth inch in diameter. Most of the commercial deposits known in the area are in the upper Chiwawa and Entiat Valleys; those farther east are widely scattered and generally small in size. The thickest known pumice bed is the 13-foot bed at the Chiwawa River (K) deposit (No. 29). In Chelan County, production has been reported from the Scholze pit (No. 24) in the Chiwawa Valley, from the Westone Construction Products, Ltd., pit (No. 32) in the First Creek area, the Sorlie pit (No. 31) in the Twenty-five Mile Creek area, the Goman pit (No. 36) in the Winesap area, and from pits at the following localities in the Entiat Valley: No. 25 (Heller A, Heller B, Entiat River J, Big Six, and Butler Bros.); No. 30 (Heller, Bortz, Griffith, Smart, Nichol, Patty Bros., Asher and Fouts); No. 35 (Heller C, Entiat A, Mud Creek, P and B, Clearwater), No. 33 (Conklin), No. 34 (Harris). Production in Okanogan County came from the Firman pit (No. 26) and Peterson pit (No. 27). Sand-size pumice has been mined at the Hicks pit (No. 28) and Moses Coulee pit (No. 37), in Douglas County and at the Soap Lake (No. 38) and Adrian (No. 39) pits in Grant County. An alluvial deposit of pumice (No. 23) near Darrington in Snohomish County was operated briefly, and a deposit (No. 40) of consolidated stream-rounded pumice gravel was mined near Zillah in Yakima County. Other deposits of pumice and pumicite are briefly described by Valentine (1960).

Pumicite for use as an admix in concrete for pumice blocks was produced for several years by Rainier Pumice Co. from a pit (No. 10) in Skagit County, and a small amount was produced from the MacDougal Canyon pit (No. 11) in Chelan County. About 79,000 tons of pumicite for use as pozzolan in the Priest Rapids and Wanapum Dams was produced in the 1950's and 1960's from the Army pit (No. 8) in Yakima County and the Beverly pit (No. 9) in Grant County. A small amount of production has been recorded from the Rider pit (No. 12) in Benton County, the Mead pit (No. 13) in Spokane County, and the Dry Gulch pit (No. 14) in Asotin County. A water-laid bed of consolidated partially decomposed pumicite 12-feet thick is exposed for 250 feet along the bank of Mill Creek (No. 15) in central Lewis County, and the topography suggests that the bed may underlie an area one-half mile long and 100 to 150 feet wide.

Volcanic cinders make up a large part of Tumac Mountain (No. 18), a volcanic cone of probable Pleistocene age that rises 1,000 feet above its base and covers about 1 square mile. The cone is 24 miles southeast of Mount Rainier and 5½ miles northeast of White Pass. A small cinder cone (No. 16) is at the head of the White Chuck River in eastern Snohomish County about 5 miles southwest of Glacier Peak, and what is probably another small cinder cone (No. 17) is reported (Russell, 1900, p. 135) to occur in Indian Pass, 7 miles to the south. These two sources of volcanic cinders (Nos. 16 and 17) are within the Glacier Peak Wilderness Area and thus are not available for use. Some of the buttes on the northern flank of Mount Adams have the topographic forms of volcanic peaks and probably these are cinder cones. On the southeastern flank of Mount Adams in Yakima County and extending southeastward a distance of 35 miles to Goldendale in Klickitat County there is a group of 70 or more basaltic scoria cones generally 150 to 300 feet high (Sheppard, R. A., 1960, "Petrology of the Simcoe Mountains Volcanic Area," Washington: John Hopkins Univ.

Ph. D. thesis, 153 pages). Volcanic cinders have been excavated and sold from at least two of these cones—Blockhouse Butte (No. 19) in the NE¼ sec. 8, T. 4 N., R. 15 E., and a cone (No. 20) at the E¼ cor. sec. 27, T. 5 N., R. 15 E. Another group of small volcanic cones in Yakima and Klickitat Counties is almost due south of Mount Adams. Some of these contain volcanic cinders of an attractive red color, as at Quigley Butte (No. 21) in sec. 26, T. 6 N., R. 11 E. Some of the cinders have been excavated and used from this cone, as well as from the Tubbs deposit (No. 22) in the NE¼ sec. 10, T. 5 N., R. 11 E.

Perlite deposits in Washington, described in a report by Huntting (1949), apparently are only small or moderate in size, and none of them have been exploited. Three deposits are in Chelan County, within 2 miles of each other, and about 1 mile south of Wenatchee. Exposures of perlite a few hundred feet in extent are found at Dry Gulch and Rooster Comb (Nos. 1 and 2). At the third locality (No. 3), a test well of the Northwest Research Corp. (Norco No. 1) encountered perlite at depths from 711 to 719 feet and from 765 to 934 feet. The interval between the two perlite zones is in rhyolite; most of the rest of the well is in sandstone, shale, and conglomerate of the Swauk Formation of Eocene age. In the White River area in southern King County (No. 4) and northern Pierce County (No. 5) is a group of small outcrops of perlite in an area of andesitic rocks of middle Tertiary age. About 30 miles to the southwest in the Mashel River area in Pierce County (No. 6), perlite is exposed in a vertical face about 15 feet high and 350 feet long. A small outcrop of perlite about 150 square feet in area is near the head of the South Fork of Satus Creek in north-central Klickitat County (No. 7).

Inasmuch as pumice deposits are all surficial accumulations, the broad outlines of the areas in which these deposits occur are well known. (See fig. 49.) As more roads are built into the mountainous areas where the deposits occur, the available resource will increase considerably. The area east and southeast of Glacier Peak probably has the greatest promise for future prospecting and possible expansion of pumice mining. It is important that land management policies be such that they will encourage development and exploitation of the deposits that are now known and those that will be discovered in the future.

SALINES

(By W. A. G. Bennett, Washington Division of Mines and Geology, Olympia, Wash.)

Salines, as the term is used in this report, include both solid deposits and brines containing sodium sulfate (Glaubers salt, $Na_2SO_4 \cdot 10H_2O$), sodium carbonate (sal soda, $Na_2CO_3 \cdot 10H_2O$, and baking soda, Na_2HCO_3), and magnesium sulfate (epsom salts, $MgSO_4 \cdot 7H_2O$) with associated calcium sulfate (gypsite, $CaSO_4 \cdot 2H_2O$, the earthy form of gypsum). Deposits of this type are the result of evaporation, concentration, and precipitation in undrained lake basins in a dry climate. In Washington they have been accumulating since the end of the glacial period.

An estimated 70 percent of the production of sodium sulfate, when dehydrated to the commercial product called salt cake, is used for

digestion of wood pulp in Kraft paper manufacture. Some 175 to 200 pounds of salt is used for this purpose per ton of pulp produced. Other uses include detergents, stock feed, medicinals, textiles, and chemicals. Sodium carbonate, called soda ash, is used in the glass industry (43.7 percent of the total production in 1962), in the chemical industry, in detergents, in the reduction of bauxite for production of aluminum, to some extent in reduction of uranium ores, and also in paper manufacture. Small amounts are used in the manufacture of cleansers, water softeners, and soap.

Natural sodium sulfate production decreased 5 percent in 1963, but the amount of salt cake manufactured from salt brought the total production of salt cake to the highest on record. More than 1 million tons of sodium carbonate from natural deposits was produced in the United States in 1963, but this was only about one-fifth of the total, the rest being manufactured from salt. Since 1960, the proportion of the production that has come from natural deposits instead of from ammonia soda plants has increased steadily. This change in source of material is due presumably to the high cost of construction of new ammonia soda plants compared to natural soda refineries. The cost of a new 1,000-ton-per-day ammonia soda plant—the smallest that can be built and operated profitably—is said to be $40 million, or about twice the capital investment needed to produce soda ash from trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) (MacMillan, 1960; 1964).

Imports of sodium sulfate for consumption from 1954–63 averaged about 156,000 short tons per year with an average annual value of $3,186,000. Exports of sodium sulfate for the same period averaged about 34,000 short tons annually with an average annual value of $1,079,000. Exports of sodium carbonate averaged 157,000 short tons per year with a value of $5,182,000. Most of the sodium sulfate exported goes to Canada and Mexico.

The United States, with an annual production of about 5 million tons, leads the world in production of sodium carbonate. Over half of the world total (1 million tons) of sodium sulfate was produced in the United States in 1958. According to the U.S. Bureau of Mines, 10 plants, mostly in the Midwest, produce manufactured sodium carbonate, and 41 plants in the eastern half of the country, produce manufactured sodium sulfate.

The first production of salines in Washington was in 1885 from Medical Lake, Spokane County, followed later by sales of salts and water from Soap Lake, Grant County (fig. 50, No. 3). Sodium sulfate from Sulphate Lake (No. 1) in southeastern Grant County was air dried and shipped to paper mills in Minnesota in 1916, and a small amount for medicinal use was produced in 1935 by the Spokanogan Chemical Co. Unsuccessful efforts to produce sodium carbonate were made at Carbonate (No. 2) and Mitchell (No. 4) Lakes in Grant County in the 1930's. Total production of salines from the State has probably exceeded 238,000 tons (Glover, 1936a).

Sodium sulfate lakes in southeastern Okanogan County have attracted the interest of various individuals and mining companies at intervals for some 30 years, and evidence of mining activity can be seen at several lakes. However, according to the U.S. Bureau of Mines no production has been recorded, except a 20-ton test run made in 1942 in a plant at Mons. The salts for this operation probably came from Lawson Lake (No. 10).

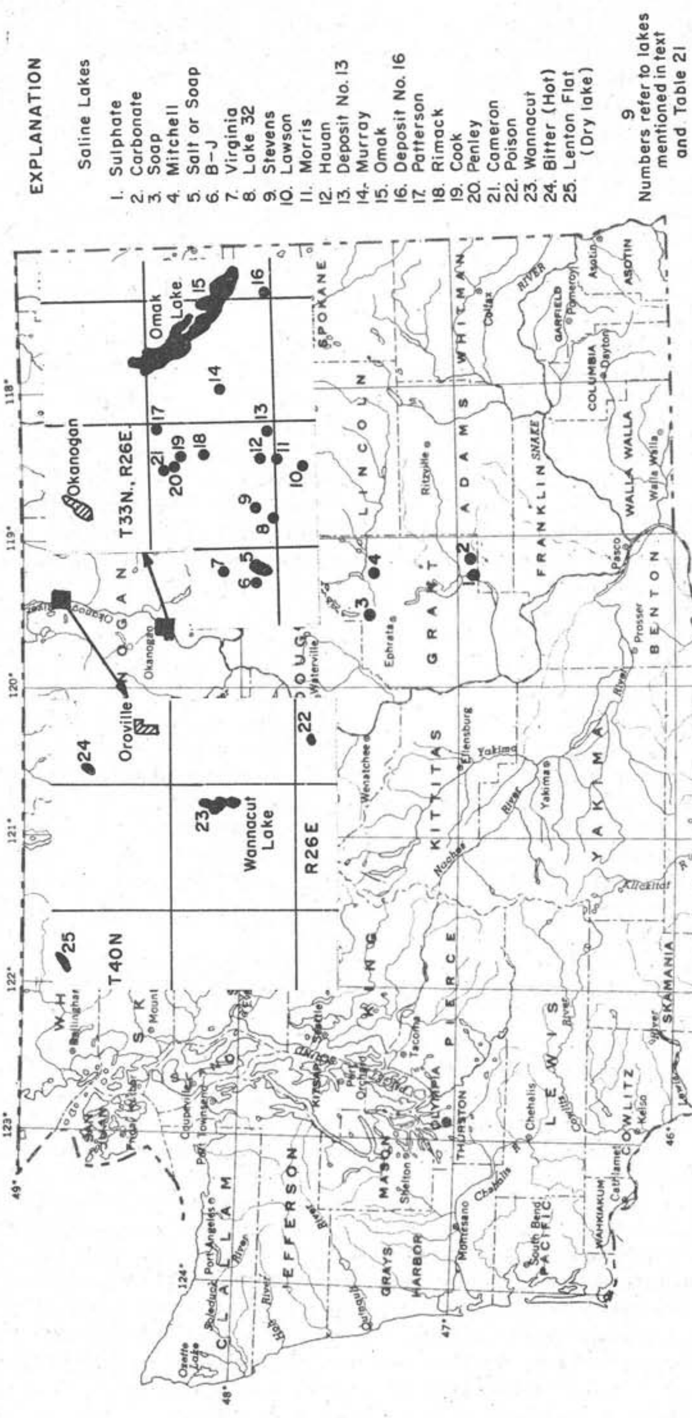

FIGURE 50.—Saline deposits in Washington.

Magnesium sulfate has been produced at Bitter (Hot) Lake (No. 24) near Oroville and from Poison Lake (No. 22) near Tonasket at intervals between 1916 and 1945. Most, if not all, of the solid salt (epsomite, $MgSO_4 \cdot 7H_2O$) has been mined out from both lakes, but brine is still present and is sufficiently pure at Poison Lake to produce epsom salts by simple evaporation. This was attempted between 1935 and 1945, first at a plant in Tonasket and later at the lake.

Gypsite (the earthy form of gypsum) is the principal product mined at Poison Lake since 1951, together with a minor amount of magnesium sulfate. Gypsite constitutes about 60 percent of the lake-bed material at Bitter Lake, which includes about 3 acres and underlies some 80 acres at Lenton Flat (No. 25).

Sodium carbonate exceeds individual amounts of all other salts in most of the lakes that occupy abandoned river channels or undrained depressions in basaltic scablands in Grant County. Sodium sulfate predominates in glaciated areas underlain mainly granite, as on the Okanogan Plateau southeast of Okanogan. Magnesium sulfate and gypsite (calcium sulfate) deposits are mainly in areas underlain by metamorphic rocks with interbedded limestone. Saline deposits form in dry climates where lake basins have little or no outflow and serve as evaporating basins. The deposits are at or just below the water surface.

The lakes with abundant carbonate salts seem to be the result of concentration of waters of deeper ground-water circulation together with water from river and stream drainage. River waters are usually rich in carbonate.

It appears that sodium sulfate salts result from oxidation of sulfides, probably mostly pyrite, forming weak sulfuric acid solutions that leach sodium from feldspar and other rock minerals and form sodium sulfate. Magnesium sulfate and gypsum probably are formed by the same process where limestone or dolomitic limestone is present in areas of metamorphic rocks. The epsomite and gypsum of Poison Lake could have come from weak sulfuric acid solutions acting on magnesian limestone or limy metasediments in the area that drains into the basin.

Carbonate salt deposits appear to represent concentrations from normal ground water or stream water, whereas sulfate salts appear to have concentrated from inflow of water of local derivation that is abnormally high in sulfate content. The crystallized salts of sodium carbonate and sodium sulfate occur generally, not as beds but as nearly circular separate masses (pans) at the surface of the lake bed (Bennett, 1962). Concentration of salts and the inwash of lake muds seem to have been on a delicate balance to attain this result instead of an interbedded deposition or the formation of a single sheet or bed of salts at the surface. The surface pattern of deposits varies from lake to lake. Usually larger irregular pans occur in the center surrounded by small pans. In some lakes such as B–J (fig. 50, No. 6), the pans are generally uniform in size and are circular, compact, and uniform in thickness, with a surrounding fringe of small pans at the shore. The epsomite mass at Poison Lake, mined underground for a time, was apparently in the deepest part of the lake bed and formed a mass about 300 feet long, 200 feet wide, and between 8 and 25 feet thick. It was overlain by 8 to 16 feet of gypsite, above which

was 3 feet of mud, and was underlain by 3 feet of black fetid mud that lay on bedrock. One other epsomite body, apparently entirely mined out, was at Bitter or Hot Lake (No. 24); it originally showed circular pans at the surface and was thought to have been a bedlike mass that connected with all the pans at depth (Jenkins, 1918).

At Bitter Lake the brine is surprisingly high in sodium sulfate, and epsomite is abundant at the surface; but contrary to what might have been expected, no epsomite was found in 1945 by auger drilling—analyses of the lake bed material showed gypsite and hydromagnesite (Bennett, 1962, p. 120). Later (1955–56) the brine was found to be unusually warm; hence the new name "Hot Lake." This phenomenon was studied in a comprehensive manner and found to result from absorption of heat from the sun. The temperature of a pool about 12 feet deep, consisting of three increasingly dense brine layers about 3, 6, and 3 feet thick, rose abruptly from 55° F. at the surface to 78° F. in the lower 1 foot of the upper layers, from which it dropped gradually to 43° F. through the middle 6-foot layer. This layer had a uniform concentration of 200 grams per liter (20 percent salinity), or about 12 times greater than the upper layer. The bottom brine layer had a temperature of 50° F. and the concentration increased gradually to a maximum of 380 grams per liter (38 percent saline) at its base (Anderson, 1958).

In table 21 the tonnage of salts in the more important saline lakes in the State is given. The locations of these lakes are shown in figure 50. Omak Lake has the greatest quantity of salts, both sodium sulfate and sodium carbonate, but in a brine that probably is too weak (about one-seventh the concentration of sea water) to be used commercially even by concentrating it by solar evaportation. Profitable recovery of salts by that method requires: large areas of low-lying flat lands, clay subsoil, low rainfall, high net evaportation, drying winds, long season free from precipitation, and nearby markets (MacMillan, 1960, p. 751).

The concentration of salts in the upper part of Soap Lake is comparable to that of sea water. In the lower part of the lake the concentration is 40 times greater. Carbonate or other salts might be recovered from the lake brine by a process similar to that used in southern California (Garrett and Phillips, 1960).

Numerous small pothole lakes are known in the scabland area west and southwest of Spokane, but none is known to contain a concentration of salts high enough to be of possible commercial interest. Although water was once sold from Medical Lake, presumably for health purposes, the concentration of salts in this lake is too low for the water to be of commercial value as a source of mineral salts.

TABLE 21.—*Quantity of various salts in the more important saline lakes in Washington*

[Short tons, anhydrous basis]

Index No.	Lake	Area (acres)	Na_2CO_3	$NaHCO_3$	Na_2SO_4	$MgSO_4$	K_2SO_4	$CaSO_4$	NaCl	Remarks
	GRANT COUNTY									
3	Soap	864	628,000		301,000				241,600	Brine; contains also 20,000 tons K_2CO_3.
4	Mitchell	8	11,000		600				800	Solid salts; contain also 3,000 tons gaylussite. Also 10,000 tons salts in solution.
	OKANOGAN COUNTY									
15	Omak	3,820	880,000		411,000	13,000	130,000		79,000	Weak brine only, specific gravity, 1.006.
5	Salt or Soap	157	24,000	35,000	194,000	800			19,000	Brine only, specific gravity, 1.041.
6	B–J	19	200	100	8,700				300	Brine.
					15,000					Solid salts; include 400 tons other salts.
7	Virginia	3½			2,000					Brine.
					4,000					Solid salts.
8	Lake 32	7			1,900					Brine; contains also 400 tons other salts.
9	Stevens	8	500		1,700				100	Brine. 4,000 tons solid salts per foot of depth.
10	Lawson	20			2,000					Brine. About 8,000 tons solid salts (mostly Na_2SO_4) per foot of depth.
11	Morris	19			1,700	60			65	Brine. 11,000 tons solid salts per foot of depth.
12	Hauan	21	20		19,800	875	940		1,700	Brine.
				400	53,900	530	530		400	Solid salts.
13	Deposit No. 13	10½			3,000	5,000	70		1,000	Brine.
			40		14,000	330		200	40	Solid salts.
14	Murray	13½	40		7,000	640			100	Brine. Solid salts, at 5,000 tons per foot of depth, may be present.
16	Deposit No. 16	19	300	200	600				100	Brine only, weak.
17	Patterson	17			300	300				Weak brine.
19	Cook	10–15			3,700	1,200				Do.
20	Penley	11	50		14,600	650		100	600	Brine.
					23,700	200		350	100	Solid salts.
21	Cameron	9	180		8,000				400	Brine. Solid salts, 27,000 tons.
22	Poison	19			2,400	12,000	210		200	Brine to depth of 10 feet in lakebed.
					6,000	23,000		355,000		Solids include also 26,000 tons of hydromagnesite and/or magnesite and less than 10,000 tons of epsomite.
23	Wannacut	334	4,500		47,900	155,000		15,900	2,200	Brine only, specific gravity 1.006 to 1.020.
24	Bitter	3	10	5	2,800	220		15	400	Brine.
						8,900		86,000		Solid salts; contain also 11,000 tons magnesite and 16,000 tons hydromagnesite.
25	Lenton Flat (dry lake)	80								Some 500,000 to 1,000,000 tons of gypsite ($CaSO_4$), marl, hydromagnesite, and clay. About 63 percent of lakebed is gypsite.

SAND AND GRAVEL

(By Tom Zimmerman, Washington Department of Highways, and W. S. Moen, Washington Division of Mines and Geology, Olympia, Wash.)

Few people think of sand and gravel as valuable mineral products; however, the sand and gravel industry in the United States is the largest mineral industry in terms of tonnage and the fourth largest in terms of dollars. It is exceeded only by crushed stone, petroleum, and portland cement. In 1963 the United States production of sand and gravel was 822 million tons valued at $849 million. California was the leading state having produced 112 million tons. The commercial production of sand and gravel in the United States amounted to 72 percent of the total, at an average price of $1.12 per ton. Government-and-contractor production accounted for the remainder, at an average price of $0.81 per ton (Cotter, 1964).

The sand and gravel consumed in the United States is classed as construction sand and gravel and industrial sand. Construction includes building, paving, fill, railroad ballast, and other uses. Industrial sands are used for glass, molding, grinding and polishing, blast sand, fire or furnace, engine, filtration, oil hydrafrac, and other uses. Building and paving consumed 88 percent of the construction sand and gravel, while glass, molding, and grinding and polishing operations consumed 75 percent of the industrial sand (Cotter, 1964a, p. 968).

Preliminary production figures for 1964 show that sand and gravel was Washington's leading mineral product (Hale and Gray, 1964, p. 2). Commercial and government-and-contractor production was valued at $20.6 million for 22.9 million tons, which represents an increase of 1 percent over 1963. A breakdown for 1964 is not available, but in 1963 Washington ranked 10th in the production of sand and gravel. About 55 percent of the production was from commercial sources, of which building, paving, and fill were the main consumers. Government-and-contractor production supplied the remaining sand and gravel mainly for the Federal highway building program. The main uses of industrial sand were glass, molding, and blast sand. In 1963, sand and gravel was produced by 145 commercial and 65 noncommercial producers. The commercial producers are shown in figure 51.

The use of sand and gravel is primarily related to construction. Almost every type or construction utilizes sand and gravel for purposes such as fill, or aggregate in concrete. Heavy construction jobs, such as highways and dams, consume large amounts of sand and gravel. In the Grand Coulee Dam alone over 10 million cubic yards of sand and gravel was used in the concrete.

At the source, washed and graded sand and gravel constitute low-cost commodities worth only around a dollar a ton. Transportation is a major item in the marketing of these mineral products; consequently the producer locates his operation as close as possible to his market. Thus, sand and gravel producers are found in most of the cities of the State. When local sand and gravel is not available, crushed rock is manufactured or, in coastal ports, the material is barged from deposits along the shores of Puget Sound, utilizing low-cost water transportation.

Deposits of sand and gravel occur in every county of the State but vary both in quantity and quality. The general distribution of these

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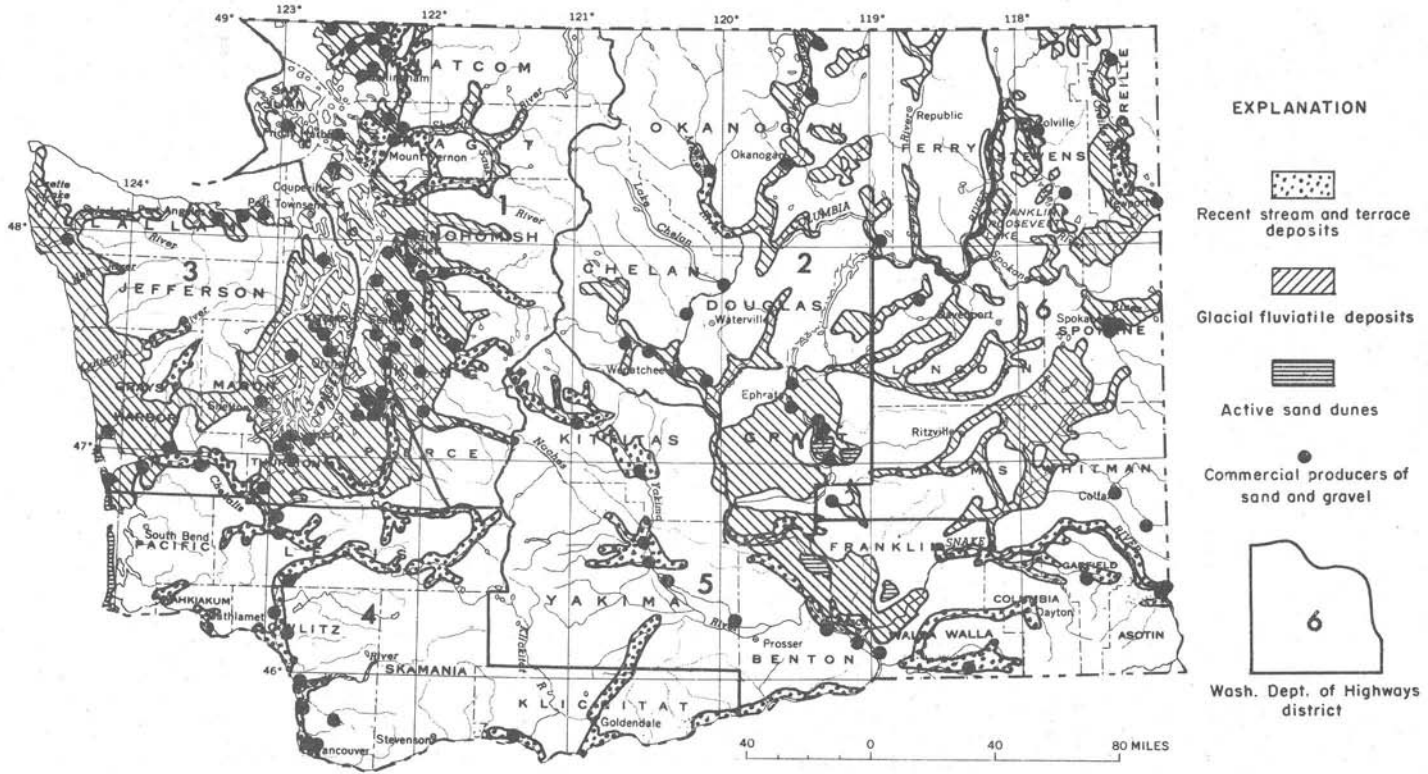

FIGURE 51.—Commercial producers of sand and gravel in Washington and boundaries of State highway districts.

deposits is shown in figure 51. Sand and gravel in Washington is mainly of glacial origin, having been formed as glacial moraines or as outwash material. The morainal material consists largely of heterogeneous accumulations of boulders, gravel, sand, silt, and clay that was carried along the base of the glacier or deposited along its margins. During the retreat and melting of the glacier, streams formed by melt water reworked much of the glacial debris and formed outwash deposits of sand and gravel. These fluvial glacial deposits are more homogeneous than the morainal deposits and are extensively worked for sand and gravel. In general, fluvial deposits occur in valleys where the valley is wide enough and has moderate to low grades that permit accumulation. In short narrow steep-graded valleys few significant deposits of sand and gravel accumulate. Terrace deposits left by streams as they cut their way to lower levels are fluvial deposits that are also sources of sand and gravel.

There are several definitions for sand and gravel. The sand and gravel producers define sand as unconsolidated granular material coarser than 200 mesh (0.074 mm.) and finer than one-fourth inch; gravel is unconsolidated granular material coarser than one-fourth inch and finer than 3½ inches. In large concrete masses such as dams the maximum size of gravel may be 6 to 8 inches. The largest proportion of gravel is made up of rock fragments; only minor amounts of pure minerals are present. In most sands, minerals such as quartz, feldspar, chert, and mica predominate over rock fragments. Most sand and gravel deposits contain varying amounts of silt, clay, as well as rock fragments larger than desired. These undesired materials in many cases must be eliminated to meet certain specifications The coarser material may be eliminated by screening or may be reduced to the proper size by crushing. Screening and washing equipment may be used to remove the silt or sticky clay. Many such plants are portable and moved from one job site to another.

The discussion of sand and gravel deposits of Washington which follows is limited to the construction class and does not include industrial sand. Discussions on some uses of industrial sand may be found in the chapters on silica sand and olivine. As a matter of convenience the sand and gravel deposits of the State are separated into six districts that coincide with the Washington Department of Highways districts (fig. 51).

District 1.—Deposits in Whatcom and Skagit Counties are widely scattered and limited in quantity. Some granular materials are found north of Bellingham in a recessional glacial moraine. Scattered eskers in the vicinity of Blaine and a morainal ridge that parallels the Canadian border are the major producers. Glacial till with high gravel content has been washed and crushed in this area to provide aggregate suitable for asphalt and concrete pavements. Gravel terraces, river bars, and deltaic deposits found along the Nooksack River are generally small and contain high percentages of the soft metamorphic rocks, thus making them unfit for use as mineral aggregate. However, they have been utilized for common borrow and gravel base.

Large deposits of sand and gravel derived from alpine glaciation are found along the upper reaches of the Skagit River. Particles of soft metamorphic rock also limit the use of these deposits as mineral aggregate. Continental glacial drift composed of hard subrounded gravel is present in the area of Sedro Woolley. Gravel sources south

and east of Mount Vernon consist of small widely scattered alluvial deposits.

The Stillaguamish River in Snohomish County contains large gravel bars that replenish themselves during high water. These bars are west of Arlington and contain hard-rounded gravel. Large reserves of gravel are present in the terraces southwest of Arlington.

The heavy population in King County, growth of housing developments, and construction of highways has virtually depleted the available aggregate sources in the urban area of Seattle. Those sources remaining are largely confined to the north-south-trending ridge east of Issaquah, large deltaic gravels southeast of Auburn, and the glacial outwash gravels in the vicinity of Kent. Many gravel terraces are evident near the shoreline of Vashon Island, indicating good potential for development.

District 2.—District 2 encompasses parts of three diverse physiographic regions; the rugged youthful topography of the Cascade Mountains in the western part, the subdued older landforms of the Okanogan Highlands in the northern part, and the level Columbia Basin in the southeastern part. Both alpine and continental glaciers have affected the mountainous areas, and the continental ice sheet covered most of the area north and east of Waterville in Douglas County. The deposits left by the glaciers are the major sources of aggregate in the northern half of the district.

North of Okanogan and Omak the gravels are generally shallow in depth, and the size of the particles is small. Southward to the confluence of the Okanogan and the Columbia Rivers the deposits are somewhat thicker and the reserves are substantial. The gravel occurrences along the Columbia River in Okanogan County are large, of excellent quality, and well sorted. The deposits occur as low-level terraces or ancient river bars. Potential resources of this material are large but will be substantially diminished in the future as many of the areas will be inundated by the construction of large dams on the Columbia River. Rhyolite and dolomite talus deposits have been used as aggregate sources in the highland area between the towns of Omak and Conconully because of the lack of sand and gravel. Another highland area where little or no gravel is found is the basaltic plateau in T. 31 N., Rs. 26 and 27 E.; basalt from quarries is the most suitable material available in this area. In Ferry County the production of aggregate is primarily from gravel terrace deposits; however, the gravels occur as thin cappings on top of other glacial debris. Along the Columbia River boundary of Ferry County the sources are limited to the gravel topping the high terraces, as the deposits at lower elevations have been covered by Lake Roosevelt. Roadway materials and commercial aggregate production in Chelan County is from glacial outwash deposits limited to the lower elevations of the major drainages. Deposits in the Wenatchee and Entiat River Valleys and the Lake Wenatchee areas have all proven to be shallow in depth and incapable of large yield per unit area. Gravel deposits along the Columbia River in Chelan County are quite extensive and have good depth; however, many of the deposits have been inundated by the lake behind Rocky Reach Dam. Real estate developments and fruit production have made other deposits unavailable. However, although limited, the reserves are adequate for many years at the present rate of production. Douglas County may be divided into

three general regions; glaciated plateau, nonglaciated plateau, and channeled scabland. Aggregate production in all of these areas has been almost entirely from basalt quarries. However, excellent sand and gravel deposits are found along the Columbia River and lower Moses Coulee in Douglas County as terrace and river bar deposits.

Sand and gravel in Grant County occurs in huge quantities in the deltaic deposits of lower Grand Coulee and Dry Coulee; also the deposits along the Columbia River between Vantage and Vernita contain vast quantities of material. With the exception of the channeled coulee areas, the aggregate produced in eastern Grant County is entirely from basalt quarries.

District 3.—In District 3 sand and gravel deposits derived from continental glaciation are practically limitless in quantity and almost all of excellent quality. Such deposits are particularly common in the eastern one-third of the district. The Kitsap Peninsula and the area south of Bremerton to Tacoma contain vast deposits of sand. Coarse gravels are sparsely distributed, however, occurring mostly as deltaic deposits that were formed in ice-marginal bodies of water. These deltaic deposits are also well developed along the west side of Hood Canal. A glacial outwash channel extends from the southern point of Hood Canal southwestward to Shelton and on to the tributaries of the Satsop River. Gravel deposits of good quality may be obtained over most of the channel. The very large outwash plain extending south and west from Tacoma to Olympia contains excellent sand and gravel deposits of almost unlimited quantity. At Steilacoom, within this area, an exceptionally large delta deposit is located. It was deposited by escaping water from glacial Lake Puyallup as it emptied into glacial Lake Russell. The gravel came from the glacier as well as from the large channel cut between the lakes. These materials were all deposited as an enormous delta that has served as a source of high-quality aggregate for more than 50 years. The quality of this material is so high that the Washington State Highway Department has set the compressive strength of portland cement concrete made with this material as a statewide standard of quality to which all other aggregates are compared. Another vast glacial outwash plain extends south and westward from Olympia to the Chehalis River. The deposits found in this area vary from pure sand to typical gravel-bar deposits, all of which provide high-quality construction material. The terraces found along the Chehalis River valley downstream to a point approximately 6 miles west of Elma contain large quantities of sand and gravel. However, because silts and clays are intermixed, the quality of this material is limited. Although several large rivers are found on the west side of the Olympic Peninsula, the sand and gravel deposited by them is of marginal quality because it is composed largely of soft sedimentary and metamorphic rocks from the Olympic Mountains. Some scattered deposits of sand and gravel are found along the northern edge of the Olympic Peninsula from Cape Flattery to Port Angeles, but because they contain generally some soft rocks, they are used only as fill materials. Eastward from Port Angeles the aggregate quality is better because of a much higher percentage of rocks of glacial origin. Quarry rock in this district is of only minor importance for uses other than large riprap material for two reasons. First, available quantities of excellent gravels in the eastern one-third of the district encompass virtually the

same area as the sound quarry rocks. Second, in the areas not richly endowed with good sand and gravel, the rock obtained from quarry sites is also of poor quality for use as any type of crushed aggregate.

District 4.—Sand and gravel deposits in District 4 may be divided into three groups: modern stream gravels, glacial outwash and terrace deposits, and older gravels which have undergone prolonged weathering.

Recent stream deposits in large quantities and of high enough quality for use in all crushed products and as concrete aggregate are confined to the channels, bars, and banks of only four rivers. The Tilton, East Fork of the Lewis, and the Columbia Rivers and the Cowlitz above the mouth of the Toutle River. Smaller deposits of good material are found along some of the smaller rivers, such as the lower Washougal, Nisqually, and many of the even smaller streams. Gravel deposits in the Toutle and Kalama Rivers, North Fork of the Lewis River and the Cowlitz below the mouth of the Toutle are composed of soft, lightweight, porous rock, and pumice sand suitable only for backfill and borrow materials. The Grays River gravels contain particles of soft shale; however, good quality gravel has been produced in areas of natural separation through an increase in the velocity of the river.

Deposits of glacial origin occur at various terrace levels along the Cowlitz and Columbia Rivers. Although these terraces contain huge quantities of sound gravel, many are very sandy or the gravel is coated with silt and clay, which necessitates washing. The use of dry scalping in strong dry winds is a very effective method of processing these materials from the terraces on the Columbia River in Klickitat County. Large deposits of outwash gravels derived from the Puget Sound glaciation are used in the vicinity of Centralia.

The usable older gravel deposits are confined to the Logan Hill Formation. This formation consists of rusty brown, well-rounded, iron-cemented, quartzite gravels with most of the sand and other fine material highly weathered. Remnants of this formation have been found in all counties of the district.

District 5.—Large quantities of high-quality sand and gravel as well as good quarry material are present in District 5. The major sources of alluvial gravels are the Yakima, Columbia, and Snake Rivers. Aggregate from these rivers is generally hard, well rounded, and of a mixed-rock type, with basic igneous rocks predominating. It is high-quality aggregate for all uses in construction.

Only one area in this district has shown any problem connected with the use of aggregate produced locally. The area from Keechelus Lake along the Yakima River to the town of Cle Elum has produced some materials of marginal quality, which contain metamorphic rocks and sandstones.

District 6.—North of the Spokane River, sand and gravel deposits are used almost exclusively for aggregate. These deposits are located along the Columbia, Kettle, Colville, and Pend Oreille Rivers, and through an area between Colville and Tiger. The deposits are very large recent river sediments that contain various rock types but do not include extrusive igneous rocks. There are, however, remnants of basalt in the Springdale Valley area of Stevens County that have been used as sources of road metal. The area roughly bounded by Sacheen Lake on the south, Tiger on the north, the Pend Oreille River

on the east, and a point about 5 miles east of Colville on the west, produces poorly sorted gravel that contains a high percentage of partially altered granite that tends to break into its individual mineral particles upon crushing.

South of the Spokane River the sources for construction aggregates are basalt gravels and basalt from quarry sites. The areas of gravel are roughly in a strip running southwest from Spokane to Washtucna and along the Crab Creek drainage. These gravels vary in quality from very good to poor. In areas where the gravels are lacking or of poor quality the crushed basalt is used. The basalt is exposed in all major drainages where the silt overburden has been removed by erosion.

SUMMARY

The sand and gravel resources of Washington are adequate for most present and near-future needs. State Highway Districts 2, 3, and 5 contain the largest reserves of high-quality sand and gravel, and in Districts 4 and 6 the deposits are scattered and of moderate size. The deposits of District 1 are scattered and limited in quantity.

In the metropolitan areas urban expansion is spreading into areas occupied by sand and gravel pits and aggregate plants. Zoning restrictions in these areas will force the closure of some operations, and relocation of these operations to rural areas will increase haulage costs. Large reserves of sand and gravel, especially in the Columbia Basin area, have been and are being depleted by flooding from hydro-electric developments and through the development of land by irrigation projects. Improved zoning regulations properly administered could be extremely helpful in conserving valuable sand and gravel resources for future use.

SILICA

(By A. E. Weissenborn and J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Silica (SiO_2, silicon dioxide) is the most abundant substance in the earth's crust. It commonly occurs in nearly pure form in silica minerals of the quartz group, but even more commonly it combines with other elements to form various silicates. Many of these enter into the composition of the rocks of the earth's crust.

Commercially valuable concentrations of silica are essentially monomineralic—they consist of some form of quartz with little or no dilution of other minerals. They occur in quartzite and sandstone, in quartz zones of pegmatites, in quartz veins and masses of hydrothermal origin, and in deposits of sand and gravel derived from quartz-bearing rocks.

This discussion is restricted to deposits of natural silica, generally of high purity, that are used for various industrial purposes. Because of its specialized use and rather distinct manner of occurrence, diatomite—another form of silica—is discussed in a separate chapter in this report. Use of sandstone and quartzite for building and construction materials is discussed in the chapter on stone. Sand and gravel for construction purposes is described in a separate chapter.

In some instances the silica of industry is derived from quartz sand, and the product can be used as mined with very little additional

preparation. Silica from other deposits must be crushed, screened, and washed, and sometimes chemically treated before it can be used. Even high-grade silica is a relatively low priced material; consequently only simple and inexpensive methods can be used to process off-grade material. Whether crushed or derived from natural sand, the commercial product is commonly known as silica "sand" or "pebble," depending on the size of the particles.

Industrial uses of silica fall into four main categories: abrasives, glass and chemical, metallurgical, and refractory. Specifications vary widely, depending on the use.

Abrasive uses include sandblasting, glass grinding sand, and similar uses. Uniform particle size is required, but great purity is not necessary as long as the sand is high in free silica.

As a raw material for the glass industry and for many chemical uses an extremely high purity is needed. For most of these uses, the content of alumina cannot exceed 0.2 percent, and lime, magnesia, and alkalies must be under 0.05 to 0.1 percent. For container glass, iron may be as high as 0.08 percent, but for the finer types of glass it may not exceed 0.02 percent. Uniformity of product is required, and specifications for particle size distribution are generally rigid.

For metallurgical use—preparation of silicon alloys or as a flux in making elemental phosphorus—specifications are nearly as high. For silicon alloys, alumina content must be under 0.4 percent; total iron cannot exceed 0.2 percent; and combined base oxides should not exceed 0.3 percent. Titanium should be held to a minimum, and phosphorus and arsenic must not be present even in trace amounts. Presence of opaline silica is undesirable. For making carborundum—one of the important uses in the State—the rock should contain more than 99.3 percent silica and no lime. For No. 1 grade material, alumina should be less than 0.15 percent. For No. 2 grade material, alumina should be under 0.70 percent. Specifications for use as flux in the production of elemental phosphorus are much more tolerant, and requirements for use as a flux in base-metal smelters are still lower.

For refractory use as various forms of foundry and moulding sands and for lining furnace bottoms and use as ganister mix, physical characteristics are more important than chemical purity.

Further details on specifications for various uses of silica sand, are given by Murphy (1960), from which most of the above was taken.

Prices for silica in the Pacific Northwest vary widely depending on the purity of the material and the use to which it is put, ranging from about $4 to nearly $8 per ton f.o.b. mine. Price of off-grade material is even lower. Price is a matter of negotiation between buyer and seller.

Complete statistics on production of industrial silica in Washington are lacking. According to the U.S. Bureau of Mines Minerals Yearbook, in 1963 the State produced 35,628 tons of glass sand valued at $254,703. Mueller [1] states that during the middle 1950's, annual consumption of industrial silica in the Pacific Northwest amounted to about 200,000 short tons per year, of which 50 to 75 percent came from Northwest deposits. About 70,000 short tons was used by glass manufacturers and 130,000 short tons was used by producers of

[1] Mueller, E. E., 1956, "Industrial Silica in the Pacific Northwest" (paper presented at Pacific Northwest Regional Minerals Conference, Am. Inst. Mining Metall. Petroleum Engineers, Seattle, Wash.).

silicon and silicon alloys. Companies in the Pacific Northwest that currently consume high-grade silica sand are listed below:

Principal companies consuming high-grade industrial silica in the Pacific Northwest (after Carter and others, 1962)

Company	Location	Product
Carborundum Co.	Vancouver, Wash.	Silicon carbide.
Electro Metallurgical Co.	Portland, Oreg.	Ferrosilicon.
Keokuk Electro Metals Co.	Wenatchee, Wash.	Ferrosilicon and silicon.
National Metallurgical Corp.	Springfield, Oreg.	Silicon.
Northwestern Glass Co.	Seattle, Wash.	Container glass.
Ohio Ferroalloys	Tacoma, Wash.	Ferrosilicon and silicon.
Owens (Illinois)	Portland, Oreg.	Container glass.
Philadelphia Quartz Co.	Tacoma, Wash.	Sodium silicate.

Washington sources of industrial silica are quartz zones in pegmatites; quartzite or sandstone beds, particularly in the Cambrian Addy Quartzite in Stevens County; and, to a lesser extent, deposits of silica sand.

For some years the State's major production of high-grade silica came from the Denison silica quarry, a large body of pegmatite quartz near Spokane (fig. 52, No. 14). This property produced industrial silica of exceptional purity until it was closed in 1957. From 1959 through 1961 the State's chief production was from a somewhat similar pegmatite quartz mass in gneissic granite on Quartz Mountain, Spokane County (No. 15). About 210,000 tons of high-grade silica was mined in the period. Some material containing more than 99.7 percent silica is reported to have been shipped, and much of it is said to have contained more than 99.3 percent silica. The mine was closed in 1962, but shipments continued from stockpiled material. A substantial tonnage of silica remains on the property, but most of the easily available high-grade silica rock has been removed.

In 1962 Lane Mountain Silica Co. began shipments of silica from the Addy Quartzite on Lane Mountain in Stevens County (No. 19). The material is used by glass and chemical plants; some was used for sandblasting. Manufacturers Mineral Co. produced silica from sand and gravel in the Chewelah area (No. 36) for foundry and refractory use and for grinding pebbles. Smith Bros. has produced silica for container glass from the weathered part of the Puget Formation from quarries near Auburn in King County (Nos. 31 and 32). Sandstone from the Swauk Formation at Wenatchee (Nos. 22 and 23) has been used as a source of foundry sand and as an additive in manufacturing portland cement. Glass sand has been recovered from sandstone in the Puget Group.

Deposits in the State that have produced industrial silica in recent years are listed in table 22. The locations of the deposits are shown on figure 52. A few undeveloped deposits with potential for moderate (over 100,000 tons) to large (over 500,000) tonnage of high-grade silica have been sampled by the U.S. Bureau of Mines. They are listed below and are plotted on figure 52.

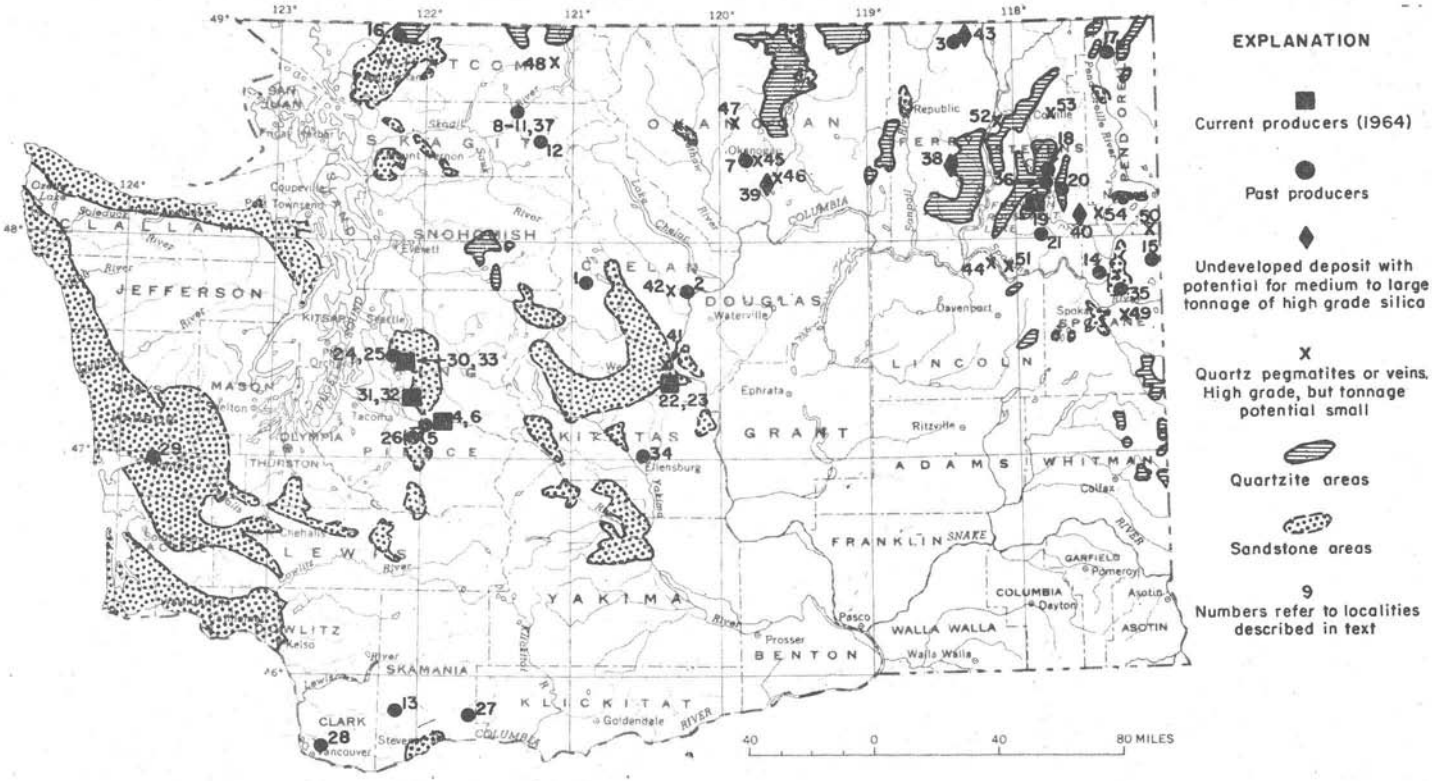

FIGURE 52.—Silica deposits in Washington.

Undeveloped deposits with potential for moderate to large tonnage of high-grade silica (after Carter and others, 1962)

Index No. on fig. 52	County and name	Type of deposit	Analysis (percent SiO_2)
38	Ferry: Lynx Creek	Quartzite in Covada Group. Good potential but would require selective mining.	91.1–98.7
39	Okanogan: Twin Lakes claim	Pegmatitic quartz mass. Medium-tonnage deposit of good grade silica.	99.7
40	Stevens: Blue Grouse Mountain	Quartz dike. Medium-tonnage deposit. Would require selective mining or beneficiation.	99.4

Numerous small but high-grade quartz pegmatites or "bull" quartz veins have been sampled by the U.S. Bureau of Mines. They are listed below and also are shown on figure 52:

Index No. on fig. 52	County	Name	Index No. on fig. 52	County	Name
41	Chelan	Burch Mountain.	48	Skagit	Mineral City.
42	do	Harris Creek.	49	Spokane	Empire granite quarry.
43	Ferry	Independent Mountain.	50	do	Glander.[1]
44	Lincoln	Egypt.	51	Stevens	Big Smoke.
45	Okanogan	Loup-Loup.	52	do	Geisbauer.
46	do	Moly-quartz pegmatite.	53	do	Keely.
47	do	Snow White.	54	do	Steinmetz.

[1] May be a quartzite bed in Precambrian gneiss.

There is a strong demand in the Pacific Northwest for high-purity silica rock. Resources of silica in the State are very large, but deposits that can meet the exacting requirements of the glass, chemical, and electrometallurgical industries are scarce. Much of the past production has come principally from large, very pure quartz bodies of pegmatitic origin, but a considerable amount has come from quartzite or sandstone, or sand derived from the weathering of these rocks. Most of the known undeveloped pegmatite deposits are either too small or are not sufficiently pure to supply the needs of the silica industry, but some may be suitable for the production of high-grade silica. Persistent search could discover other deposits. Present production of high-grade silica is coming from a few quarries in the Addy Quartzite. The Addy Quartzite occupies over 250 square miles in Stevens County and may be pure enough to provide high-grade silica rock at other places than those now being worked. Other sandstone and quartzite deposits underlie many hundreds of square miles of the State (fig. 52). In most places they are too impure to be valuable for the better grades of industrial silica. However, they have been sampled and examined in detail in only a few places. Careful investigation could uncover areas containing valuable deposits of high-grade industrial silica. High-grade silica is being shipped into the Pacific Northwest from points as far away as Montana and Minnesota. The freight differential in favor of the local product offers the possibility of upgrading silica that does not quite meet specifications. Not all deposits would be amenable to this procedure but in some instances in may be feasible.

TABLE 22.—*Producers of silica*

MASSIVE QUARTZ

Index No. on fig. 52	Property and location	Remarks	Reference
	CHELAN COUNTY		
1	Merritt, sec. 6, T. 26 N., R. 16 E.	Lenses of pegmatitic quartz in schist. Mined for use in ferrosilicon.	Valentine, 1960.
2	Winesap area, T. 26 N., R. 21 E.	Pegmatitic quartz mass. Produced crushed quartz in 1952 and 1953.	Purdy, 1953.
	FERRY COUNTY		
3	Orient area, sec. 36, T. 40 N., R. 35 E.	Silica produced in 1959.	Thorsen, 1959.
	KING COUNTY		
4	White River, sec. 1, T. 19 N., R. 7 E.	Completely silicified andesite. Quarried for making silica brick.	Valentine, 1960.
5	Superior, sec. 7, T. 19 N., R. 7 E.	Completely silicified andesite. Quarried by cement company.	Do.
6	Denny Renton, sec. 1, T. 19 N., R. 7 E.	Completely silicified andesite. Operating since 1959.	Thorsen, 1963.
	OKANOGAN COUNTY		
7	Buzzard Silica, sec. 6, T. 33 N., R. 25 E.	Massive quartz. Produced silica 1959–60.	Thorsen, 1961.
	SKAGIT COUNTY		
8	Marblemount, sec. 10, T. 36 N., R. 11 E.	Lenses of quartz in slaty schist. Used in cement blocks as "self-sharpening burrs."	Hodge, 1938a.
9	Stoner, sec. 10, T. 36 N., R. 11 E.	Lens of quartz in schist. Has been quarried by several organizations.	Popoff, 1949.
10	Silica Camp, sec. 15, T. 36 N., R. 11 E.	Large quartz lens in schist. Quarried in 1943.	Valentine, 1960.
11	Scheel, sec. 16, T. 36 N., R. 11 E.	Quartz veins in dark green schist. Quarried for silica and pulp stone.	Popoff, 1949.
12	Bear Creek Claims, sec. 31, T. 35 N., R. 13 E.	Massive quartz. Produced in 1960.	Thorsen, 1961.
	SKAMANIA COUNTY		
13	Lookout Mountain, sec. 13, T. 4 N., R. 5 E.	Quartz vein in andesite. In production 1960.	Do.
	SPOKANE COUNTY		
14	Denison, sec. 14, T. 27 N., R. 42 E.	Pegmatitic quartz in granite. Produced silica of remarkable purity for many years. Now exhausted.	Valentine, 1960.
15	Quartz Mountain, sec. 35, T. 28 N., R. 45 E.	Pegmatitic quartz in granite gneiss at border of intrusion. Produced 210,000 tons high-grade silica from 1959–62. Large tonnage remains, but most of easily recovered high-grade silica has been mined.	Carter and others, 1962.

	WHATCOM COUNTY		
16	Olympic, sec. 17, T. 40 N., R. 5 E.	Lens of massive quartz in greenstone. Used as retarding agent in cement.	Hodge, 1938a.

QUARTZITE

	PEND OREILLE COUNTY		
17	Metaline Falls, sec. 27, T. 39 N., R. 43 E.	Production from Gypsy Quartzite. Used in manufacture of portland cement.	Valentine, 1960.
	STEVENS COUNTY		
18	Chewelah, sec. 4, T. 32 N., R. 40 E.	Light gray Addy Quartzite	Carter and others, 1962.
19	Lane Mountain, sec. 34, T. 31 N., R. 39 E.	Production from Addy Quartzite. Supplies silica for glass, chemical, and metallurgical plants, and for sandblasting, foundry sand, and other uses.	Carter and others, 1962; Thorsen, 1963.
20	Cottonwood Creek, sec. 6, T. 31 N., R. 41E.	Gray to pink, hard Addy Quartzite. Worked in 1957	Carter and others, 1962.
21	Lyons Hill, sec. 13, T. 29 N., R. 39 E.	Easily disaggregated quartzite of high purity. In production 1952, 1953, 1957, and 1958.	Do.

SANDSTONE

	CHELAN COUNTY		
22	Brown Quarry, sec. 22, T. 22 N., R. 20 E.	Swauk Formation. Yields marketable silica on crushing for use in foundries and cement plants.	Glover, 1936a; Valentine, 1960.
23	L-D mines, sec. 21, T. 22 N., R. 20 E.	Silica from Swauk Formation. Shipped in 1964 for use in manufacture of portland cement.	Huntting (written communication, 1965).
	KING COUNTY		
24	Renton mine, sec. 17, T. 23 N., R. 5 E.	Puget Group, sandstone from coal mine. Used in glass factory	Evans, 1912.
25	Renton Junction, sec. 19, T. 23 N., R. 5 E.	Iron-stained sandstone. Washed sand used in glass factory in 1942	Valentine, 1960.
	PIERCE COUNTY		
26	Walker Quarry, sec. 27, T. 19 N., R. 6 E.	Arkosic sandstone. Used for grindstones, pulpstones, and as building stone.	Do.
	SKAMANIA COUNTY		
27	Wood Bros. quarry, sec. 26, T. 4 N., R. 9 E.	Interbasalt sandstone. Used for whetstones and as building stone	Do.

TABLE 22.—*Producers of silica*—Continued

SILICA SAND

Index No. on fig. 52	Property and location	Remarks	Reference
	CLARK COUNTY		
28	Wilde, sec. 7, T. 2 N., R. 2 E.	Silica sand. Molding sand produced 1947 to 1959	(1).
	GRAYS HARBOR COUNTY		
29	West Aberdeen, sec. 10, T. 17 N., R. 9 W.	Produces foundry sand	Valentine, 1960.
	KING COUNTY		
30	Cavanaugh, sec. 30, T. 23 N., R. 6 E.	Weathered Puget Group. Considerable production from 1948 to present.	(1).
31	Smith Brothers, sec. 28, T. 21 N., R. 6 E.	Weathered material from Puget Group; washed and used for manufacturing brown bottles.	Valentine, 1960.
32	Smith Brothers, sec. 30, T. 21 N., R. 7 E.	do	Huntting (written communication, 1965).
33	Wilde, sec. 29, T. 23 N., R. 6 E.	Weathered sandstone of Puget Group. Molding sand produced	Valentine, 1960.
	KITTITAS COUNTY		
34	Ellensburg, sec. 36, T. 18 N., R. 18 E.	Clayey sand. Used for foundry sand	Glover, 1936a.
	SPOKANE COUNTY		
35	Mead, sec. 13, T. 26 N., R. 43 E.	Silica sand produced in past	Valentine, 1960.
	STEVENS COUNTY		
36	Chewelah, secs. 21 and 28, T. 32 N., R. 40 E.	Grinding pebbles and loose silica sand. Used as filter and molding sand.	Do.
	SKAGIT COUNTY		
37	Scheel, sec. 10, T. 36 N., R. 11 E.	Silica produced for furnace and molding sand	Thorsen, 1963.

[1] Data from Directories of Washington mining operations; (issued annually by Washington Div. Mines and Geology).

Few natural sand deposits in the State have produced high-grade silica. Further search seems justified, but the chances of a large discovery of high-purity silica do not appear as good as in the quartzites. The possibility of the discovery of deposits suitable for foundry sand or for abrasive sand would seem to be fairly good.

STONE, INCLUDING LIMESTONE AND DOLOMITE

(By W. S. Moen, Washington Division of Mines and Geology, Olympia, Wash.)

The principal products of the stone industry are dimension stone and crushed and broken stone. Dimension stone consists of cut stone, rough building stone, ashlar (hewn or squared stone), rubble, monumental stone, paving blocks, curbing, and flagging. Crushed and broken stone consists of large irregular fragments of rock that are crushed or ground to smaller size. The major uses of dimension stone and crushed and broken stone in the United States and Washington are shown in figure 53.

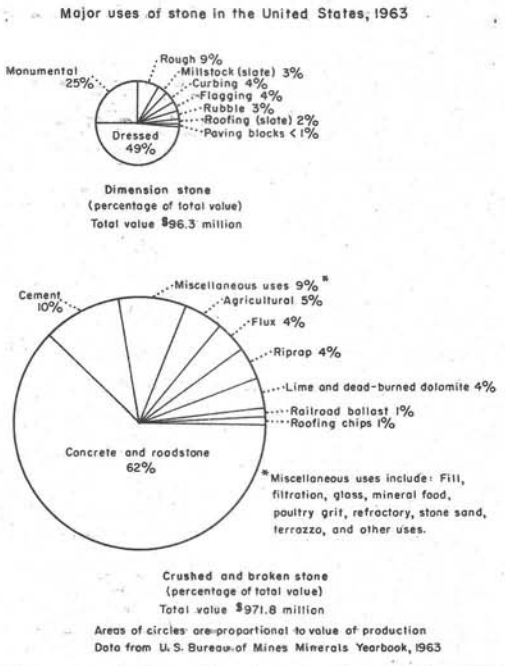

FIGURE 53.—Major uses of dimensionst one and crushed and broken stone in the United States, 1963.

In 1963, the domestic production of crushed and broken stone was 686 million tons worth $971.8 million. Also during 1963, over 2.6 million tons of dimension stone valued at $96.3 million was produced (Cotter, 1964, p. 1045). Washington during 1963 produced 12.9 million tons of crushed and broken stone and dimension stone worth

$16.3 million and ranked 25th in stone production. Stone production in Washington from 1954 to 1964 is shown in figure 54.

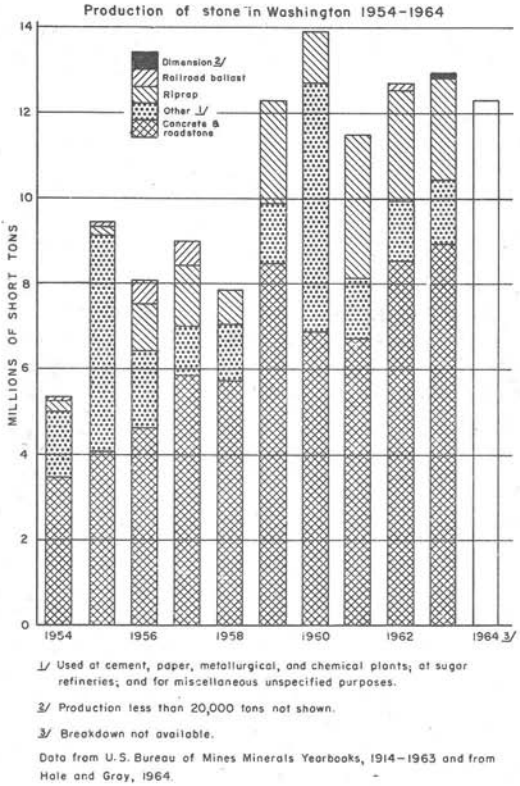

FIGURE 54.—Stone production in Washington, 1954–64.

Large resources of basalt and andesite, granite, sandstone, limestone and marble, and quartzite are present in Washington. Much of this rock is suitable for crushed and broken stone and building stone and can supply many of the demands of the State's stone industry. Because of the low price of rough stone, very little is shipped out of the State. However, markets do exist in other states for stone products such as cut stone, and crushed marble in the form of terrazzo and roofing chips. The demand for stone is greatly influenced by building trends. Because of the steady industrial and residential growth that is taking place in Washington, the market outlook for stone appears favorable.

In 1964 stone was quarried in 37 of the State's 39 counties. Sixty-five percent of the stone consisted of basalt and andesite that was used mainly for concrete aggregate, roadstone, riprap, and road ballast. In order of decreasing production, the other major rock types used in Washington were limestone and marble, sandstone, and granite. Figure 55 shows the locations of quarries that produced these rocks as well as the general distribution of the various rock types in the State.

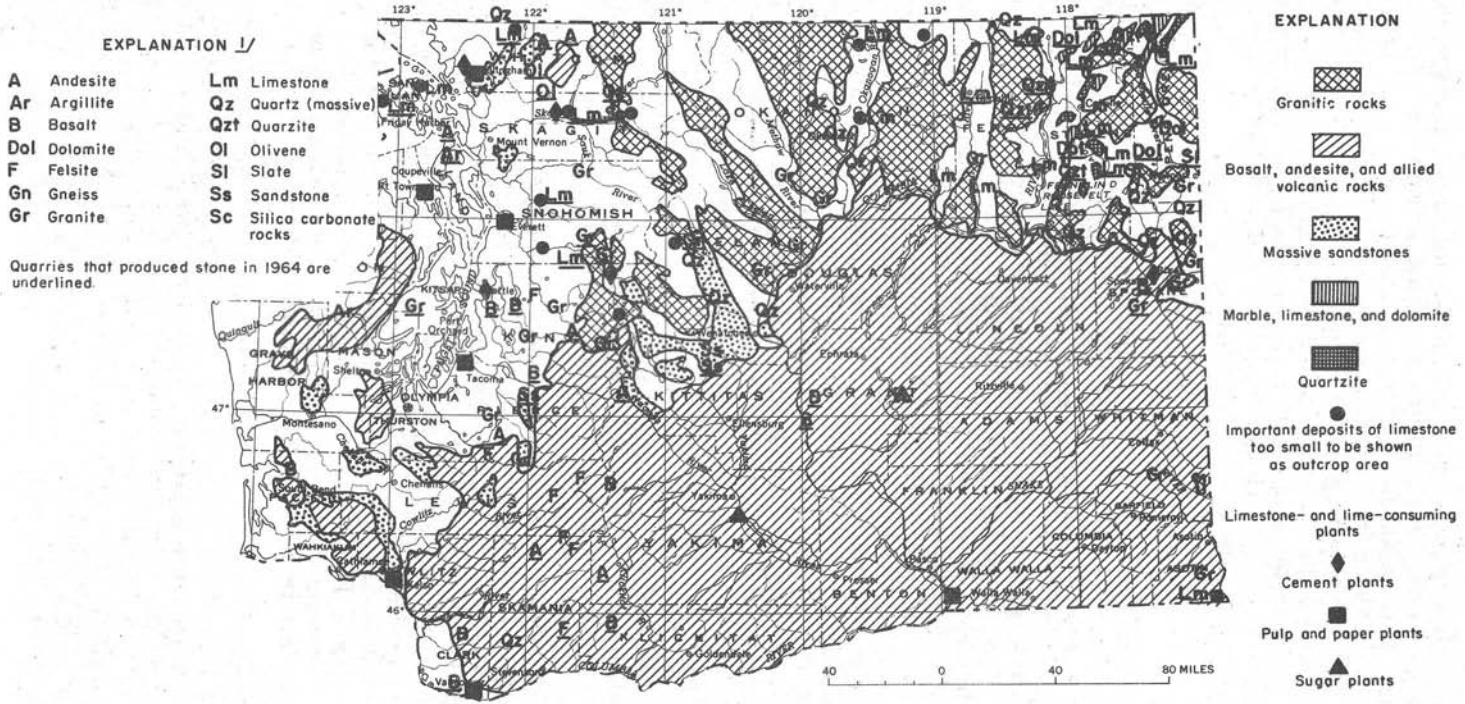

FIGURE 55.—Stone quarries in Washington.

55-883 O—66——18

Certain physical and chemical properties are important in the selection of stone. For concrete aggregate; roadstone; and riprap; properties such as hardness, strength, and porosity are important. When used in the manufacture of concrete and lime; as furnace flux; and for agriculture purposes; the chemical composition of the rock is more important than its physical character (Bowles, 1934, p. 378). For use as dimension stone; uniform texture and grain size, attractive color, freedom from cracks, workability, and stability of the rock-forming minerals are desirable qualities.

BASALT AND ANDESITE

Over 50 percent of Washington is underlain by basalt and andesite of Tertiary age. Basalt and andesite are fine-grained volcanic rocks that are composed mainly of plagioclase feldspar (sodium calcium aluminum silicate) and pyroxene (magnesium iron silicate). Fine-grained, dark colored rocks such as basalt and some andesite are called "trap" by the stone producers. Although "trap" is commonly used for concrete aggregate, roadstone, riprap, and ballast, most of it is not particularly attractive when used as building stone.

Basalt that is used for building stone generally contains brownish-red or yellowish-brown iron oxide stains that provide color to the otherwise monotonous dark tone of the rock. If basalt possesses platy jointing, it can be quarried for use as flagstone and other decorative purposes. Some light-colored andesites are used as building stone. In Washington, andesite in shades of gray and green is widely used as rubble and rough building stone. Fine-grained light-colored volcanic rocks that contain mainly potash feldspar and quartz are called felsite. Felsite is often associated with volcanic rocks such as andesite and basalt but is not as abundant. Several quarries produce felsite in Washington for uses such as rubble, rough building stone, ashlar, and fireplace mantles. Many felsites show attractive patterns in shades of red, brown, and yellow that are caused by iron oxide staining on fracture surfaces.

In 1963 the major production of basalt came from Clark, Jefferson, King, Lewis, Pierce, Snohomish, Spokane, and Whitman Counties. Pierce, Skamania, Skagit, Yakima, and Whatcom Counties were the major producers of andesite. Small amounts of felsite, all of which was used as building stone, came from Lewis, Pierce, and Skamania Counties. The production of basalt, andesite, and felsite in Washington during 1963 was 10.5 million tons valued at $12.3 million (Cotter, 1964b, p. 1058).

MARBLE, LIMESTONE, AND DOLOMITE

Marble and limestone are composed mainly of calcium carbonate ($CaCO_3$) with variable amounts of magnesium carbonate. In addition, impurities such as iron carbonate and manganese carbonate are often intimately mixed with the calcium carbonate. They originated from chemical precipitation and biological reactions and were deposited as sediments mainly in lakes and shallow seas. The limestones of Washington are mainly of marine origin, having been deposited on the bottom of the seas chiefly during middle and late Paleozoic time. The term "marble" applies to limestone that has

been recrystallized by heat or pressure into a metamorphic rock. The calcite grains in marble are larger than those in limestone, and any impurities that were present in the original rock tend to be spread out into wavy streaks. The streaking of the marble produces the varicolored "marbling" of many ornamental marbles. However, in the stone trade, the term "marble" is applied to any limestone that takes a polish. Dolomite is a calcium-magnesium carbonate ($CaMg(CO_3)_2$) that is commonly associated with limestone. In Washington, deposits of dolomite are quarried mainly for use as building stone.

Approximately 95 percent of the marble, limestone, and dolomite produced in Washington is crushed and used by cement plants, sugar refineries, and pulp and paper plants, or is utilized as agriculture limestone, and as terrazzo and roofing chips. The remaining 5 percent is used in lump form as rubble and rough building stone. In 1963 Washington produced about 2.3 million tons of crushed limestone and marble valued at $3.8 million (U.S. Bur. Mines unpublished figures).

The largest consumer of crushed limestone in Washington is the cement industry, which in 1963 consumed 1.1 million tons of limestone valued at $1.7 million. The cement companies in operation at present (1965) are: Ideal Cement Co., with plants at Grotto in King County and Irvin in Spokane County; Lehigh Portland Cement Co., with a plant at Metaline Falls in Pend Oreille County; Lone Star Cement Corp., with plants at Seattle in King County and at Concrete in Skagit County; and the Olympic Portland Cement Co., with a plant at Bellingham in Whatcom County (fig. 55). About 90 percent of the limestone consumed by these plants is produced in Washington; the remaining limestone comes from British Columbia, Canada, to supply the plants at Seattle and Grotto.

The CaO content of limestone used in the manufacture of cement may be as low as 75 percent but 85 to 90 percent CaO is preferred. The limestone should contain less than 3 percent MgO; silica and alumina are desired impurities. In addition to limestone, large amounts of clay, shale, and argillite are used in the manufacture of cement. Some limestones, such as those used by the cement plant at Concrete, contain the proper proportions of argillaceous, siliceous, and ferriferous material. This is known as cement rock and contains a natural mixture of the necessary minerals needed for the manufacture of cement.

The pulp and paper industries are the second largest consumers of limestone in Washington. In 1963, nine plants in the State used substantial amounts of limestone and lime in the manufacture of paper. The locations of these pulp and paper plants of Washington are shown in figure 55. The specifications for limestone used in the manufacture of paper vary. Limestone having the following composition would probably satisfy most requirements: $CaCO_3$, not less than 95 percent; MgO, less than 3.0 percent; SiO_2, less than 1.5 percent; and total iron, less than 0.5 percent (Mills, 1962, p. 31). The amount of limestone consumed cannot be revealed, but 388,040 tons of quicklime and hydrated lime valued at $8,158,190 was used.

The third major consumer of limestone in Washington is the sugar industry. A moderate amount of quicklime is consumed by the Utah-Idaho Sugar Co. at plants near Moses Lake in Grant County and at

Toppenish in Yakima County (fig. 55). At these plants, the limestone that is used to manufacture lime is supplied by producers in Canada. The limestone used in the refining of beet sugar must contain not less than 97 percent $CaCO_3$, not more than 2.5 percent MgO, and not more than 1.0 percent SiO_2. Even if the limestone meets these requirements, it must be subjected to use-tests before its suitability for sugar refining can be determined.

Most of the lime consumed in Washington is supplied by out-of-State producers, but Pacific Lime, Inc., of Tacoma, manufactures a small amount of quicklime and hydrated lime for local use. However all of the limestone consumed by this plant is supplied from deposits 200 miles north in British Columbia, Canada.

In 1963 the production of limestone and dolomite in the State for agricultural purposes was 3,383 tons valued at $6,931. Powdered limestone or dolomite is added to the soil to replenish calcium and magnesium and to correct soil acidity. In addition, limestone and dolomite contain small amounts of trace elements such as manganese, copper, zinc, boron, cobalt, and molybdenum, which are essential to plant growth. Agriculture limestone may contain as little as 75 percent $CaCO_3$, but 90 percent or more $CaCO_3$ is preferred.

Limestone and dolomite are also used as a fluxing stone in the smelting of iron and other metals. The main purpose is to supply CaO and MgO, which combine with undesirable constituents in the ores to form slag that can be separated from the molten metal. Limestone for the steel industry should contain less than 3 percent SiO_2, if used in blast furnaces; the MgO content is not critical. For use in open-hearth furnaces, the chemical requirements are more critical. Silica must be less than 2 percent, and not more than 5 percent magnesia should be present. For both blast and open-hearth furnaces, the fluxing stone should contain no more than 0.01 percent phosphorus (P_2O_5) and 0.05 percent sulfur. Limestone flux for copper and lead smelting is used when the ores are more acidic than basic. For this purpose, a high-calcium limestone with low silica is required (Mills, 1962, p. 28). Dolomite from deposits near Riverside in Chelan County has in the past been used as flux by Bethlehem Steel Co. at their plant in Seattle. As recently as 1963, quarries near Northport in Stevens County supplied limestone for the smelting of lead and zinc ores at Trail in British Columbia, Canada.

Other uses of limestone in Washington, exclusive of dimension and building stone, include: poultry grit, road metal, riprap, ballast, fertilizer filler, and the manufacture of glass.

To a large extent, the limestone-consuming industries of Washington, with the exception of the cement industries, are dependent upon out-of-State sources. In 1959, according to the Washington Department of Commerce and Economic Development, 65 percent of the limestone used in the State was mined outside the State. Only 12 percent of the limestone used by the pulp and paper, steel, and sugar industries was produced in Washington.

Limestone, marble, and dolomite that are used as building stone come mainly from quarries in Stevens and Pend Oreille Counties. These counties contain the most extensive deposits of calcium carbonate rocks in the State (fig. 55). Considerable "marble" was produced in former years for building stone, trim, and monuments, mainly from quarries in Stevens County. Later it was realized that

the stone was not marble but magnesite ($MgCO_3$). Today the magnesite is quarried for use as a refractory. (See chapter on magnesite.) The predominant colors of limestone and dolomite are gray and white, although shades of red, green, yellow, and blue are abundant. These colors make an attractive stone for roofing and decorative uses. Stevens County is a center of a small but thriving industry that produces crushed limestone, dolomite, and marble for terrazzo, stucco dash, and roofing chips. Plants for this purpose are near Northport and at Addy and Valley.

GRANITE

The term "granite," as used in the stone industry, includes true granite, granodiorite, quartz monzonite, quartz diorite, gabbro, and gneiss. In Washington, granitic rocks, mainly of Mesozoic and Tertiary ages, occur in 22 counties of the State. The granitic rocks are confined mainly to the north half of the State in Whatcom, Skagit, Snohomish, King, Chelan, Okanogan, Ferry, Stevens, Pend Oreille, and Spokane Counties (fig. 55). Nearly 8,000 square miles of the State are underlain by granitic rocks, but not all the granite is suitable for use as building stone, and much of the area is too remote and inaccessible to permit the stone to be utilized. Since the opening of the first granite quarries in the late 1880's, at least 20 quarries have produced granite at one time or another. These quarries have never operated on as large a scale as the granite quarries of the eastern States, and most of the production has been sporadic. Spokane, Chelan, Snohomish, and King Counties have been the major producing counties of the State.

The major uses for granite in Washington include riprap, roadstone, and poultry grit. Production of these commodities in Washington during 1963 amounted to about $930,000, most of which came from quarries in Chelan, Douglas, King, Kittitas, Okanogan, and Spokane Counties. Rubble and rough building stone were produced intermittently from several small quarries, but production figures are not available. During 1963 only one quarry was in operation. This quarry, the Keene & Son Monumental Co. quarry near Medical Lake in Spokane County, produced a limited amount of monumental granite. Intermittent production in the past has come from the Empire Granite quarry at Dishman in Spokane County.

SANDSTONE

Sandstone from quarries in western Washington was one of the first rocks to be quarried in the State. From 1889 to 1935, large amounts of sandstone were produced from 21 quarries in Whatcom, King, Pierce, and Thurston Counties. The first State Capitol of Washington, as well as important buildings in the larger cities along the west coast, was constructed from sandstone quarried near Bellingham and Tenino. The sandstone was also used as flagging and monumental stone and in the construction of culverts and bridges. By 1935 the use of sandstone in buildings declined, having been replaced by brick, concrete, and terra cotta. In 1964 only three quarries produced sandstone commerically for building purposes.

The Wilkeson quarry at Wilkeson in Pierce County was the only producer of structural and ornamental sandstone in the State. Other stone products from this quarry included ashlar, flagstone, rubble, and mantles. On the east side of the Cascade Mountains, two small quarries near Liberty in Kittitas County produced small amounts of rubble, natural ashlar, and flagstone. The total production of sandstone, which was used as building stone in Washington during 1963, was about 4,200 tons valued at $202,000 (Cotter, 1964b, p. 1052).

The sandstone deposits of Washington, from which suitable building stone has been quarried, occur mainly in western Washington (fig. 55). These deposits are of early and middle Tertiary age and consist mainly of continental arkosic sandstones. When freshly broken, they are bluish gray, but upon weathering most of the sandstones become tan or buff. Sandstones from quarries in Kittitas County exhibit a wider variety of colors than those of Whatcom, King, Pierce, and Thurston Counties. Common colors of Kittitas County sandstones are green, red, and brown. Staining by iron oxides produces attractive patterns on some of the stone.

QUARTZITE

In Washington, quartzite has not been used as widely as limestone and marble, granite, and sandstone for building purposes. Only during the past 5 years has there been any noticeable production of quartzite in the State. Deposits of quartzite for use as building stone are confined to northeastern Washington, mainly in Ferry and Stevens Counties (fig. 55). Although many deposits of quartzite occur elsewhere in the State, most of them are not particularly attractive for use as building stone. They lack the color or the workability, or both, required of quartzites. Flagstone is being produced in Ferry County from several deposits of platy quartzite near Kettle Falls. The quartzite contains flakes of mica on its cleavage surfaces, and iron oxide stains in shades of red, yellow, and brown provide attractive patterns and colors to the rock. The annual production from these quartzite deposits is about 1,000 tons valued at $18,000.

In addition to building stone, quartzite is also used as grinding pebbles and in the manufacture of glass. Near Chewelah in Stevens County, small amounts of quartzite pebbles and cobbles are produced yearly from a gravel pit. The pebbles and cobbles range from a quarter of an inch to 3 inches in diameter and are used for grinding ores, ceramic minerals, and other substances. High-purity quartzite used for the manufacture of glass and in the electrochemical industry is discussed in the chapter on silica.

OTHER BUILDING STONES

Other rocks have been used as building stone in Washington, but the production has generally been small and erratic. Gneiss, schist, green-stained silica carbonate rock, quartz, and tuff are used as rubble or flagging. Platy argillite and siltstone that resembles slate are quarried for use as flagstone and as veneer on walls. Deposits of massive white quartz yield stone that is used for roofing chips and exposed aggregate.

In summary, the amount of basalt and andesite, granite, and sandstone in Washington available to industry is virtually unlimited. The State has numerous deposits of marble, limestone, dolomite, and quartzite suitable for use as building stone, although rocks in colors other than gray, white, or black are much less abundant. New sources of limestone suitable for the electrochemical industry, for smelter flux, and for the manufacture of cement are not abundant in western Washington, but large reserves of good quality limestone are available in the eastern part of the State. The dolomite deposits are not as extensive as the limestone deposits, but substantial reserves of dolomite occur in eastern Washington (Bennett, 1944; State of Washington, 1945).

TALC AND SOAPSTONE

(By J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Talc is a mineral with the composition $Mg_3(OH)_2Si_4O_{10}$; it is very soft, has perfect basal cleavage with the laminae flexible and somewhat elastic. Commercially, "talc" consists of the mineral talc mixed with a number of other minerals, such as chlorite, sericite, tremolite, calcite, and dolomite. When massive, and usually with one or more of the above impurities it is called soapstone. Talc has a wide variety of uses in our civilization, some of which are fairly obvious—talcum powder, chemical sinks, marking crayons—and many more in which it is less obvious but essential. A special variety known as "block steatite" or "lava talc" is used in the electronic industry to support elements in vacuum tubes because it is a nonconductor, can be machined into definite shapes, and does not shrink on firing. Talc is also used for making pottery and tile and is used extensively as a filler in rubber, paint, paper, and insecticides. The two largest uses are in ceramics and in paint. The U.S. Bureau of Mines Minerals Yearbook for 1963 lists at least 21 types of uses. Another mineral with similar properties, pyrophyllite $(Al_2(OH)_2Si_4O)_{10}$, will not be discussed here as no deposits of economic value are known in the State.

The average annual consumption of talc and soapstone for the years 1961, 1962, and 1963 is 634,207 tons. The United States is self-sufficient in talc except for block steatite. In 1963, talc and soapstone were produced by 65 mines in 13 states; New York, California, and North Carolina were the leading producers. Washington ranked seventh with a production of 2,969 tons valued at about $18,000.

Talcose rocks, being high in magnesium, are formed in two different geologic environments—either by hydrothermal alteration of ultramafic rocks during strong dynamic disturbance, or by contact metamorphism of sedimentary rocks high in magnesium, such as dolomite and dolomitic limestone. Both types of deposits exist in Washington. They are either in older dolomitic rocks near intrusive contacts, or near the edges of serpentine bodies. Twenty-seven occurrences are listed by Valentine (1960), of which some are quarries and mines, and others are prospects in areas of favorable geology. Deposits that have had production during the last 10 years are limited to Skagit

County, mostly near Marblemount. Properties from which talc and soapstone have been produced in recent years are listed below:

Operator	*Location*
Otto Binchus	Marblemount area: Sec. 15, T. 36 N., R. 11 E.
Cascade Talc & Silica Co.	Cascade River: Secs. 21 and 22, T. 35 N., R. 12 E.
Martin & Pressentin	Marblemount area: Secs. 10 and 15, T. 36 N., R. 11 E.
Northwest Talc & Magnesium.	Clear Lake area: Sec. 17, T. 34 N., R. 5 E. Wilson Quarry: Sec. 21, T. 36, N., R. 11 E.
Norman Scheel	Marblemount area: Sec. 10, T. 36 N., R. 11 E.
Skagit Talc Products	Marblemount area: Secs. 11, 14, and 21, T. 36 N., R. 11 E.
Herman Smith	Marblemount area: Sec. 16, T. 36 N., R. 11 E.

The talc and soapstone deposits in the vicinity of Marblemount occur in a complex of greenschist, derived from mafic volcanic rocks, and of serpentine. Both the schist and the serpentine have been metamorphosed by intrusive granodiorite of pre-Carboniferous age (Glover, 1936a). Both ground talc and dimension soapstone are produced from these deposits. Some of the soapstone is of high enough quality to be usable as "lava talc."

Mineral Fuels Resources

COAL

(By H. M. Beilkman and H. D. Gower, U.S. Geological Survey, Menlo Park, Calif.)

Coal is plant material that accumulated in swamps, was buried, and subsequently transformed into a mineral fuel by geologic processes that chemically and physically altered the original plant remains. The relative amount of change that has taken place in the coal is designated by its rank, which is based on the ratio of fixed carbon to volatiles and physical properties of the coal. Lignite, the lowest rank of coal, has undergone the least change and retains a woody or fibrous texture. Anthracite, the highest rank coal, has undergone the most change and is nearly pure carbon. Subbituminous and bituminous coals are intermediate between lignite and anthracite.

The principal coal deposits of Washington are subbituminous and bituminous coals, with some small deposits of lignite and anthracite. Both subbituminous and bituminous coal burn readily and can be used for household heating, industrial plants, and as fuel in plants that generate electricity with steam. The coal deposits of Washington therefore constitute a substantial supply of energy that is easily available to supplement hydroelectric power, petroleum, and natural gas should these sources of heat and energy become inadequate to meet increasing demands.

Coal has been known to occur in Washington since the early days of settlement and by 1870 all the major occurrences as they are known today had been discovered. A total of 150 million tons of coal has been produced in the State. The annual coal production and cumulative production by county are shown on figures 56 and 57. Coal production was at its greatest during the first decades of the twentieth century when coal was used as a domestic fuel and for railroad operations. The peak of production was reached in 1918 when more than 4 million tons of coal was mined. In the 1920's production had begun to decline because of increased use of oil as a fuel, availability of low-cost hydroelectric power, and increased imports of coal from Wyoming and Utah. In 1964, production for the State was about 69,000 tons.

The coal-bearing rocks in Washington occur in relatively small areas separated by expanses of older non-coal-bearing rocks or by a cover of younger rocks (fig. 58). Most of the principal coal deposits are in the western one-third of the State along the western margin of the Cascade Range in a discontinuous belt that extends from the Canadian border south to the Columbia River. The Kittitas County coalfields, an important exception, are on the east side of the Cascades in the central part of the State. In addition to these larger deposits,

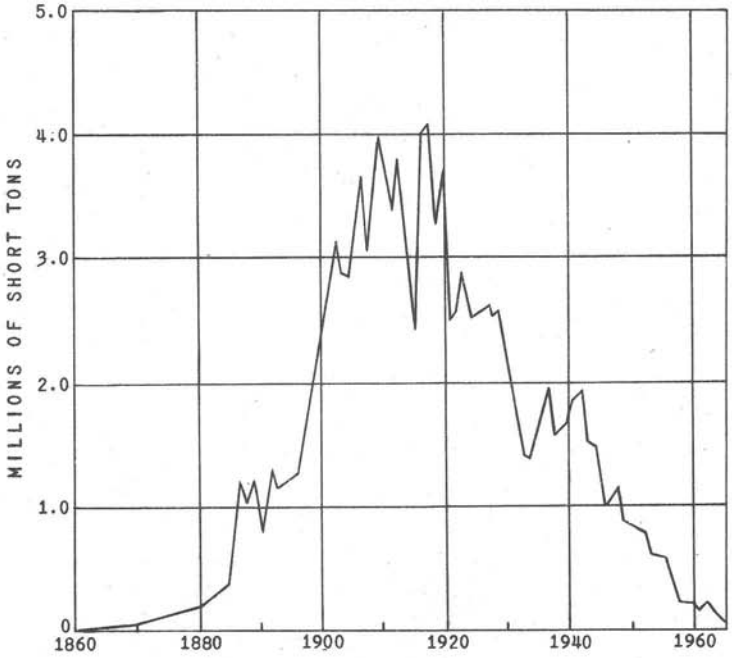

FIGURE 56.—Coal production in Washington, by year.

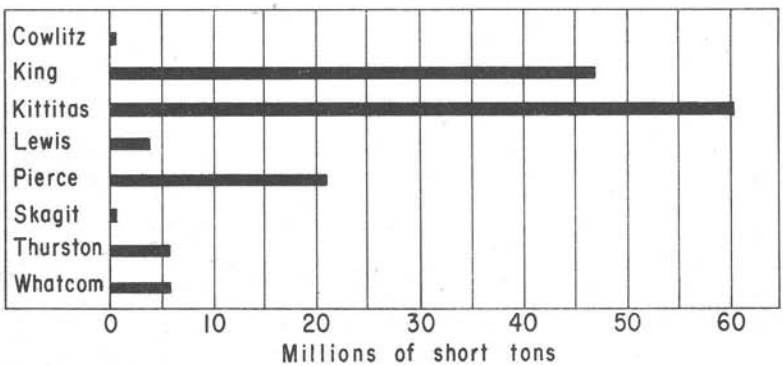

FIGURE 57.—Cumulative coal production in Washington, by county.

many small isolated occurrences of coal are known throughout the State (fig. 59).

All known commercial deposits of coal in Washington are of Tertiary age, and most are of Eocene age. Local pre-Tertiary coals occur in San Juan County, and coals of Oligocene age occur in Cowlitz County, and of Miocene age in Clallam County. The rank of the coal generally increases with age; lower to middle Eocene deposits are bituminous

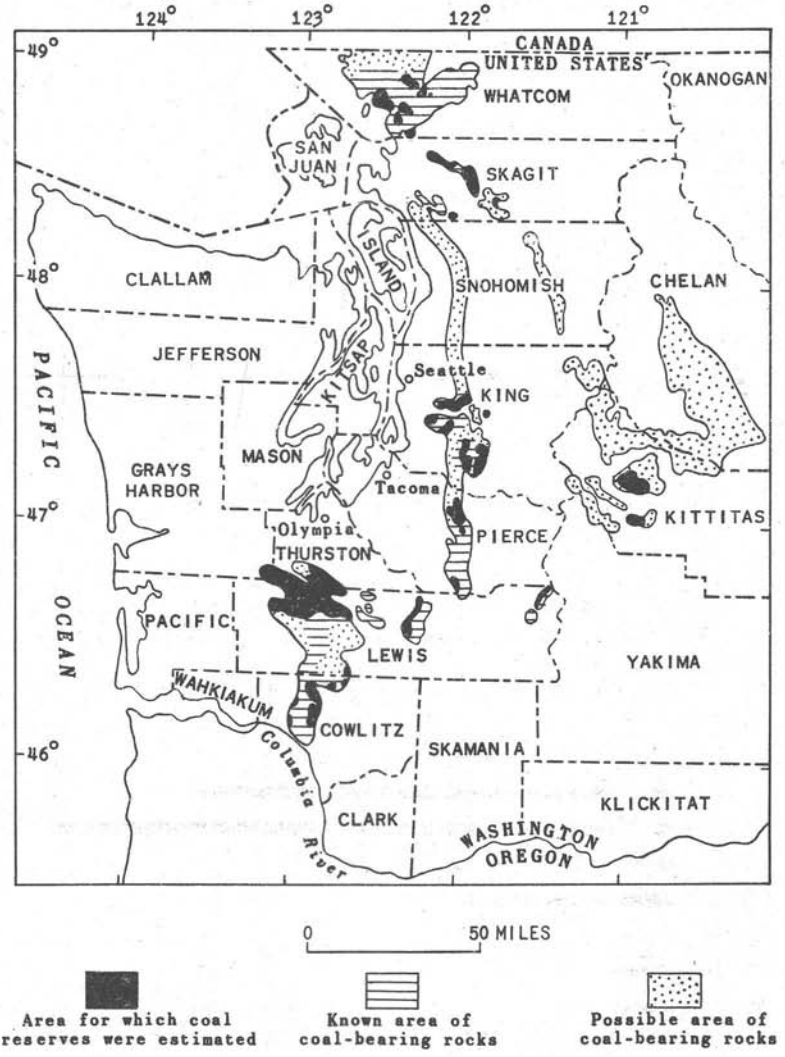

FIGURE 58.—Known and possible areas of coal-bearing rocks in western Washington.

coals, most upper Eocene deposits are subbituminous coals, and Oligocene deposits are lignites.

The coal deposits were formed in swamps on low-lying coastal plains along the eastern and northeastern margins of a north-trending basin of deposition that occupied most of western Washington throughout Eocene time. The coal-bearing rocks interfinger with and grade into marine non-coal-bearing rocks to the west. Local volcanism was

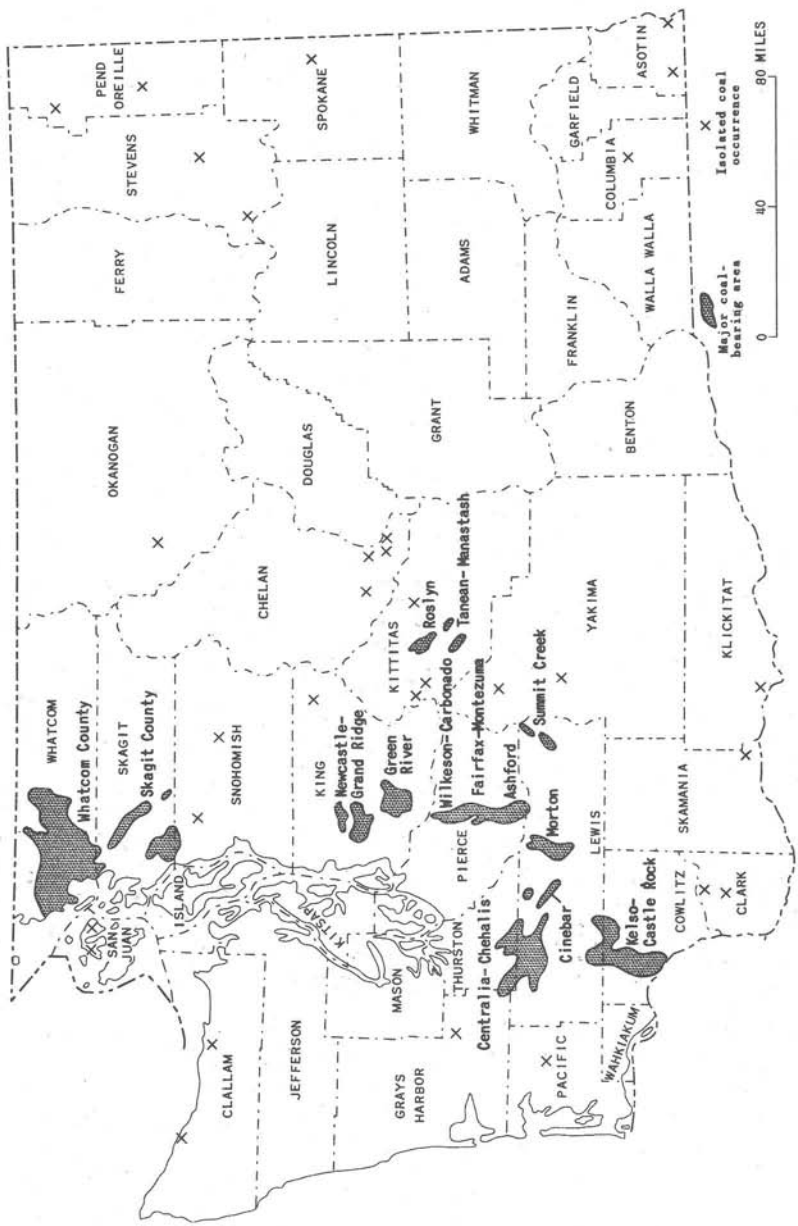

FIGURE 59.—Major coal-bearing areas and isolated occurrences of coal in Washington.

contemporaneous with the deposition of the coal-bearing sediments, and in some places volcanic rocks are equivalents of the coal-bearing sequence. The high ash content of many of the coal beds is due to volcanic ash falls that occurred during the accumulation of the coal-forming plant material. The rocks in all the coal-bearing areas have been folded and faulted, but the amount and type of deformation varies greatly.

Coking coal, which is coal that will fuse or become semi-liquid during destructive distillation and form a hard cellular residue of carbon and inert constituents, occurs in Washington. These deposits are of particular interest because coking coal is relatively limited in distribution and the coke it is used to make is of special importance in metallurgical industries and as an export.

The important coking-coal deposits in Washington are in the Wilkeson-Carbonada field and Fairfax-Montezuma area in Pierce County and in the Roslyn field in Kittitas County. Other deposits of coal that may be of coking quality, but that have not been adequately tested, extend from eastern Lewis County, through the Ashford area in southern Pierce County, and into King, Skagit, and Whatcom Counties, nearly to the northern boundary of the State (Warren and others, 1945; Vine, 1962; Gower and Wanek, 1963; and Jenkins, 1923, 1924).

The estimated remaining reserves of coal in Washington, based on exploration and mapping as of January 1, 1960, are 6,185 million tons (Beikman, Gower, and Dana, 1961). Of this total 117 million tons is lignite, 4,194 million tons is subbituminous, 1,869 million tons is bituminous, and about 5 million is anthracite. This estimate includes anthracite and bituminous coal in beds 14 or more inches thick and subbituminous coal and lignite in beds 2½ or more feet thick, all less than 3,000 feet below the surface. Coal reserves by area and by county are given in table 23.

This estimate of more than 6 billion tons of coal reserves is based on specific data concerning the location, thickness, and quality of coal beds, and therefore is conservative. It represents only a minimal estimate because similar specific information is lacking for large areas of known coal-bearing rocks. As a result, reserves could be estimated for only about one-third of the known area of coal-bearing rocks and much of the area for which reserves were estimated contains additional coal beds of unknown thickness and extent.

Other large areas that may contain coal-bearing rocks are concealed beneath a mantle of glacial drift or alluvium (fig. 58). The principal areas where such conditions may exist are: In the northwest part of Whatcom County, in the north- to northwest-trending belt along the west side of the Cascade Range between the Skagit and King County areas, between the King and Pierce County areas, and between the Centralia-Chehalis coal district and the Kelso-Castle Rock area. No doubt many of these areas contain significant coal deposits. Resource estimates will be increased as additional information is acquired through detailed geologic studies.

TABLE 23.—*Summary of estimated remaining reserves of coal in Washington*

[In millions of short tons]

[Rank: A, anthracite; B, bituminous; S, subbituminous; L, lignite]

	Thin [1]	Intermediate [2]	Thick [3]	Total	Rank
Whatcom County	54.91	110.79	159.17	324.87	B, A.
Skagit County	147.64	39.40	319.92	506.96	B.
Kittitas County:					
Roslyn field	7.07	105.79	128.47	241.33	
Taneum area	1.10			1.10	
Manastash area	39.37			39.37	
Total	47.54	105.79	128.47	281.80	B.
Pierce County:					
Wilkeson-Carbonado field	8.80	29.79	183.48	222.07	
Spiketon area	12.21	20.98	55.65	88.84	
Melmont area		1.64	14.85	16.49	
Fairfax-Montezuma area	10.26	9.89	0.99	21.14	
Ashford area			13.41	13.41	
Total	31.27	62.30	268.38	361.95	B.
King County:					
Renton area	17.76	32.59		50.35	S.
Newcastle-Grand Ridge area	140.86	168.74		309.60	S.
Tiger Mountain area	3.28	5.73		9.01	S.
Cedar Mountain area	33.66	30.61	2.49	66.76	B, S.
Niblock area		2.69	11.49	14.18	B.
Taylor area	1.67	3.04	15.75	20.46	B.
Green River district	30.22	55.33	271.76	357.31	B, S.
Total	227.45	298.73	301.49	827.67	B, S.
Lewis and Thurston Counties:					
Centralia-Chehalis district	749.79	2,254.03	689.96	3,693.78	S.
Morton area	1.62		41.95	43.57	B.
Summit Creek area			3.75	3.75	B.
Cedar Creek area		17.35	45.74	63.09	L.
Total	751.41	2,271.38	781.40	3,804.19	B, S, L.
Cowlitz County	16.98	48.05	13.01	78.04	S, L.
State total	1,277.20	2,936.44	1,971.84	6,185.48	

[1] Thin coal includes anthracite and bituminous coal 14 to 28 inches thick and subbituminous coal and lignite 2.5 to 5.0 feet thick.

[2] Intermediate coal includes anthracite and bituminous coal 28 to 42 inches thick and subbituminous coal and lignite 5.0 to 10.0 feet thick.

[3] Thick coal includes anthracite and bituminous coal 42 or more inches thick and subbituminous coal and lignite 10.0 or more feet thick.

Knowledge of the coal deposits of Washington is confined to individual coal-bearing areas and little is known about the intervening areas or the relation of one area to another. For this reason, the following descriptions of coal deposits are given by county and by separate geographic areas within the counties.

WHATCOM COUNTY

Coal-bearing rocks in the Chuckanut Formation of McLellan (1927) of Eocene age underlie an area of more than 500 square miles in Whatcom County. Most of the coal-bearing strata occur in a northwest-plunging basin bounded on the southwest, south, and east by pre-Tertiary metamorphic and igneous rocks and concealed on the northwest and north by glacial drift. In the southern part of the county, the rocks have been tightly folded into a series of northwest-plunging structures, the limbs of which dip 45° to 60°. The amount of deformation probably decreases toward the northwest. The coal-bearing rocks have been faulted an undetermined amount.

The coal-bearing rocks in Whatcom County are about 12,000 feet thick (Jenkins, 1923, pp. 47–49; 1924, pl. 1). The two principal coalbeds are more than 10,000 feet apart stratigraphically, with the Blue Canyon bed at the base of the coal-bearing sequence and the Bellingham bed near the top. According to Jenkins (1924, pl. 1), 15 or more coalbeds ranging in thickness from a few inches to 14 feet (Bellingham No. 1) occur in the county; however, the areal extent of the various beds has not been determined. Because of its thickness and accessibility, the Bellingham No. 1 is the most commercially significant coalbed in the county. The total reserves of coal in Whatcom County are estimated to be 325 million tons.

The total coal produced in Whatcom County from 1891 to 1955, when production ceased, is about 6 million tons, of which 5½ million tons were from the Bellingham No. 1 coalbed at the Bellingham mine. Two other mines, at Blue Canyon and Glen Echo, have a recorded production of about 280,000 and 65,000 tons, respectively.

Most of the coal is of high-volatile C bituminous rank. The one known occurrence of anthracite in the State is in the Glacier field in the north-central part of the county. The Glacier field contains many steeply dipping coalbeds that have been fractured and crushed by intense folding and faulting. At one time this field attracted considerable attention because it contains anthracite, but although much prospecting has been done, the reported production is less than 1,000 tons.

SKAGIT COUNTY

The coal-bearing rocks in Skagit County are probably the same age as the lowermost few hundred feet of the sequence in Whatcom County, from which they are separated by an east-trending belt of pre-Tertiary metamorphic rocks. The coal-bearing rocks occur in four separated areas called the Cokedale, Hamilton, Rick Creek, and McMurray areas. The strata in the Cokedale and Hamilton areas, which are separated by the Skagit River, probably connect beneath alluvial deposits of the river, and together may form a troughlike belt of structurally disturbed rocks, with dips ranging from vertical to as little as 10° (Jenkins, 1924, p. 24). The coal-bearing rocks in the Rick Creek area, which are less than 4 miles to the southeast, may be a continuation of those at Cokedale and Hamilton. These three areas together cover about 25 square miles. The McMurray area, which is much more structurally complex and irregular in outline, covers about 45 square miles.

The Cokedale and Hamilton areas contain several coalbeds ranging in thickness from a few inches to more than 10 feet (Jenkins, 1924, p. 30), but the exact number and correlation of the coalbeds there, or in the other areas of the county, have not been determined nor has their continuity been established. The total reserves of coal in the county are estimated to be 507 million tons. The few complete analyses of coals in Skagit County indicate that they are of bituminous rank. The total production of coal in the county is about 180,000 tons, part of which was made into coke (fig. 57).

KITTITAS COUNTY

The Roslyn coalfield is the major coal-producing area in Kittitas County. Two other coal areas in the county, Taneum and Manastash,

which cover about 1 square mile and 7 square miles respectively, have had little or no development and are considered of minor economic importance. The geology of the area has been described by Saunders (1914).

The Roslyn coalfield covers an area of about 30 square miles on the east slope of the Cascade Range, approximately 75 miles east of Tacoma, and has produced about 63 million tons, which is more than any other area in the State. The coal beds are confined to the upper 1,560 feet of the Roslyn Formation, a 6,500-foot-thick sequence of sandstone and shale of Eocene age. This upper zone includes eight major coalbeds, ranging in thickness from less than 2 feet to 21 feet, of which five have been mined. The remaining coal reserves in the field are estimated to be 241 million tons.

The Roslyn (No. 5) coalbed has been worked throughout the entire area of the field. The bed ranges in thickness from about 4.5 to 7 feet and contains an average of 4.4 feet of clean coal. The Big Dirty (No. 1) coalbed, 15 to 19 feet thick and relatively high in ash, is the uppermost bed in the field and economically second in importance. Only the lower part of the coalbed, which contains an average of 4.6 feet of coal, is sufficiently clean to be minable. The remaining three minable coalbeds have been worked to a lesser extent. The Plant (No. 6) bed is about 2.9 feet thick and is about 410 feet below the Roslyn bed; the Green (No. 7) bed is about 1.8 feet thick and is about 90 feet below the Plant bed; and the Wright (No. 8) bed, the lowest in the stratigraphic section, is 3 feet thick and 150 feet below the Green bed.

The major structure of the Roslyn coalfield is a syncline that plunges southeast. The coal-bearing sediments dip toward the center of the syncline at angles of 10° to 30°. In general the structure is simple; however, along the southwest margin it is more complex and consists of a series of anticlines and synclines that trend parallel to the major syncline.

The coalbeds in the Roslyn field are of high-volatile A bituminous rank, with the exception of the Roslyn coalbed, which in the southeastern part of the field is of high-volatile B bituminous rank.

KING COUNTY

Six coal-bearing areas—the Renton, Newcastle-Grand Ridge, Cedar Mountain, Tiger Mountain, Taylor, and Niblock areas—are in the central part of King County. The Green River district, the largest and most extensively mined area, is in the southern part of the county. The King County coals occur in the Puget Group of middle Eocene through early Oligocene age. The coal-bearing strata have been moderately folded and faulted in the Renton, Newcastle-Grand Ridge, and Cedar Mountain areas, where most of the coalbeds dip less than 35°. Deformation of the rocks is more intense in the other coal-bearing areas, particularly those in the Green River district, where dips of 50° or more are common. The coals in King County range in rank from subbituminous B to high-volatile A bituminous coal. The total recorded production is about 47 million tons, more than half of which has come from the Green River district. Much of the information presented here is from reports by Evans (1912) and by Warren and others (1945).

Newcastle-Grand Ridge area.—The Newcastle-Grand Ridge area, the northernmost coal-bearing area in King County, is about 5 miles east of Seattle. Throughout most of this area the structure is relatively simple and the rocks strike eastward and dip 30° to 40° northward. The rocks have been broken locally by small cross faults. Some of the coalbeds in the area have been called by different names in different mines and correlation of beds is difficult and uncertain. Reserves of 310 million tons were estimated for eight coalbeds in the area (Beikman, Gower, and Dana, 1961). The coals are for the most part subbituminous A; however, some may be high-volatile C bituminous in rank.

Renton area.—The Renton area, about 3 miles southeast of Seattle, includes the prospects and small mines located between Renton and the Duwamish River. Most of the rocks in the area have been gently folded and dips of 10° to 20° are common, but in the southern part of the area deformation has been more intense and the strata dip as much as 65°. The rocks in the area are cut by several west- to northwest-trending faults, which appear to be major faults. Reserves of 50 million tons have been estimated for five coalbeds in the area. As in the Newcastle-Grand Ridge area, the coals are for the most part subbituminous A; however, some may be high-volatile C bituminous in rank.

Cedar Mountain area.—At the Cedar Mountain area, about 4 miles southeast of Renton, the principal structure is a southwest-plunging anticline, cut by several northwest-trending faults, one of which is a major fault. Southwest of this fault the coal-bearing rocks have been intruded by andesite. Reserves totaling 67 million tons were estimated for five coalbeds southwest of the fault and for two coalbeds northeast of the fault. The coal of the Cedar Mountain area ranges in rank from subbituminous A to high-volatile C bituminous.

Tiger Mountain and Niblock areas.—The Tiger Mountain and Niblock areas are about 14 and 20 miles east-southeast of Seattle, respectively. Little is known about the geology of these two areas and the stratigraphic relation of the coalbeds to other coalbeds in King County is unknown. The coal-bearing strata in the Tiger Mountain area strike north to northeast and dip about 45° west. The strata at Niblock strike north to northwest and dip steeply to the southwest. Reserves of 9 million tons were estimated for two coalbeds in the Tiger Mountain area and of 14 million tons for three coalbeds in the Niblock area. Other coalbeds have been reported in both places. The coals at Tiger Mountain are of subbituminous B rank and those at Niblock are of high-volatile A bituminous rank.

Taylor area.—The Taylor area is about 20 miles southeast of Seattle. The coal-bearing rocks occur in a southeast-plunging syncline with steeply dipping limbs and are cut by several igneous dikes and sills. Throughout most of the area the coalbeds dip about 70°. To the southeast they are covered by glacial drift. Ten coalbeds are known to occur in the area. Data were sufficient to estimate reserves totalling 20 million tons for five of these. The coals in the Taylor area range in rank from high-volatile B bituminous to high-volatile A bituminous.

The Green River district.—The Green River district is about 15 miles southeast of Renton, in the south-central part of King County. The coal-bearing rocks are about 6,200 feet thick, and have been folded into

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tight north- to northeast-trending anticlines and synclines cut by numerous west- to southeast-trending faults. An extensive cover of glacial drift makes it difficult to trace the faults, some of which have displacements of more than 1,000 feet.

The principal coalbeds of the Green River district are in the upper and middle parts of the Puget Group. In the western part of the district the structure and stratigraphy are known in sufficient detail to permit correlation of coalbeds, but in other parts of the district coalbeds can rarely be correlated from one mine to the next, although the distances between the mines may be short. At least 14 coalbeds have been recognized in the Green River district and reserves are estimated to be 357 million tons. The principal coalbed, the McKay, is the most widely recognized and most extensively mined. The rank of the coal in the district ranges from subbituminous B to high-volatile A bituminous; however, most of the coal is of high-volatile B bituminous rank.

PIERCE COUNTY

The coal deposits in Pierce County occur in six structurally separate areas, of which the Wilkeson-Carbonado field is economically the most important. The coal-bearing rocks are in the Puget Group (Daniels, 1914, pp. 22–27) and are confined to a narrow north-south belt 3 to 6 miles wide near the center of the county. On both the east and west sides of this belt, the coal-bearing rocks dip beneath volcanic rocks of Tertiary age. In the northern part of the county, much of the coal-bearing sequence is covered by glacial drift, and in places in the vicinity of the Puyallup River, flat-lying Quaternary(?) lava flows from Mount Rainier cover the coal-bearing rocks. The coal-bearing strata have been intensely folded and faulted. Most of the folds are narrow, north-trending structures with steeply dipping limbs. Dips of 60° or more are common. The faults are normal and high-angle reverse, with displacements ranging from a few inches to more than 1,500 feet. The coalbeds in Pierce County, which have the highest rank of any major coal-bearing area in the state, range in rank from high-volatile A bituminous to low-volatile bituminous. Total production for the county is about 21 million tons, of which more than 18 million tons or nearly 90 percent, was from the Wilkeson-Carbonado field.

Wilkeson-Carbonado coalfield.—The Wilkeson-Carbonado coalfield, the northernmost field in Pierce County, includes the Burnett, Wilkeson, Gale Creek, and Carbonado areas. The principal structure of the field is a northwest-trending anticline, at least 5 miles in length, flanked on the west by smaller plunging anticlines and synclines. The strata, which have an average dip of about 55° have been cut by faults, most of which are parallel or subparallel to the fold axes. The field has been extensively mined. At least nine coalbeds, ranging from a few inches to 8 feet in thickness, are present, and reserves are estimated to be 222 million tons.

Spiketon area.—The Spiketon area is in the northeast flank of the major anticlinal structure of the Wilkeson-Carbonado coalfield and includes the coalbeds that were mined at the Spiketon and South Willis mines. They are stratigraphically above those of the Wilkeson-Carbonado coalfield. The coalbeds all dip about 60° to the east. At

least 10 coalbeds, ranging in thickness from a few inches to as much as 5 feet are present, and reserves are estimated to be 89 million tons.

Melmont area.—The Melmont area is south of the Wilkeson-Carbonado coalfield. The coalbeds appear to underlie the coalbeds of the Carbonado area, but the stratigraphic relations cannot be determined with certainty. Seven coalbeds that range in thickness from 3 to 13 feet and have an average dip of 55° are present, and reserves are estimated to be 16 million tons.

Fairfax-Montezuma and Ashford areas.—The Fairfax-Montezuma and Ashford areas, in central and south-central Pierce County, contain coal-bearing strata that are greatly faulted, and those at Ashford are also intruded by igneous rocks. Although at least six coalbeds have been opened or mined to varying extents at Fairfax and Montezuma, the total number of beds present and their extent and thickness is not known. The reserves in the area are estimated to be 21 million tons. Numerous coalbeds are believed to occur near Ashford, but according to Daniels (1914, p. 42): "They are not commercially minable because of the structural difficulties involved." The amount of coal present is estimated at 13 million tons.

LEWIS AND THURSTON COUNTIES

The Centralia-Chehalis coal district is the largest subbituminous coalfield in Washington. Coal-bearing sedimentary rocks are also known to crop out in three smaller areas in eastern Lewis County, in the vicinity of Cinebar, Morton, and Summit Creek.

Centralia-Chehalis coal district.—The Centralia-Chehalis coal district in northwestern Lewis and southwestern Thurston Counties extends over an area of more than 200 square miles. It lies midway between Seattle, Washington and Portland, Oregon. The information presented here is summarized from a report by Snavely and other (1958), which was based on surface mapping of coalbeds supplemented by a small amount of test drilling.

The coalbeds in the Centralia-Chehalis district are in the upper and lower parts of the Skookumchuck Formation of late Eocene age and are separated by about 1,000 feet of non-coal-bearing rocks. The rocks have been folded and faulted, and most of the major structural elements trend northwest. Most of the faults are high angle and are downthrown to the south or southwest. Displacements are as much as 1,500 feet, but most are less than 200 feet. The strata in the western half of the area are folded into broad open structures, whereas the strata in the eastern half are generally more closely folded.

At least 14 coalbeds, whose dip ranges from horizontal to vertical, crop out in the Centralia-Chehalis district. Individual coalbeds range in thickness from a few inches to more than 40 feet; the average thickness of most beds is between 6 and 8 feet. Coal reserves for the district are estimated to be 3,694 million tons. The coalbeds range in rank from lignite to subbituminous B; most of the coal is subbituminous C. About 9 million tons of coal has been mined from the district.

Eastern Lewis County coal deposits.—Information on coal-bearing rocks in eastern Lewis County was obtained through reconnaissance mapping of the Cinebar and Morton areas by Howard D. Gower and

of the Summit Creek area by J. A. Ellingson of the Washington Division of Mines and Geology, and from a report by Culver (1919, pp. 103–130). The coal in these areas ranges in rank from high-volatile C bituminous to high-volatile A bituminous.

In the Cinebar area, the coalbeds occur in rocks of middle to late Eocene age. The number of coalbeds present and the extent of the beds along the strike and downdip is unknown. The structure is so complex that correlation of exposures only a few hundred yards apart is impractical. The coal has been subjected to such severe deformation that it is probably of little value.

In the Morton area, the coalbeds occur in the Puget Group of middle Eocene through early Oligocene age. Coalbeds have been found throughout most of the area that contains sedimentary rocks, but they cannot be correlated from one outcrop to another. The coal-bearing rocks have been intruded by igneous rocks, which have intensely sheared some of the coalbeds, but also may have improved the rank of the coal locally through increased devolatization. The coal in the area is mostly of high-volatile bituminous rank, but some that approaches anthracite or natural coke in composition has been found in the immediate vicinity of intrusive rocks. Several mines have been operated to a limited extent and at least three coalbeds have been mined. Coal reserves are estimated to be 45 million tons.

In the Summit Creek area, sedimentary rocks of Eocene age occur in a narrow west-dipping belt. The coal has been subjected to deformation and some of it reportedly transformed to anthracite. The area has been actively prospected but only a small amount of mining has been done. Reserves are estimated to be 4 million tons.

COWLITZ COUNTY

Coal-bearing strata crop out in the vicinity of Kelso and Castle Rock in north-cental and western Cowlitz County and extend for a short distance northward into Lewis County. In this area the coal-bearing rocks are gently folded and dips of beds generally range from 10° to 20°. The rocks are faulted, but most of the faults have displacements of only a few feet. The coal beds occur in the Cowlitz Formation of late Eocene age and the Toutle Formation of late Eocene and early Oligocene age. Although very little information about past mining in this area has been recorded, past production is negligible.

Four coalbeds are known in the Cowlitz Formation in the area east of the Cowlitz River; however, little is known about the geology and coal deposits in the area west of the river. The coal in the Cowlitz Formation ranges in rank from lignite to subbituminous B, but most is subbituminous C.

Five lignite beds are known to occur in the Toutle Formation, which is confined to the area seat of the Cowlitz River. The coal reserves in Cowlitz County are estimated to be 78 million tons. The extent and depth of lignite beds in the Cedar Creek area in secs. 15, 16, and 22, T. 11 N., R. 1E. in Lewis County have been determined from drillhole data obtained during a drilling program conducted by the U.S. Bureau of Mines (Toenges and others, 1947). The area for which reserves are estimated to be 63 million tons is considered suitable for strip mining.

PETROLEUM AND NATURAL GAS

(By H. C. Wagner, U.S. Geological Survey, Menlo Park, Calif.)

Exploratory test wells in the State of Washington have discovered evidence of petroleum and natural gas in more than 100 wells, but only minor production of these commodities has been obtained and neither is yet economically important. Solid hydrocarbons have been found only in small local occurrences; and no deposits of rocks classifiable as oil shale are known in the State. Nevertheless, Washington contains within its confines, areas that possess the three geologic characters that are required for the accumulation of commercial quantities of petroleum and natural gas. These are:

(1) An adequate source of petroleum-generating material in the form of abundant marine animal or plant life;

(2) The presence of reservoir rocks in which important amounts of oil and gas can accumulate and from which they can be made to flow to wells for production at satisfactory rates;

(3) Suitable structural or stratigraphic conditions that provide a means of localizing and entrapping the oil or gas in the reservoir rocks.

Whether these three factors are to be found in a combination that would provide major commercial production of petroleum has yet to be determined definitely in Washington, although surface and subsurface indications are favorable in many areas. The most obvious indications of the presence of petroleum and natural gas are oil seeps and gas at the surface of the ground. Such seeps have been reported in several places along the west and north coasts of the Olympic Peninsula, at two localities adjacent to Willapa Bay in southwesternmost Washington, in the vicinity of Bellingham in Whatcom County, near Wenatchee in southern Chelan County, and near the Columbia River in southern Skamania County. These areas containing oil seeps were, of course, among the first to be prospected. In searching for other areas to test in Washington, the petroleum geologist must search for less obvious indications and must use basic geologic data gained through geologic and geophysical mapping, and test drilling. Many anticlinal structures suitable for oil accumulation have been mapped in Washington, and many that have been tested by drilling have had promising shows of oil and gas. Many similar structures are probably present but are hidden beneath the thick cover of sand and gravel deposited in Pleistocene time, are obscured by the dense vegetation, are buried under the great basalt flows of the Columbia Basin, or are concealed beneath the Pacific Ocean on the Continental Shelf. Other traps, such as those that form where a sand lens reservoir rock is entirely encased in impervious shale and is tilted so that the wedge edge points slightly upward, may be common near former shore lines of the Oligocene and Miocene seas. Such shore lines exist at the surface and in the subsurface near the eastern and southern limits of the Puget Lowland, along the north and west coasts of the Olympic Peninsula, and surrounding some of the large outcrop areas of lower to middle Eocene volcanic rocks in the Willapa Hills region.

The oil and gas possibilities of different parts of the State of Washington are dependent principally upon the types of rocks underlying

the land surface. Intrusive igneous rocks, such as granite, and extrusive igneous rocks, such as basalt, in themselves afford practically no possibility of commercial petroleum production. Strongly metamorphosed rocks, whether originally sedimentary or not, have generally undergone such radical changes that they have retained little potential as petroleum producers. In general, only those areas that are underlain by marine sediments, and specifically, dark-colored organic-rich shales and porous sandstones, can be considered as good prospects for petroleum generation and accumulation. Consideration must, however, be given to the possibility of petroleum production from marine strata that underlie sediments of continental origin or thick sequences of basalt where adequate stratigraphic traps or structural closures exist.

In figure 60 is depicted a much generalized geologic map of Washington on which the wells drilled to date (April 1965) for petroleum are shown (locations taken mainly from Livingston, 1958), and on which the rocks have been grouped into categories that can be used to discuss the petroleum potential of the six major physiographic regions of Washington. These regions are: the Okanogan Highlands, the Columbia Basin, the Cascade Mountains, the Puget Lowland, the Olympic Mountains, and the Willapa Hills (fig. 1). Each region possesses many distinctive geologic characteristics which in turn affect the petroleum potential of the area.

In this discussion of the oil and gas possibilities of Washington, the author has benefitted greatly from discussions with his associates and has drawn heavily upon published material.

OKANOGAN HIGHLANDS

The Okanogan Highlands in northeast Washington consist principally of igneous and metamorphic rocks in about equal proportions (fig. 60). The igneous rocks are largely granites and associated intrusive rocks of Cretaceous and Tertiary age; the metamorphic rocks are primarily quartzite, crystalline limestone, argillite, and greenstone ranging in age from Precambrian to Jurassic. In the western part of the Okanogan Highlands the rocks include indurated marine sediments of Permian and Triassic age that have been intruded by large bodies of Cretaceous granite. Thin patches of nearly flat-lying to gently warped volcanic rocks of Eocene and Miocene age overlie the intrusive and metasedimentary rocks in the central and southern parts of the Highlands. The older rocks have been faulted and closely folded into anticlines and synclines.

Some of the shale and limestone beds may have served as source beds for oil and gas, but any petroleum originally present would have been destroyed at the time of the Mesozoic and later igneous intrusions and tight folding. The possibilities of finding oil or gas in commercial quantities in this area are very unfavorable. Nine exploratory wells drilled in Stevens and northern Spokane Counties bottomed in Paleozoic sediments and granite. The deepest is reported to have gone 5,280 feet. No shows of oil and gas have been verified in these wells.

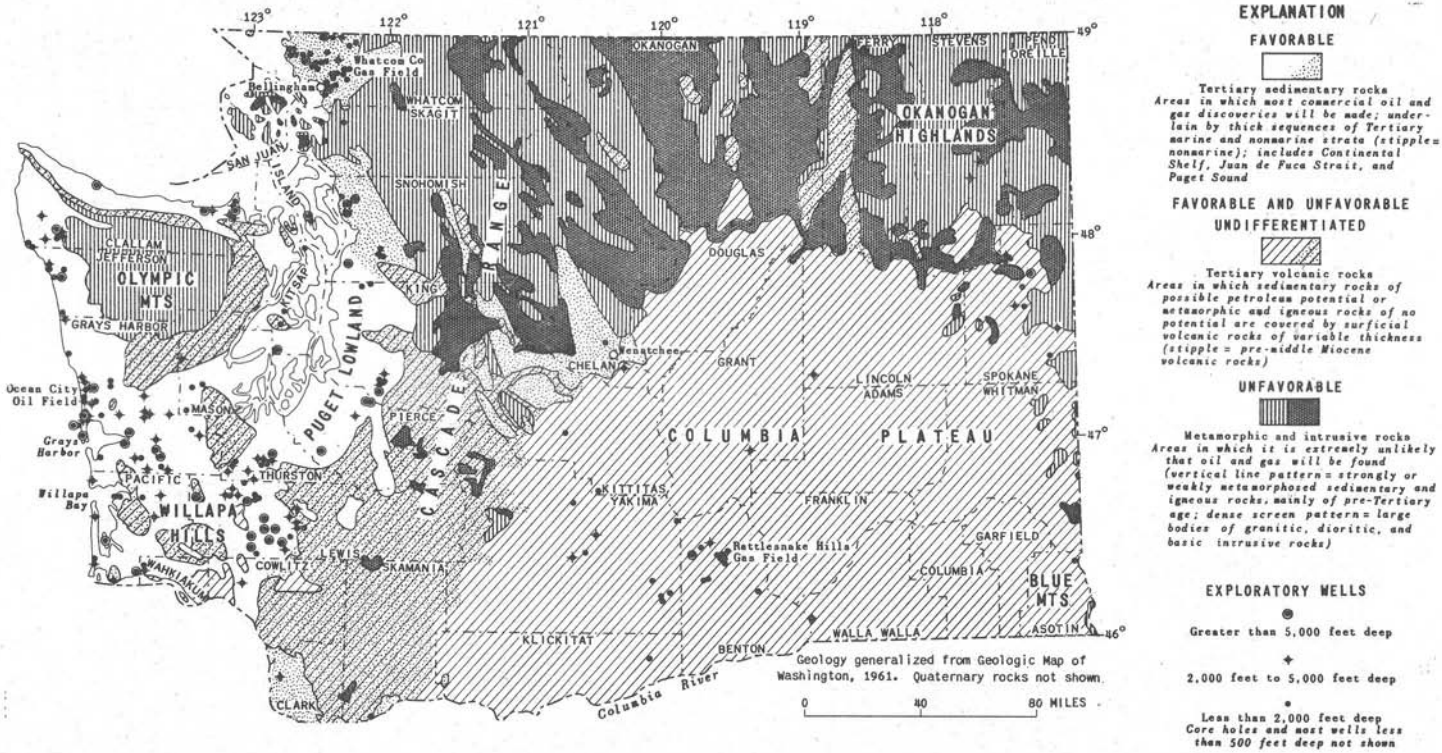

FIGURE 60.—Generalized geologic map of Washington showing areas classified according to their petroleum potential, and the locations of wells drilled for petroleum between 1900 and 1964.

COLUMBIA BASIN

The Columbia Basin occupies approximately the southeastern quarter of Washington. It lies south of the Okanogan Highlands and east of the Cascade Mountains, and extends southward far into Oregon and eastward into Idaho to the foothills of the Rocky Mountains. The plateau is underlain mainly by basaltic lava flows, with very minor pyroclastic materials and tuffs all of middle Miocene to early Pliocene age. In many places post-Miocene sedimentary rocks of continental origin (not shown on fig. 60) overlie the basalt and are in turn overlain by gravels, sands, silts and clays of Quaternary age. Subordinate local deposits of lignitic fluviatile and lacustrine sediments intercalated within the lava flows probably accumulated in temporary shallow depressions caused by the damming of stream valleys by lava. The lava flows gradually rise toward the southwest onto the broad north-south axial upwarp of the southern part of the Washington Cascades. The Blue Mountains of Oregon extend as an uplifted area in the southeastern corner of the State. In this extension metamorphic rocks of Carboniferous to Triassic age are exposed in river bottoms unconformably under a cover of 2,000 feet or more of basalt.

The basaltic lavas of the Columbia River Group lie in a shallow downwarp into which at least 10,600 feet of lava was extruded. Toward the margin of the basin the number of flows and the total thickness become progressively less. The volcanic rocks in the western part of the basin have been folded into several asymmetric ridges that trend northwest-southeast or east-west generally with low dips on the south and steep to overturned dips to the north.

The lithologic character of the rocks on which the basalt of the Columbia Basin rests is of importance in considering the possibilities of obtaining oil or gas in this region. Along the entire northern boundary of the plateau and southward along the State's eastern boundary to the southesatern corner the basalt flows rest on argillite, schist, crystalline limestone, and quartzite or on granite and similar intrusive rocks. Presumably these metamorphic and igneous rocks extend south and west considerable distances beneath the lavas of the plateau. Along the western margin the lavas lap onto a floor composed generally of folded older lavas and continental sedimentary rocks of Eocene age; sheared argillite, graywacke, and altered lava flows, shown as unfavorable on figure 60, crop out in a small area in western Yakima County. The subsurface extent of these continental sediments is unknown, but it is possible that they may extend southeast to the Rattlesnake Hills area (Weaver, 1938, p. 10). Along the southern boundary of the State the Columbia River has failed to cut through the basalt cover and nothing is known concerning either the age or lithology of the underlying rocks. About 80 miles to the south in north-central Oregon, however, late Mesozoic marine strata occur in an embayment that may extend to Washington; but no evidence is yet available to indicate how far. In the western part of the Columbia Basin, parts or all of Chelan, Douglas, Grant, Kittitas, Yakima, Klickitat, Adams, Franklin, Walla Walla, and Benton Counties may be underlain in the subsurface by sedimentary rocks possibly productive of petroleum if the structural conditions are favorable.

The Columbia Basin area is not, however, barren of petroleum indications or products. In 1913 a well that was being drilled for water on the northeast slope of the Rattlesnake Hills in northern Benton County encountered a flow of gas estimated at between 70,000 and 500,000 cubic feet per day under about 5½ pounds per square inch pressure. The Rattlesnake Hills gas field, located on a faulted anticline (Hammer, 1934, p. 852), was not immediately developed, but by 1936 fifteen wells were in production and nearly a billion cubic feet of gas had been distributed to seven towns in the Yakima Valley (Glover, 1936b, pp. 11, 12). The gas came from porous vesicular zones in the basalt at depths of 700 to 1,260 feet. Analyses of the gas showed an average nitrogen content of nearly 10 percent, a small amount of oxygen, no ethane or heavier hydrocarbons, and an average methane content greater than 80 percent (Kirkham, 1935, p. 229; Glover, 1936b, p. 12). The source of the gas is unknown, but the very high methane content and presence of substantial nitrogen suggest a vegetal origin. The Rattlesnake Hills gas field was abandoned in 1951. In 1958 an attempt was made in that area to drill through the basalt to determine the presence or absence of marine Cretaceous or Eocene strata. At the total depth of 10,655 feet the bit was still drilling in volcanic rock (Popenoe, 1959, p. 1389); but chemical, lithologic, and electric log data suggest that the Miocene basalt flows were drilled through at about 4,000 feet and that the hole bottomed in volcanics of Eocene or Oligocene age.

Exclusive of the drilling in the Rattlesnake Hills gas field area of Benton County about 25 wells have been drilled in the Columbia Basin area in Spokane, Asotin, Lincoln, Grant, Chelan, Kittitas, Yakima, Klickitat, and Walla Walla Counties. A deep test in southwestern Lincoln County drilled completely through the basalt at 4,465 feet and passed through more than 200 feet of unconsolidated sand and clay before bottoming in 15 feet of Oligocene(?) quartz latite at 4,682 feet. Two of the Spokane County wells bottomed in granite and gneiss; all others bottomed in basalt. A deep test in Grant County has a total depth of 4,575 feet, and recorded a gas and tar-like oil show. Two Yakima County wells also recorded gas and tar-like oil shows; and a total of 14 other wells in Kittitas, Yakima, and Klickitat Counties recorded shows of gas. The tar-like oil shows, in addition to the more widely distributed gas, may owe their origin to the heat from a thick basalt flow as it overrode a peat swamp or thin, wet lignitic sediment (Felts, 1954, p. 1669).

CASCADE MOUNTAINS

The Cascade Mountains of Washington consist primarily of a deeply dissected high plateau surface upon which volcanic cones of andesitic lava formed in Quaternary time. The northern part of the range differs markedly from the southern part both topographically and geologically (Weaver, 1945, p. 1390). The northern part is composed largely of Cretaceous and Tertiary granitic intrusive rocks and of pre-Tertiary metamorphic rocks (figs. 60 and 4) that have been folded into a series of anticlines and synclines trending about N. 40° W. The oldest rocks consist largely of pre-Devonian gneissic amphibolite and quartz diorite overlain by lower to upper Paleozoic sandstones, quartzites, crystalline limestones, argillites, phyllites, and greenstones

that have been intruded by granite and associated plutonic rocks. Marine shales, sandstones, and conglomerates of Cretaceous age unconformably overlie the older rocks in a large southeast-trending synclinal graben east of the Cascade crest. In western Whatcom County and southeastward to Chelan, Kittitas, and western Yakima Counties the older rocks are overlain unconformably by continental lake and stream deposits of Cretaceous to Eocene age in which coal beds and basalt flows occur locally. The Eocene beds were folded, eroded, and covered unconformably by andesitic rocks of Eocene to Miocene age.

In the southern part of the Cascade Mountains of Washington the pre-Tertiary rocks are overlain by a thick cover of Tertiary volcanic flows and debris, and subordinate amounts of intercalated continental sedimentary rocks, all of which are gently warped upward along a north-south axis (Weaver, 1945, p. 1391). The volcanic rocks consist of Eocene and Oligocene sequences of tuffs, breccias, and lava flows of basaltic to rhyolitic composition. These volcanic rocks are as much as 5,000 feet thick and contain interbedded sedimentary rocks of lacustrine and fluviatile origin. They are overlain by basaltic and andesitic flows of Miocene, Pliocene, and Quaternary ages.

No marine Tertiary sedimentary rocks are known to occur in either the northern or southern parts of the Cascade Mountains and although small quantities of methane gas may have been formed from vegetal material in the lacustrine clays, the limited areal extent of these nonmarine rocks makes accumulations of commercial importance doubtful. Although shown in the unfavorable category relatively unmetamorphosed Mesozoic marine sedimentary rocks in a large elongate synclinal graben trending S. 40° E. from the 121° longitude line at the Canadian border may have petroleum possibilities. No indications of oil and gas have been reported from them, however.

The only exploratory well in the northern part of the Cascade Mountains was drilled 4,903 feet into the Paleocene strata northwest of Wenatchee in Chelan County. As stated above, these fresh-water strata contain a few beds of subbituminous coal and much carbonaceous shale which could be a source of gas and, possibly, oil (Glover, 1936b, p. 10). This well had reported shows of oil, and in several zones a considerable volume of gas. Oil seeps are reported in and near the town of Wenatchee. In the southern part of the Washington Cascades the only well drilled was near an oil seep in southern Skamania County. An oil show was reported at 250 feet, and the well was abandoned at 750 feet after having drilled 160 feet in basalt.

PUGET LOWLAND

The nearly level plain that lies between the Cascade Mountains on the east and the Olympic Mountains and Willapa Hills on the west composes the Puget Lowland. The lowland is underlain primarily by Tertiary sedimentary rocks with a locally thick cover of Pleistocene glacial debris. On the south the lowland is limited by a westward extension of the Cascade Mountains held up by Eocene and Miocene volcanic rocks. North of the San Juan Islands the southernmost part of the Georgia Straits embayment extends into the Bellingham area; an extension of the Willamette Lowland of Oregon barely enters western Clark County.

Resting upon the older granites and schists in the eastern portion of the Puget Lowland, and extending disconnectedly under the central part of the Cascade Mountains, are Cretaceous and Eocene shales and sandstones as much as 14,000 feet thick. They are largely of continental and brackish-water origin, and contain interbedded volcanic rocks and a large number of commercially important coal beds. Somewhat farther west, these Eocene rocks are interbedded with fine-grained sedimentary rocks containing marine fossils and are overlain by strata of Oligocene age that are largely of brackish water or near-shore marine origin. In the westernmost parts of the lowland, thick sequences of marine siltstone of late Eocene age could be source beds of petroleum, and their interbedded sandstones could form reservoir rocks. These siltstones are overlain by Oligocene and Miocene sedimentary rocks in which are sandstone beds that could serve as reservoir rocks for oil or natural gas that migrated upward along shear zones or fault planes.

Surface geologic mapping has delineated several anticlinal structures and faults in the area of the Puget Lowland (Snavely and others, 1958, pp. 84–93; Vine, 1962; Gower and Wanek, 1963), and geophysical investigations have outlined a few deep structures in the axial part of the basin. Considerable drilling on the surface structures has been done in central Lewis and southern King Counties with oil traces or shows reported in 12 tests and gas shows reported in 16.

About 35 other test wells have been drilled in the Puget Lowland in parts of Snohomish, Island, Kitsap, Pierce, Thurston, and Cowlitz Counties. Of these, about 15 reported traces or shows of oil and 20 had shows of gas. A few surface structures and most of the deep structures await test drilling, and stratigraphic traps that formed where wedges of sandstone were overlapped by shale units along the eastern margin of the lowland provide additional exploration targets.

In western Whatcom County, about 5 miles northwest of Bellingham in the southern part of the Georgia Strait embayment, gas in sufficient quantity for domestic use is obtained from glacial sand lenses in Pleistocene sediments at depths less than 500 feet, and commonly at about 170 feet (Livingston, 1958). The gas has a high methane-nitrogen content and possibly originated from the decay of vegetal matter in Upper Cretaceous(?) to lower Eocene continental sandstones and shales that unconformably underlie the glacial debris, or possibly from marine organic remains and vegetal matter within the Pleistocene clays, sands and gravels (Glover, 1935, p. 42). More than 90 wells have been drilled in western Whatcom County, many of which are not shown on figure 60. Most were shallow wells, only 3 having been drilled deeper than 5,000 feet, 5 deeper than 2,000 feet, and 20 deeper than 1,000 feet. Only 5 wells recorded oil shows, but most of the wells had good gas shows or domestic production.

A domal structure located by seismic methods in western Lewis County is currently being developed as a gas storage project. Sixteen input and observation wells have been drilled to date (April 1965).

OLYMPIC MOUNTAINS

Oil was first reported in Washington as early as 1881 along the beach on the western side of the Olympic Peninsula (Lupton, 1915,

p. 23) where there are outcrops of sandy shale having a kerosene odor (the "smell muds" of the Indians). At some places a small amount of 40- to 47-gravity paraffin-base oil seeps from the outcrop. In this same general area gas mounds have been formed where mud-laden water saturated with petroleum gas has bubbled to the surface and built up mud cones.

The Olympic Mountains occupy an area of about 4,000 square miles, in the northwestern corner of the State. The core of the range consists of more than 20,000 feet of indurated, complexly folded and faulted argillites and graywackes that presumably have little petroleum potential and are classed as unfavorable on figure 60. Uplifted and eroded lower to middle Eocene basaltic pillow lavas as much as 15,000 feet thick overlie these beds and form a horseshoe-shaped rim around the north, east, and south sides of the mountains. On the north side of the Olympics upper Eocene and Oligocene siltstones and sandstones, more than 15,000 feet thick overlie the lavas and are in turn overlain by as much as 2,500 feet of Oligocene and Miocene sandstone. Some of the siltstones have a decided petroliferous odor on freshly broken surfaces and are considered to be possible source beds for petroleum.

A few anticlinal structures north and west of the Olympic Mountains have been tested but have not as yet yielded commercial quantities of gas or oil. About 35 wells have been drilled in Clallam and Jefferson Counties of which 15 were drilled deeper than 2,000 feet and 5 deeper than 5,000 feet. More than half (about 20) had oil shows, and 15 recorded gas shows. In two wells drilled in 1931 and 1936 in northwestern Jefferson County, oil was encountered at shallow depths and might have proved commerical under modern completion techniques. The 1931 test encountered 5 sands saturated with 39.5° paraffin-base oil between 200 and 2,200 feet. The 1936 test struck oil at 287 feet, was completed and, on the pump, partially filled a 50-barrel tank at the rate of approximately 3½ barrels of 40-gravity oil per hour (Glover, 1936, p. 22) before mechanical difficulties led to its abandonment.

WILLAPA HILLS

The Willapa Hills and adjacent areas of southwestern Washington include all the territory south of the Olympic Mountains and west of the Puget Lowland, an area of approximately 3,500 square miles. The stratigraphic sequence consists entirely of Tertiary rocks. The basal unit is early to middle Eocene in age and consists of 2,000 to 10,000 feet of basaltic pillow lavas and breccia. These lavas are overlain locally by a sequence of impure sandstones, but in most places are covered by middle to upper Eocene foraminifera-bearing dark siltstones and silty sandstones as much as 6,000 feet thick. Such fine-grained organic-rich rocks could be source beds for petroleum.

In the eastern part of the Willapa Hills area, the upper Eocene strata consist largely of coal-bearing sandstones as much as 3,000 feet thick. Thin to thick units of basaltic lava and lapilli tuff commonly occur interbedded in this sandstone and siltstone sequence which is overlain in most places by a basaltic sandstone or conglomerate of early Oligocene age. Tuffaceous marine siltstones,

also of Oligocene age, overlie the basaltic sandstone and are as much as 7,000 feet thick in the central western part of the area. They pinch out eastward near the southwestern border of the Cascade Mountains where thick deposits of basaltic fragmental debris and andesitic lavas were being extruded onto the land surface throughout much of early Oligocene time.

A thick sequence of sandstone and pebble conglomerate accumulated in the marine and continental environments of Miocene and Pliocene time, particularly in the western and northern parts of the Willapa Hills area. These younger beds locally are sufficiently porous and permeable to serve as producible reservoir rocks. Thus, in southwestern Washington there are strata that are potential source beds for petroleum generation and potential reservoir rocks for petroleum accumulation. These rocks have been tested locally, excellent indications of petroleum have been found in many tests, and subcommercial production has been obtained in four wells.

The most notable success was based on seismic testing along the Pacific Ocean beach near Ocean City just northwest of Grays Harbor in a faulted anticline in strata that may represent the eastern limit of an offshore basin. In reporting on this test, the West Coast Subcommittee on Statistics of Exploratory Drilling classed Washington as the 31st oil-producing State in the Nation when the Tanner-Sunshine et al. Medina No. 1 well was completed August 20, 1957, with a rated flow of 178 barrels per day of 39° gravity oil from 3,952–3,958 feet in the Hoh Formation of Weaver (1915) of early Miocene age (Popenoe, 1958, p. 1394). The well was produced intermittently, and flowed approximately 4,500 barrels in 1957, 4,000 in 1958, and 2,000 in 1959. By the end of December 1959, the Medina No. 1 was reported to have become uneconomic and was shut in. Pumping in 1960 and 1961, however, produced about 2,000 additional barrels, bringing the approximate cumulative total to 12,500 barrels of oil. Three other near-commercial wells—the Union Oil Co. State No. 1 and State No. 3; and the Oil and Gas Development Co. Hawksworth-State No. 4—had been drilled in the same area in 1947, 1950, and 1951. Each produced 100 or more barrels of oil. Problems in completion played a large part in the abandonment of the latter of these wells. In 1962, two wells were attempted offshore on an extension of the Ocean City oil field, but were abandoned because of mechanical problems; in 1964 a well was drilled 2½ miles offshore to a depth of more than 5,000 feet before being abandoned. In all, 17 wells were drilled in the general area. Other structures in the Willapa Hills have been tested but with less success.

The only other well of note in the Willapa Hills area was the Continental Oil Co. Sims Royalty No. 1, drilled in 1954 in the Wishkah area of Grays Harbor County. The well was completed flowing 50,000 to 60,000 cubic feet of dry gas per day, but was not considered to be commercial.

CONCLUSIONS

Exploratory drilling for petroleum production in Washington in the near future seems destined to be concentrated in Continental Shelf waters off the west coast of the State as a result of the expenditure in October 1964 of more than $7.7 million by six major oil companies (Atlantic Refining Co., Pan American Petroleum Corp., Shell Oil Co.,

Standard Oil Co. of California, Superior Oil Co., and Union Oil Co.) in acquiring offshore leases from the Federal Government. Structures to be tested were outlined by aeromagnetic, sparker, and marine-gravity and seismic surveys conducted during 1963–64. Onshore exploration at this time (April 1965) consists of the drilling of a single deep test near the Canadian border in Whatcom County. The well is scheduled to reach a depth of more than 8,000 feet to assess the petroleum possibilities of Upper Cretaceous to lower Eocene strata.

Although more than 350 wells have been drilled in the State of Washington, this exploratory effort does not in any way provide a measure of the state of knowledge of the petroleum possibilities of the State, because very few tests, proportionately, were located on the basis of sound geologic or geophysical data, and few of these provided detailed subsurface information. As was pointed out by Glover (1947, pp. 4, 5):

> * * * of the 244 or so wells drilled, only some 27 were at sites whose selection was determined by carefully, properly conducted geological investigations, and possibly 6 to 10 additional ones were based upon less detailed but fairly adequate geological study. * * * Too much of the work done has been wasted effort; the State would be better off had it never been done.

Since 1947, another 60 or so wells have been drilled at carefully selected sites. Thus, the 100 or so wells drilled to date on scientifically located sites provide an average coverage of only 1 well per 100 square miles in the nearly 10,000 square miles of favorable area in the western part of the State, or 1 well per 200 square miles if potentially favorable areas in the western part of the Columbia Basin are included.

It is certain that exploratory tests spaced closer than an average of one well per each 100 or 200 square miles must be drilled before the petroleum resources of this region of poor exposures and complex structure and stratigraphy can be adequately appraised. The gas fields in Benton and Whatcom Counties and oil production in Grays Harbor and Jefferson Counties have proven that sources of petroleum are present. Future test drilling alone can establish whether or not oil and gas in commercial quantity occur in Washington State.

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MINERAL AND WATER RESOURCES OF WASHINGTON

SECTION 2

WATER RESOURCES AND DEVELOPMENT

PREPARED BY

THE UNITED STATES GEOLOGICAL SURVEY

THE UNITED STATES BUREAU OF RECLAMATION

AND

THE BONNEVILLE POWER ADMINISTRATION

SECTION II

WATER RESOURCES AND DEVELOPMENT

WATER RESOURCES

(By F. T. Hidaka, U.S. Geological Survey, Tacoma, Wash.)

INTRODUCTION

The total water supply in Washington is large; however, its distribution is uneven both areally and seasonally. The maldistribution leads to overall shortages in parts of eastern Washington and to summertime shortages and winter floods in the western part of the State. Ground water is available in small to very large quantities from basalt and glacial outwash in the area east of the Cascade Mountains. West of the Cascades, ground water is obtained largely from alluvium and glacial outwash that is highly productive in some areas. The chemical quality of most ground and surface water generally is excellent, being satisfactory for municipal, industrial, and agricultural uses. Large concentrations of fluvial sediment are transported by rivers in the southeastern part of the State. The Columbia River carries appreciable amounts of sediment that require the lower reach of the river to be continually dredged to maintain the navigation channel.

Topography and climate determine the amount of water available in Washington. The Olympic Mountains in the northwestern part of the State extend over most of the Olympic Peninsula. The mountains are characterized by many sharp ridges and crags rising to altitudes from 4,000 to almost 8,000 feet; the highest peak is Mount Olympus, 7,920 feet in altitude. The Willapa Hills in southwestern Washington comprise a low, rolling terrain that reaches a maximum altitude of 3,000 feet.

The Puget Sound basin is a wide, long valley enclosed by the Olympic Mountains on the west and the Cascade Mountains on the east. A large part of the area is covered by Puget Sound, a great inland sea, which is connected to the Pacific Ocean through the Strait of Juan de Fuca. The land area is generally less than 500 feet in altitude and is largely underlain by glaciofluvial material.

The Cascade Mountains distinctly separate the coastal and interior regions of the State. Most of the sharp peaks and ridges of the mountain range rise to about 6,000 to 8,000 feet in altitude, except for some volcanic peaks, Mount Rainier, Mount Adams, Mount Baker, and Glacier Peak, which rise above 10,000 feet. Many glaciers occupy the high mountains and over half of the glaciers in the United States outside of Alaska, are located in the State (Meier, 1960).

The Okanogan Highlands—a series of ridges, valleys, and rolling uplands—are located in the north-central part of Washington. East of the Highlands are the Selkirk Mountains, which extend into the northeast corner of the State. These mountains are a part of the

Rocky Mountain range and many of the peaks reach an altitude of 5,000 to 8,000 feet.

The Columbia Plateau covers almost all of southeastern Washington. The area slopes gently from 4,000 feet altitude along the outer edges to 1,000 feet along the Columbia River gorge. Extensive plains lie between structural ridges and channels of larger streams, and are nearly all underlain by volcanic rocks. The northern end of the Blue Mountains of Oregon extends into the extreme southeastern part of Washington.

The State is divided by the Cascade Mountain Range into two distinct climatic regions. The area west of the Cascade Mountains, about 40 percent of the State, has a temperate maritime climate characterized by dry moderately warm summers and wet mild winters. The eastern 60 percent of the State has an arid to semiarid climate bordering on the continental type with greater extremes in temperature during the summer and winter than western Washington.

The average annual precipitation in the State is about 40 inches; the western part receives about 70 inches and the eastern about 20 inches. Locally, average precipitation ranges from as little as 5 inches per year in the driest part of central Washington to more than 200 inches annually in the rain forests of the Olympic Mountains. The areal distribution of precipitation is shown by figure 61.

Although the annual precipitation over western Washington is large, much of it falls during the winter and very little falls during the summer. In July and August, an average of less than 1 inch of precipitation occurs per month over much of the agricultural lowlands of Puget Sound—less than one-quarter of the average crop requirement. Precipitation normally begins to increase in September, reaching a maximum in December. About 40 percent of the annual total falls during the last quarter of the year. Another 40 percent falls during the first 4 months of the year. Therefore, about 80 percent of the annual precipitation occurs during the months of least demand for water.

In the eastern part of the State the distribution of annual precipitation is similar to that to the west, although there is a smaller range in the amounts of monthly precipitation.

GROUND WATER

Largely for convenience in describing ground-water conditions within Washington, the State has been divided into 11 areas, as shown in figure 62 (Eakin and others, 1946, pp. 147–152). To a large extent the boundaries of these areas are based on surface-drainage characteristics and therefore are in part arbitrary insofar as ground-water occurrence is concerned.

Large amounts of ground water are available in the basaltic lava rocks of the scabland, and in glacially derived or other unconsolidated sedimentary deposits in the Yakima River, the Clark Fork, and Puget Sound area. Ground water is scarce or lies at great depths in most of the Selkirk Mountains, Cascade Mountains, and Olympic Mountains. The coastal slope contains little ground water, except in some local areas where large quantities are available in sand plains. Figure 63 shows a generalized picture of the yield of typical wells in the State.

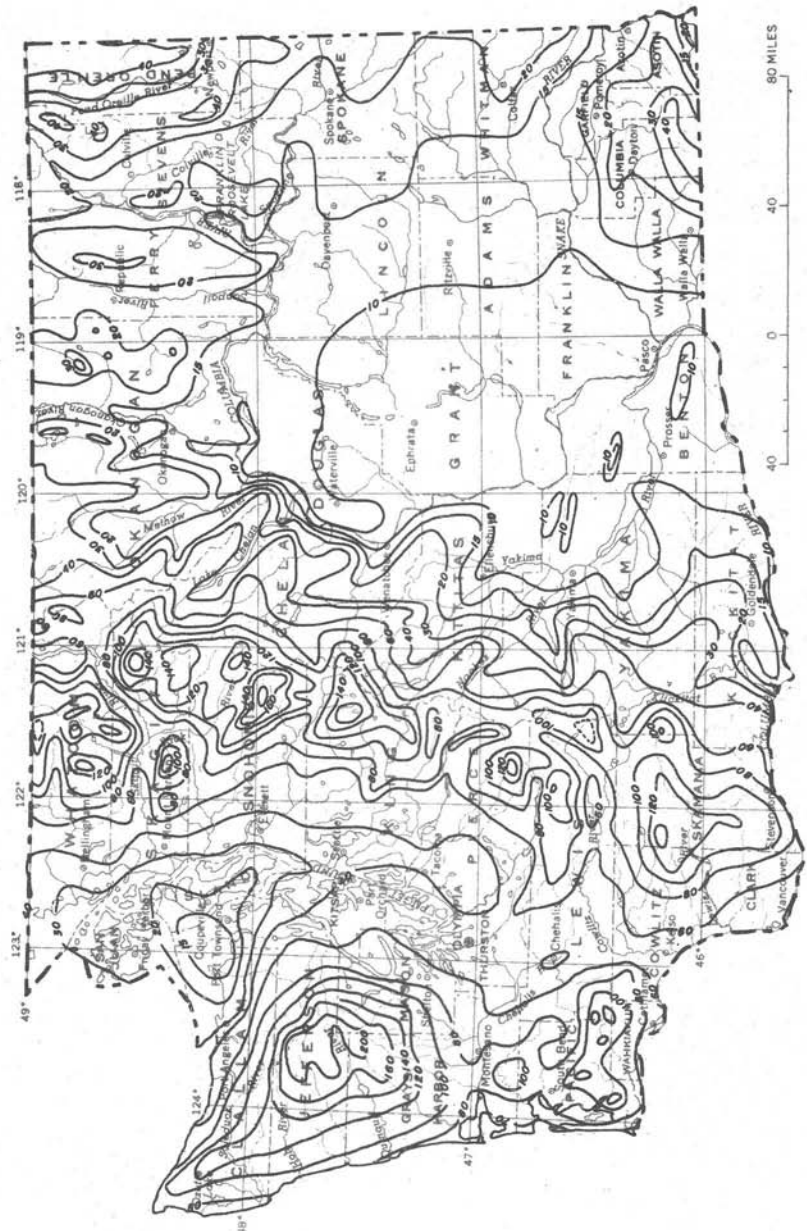

FIGURE 61.—Areal distribution of average annual precipitation (in inches).

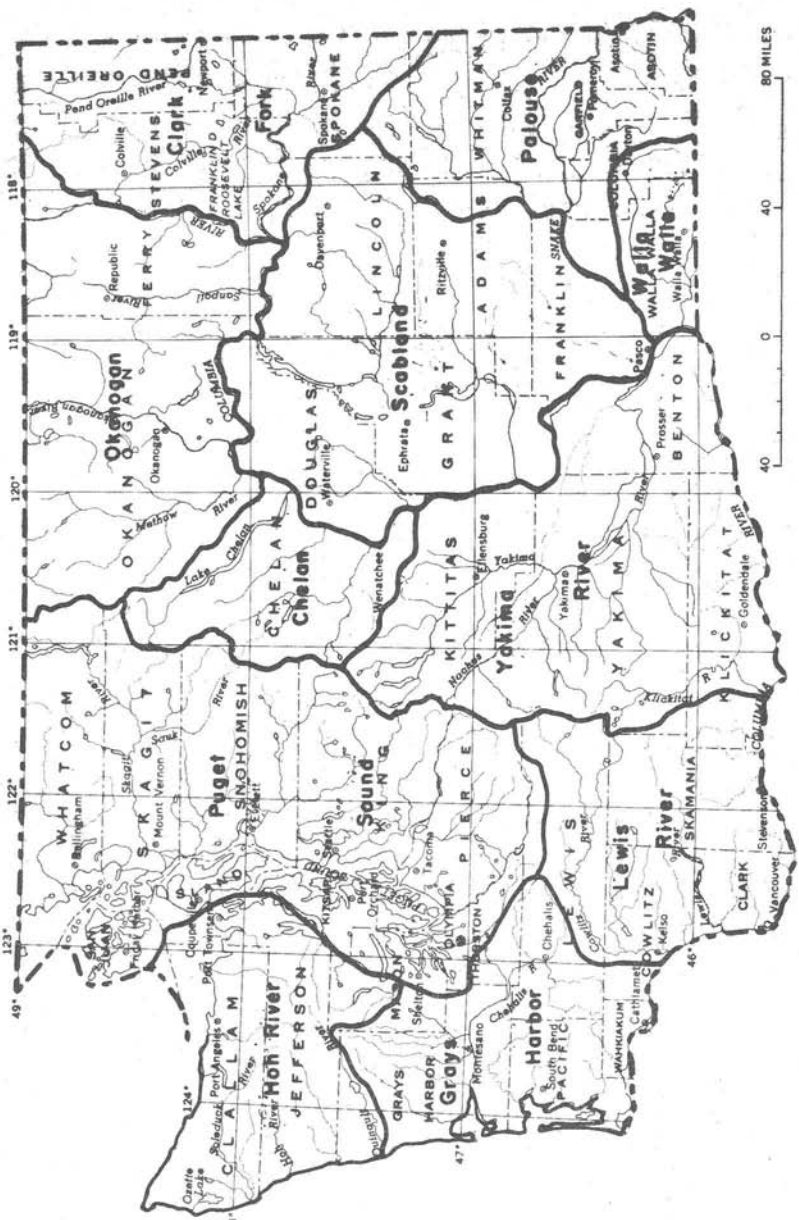

FIGURE 62.—Ground-water areas.

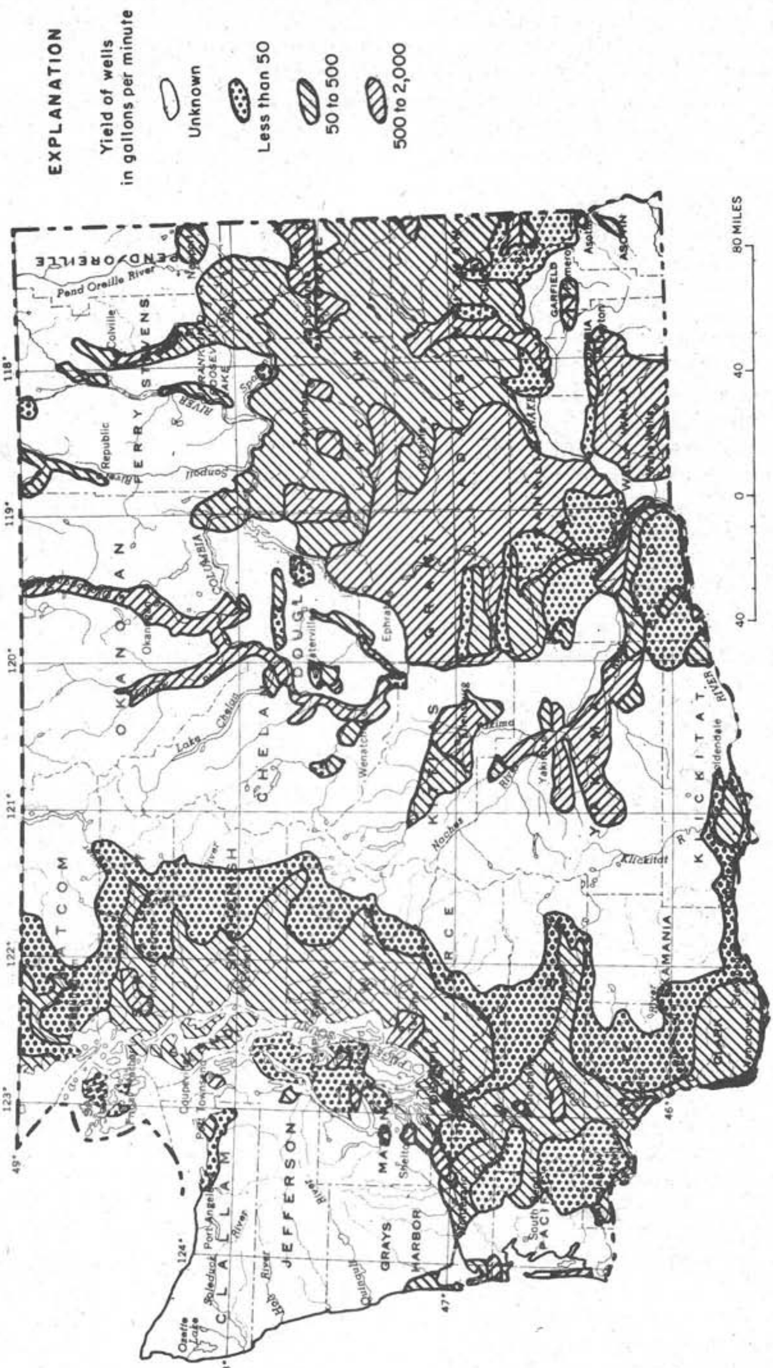

FIGURE 63.—Yield of typical wells.

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The chemical quality of most ground water is excellent for most uses and suitable for municipal, industrial, and agricultural uses. The water generally contains less than 250 ppm (parts per million) dissolved solids and is classified as soft or moderately hard.

The allowable dissolved-solids content of a water varies considerably depending on the particular water use. For drinking-water supplies, the U.S. Public Health Service (1962, p. 7) recommends that waters containing more than 500 ppm not be used if other less mineralized supplies are available.

Hardness of water is a measure of the amount of soap needed to form a lather and is expressed as an equivalent amount of calcium carbonate, in ppm. Calcium and magnesium are the principal ions that cause hardness but ions such as aluminum, iron, and manganese also contribute to hardness. In U.S. Geological Survey publications, water of 0 to 60 ppm hardness is considered to be soft, that of 61–120 ppm is moderately hard, that of 121–180 ppm is hard, and that of more than 180 ppm is very hard.

Areas where ground water commonly contains more than 250 ppm of dissolved-solids or has hardness exceeding 120 ppm are shown in figures 64 and 65. Calcium and bicarbonate are the principal ions in most ground waters. Notable exceptions to this characteristic are described in the following discussions.

HOH RIVER AREA

The Olympic Mountains cover most of the Hoh River area (fig. 62), and the remainder includes adjoining slopes and coastal plains. The area is mountainous, heavily forested, and drained by many perennial streams. The surface is underlain by fine-grained sedimentary rocks that are impermeable below the zone of weathering.

In the mountains, ground-water occurrence is restricted chiefly to gravel deposited in the major stream valleys. Large quantities of ground water are not available because many of these deposits stand above the water table. In the northeastern part of the area, near Sequim, much ground water is pumped from wells that tap aquifers in sand and gravel deposits of glacial outwash. These wells are mostly less than 200 feet deep and many yield more than 200 gallons per minute (gpm). Recharge is chiefly from precipitation and infiltration from streams, but in a few areas infiltration from irrigation water raises water levels to within a few feet of the ground surface during the latter part of the season.

Water obtained from wells sampled in the area is of excellent quality for most uses, contains less than 250 ppm of dissolved solids, and is soft to moderately hard.

GRAYS HARBOR AREA

The Grays Harbor area, in the southwestern part of the State (fig. 62), includes all of the Chehalis River basin and the low Willapa Hills. Ground water is extensively developed in the Chehalis River basin where alluvial deposits along the stream valley are thick enough to yield economic quantities of water to wells. North and south of Grays Harbor, terrace deposits supply moderate amounts of water to wells and springs, and are the principal source of domestic supply.

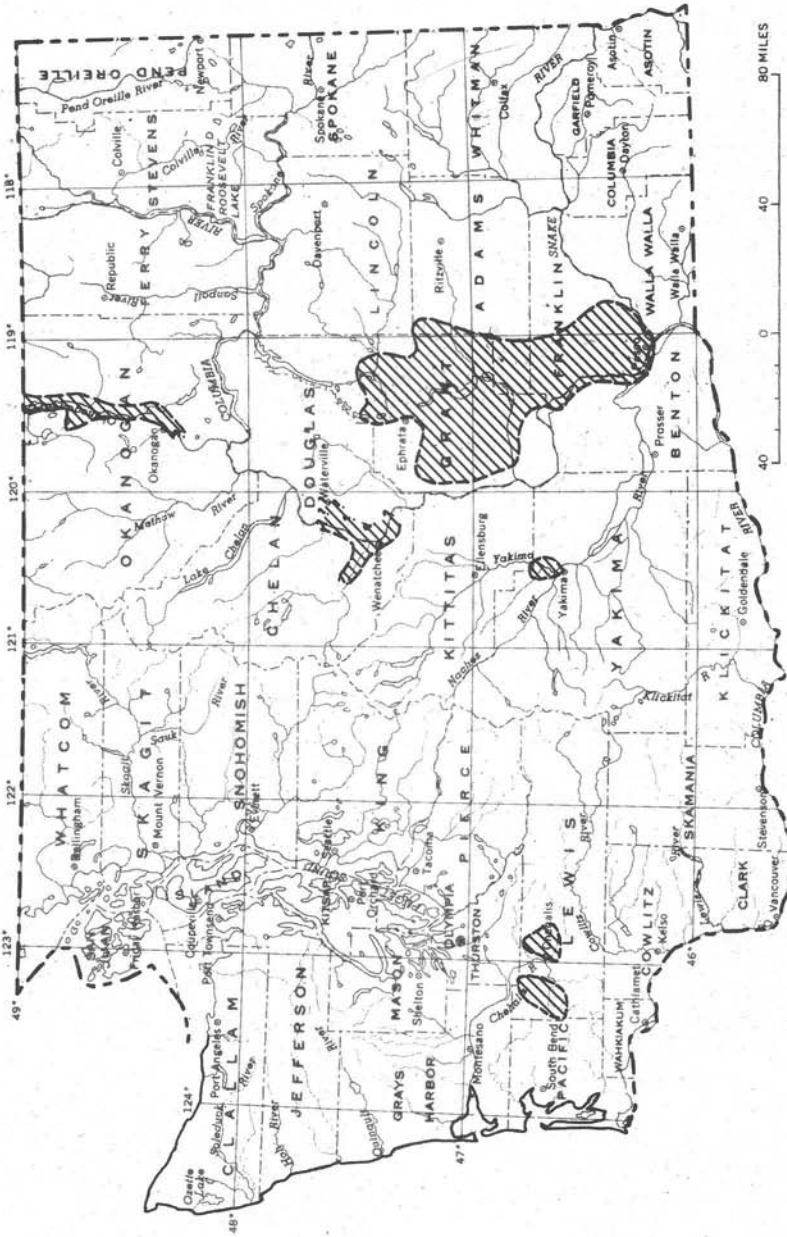

FIGURE 64.—Areas where ground water commonly contains more than 250 ppm of dissolved solids.

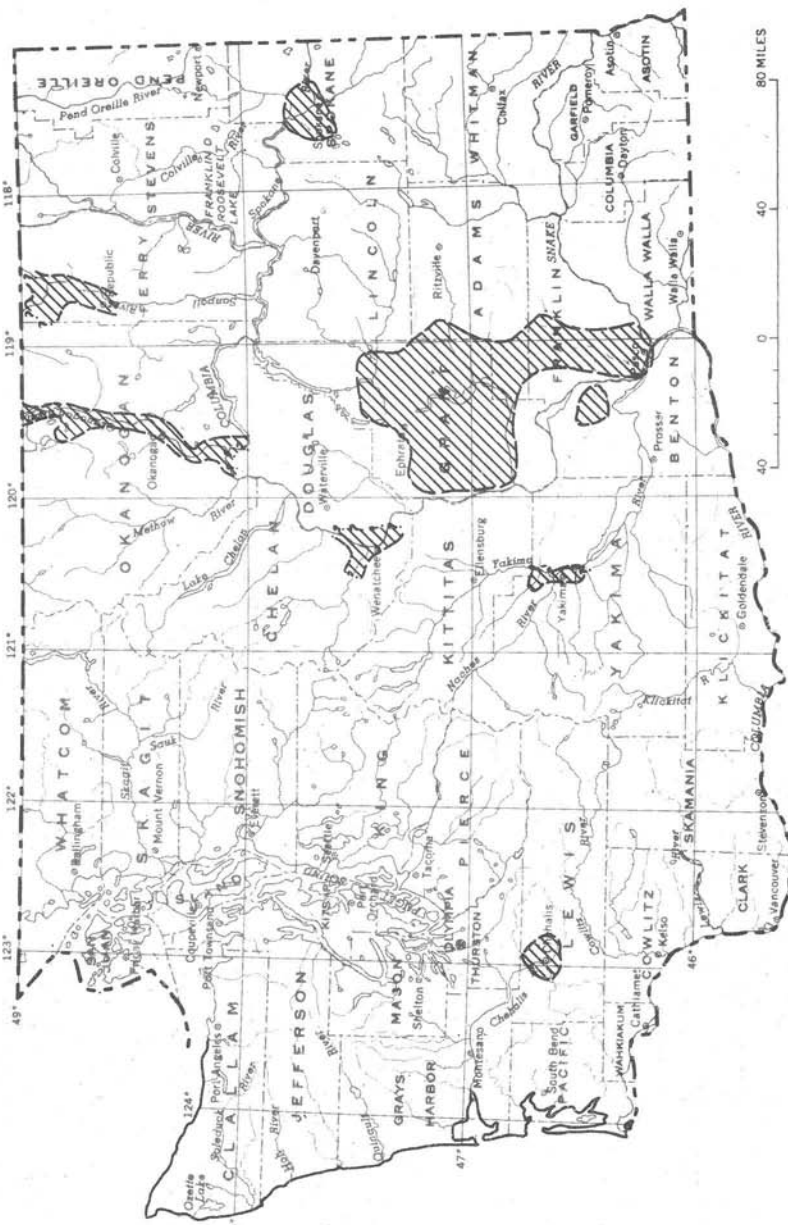

FIGURE 65.—Areas where ground-water hardness commonly exceeds 120 ppm,

In addition, ground water is used extensively on the coastal plain adjacent to Grays Harbor and Willapa Bay. The sand deposits that underlie the area are very permeable, and shallow large-diameter wells yield as much as several hundred gallons per minute. These ground-water reservoirs are believed to be capable of supporting a withdrawal of several hundred million gallons per year to properly spaced and operated wells (Newcomb, 1947). Near the coast, encroachment by salt water is a potential problem if water is withdrawn excessively. In the upper Chehalis River basin, in western Lewis County, many deeper wells tap marine sedimentary rocks and produce generally small supplies of water.

Most of the well water in the area is of excellent quality for most purposes. It contains less than 250 ppm dissolved solids, except for saline water obtained from the deeper wells in western Lewis County in which sodium and chloride are the dominant ions. Most hardness-of-water values are less than 100 ppm and the water therefore is soft or only moderately hard. The principal dissolved constituents normally are silica, calcium, and bicarbonate. The chemical quality of the sodium chloride type water is marginal or poor; dissolved-solids content is greater than 500 ppm, and hardness exceeds 180 ppm.

PUGET SOUND AREA

The Puget Sound area includes all the river basins draining to Puget Sound (fig. 62). The lowland area is underlain by unconsolidated sediments, largely of glacial origin, that are at least 2,300 feet thick in some places. The mountains in the eastern part of the area consist largely of igneous and metamorphic rocks, with alluvial and sedimentary deposits along the many stream valleys. In the lowlands east and south of Puget Sound, ground water is the most extensively developed in the State.

Large quantities of ground water are obtained from wells penetrating sand and gravel zones that range in depth from 100 to 500 feet. Water levels in these wells show very small seasonal change. Wells of this type are used for municipal and industrial supply, and have yields as great as 1,000 gpm—a few exceeding 9,000 gpm. Artesian wells located at low altitudes are fairly common, and some flow as much as 2,000 gpm (Molenaar, 1961). However, many wells tap shallow water-bearing zones in glacial drift and are used to supply water for rural domestic use and stock supply. Because the recharge depends upon precipitation and streamflow, some of these wells go dry in the latter part of the summers of drought years.

In the Cascade Mountain part of the area, small to moderate supplies of ground water occur in fractures and joints of bedrock. Other supplies are obtained from springs and from wells that tap small deposits of alluvium along stream valleys.

The chemical quality of most of the ground water in the Puget Sound area is good or excellent. Generally, it contains less than 150 ppm of dissolved solids, and in only a few samples does the concentration exceed 250 ppm. Silica, calcium, and bicarbonate are the main constitutents present in solution. The water ranges from soft to very hard; however, most ground water of the area is soft or only moderately hard.

Large amounts of dissolved solids occur in a few places near Puget Sound where the ground water is contaminated by sea water. Aquifers in marine sedimentary deposits also produce water that contains large quantities of dissolved solids. Iron concentrations greater than 0.30 ppm, the recommended limit for drinking water, are particularly evident in ground water in the Everett area, and occur in other parts of the area as well.

LEWIS RIVER AREA

Most of the Lewis River area (fig. 62) is mountainous and is underlain chiefly by volcanic rocks. The lowland area adjacent to the Columbia River in the southwestern part is underlain by sedimentary deposits. Ground water in the mountainous central and eastern areas is insignificant, and potential development is limited. The sand and gravel deposits in the lowlands east and north of Vancouver yield supplies of ground water that are generally good or excellent. Many industrial and municipal wells produce more than 2,000 gpm; one well is reported to yield more than 4,600 gpm (Mundorff, 1960).

The chemical quality of most ground water in the subprovince is excellent for most uses. Dissolved-solids content characteristically is less than 150 ppm. Hardness is generally less than 100 ppm and the water therefore is soft or only moderately hard. As with most ground water west of the Cascade Mountains, the principal constituents are silica, calcium, and bicarbonate. Nitrate concentrations in water from a few shallow wells in the Vancouver area have been greater than 5.0 ppm—a possible sign of contamination. Water from some of the deeper wells in the northwestern part of the subprovince contain more than 10,000 ppm dissolved solids (Weigle and Washburn, 1956). These wells probably tap marine sedimentary deposits and yield saline water similar to that occurring in the adjacent western Lewis County.

YAKIMA RIVER AREA

The Yakima River area, in the south-central part of the State (fig. 62), includes the Yakima River basin and adjacent streams tributary to the Columbia River. Ground water is extensively developed in the valleys of the Yakima River and its tributaries. Alluvial and glacial deposits, in some places exceeding 500 feet in thickness, contain considerable amounts of ground-water storage in these valleys. Because the ground-water reservoirs are easily recharged by infiltration from streams and irrigation water, water is available to wells on a sustained basis in moderate to large quantities in many parts of the area. The rugged mountainous region in the western part of the area is underlain chiefly by volcanic rocks that have low porosity and permeability and yield little or no water to wells. Domestic ground-water supplies are obtained from shallow aquifers within the stream-valley alluvium. The thick series of basaltic lava flows that underlies a large part of the area have a wide range in permeability and yield.

The chemical quality of most of the ground water in the subprovince is good to excellent for most purposes; the amounts of dissolved solids generally are less than 250 ppm. Most of the water is classed as soft to moderately hard. Greater dissolved-solids content is found in water from wells in sand and gravel deposits adjacent to the channels of the Yakima River and Wenas Creek in a small area north of Yakima.

The wells are less than 150 feet deep and the larger concentrations may be attributed to the influence of irrigation, which is widespread in the vicinity of Yakima. This supposition is supported by the occurrence of sulfate and nitrate concentrations and hardness-of-water values greater than those found in other ground water in the area.

SCABLAND AREA

The Scabland area is in the east-central part of the State and includes the Columbia Basin Irrigation Project area (fig. 62). Basalt is the principal aquifer in the area and yields ground water nearly everywhere, but at varying depths and in varying quantities. Large quantities of water are obtained from wells drilled into the zone of contact between one basalt flow and another. The dense middle and lower parts of the flows usually yield little or no water to wells. Sedimentary deposits that overlie the basalt are important sources of ground water along stream valleys and glacial meltwater channels. Water-bearing zones are generally thin in these deposits, but in places are thick enough to yield large quantities of water. Infiltration from irrigation return flow has raised the water table substantially in some areas and drainage problems have resulted.

The chemical quality of the water from many shallow to moderately deep (less than 500 feet) wells within the Columbia Basin Irrigation Project area is poor; hardness exceeds 180 ppm and dissolved-solids content exceeds 250 ppm. The poor quality is probably due to the influence of irrigation. Calcium, magnesium, bicarbonate, and sulfate are the important constituents, and concentrations of nitrate and chloride are often appreciable. Deeper ground water commonly contains silica, sodium, and bicarbonate as principal dissolved constituents, with appreciable amounts of potassium and fluoride but very little calcium and magnesium.

PALOUSE AREA

In the Palouse area (fig. 62) ground water is available in large quantities from basalt except where the basalt thins on flanks of areas underlain by older rock. Most deep wells yield from one to two gallons per minute for each foot of penetration below the regional water table. The principal area of water use is near Pullman, and average withdrawals are 800 million gallons per year. Of this, an estimated 65 million gallons per year is being withdrawn from storage (Foxworthy and Washburn, 1963, p. 2). Indications are that potentially good aquifers lie below those now extensively developed in the Pullman area and that hydraulic continuity between the deeper and shallower aquifers is poor. The lower aquifers probably could be tapped without undue effect on the upper zone.

Ground water in the Palouse area is of good chemical quality and ranges from soft to hard. Concentrations of dissolved solids are uniform, and hardness varies from 75 to 200 ppm. Iron concentrations greater than 0.30 ppm (the recommended maximum concentration for domestic use) have been detected in ground water sampled in the Pullman area.

WALLA WALLA AREA

Significant quantities of ground water are obtained from basalt and from gravel deposits that overlie the basalt in the Walla Walla area (fig. 62). Though there have been declines in water levels in some wells in the eastern part of the valley, there is no evidence that the ground-water resource as a whole has been overdeveloped. A much larger additional supply of water can be developed from the basalt.

Most of the ground water is of excellent chemical quality for most uses; hardness varies from soft to extremely hard. The dissolved mineral content is low, generally less than 250 ppm.

CHELAN AREA

The Chelan area (fig. 62), in the north-central part of the State, covers approximately the same area as Chelan County. The chief use and development of ground water is concentrated in the Wenatchee River valley and in the area near the southeast end of Lake Chelan. No detailed ground-water studies have been made in the area.

Ground water in the area characteristically contains more than 250 ppm of dissolved solids and has hardness greater than 180 ppm.

OKANOGAN AREA

The Okanogan area, in the north-central part of the State (fig. 62), is an area of fairly low rounded mountains, upland plateaus, and basins. Ground water is developed mainly in the valley bottoms and on the terraces along some of the main streams. It occurs in the sand and gravel deposits along the perennial streams and in moderately productive water-bearing zones in volcanic rock. Most of the bedrock has poor water-storage characteristics and does not yield much ground water. However, the ground-water supply, in general, appears to be adequate to meet any demands that can reasonably be anticipated.

Ground water obtained from the sedimentary deposits in the stream valleys commonly contains about 250 to 350 ppm dissolved solids. Extreme hardness has been found in most of the well waters in the Okanogan River valley, commonly exceeding 180 ppm.

CLARK FORK AREA

The Clark Fork area lies in the extreme northeastern corner of the State (fig. 62). The northern Rocky Mountains, which are heavily forested, extend over the northeastern part of the area, and low mountains and upland plateaus cover the western and southern parts. The major ground-water reservoirs in the area occur in the principal intermontane valleys, of which the Spokane Valley is the most important. The gravel in the Spokane Valley is clean and extremely permeable. The gravel yields very large quantities of water to wells even though they extend only a few feet below the water table. Yields of more than 9,000 gpm have been reported from wells tapping these deposits. Ground water in the valley consists mostly of underflow from Pend Oreille and Coeur d'Alene Lakes and natural drainage from Rathdrum Prairie in Idaho. The underflow emerges as springs

along the Spokane and Little Spokane Rivers in the vicinity of Spokane.

Ground water in the area adjacent to the Spokane River generally contains less than 200 ppm of dissolved solids. The water ranges from soft to hard, and most has less than 150 ppm of hardness.

SURFACE WATER

General Characteristics of Streamflow

Surface-water runoff in Washington averages about 26 inches per year—more than 2½ times the average for the United States. This represents a volume of 95 million acre-feet of water per year, or 85 billion gallons per day (bgd)—probably the largest amount generated in any of the conterminous States. In addition, the State receives an average flow exceeding 100 bgd from rivers that enter from outside its borders, the principal contributors being the Columbia, Snake, Pend Oreille, Spokane, Kettle, Okanogan, and Skagit Rivers. The surface water crossing the Canadian border is subject to the general provisions of the Boundary Water Treaty of 1909 and subsequent orders of the International Joint Commission.

The Columbia River is the largest river in Washington; it drains about 70 percent of the State. The river enters the State from Canada in the northeast corner, and flows south and west for about 450 miles through central and eastern Washington. The Columbia River then flows westward to the Pacific Ocean, forming the border between Washington and Oregon for about 320 miles. The Snake River, largest tributary to the Columbia River, enters Washington from the southeast and flows westward to join the Columbia River at Pasco. Other principal tributaries to the Columbia River from the east are the Pend Oreille and Spokane Rivers. The Kettle and Okanogan Rivers have their headwaters in Canada and are the major tributaries to the Columbia from the north. Other principal streams entering the Columbia River are the Methow, Chelan, Wenatchee, Yakima, Klickitat, Lewis, and Cowlitz Rivers; all of which have their source in the Cascade Mountains.

The remainder of the State outside the Columbia Basin is drained by many streams flowing directly to Puget Sound or the Pacific Ocean. Except for the Chehalis, Snohomish, and Skagit Rivers, these streams have drainage areas of less than 1,000 square miles. They include the Quinault, Hoh, Bogachiel, Nisqually, Puyallup, Green, Stillaguamish, and Nooksack Rivers.

The principal rivers of Washington and their relative average flows are shown in figure 66.

In spite of the large total supply, water may not be available where and when it is needed to meet existing and future needs. Extreme variations occur in the areal distribution of annual runoff, as shown in figure 67. In western Washington, large amounts of precipitation generate an average annual runoff that exceeds 100 inches in a substantial area of the Olympic and Cascade Mountains. (Average annual runoff is the total stream discharge during a year expressed as an average equivalent depth of water, in inches, over the entire basin.) In contrast, runoff averages 0.5 inch or less per year in much of the

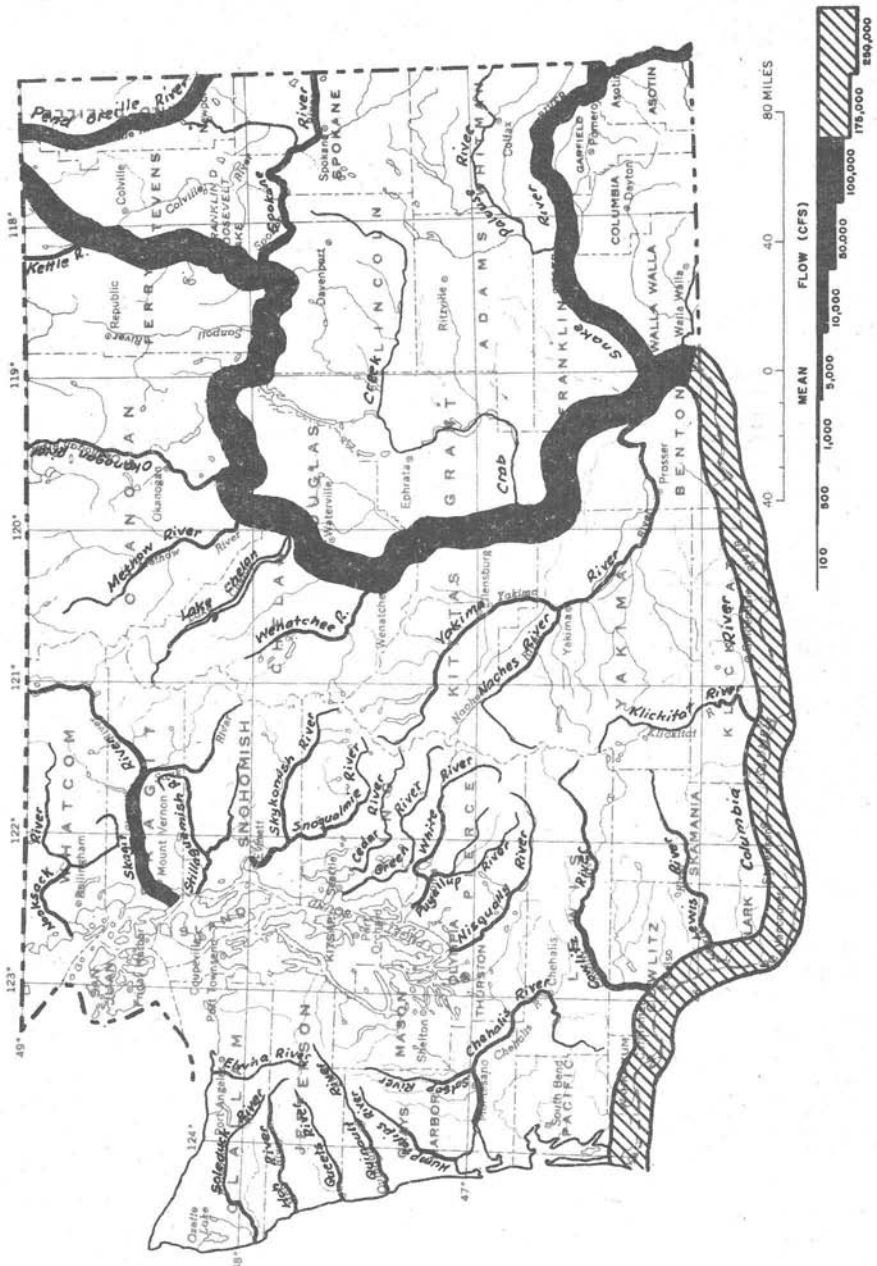

FIGURE 66.—Average discharge of principal streams.

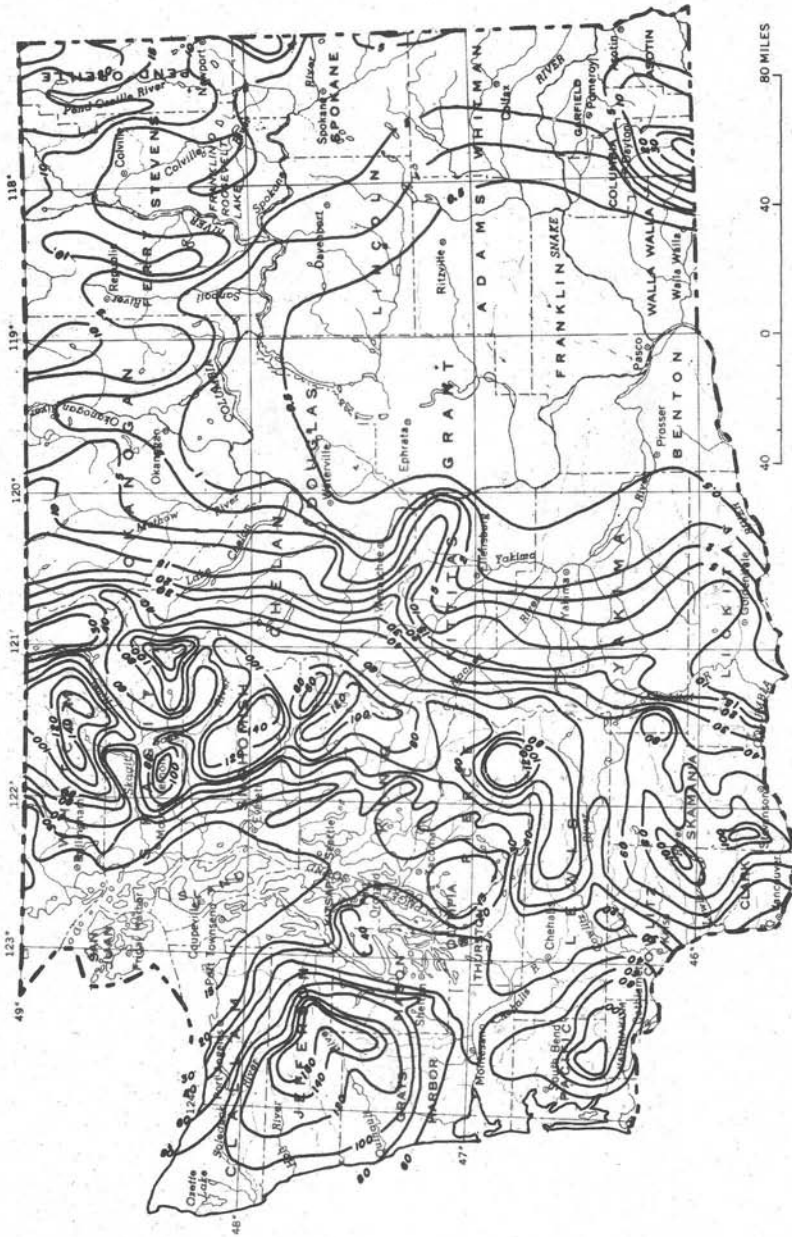

FIGURE 67.—Areal distribution of average annual runoff (in inches).

south-central part of the State east of the Cascade Mountains. North and east of the Columbia Plateau, annual runoff increases and exceeds 20 inches in the northeastern corner of the State. In a small area in the vicinity of Walla Walla in the Blue Mountains, runoff is greater than 30 inches. Westward into the Cascade Mountains, west of the Columbia Plateau, runoff increases rapidly; exceeding 60 inches per year in most of the Cascade Mountains, and reaching as much as 100 inches in the headwaters of some of the principal rivers. In the Puget Sound area, runoff decreases to less than 20 inches per year along the shores of the Sound, but increases to the west, exceeding 100 inches per year in the Olympia Mountains and in parts of the Willapa Hills.

In addition to the uneven distribution of runoff from one location to another, large variations in streamflow occur on a monthly, yearly, and long-term basis. Examples of the variation in monthly distribution of runoff within the State are shown in figure 68.

The contrasting distribution patterns in figure 68 reflect differences in physiography and climate, as follows:

(1) In the Naselle River, a coastal stream flowing directly to the Pacific Ocean, the major part of the runoff occurs in the winter—about 65 percent occurs during the 4 months from November to February, and only 10 percent occurring in the 5 months from May to September. Runoff is closely related to precipitation: all heavy winter precipitation occurs as rain, which runs off quickly.

(2) The Cedar River rises in the Cascade Mountains, and experiences two high-water periods, one in the winter and the other in the spring. High runoff in the winter is the result of precipitation falling as rain in the lower elevations of the basin; whereas high water in the spring is attributed to melting of the snowpack that accumulated at higher elevations.

(3) Thunder Creek, a glacier-fed stream tributary to the Skagit River drains high areas that receive almost all of their winter precipitation as snow. The distribution of runoff is opposite to that shown by the Naselle River. The maximum discharge on Thunder Creek occurs in July and the high-water period extends from May to September, when 70 percent of the annual flow occurs. The period of low flow is in the winter; only 17 percent of the runoff occurs from November to February.

(4) The Colville River shows the typical runoff pattern for a stream in eastern Washington. Much of the winter precipitation falls as snow, and the period of high runoff is caused by the melting of the snowpack in the springtime. By July, the water supply becomes inadequate because most of the snow has melted.

Annual runoff in the State varies considerably from year to year as shown by figures 69 and 70. Streamflow records for the Columbia River at The Dalles, Oregon (fig. 69), have been collected continuously since 1879. During this period, the annual runoff has varied from 161 percent of the 85-year average in 1894 to 61 percent in 1926. Large variations can occur in consecutive years, as illustrated by the records for 1928 and 1929 when the flow was 119 and 68 percent of the average, respectively. Flow of Quinault River, a coastal stream, also varies annually as shown by 52 years of streamflow records at

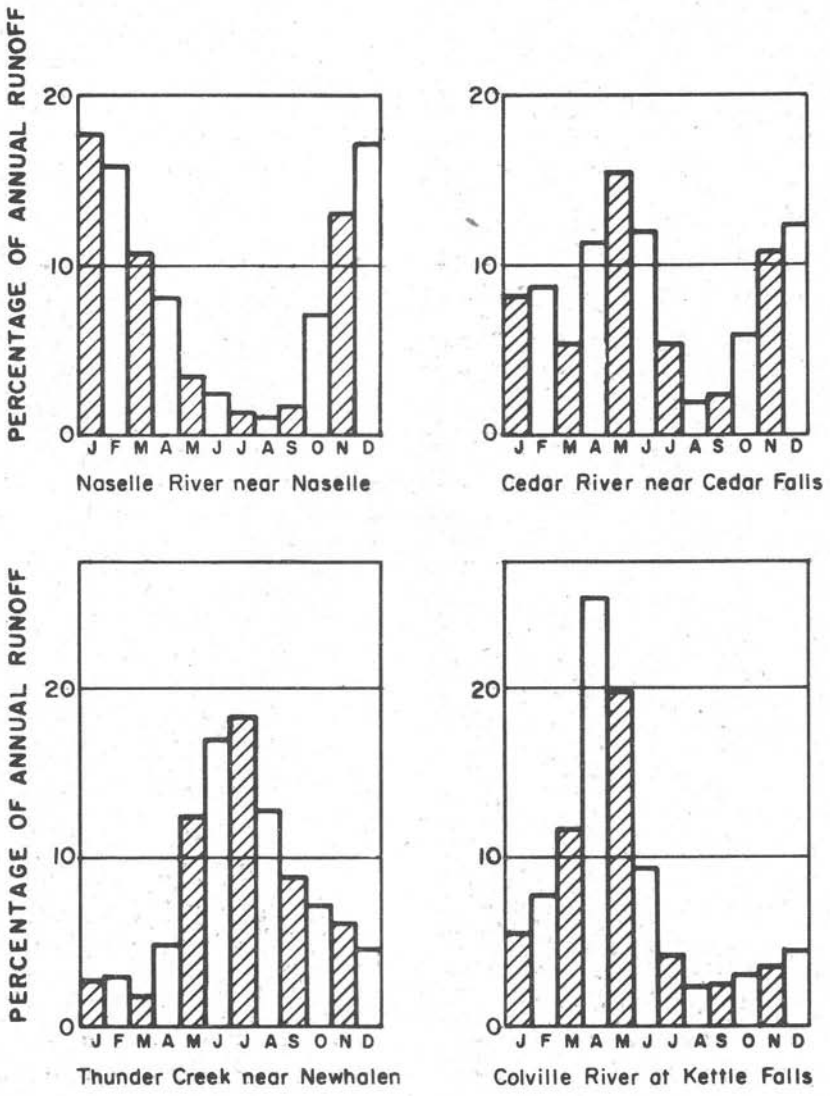

FIGURE 68.—Monthly distribution of runoff for four rivers.

Quinault Lake (fig. 70). The range between the maximum and minimum annual flows is not as large as the range for the Columbia River; the flow has varied from 129 percent of average in 1961 to 64 percent in 1930.

The annual runoff records for the Columbia River show four significant long-term trends. To smooth out the large annual variations and to reveal these long-term trends, a 10-year moving average is shown in figure 69. The earliest records indicate that a period of generally above-average runoff ended about 1905, after which the period of near-average flows occurred until 1920. The next trend

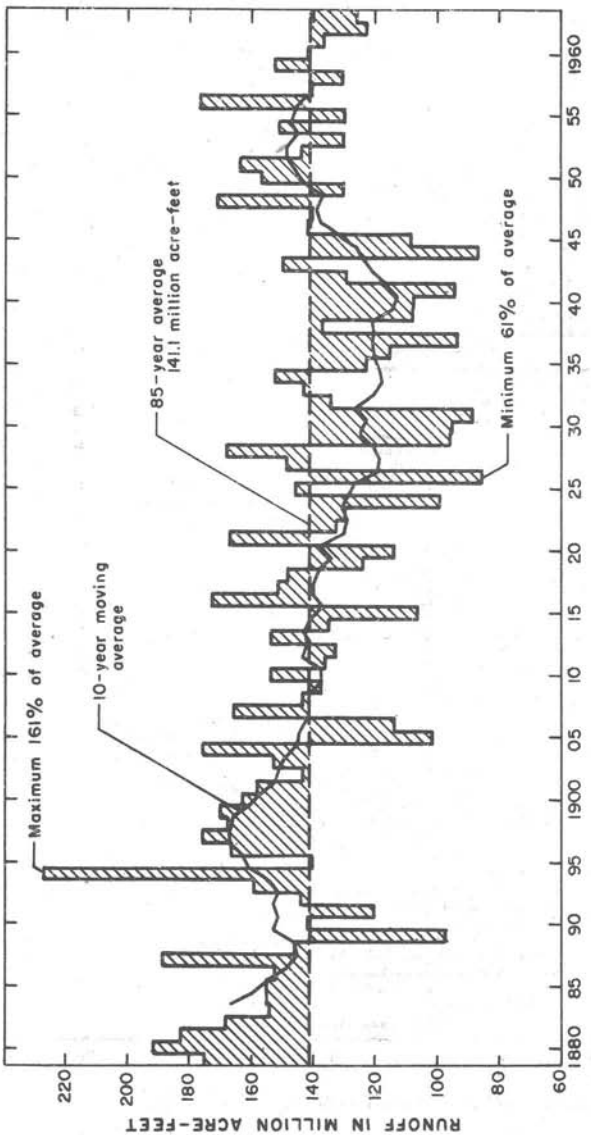

FIGURE 69.—Yearly streamflow for Columbia River at The Dalles, Oreg., since 1882.

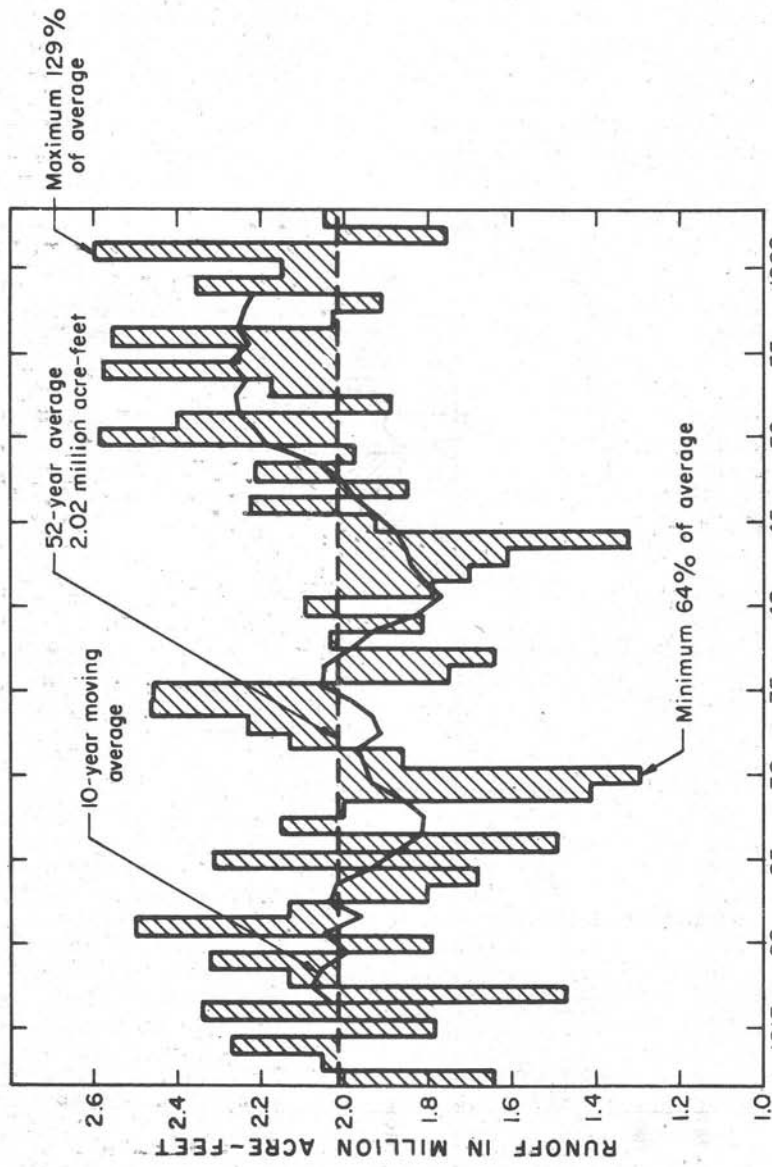

FIGURE 70.—Yearly streamflow for Quinault River at Quinault Lake since 1912.

was one of general deficiency in streamflow, lasting until 1948. This below-average trend was followed by a period of slightly above-average flows that continued at least until 1959. The 10-year moving average for the Quinault River (fig. 70) shows approximately the same trends as that for the Columbia River, except for the short period of above-average runoff in the mid-thirties. The usefulness of streamflow is directly related to its seasonal and annual dependability; therefore, large variations create problems in the complete utilization of surface water.

Lakes and Reservoirs

Lakes and reservoirs are an integral part of the water resources of Washington. Data on lakes and reservoirs in the State that cover an acre or more have been compiled in two volumes, for the areas west and east of the Cascade Mountains (Wolcott, 1961; 1964). These two volumes list 7,864 lakes and reservoirs covering a total area of 955 square miles. Except for recreational uses, lakes are mainly undeveloped but are a source of much usable water. Reservoirs store large amounts of water during high flows and release it during periods of deficient flow, when it will be of maximum benefit.

Glaciers

Of the nearly 1,000 glaciers in the United States south of Alaska, about 670 are in Washington (Meier, 1960). They cover an area of 149 square miles and represent 77 percent of the glacier area in the conterminous United States. Approximately 40 million acre-feet of water is currently stored as glacier ice in the State. The largest single glacier is Emmons, on Mount Rainier, which is 4.3 miles long and 4.1 square miles in area. However, the Emmons Glacier is exceeded in size by the Carbon-Russell glacier system, chiefly a single trunk glacier fed by two tributaries; it is 6.0 miles long and 5.0 square miles in area and is also located on Mount Rainier. The largest concentration of glacier ice is in the heart of the Northern Cascade Range, from Glacier Peak north to Snowfield Peak.

Of all the major drainage basins in the State, the Skagit Basin contains the most glaciers (270) and the largest area of glacier ice (66 square miles). The Puyallup River heads in 23 square miles of glacier ice on Mount Rainier. The Nooksack, Cowlitz, and Chelan Rivers each drain about 10 square miles of glaciers; the Hoh, Nisqually, and Wenatchee Basins contain, respectively, 7, 6, and 5 square miles of ice. Many other river basins contain a few small glaciers which are of local importance. Almost all of the glaciers in Washington occur where the annual precipitation exceeds 100 inches, and they produce each year an average of about 9,000 acre-feet of streamflow per square mile of glacier.

Streamflow from these frozen reservoirs has several unique characteristics which are pertinent to water-resource development in the State: (1) precipitation is stored in the winter and released during the summer dry period, especially in July and August; (2) although runoff from the glaciers approximately equals the precipitation when averaged over many decades or centuries, these ice reserves are so large that in hot, dry years the runoff can greatly exceed the total

precipitation, and in cool, wet years an appreciable amount of water is stored; (3) this frozen storage is virtually free from evaporation, transpiration, or other losses; and (4) the glacier rivers carry high sediment loads, partly due to "glacier flour," and partly due to the pronounced daily fluctuation in streamflow which causes river channel instability. Although the streamflow from Washington glaciers is a relatively small part (about 1.4 million acre-feet per year) of the total runoff, its timing and natural regulation is of considerable importance to man.

The contribution of water from glaciers in Canada to the Columbia River is also significant. According to existing maps, about 1,000 square miles of ice and permanent snowfields occur within the Columbia Basin in British Columbia. These snow and ice covered areas deliver about 6 percent of the annual flow to the Columbia River at the international boundary, and about 12 percent of the July and August flow.

Surface-Water Quality

Most surface water in Washington is of excellent chemical quality and is suitable for municipal, industrial, and agricultural uses. The dissolved-solids content of most stream waters in the State is less than 250 ppm. West of the Cascade Mountains and in the mountainous part of eastern Washington, surface water generally contains less than 100 ppm of dissolved solids; higher concentrations, as much as 876 ppm, occur in the surface water at lower altitudes in the eastern part of the State. Surface water west of the Cascades generally is classed as soft, containing less than 60 ppm of hardness. In eastern Washington, most surface water is moderately hard to extremely hard, with values exceeding 100 ppm. Figures 71 and 72 show the areal distribution of dissolved-solids content and hardness for surface water in Washington.

Available sediment transport information for streams in Washington is limited, and additional investigations are needed in areas where fluvial sediment problems are known or suspected to exist. The Columbia River carries an appreciable amount of suspended sediment. The concentration is low, usually less than 25 ppm, but the tonnage of sediment moved is large. From October 1962 to September 1963, the Columbia River transported 8.4 million tons past Vancouver, Washington. Many streams heading in the Cascade Mountains have glaciers as their sources, and carry much fine sediment derived from the melting of the glaciers. These streams also move appreciable amounts of sand and gravel. The Palouse and Walla Walla River basins in southeastern Washington are areas where sediment problems are intense. The soils in the basins are easily eroded, and storm runoff causes the movement of very large amounts of fluvial sediment. Annual average concentrations of suspended sediment transported by streams in the State are shown in figure 73.

Turbidity can be a problem in the use of stream water even though a stream may move only small tonnages of sediment. The very fine particles of sediment that produce turbidity have very little weight and settle very slowly. Chemical treatment or filtration may be necessary to remove turbidity prior to municipal or some industrial uses. Data to define ranges of turbidity for Washington streams are not available, but the most turbid streams are known to be those of

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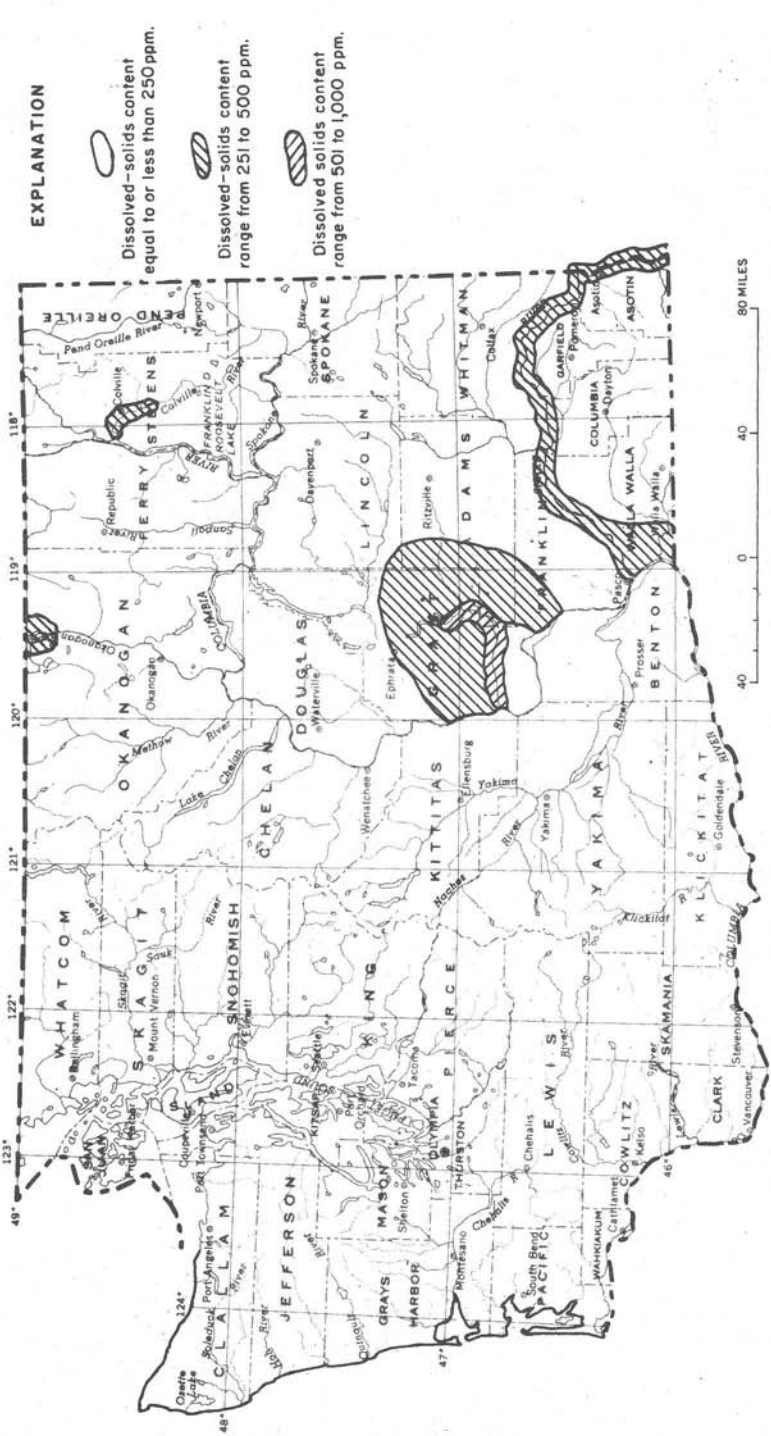

FIGURE 71.—Characteristic dissolved-solids content of surface water.

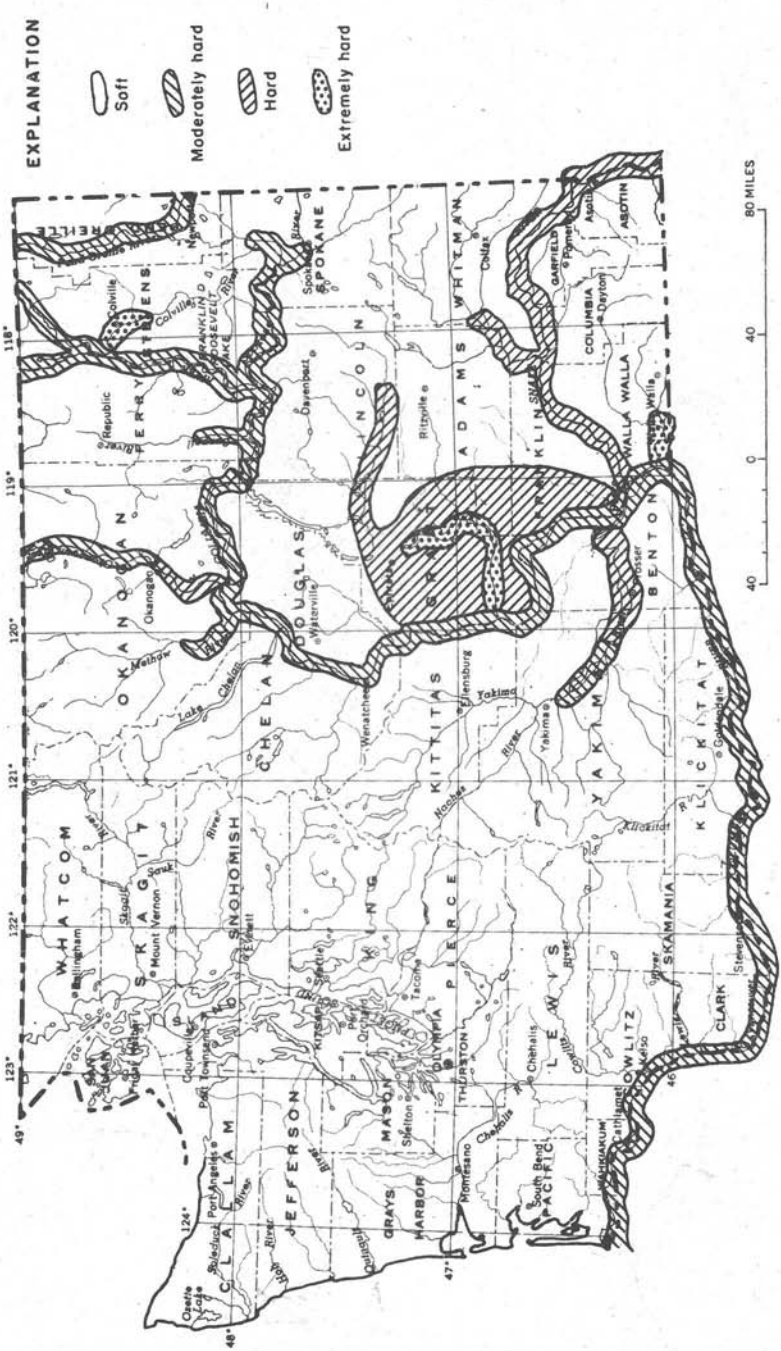

FIGURE 72.—Characteristic hardness values for surface water.

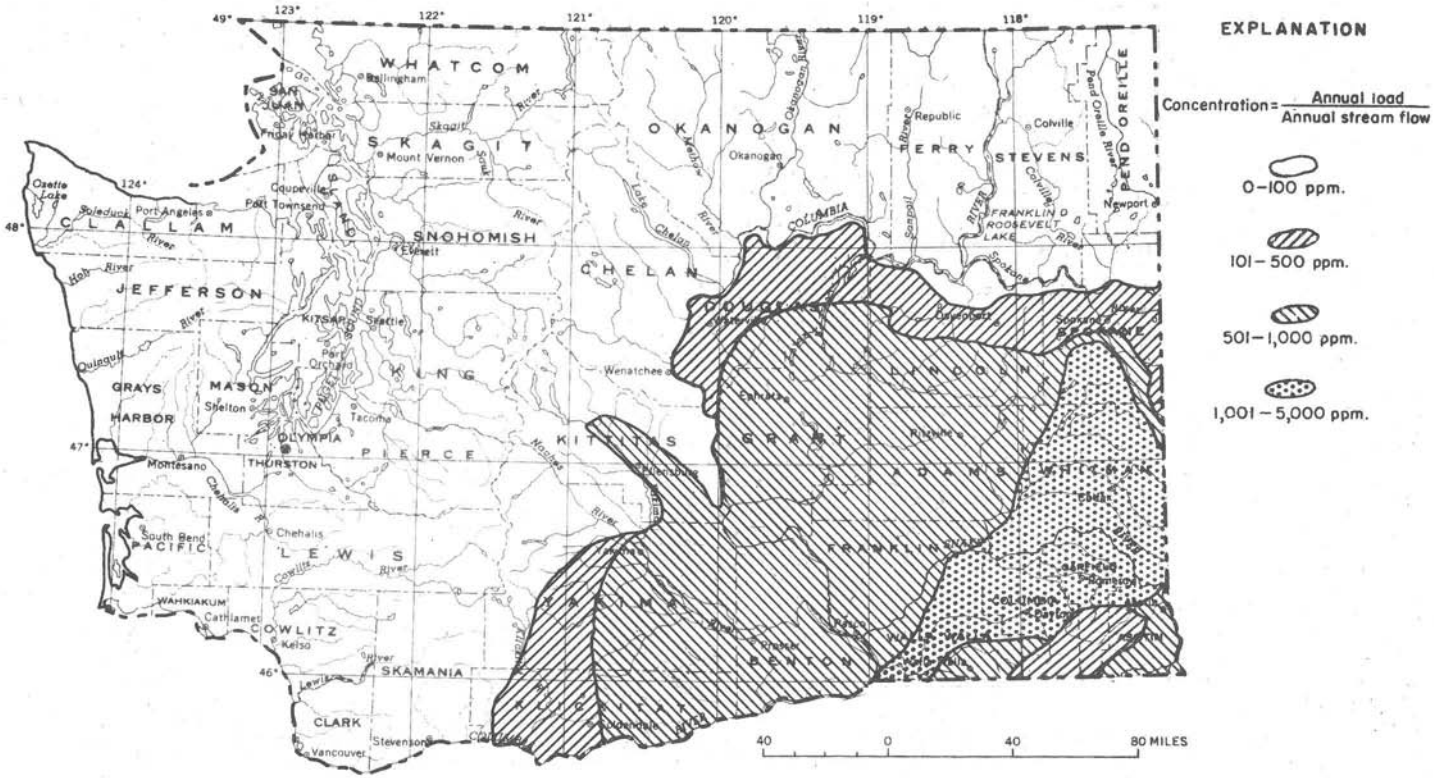

FIGURE 73.—Annual average concentrations of suspended sediment transportedby streams.

glacial origin and those in the southeastern part of the State. Stream turbidity in some places is sometimes related to man's use of the watershed—the more intensive the use of the land, the greater the turbidity.

Principal Basins in the State

PACIFIC COAST

The Pacific Coast basins, located in the extreme western part of the State, include the coastal plains and the western slope of the Coast Range, extending from the Columbia River to the Strait of Juan de Fuca. The Coast Range is divided by the Chehalis River valley into the Olympic Mountains to the north, and the Willapa Hills to the south. These basins cover an area of 6,300 square miles, or only 9 percent of the State's area, yet they contribute slightly over 25 percent of the runoff, averaging 73 inches per year. The area is drained by many short streams that flow directly to the Pacific Ocean (fig. 66). Each of the streams drains an area of less than 700 square miles, except for the Chehalis River, which drains 2,110 square miles. The many streams are fed by large amounts of precipitation, and receive relatively small amounts of water from ground-water storage. Except at the higher elevations in the Olympic Mountains, the seasonal pattern of flow closely follows the rainfall pattern, as only a small part of the precipitation accumulates as snow.

The basins are divided into two regions that have distinctly different runoff characteristics. The principal rivers of the northern region are the Humptulips, Quinault, Queets, and Quillayute Rivers. All of these flow westward from the Olympic Mountains to the Pacific Ocean and produce large amounts of streamflow—averaging about 100 inches annually. The Quinault River has a drainage area of 264 square miles at the gaging station and has had an average annual runoff of 143 inches during the last 50 years. The headwaters of streams in the northern area are in the Olympic Mountains, the site of many small alpine glaciers and perennial snowfields. These glaciers and snowfields tend to make the runoff more uniform throughout the year by storing some of the abundant winter precipitation as snow or ice. Rainfall still has a definite effect on streamflow—about 50 percent of the runoff occurs from November to February, the period of heavy precipitation. The melting of accumulated winter snow during April to June produces about 25 percent of the annual total.

The southern part of the area includes the basins of the Chehalis River and smaller coastal streams to the south. All streams in this area head in the Willapa Hills and on the southern slope of the Olympic Mountains. Very little of the abundant precipitation falls as snow, and seasonal distribution of runoff is similar to that of rainfall. About 75 percent of the annual streamflow occurs from November to March, in contrast to about 10 percent from May to September. The largest river system in the area is that of the Chehalis River and its principal tributaries (the Newaukum, Skookumchuck, Satsop, and Wynoochee Rivers). The average annual runoff of the Chehalis River is 42 inches near Grand Mound; the Satsop and Wynoochee Rivers, which are tributary below this point, produce nearly 100

inches per year. Other important rivers in the area are the Naselle, Willapa, and North Rivers. The Naselle River, in the extreme southwestern part of the area, has an average annual flow of over 100 inches. The North River, which flows into the north end of Willapa Bay, averages only about 60 inches.

Streamflow data for selected long-term gaging stations in the basin are given in table 24.

TABLE 24.—*Summary of streamflow data at selected sites in the Pacific Coast basins*

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Maximum (cfs)	Minimum (cfs)
			Cfs	Acre-feet per year		
Naselle River near Naselle	54.8	33	432	312,800	11,100	19.0
North River near Raymond	219.0	35	954	690,700	35,000	21.0
Chehalis River near Grand Mound	895.0	34	2,783	2,015,000	48,400	90.0
Skookumchuck River near Centralia	61.7	27	247	178,700	6,710	15.5
Satsop River near Satsop	299.0	33	1,976	1,431,000	46,600	166.0
Wynooche River above Save Creek	74.1	37	805	582,800	23,600	64.0
Humptulips River near Humptulips	130.0	21	1,325	959,300	33,000	82.0
Quinault River at Quinault Lake	264.0	51	2,786	2,017,000	50,200	276.0
Hoh River near Forks	208.0	36	2,015	1,459,000	38,700	247.0
Soleduck River near Fairholm	83.8	33	622	450,300	23,500	51.0

The chemical quality of surface water in the Pacific Coast basins is excellent. Stream water is low in dissolved solids (seldom more than 100 ppm) partly because high precipitation has leached much of the readily soluble minerals from the ground. The water is classed as soft with hardness generally less than 60 ppm. The principal dissolved constituents are calcium and bicarbonate.

The physical and bacteriological quality of the surface water is generally good to excellent. Physical qualities such as color, turbidity, and temperature are within the limits for most uses, except during periods of high runoff. Some pollution from sewage wastes occurs below population centers, but in many areas the concentration is reduced by dilution and natural processes.

PUGET SOUND

The Puget Sound basins, as used in this report, include all of the area south of the international boundary that is drained by streams flowing into Puget Sound, Hood Canal, Georgia Straits, and the Strait of Juan de Fuca east of and including the Elwha River. The area is bounded on the east by the crest of the Cascade Mountains, and on the west by the Olympic Mountains. It extends over about 15,000 square miles, including 2,500 square miles of salt water, and represents about 20 percent of the area of the State. Streams in the Puget Sound basins discharge about 58 inches of water per year, second only to streams of the Pacific Coast basins. Many perennial streams drain areas less than 1,000 square miles. Much of the winter precipitation in the Puget Sound basins falls as snow above 3,000 feet, and does not contribute immediately to surface runoff. The cities of Seattle, Tacoma, Everett, and Bellingham are located in the region

and the concentration of population is the highest of any area of similar size in the Pacific Northwest.

The area has been divided into (1) basins that drain the east slope of the Olympic Mountains and discharge into Hood Canal and the Strait of Juan de Fuca, and (2) those that drain the west slope of the Cascade Mountains and flow to the Puget Sound and Straits of Georgia.

Rivers having their source in the eastern Olympic Mountains have runoff characteristics similar to those on the west side in the Pacific Coast basins, but generally have smaller flows per square mile. A large percentage of the streamflow occurs during the winter from rainfall, with a smaller proportion in the spring from snowmelt. The principal rivers are the Elwha and Skokomish Rivers, both of which have been developed for hydroelectric power. A potential still exists for further development of these rivers. The Elwha River flows northward to the Strait of Juna de Fuca and drains an area of 321 square miles. About 75 inches of water runs off annually from the basin. The Skokomish River lies on the southeastern slope of the Olympic Mountains and discharges into Hood Canal. The basin has a drainage area of 240 square miles and contributes about 100 inches of runoff per year.

Less important streams include the Dungeness, Dosewallips, Duckabush, and Hamma Hamma Rivers. The Dungeness River discharges only about one-third as much runoff as adjacent streams, because the basin lies in the rain shadow of the Olympic Mountains.

Urban and agricultural development exist only near the mouths of major rivers. Winter flooding of these deltas may be a problem to further development in the area.

Numerous rivers drain the west slope of the Cascade Mountains. Many of these originate in the numerous glaciers in the North Cascades. These glaciers tend to regulate streamflow by accumulating and storing precipitation during cold, wet years and releasing more than average amounts of water during hot, dry years. This natural regulation of the runoff by glaciers results in a fairly uniform seasonal distribution. The principal rivers in the western Cascade Mountains are the Nisqually, Puyallup, Green-Duwamish, Cedar, Snohomish, Stillaguamish, Skagit, and Nooksack Rivers.

The Nisqually River heads in glaciers in Mount Rainier National Park, and flows 81 miles northwesterly to Puget Sound. Its drainage area of about 720 square miles is mostly mountainous and heavily timbered. Runoff averages 55 inches annually and is fairly uniformly distributed because of its glacial origin. The Puyallup River and its two major tributaries, the White and Carbon Rivers, also have their sources in Mount Rainier National Park and are fed by glaciers. The Puyallup River basin covers 972 square miles and generates about 50 inches of runoff annually. The seasonal distribution is similar to that for the Nisqually River. The Puyallup, the White, and the Nisqually are all used for hydroelectric power generation. Mud Mountain Dam on the White River provides flood storage to alleviate floods in the lower Puyallup River.

The Green-Duwamish River and Cedar River have nonglacier origins in the Cascade Mountains and drain areas of 483 and 188 square miles respectively. They flow northwesterly from their sources to Puget Sound in the vicinity of Seattle. Large amounts of water for municipal supply are obtained from these rivers—71 million gallons

per day (mgd) is diverted by Tacoma from the Green River, and 130 to 195 mgd is obtained by Seattle from the Cedar River. Above the points of diversion, runoff from the Green and Cedar Rivers averages 65 and 81 inches annually. The seasonal distribution varies considerably more than for the glacial streams; the bulk of the flow occurs during the winter and early spring, with much less during the summer. Howard A. Hanson Dam, located in the upper Green River basin, provides storage for flood control and low-flow augmentation. A small amount of hydroelectric power is developed in the upper Cedar River basin.

The Snohomish River is formed by the confluence of the Skykomish and Snoqualmie Rivers, and drains an area of 1,780 square miles. The Skykomish River heads in glaciers of the Cascade Mountains whereas the Snoqualmie River is nonglacial. Annual runoff in both of these basins is large, averaging over 80 inches. Seasonal variations in flow pattern reflect the two contrasting sources of discharge. During 1964, Seattle supplemented its municipal supply from the Cedar River by diversion of 16 to 20 mgd from the South Fork Tolt River, a tributary of the Snoqualmie. Some hydroelectric power is developed on the Snoqualmie River at Snoqualmie Falls.

The Stillaguamish River drains 684 square miles, and also heads on the western slope of the Cascade Mountains. The river flows westward from its source to Puget Sound, and discharges annually a quantity of water equivalent to a depth of about 100 inches over the entire basin. Runoff varies with the seasons according to the distribution of precipitation. Generally, the flow is fairly high in the spring because of the melting snowpack at higher elevations.

The Skagit River heads in Canada and has a total drainage area of 3,100 square miles. The 400 square-mile area in Canada has an annual runoff of about 40 inches of water. A total of 72 inches per year is discharged to Puget Sound from the entire basin, indicating that a large portion of the streamflow comes from within the State. Sauk River is the largest tributary to the Skagit and drains 732 square miles. Other important tributaries that add substantial amounts of water are the Baker and Cascade Rivers and Thunder Creek. All these streams have their source in the many glaciers of the North Cascades and have fairly uniform runoff distribution that is characteristic of rivers of the Pacific Northwest that are fed by rainfall in the winter and melting snow and ice in the summer. The Skagit River is the only stream in the Puget Sound basin that is developed to a large extent, with important hydroelectric facilities in the upper basin and on a tributary, the Baker River.

The Nooksack River also has its origin in a glacier; it heads on the northwest slope of Mount Shuksan and flows westward to Georgia Strait. The drainage area of 826 square miles produces 78 inches of water annually, with a very small part coming from Canada.

Other smaller streams that are important parts of the surface water system in the Puget Sound area are the Deschutes, Sammamish, and Samish Rivers. In addition, the Sumas River heads in the United States and is tributary to the Fraser River in Canada. Streamflow records for selected gaging stations in the area are listed in table 25.

Surface water in the Puget Sound basins is of excellent quality with characteristic values less than 100 ppm for dissolved-solids content and 50 ppm for hardness. Similar to the Pacific Coast basin, calcium

and bicarbonate, with some silica, are the principal dissolved solids in in the surface water.

TABLE 25.—*Summary of streamflow data at selected sites in the Puget Sound basins*

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Maximum (cfs)	Minimum (cfs)
			Cfs	Acre-feet per year		
Elwha River at McDonald Bridge	269.0	48	1,489	1,078,000	41,600	10
Dungeness River near Sequim	156.0	32	372	269,300	8,400	77
Duckabush River near Brinnon	66.5	24	411	297,600	8,960	45
North Fork Skokomish River below Staircase Rapids	57.2	38	491	355,500	27,000	16
Nisqually River near McKenna	445.0	21	1,794	1,299,000	20,800	85
White River at Greenwater	216.0	33	857	620,400	18,100	120
Puyallup River at Puyallup	948.0	48	3,354	2,428,000	57,000	400
Green River near Palmer	230.0	31	1,095	792,700	27,800	81
Cedar River near Landsburg	117.0	67	694	502,400	14,200	83
South Fork Skykomish River near Index	355.0	54	2,409	1,744,000	55,000	165
Snoqualmie River near Carnation	603.0	34	3,782	2,738,000	59,500	396
South Fork Stillaguamish River near Granite Falls	119.0	34	1,063	769,600	32,400	55
North Fork Stillaguamish River near Arlington	262.0	34	1,820	1,318,000	30,600	117
Sauk River near Sauk	714.0	34	4,309	3,120,000	82,400	572
Skagit River near Concrete	2,737.0	38	14,840	10,740,000	154,000	2,610
Nooksack River near Lynden	648.0	18	3,712	2,687,000	46,200	595

Water from nonglacial streams in the Puget Sound basins has very little turbidity and color, except during periods of high flow. In contrast, glacial streams tend to remain slightly turbid. Water temperatures are between 36° and 75° F., and are therefore within the range that is adequate for most uses. Most streams are not seriously affected by pollution. An exception is the lower reach of the Green-Duwamish River, where bacterial counts show the presence of raw or untreated sewage. The lower reaches of many rivers are subject to tidal influences that force salt water upstream. Salt water may penetrate more than 10 miles upstream from the mouths of some of the rivers in this area.

Very little information is available on the fluvial sediment transport by glacial streams. Large quantities of fine materials and appreciable amounts of sand and gravel are carried by these rivers almost all the time.

UPPER COLUMBIA RIVER

The upper Columbia River basin includes most of northeastern Washington, and consists of the large area drained by the Columbia River from the Canadian border to the mouth of the Yakima River. The basin covers about 25,600 square miles, or about 40 percent of the State. Though the drainage basin is large, its average annual runoff of 6 inches represents only 9 percent of the runoff of the entire State. The basin receives a total of 76,800,000 acre-feet of water annually from outside the State, principally from the Columbia, Pend Oreille, Kettle, Spokane, and Okanogan Rivers. The Columbia River is highly developed, with many large dams for hydroelectric power and irrigation. The largest dam is Grand Coulee, which backs the water 130 miles to the international boundary and forms Franklin D. Roose-

velt Lake. Other dams are: Chief Joseph, Rocky Reach, Rock Island, Wanapum, and Priest Rapids. Presently under construction is Wells Dam.

The Pend Oreille River, an important tributary to the Columbia, heads on the west slope of the Continental Divide in Montana, flows through the Idaho panhandle, and enters Washington at Newport. It leaves the State again, flowing northward into Canada where it joins the Columbia River half a mile north of the international boundary. Of the total drainage area of approximately 25,400 square miles, only 1,250 square miles of the Pend Oreille basin is in Washington. Runoff from the area within the State is 15 inches per year. Nearly 50 percent of the annual runoff occurs during May to July, when the spring rains augment the snowmelt. Hydoelectric power development has been completed at Albeni Falls and Box Canyon, and Boundary Dam is under construction near the international boundary.

The Kettle and Okanogan Rivers have their sources in Canada and are tributary to the Columbia River from the north. The larger part of both basins is in Canada and very little streamflow is added within the State. The parts of the basins that are in Washington include 1,030 of the 4,140 square miles in the Kettle River basin, and 2,300 of the 8,340 square miles in the Okanogan River basin. Over 50 percent of the annual runoff occurs in May and June. Irrigation is the principal use of the water. Some irrigation is practiced in the lower Okanogan River basin, but the largest irrigation is in Canada.

The Spokane River begins at the outlet of Coeur d'Alene Lake in Idaho and enters the State near Spokane. The drainage area of 4,330 square miles in Idaho contributes about 23 inches of water per year, and the 2,250 square miles in Washington has an annual runoff of 11 inches. The runoff pattern is similar to that of most other streams in the area, with the bulk occurring during the spring snowmelt period. Water is used for irrigation and power development—the larger part of the irrigation use is in Idaho.

Other major streams in the area are the Methow, Chelan, and Wenatchee Rivers. They head on the east slopes of the Cascade Mountains and flow eastward to the Columbia River. The Methow River drainage area is 1,790 square miles, much of it in the high rugged mountains of north-central Washington. Of the three, the Methow basin has the smallest annual yield per unit area, averaging about 13 inches of water. The Chelan River flows the short distance between Lake Chelan and the Columbia River, and drains an area of 924 square miles. The area is mountainous undeveloped forest land, with an annual runoff of 30 inches of water. Hydroelectric power is produced on the Chelan River, and much water is used for irrigation in the lower valleys. The Wenatchee River has the highest runoff of rivers in the upper Columbia Basin, averaging 42 inches of water annually from 1,330 square miles. Runoff is characterized by some high flows in the winter from rainfall at lower elevations, and by the typical May-June high water from snowmelt.

Crab Creek, tributary to the Columbia River from the east, has a large drainage area—4,860 square miles. The creek drains the Columbia Plateau area, which has the lowest precipitation in the State, and it contributes very little surface runoff. Most of the basin is included in the Columbia Basin Irrigation Project area, and is

extensively developed for irrigation. The creek is the main wasteway for irrigation return flow.

Other streams in the area that are of minor importance are the Colville, Sanpoil, Nespelem, and Entiat Rivers.

Table 26 shows pertinent streamflow data for selected gaging stations in the upper Columbia River basin area.

Surface water in the upper Columbia River basin is more mineralized than the water west of the Cascade Mountains. Most of it contains less than 250 ppm of dissolved solids. The lower reach of Crab Creek is the only stream in the State where water has been found to contain more than 500 ppm dissolved solids (fig. 71). Surface water in the basin is moderately hard to hard, and at minimum flows may be extremely hard. Downstream from populated or irrigated areas, and in the lower reaches of most of the rivers, water has the greatest amounts of dissolved solids. The principal dissolved constituents are calcium, magnesium, and bicarbonate; in some streams concentrations of silica are relatively large.

TABLE 26.—*Summary of streamflow data at selected sites in the upper Columbia River basin*

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Maximum (cfs)	Minimum (cfs)
			Cfs	Acre-feet per year		
Pend Oreille River below Z Canyon	25,200	50	26,890	19,470,000	171,300	2,500.0
Columbia River at international boundary	59,700	25	98,680	71,440,000	550,100	18,000.0
Kettle River near Laurier	3,800	33	2,885	2,089,000	35,000	88.0
Colville River at Kettle Falls	1,007	40	303	219,400	3,230	.5
Spokane River at Spokane	4,290	71	6,871	4,974,000	49,000	95.0
Columbia River at Grand Coulee Dam	74,100	49	109,700	79,420,000	637,800	14,900.0
Okanogan River near Tonasket	7,270	33	2,951	2,136,000	40,900	126.0
Methow River at Twisp	1,330	43	1,327	960,700	40,800	134.0
Chelan River at Chelan	951	58	2,053	1,486,000	16,000	0
Wenatchee River at Peshastin	1,000	34	3,070	2,223,000	32,300	183.0
Columbia River at Trinidad	89,700	49	120,400	87,170,000	692,600	4,120.0
Crab Creek at Irby	1,057	20	89	64,360	8,370	2.0

A number of closed-basin lakes, such as Soap, Omak, and Medical Lakes, are located in the upper Columbia River basin. Their water is highly mineralized, with dissolved-solids contents greater than 10,000 ppm. Sodium, bicarbonate, sulfate, and chloride are the principal dissolved minerals.

The physical and bacteriological quality of the stream waters, expecially in the lower reaches, is somewhat deteriorated. Turbidity and color are not much of a problem, except during high flows. Water temperatures usually exceed 70° F. during the summer and in some streams may reach 80° F. The lower Spokane River, downstream from Spokane, is a problem area of organic pollution from municipal and domestic wastes. The pollution problem has been decreased considerably by the installation of a sewage treatment plant.

YAKIMA RIVER

The Yakima River basin in south-central Washington is bounded by the Wenatchee River basin on the north, the Klickitat River basin on the south, and the crest of the Cascade Mountains on the west. The Yakima River drains an area of 6,155 square miles. It heads on the east slope of the Cascade Mountains and follows a generally southeasterly course to the Columbia River. The western part of the basin is an extremely rugged and irregular mountainous area. The eastern part, in the Columbia Plateau, consists of long ridges and troughs. Natural streamflow conditions prevail only in the upper reaches of the Yakima River because of the extensive use of water for irrigation farther downstream. Only about 10 inches of water per year is discharged from the basin to the Columbia River, but runoff varies greatly from a maximum of 80 inches in the headwaters to less than 1 inch in the lower part. Streams in the upper basin have streamflow characteristics somewhat similar to those draining the west side of the Cascade Mountains. Rain-type floods in the fall and winter are common, but the greatest incidence of floods is in May or June when the snow is melting rapidly at higher elevations.

The principal tributaries are the Kachess, Cle Elum, and Teanaway Rivers in the upper basin and the Naches River in the lower basin. The Naches River, the most prominent tributary, drains much of the northwestern part of the basin, including 18 percent of the total drainage area. Five major storage reservoirs—Keechelus, Kachess, Cle Elum, Bumping, and Rimrock Lakes—store about 60 percent of the average annual runoff.

Streamflow records at selected gaging stations in the basin are given in table 27.

Surface water in the upper reaches of the Yakima River basin is of excellent quality and is soft. Farther downstream, the dissolved-solids content increases to almost 250 ppm and water becomes moderately hard to hard. This increase is attributed in large part to the development of irrigation in the valley and seepage from waterlogged lands. Principal minerals dissolved in the water are calcium, magnesium, sodium, bicarbonate, and sulfate. An increase in nitrate concentrations as the water moves downstream is caused by raw or treated sewage effluents and by runoff from land fertilized by nitrate fertilizers.

TABLE 27.—*Summary of streamflow data at selected sites in the Yakima River basin*

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Maximum (cfs)	Minimum (fs)
			Cfs	Acre-feet per year		
Yakima River near Martin	55.8	59	334	241,800	7,370	0
Yakima River at Cle Elum	500.0	56	2,008	1,454,000	25,600	46.0
Yakima River at Umtanum	1,590.0	56	2,419	1,751,000	41,800	138.0
Bumping River near Nile	68.6	53	295	213,600	5,180	0
Naches River below Tieton River	941.0	54	1,720	1,245,000	32,200	1.0
North Fork Ahtanum Creek near Tampico	68.9	38	69	49,880	823	4.3
Yakima River near Parker	3,650.0	54	2,564	1,856,000	65,000	10.0
Yakima River at Kiona	5,600.0	47	4,003	2,898,000	67,000	105.0

Water temperatures exceeding 80° F. in the lower reach of the river may have some adverse effect on fish. Turbidity and color are within the limits required for most uses, except at high flows. Fairly large values of bacterial count have been found near Parker. The high bacterial concentrations are reduced considerably by self-purification in the 72-mile reach of the Yakima River between Parker and Kiona (Sylvester and Seabloom, 1962, p. 81).

SNAKE RIVER

The Snake River basin covers 109,000 square miles, including most of Idaho and parts of Wyoming, Nevada, Oregon, and an area of 5,870 square miles in the southeastern corner of Washington. This area in Washington consists of low-lying hills which characterize the Columbia Plateau. The river forms the boundary between Washington and Idaho for a short distance and then flows westward to the Columbia River. Above their confluence, both rivers drain approximately equal areas, but the Snake River contributes less than half as much runoff as the upper Columbia River. Runoff from the part of the Snake River basin within Washington averages about 3 inches annually and represents only 1 percent of the total runoff of the State. Extensive irrigation in the upper reaches alters the natural-flow regimen of the stream. Even so, the biggest part of the runoff occurs during May and June from melting of the snowpack. The principal tributaries to the Snake River within the State are the Palouse and Tucannon Rivers.

The Palouse River drains an area of 3,280 square miles, most of which is in the State. The river rises in the mountainous area of Latah and Benewah Counties, Idaho, and flows in a westerly direction over basalt of the Columbia Plateau before discharging to the Snake River. The average annual runoff is only about 3 inches. The runoff pattern differs from that of the Snake River; the major part of annual flow occurs from February to April, when the winter snow melts from the low-lying hills.

The source of the Tucannon River is in the foothills of the Blue Mountains. Its basin covers an area of 504 square miles, entirely within the State.

Runoff from the basin is very low—about 5 inches annually—and the seasonal distribution resembles that for the Palouse River.

Table 28 presents streamflow data for selected gaging stations in the Snake River basin.

The chemical quality of the surface water in streams tributary to the Snake River is excellent for most uses. The water usually contains less than 100 ppm of dissolved solids. As the water flows downstream, the amount of dissolved solids increases, rising to more than 200 ppm during the summer low-flow period. The water is moderately hard to hard. Calcium and bicarbonate are the principal constituents but silica, magnesium, and sodium concentrates are relatively high. Water of the Snake River is of good chemical quality for many uses, containing less than 300 ppm of dissolved solid. Hardness values are variable, depending on the quantity of water flowing. Soft water occurs during high flows, moderately hard water at medium flows, and hard water at low flows.

TABLE 28.—*Summary of streamflow data at selected sites in the Snake River basin*

Stream	Drainage area (square miles)	Years of record	Streamflow			
			Average		Maximum (cfs)	Minimum (cfs)
			Cfs	Acre-feet per year		
Asotin Creek near Asotin	156	31	68	49,520	1,180	16
Snake River near Clarkston	103,200	53	49,500	29,340,000	369,000	6,660
Tucannon River near Starbuck	431	10	165	119,500	6,000	15
Palouse River at Hooper	2,540	24	618	447,400	29,800	0

High values of turbidity and color occur in surface water of the Palouse River and pollution from domestic wastes affects its bacteriological quality at times. The Palouse River carries large quantities of suspended sediment, which deteriorate the quality of the water. The type of soil found in this region is called loess—a fine windblown deposit that is highly susceptible to erosion. The erosion produces a high sediment load in most of the streams, and also increases the concentrations of dissolved minerals.

LOWER COLUMBIA RIVER

The lower Columbia River basin includes all the tributaries to the Columbia River in Washington below the mouth of the Snake River. It extends over most of the southern part of the State, covering 10,000 square miles. An average of 33 inches of water runs off from the area annually. As the Columbia River flows westward between Washington and Oregon, it receives inflow from many streams that have widely divergent runoff patterns and large differences in yield. The principal tributary in the eastern part of the area is the Walla Walla River, which has runoff characteristics typical of the streams draining the Columbia Plateau. Tributaries that have their sources in the Cascade Mountains have a seasonal distribution similar to the streams in the Puget Sound Basin, while those in the extreme western part resemble the streams of Pacific Coast basins. The principal tributaries to the lower Columbia River are the Walla Walla, Klickitat, Lewis, and Cowlitz Rivers. Many smaller rivers also contribute substantial amounts of streamflow.

The Walla Walla River heads in the Blue Mountains of northeastern Oregon and drains an area of 1,760 square miles. The basin includes 1,280 square miles in Washington, mostly low, rolling hills and flat plateaus. The main tributary, the Touchet River, has its source in the Blue Mountains of southeastern Washington and drains a total of 721 square miles. Only 5 inches of water runs off the Walla Walla River basin annually, and extensive irrigation in summer depletes the streamflow to a very small amount. High flows occur during the winter and spring from rain and snowmelt. As much as 90 percent of the annual flow occurs during the 6 months from December to May, leaving only a small amount for the growing season.

The Klickitat River drains the eastern slope of the Cascade Mountains with some important tributaries heading on the east side of Mount Adams. The river flows generally southward, paralleling the

Cascade Range, and empties into the Columbia River. The streams in the Klickitat basin flow in deep steep-walled canyons cut into basalt. The drainage area of 1,340 square miles contributes about 17 inches of streamflow that is fairly well distributed throughout the year. This uniformity of flow is attributed to the porous nature of the volcanic rocks that provide large amounts of ground water storage and to the water supplied by the glaciers of Mount Adams.

The Lewis River flows from its source on the northwest slope of Mount Adams southwesterly to the Columbia River. Its largest tributary, the East Fork Lewis River, drains much lower elevations and joins the main stem 3¼ miles upstream from the mouth. Two other tributaries are the Muddy River and Swift Creek, which have headwaters on the south slope of Mount St. Helens. The Lewis River basin covers an area of 1,050 square miles, and is characterized by rugged mountains and ridges. Similar to streams in the Klickitat basin, the streams of the Lewis River system flow in deep canyons cut in basalt and lava. Large amounts of runoff, averaging about 80 inches annually, are generated by the abundant precipitation in the area. Water from glaciermelt and ground water in the volcanic rocks help to maintain moderate discharges during the summer months when precipitation is low.

The Cowlitz River is formed by the junction of the Ohanapecosh River and the Muddy Fork, which have their headwaters in the Cascade Mountains and on Mount Rainier. Throughout most of the basin, the river flows over a broad valley composed of gravel and clay overlain by alluvial deposits and glacial outwash. The basin includes 2,480 square miles and much of it is mountainous and densely timbered. A large amount of runoff is discharged from the basin; it averages 55 inches annually. Because the sources of many of the tributaries are at glaciers, the runoff distribution is characteristic of glacial-fed streams. The principal tributaries to the Cowlitz River are the Cispus, Tilton, Toutle, and Coweman Rivers.

Many other streams in Washington contribute considerable amounts of water to the Columbia River. The larger ones are the White Salmon, Wind, Washougal, Kalama, and Elochoman Rivers. Each stream has a drainage area of less than 400 square miles, and an annual runoff of as much as 85 inches.

Discharge data for 15 selected gaging stations in the lower Columbia Basin are given in table 29.

The chemical quality of the surface water in the lower Columbia Basin is in general excellent, except in the lower reach of the Walla Walla River. Streams heading in the Cascade Mountains and the Coast Range contain less than 100 ppm of dissolved solids and have hardness-of-water values less than 50 ppm. The principal constituents are calcium, magnesium, and bicarbonate. In the eastern part of the basin the upper reaches of the principal streams have a similar chemical quality. However, return flow from irrigation increases the dissolved-solids content and hardness values in the lower reaches. Major irrigation areas in the lower Walla Walla River basin are responsible for the large amounts of dissolved solids and the extremely hard water. Dissolved-solids values as high as 500 ppm have occurred during periods of low flow.

TABLE 29.—*Summary of streamflow data at selected sites in the lower Columbia River basin*

Stream	Drainage area (sq mi)	Years of record	Streamflow			
			Average		Maximum (cfs)	Minimum (cfs)
			Cfs	Acre-feet per year		
Walla Walla River near Touchet	1,660.0	11	594	430,000	16,300	1.9
Columbia River at The Dalles, Oregon	237,000.0	84	194,900	141,100,000	1,240,000	35,000.0
Klickitat River near Pitt	1,297.0	36	1,598	1,157.000	25,500	466.0
White Salmon River near Underwood	386.0	42	1,112	805,100	9,700	0
Wind River near Carson	225.0	28	1,182	855,700	26,400	123.0
Washougal River near Washougal	108.0	18	898	650,100	17,700	41.0
Lewis River at Ariel	731.0	39	4,773	3,456,000	129,000	0
East Fork Lewis River near Heisson	125.0	33	751	543,700	15,600	29.0
Kalama River below Italian Creek	198.0	16	1,256	909,300	16,000	155.0
Cowlitz River at Packwood	287.0	41	1,646	1,192,000	36,600	130.0
Cispus River near Randle	321.0	34	1,319	954,900	20,000	183.0
Toutle River near Silver Lake	474.0	38	2,029	1,469,000	37,600	240.0
Cowlitz River at Castle Rock	2,238.0	35	9,108	6,594,000	139,000	998.0
Coweman River near Kelso	119.0	12	436	315,700	7,490	22.0
Elochoman River near Cathlamet	65.8	22	377	272,900	7,300	18.0

Pollution from sewage disposal has reached serious levels in the Walla Walla River and the Columbia River between Portland, Oregon and Puget Island. Bacteria concentrations exceed the limit for safe swimming and at times are so high as to cause a potential health hazard in the Walla Walla River (Santos, 1965, p. 13). Industrial, municipal, and radioactive wastes are the principal types of pollution in the main stem of the lower Columbia River. Radioactive wastes from cooling water used at the Hanford Atomic Energy Plant have been detected in small quantities in the sediment and in plant and fish life. However, the concentration level is not great enough to be considered a hazard.

Fluvial sediment transport has received very little study in the lower Columbia River and its tributaries. Only a small amount of work has been done in local problem areas and no comprehensive studies have been conducted to evaluate sediment production and transport. Sedimentation in the lower Columbia River has necessitated the expenditure of millions of dollars annually to maintain the navigation channel.

WATER USE

The use of water generally reduces the amount available, and frequently deteriorates water quality. There are two general classifications of water use: consumptive and nonconsumptive. Water used for irrigation, municipal, domestic, and most industrial purposes actually depletes the supply and is returned in a degraded condition. These uses are consumptive. Water that is used for hydroelectric power, navigation, recreation, waste dilution, and fish and wildlife is not removed from the stream or lake. These are nonconsumptive uses of water.

A large quantity of water is used consumptively in Washington. Estimates indicate a total withdrawal of 6,300 mgd in 1960; 800 mgd from ground water and 5,500 mgd from surface water (MacKichan and Kammerer, 1961).

Irrigation is the greatest use of water in the State, requiring 4,720 mgd, of which 4,300 mgd is surface water and 420 mgd is ground water. Of the total surface-water diversion, approximately 1,000 mgd of water is lost between the points of diversion and points of delivery on the cropland. The 4,720 mgd is diverted for irrigation of about 1 million of the more than 3 million acres of irrigable lands in the State (MacKichan and Kammerer, 1961, p. 17). Ground-water use for irrigation is increasing, owing to more efficient equipment and methods of application. For these reasons, irrigation is becoming economically feasible during the dry summer months on lands that were previously dry-farmed. The overall demand for irrigation water probably will increase, although improved irrigation practices that result in a more efficient use of water could slow the rate of increase to some extent.

Municipal and domestic supplies in the State are the next largest uses of water, requiring 770 mgd (570 mgd of surface water and 200 mgd of ground water; MacKichan and Kammerer, 1961, p. 13). Table 30 shows the source of supply for municipal systems which served more than 5,000 people in 1963, and the estimated number of people supplied by each. The expected population growth in Washington will necessitate the increased development of water for this purpose. In the past, the use of water has increased at a faster rate than the population growth. The increased cost of bringing water to the home, and water-management practices to control water consumption, will tend to reduce the increase in per-capita rate of consumption. Whether such factors will eventually stabilize per-capita consumption remains to be seen.

Industry in the State uses 738 mgd of self-supplied water, including 520 mgd of surface water, 170 mgd of ground water, and 48 mgd of saline water (MacKichan and Kammerer, 1961, p. 19). As a result of the rapid growth of industries producing timber products, petrochemicals, and metals, a proportionally rapid growth of industrial water use is expected.

Only 47 mgd is withdrawn for rural use; this amount includes that used for domestic supply and livestock but not for irrigation (MacKichan and Kammerer, 1961, p. 15). Rural water use has decreased in the past, reflecting the shift in population from rural to urban and suburban areas. This decrease is offset, at least in part, by the modernization of rural and farm homes and the utilization of water-using appliances like those found in urban homes.

Next to New York and Oregon, Washington is the third largest user of water for hydroelectric power in the United States, with an average use of 170,000 mgd. Electric power consumption per customer is more than 2½ times the national average, and all indications point to a higher rate of consumption in the future.

No water within the State was diverted for thermal power in 1960, but the development of this source of power may become necessary to supplement seasonal deficiencies of hydroelectric plants. The development of atomic power, which is now in process at Hanford, may require the nonconsumptive use of large amounts of water for cooling purposes.

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TABLE 30.—*Municipal water supplies serving 5,000 people or more in Washington, 1963*

Municipality	Estimated number of people served	Source of water			
		Spring	Well	Stream	Lake
Aberdeen	20,500			X	
Alderwood Manor	33,750		X	X	
Anacortes	10,000		X	X	
Auburn	17,500	X	X		
Bellevue	24,000				X
Bellingham	36,000				X
Bremerton	38,000		X	X	
Bryn Mawr	10,000	X	X		
Buckley	6,000			X	
Camas	7,100		X	X	
Centralia	10,500		X	X	
Chehalis	6,800			X	
Clarkston	13,500		X		
Dishman	5,000		X		
East Wenatchee	7,500		X		
Ellensburg	9,500		X		
Enumclaw	6,000	X			
Ephrata	8,100		X	X	
Everett	110,000			X	
Hazel Dell	6,800		X		
Hoquiam	12,000			X	
Kelso	10,000			X	
Kennewick	20,000		X		
Kent	8,000	X	X		
Lake Hills			X		X
Lakewood	30,000		X		
Longview	33,500			X	
McMicken Heights	6,000		X		
Midway	26,000		X		
Moses Lake	12,500		X		
Mount Vernon	7,900		X	X	
Nob Hill	6,000		X		
Olympia	20,000	X			
Omak	5,500		X		
Parkland	15,500		X		
Pasco	16,000			X	
Port Angeles	11,850			X	
Port Orchard	5,000		X		
Port Townsend	7,500			X	
Pullman	7,000		X		
Puyallup	14,000	X	X		
Renton	24,500	X	X		
Richland	24,000		X	X	
Seattle	750,120			X	
Shelton	7,000	X	X		
Southeast Tacoma	6,400		X		
Spokane	190,000		X		
Spokane County	12,100		X		
Sunnyside	6,200		X		
Tacoma	160,000		X	X	
Toppenish	6,000		X		
Vancouver	56,000	X	X		
Veradale	6,900		X		
Walla Walla	27,500		X	X	
Wenatchee	18,000			X	
West Clarkston	6,000		X		
Yakima	43,000		X	X	

Source: Data from U.S. Public Health Service, 1964.

Other nonconsumptive uses—navigation, recreation, fish and wildlife, and waste dilution—play a major role in the development of surface water. Navigation is confined mostly to the Columbia River and its tributaries, although some transportation utilizes the lower Skagit River. Recreation is becoming more important because of increases in personal income and leisure time, and because of easier and better methods of travel. Trends indicate a rapidly growing interest and participation in water recreation activities, especially in swimming, boating, water skiing, and skin diving. The abundant fish and wildlife populations in the State are a major economic and

recreational resource. Salmon provide the basis for a large commercial fishing industry and extensive sport fishing. The processed value of commercial salmon was about $20 million, and 1½ million sport anglers caught 1,130,000 salmon in 1963 (Washington State Department of Fisheries, p. 138). The numerous lakes and ponds provide nesting, feeding, and resting places for migrating fowl. Many of the rivers are used as wasteways for domestic and industrial wastes. Pollution from wastes discharged in some of the larger rivers has become dangerous, but in most streams, the steep gradient and large flows make possible a rapid natural oxidation and dilution of the waste resulting in only a minor influence on the quality of the water and the aquatic biologic system.

WATER PROBLEMS

The problems of water development and management in the State are complex because precipitation and water supply are highly variable, water uses are varied and in part competitive, and interstate and international interests are involved.

The chief water problem in Washington is related to distribution and seasonal variability. Large variations in demand as well as supply contribute to the problem. The large water supply within the State would be sufficient to meet all foreseeable needs if precipitation and streamflow were uniformly distributed over the State and during the year. Much of the water is not available when and where it is needed, and at times there is too much water in the form of floods. To illustrate the extremes that can occur in a Washington river, a 27-year record of the Green River near Auburn shows a maximum discharge of 28,100 cubic feet per second (cfs) in November, a minimum discharge of 81 cfs in September, and an average discharge of 1,333 cfs.

A large amount of surface water is discharged into the Pacific Ocean and into Puget Sound by streams in the State—about 234 billion gallons per day (bgd), including the entire flow of the Columbia River at the mouth (176 bgd). The quantity of ground-water outflow to the ocean and Puget Sound is unknown; nonetheless, sufficient information is available to indicate that the ground-water contribution is small compared to the total surface-water discharge to the ocean. Thus, assuming that half of the Columbia River flow is available for use in Oregon, the total water supply "available" to Washington can be estimated as approximately 146 bgd. Consumptive uses require a withdrawal of about 6.3 bgd, leaving a seemingly large quantity of water still available for use. It must be recognized that this supply is the amount discharging into salt water and not the quantity available where it can be utilized. Distribution of water over the State is far from uniform and differs appreciably from west to east.

Nonconsumptive uses demand a large part of the remaining 140 bgd; the amount required to fill these nonconsumptive needs cannot be determined at the present time, because the needs have not been accurately defined. For example, the ecological balance may be upset, particularly during low-flow periods, by the introduction of municipal or industrial waste products. Unless the system is well understood it

is difficult to determine the amount and quality of additional flow necessary to offset the introduction of this waste.

Seasonal variations in streamflow are such that only 7 to 14 percent of the runoff occurs from July to September, when demand is the greatest. During these summer months an estimated 60 bgd may be available, and more than 10 bgd is needed for consumptive use. Because nonconsumptive uses of water greatly exceed the consumptive use, and because areal distribution is not uniform, it is apparent that some parts of Washington may be short of water during the summer months. The possibility of shortage is increased during years of below average discharge or drought.

Floods—too much water—are a wintertime problem particularly in the western and southeastern parts of the State. Prevention of flood damage can be accomplished by the construction of reservoirs to store storm runoff, the improvement of stream channels to increase the carrying capacity, the use of levees or dikes to confine the flow, and limitations on the type of construction permitted on the flood plain. The present trend in planning for flood control is to use large storage reservoirs to hold back part of the storm runoff until the stream can carry it without flooding. Channel improvements are used to remove obstacles that impede the flow, and are usually made near cities. Levees or dikes have until recently been the most common flood-control structure; however, they increase the elevation of the water in the confined channel for any given flood because the natural storage on the flood plain is no longer available.

Pollution is a problem wherever industry and population are concentrated. Water of good quality is needed for many uses, especially where municipal, industrial, fish, and recreational needs are concerned. Surface water is the source of about 75 percent of the municipal supply in Washington, and many small public-supply systems use untreated water. Where facilities are lacking to treat highly contaminated water the discharge of harmful wastes is of special concern. The problem of waste disposal is not how to stop it, but rather how to control and regulate the wastes so as to protect the value of the water resource. The impact of wastes on the receiving waters must be studied, not only to protect the water for other uses, but also to allow the formulation of realistic regulations on waste disposal.

Two of the most important problems in connection with ground water are the variation in availability from place to place and the lack of sufficient information on the occurrence and quality of ground water in many areas. Information is especially needed in areas where ground-water data are meager but quantitative data should be gathered on all areas to enable optimum development. Some salt-water encroachment of ground water has developed in regions near tidelands but has not reached a serious scale. Further encroachment may result in long lasting damage to important aquifers.

In the Columbia Basin Irrigation Project area, large quantities of irrigation water have percolated downward to the ground-water body and have raised the water levels enough to form many lakes and swamps. As more land is put under irrigation, it is probable that ground-water levels will be very close to the surface in nearly all of the area (Mundorff, 1953, p. 22).

Irrigation has influenced the chemical quality of ground water in the Columbia Basin Irrigation Project area, the Yakima Basin, and other areas, particularly in the eastern part of the State. Irrigation water leaches appreciable amounts of salts from the soils and rocks of this semiarid area. The mixing of waste irrigation water with "natural" ground water has produced a composite water with greater hardness and dissolved-solids content, and other chemical characteristics that differ from those of the pre-irrigation ground water.

Problems are created by the competition for water for various uses. Diversions of water for irrigation or other uses may reduce streamflow, this can increase pollution problems, because less water is available to dilute waste discharges, and the resulting high levels of pollution have correspondingly greater impact on other uses of water. Excessive waste disposal under low-flow conditions can be a particular detriment to fish, wildlife, and recreational use.

Construction of dams for storage of flood water or for power generation may interfere with the passage of fish. Maximum power is produced by keeping the reservoir as full as possible, but for purposes of flood control the reservoir should be kept empty. Not all uses of water are competitive in all respects. An example of compatible use would be the maintenance of adequate low flows by reservoir management for navigation, waste dilution, fisheries, recreation, and other downstream needs.

Other important water problems in the State are the maintenance of the fish resources, the lack of data on fluvial sediment transport, and the needs for recreational use of water in some places.

Throughout the discussion of water problems there is a continuing thread of data shortage, inadequate technical definition of the problems, and uncertainty as to the hydrologic system within which the problems occur. The U.S. Geological Survey, Washington State Department of Conservation, U.S. Corps of Engineers, U.S. Bureau of Reclamation, and many other Federal, State and local agencies are cooperating in the collection of basic facts and in carrying out studies needed to provide the answers to some of the problems. The best and wisest development of Washington's water resources will depend on the better understanding of (1) the occurrence, movement, and use of water in the highly complex hydrologic system in the State; (2) the relative needs and values of water utilization to satisfy the many conflicting demands for this resource; and (3) the impact of the various plans of development on the hydrologic system. A well-balanced development of water resources will have direct benefits to the whole State.

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WATER RESOURCE DEVELOPMENT

HYDROELECTRIC POWER DEVELOPMENT

(By E. N. Freeman, Bonneville Power Administration, Portland, Oreg.)

The story of electric power development in the Territory of Washinton began in 1882 when the first fuel-fired electric-light plant started operation in Tacoma. Washington's first hydroelectric plant started generating in 1885 at the site of Spokane Falls in the heart of Spokane, Washington.

Development of the main stem of the Columbia River began with the completion of the Rock Island plant by the Puget Sound Power and Light Co. in 1933. The initial installation of 4 units was later expanded to 10 units, and in 1956 the plant was transferred to its present owner, Chelan County PUD.

The first Federal generation in Washington was at Bonneville Dam in 1938, followed by the Grand Coulee project with initial generation in 1941. They were the first Federal projects authorized for construction on the Columbia River. These projects provided the foundation for an expanding system, which now consists of 11 Federal projects in the State of Washington.

From these pioneering developments a statewide complex of hydroelectric projects evolved, which include some of the largest generating plants in the world. Fifty-eight existing hydroelectric projects in 1964 had an installed capacity of nearly 9,300,000 kilowatts. Projects which are currently under construction will increase the State's installed capacity to over 12,600,000 kilowatts. Fifteen other projects under active consideration would utilize still another block of Washington's vast hydroelectric potential.

The largest source of developed and undeveloped hydroelectric potential in the United States is still the Columbia River and its tributaries. Except for a portion that serves as the Oregon-Washington border, the United States portion of the main stem of the Columbia River lies entirely within the borders of Washington.

Of the 11 existing Federal projects in Washington, Bonneville, McNary, and The Dalles are on the lower Columbia River where it forms the boundary between Oregon and Washington. When tabulating the State's resources, projects on the border are considered to be one-half in Washington. The 8 Federal projects located wholly in Washington include Grand Coulee and Chief Joseph on the Columbia River; Ice Harbor on the lower Snake River; Paradise on the Nisqually River; and Chandler, Roza, and Wapato Drop No. 2 and No. 3 in the Yakima River Basin. These projects have a total installed capacity of nearly 4,600,000 kilowatts.

There are 47 existing non-Federal hydroelectric plants in Washington, publicly or privately owned with an installed capacity of over 4,700,000 kilowatts. Non-Federal plants located on the Columbia River are Wanapum and Priest Rapids owned by the Grant County PUD, and Rock Island and Rocky Reach owned by the Chelan

County PUD. Other principal public agency projects include the Skagit River plants of the City of Seattle, Ross, Diablo, and Gorge, the City of Tacoma's LaGrande, Alder, Cushman, and Mayfield projects, Cowlitz County PUD's Swift No. 2 plant and the Box Canyon development of the Pend Oreille County PUD. Principal existing private utility developments include the Baker River, White River, and Electron plants of the Puget Sound Power and Light Co., the Pacific Power and Light Co. developments at Swift, Yale, and Merwin, and Washington Water Power Co.'s Spokane River complex.

Federal plants under construction in Washington are Lower Monumental and Little Goose on the Snake River, and John Day on the Washington-Oregon border portion of the Columbia River.

Projects under construction by non-Federal entities include the City of Seattle Boundary plant located on the Pend Oreille River; Wells, a Douglas County PUD project located on the Columbia River; and Mossyrock, on the Cowlitz River, being built by the City of Tacoma.

Federal projects authorized or recommended for construction include China Gardens, Asotin, and Lower Granite on the Snake River; Wynoochee on the Wynoochee River; and a third powerplant at Grand Coulee on the Columbia River. The third powerplant addition of 3,600,000 kilowatts would make Grand Coulee the largest powerplant in the world, with a total of 5,544,000 kilowatts of installed capacity. A further increment of power contemplated at Grand Coulee would be the installation of six reversible pump turbines with an aggregate capacity of 291,000 kilowatts in lieu of the conventional pumps originally planned. By pumping water from Franklin D. Roosevelt Lake to Banks Lake during low-demand periods and releasing water from Banks Lake through the reversible units in periods of peak demand, a more complete use is made of Columbia River streamflows. This installation would be the first pumped storage project in the Pacific Northwest.

The Federal Power Commission has issued licenses for construction of the three Sultan projects proposed by the Snohomish County PUD and the Sullivan Creek project proposed by the Pend Oreille County PUD. Other non-Federal utilities have applied to the Federal Power Commission for a license or a preliminary permit for the future construction of hydroelectric projects. These contemplated projects would provide an additional 843,400 kilowatts of installed capacity.

Projects located in Washington that are existing, under construction, or under active consideration are listed in table 31 and shown on figure 74.

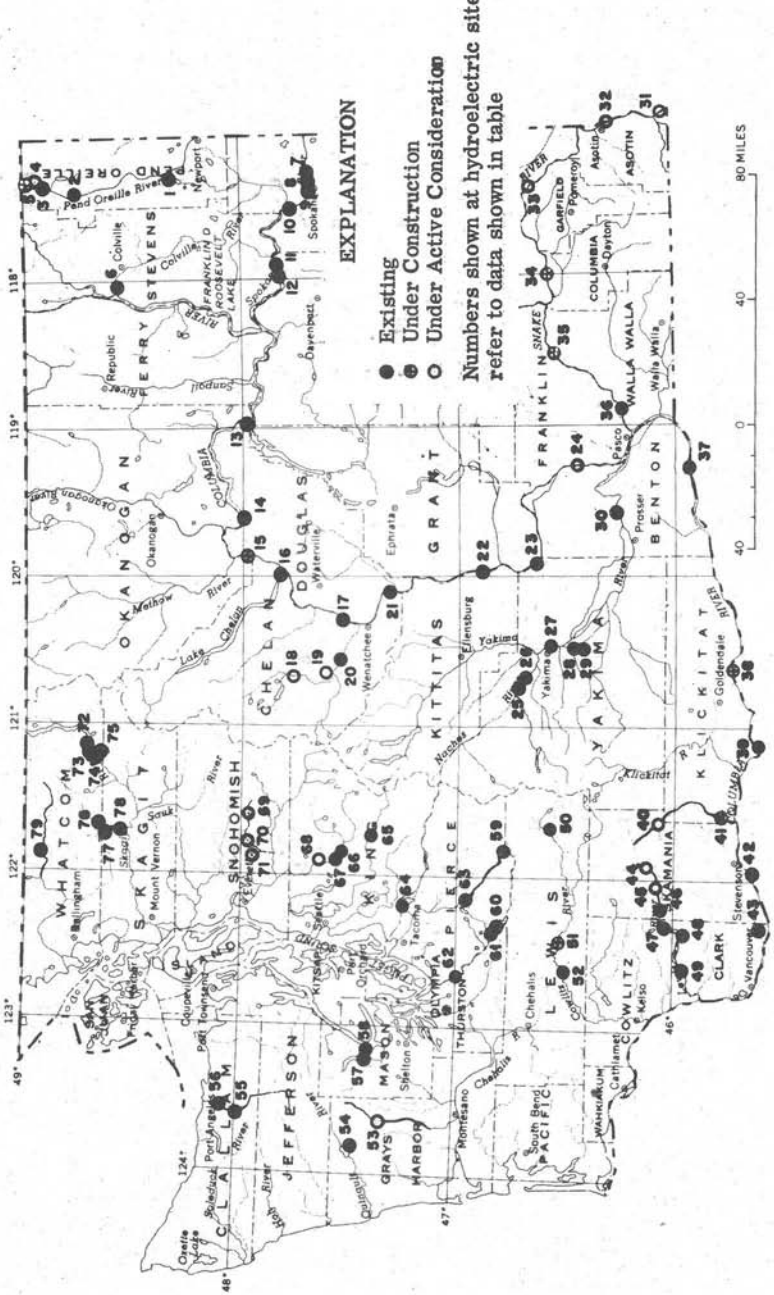

FIGURE 74.—Hydroelectric power resources in Washington—existing, under construction and under active consideration.

TABLE 31.—*Hydroelectric power resources in Washington—Existing, under construction, and under active consideration, April 1965*

Index No. on fig. 74	Project	Stream	Ownership	Gross head feet	Number of units	Total capacity (kilowatts)	Ultimate installed capacity (kilowatts)	Date in service, initial unit
1	Calispell Creek	Calispell Creek	Pend Oreille County PUD	309	2	560	560	1920.
2	Box Canyon	Pend Oreille	do	40	4	60,000	60,000	June 1955.
3	Metaline Falls	do	Pend Oreille Mines & Metals	30	2	3,600	3,600	1937.
4	Sullivan Creek	Sullivan Creek	Pend Oreille County PUD	548	2	13,600	20,400	Under active consideration.
5	Boundary	Pend Oreille	Seattle, City of	261	4	551,000	826,500	Under construction.
6	Meyers Falls	Colville	Washington Water Power Co	125	2	1,200	1,200	1915.
7	Spokane	Spokane	Spokane, City of	35	3	3,900	3,900	1937.
8	Upper Falls	do	Washington Water Power Co	64	1	10,000	10,000	1922.
9	Monroe Street	do	do	68	5	7,200	7,200	1903.
10	Nine Mile	do	do	65	4	12,000	12,000	1908.
11	Long Lake	do	do	171	4	70,000	70,000	1915.
12	Little Falls	do	do	73	4	32,000	32,000	1910.
13	Grand Coulee	Columbia	Bureau of Reclamation	343	18	1,944,000	5,835,000	September 1941.
14	Chief Joseph	do	Corps of Engineers	175	16	1,024,000	1,728,000	August 1955.
15	Wells	do	Douglas County PUD	71	10	774,250	774,250	Under construction.
16	Chelan	Chelan	Chelan County PUD	393	2	48,000	120,000	1927.
17	Rocky Reach	Columbia	do	92	7	711,550	1,118,150	June 1961.
18	Beaver Creek	Wenatchee	do	60	1	8,700	17,400	Under active consideration.
19	Leavenworth	do	do	622	2	120,000	180,000	Do.
20	Dryden	do	do	55	3	2,450	15,000	1908.
21	Rock Island	Columbia	do	37	10	212,100	212,100	1933.
22	Wanapun	do	Grant County PUD	81	10	831,250	1,330,000	September 1963.
23	Priest Rapids	do	do	78	10	788,500	1,261,600	October 1959.
24	Ben Franklin	do	Washington Public Power Supply	42	16	352,000	352,000	Under active consideration.
25	Naches Drop	Naches	Pacific Power & Light Co	54	1	1,400	1,400	1914.
26	Naches	do	do	149	2	6,370	6,370	1909.
27	Roza	Yakima	Bureau of Reclamation	160	1	11,250	11,250	August 1958.
28	Wapato Drop No. 2	do	Bureau of Indian Affairs	------	1	1,360	1,360	1942.
29	Wapato Drop No. 3	do	do	------	2	2,000	2,000	1932.
30	Chandler	do	Bureau of Reclamation	121	2	12,000	12,000	February 1956.
31	China Gardens [1]	Snake	Corps of Engineers	67	3	180,000	240,000	Under active consideration.
32	Asotin [1]	do	do	107	2	270,000	540,000	Do.
33	Lower Granite	do	do	100	3	405,000	810,000	Do.
34	Little Goose	do	do	98	3	405,000	810,000	Under construction.
35	Lower Monumental	do	do	100	3	405,000	810,000	Do.
36	Ice Harbor	do	do	98	3	270,000	540,000	December 1961.
37	McNary [1]	Columbia	do	75	14	980,000	1,400,000	November 1953.
38	John Day [1]	do	do	105	14	1,890,000	2,700,000	Under construction.
39	The Dalles [1]	do	do	86	16	1,119,000	1,743,000	May 1957.

40	Trout Creek	White Salmon	Klickitat County PUD	890	2	40,000	40,000	Under active consideration.
41	Condit	do	Pacific Power & Light Co	178	2	9,600	9,600	1913.
42	Bonneville [1]	Columbia	Corps of Engineers	59	10	518,400	842,400	June 1938.
43	Washougal	Washougal	Western Light & Power Co	22	3	750	750	Prior 1952.
44	Meadows Lower Drop	Rush Creek	Pacific Power & Light Co	1,050	1	25,000	85,000	Under active consideration.
45	Muddy	Lewis	do	300	2	110,000	110,000	Do.
46	Swift No. 1	do	do	396	3	204,000	204,000	December 1958.
47	Swift No. 2	do	Cowlitz County PUD	130	2	70,000	70,000	Do.
48	Yale	do	Pacific Power & Light Co	250	2	108,000	216,000	September 1953.
49	Merwin	do	do	185	3	135,000	180,000	September 1931.
50	Packwood	Lake Creek	Washington Public Power Supply	1,800	1	26,000	26,000	May 1964.
51	Mossyrock	Cowlitz	Tacoma, City of	345	2	300,000	450,000	Under construction.
52	Mayfield	do	do	185	3	120,000	160,000	May 1963.
53	Wynoochee	Wynoochee	Corps of Engineers	280	1	33,000	66,000	Under active consideration.
54	Quinault	Zeigler	Quinault Light, Inc	876	1	250	250	1938.
55	Glines Canyon	Elwha	Crown Zellerbach Corp	192	1	10,670	10,670	Approximately 1928.
56	Elwha	do	do	104	1	9,870	9,870	Approximately 1929.
57	Cushman No. 1	North Fork Skokomish.	Tacoma, City of	255	2	43,200	43,200	1926.
58	Cushman No. 2	do	do	480	3	81,000	81,000	1930.
59	Paradise	Paradise Creek	National Park Service	486	2	800	800	1923.
60	Alder	Nisqually	Tacoma, City of	273	2	50,000	50,000	1945.
61	LaGrande	do	do	419	5	64,000	64,000	1912.
62	Yelm	do	Centralia, City of	208	3	9,000	9,000	1930.
63	Electron	Puyallup	Puget Sound Power & Light Co	874	4	25,500	25,500	1904.
64	White River	White	do	489	4	70,000	127,000	1912.
65	Cedar Falls	Cedar	Seattle, City of	630	2	22,860	22,860	October 1904.
66	Snoqualmie No. 1	Snoqualmie	Puget Sound Power & Light Co	271	5	11,600	11,600	1898.
67	Snoqualmie No. 2	do	do	287	2	30,090	30,090	1910.
68	Carnation	North Fork Snoqualmie.	King County Water Distribution	510		34,100	34,100	Under active consideration.
69	Sultan No. 1	Sultan	Snohomish County PUD	390	2	84,000	84,000	Do.
70	Sultan No. 2	do	do	398	2	32,000	32,000	Do.
71	Sultan No. 3	do	do	300	1	24,000	24,000	Do.
72	Ross	Skagit	Seattle, City of	395	4	360,000	360,000	December 1952.
73	Diablo	do	do	330	2	120,000	240,000	1936.
74	Gorge	do	do	380	4	134,400	134,400	1924.
75	Newhalem	Newhalem Creek	do	500	1	2,000	2,000	1921.
76	Upper Baker	Baker	Puget Sound Power & Light Co	285	2	94,400	94,400	1959.
77	Bear Creek	Bear Creek	Lone Star Cement Corp	420	3	1,800	1,800	Prior 1940.
78	Lower Baker	Baker	Puget Sound Power & Light Co	259	3	103,500	103,500	1925.
79	Nooksack	Nooksack	do	195	1	1,500	1,500	1906.

[1] Plant located on border stream. One-half of the project considered to be in Washington.

The treaty between Canada and the United States of America relating to Cooperative Development of the Water Resources of the Columbia River Basin was implemented in 1964. The treaty states that Canada snall provide in the Columbia River Basin in Canada 15,500,000 acre-feet of storage usable for improving the flow of the Columbia River. Since the United States portion of the Columbia River is either entirely in Washington or serves as part of its border, the downstream benefits of treaty storage projects will accrue primarily to Washington projects. Increased regulation of the river will enhance the feasibility of installing additional units at existing plants on the Columbia River. In addition, new powerplants are contemplated at Bonneville and Grand Coulee to make use of improved streamflows. Additions that can be made to existing Columbia River projects and those under construction would add 7 million kilowatts of nameplate capacity to Washington hydroelectric resources.

Ultimate development at Federal plants on the Washington portion of the Snake River would increase the State's capacity by 1,700,000 kilowatts. Other plants in Washington have provisions for additional units. Complete development at these plants would increase the installed capacity in the State an additional 1 million kilowatts. Ultimate capacity of the 79 projects listed in table 31 would be 23,900,000 kilowatts. Used primarily as standby generation are 11 small fuel-fired electric generating plants that contribute 260,000 kilowatts of nameplate capacity to the State's total electric resources.

The Pacific Northwest's first nuclear-fired steam electric generating plant is under construction in Washington State. When completed in late 1965, NPR (new production reactor) will add 800,000 kilowatts of new capacity to the area's resources.

As a corollary of the Canadian Treaty, Bonneville Power Administration, the Corps of Engineers, and 14 generating utilities signed a 39-year coordination agreement in August 1964. Ten of these utilities are headquartered in the State of Washington. Coordinated operation of all the utilities serving the State assures fullest use of the available power resources and makes it possible to obtain savings in operating and transmission costs.

The Bonneville Power Administration was created by the Bonneville Project Act of August 20, 1937. The act, as modified by later amendments and Executive orders, designates the Bonneville Power Administration as the marketing agency for power generated at Federal projects in the Pacific Northwest. BPA constructs, operates, and maintains the electric transmission lines and substation facilities needed to deliver the power generated at federally owned power plants to Pacific Northwest load areas.

Within Washington, BPA operates over 5,000 miles of high-voltage transmission lines and over 130 substations with installed transformer capacity of about 9,300,000 kva. These facilities constitute over 60 percent of BPA's physical plant in the Pacific Northwest. All existing BPA substations in Washington are listed in table 32; table 33 lists the State's existing transmission mileage by type and voltage; and figure 75 locates the major substations and the interconnecting high-voltage grid in Washington. BPA's grid serves as the "backbone" for the interconnected public and private utility systems of the State and the Northwest Power Pool.

TABLE 32.—*Bonneville Power Administration substations in the State of Washington*

MAIN GRID SUBSTATIONS

Index No. on fig. 75	Substation	KVA capacity (as of Dec. 31, 1964)	Date first placed in service
1	Bell	825,400	Apr. 21, 1942
2	Chief Joseph	600,000	Jan. 15, 1958
3	*St. Andrews		July 29, 1952
4	Columbia	500,000	Aug. 12, 1945
5	*Rocky Ford		Mar. 21, 1952
6	Potholes	250,000	Nov. 20, 1958
7	*Vantage		June 26, 1963
8	Midway	250,000	June 24, 1941
9	Franklin	268,000	Apr. 14, 1948
10	*North John Day		Sept. 6, 1960
11	North Bonneville	12,500	Aug. 4, 1940
12	Ross	900,000	Apr. 28, 1940
13	Longview	534,000	July 22, 1941
14	Silver Creek	20,000	Aug. 23, 1958
15	Chehalis	131,000	May 14, 1941
16	Olympia	900,000	June 29, 1949
17	*South Tacoma		Apr. 12, 1953
18	Tacoma	75,000	July 29, 1942
19	Covington	700,000	Mar. 6, 1942
20	*Maple Valley		Oct. 19, 1961
21	Snohomish	500,000	Dec. 23, 1947
22	Bellingham	250,000	Oct. 15, 1954

OTHER EXISTING SUBSTATIONS

	Aberdeen	130,000	Feb. 23, 1950
	Alcoa	250,000	Aug. 31, 1940
	Angus	20,000	Dec. 5, 1963
	*Area 300		July 1, 1955
	Bangor	12,000	Jan. 10, 1964
	Belfair	3,000	May 25, 1951
	*Benton		Sept. 12, 1948
	Benton City	6,000	Dec. 18, 1951
	Bingen	7,500	Mar. 5, 1948
	Blackrock	1,000	June 5, 1956
	Bremerton	16,000	Oct. 31, 1942
	Brewster	13,500	Jan. 3, 1947
	Burbank	3,000	Feb. 13, 1955
	Burke	6,000	Apr. 10, 1956
	Camas	22,000	Dec. 14, 1949
	Carborundum	57,500	Dec. 8, 1953
	*Cardwell		May 15, 1963
	Carson	6,000	Dec. 20, 1963
	Cathlamet	6,000	Oct. 23, 1952
	Centralia	12,000	Sept. 29, 1950
	Chelatchie	20,000	Apr. 14, 1960
	Clarkston	3,000	Jan. 28, 1958
	Colfax	3,000	Dec. 29, 1941
	Coulee City (WWP Co.)	3,000	July 25, 1946
	Cowlitz	100,000	Feb. 1, 1946
	Creston	11,000	May 1, 1947
	Dayton	1,500	May 10, 1948
	Deer Park	8,000	Oct. 10, 1949
	Duckabush	1,000	Oct. 25, 1960
	Eagle Lake	12,000	Oct. 29, 1959
	*East Arlington		July 1, 1954
	Eastmont	28,000	July 17, 1962
	Ellensburg	47,000	Apr. 1, 1941
	Ephrata	12,000	Mar. 6, 1947
	Fairmount	50,000	Nov. 4, 1958
	Fidalgo	6,000	July 18, 1951
	Fishers Road	20,000	Oct. 9, 1962
	Foster Creek (new)	12,000	Sept. 17, 1950
	Four Lakes	12,000	Aug. 15, 1952
	Gilmer	3,000	Apr. 17, 1951
	Glade	6,000	Mar. 16, 1951
	Goldendale	12,000	Nov. 17, 1957
	Grand Coulee	400,000	Dec. 8, 1954
	Grandview	32,500	May 29, 1947
	Green Bluff	7,500	Oct. 8, 1964
	Hedges	20,000	Oct. 8, 1958
	Highlands	20,000	Nov. 29, 1951
	*Holcomb (new)		July 1, 1955
	Jericho	6,000	Dec. 1, 1959
	Jerita	3,000	May 27, 1954
	Jim Creek	5,000	Mar. 20, 1952

*Switching station.

TABLE 32.—*Bonneville Power Administration substations in the State of Washington*—Continued

OTHER EXISTING SUBSTATIONS—Continued

Index No. on fig. 75	Substation	KVA capacity (as of Dec. 31, 1964)	Date first placed in service
	Kennewick	40,000	Aug. 25, 1949
	Keokuk	50,000	Dec. 18, 1942
	*Kitsap		Feb. 17, 1955
	Larson	33,333	July 30, 1959
	Ledbeder	6,000	Oct. 17, 1956
	*Lexington		Feb. 21, 1962
	*Lone Pine		July 15, 1949
	Long Beach	20,000	Oct. 26, 1956
	Mason	37,500	July 9, 1949
	Metaline Falls	16,000	Feb. 6, 1948
	Mill Plain	50,000	July 25, 1942
	Morton	6,000	Dec. 8, 1947
	Moses Lake	32,000	Mar. 6, 1947
	Mossyrock	3,000	Sept. 9, 1951
	*Moxee		Mar. 5, 1954
	Naselle (new)	6,000	Oct. 2, 1949
	Newport	6,000	Oct. 26, 1950
	Nilles Corner	3,000	June 13, 1957
	North Ephrata	20,000	Dec. 12, 1957
	North McNary	3,000	July 29, 1957
	Odessa	7,500	Dec. 7, 1961
	Okanogan (new)	20,000	Dec. 4, 1955
	Orondo	6,000	May 27, 1954
	Oroville	6,000	Sept. 27, 1960
	Pe Ell	3,000	June 17, 1955
	Pelican Horn	33,333	Nov. 4, 1956
	Pomeroy	10,500	July 17, 1947
	Port Angeles	66,667	Oct. 31, 1949
	Potlatch	3,000	Oct. 27, 1960
	Prosser (new)	12,000	Jan. 21, 1951
	Quincy (new)	12,000	Mar. 9, 1954
	Raymond	15,000	Sept. 27, 1940
	Republic	6,000	Oct. 28, 1953
	*Richland		Jan. 25, 1949
	Ringgold	16,000	Mar. 9, 1954
	Riparia	5,000	Apr. 22, 1964
	Ritzville	6,000	Apr. 19, 1963
	Riverview	40,000	Jan. 12, 1953
	Royal	12,000	Apr. 10, 1957
	*Sand Dunes		Oct. 9, 1958
	Scooteney	19,500	Apr. 1, 1953
	*Shelton		Sept. 4, 1947
	*Sifton		Sept. 20, 1962
	Soap Lake	20,000	Dec. 20, 1951
	South Elma	15,000	Oct. 23, 1952
	Spearfish (new)	6,000	Nov. 25, 1952
	Springhill	6,000	Oct. 17, 1959
	Stevens Drive	26,666	Jan. 1, 1955
	Svenson (new)	3,000	June 19, 1958
	Thayer Drive	26,666	Jan. 1, 1955
	Tonasket (new)	7,500	Nov. 1, 1953
	Trentwood	75,000	Nov. 16, 1942
	Underwood	3,000	Nov. 28, 1950
	Valhalla	250,000	May 22, 1952
	Valley Way	12,000	Nov. 27, 1946
	Vancouver Shipyard (new)	33,333	Sept. 22, 1957
	Vera	12,000	Dec. 9, 1958
	Walla Walla	58,000	June 1, 1941
	Warden	12,000	Dec. 5, 1952
	White Swan	3,000	May 16, 1952
	Willapa River	12,000	Nov. 6, 1958
	*Woodland Tap		Sept. 12, 1958

*Switching station.

Bonneville's present high voltage system is to be expanded with an EHV transmission grid. This will more efficiently transmit the output of the area's hydroelectric plants to load centers. Exclusive of intertie lines, over 1,600 miles of 500 kv transmission lines are programmed for construction within the next 10 years. Nearly 1,100 miles of this overlay grid is to be constructed in the State of Washington.

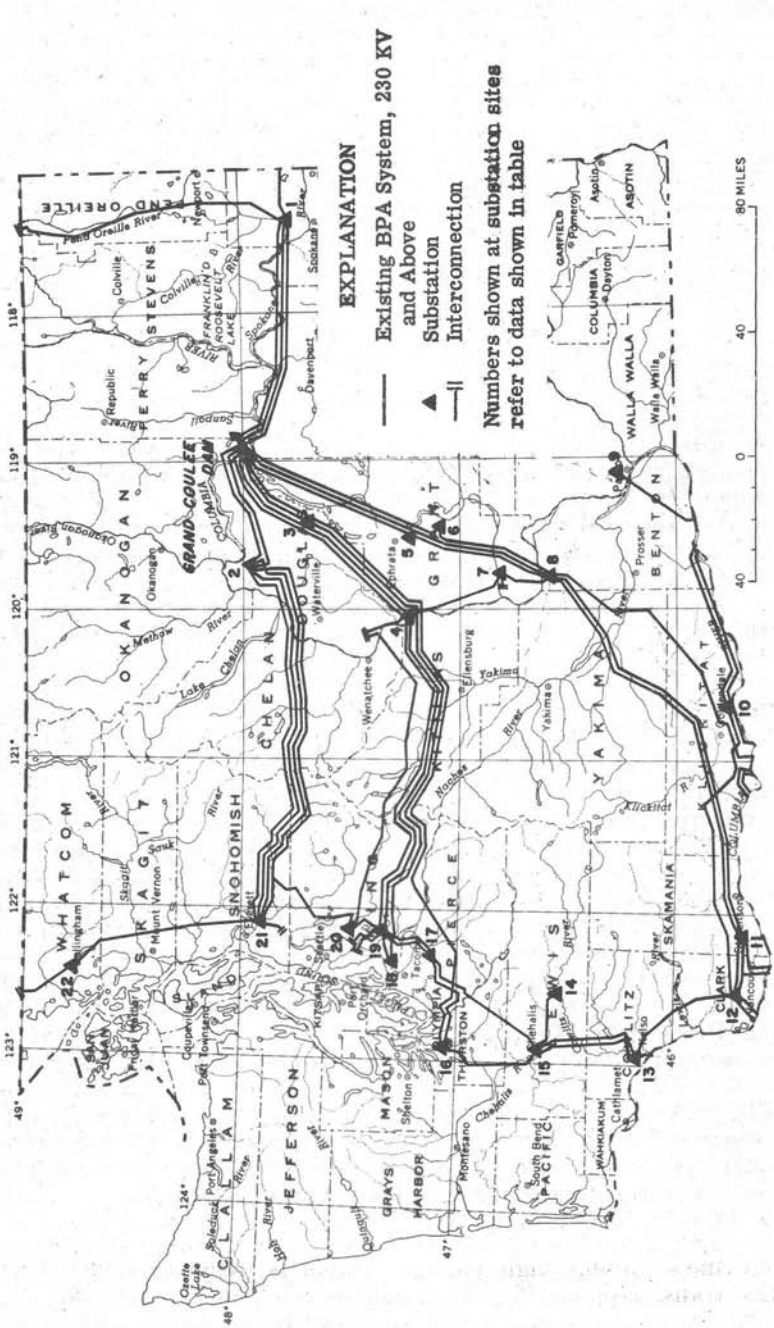

FIGURE 75.—Bonneville Power Administration, main grid in Washington.

TABLE 33.—*State of Washington energized line miles* [1]*—Design voltage*

	Steel tower miles	Wood pole miles	Total miles
345 kilovolts	518.6		518.6
287 kilovolts	771.1		771.1
230 kilovolts	1,559.1	373.3	1,932.4
115 kilovolts	111.4	1,700.0	1,811.4
Lower	1.5	[2] 96.6	[2] 98.1
Total	2,961.7	2,169.9	5,131.6

[1] Includes 422.9 miles of double circuit construction.
[2] Includes 8.4 miles submarine cable.

POTENTIAL WATERPOWER

(By G. C. Giles, U.S. Geological Survey, Tacoma, Wash.)

Washington, with an estimated 21,889 MW (1,000 kilowatts) of gross theoretical power from its potential and developed sites, ranks first amongst the States in the extent of this resource. This is over 15 percent of the national total. By way of comparison, Washington has 20 percent more waterpower resources than Alaska, and 40 percent more than California, the second and third ranking States in the nation. As of December 31, 1964, more than 55 percent of the gross theoretical potential, or 12,156 MW based on mean flow, was already developed at 58 separate waterpower sites located throughout the State. This places Washington first in the United States in the actual installed capacity (9,295 MW) at developed waterpower sites. Approximately 70 percent of the gross theoretical waterpower potential of the State will be developed upon completion of six projects presently under construction.

The waterpower resources of Washington at developed and undeveloped sites are summarized in table 34. Where powersites are located on boundary streams between States, half of the potential power is assigned to each State. The gross theoretical power capability has been evaluated in accordance with standards recommended by the World Power Conference (1962). These standards assume utilization of the total available head at 100 percent efficiency for flows available 95 percent of the time (Q95), 50 percent of the time (Q50), and mean flow (Q mean).

On streams that do not have storage to equalize seasonal variation, the Q95 flow indicates approximately the minimum dependable power potential, and the Q50 flow suggests the average power output. Power values based on mean flow (Q mean) represent the maximum attainable assuming complete equalization of all streamflow for the purpose of power generation, a condition seldom attainable.

Table 34 shows the total gross theoretical power for the State at all developed and undeveloped sites as 21,889 MW, based on mean flow. Table 31 shows an ultimate installed capacity of 23,900 MW at the developed sites and those now under construction or active consideration. This difference is due to the fact that the installed capacity in powerplants is generally greater than the potential power of the site in order to effectively utilize variations in streamflow as well as meet variations in power demand.

The values shown in table 34 are based on all possible sites. It is recognized that many of these, even though representing a definite

TABLE 34.—*Developed and undeveloped waterpower in Washington, Dec. 31, 1964*

[MW=megawatt=1,000 kilowatts]

Principal drainage area and subdivisions	Drainage basin index No.	Developed waterpower sites				Installed capacity (MW)	Undeveloped waterpower sites				Total gross theoretical power (MW) developed and undeveloped sites based on mean flow
		Number of sites	Gross theoretical power (MW), gross head, 100 percent efficiency, flows at—				Number of sites	Gross theoretical power (MW), gross head, 100 percent efficiency, flows at—			
			Q95	Q50	Q mean			Q95	Q50	Q mean	
COLUMBIA RIVER BASIN SUBDIVISIONS											
Pend Oreille River basin	12-D	3	50.69	125.07	166.86	64.16	2	184.18	417.32	575.28	742.14
Columbia River and tributaries, International Boundary to and including Spokane River	12-E	7	61.11	186.68	316.89	136.30	6	25.38	81.16	170.01	486.90
Columbia River and tributaries, Spokane River to Snake River	12-F	14	3,614.83	5,000.13	8,043.29	5,596.23	34	693.73	1,294.18	2,183.74	10,227.03
Snake River basin to and including Grande Ronde [1]	12-H						11	184.15	333.14	531.88	531.88
Snake River basin, Grande Ronde to mouth	12-L	1	149.60	297.50	465.80	270.00	10	420.17	795.00	1,315.79	1,781.59
Columbia River and tributaries, Snake River to Willamette River [1]	12-M	5	839.91	1,327.90	1,871.73	1,319.05	37	566.18	1,065.46	1,437.36	3,309.09
Columbia River and tributaries, downstream from Willamette River	12-N	6	88.20	389.42	401.58	663.00	31	175.37	715.37	859.61	1,261.19
Total, Columbia River basins		36	4,804.34	7,326.70	11,266.15	8,048.74	131	2,249.16	4,701.63	7,073.67	18,339.82
Pacific Coast river basins	12-O	1	.15	1.12	1.56	.25	14	65.97	217.47	309.91	311.47
Puget Sound river basins	12-P	21	335.18	753.96	888.44	1,246.19	108	611.13	1,767.08	2,349.28	3,237.72
Total for State		58	5,139.67	8,081.78	12,156.15	9,295.18	253	2,926.26	6,686.18	9,732.86	21,889.01

[1] For waterpower sites located on boundary river between States, the gross theoretical potential or installed capacity is divided equally between the States.

power potential, are not likely to be considered for development for various reasons. Among these are small power potential, absence of feasible damsites and reservoir sites for regulation of streamflow, conflicts with existing cultural developments, or higher value for other uses of the water than for power.

The locations of undeveloped waterpower sites having a potential capacity of 10 MW or more based on the flow available 50 percent of the time are shown on figure 76. These sites have been grouped within nine geographical areas, delineated in figure 74, for the purpose of showing the availability and distribution of these resources. Seven of these geographical subdivisions, identified by basin index numbers 12–D through 12–N, comprise the portion of the Columbia River Basin and its tributaries that lie within the boundaries of the State. Subdivision 12-O includes those river basins draining to the Pacific Ocean between the mouth of the Columbia River and Cape Flattery, at the entrance to the Strait of Juan de Fuca, and subdivision 12–P contains those river basins draining to Puget Sound and the Strait of Juan de Fuca.

The State of Washington owes its predominance in respect to waterpower resources largely to the Columbia River and its major tributaries. Although second in discharge following the Mississippi, the Columbia River ranks first in waterpower potential amongst the major rivers in the United States. The total gross theoretical power at developed and undeveloped sites assignable to that portion of the Columbia River Basin within the State of Washington is 18,340 MW. This is 41 percent of the total potential power in the Columbia River Basin within the United States, and accounts for nearly 84 percent of the total waterpower resources of the State. The river basins draining to Puget Sound and the Strait of Juan de Fuca account for about 15 percent of the power resources of the State. Only slightly more than 1 percent of the power resources are located in the Pacific Coast river basins.

The undeveloped gross theoretical power, summarized in table 34, includes 253 sites, each with a potential capacity of 1 megawatt or more based on flows available 50 percent of the time. Included in the 253 undeveloped sites are 6 with an aggregate capacity of 2,142 MW which are presently under construction, and 15 sites with an aggregate capacity of 986 MW which are under active consideration. The distribution of the remaining undeveloped powersites according to potential capacity is shown in the following:

Distribution of undeveloped waterpower sites according to potential capacity

Potential power of sites based on Q50 flow (MW)	Number of sites in each geographical subdivision [1]									Total Number of sites	Gross theoretical power (MW) at Q50 flows
	12–D	12–E	12–F	12–H	12–L	12–M	12–N	12–O	12–P		
Less than 5.0	-------	2	9	4	6	16	2	1	18	58	180.11
5.0 to 10.0	-------	1	5	-------	1	3	6	4	24	44	335.83
10.0 to 20.0	-------	2	8	3	-------	8	11	4	29	65	955.60
20.0 to 50.0	-------	1	8	2	-------	8	8	4	28	59	1,723.95
50 to 100.0	-------	-------	-------	-------	-------	-------	1	-------	4	5	362.33
Total	0	6	30	9	7	35	28	13	103	231	3,557.82

[1] See fig. 76 for subdivisions.

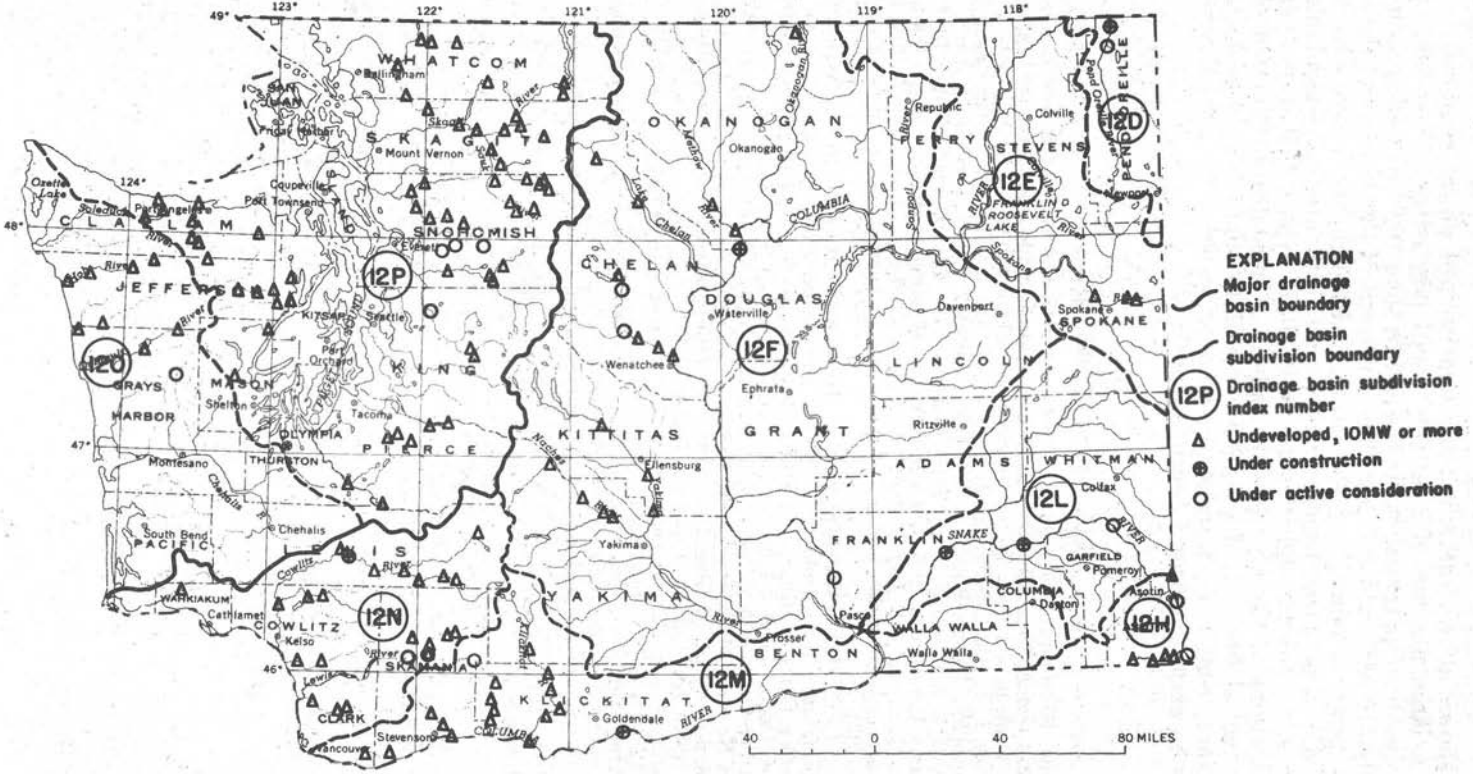

FIGURE 76.—Potential waterpower sites in Washington.

As shown above, the remaining undeveloped power resources include a large number of relatively small powersites. Over 100 of these sites have potential capacities of less than 10 MW, and account for only 516 MW which is less than 4 percent of the total gross theoretical power potential of the State. Although the above shows 3,558 MW of potential waterpower resources estimated to be available for development throughout the State, it is expected that further investigations of these sites will result in a substantial reduction of the potential because of economic feasibility, unfavorable geologic conditions, conflicting interests in land or water uses, and adverse effects on existing cultural developments.

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WATER RESOURCE DEVELOPMENT

Other Than for Municipal Water Supply and Hydroelectric Power

(By G. V. Schirk and T. P. Lynott, U.S. Bureau of Reclamation, Boise, Idaho)

This part of the report describes, in summary form, water resource developments in Washington exclusive of those dealing with hydroelectric power and municipal and industrial water supply. Both of these subjects are covered in other sections. Existing information and data have been brought together in a manner designed to show the magnitude and types of major existing developments and to furnish some indication of potentialities yet to be realized.

Six primary subbasins have been designated to facilitate the compilation and presentation of information. The location, number, and relation of the various subbasins within the State and their relation to other parts of the Columbia River Basin are shown on figure 77.

Since land use and water resource developments are so closely related, the initial portion of this writeup has been devoted to summary information on the two largest land-use activities, agriculture and forestry, in the State of Washington, under the heading "Introduction." Also included here is a brief writeup on certain historical aspects of the State. This is followed, in turn, by two main categories of information under the headings of "existing" and "potential" developments.

INTRODUCTION

Beginning about 1825 with the fur traders, missionaries, and other immigrants, agriculture has grown steadily in importance in the State of Washington. Around the turn of the century an overland influx of thousands of immigrants from eastern America, Europe, and Asia spread over the State on numerous small holdings. That pioneering type of general farming has evolved into the highly specialized commercial farming of today.

Many factors, both human and natural, have helped to develop and shape the complex pattern of agriculture in Washington. Included among the human factors were the agricultural companies, the land laws and settlement acts, the development of irrigation, and the development of mechanized farms. The important natural factors include topography, climate, soils, vegetation, and drainage.

Early commercial agriculture was dominated by the Hudson's Bay Company. Under the leadership of Dr. John McLoughlin, several thousand acres of land were developed during the period 1824–35 at Fort Vancouver on the north bank of the Columbia River. In addition to being self-sufficient in foodstuffs, this company produced enough farm products for maritime trade and for sale to immigrants traveling the Oregon Trail.

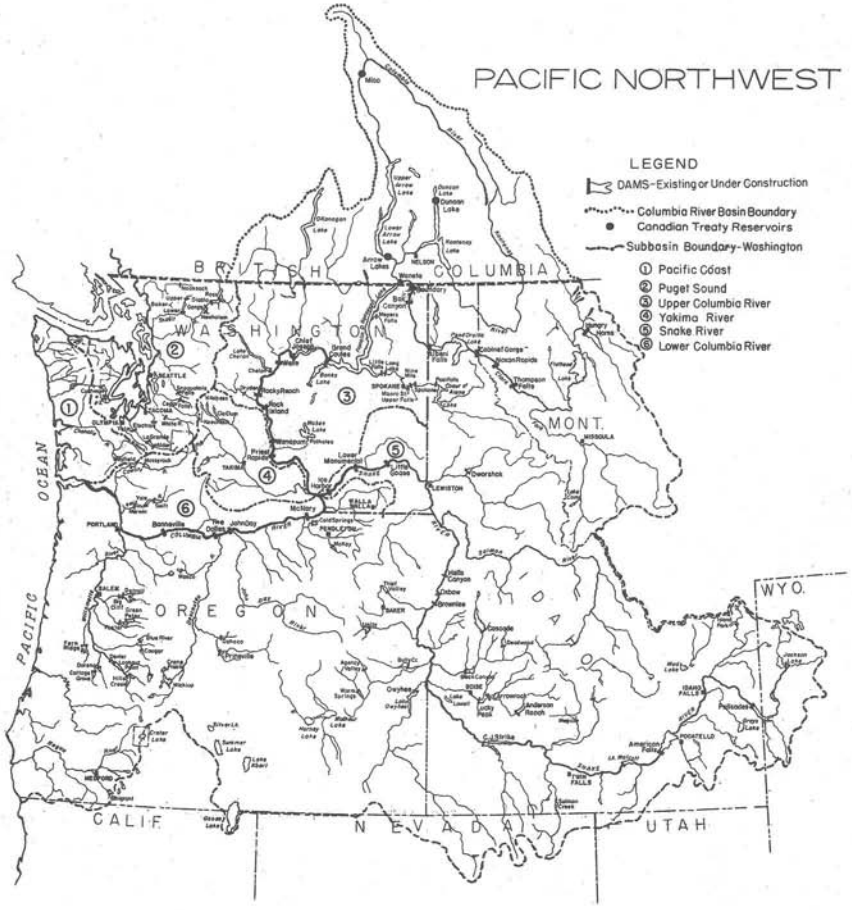

FIGURE 77.—Washington and the Pacific Northwest.

Because the trading of agricultural products proved increasingly profitable, Hudson's Bay Co., in 1839 organized the Puget Sound Agricultural Co. as a subsidiary. Four thousand acres were developed by this large farming company on Cowlitz Prairie in what is now Lewis County. Another British farming estate was developed in 1833 at Fort Nisqually on Puget Sound. A vast livestock ranch covering several thousand acres in present Thurston and Pierce Counties, the Nisqually Farm was exporting beef cattle, butter, cheese, and other fresh products by 1841.

An important influence on farming in the State was developed by these two companies. Many of the species and varieties of livestock, poultry, grains, grasses, berries and fruits from Europe and elsewhere were introduced to the American pioneers by British overseers and managers. These men helped demonstrate that many European practices of animal husbandry and horticulture were highly adaptable to the Pacific Northwest, which they found similar in climate to that of northwestern Europe.

Early important settlements of Americans in this territory were those led by missionary groups. In 1836 Dr. Marcus Whitman and party settled in the Walla Walla Valley at Mill Creek to work among the Cayuse Indians. Subsistence crop agriculture and rudiments of livestock agriculture were introduced in the Touchet and Walla Walla Valley regions. In 1846, Dr. Whitman and his party constructed a ditch to divert water from Doan Creek for agricultural development. This is believed to be the first attempt at irrigation in what is now Washington State. Prior to his death in 1847, Whitman made the Walla Walla Valley an important provision center and rest station.

The Oregon Donation Land Law of 1850 was the first of a series of acts and grants designed to stimulate early agricultural settlement in the Pacific Northwest. More than 300,000 acres of public domain were settled in Washington under the influence of this law.

Due to isolation and limited market outlets, the donation claims generally were livestock farms, with some small clearings devoted to hay and grain, and with small orchards and gardens for family use. Pasture dominated the land use. Major cash items included livestock which could be driven over trails and wagon roads. Each farm became nearly self-supporting. Numerous western Washington communities were founded and settled by farm families taking up Donation Land Law claims.

The Homestead Act of 1862 was another Federal act designed to encourage westward movement and agricultural settlement. Thousands of farms of 160 acres were claimed in Washington between 1863 and 1910 under the provisions of this law.

Also in 1862, Congress passed an act which granted large amounts of land from the public domain to western railroad companies. Several systems were developed to handle the disposition of these lands. Many sales in the western part of the State were made in 20-, 40-, and 80-acre plots. In eastern Washington 640-acre sections in the Palouse Hills, Waterville Plateau and Basins, and Central Plains were commonly sold or long-termed leased. Thus the sale and settlement of the grant lands contributed to a pattern of small farms in western Washington and to relatively larger farms in the eastern portion of the State.

When admitted to the Union in 1889, the State of Washington was granted approximately 2 million acres from the public domain for schools and universities. The public land commissioner, after classifying the lands, had authority to sell or lease more than 1 million acres under various contracts. Disposition of State land in western Washington resulted in the establishment of many small farms on cut-over lands devoted primarily to livestock and dairy production. In eastern Washington, school lands suitable for wheat or irrigation in the Yakima and Wenatchee Valleys were sold or leased in larger units.

The enactment of the Federal Reclamation Act in 1902 and the development of a State water code in 1917 were important factors in the development of irrigation agriculture in Washington. A pattern of small, intensive farms on private and public irrigation projects was developed throughout the State, with emphasis in the eastern portion of the State—largely in the Yakima and Wenatchee Valleys—and later, on the Central Plains.

The development of railroads and other transportation facilities, the growth and spread of the population, and the increasing trend toward greater urbanization throughout the State have altered the agricultural patterns in Washington. Guided for the most part by the experience of the individual farmer and assisted by the agricultural research and extension services of the Federal and State governments, agriculture in the State has become more productive and more specialized. Many farmers now specialize in high-value cash crops, due largely to the development of rapid transport to eastern markets, the development of maritime shipping, and the increase in irrigation.

AGRICULTURAL REGIONS

Nineteen agricultural regions are identified by the Washington State Department of Agriculture in its 1963 Atlas of Washington Agriculture. The differentiation is based on both cultural and physical factors of environment, the predominant type of agricultural activity, and market orientation.

The Cascade Range, over 50 miles wide, traverses the State in a north-south direction. This rugged mountain range divides the State into two broad, contrasting sections. Western Washington is characterized by forested mountains, a broad, central lowland area, moderate to heavy rainfall, mild temperatures, and the largest urban complex in the State. Eastern Washington, which encompasses roughly two-thirds of the State area, includes a mountainous northern section; the Columbia River and valleys of its principal tributaries; a semiarid central section composed of plateaus, plains, ridges, scablands, coulees and hills commonly referred to as the Columbia Basin; and an area of low, rolling hills which abut a mountainous area in the southeastern corner of the State.

The climate of Washington is greatly modified by the influence of the Pacific Ocean and the north-south trending mountain ranges. The climate of the western part of the State is much milder than that of any other section of the continent lying in the same latitude. The marine influence is most pronounced on the coast and decreases inland, especially east of the Cascade Range. However, even eastern Washington has milder temperatures than the northern plain States. Although the average annual temperatures, which range from 48° to 50°, are about the same for western and eastern Washington, the moderating effect of the ocean wind keeps summer temperatures cool and winter temperatures warm in western Washington, while in eastern Washington summers are warmer and winters colder, with daily extremes of 118° and − 22° having been recorded. Rainfall is heaviest near the ocean and on the windward, or southwesterly, mountain slopes. In certain parts of the Olympic Peninsula, annual precipitation of up to 200 inches has been measured, while many of the arid portions of eastern Washington have an annual precipitation of 5 inches. Seasonally, precipitation is heaviest in the winter. The dry season reaches its peak in July and August, after which the rainy season develops gradually, reaching its peak in December and January. Average annual precipitation in the western part of the State is about 58 inches; in the eastern part, 17 inches.

Agriculture ranks second to manufacturing in importance to the economy of the State. Each year it constitutes over $600 million in direct value to producers and, in addition, generates several times this sum in the value of services, supplies, labor, equipment and transportation associated with the marketing and processing of farm commodities.

Farmland amounted to slightly over 18.7 million acres, or 44 percent of the total land area of the State, in the 1960 U.S. Census. Of this total, about 7.9 million acres were classed as cropland and crops were harvested from some 4.4 million acres. Cropland not harvested included 29 percent in cultivated summer fallow; 9 percent used for pasture; and 6 percent used either for soil improvement or was idle. Crops provide more income to Washington farmers than do livestock and livestock products. This is true regardless of the measure of farm income. Over the 5-year period 1957–61, crops accounted for 62 percent of the value of farm production compared with 38 percent for livestock and livestock products.

The composition of the total average value of Washington farm production for the period 1956–61 and the composition of the three primary categories making up the total average values are shown in figure 78.

Information on the 19 agricultural regions has been briefed and consolidated for this report in terms of the six subbasins. The location and name of the agricultural regions are shown on figure 79, along with the boundaries of the six subbasins adopted for this report.

SUBBASIN NO. 1 (PACIFIC COAST)

This subbasin includes the drainages and headwater areas of the west coast streams in Washington which flow directly into the Pacific Ocean, and the north coast streams, west of the Elwha River, which flow north into the Strait of Juan de Fuca. A large part of this subbasin is made up of the coast range mountains. Rainfall is heavy in the northern part and the climate is too cool, cloudy and wet for many crops. Dairying, poultry and egg production, and livestock raising are the dominant agricultural activities. The Puget Sound Lowland Prairies are devoted mainly to feed crops such as hay, grass silage and small grains for local livestock feed. The Chehalis prairies and uplands are major production areas for clover-timothy hay. The Chehalis River lowlands and tributary valleys contain important concentrations of cattle. Sheep are grazed in the mountain foothills and on forested and cut-over pasture land. Forest products have always been important. In addition to marketing sawlogs and pulpwood, many farmers have developed Christmas tree farms that are managed explicitly for this seasonal item. The Willapa-Grayland Coastal Plain is the major cranberry district of Washington and of the Western States.

SUBBASIN NO. 2 (PUGET SOUND)

The Puget Sound Lowland and the Dungeness and Elwha River basins are included in this subbasin. Most of the subbasin is located in the trough or valley between the Coast Range and the Cascade

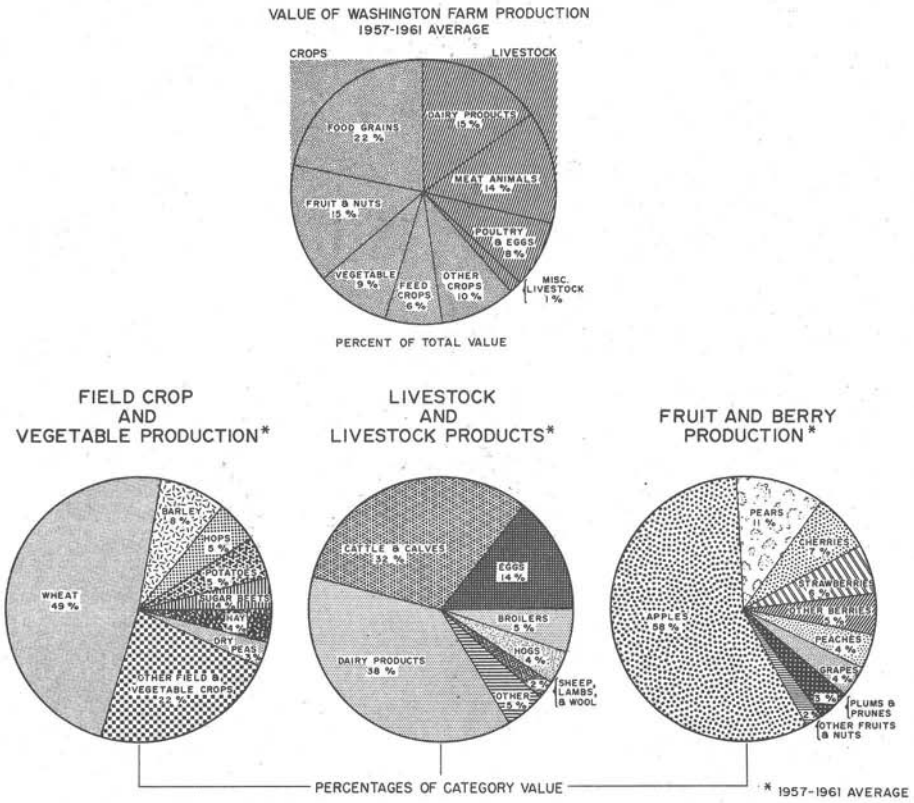

FIGURE 78.—Average composition of Washington farm production.

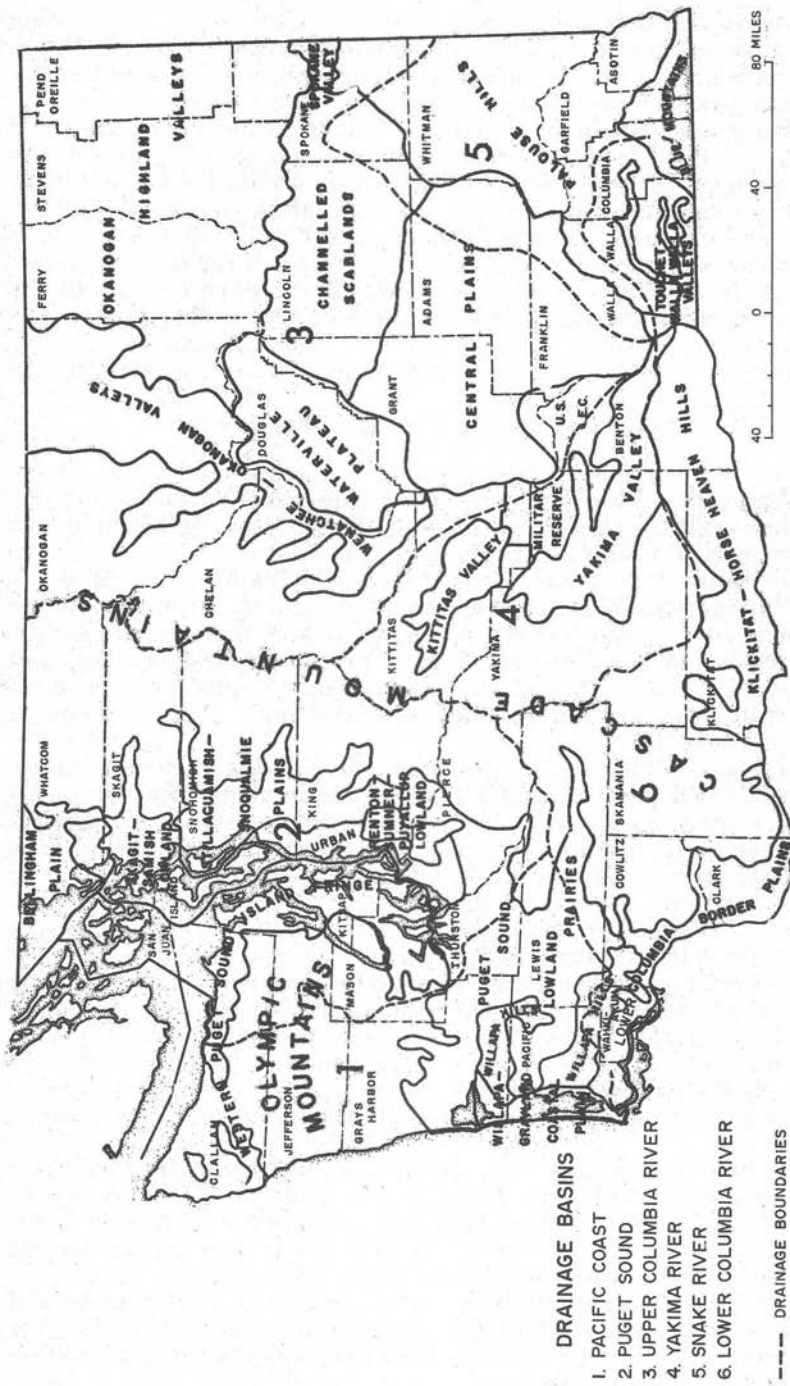

FIGURE 79.—Subbasins and agricultural regions.

Mountains. This is primarily a glaciated, alluvial plain extending south from the Strait of Juan de Fuca almost to the Columbia River.

Puget Sound Lowland contains the largest metropolitan and industrial complex and one of the most important concentrations of food processing industries in Washington. It is the leading dairy region of the State. It contains the greatest clover-timothy acreage and is the top producer of fresh eggs, strawberries, certified seed potatoes, broccoli, snap beans, cauliflower, lettuce, cabbage, rhubarb, celery, cucumbers, caneberries, vegetable seeds, and flower bulbs in the State. Beef cattle, sheep and lambs are raised on many of the farms. Forest products from private farmer-owned woodlands have become an important source of income to farmers in recent years. The Dungeness-Sequim portion of the subbasin is noted for its dairy herds. More hay and pasture land is irrigated here than in any other district in the subbasin.

SUBBASIN NO. 3 (UPPER COLUMBIA RIVER)

All of the Columbia River drainage lying upstream from Pasco, Wash., excepting the drainage of the Yakima River, is included in this subbasin. This is the largest subbasin in the State and includes six primary agricultural producing regions.

Benchlands along the Columbia River and the lower slopes of the main valleys from Wenatchee upstream, commonly referred to as the Wenatchee-Okanogan Valleys, constitute one of the most important fruit regions in the Nation. Apples, pears, cherries, peaches, and apricots are grown throughout this region. Apples are the chief crop with pears ranking second. Cherries rank high in terms of national production.

Livestock farming, with beef production as the main enterprise, is highly developed. A major part of the cropland, aside from orchards, is used to grow hay, mainly alfalfa, and most of it is irrigated. Wheat and other grains generally are grown in small fields as a secondary crop, and most of it is consumed locally.

The northeast section of subbasin No. 3 is referred to as the Okanogan Highlands; roughly the area lying east of the Okanogan and north of the Spokane River Valleys. It is primarily a livestock farming region. Beef cattle are of major importance. Dairy farming is prevalent throughout the valley lowlands; irrigated alfalfa hay is the principal crop produced in these same locations. Wheat, oats, and barley are the primary grain crops and grow mainly on the uplands, chiefly for livestock feed. Farm forestry is rapidly becoming an important supplementary source of income in the agriculture of this region.

Adjoining the southwest corner of the Okanogan Highlands and lying east of the Columbia River, is the Waterville Plateau region, noted for its extensive wheat fields and large cattle herds. It forms a part of the "Big Bend Country" and is one of the highest farming areas in the State with elevations ranging from 2,200 to 2,700 feet. The climate is semiarid and is characterized by hot, dry summers and cold, humid winters. Wheat has been the most important crop for many years and farming methods have been adapted to precipitation of 12 inches or less per year.

Lying directly south of the Okanogan Highlands and east of the Waterville Plateau is an extensive area of Channeled Scablands

characterized by lava outcrops, a series of abrupt coulees, and interspersed gently rolling tablelands with wide expanses of wind-deposited soil suitable for grain farming. Agriculture is highly specialized with the large farms well mechanized for the production of wheat and barley. Native grass provides pasture for white-faced Herefords and Black Angus cattle and an increasing acreage is being devoted to hay crops. The major marketing activity is the handling of wheat and barley; facilities for grain trading, storage, and shipping are well developed.

The Spokane River Valley region is a lowland geographic unit extending from the western border of Idaho to the eastern edge of the Channeled Scablands. Essentially, it is a narrow river plain enclosed by flat to rolling prairies. Farming is more diversified than in the neighboring wheat and cattle regions. Principal crops are seeds, tree fruits, vegetables, and nursery and greenhouse products. Farms are favorably located with respect to the second largest urban market in the State—metropolitan Spokane.

The balance of the Upper Columbia subbasin is composed of a large Central Plains region. This is an important region of irrigated agriculture and includes the Columbia Basin Irrigation Project which covers its western half. Irrigated, commercial crops such as hay, potatoes, dry onions, dry beans, field corn, and sugarbeets have made this one of the principal agricultural regions in Washington. Outside the irrigated area, large, cash-grain farms are the rule, with wheat constituting the most important crop in terms of both acreage and value. The transition of the western portion of this region to intensive agriculture through the application of irrigation has brought noticeable changes in the economy and marketing activities. Dryland grains are no longer the dominant agricultural enterprise.

SUBBASIN NO. 4 (YAKIMA RIVER)

The Yakima Valley is one of Washington's foremost agricultural areas. It consists primarily of broad, alluvial plains and terraces formed by the Naches and Yakima Rivers. The upper portion of the valley, which extends from the headwaters of Yakima River downstream to the Manastash Ridge immediately below Ellensburg, is commonly referred to as the Kittitas Valley. The remaining downstream portions of the Yakima and Naches River drainages are referred to as the Yakima Valley. Both sections contain extensive irrigation systems but differ somewhat in their agricultural development.

Livestock is the major specialty of the Kittitas Valley. A multimillion-dollar livestock enterprise has been developed by enlarging and improving ranges in the adjacent uplands and using field and forage crops for feed. High value cash crops grown on irrigated land include sweet corn, potatoes, and sugarbeets. Baled alfalfa is perhaps the most important commercial crop, locally exchanged and sold on outside farm markets. While there are some apple, peach, and pear orchards, tree fruits have never developed in the Kittitas Valley as they have in other irrigated areas along the Columbia River of central Washington.

Yakima Valley is known locally and nationally as an outstanding tree fruit district. It is one of the two important apple-producing

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regions of the State. It ranks first in pear production. Peaches, apricots, cherries, and prunes are important soft fruits. It is the major grape-producing region in the Northwest. It leads the State in a number of high-value cash crops such as hops, asparagus, sweet corn, green peas, tomatoes, onions, beans, rutabagas, turnips, carrots, cantaloups, and watermelon. Sugarbeet and mint crops, which occupy nearly equal acreages, are also important commercially. This region is also the predominant potato producer of the State. The valley is noted for its large numbers of beef cattle, sheep, and hogs, and for its well-developed poultry farming. This is the principal feedlot district in the State and the livestock industry is supported by a large acreage devoted to alfalfa, field corn, and pasture. The Yakima Valley is a prominent center for livestock slaughtering and food packing and processing.

SUBBASIN NO. 5 (SNAKE RIVER)

The Palouse Hills form the bulk of this subbasin. This is one of America's leading wheat-growing regions. It is the State's leader in the production of wheat, barley, and dry field peas. Wheat and barley make up almost three-fourths of the harvested cropland. Beef cattle, along with the grain crops, form the major support of the region and contribute greatly to the local and State economy. Low, rounded hills are characteristic topographic features. The southeastern portion includes a small part of the Blue Mountains. Facilities for processing and handling agricultural products are well developed within and adjacent to the region.

SUBBASIN NO. 6 (LOWER COLUMBIA RIVER)

The Columbia River and its north side tributaries from Pasco, Washington, downstream to the Pacific Ocean, are included in this subbasin. The Walla Walla River Basin is also included here. This latter area, commonly known as the Walla Walla and Touchet Valleys, is located east of the Columbia River and forms the eastern portion of the subbasin. It consists of the valley bottom lands of the Touchet and Walla Walla Rivers and tributary creek valleys. Irrigated bottom lands and dry-farmed adjacent hill land characterize its development. It is primarily a commercial crop producer with vegetables constituting an important part of the production. It ranks first in the State in production of canning and freezing peas. Asparagus is the second major vegetable crop; and sweet corn, early onions, carrots, and spinach are produced in quantity. Alfalfa is an important crop both for feed and seed production. Sugarbeets are grown extensively and early potatoes are of commercial significance. Once an important prune-producing region, fruit and berries now constitute a minor segment of the region's production.

West of the Walla Walla Basin and extending downstream along the Columbia River is a second portion of this subbasin known as the Klickitat-Horse Heaven Hills. It includes the valleys of the north-side tributary streams down to and including the White Salmon River. Agriculture varies from fruit, vegetable, dairy and livestock types of farm enterprises in its western section to a cash-grain economy in its semiarid eastern section. Wheat, rye, barley, and alfalfa are

the leading commercial crops. Beef production and sheep raising are important enterprises. Farm forest products are important to the region's economy.

The third portion of this subbasin includes the north-side tributary valleys from the White Salmon River downstream to the Pacific Coast. It encompasses areas of benchlands, sloping terraces, and flood plain islands along the shoreline of the Columbia. The river valleys and alluvial flood plains include the major agricultural developments. Dairying and poultry products are important sources of farm income. Beef cattle are increasing in number, and this region contains the second highest concentration of sheep west of the Cascade Mountains. Clover-timothy and mixtures of clover and grasses are popular hay crops, and clover seed production is important in several sections. A wide range of vegetable and fruit crops are grown on the alluvial bottom lands, and fruit and nut orchards are scattered over the river terraces.

FORESTRY

One of the dominant natural resources and a primary land-use feature of the State of Washington is its forests. Of the 43 million acres of land within the State's boundaries, over 23 million are classified as forest lands. Of this total about 19.5 million acres are classed as commercial forest. Figure 80 shows the location of Washington's forest and alpine lands. Washington is aptly called the Evergreen State.

There are two distinct forest regions in the State, the Douglas fir forest west of the Cascades and the western pine forest east of the Cascades. The Douglas-fir forest covers almost 11 million acres; the western pine forest, 8.5 million acres. Intermixed with the fir forest are other important species of timber, including western hemlock, western red cedar, Sitka spruce, and several other species of fir. Intermixed in the pine forest are ponderosa pine, spruce, larch, white fir, Douglas-fir, and lodgepole pine.

Table 35 presents a breakdown of the commercial forest lands in the State. The public, private, and total ownerships for the Douglas-fir subregion and the Ponderosa pine subregion are shown by types of trees. A very small amount, only 3,000 acres, of Ponderosa pine is located in the Douglas-fir subregion; however, Douglas-fir is the second ranking tree in terms of acreage (2,931,000 acres) in the Ponderosa pine subregion. Most of the hardwoods found in the State are located in the Douglas-fir subregion. Dominant hardwood species are red alder, maple, and cottonwood, all of which are harvested commercially. Aspen is fairly abundant in eastern Washington but is not commercially important.

A breakdown by ownership classes of the two forest subregions in the State is shown in table 36. Private ownership is predominant in the Douglas-fir subregion, while public ownership predominates in the ponderosa pine subregion. Of the 19,510,000 acres of commercial forest land in Washington, 10,359,000 acres are in public ownership and 9,151,000 acres are in private ownership.

One-sixth of the Nation's standing timber is located in the commercial forests of Washington. The estimated volume of 315 billion board feet within its forests ranks Washington second in the Nation.

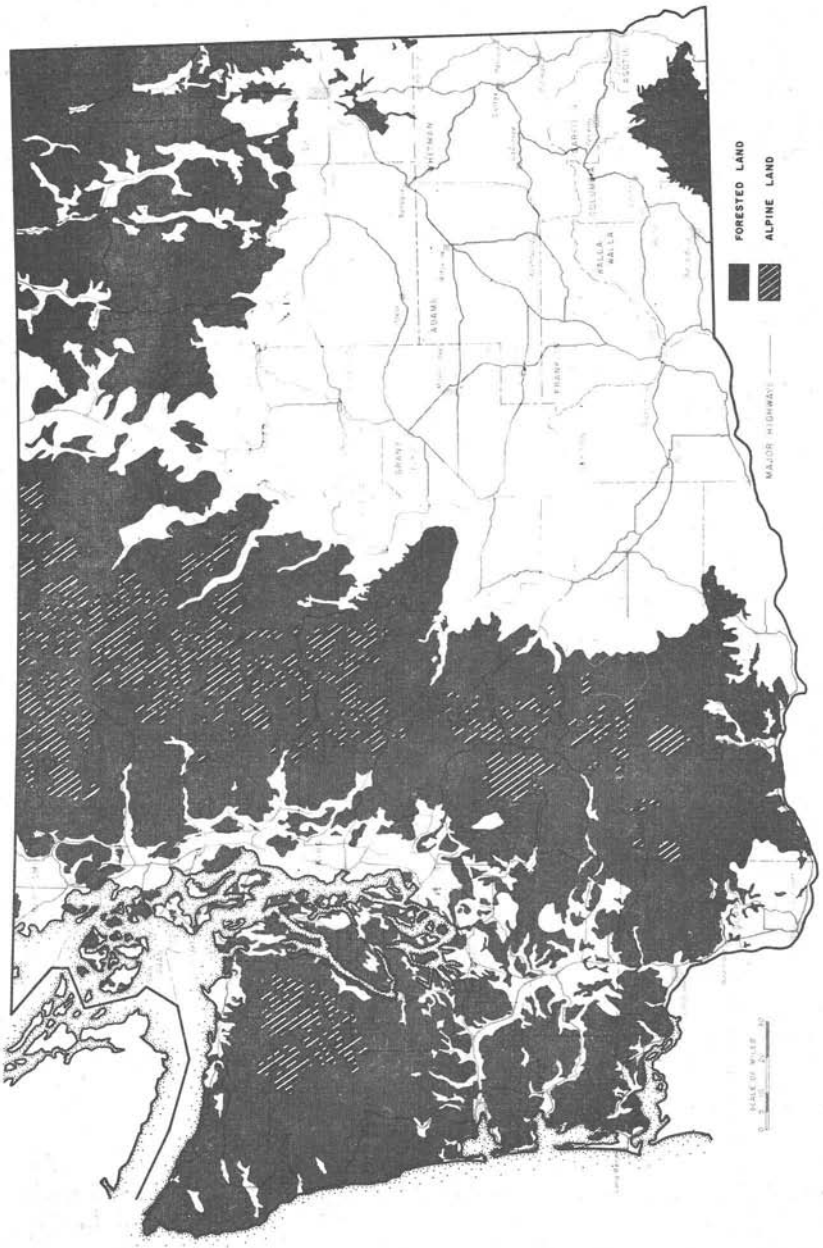

FIGURE 80.—Forest and alpine land.

TABLE 35.—*Area of commercial forest land in Washington, by forest type and ownership class, as of January 1963*

[Thousands of acres]

Type	Western Washington			Eastern Washington			Total for State
	All ownerships	Public ownerships	Private ownerships	All ownerships	Public ownerships	Private ownerships	
Softwoods:							
Douglas-fir	5,394	2,053	3,341	2,931	2,034	897	8,325
Hemlock-Sitka spruce	2,762	1,281	1,481				2,762
Ponderosa pine	3	3		3,413	2,182	1,285	3,416
White pine	26	23	3	111	93	18	137
Lodgepole pine	47	32	15	712	504	208	759
Larch				471	342	129	471
Fir-spruce	984	822	162	684	545	139	1,668
All softwoods	9,216	4,214	5,002	8,322	5,646	2,676	17,538
Hardwoods	1,275	218	1,057	63	27	36	1,338
Nonstocked [1]	459	169	290	175	85	90	634
All types	10,950	4,601	6,349	8,560	5,758	2,802	19,510

[1] Commercial forest land stocked with less than 10 percent growing-stock trees.

TABLE 36.—*Area of commercial forest land in Washington, by ownership class, as of January 1963*

[In thousand acres]

Ownership class	Western Washington (Douglas-fir subregion)	Eastern Washington (Ponderosa pine subregion)	Total
National forest [1]	2,752	3,408	6,160
Other Federal:			
Bureau of Land Management	23	164	187
Indian	234	1,452	1,686
Miscellaneous	66	60	126
Subtotal, Federal	3,075	5,084	8,159
State	1,339	662	2,001
County and Municipal	187	12	199
Subtotal, public ownership	4,601	5,758	10,359
Forest industry:			
Pulp and paper	1,313	38	1,351
Lumber	2,361	574	2,935
Other	115		115
Subtotal, forest industry	3,789	612	4,401
Farmer owned	867	1,700	2,567
Miscellaneous private	1,693	490	2,183
Subtotal, private ownership	6,349	2,802	9,151
All ownerships	10,950	8,560	19,510

[1] Includes both operable and inoperable areas.

Washington leads the Nation in woodpulp production. The State's forest industries, including plywood, pulp, and assorted wood and forest products, employ more than 60,000 people and have a $300 million annual payroll.

Carefully planned and well-organized conservation activities to perpetuate Washington's valuable forest resources started about 50 years ago using modern tree-farming methods which include harvesting to provide natural regeneration. On areas denuded by repeated fires,

land clearing, or other causes, reforestation is being accomplished by seeding and planting. Six large tree nurseries with a combined production of 35 to 40 million trees per year are located in Washington. In all, more than 400,000 acres have been reforested to date by planting or direct seeding; about 150,000 acres of which is private land.

The most recent economic base study (U.S. Department of Agriculture, 1965) for the Pacific Northwest indicates that future loss of commercial forest land to urban development will be minor. It also indicates that increased demand for farm products will not require increased clearing of forest land. There is some indication that the dedication of commercial forest land to recreational use will increase particularly on public land areas. The extent of this shift is not now known.

EXISTING WATER RESOURCE DEVELOPMENTS

Hydroelectric power, irrigation, navigation, and municipal and industrial water supply are the project purposes that have in the past formed the principal justification for constructing the major existing water resource developments in the State of Washington. Not all of these purposes are served by every development, and additional purposes such as flood control, fish and wildlife conservation and enhancement, water quality control, and recreation are associated with many of them.

Developments on the main stem of the Columbia River, downstream from Chief Joseph Dam, have provided substantial power and navigation benefits. Grand Coulee Dam on the main stem and most of the major developments on tributary streams have provided substantial irrigation, power, fish and wildlife, recreation, flood control, water quality control, and municipal and industrial water supply benefits.

Many of the early developments were constructed to meet the needs of a single project purpose such as irrigation or power. Subsequently, the reservoirs have become important centers for all forms of water-based recreation activities and many of them have provided flexibility in river control for other purposes as well. Development of the Yakima basin is an excellent example of this extended use. The Yakima basin storage system, constructed primarily to meet the needs of irrigation, has provided flood control and recreation benefits of ever-increasing value.

In recent years, water resource developments have been analyzed as multiple-purpose undertakings with the view of providing for as many project purposes as possible with all State and Federal agencies coordinating their efforts to achieve the more extensive benefits resulting from basinwide planning.

A summary of existing major water resource developments in the State is given in the following paragraphs under the main headings of irrigation, recreation, navigation, and flood control. As noted earlier, information on power and municipal and industrial water supplies is presented in other sections of the report.

IRRIGATION

Beginning with the simple creek diversions at the Whitman Mission in the Walla Walla valley in 1846 and at the Yakima valley mission of the Oblate Fathers on Ahtanum Creek in 1852, irrigation in Washington has grown to the present-day multiple-purpose projects with their complex storage, distribution, and drainage systems. The U.S. Census of Agriculture reports the development by decades as follows:

Washington land irrigated

Census year:	*Acres*	Census year—Continued	*Acres*
1890	48, 799	1930	405, 027
1900	135, 470	1940	493, 982
1910	(1)	1950	589, 035
1920	(1)	1960	1, 006, 969

[1] Available data not comparable.

It is estimated that irrigation water was supplied to 1,123,000 acres in 1962.

Probably the first irrigated orchard in the State was developed near Osoyoos Lake in Okanogan County. In 1858 a ditch was constructed to divert water from Nine Mile Creek to irrigate lands on which 1,200 apple trees had been planted.

From the 1850's to the 1890's irrigation was developed by individuals and small groups, diversions being for the most part from creeks and small streams, with a few from the larger rivers. The peak of this type development was reached during the 1880's. Most of the waters of the small streams in central and eastern Washington had been appropriated and those irrigation systems most easily constructed had been built by the early 1890's. Attention then turned to the larger enterprises, the construction of which was necessarily undertaken by corporations and irrigation districts. The first irrigation district law was enacted in 1890.

Most of the early large projects were promoted by private groups and corporations. In some cases the irrigation works proved to be inadequate and were not long-lasting. In other cases the capacities of the ditches were inadequate to serve all the lands under them; in still others the available water supply could not fully serve the project lands. The settlers on these projects, after taking over the irrigation works, were immediately confronted with the necessity of constructing adequate and more lasting irrigation works. This cost, added to their investment in unimproved lands, the cost of land development, and the obligation incurred in the purchase of the original inadequate irrigation system and water rights, totaled more than the landowners could bear.

The Northern Pacific Railway Co. gave much financial and other assistance to the early irrigation projects along the railroad lines, particularly the Columbia Irrigation District works at Kennewick, the Sunnyside Project, the Cascade Canal Project in Kittitas County, and the Roza Project. The first surveys and investigations of the Roza Project were financed by the Northern Pacific in 1911–12.

STATE AND FEDERAL DEVELOPMENT

Bartholet (1940) stated:

> The coming in of the United States Bureau of Reclamation is probably the greatest event in the history of irrigation development in the State of Washington. The first activity of the Federal Government, preliminary to investigating irrigation projects in the State of Washington, was by the United States Geological Survey, which established the first gaging stations on the Yakima River in 1893, for the purpose of determining the quantity of water available for irrigation projects in the Yakima Valley.

The Federal Reclamation Act of 1902 provided for the appropriation of receipts from the sale and disposal of public lands in certain

states and territories into a special fund. This money was to be reserved for survey, construction, etc., of irrigation systems for the reclamation of arid lands in those states. Preliminary investigations began in 1903 by the U.S. Reclamation Service on the Okanogan, Yakima, and Palouse projects. Construction of the Sunnyside and Tieton units of the Yakima Project was authorized in 1905.

In 1905 the State legislature passed a law which withdrew from appropriation "all waters of streams which would supply projects under investigation by the Reclamation Service, and reserving water for such projects if they prove feasible." By the same law, State lands were reserved for use in connection with such projects in the event they should be required. Congress in 1924 appropriated the first funds for construction of the Kittitas Unit of the Yakima Project, to reclaim 70,000 acres.

The first State legislature, during the winter of 1889–90, sent a memorial to Congress requesting an appropriation of $50,000 to drill artesian test wells, in Yakima, Klickitat, Douglas, Adams, and Walla Walla Counties, in the hope of finding an adequate water supply for irrigation. This, perhaps the first move on behalf of large-scale irrigation development in the Columbia Basin, correctly predicted things to come:

> * * * And should said wells prove successful, this vast domain which is now but sparsely settled, would in a few years be thickly studded with large fields of grain, with a few thousand orchards bearing nearly every kind of fruit, and many a happy home.

Perhaps the first published proposal to bring water to the lands of the Columbia Basin was made by O. R. Holcomb, the second man in the State to bear the title of "Commissioner of Arid Lands." The report containing his proposal was written in 1898 and printed for the legislature that met the following year.

The report stated that perhaps 1 million acres at least would be valuable with water in the area known as the big desert in Douglas, Lincoln, and Adams Counties. Holcomb thought that the source of water could be Coeur d'Alene Lake or its tributaries, the St. Joe and the St. Mary Rivers.

The U.S. Reclamation Service made an investigation of the project in 1903. Beginning in 1918, the State made surveys and studies of both the gravity and the pumping project. The plan most favorably considered at that time was the gravity system, with water to be diverted from the Pend Oreille River for irrigation of basin lands. In 1934 Congress made available to the U.S. Bureau of Reclamation $63 million for the beginning of construction of Grand Coulee Dam.

The State Water Code was enacted in 1917, giving central authority of the State's water resources to the supervisor of hydraulics. Subsequently this authority has been vested in the Division of Water Resources. The code provided a means of establishing definite water right titles, so necessary for the orderly development and utilization of the State's water resources.

During World War I and the years that immediately followed, farm products brought high prices; consequently, farming and reclamation were stimulated. However, no private capital was available for developing irrigation projects. Those interested in irrigation in the State found it desirable to draft a State reclamation law which would provide funds and legal machinery for further development of irriga-

tion projects. The act was passed by the legislature in 1919 and is known as the State Reclamation Act. The act is administered by the Director of the Department of Conservation through the Division of Reclamation. In addition to financing new projects, the act provided for the refinancing of existing irrigation districts. A great benefit to reclamation in the State came from refinancing 45 irrigation districts which were facing bankruptcy. Bond payments of all districts are current and many have paid several years in advance, reflecting the generally stable condition of the reclamation districts of the State. The State revolving fund account as of June 30, 1964, totaled $3,011,952.49 and included the following assets:

Cash on hand with State treasurer	$1, 097, 328. 79
Bonds on hand with State treasurer	1, 725, 339. 20
Advances to districts (unsecured)	189, 284. 30
Assets	3, 011, 952. 29

Bonds on hand and advances to districts as of the same date are shown in table 37.

TABLE 37.—*Bonds and advances to districts*

BONDS ON HAND

County	District	Par and book value	Interest rate (percent)
Chelan	Beehive Irrigation District	$35, 000. 00	2
Kittitas	Cascade Irrigation District	40, 000. 00	3
Clark	Clark County Drainage Improvement District No. 5	39, 000. 00	3
Do	Clark County Drainage Improvement District No. 11	2, 000. 00	3
Do	Clark County Drainage Improvement District No. 12	2, 000. 00	3
Clallam	Cline Irrigation District	14, 000. 00	1½
Cowlitz	Drainage Improvement District No. 1	55, 000. 00	3
Walla Walla	Gardena Farms Irrigation District No. 13	179, 500. 00	3
Benton	Kennewick Irrigation District	3, 000. 00	3
Okanogan	Methow Valley Irrigation District	40, 000. 00	1
Spokane	Model Irrigation District	14, 400. 00	3
Do	Model Irrigation District No. 18	64, 000. 00	3
Yakima	Naches-Selah Irrigation District	447, 000. 00	3
Do	Naches-Selah Irrigation District, L.I.D. No. 2 P.H	4, 000. 00	3
Klickitat	North Dalles Irrigation District	48, 000. 00	3
Okanogan	Oroville-Tonasket Irrigation District (refunding)	21, 000. 00	1
Do	Oroville-Tonasket Irrigation District	4, 000. 00	1
Douglas	Palisades Irrigation District	40, 500. 00	3
Okanogan	Pateros Irrigation District	8, 800. 00	3
Pierce	Drainage District No. 10	1, 569. 20	3
Skagit	Drainage District No. 19	70, 000. 00	3
Snohomish	Diking District No. 1	7, 000. 00	2
Do	Drainage District No. 6	7, 500. 00	3
Franklin	South Columbia Basin Irrigation District, L.I.D. No. 1	750. 00	3
Spokane	Spokane Valley Irrigation District (refunding)	121, 500. 00	2
Do	Spokane Valley Irrigation District (general)	136, 500. 00	2
Chelan	Stemilt Irrigation District	40, 500 00	1¼
Do	do	38, 000. 00	3
Benton	Sunnyside Irrigation District	36, 500. 00	2
Spokane	Vera Irrigation District	4, 000. 00	3
Whatcom	Drainage Improvement District No. 15	3, 000. 00	3
Do	Drainage Improvement District No. 25	20, 000. 00	3
Klickitat	White Salmon Irrigation District	48, 000. 00	3
Okanogan	Whitestone Reclamation District (Jan. 1, 1949)	19, 250. 00	2
Do	Whitestone Reclamation District (Jan. 1, 1948)	28, 000. 00	2
Do	Wolf Creek Reclamation District (Jan. 1, 1948)	36, 000. 00	1
Do	Wolf Creek Reclamation District (Jan. 1, 1954)	19, 000. 00	3
Yakima	Yakima-Tieton Irrigation District, L.I.D. No. 2	27, 000. 00	3
Total par value		1, 725, 269. 20	
Total book value		1, 725, 339. 20	

TABLE 37.—*Bonds and advances to districts*—Continued

ADVANCES TO DISTRICTS

County	District	Date of contract	Amount due	Interest rate (percent)
Benton	Diking District No. 1	Dec. 31, 1959	$35,541.00	3
Clallam	Cline Irrigation District	Dec. 15, 1961	1,928.50	3
Cowlitz	Consolidated Diking Improvement District No. 3	Aug. 25, 1961	11,165.00	3
Douglas	Greater Wenatchee Irrigation District, L.I.D. No. 1.	Sept. 5, 1962	18,611.28	3
Do	Greater Wenatchee Irrigation District, L.I.D. No. 2.	Apr. 26, 1963	8,034.43	3
Do	Greater Wenatchee Irrigation District, L.I.D. No. 3.	Apr. 26, 1963	2,271.73	3
Do	Greater Wenatchee Irrigation District, L.I.D. No. 4.	Apr. 26, 1963	45,894.74	3
Do	Greater Wenatchee Irrigation District, L.I.D. No. 5.	Nov. 6, 1963	48,368.65	3
Do	Greater Wenatchee Irrigation District, L.I.D. No. 6.	Nov. 6, 1963	10,182.87	3
Snohomish	Diking District No. 2	Mar. 5, 1963	4,350.00	3
Chelan	Wenatchee-Chewawa Irrigation District	July 3, 1956	2,936.10	3
Total			189,284.30	

According to the 1960 U.S. Census of Agriculture and the 1962 Washington Soil and Water Conservation Needs Inventory, every county in the State of Washington had some irrigated cropland and some irrigated pasture. Table 38 shows a county breakdown of the total irrigated land in Washington. East of the Cascades, every county had more irrigated cropland than irrigated pasture. In many of the counties west of the Cascades the reverse is true. Figure 81 shows tne percentage of irrigated land in crops andi n pasture. The circles on the map are proportional to the total acreage of irrigated land.

TABLE 38.—*Irrigated farms and irrigated land in farms, Washington, 1959*

County	Irrigated [1] farms	Irrigated [1] farms as percent of all farms	Total [2] irrigated acres	County	Irrigated [1] farms	Irrigated [1] farms as percent of all farms	Total [2] irrigated acres
Adams	321	40.8	49,400	Lincoln	90	9.4	200
Asotin	187	57.5	3,000	Mason	54	16.5	2,100
Benton	1,141	89.1	66,700	Okanogan	1,401	79.5	40,100
Chelan	1,544	94.4	38,100	Pacific	160	32.1	1,800
Clallam	288	39.8	16,100	Pend Oreille	56	15.3	4,300
Clark	331	11.9	6,000	Pierce	387	15.3	4,100
Columbia	86	25.8	3,500	San Juan	6	2.9	100
Cowlitz	66	6.5	3,000	Skagit	148	8.5	2,700
Douglas	514	55.0	12,100	Skamania	13	7.3	1,000
Ferry	56	19.8	2,800	Snohomish	203	7.0	4,600
Franklin	617	83.2	53,300	Spokane	462	15.5	17,800
Garfield	59	21.5	2,500	Stevens	283	17.6	10,300
Grant	1,283	85.7	183,000	Thurston	255	20.9	5,700
Grays Harbor	170	19.0	5,700	Wahkiakum	16	5.3	500
Island	33	6.7	900	Walla Walla	605	61.7	34,900
Jefferson	29	10.9	1,000	Whatcom	597	18.9	9,000
King	450	15.2	5,700	Whitman	155	8.5	3,100
Kitsap	151	16.7	2,500	Yakima	5,804	96.6	348,100
Kittitas	829	91.6	162,500				
Klickitat	228	30.8	13,500	State total	19,292	37.4	1,123,000
Lewis	214	9.6	1,500				

[1] U.S. Census of Agriculture, 1960.
[2] Estimated as of 1962.

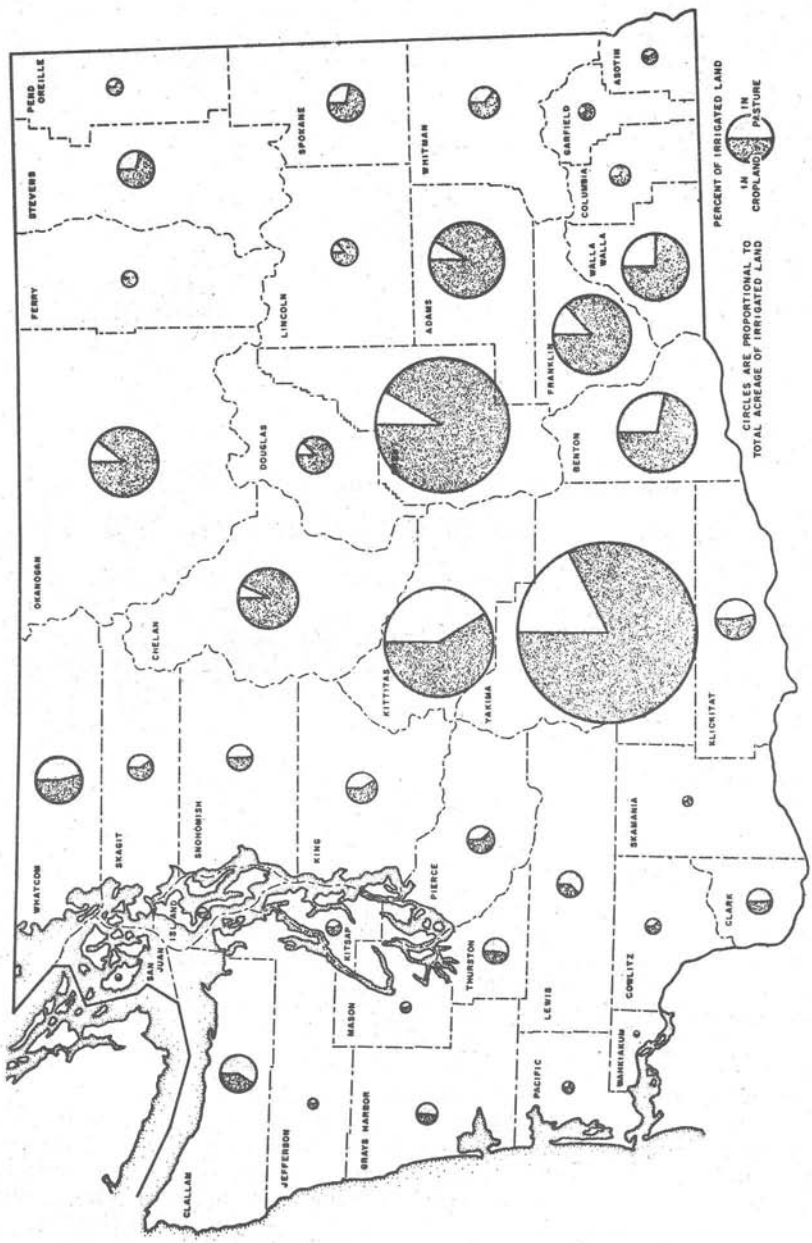

FIGURE 81.—Irrigated cropland and irrigated pasture.

SUBBASIN NO. 1 (PACIFIC COAST)

More than 15 percent of all the farms in this subbasin were termed irrigated farms in the 1960 U.S. Agricultural Census. Much of the irrigated land was devoted to pasture; however, some of the smaller compact areas were associated with berry or vegetable farms. It is estimated that more than 9,000 acres are presently irrigated in this subbasin. With the summer dry season, development of irrigation has steadily increased.

SUBBASIN NO. 2 (PUGET SOUND)

Nearly 15 percent of all farms in the Puget Sound subbasin are irrigated farms. More than 54,000 acreas are irrigated in this subbasin. In northwestern King County lies an area of intensive, irrigated truck farming. In northeastern Clallam County and in the western portion of Whatcom County are relatively large areas of irrigated pasture. These two counties lead all other counties on the west side of the Cascades in total irrigated acreage and in irrigated pasture.

SUBBASIN NO. 3 (UPPER COLUMBIA RIVER)

Forty-eight percent of all farms in the Upper Columbia River subbasin are irrigated farms.

Two divisions of the Chief Joseph Dam Project are presently being irrigated. The Foster Creek Division contains approximately 2,860 acres of land lying along the Columbia River near the town of Brewster in Okanogan County. The Greater Wenatchee Division near the town of Wenatchee in Chelan County contains a total of 7,096 acres in the recently constructed Howard Flat, Brays Landing, and East Units.

Facilities for the Foster Creek Division include pumping plants, equalizing reservoirs, and distribution systems. Irrigation water is pumped from the Columbia River into pipelines for distribution through a pressure-pipe system for sprinkler irrigation. Facilities for the Greater Wenatchee Division include wells, pumping plants, concrete-lined reservoirs, and a distribution system.

Construction has begun on the Oroville-Tonasket Unit of the Okanogan-Similkameen Division, Chief Joseph Dam Project. This unit, located in Okanogan County, encompasses an area about 25 miles long and 3 miles wide, extending from about 4 miles north of the town of Oroville to about 4 miles south of the town of Tonasket. Planned facilities include a diversion dam, a new siphon, auxiliary pumping plants and rehabilitation of the existing main canal.

The Okanogan project is located along the west side of the Okanogan River in Okanogan County. Facilities include Conconully Dam and Reservoir, Salmon Lake Dam and Reservoir, a diversion dam and more than 90 miles of canals and laterals to serve 5,307 acres of land. The functions of irrigation, recreation, and the enhancement of the fishery are served by this project.

Located along the banks of the Spokane River between the city of Spokane, and the Washington-Idaho State boundary is the Spokane Valley Project. A total of 7,240 acres will be provided an irrigation water supply and domestic needs will be provided through a system of wells, pumps, and a distribution network of closed pressure pipe.

The Columbia Basin Project is designed to serve an ultimate area of at least 1,029,000 acres. The primary features of this project are Grand Coulee Dam, Powerplant, and Franklin D. Roosevelt Lake. Construction began in 1933 and the first power was generated in 1941. Other principal irrigation features include the Pumping Plant, Feeder Canal, Banks Lake formed by the North and Dry Falls Dams, the Main, West and East Low Canals, O'Sullivan Dam and Potholes East Canal. Presently irrigated lands of the project lie in Adams, Douglas, Franklin, Grant, Lincoln, and Walla Walla Counties. The functions of irrigation, navigation, power production, flood control, recreation, and fish and wildlife enhancement are served by this project.

Three intensively irrigated areas are located within the Columbia Basin Project. The largest is in the Quincy area, where 40 to 49 percent of the farmland is irrigated. Near Moses Lake and Warden in Grant County is a smaller but even more intensive area where more than 50 percent of the land in farms is irrigated. The third intensive area is located west of Mesa and Connell in Franklin County.

In the eastern portion of Chelan County are three areas of concentrated irrigation development. Other intensively developed irrigation areas are located along the lower Okanogan River and in the Spokane Valley.

SUBBASIN NO. 4 (YAKIMA RIVER)

The foremost percentage leader in irrigated farms in the State is the Yakima River subbasin. Nearly 95 percent of all the farms and more than 577,000 acres of land are irrigated in this subbasin. The Federally developed Yakima Project, one of the oldest and most successful irrigation projects in the United States, is located in the Yakima Valley.

This project provides irrigation water for a strip of fertile land extending 175 miles along both sides of the Yakima River in Benton, Yakima, and Kittitas Counties. Storage dams and reservoirs include Bumping Lake, Clear Creek, Tieton, Cle Elum, Kachess, and Keechelus. Other facilities include 5 diversion dams, more than 2,000 miles of canals, laterals and drains, 30 pumping plants, 2 powerhouses, and 77 miles of transmission lines. Functions served include irrigation, power, recreation, fish and wildlife, and water quality control. Construction of the Tieton and Sunnyside Units of the project began in 1906. The first water for irrigation on project lands was available for the 1907 season.

Yakima County leads all counties in Washington in total acreage of irrigated cropland and pasture. Kittitas County ranks third overall, but has a larger percentage of irrigated pasture than any other county.

In terms of acreage, the most intensive irrigation lies in the Yakima Valley. Largest intensively irrigated area in this valley extends from Union Gap southeastward along both sides of the Yakima River almost to Prosser. In this large area more than 50 percent of the land is irrigated. Another intensively irrigated area in the Lower Valley lies north and east of Prosser. In the Upper Valley, two small areas, the Naches-Selah area and the Ahtanum area, have between 40 and 49 percent of the total farmland irrigated.

SUBBASIN NO. 5 (SNAKE RIVER)

Due largely to the extensive development of dry farming of winter wheat, barley, and dry field and seed peas, only 15 percent of the farms are classified as irrigated farms. In terms of both acreage and value, winter wheat is the most important field crop grown in Washington.

Approximately 9,000 acres are irrigated in this subbasin. The Snake River benchlands in Asotin County support some irrigated orchards. No real intensive development of irrigated agriculture occurs in this subbasin.

SUBBASIN NO. 6 (LOWER COLUMBIA RIVER)

The Lower Columbia River subbasin is unique in that it stretches along the Columbia River from the Pacific Ocean to the Touchet-Walla Walla Valleys; thus areas on both sides of the Cascades are included.

Irrigation is practiced throughout the subbasin, with the most intensively developed areas located in the northwest corner of Klickitat County and in the southern portion of Clark County. According to the 1960 U.S. Census of Agriculture, 21 percent of all farms are classified as irrigated farms. More than 62,000 acres are irrigated in this subbasin.

The foregoing is a brief description of the location of the irrigated lands in each of the six subbasins, with special emphasis on the federally developed reclamation projects. The 1,123,000 acres of presently irrigated land in Washington are located in the six subbasins as follows: Pacific Coast, 9,000 acres; Puget Sound, 54,000 acres; Upper Columbia River, 412,000 acres; Yakima River, 577,000 acres; Snake River, 9,000 acres; and Lower Columbia River, 62,000 acres.

Figure 82 and table 39 present information regarding the major existing irrigation, dam and reservoir developments in the State. To facilitate handling of the data the existing features were grouped according to the six subbasins. The numbers on the map correspond to the numbers on the table. The shaded areas on the map show the location of presently irrigated land.

SOURCE OF IRRIGATION WATER SUPPLY

Existing irrigation developments draw their water supply largely from storage reservoirs and the natural flow of surface streams. Ground-water sources are important locally. Figure 83 indicates the location and relative magnitude of the utilization of both sources of water supply for irrigation.

The Division of Water Resources, Department of Conservation, State of Washington, reported in June 1964 that a total of 18,586 applications for surface water permit and 7,231 applications for ground-water permit had been received and processed since the year 1917. Of these totals, 9,086 surface water filings and 4,848 ground-water applications had been perfected to certificates of water right. The report also noted that although the beneficial uses to which the waters of the State are applied are numerous, power generation, irrigation, and municipal and industrial uses constitute the major demand

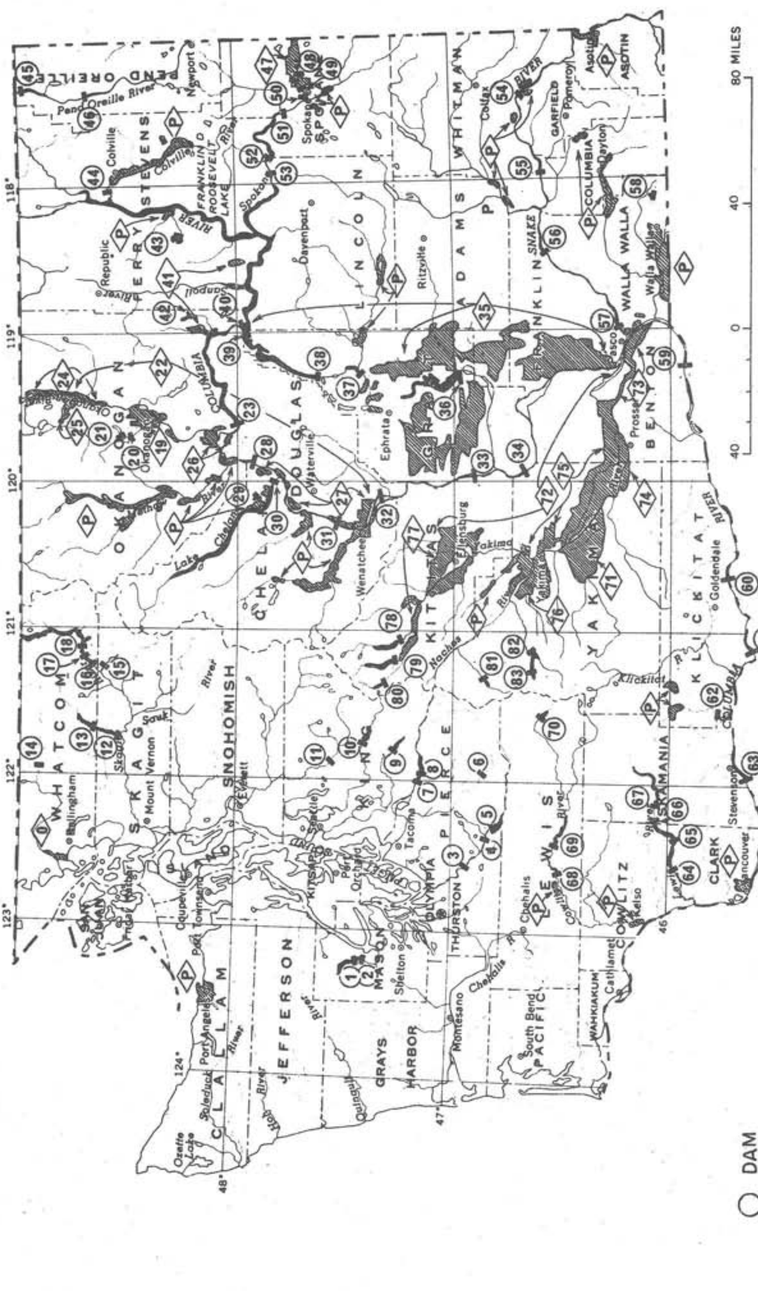

FIGURE 82.—Major existing irrigation, dam and reservoir developments. (Numbers refer to localities listed on table 39.)

TABLE 39.—*Major existing irrigation, dam and reservoir developments*

Subbasin	Index No. on fig. 82	Name	Principal feature	Stream	Gross storage (acre-feet)	Irrigated land (acres)	Developed by—[1]	Year completed	Project purpose [2]	Remarks
Pacific Coast						9,000	Private			No major dams or irrigation projects exist in this basin. All existing irrigation is by private means.
Puget Sound	0	Lummi Indian	Irrigation	Nooksack		1,000	U.S.B.I.A.		I	
	1	Cushman No. 1	Dam, reservoir, and powerplant	North Fork Skokomish	453,350		City of Tacoma	1926	P	
	2	Cushman No. 2	do	do	8,000		do	1930	P	Formerly Potlatch.
	3	Yelm	Dam and powerplant	Nisqually	Pondage		City of Centralia	1930	P	
	4	La Grande	do	do	2,700		City of Tacoma	1944	P	
	5	Alder	Dam, reservoir, and powerplant	do	201,800		do	1945	P	
	6	Electron	Dam and powerplant	Puyallup	Pondage		P.S.P.L.	1904	P	
	7	White River	Dam, reservoir, and powerplant	White	44,140		P.S.P.L.	1912	P	
	8	Mud Mountain	Dam and reservoir	do	106,000		U.S.C.E.	1949	F, C	Formerly Stevens.
	9	Howard A. Hanson	do	Green	106,000		U.S.C.E.	1962	F, C	Formerly Eagle Gorge.
	10	Cedar Falls	Dam, reservoir, and powerplant	Cedar	110,000		City of Seattle	1915	P, M	Forms Morse Lake.
	11	Snoqualmie Falls	Dam and powerplants	Snoqualmie	Pondage		P.S.P.L.	1910	P	2 powerplants.
	12	Lower Baker	Dam, reservoir, and powerplant	Baker	130,000		P.S.P.L.	1925	P	Forms Lake Shannon.
	13	Upper Baker	do	do	285,470		P.S.P.L.	1959	P	Natural lake dammed.
	14	Nooksack	Dam and powerplant	Nooksack	Pondage		P.S.P.L.	1906	P	
	15	Newhalem	do	Newhalem	Pondage		City of Seattle	1921	P	Reregulating reservoir.
	16	Gorge	Dam, reservoir, and powerplant	Skagit	9,000		do	1924	P	Forms Gorge Lake.
	17	Diablo	do	do	90,000		do	1930	P	
	18	Ross	do	do	1,405,000		do	1949	P, FC, M	Forms Ross Lake.
Upper Columbia	19	Okanogan	Irrigation	Salmon Creek		4,133	U.S.B.R.		Multipurpose	
	20	Conconully	Dam and reservoir	do	13,000		U.S.B.R.	1910	I	
	21	Salmon Lake	Dam and offstream storage	do	22,500		U.S.B.R.	1921	I	
	22	Chief Joseph Dam Project	Irrigation	Columbia and Okanogan		18,970	U.S.B.R.		Multipurpose	
	23	Chief Joseph	Dam, reservoir, and powerplant	Columbia	480,000		U.S.C.E.	1955	P, I	Forms Rufus Woods Lake.
	24	Oroville-Tonasket Unit	Irrigation	Okanogan		7,150	U.S.B.R.	[3]	I	
	25	Whitestone-Coulee Unit	Spectacle Lake Dam and Reservoir	Sinlahekin	3,900	1,955	Whitestone Irrigation District	1924	I	
	26	Foster Creek Division	Irrigation	Columbia and Okanogan		2,855	U.S.B.R.		I	Lands are served by pumping from the Columbia River.
	27	Greater Wenatchee Division	do	Columbia		7,010	U.S.B.R.		I	
	28	Wells	Dam, reservoir, and powerplant	do	931,000		Douglas County P.U.D.	[3]	P	
	29	Antilon	Dam and reservoir	Antilon Creek	1,600	N.A.	Lake Chelan Irrigation District	1941	I	2 dams, 1 at each end on Antilon Lake.
	30	Chelan	Dam, reservoir, and powerplant	Chelan	676,100		Chelan County P.U.D.	1928	P, R	Natural lake dammed.
	31	Rocky Reach	do	Columbia	390,000		do	1962	P	
	32	Rock Island	Dam and powerplant	do	4,550		do	1953	P	
	33	Wanapum	Dam, reservoir, and powerplant	do	600,000		Grant County P.U.D. No. 2	1963	P, FC, R	
	34	Priest Rapids	do	do	200,000		do	1959	P, FC, R, N	
	35	Columbia Basin	Irrigation	do		483,219	U.S.B.R.		Multipurpose	Ultimately will serve 1,029,000 acres.
	36	O'Sullivan Dam	Dam and potholes reservoir	Offstream	675,000		U.S.B.R.	1949	I, R, FC	Forms Potholes Reservoir.
	37	Long Lake	Dam and Reservoir	Long Lake	62,700		U.S.B.R.	1948	I, FC	Fills Long Lake Coulee.
	38	Dry Falls	Dam, forms Banks Lake	Offstream	1,275,000		U.S.B.R.	1949	I, R	
	39	North	do	do			U.S.B.R.	1951	I, R	
	40	Grand Coulee	Dam, reservoir, powerplant, and pumping plant	Columbia	9,402,000		U.S.B.R.	1942	P, I, N, FC, M	Forms F. D. Roosevelt Lake.
	41	Colville Indians	Irrigation	Nespelem		500	U.S.B.I.A.		I	
	42	Owhi	Dam and reservoir	Little Nespelem	5,250		U.S.B.I.A.	1916	I	Serves also as a broodstock lake.
	43	Twin Lakes	do	Stranger Creek	15,125		U.S.B.I.A.	1930	I	Natural lake dammed.
	44	Meyers Falls	Dam and powerplant	Colville	Pondage		W.W.P.	1915	P	
	45	Boundary	do	Pend Oreille	Pondage		City of Seattle	[3]	P	
	46	Box Canyon	do	do	Pondage		Pend Oreille County P.U.D.	1955	P	
	47	Spokane Valley	Irrigation	Wells		6,792	U.S.B.R.	[3]	I, M	Ground water supply.
	48	Spokane	Dam and powerplant	Spokane	Pondage		City of Spokane	1937	P	
	49	Upper Falls	do	do	Pondage		W.W.P.	1922	P	
	50	Monroe Street	do	do	Pondage		W.W.P.	1903	P	Reregulating reservoir.
	51	Nine Mile	do	do	5,800		W.W.P.	1908	P	
	52	Long Lake	do	do	105,000		W.W.P.	1914	P	
	53	Little Falls	do	do	4,250		W.W.P.	1909	P	
Snake River	54	Lower Granite	Dam, reservoir, and powerplant	Snake	285,000		U.S.C.E.	[3]	P, N, I	
	55	Little Goose	do	do	460,000		U.S.C.E.	[3]	P, N, I, FC	
	56	Lower Monumental	do	do	247,000		U.S.C.E.	[3]	P, N, FC	
	57	Ice Harbor	do	do	417,000		U.S.C.E.	1961	P, I, N, FC	
Lower Columbia	58	Mill Creek	Dam and reservoir	Mill Creek	6,700		U.S.C.E.	1942	FC	Offstream storage.
	59	McNary	Dam, reservoir, and powerplant	Columbia	1,345,000		U.S.C.E.	1957	P, N, I, FC	Forms Wallula Lake.
	60	John Day	do	do	2,500,000		U.S.C.E.	[3]	P, FC, N	
	61	The Dalles	do	do	330,000		U.S.C.E.	1957	P, N, R	
	62	Condit	Dam and powerplant	White Salmon	1,100		P.P.L.	1913	P	Forms Northwest Lake.
	63	Bonneville	Dam, reservoir, and powerplant	Columbia	537,000		U.S.C.E.	1943	P, N, R	
	64	Merwin	do	Lewis	650,200		P.P.L.	1931	P	Forms Lake Merwin.
	65	Yale	do	do	590,300		P.P.L.	1953	P	Forms Yale Lake.
	66	Swift No. 2	Dam and powerplant	do	Pondage		Cowlitz County P.U.D.	1958	P	
	67	Swift No. 1	Dam, reservoir, and powerplant	do	1,190,000		P.P.L.	1958	P	
	68	Mayfield	Dam and powerplant	Cowlitz	127,000		City of Tacoma	1962	P, FC	
	69	Mossyrock	Dam, reservoir, and powerplant	do	1,371,900		do	[3]	P, FC	
	70	Packwood	do	LakeCreek	3,500		Lewis County P.U.D.	1964	P	
Yakima	71	Wapato	Irrigation	Yakima		136,000	U.S.B.I.A.	1907	I	Operated by Indians, receives water from Yakima Project.
	72	Yakima	do	do	1,070,700	475,000	U.S.B.R.			This project has 7 divisions, other project features include 5 diversion dams, 436 miles of canals, 1,580 miles of laterals and drains, 30 pumping plants, 2 powerplants, and 77 miles of transmission lines.
	73	Kennewick Division	Chandler diversion dam	do		19,171	U.S.B.R.	1956	P, I	
	74	Sunnyside Division	Sunnyside diversion dam	do		103,300	U.S.B.R.	1907	I	
	75	Roza Division	Roza diversion dam	do		72,730	U.S.B.R.	1940	P, I	
	76	Tieton Division	Tieton diversion dam	Tieton	2,200	27,300	U.S.B.R.	1907	I	
	77	Kittitas Division	Easton diversion dam	Yakima	1,320	57,400	U.S.B.R.	1929	I	
	78	Cle Elum	Dam and reservoir	Cle Elum	529,008		U.S.B.R.	1933	I, R	Part of storage division.
	79	Kachess	do	Kachess	239,000		U.S.B.R.	1912	I, R	Forms Lake Kachess, part of storage division.
	80	Keechelus	do	Yakima	170,500		U.S.B.R.	1917	I, R	Part of storage division.
	81	Bumping Lake	do	Bumping	37,300		U.S.B.R.	1910	I, R	Do.
	82	Tieton	Dam and Rimrock Lake	Tieton	198,000		U.S.B.R.	1925	I, R	Forms Rimrock Lake, part of storage division.
	83	Clear Creek	Dam and reservoir	do	5,300		U.S.B.R.	1914	I	Part of storage division.

[1] Abbreviations are as follows:
U.S.B.I.A.=Bureau of Indian Affairs.
U.S.B.R.=Bureau of Reclamation.
U.S.C.E.=Corps of Engineers.
P.S.P.L.=Puget Sound Power & Light.
W.W.P.=Washington Water Power.
P.P.L.=Pacific Power & Light.

[2] I=Irrigation.
P=Power.
M=Municipal.
R=Recreation.
FC=Flood control.
N=Navigation.

[3] Under construction.

FIGURE 83.—Source of irrigation water supply.

upon the rivers and streams; whereas withdrawals for municipal and industrial and irrigation purposes constitute the major draft on ground-water resources.

The number of applications processed annually for both sources of water supply are shown on figure 84.

Since the adoption of the State Water Code on June 7, 1917, 57 streams have been adjudicated. Many of these adjudications encompassed only a portion of a particular stream, rather than its entire drainage area. Present State policy is to include the complete drainage area of a stream in the adjudication proceedings.

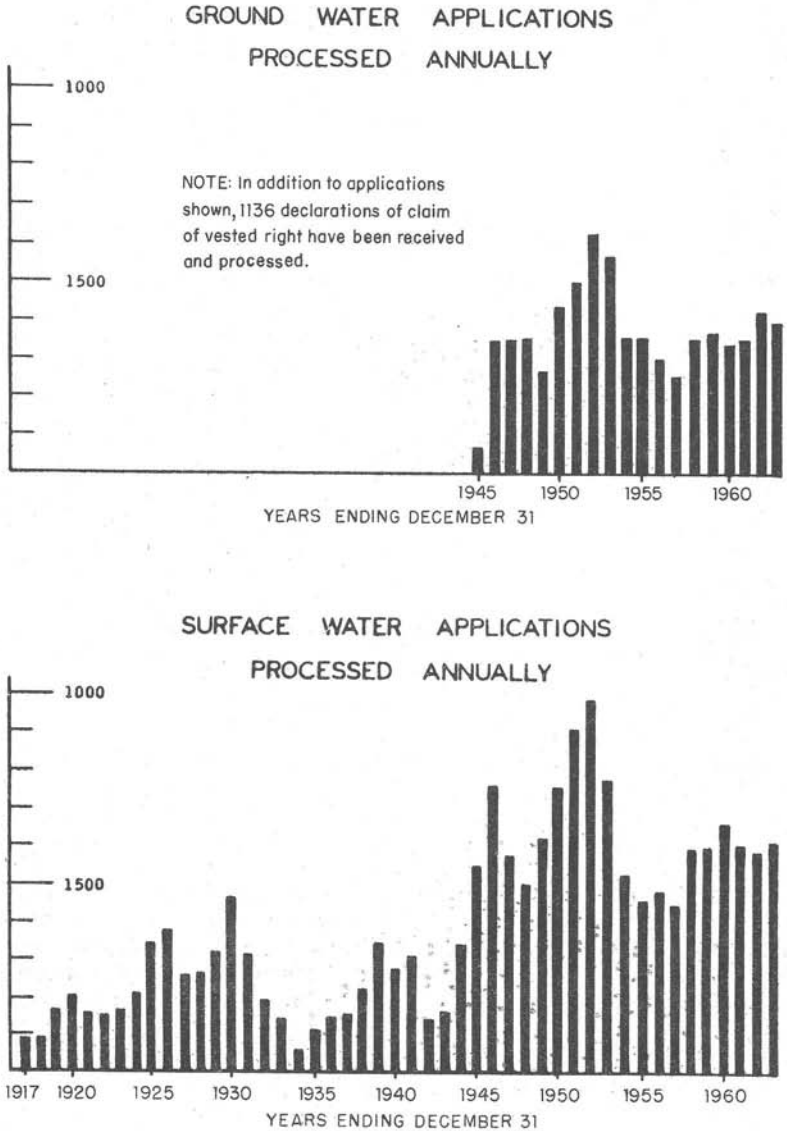

FIGURE 84.—Ground and surface water permit applications.

FLOOD CONTROL AND NAVIGATION

In 1935 the State of Washington accepted certain responsibilities for and declared its intent to exercise its police powers over matters of flood control. In "Chapter 159: Laws of 1935," the Washington legislature stated:

> * * * the prevention and alleviation of flood damages is a matter of public concern as affecting the health, safety, and general welfare of the State, and therefore the State assumes full regulatory control over all waters in the State, subject to Federal control of navigation, necessary to accomplish the purposes of this chapter.

Through a series of legislative enactments the Division of Flood Control and the office of Supervisor of Flood Control were created within the Department of Conservation. The supervisor is charged, for the State, with the administration and enforcement of all laws relating to flood control.

During 1935, the year of the flood control zone law enactment, 16 zones were established on as many of the State's major rivers, and within these zones no structures or works may be erected without first obtaining a permit from this division.

The State flood control maintenance policy was established by the 1941 Washington legislature. It provides that when funds have been appropriated, the State may participate with corporate municipalities, agencies of the United States and State institutions in such flood control construction, maintenance and betterment projects as affect general public and State interests, as differentiated from private interests. During the 21-year period 1943–64 the State legislature has regularly appropriated matching funds for the State flood control participation program. A summary of the State's participation expenditures is given in table 40.

Existing flood control and navigation projects of the U.S. Army Corps of Engineers are set forth by that agency in its report "Water Resources Development" by the U.S. Army Corps of Engineers, Washington, January 1963. Locations of the Corps projects are shown on figure 85, and a summary is listed in table 41.

In addition to the regular activities of the Division of Flood Control as provided for by statute, the division, by designation of the Governor in 1954, is charged with administration of Public Law 566, as amended, Watershed Protection and Food Prevention Act, 1954, 83d Congress, on behalf of the State of Washington.

During the 10 years the Small Watershed Program has been in operation in Washington State, 40 applications have been approved by the Director of Conservation. Fourteen of the applications have been assigned priorities for preliminary work plan preparation. Six projects have been authorized for construction, three projects are under construction, and two projects have been completed. A complete summary of Public Law 566 status and progress is shown in table 42.

The 1939 Soil Conservation District Enabling Act provided for the voluntary formation of nontaxing soil conservation districts wherever needed and desired by the local people. The declared policy of the legislature was to provide for the conservation of the soil and water resources of the State, and for the control and prevention of soil erosion, and thereby to preserve natural resources, control floods, prevent impairment of dams and reservoirs, assist in maintaining the

TABLE 40.—*Summary of State flood control participation program, Apr. 1, 1943, to June 30, 1964*

County	Apr. 1, 1943, to Mar. 31, 1953	Apr. 1, 1953, to June 30, 1955	July 1, 1955, to June 30, 1957	July 1, 1957, to June 30, 1959	July 1, 1959, to June 30, 1961	July 1, 1961, to June 30, 1963	July 1, 1963, to June 30, 1964 [1]	Totals
Adams								
Asotin								
Benton						$4,500.00	$1,200.00	$5,700.00
Chelan	$27,182.34	$1,507.16	$3,701.88					32,391.33
Clallam	32,875.53		4,829.28	$47,318.66	$2,527.36	6,520.82	12,329.38	106,401.08
Clark	13,275.64	19,041.02	13,211.88	16,209.18	17,088.93	20,205.54	28,397.60	127,429.79
Columbia	83,119.32		1,367.64				892.50	85,379.46
Cowlitz	296,603.23	69,529.91	48,121.37	72,427.72	11,194.56	2,441.59		500,318.38
Douglas	6,065.60							6,065.60
Ferry			5,397.74					5,397.74
Franklin			3,812.51	5,170.82	1,513.24			10,496.57
Garfield								
Grant	1,953.06			22,970.31	640.00	2,425.51	1,011.51	29,000.39
Grays Harbor	116,702.32	23,242.68	7,242.60	16,447.70	9,534.69		793.40	173,963.39
Inter-County (King-Pierce)	120,874.89	49,589.99	27,770.88	54,665.66	20,125.50	20,206.22	11,529.85	304,762.99
Island								
Jefferson	22,009.12	3,000.13	9,205.73	8,194.00				42,408.98
King	587,982.13	13,685.03	43,627.29		134,838.95	106,184.72	28,464.00	914,782.12
Kitsap	2,134.75							2,134.75
Kittitas	58,754.59	3,592.57	18,299.72	3,794.90	6,080.67			90,552.45
Klickitat		1,196.90				7,371.71	14,421.34	22,989.95
Lewis	101,370.99	2,050.53	5,458.10		7,702.70		1,999.92	118,582.24
Lincoln	13,694.90	7,544.79		3,003.52		9,200.00		33,443.21
Mason	9,026.49	10,108.60				2,662.40		21,797.49
Okanogan	150,508.40		21,128.44	11,185.42	2,670.88	4,546.06		190,089.20
Pacific	17,028.16	7,000.00	2,201.07		47,694.41	10,316.59	1,324.00	85,564.23
Pend Oreille	1,677.60							1,677.60
Pierce	262,282.85	76,979.82	55,389.81	130,999.19	45,995.37	50,538.63	25,180.05	647,365.72
San Juan			1,239.80			3,702.13	4,000.00	8,941.93
Skagit	383,159.75	101,969.94	129,931.48	185,317.45	60,129.03	71,176.53	82,190.26	1,013,874.44
Skamania								
Snohomish	406,378.90	32,601.06	29,448.70	90,708.06	268,731.85	276,040.58	35,121.58	1,139,030.73
Spokane	6,474.70	411.12		40,181.90				47,067.72
Stevens	35,780.05	1,440.00						37,220.05
Thurston	7,081.01							7,081.01
Wahkiakum	53,242.20	25,519.98	20,308.85	14,229.52	4,894.00	7,380.82	2,903.53	128,478.90
Walla Walla	43,812.99	24,419.59			10,786.41	12,665.43		91,684.42
Whatcom	342,432.48	31,479.21	25,736.41	52,350.71	36,334.94	61,827.77	9,726.24	559,887.76
Whitman	62,705.43	3,275.58					40,300.00	106,281.01
Yakima	26,144.45	1,509.40	6,406.09	6,688.26		10,873.59		51,621.79
State funds allotted	4,090,000.00	562,500.00	600,000.00	850,000.00	700,000.00	710,000.00	354,000.00	7,866,500.00
State funds expended	3,292,333.87	510,695.01	483,837.22	781,862.98	688,483.49	690,786.64	301,785.16	[2] 6,749,784.37
Total project costs	5,599,237.00	1,280,343.00	1,221,619.00	1,840,435.00	1,607,136.00	4,471,807.00	6,274,824.00	[3] 22,295,401.00
Total number of projects	717	181	136	184	145	133	72	1,568

[1] Expended or committed.
[2] $1,500,000 for Howard A. Hanson Dam not included.
[3] $42,000,000 for Howard A. Hanson Dam not included.

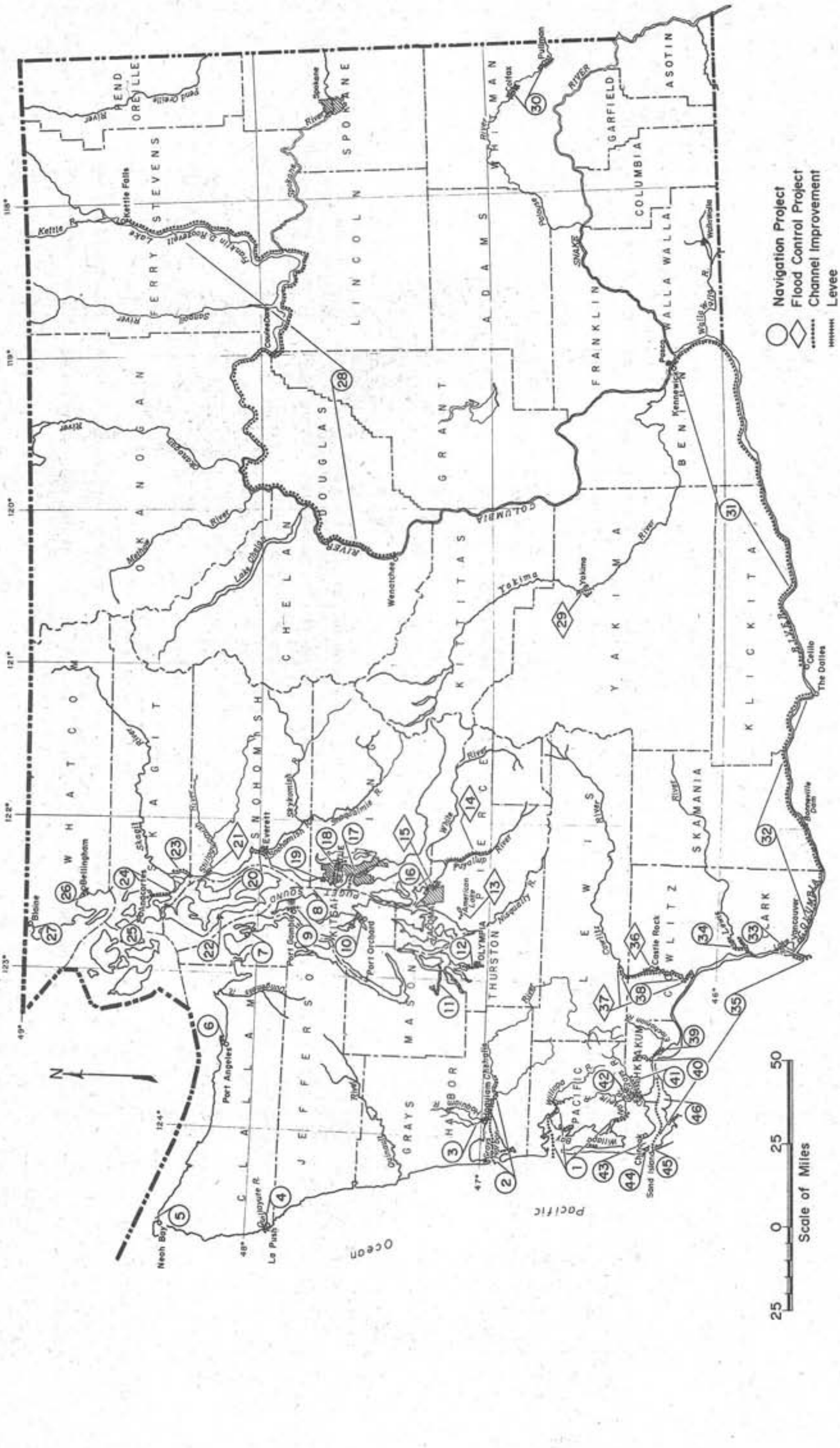

FIGURE 85.—Existing navigation and flood control developments. (Numbers refer to projects listed in table 41.)

TABLE 41.—*Existing navigation and flood control projects other than storage*

Subbasin	Index No.	Name	Principal features	Year completed	Remarks
Pacific coast	1	Willapa River and Harbor	Channels, dikes, mooring and turning basins, and breakwaters.	1958	507,673 average annual tonnage transported.
	2	Grays Harbor and Chehalis River	Channels, turning basins, jetties, and breakwaters.	1959	1,846,074 average annual tonnage transported.
	3	Hoquiam River	Navigation channel	1933	556,058 average annual tonnage transported.
	4	Quillayute River	Channel, jetty, dike, and boat basin	1960	1,333 average annual tonnage transported.
	5	Neah Bay	Rubblestone breakwater and rock revetment	1956	167,461 average annual tonnage transported.
Puget Sound	6	Port Angeles Harbor	Boat mooring basin and breakwaters	1959	1,987,722 average annual tonnage transported.
	7	Oak Bay Canal	Canal, jetties, and bulkhead connects Oak Bay to Port Townsend Bay.	1915	457,285 average annual tonnage transported.
	8	Puget Sound and tributary waters	Snag boat—maintenance of Puget Sound and tributary waters.	------	Boat removes hazards to navigation.
	9	Port Gamble	Navigation channel	1920	293,704 average annual tonnage transported.
	10	Port Orchard Bay	Removal of a shoal to provide better access	1928	
	11	Hammersley Inlet	Navigation channel	1912	1,046,917 average annual tonnage transported.
	12	Olympia Harbor	Channel and turning basin	1939	Project is 85 percent complete, remainder inactive.
	13	American Lake	Open channel and concrete pipe	1957	Alleviates perimeter flooding.
	14	Upper Puyallup River	Bank protection upstream from Puyallup	1936	Completed as a WPA project.
	15	Tacoma, Puyallup River	Flood control levees and channel	1950	Built in conjunction with Mud Mountain Dam.
	16	Tacoma Harbor	Channels, waterways, training walls, and turning basins.	1956	4,893,762 average annual tonnage transported.
	17	Seattle Harbor	Waterways and turning basins	1931	USCE is responsible for maintenance.
	18	Lake Washington ship canal	Canal locks	1934	1,850,226 average annual tonnage transported.
	19	Shilshole Bay	Small boat basin and breakwater	1961	One of largest West Coast small-boat basins.
	20	Everett Harbor and Snohomish River	Training dikes, settling basins, and channels	1963	3,067,056 average annual tonnage transported.
	21	Stillaguamish River	Bank revetment, cutoff channels, and control weir.	1939	Reduced bank erosion and limited channel changes.
	22	Lake Crockett	Harbor, entrance channel and breakwater	1948	Repairs made in early 1960's.
	23	Skagit River	Complete works, including sills, closing dikes, and training dike.	1911	Project is 46 percent complete, remainder inactive.
	24	Swinomish Channel	Dredging and diking	1938	545,666 average annual tonnage transported.
	25	Anacortes Harbor	Channel, mooring basin, and breakwaters	1957	3,277,750 average annual tonnage transported.
	26	Bellingham Harbor	Dredging channels, small-boat basin, and breakwaters.	1961	1,553,509 average annual tonnage transported.
	27	Blaine Harbor	Improvement and extension of existing breakwater and boat basin.	1957	24,428 average annual tonnage transported.
Upper Columbia River	28	Columbia Rivers, Wenatchee to Kettle Falls.	Rock removal and dredging	1917	4 dams have created a 242-mile-long channel.
Yakima River	29	Yakima River	A system of levees, drainage and control structures.	1948	Protects city of Yakima and lands along river.
Snake River	30	Palouse River, Colfax and Pullman	Concrete lining of channels, levees, floodwalls, and rock revetments.	1963	Colfax work completed; Pullman work not started.

Lower Columbia River	31	Columbia River, Celilo Falls to Kennewick.	Channel improvements	1938	113 miles of slack water created by 2 dams.
	32	Columbia River, Vancouver to The Dalles.	Channels, turning and boat basins, and breakwaters.	1962	97 percent complete in 1962.
	33	Lake River	Channel 3 miles long	1931	21,947 average annual tonnage transported.
	34	Lewis River	Navigation channels, dredging and regulating works.	1927	47,007 average annual tonnage transported.
	35	Columbia and Lower Willamette Rivers.	Navigation channels, turning basins, side channels, and dikes.	1950	20,355,639 average annual tonnage transported.
	36	Castle Rock, Cowlitz River	Raising and strengthening existing levee	1956	Protects city of Castle Rock.
	37	Lower Cowlitz River	Channel clearing, channel improvement, and revetment.	1961	Protects Toledo, Castle Rock, Lexington, and Kelso.
	38	Cowlitz River	Navigation channel from Columbia River to Toledo, Wash.	1913	Maintained only to Castle Rock.
	39	Elochowen Slough	Navigation channel and turning basin	1939	198,087 average annual tonnage transported.
	40	Skamokawa Creek	Boat channel	1920	27,258 average annual tonnage transported.
	41	Grays River	Channel clearing and removal of overhanging trees.	1909	29,281 average annual tonnage transported.
	42	Deep River	Navigation channel	1928	404,606 average annual tonnage transported.
	43	Columbia River, Chinook to Sand Island.	Navigation channel, breakwater, turning and mooring basins.	1958	20,355,639 average annual tonnage transported.
	44	Columbia River, at Baker Bay	Navigation channel, mooring basin, and breakwaters.	1957	17,737 average annual tonnage transported.
	45	Columbia River at mouth	Navigation channels, jetties, and dikes	[1]	Repairs and new construction are underway.
	46	Lower Columbia River flood control	Levees, dikes, pumping plants, tide boxes, and drainage systems.	[1]	Repairs and improvements to alleviate floods.

[1] Under construction.

navigability of rivers and harbors, preserve wildlife, protect the tax base, protect public lands, and protect and promote the health, safety, and general welfare of the people of this State.

A soil and water conservation district is unique among the various divisions and subdivisions of State government. It is authorized to carry out any and all necessary functions to assist farmers and landowners in applying soil and water conservation practices on the lands of the State so long as it (1) does not levy taxes, (2) does not condemn property, (3) does not indebt the people of the district, and (4) does not impose compulsory land-use regulations.

During the last 24 years, the soil and water conservation districts have worked to reduce wasteful land management practices, erosion, flood threats, and water depletion in the State. Since the formation of the first district in 1940, many permanent conservation practices have been accomplished, including 61,900 acres of strip-cropping, 3,066 stock ponds, 226 miles of terraces, 33,040 acres of grassed waterways, 120,339 acres of wildlife habitat developments, 12,409 sprinkler irrigation systems, 554 irrigation storage reservoirs, 4,587 miles of open drains, 498,093 acres of pasture plantings, and 70,151 acres of range seeding.

RECREATION

Washington has a variety of recreation resources, including the Olympic and Cascade Mountains, the Columbia River, and 2,846 miles of tidal shoreline along the Pacific Ocean, Strait of Juan de Fuca, and Puget Sound. The two principal mountain ranges offer hiking, camping, fishing, and hunting activities. Five snow-capped volcanic peaks ranging in elevation from 9,671 to 14,410 feet, together with many lesser peaks, provide outstanding scenery, winter sports, and mountaineering. The ocean beaches provide clamming, fishing, and swimming; Puget Sound, the Strait of Juan de Fuca, and several other salt-river bays and waterways provide boating, swimming, fishing, camping, and picnicking opportunities. Chinook Point and San Juan Island possess exceptional value in commemorating the history of the United States.

There are over 23 million acres of forest lands and hundreds of mountain lakes and streams which offer excellent opportunities for camping, fishing, hiking, and picnicking. Many salt-and-fresh-water marshes, cultivated fields, and wheatlands furnish waterfowl and upland-bird hunting.

Recreation ranks fourth in economic importance and in 1960 recreation activities contributed an estimated $428 million to the economy of the State.

National.—Two national parks, two national historic sites, and one national recreation area, having a total of 1,228,750 acres, are located within the State. More than 9,500,000 acres are contained in nine national forests. These national forests provide access for numerous recreation activities, including winter sports. A wilderness area, two wild areas, and one primitive area are also located in the forests of Washington. The State's section of the Pacific Crest Trail is in the national forests. Reservoirs developed by the Corps of Engineers and the Bureau of Reclamation provide many water-oriented

TABLE 42.—*Status of watershed planning and operations, Public Law 566 projects, State of Washington*

Watershed	Area [1]	County	Application [2]		Field examination, preliminary investigation, or reconnaissance survey completed [3]	Work plan development		Operations		Additional notes on progress
			Made	Approved		Authorization	Status	Authorization	Status	
Ahtanum Creek	107.2	Yakima	July 22, 1958							Study being made by Bureau of Reclamation.
Bacon Tr. Irrigation District	.2	Spokane	Feb. 2, 1962	Mar. 30, 1962	PI Aug. 9, 1962					Qualified under Small Reclamation Projects Act of 1956.
Black River	87.7	Thurston	Dec. 20, 1957	Jan. 24, 1958						Pending preliminary investigation.
Rockemuehl Canyon	67.5	Lincoln	July 11, 1962	Sept. 10, 1962						Do.
Calispel-Trimble	99.5	Stevens and Pend Oreille	Nov. 26, 1956	Dec. 17, 1956	FE July 28, 1955					Army Engineers report not feasible under Public Law 685. SCS action now pending sponsor's decision.
Burntbridge Creek	18.6	Clark	Dec. 17, 1962	Mar. 26, 1963						
Chewelah Creek	67.5	Stevens	Sept. 17, 1957	Jan. 24, 1958						Awaiting local action.
Chimicum Creek	25.0	Jefferson	Dec. 14, 1954	Mar. 29, 1955	FE Mar. 3, 1955	Aug. 25, 1955	Completed	Mar. 20, 1957	Inactive	Do.
Church Creek	7.7	Snohomish	Sept. 26, 1957	Jan. 24, 1958						Area included in Army Engineers' Stilliguamish River study.
Cowiche Creek	83.5	Yakima	May 21, 1963 [4]	July 29, 1963	PI begun					
Douglas Creek and Lower Moses Coulee.	183.6	Douglas and Grant	July 13, 1962	Sept. 10, 1962	FE Feb. 16, 1955					Preliminary feasibility study made in December 1963.
French Creek	18.4	Snohomish	Sept. 8, 1955	Jan. 3, 1956	FE Feb. 8, 1956	Mar. 21, 1956	Completed	Aug. 7, 1959	Underway	
Green River, east and lower	87.5	King	May 11, 1964 [5]	June 19, 1964	PI Aug. 29, 1961	Sept. 25, 1961	Active			
Green River, west side	68.9	do	do. [5]	do	do	do	do			
Grayland	6.7	Grays Harbor and Pacific	Jan. 10, 1955	Mar. 29, 1955	FE June 9, 1955	Jan. 18, 1956	Abeyance			Pending acceptance of tentative work plan.
Grays River	96.5	Wahkiakum and Pacific	Feb. 8, 1963	Feb. 10, 1964						
Klickitat Creek	174.5	Klickitat	May 11, 1959 [6]	June 1, 1959	FE Aug. 26, 1955					
Lacamas Creek tributaries	14.0	Clark	Jan. 19, 1955	Mar. 29, 1955	FE Apr. 8, 1955	Apr. 28, 1955	Completed	Aug. 23, 1957	Underway	
Lexington	2.5	Cowlitz	May 25, 1956	July 12, 1956	FE May 1, 1957					
Little Pend Oreille	117.6	Stevens and Pend Oreille	Sept. 24, 1957	Jan. 24, 1958	PI begun					Damsite report submitted to sponsors.
Locke	2.5	Pend Oreille	June 5, 1962	Sept. 10, 1962	PI underway	June 29, 1964				Studies underway for feasibility.
Long Beach Peninsula [7]	58.3	Pacific	Feb. 9, 1962	Mar. 30, 1962	PI begun					
Lynden	24.8	Whatcom and British Colombia	June 3, 1958	Jan. 19, 1959	do					RS shows feasibility; pending PI.
Manastash-Taneum	128.0	Kittitas	Oct. 8, 1956	Oct. 15, 1956	FE Feb. 20, 1958					PI pending.
Marshland	14.0	Snohomish	Feb. 15, 1955	Jan. 3, 1956	FE July 19, 1955	Mar. 21, 1956	Completed	Aug. 7, 1959	Underway	
Mill Creek	97.3	Stevens	Apr. 12, 1955	Sept. 20, 1955	PI begun					Damsite reconnaissance completed.
Ohop Creek	28.5	Pierce	Jan. 28, 1955	Mar. 29, 1955	FE Dec. 14, 1954					Lack local interest to date.
Saar Creek	11.2	Whatcom	Dec. 16, 1954	do	FE Jan. 5, 1955	Apr. 15, 1955	Completed	Feb. 14, 1957	Completed	Completed in 1959. Cost of structure, $125,310.
Silver Lake	28.6	Cowlitz	Jan. 13, 1964	Feb. 10, 1964	PI begun					
Skokomish River	164.0	Mason	May 10, 1957	May 28, 1957	PI June 30, 1959	July 28, 1959	Active			
Palouse River, South Fork	52.5	Whitman (+45 Idaho)	Jan. 10, 1956	Mar. 20, 1956	FE Jan. 21, 1957					Awaiting local decisions. Possibly included in Army Engineers project.
Swale Creek	58.2	Klickitat	Dec. 27, 1954	May 1, 1955	FE Aug. 8, 1955					Progress pending local interest.
Toats Coulee	92.1	Okanogan	Dec. 28, 1954	June 6, 1955	FE Sept. 28, 1956					Area included in Bureau of Reclamation project. Pending local interest.
Twin Buttes	4.3	Klickitat	Feb. 19, 1959	Apr. 1, 1959	FE Aug. 26, 1955	June 2, 1959	Completed	July 20, 1959	Completed	
Upper Coulee	234.6	Douglas and Grant	July 13, 1962	Sept. 10, 1962						If feasible, to be planned with Lower Moses Coulee.
Wenas Creek	138.0	Yakima	Dec. 21, 1954	Apr. 1, 1956	FE Nov. 1, 1956					Pending PI.
Willapa River	43.6	Pacific	Apr. 18, 1960	June 1, 1960	FE Sept. 15, 1960					At request of ARA, Bureau of Reclamation began study December 1962 on multipurpose development.
Wilson-Nanum	249.0	Kittitas	Apr. 5, 1956	May 3, 1956	FE Oct. 16, 1956	Jan. 8, 1957	Active			Preliminary work plan presented to sponsors in early 1963. Awaiting local decision.

[1] In thousands of acres.
[2] By Department of Conservation, State of Washington.
[3] Field examination (FE) and reconnaissance surveys (RS) are optional; preliminary investigation (PI) is required prerequisite to planning authorization.
[4] Amended Nov. 26, 1957, application.
[5] Amended Sept. 8, 1960, application.
[6] Amended by Twin Buttes application.
[7] Complete name of watershed is Long Beach Peninsula-Chinook, Wallicut, and Bear River.

NOTE.—Revised Sept. 2, 1964.

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recreation activities. More than 101,444 acres are located in 13 wildlife refuges within the State.

State.—The State Parks and Recreation Commission has 103 parks and recreation areas, with 75,638 acres. There are 274 public fishing access areas and 19 game management areas administered by the State Department of Game. Many roadside rest and picnic areas are maintained throughout the State.

Private.—Several lumber and private utility companies maintain camping and picnic areas which are open to the public. Twenty-two sites have been developed on private timber holdings and six sites on four reservoirs are operated by power companies.

Figure 86 shows the major existing recreation facilities and the location of the 10 principal Indian reservations. Table 43 is coordinated with the numbers on the map and presents a breakdown of acreages, significant features, types of use, and activities by existing Federal, State, and local recreation areas.

INDIAN RESERVATIONS

Approximately 9,000 Indians occupy the 2,534,000 acres of reservation land in Washington.

The largest reservation is the Yakima, containing more than 1,100,000 acres. It is located in central Washington, 5 miles south of the city of Yakima in the heart of the agricultural valley. Lumbering, grazing, and farming are the chief activities on this reservation. The second largest reservation is the Colville, containing more than 1 million acres. It is located in northeast Washington, primarily in Ferry and Okanogan Counties, about 100 miles northwest of Spokane. The reservation is largely forested, with some open areas for grazing and farming. Timber, livestock, and farming are the chief sources of income.

Six of the principal reservations are located west of the Cascades. Three, the Makah in the northwestern tip of Callam County, the Quinault in Grays Harbor County, and the Quillayute in Clallam County, border on the Pacific Ocean. The other three, the Swinomish in Skagit County, the Tulalip in Snohomish County, and the Lummi in Whatcom County, border on Puget Sound.

The Makah Reservation contains 27,035 acres and is predominantly mountainous timberland. Logging and fishing are the principal activities. The Quinault Reservation has 145,258 acres. Lumbering, fishing, and tourism are the major activities. The Quillayute Reservation contains 595 acres of rough, hilly timberland. Fishing and lumbering are the principal activities.

More than 4,900 acres of heavily wooded timberlands comprise the Swinomish Reservation. Lumbering and fishing are the principal activities. The Tulalip Reservation has more than 13,800 acres. Tourism, fishing, and lumbering are the primary activities. The Lummi Reservation contains 8,336 acres. Fishing and tourism are important activities.

The Spokane Reservation is primarily in Stevens County and is separated from the Colville Reservation by Roosevelt Lake. The majority of the 141,380 acres in the Spokane Reservation are forested.

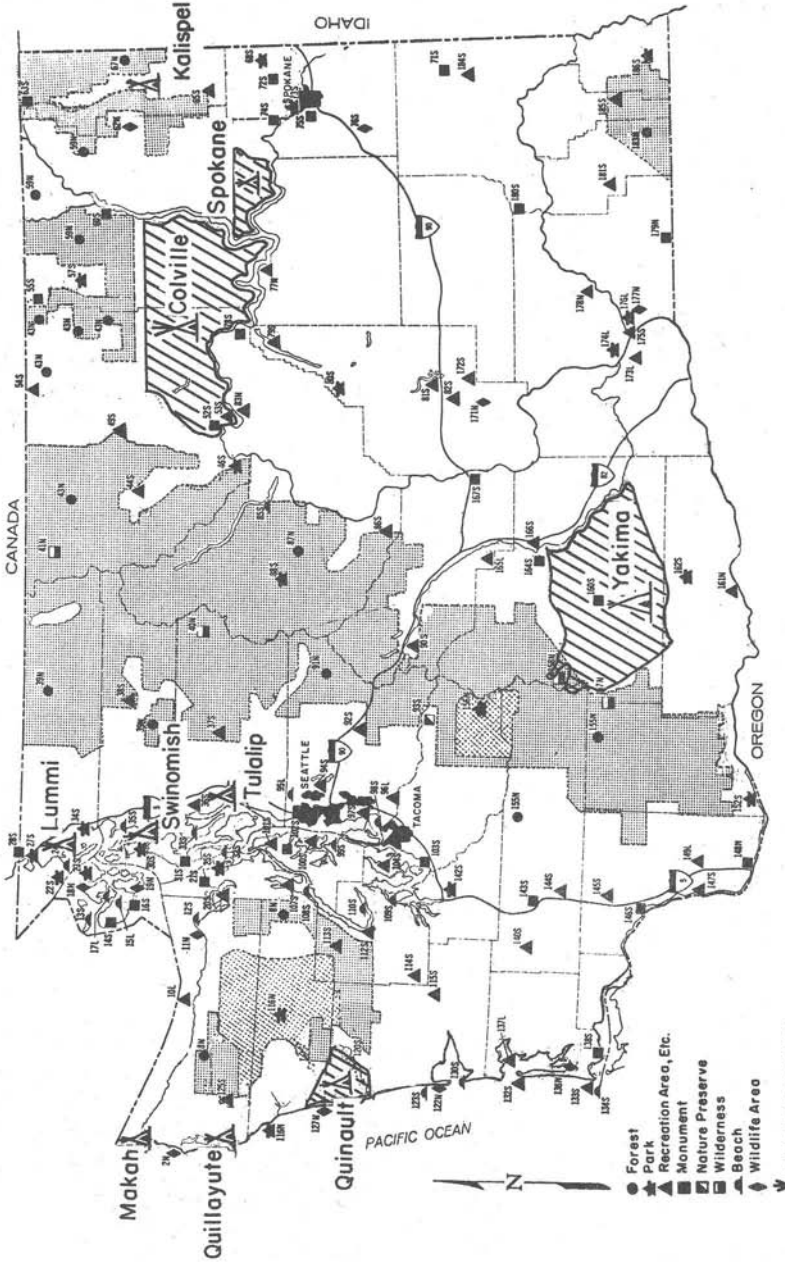

FIGURE 86.—Existing recreation developments and principal Indian reservations.

TABLE 43.—*Major existing recreation developments*

Washington, existing areas	Index on fig. 86	Acreage		Significant features											Type of use				Activities									
		Total land and water within area	Water surface [1]	Lake [2]	Reservoir [2]	River	Seashore	Forest	Prairie	Desert	Mountains	Biological	Historical or archeological	Geological	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness experience
FEDERAL																												
Parks:																												
Olympic National Park	116N	888, 558. 0	L	A	---	x	x	x	---	---	x	x	---	x	x	x	x	x	x	x	x	x	x	x	---	x	x	x
Mount Rainier National Park	156N	241, 571. 0	M	x	---	x	---	x	---	---	x	x	---	x	x	x	x	x	x	x	x	---	---	x	---	x	x	x
Recreation areas:																												
Coulee Dam National Recreation Area	77N	98, 500. 0	81, 280	---	x	---	---	---	---	---	---	---	---	---	x	x	x	x	x	---	x	x	x	x	---	---	---	---
Rufus Woods Lake	83N	7, 507. 0	7, 500	---	A	---	---	---	---	---	---	---	---	---	x	---	---	x	x	---	x	x	x	x	---	---	---	---
The Dalles Reservoir	161N	9, 406. 0	9, 400	---	A	---	---	---	---	---	---	---	---	---	x	---	---	x	x	---	---	x	x	x	---	---	---	---
Ice Harbor Reservoir	178N	13, 200. 0	9, 200	---	A	---	---	---	---	---	---	---	---	---	x	---	---	x	x	---	x	x	x	x	---	---	---	---
Monuments, historic:																												
Fort Vancouver National Historic Site	148N	75. 0	---------	---	---	---	---	---	---	---	---	---	x	---	x	---	---	x	---	---	---	---	---	---	---	---	---	---
Whitman Mission National Historic Site	179N	46. 0	---------	---	---	---	---	---	---	---	---	---	x	---	x	---	---	x	---	---	---	---	---	---	---	---	---	---
Forests:																												
Olympic National Forest	8N	621, 756. 0	M	x	A	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	x	x	x	x	x	---	---
Mount Baker National Forest	39N	1, 818, 294. 0	L	x	x	x	---	x	---	---	x	---	---	---	x	x	x	x	x	x	x	---	x	x	---	x	---	x
Okanogan National Forest	43N	2, 042, 213. 0	S	x	---	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	---	---	x	---	x	---	---
Colville National Forest	59N	928, 312. 0	M	x	---	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	---	---	x	---	x	---	---
Kaniksu National Forest (Washington portion)	67N	287, 684. 0	M	x	---	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	---	---	x	---	---	---	---
Wenatchee National Forest	87N	1, 205, 437. 0	L	x	x	x	---	x	---	---	x	---	---	---	x	x	x	x	x	x	x	x	x	x	---	x	---	x
Snoqualmie National Forest	19N	1, 207, 815. 0	M	x	x	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	x	x	x	---	x	---	x
Gifford Pinchot National Forest	155N	1, 263, 300. 0	L	x	A	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	x	x	x	---	x	---	x
Umatilla National Forest (Washington portion)	183N	313, 780. 0	S	x	---	x	---	x	---	---	x	---	---	---	x	x	---	x	x	x	x	---	---	x	---	---	---	---
Wilderness:																												
Glacier Peak Wilderness Area [3]	40N	458, 105. 0	M	x	---	x	---	x	---	---	x	---	---	---	---	x	x	---	---	x	x	---	---	x	x	---	---	x
North Cascade Primitive Area [3]	41N	801, 000. 0	L	x	A	x	---	x	---	---	x	---	---	---	---	x	x	---	---	x	x	---	---	x	x	---	---	x
Mount Adams Wild Area [3]	157N	42, 411. 0	S	x	---	x	---	x	---	---	x	---	---	---	---	x	x	---	---	x	x	---	---	x	x	---	---	x
Goat Rocks Wild Area [3]	158N	82, 680. 0	M	x	---	x	---	x	---	---	x	---	---	---	---	x	x	---	---	x	x	---	---	x	x	---	---	x

See footnotes at end of table, p. 409.

TABLE 43.—*Major existing recreation developments*—Continued

Washington, existing areas	Index on fig. 86	Acreage		Significant features											Type of use				Activities										
		Total land and water within area	Water surface [1]	Lake [2]	Reservoir [2]	River	Seashore	Forest	Prairie	Desert	Mountains	Biological	Historical or archeological	Geological	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness experience
FEDERAL—continued																												
Wildlife areas:																												
Flattery Rocks National Wildlife Refuge	2N	125.0					x					x			x										x		
Dungeness National Wildlife Refuge	11N	556.0					x					x			x										x		
Jones Island National Wildlife Refuge	18N	179.0					x					x			x										x		
Matia Island National Wildlife Refuge	18N	145.0					x					x			x										x		
Smith Island National Wildlife Refuge	19N	65.0					x					x			x										x		
San Juan National Wildlife Refuge	19N	52.0					x					x			x										x		
Little Pend Oreille National Wildlife Refuge	62N	43,959.0	S	x				x			x	x			x				x		x			x	x	x		
Turnbull National Wildlife Refuge	76N	17,171.0	M	x								x			x										x		
Copalis National Wildlife Refuge	122N	5.0					x					x														x		
Quillayute Needless National Wildlife Refuge	127N	117.0					x					x														x		
Willapa National Wildlife Refuge	136N	8,175.0					x					x							x						x	x		
Columbia National Wildlife Refuge	171N	27,861.0	M	x	x							x			x									x	x	x		
McNary Wildlife Management Area	177N	3,034.0	49,500		A							x			x									x		x		
STATE																												
Parks:																												
Sucia Island State Marine Park	22S	520.0					x								x	x			x	x	x	x	x	x				
Moran State Park [4]	23S	4,804.0	S	x			x				x				x	x	x		x	x	x		x	x				
Fort Flagler State Historical Site	25S	705.0					x						x		x				x		x		x	x				
Old Fort Townsend State Park	25S	241.0					x								x				x		x	x	x	x				
Birch Bay State Park	27S	194.0					x								x				x	x	x		x	x				
Deception Pass State Park	30S	1,746.0					x								x	x	x	x	x	x	x	x	x	x				
Larrabee State Park	34S	1,980.0					x								x	x		x	x	x	x	x	x	x				
Alta Lake State Park [4]	46S	186.0		A											x				x	x	x	x	x	x				
Curlew Lake State Park [4]	57S	122.0		A											x			x	x		x	x	x	x				
Mount Spokane State Park [4]	68S	24,330.0									x	x			x				x	x	x						x	
Riverside State Park [5]	73S	5,510.0			A									x	x				x	x	x	x		x				
Sun Lakes State Park	80S	2,548.0		x										x	x	x	x		x	x	x	x	x	x				

Lake Wenatchee State Park [4]	88S	358.0	M	A							x				x	x			x	x	x	x	x	x			
Millersylvania State Park [4]	142S	835.0	S	A				x							x	x	x		x	x	x	x	x	x		x	
Beacon Rock State Park	152S	3,696.0				A							x	x	x			x	x	x	x	x		x			
Brooks Memorial State Park	162S	733.0						x			x				x			x	x	x	x						x
Fields Spring State Park	186S	360.0									x				x			x	x	x	x						
Recreation areas:																											
Sequim Bay State Park	20S	76.0					x								x				x	x	x	x	x	x			
Wenberg State Park	36S	55.0	S	A											x				x		x	x	x	x			
Mount Pilchuck State Park	37S	2,000.0									x				x				x	x							x
Rockport State Park	38S	447.0						x							x				x		x						
Pearrygin Lake State Park [4]	44S	500.0	S	A											x				x	x	x	x	x	x			
Conconully State Park	49S	46.0	S		A										x				x	x	x	x	x	x			
Bridgeport State Park	53S	583.0	M		A										x			x	x		x	x	x	x			
Lake Osoyoos State Park	54S	30.0	M	A											x			x	x		x	x	x	x			
Pend Oreille State Park	65S	393.0						x							x				x		x						
Steamboat Rock State Recreation Area	79S	300.0	L		A										x			x	x	x	x	x	x	x			
Moses Lake State Park	81S	15.0	M		A										x			x	x			x	x	x			
Potholes Reservoir State Recreation Area	82S	2,573.0			A										x				x		x	x	x	x			
Squilchuck State Park	86S	290.0									x				x				x	x	x						x
Lake Easton State Park [4]	90S	273.0	S		A										x	x		x	x	x	x	x	x	x			
Twin Falls State Recreation Area	92S	160.0				A									x			x	x								
Lake Sammamish State Park	94S	333.0	M	A											x				x			x	x	x			
Saltwater State Park	97S	90.0					x								x				x		x	x	x	x			
Fay-Bainbridge State Park	100S	16.0					x								x				x		x	x	x	x			
Fort Ward State Park	100S	79.0					x								x				x		x	x		x			
Illahee State Park	100S	70.0					x								x				x		x	x	x	x			
Kitsap Memorial State Park	101S	45.0					x								x				x		x	x	x	x			
Kopachuck State Park [4]	104S	84.0					x								x				x		x		x	x			
Penrose Point State Park [4]	104S	125.0					x								x				x		x	x	x	x			
Dosewallips State Park	107S	509.0				A									x			x	x		x			x			
Potlatch State Park [4]	112S	57.0					x								x			x	x		x	x	x	x			
Lake Cushman State Park	113S	480.0	M		A										x				x		x	x	x	x			
Schafer State Park	114S	106.0				A									x				x	x	x		x	x			
Lake Sylvia State Park	115S	234.0	S	A											x				x	x	x	x	x	x			
Bogachiel State Park	125S	123.0				A		x							x			x	x		x	x		x			
Leadbetter Point State Park [4]	132S	3,100.0					x								x	x	x		x	x	x	x	x	x			
Fort Canby State Park	133S	791.0					x						x		x	x	x		x	x	x	x	x	x			
Rainbow Falls State Park	140S	116.0				A									x				x	x	x			x			
Lewis and Clark State Park	144S	530.0						x							x	x		x	x	x	x						
Seaquest State Park	145S	154.0	S	A											x				x	x	x			x			
Paradise Point State Park	147S	64.0				A									x			x	x		x	x	x	x			
Yakima Sportsmen State Park	166S	213.0				A									x				x		x	x		x			
Goose Lake State Recreation Area	172S	1,030.0	S		A										x				x		x	x	x	x			
Sacajawea State Park	175S	30.0	L		A										x				x			x	x	x			
Lewis and Clark Trail State Park	181S	35.0				A							x		x				x		x			x			
Kamiak Butte State Park	184S	280.0									x				x				x	x							
Camp Wooten State Group Camp [4]	185S	40.0				A										x					x						

See footnotes at end of table, p. 409.

TABLE 43.—*Major existing recreation developments*—Continued

Washington, existing areas	Index on fig. 86	Acreage		Significant features										Type of use				Activities										
		Total land and water within area	Water surface [1]	Lake [2]	Reservoir [2]	River	Seashore	Forest	Prairie	Desert	Mountains	Biological	Historical or archeological	Geological	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picknicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness experience
STATE—continued																												
Monuments:																												
Scientific:																												
Crawford Cave State Geologic Site	63S	40.0												x	x				x	x								
Steptoe Butte State Vista Site	71S	136.0												x	x				x									
Crown Point State Vista Site	78S	13.0												x	x													
Ginkgo State Park	167S	5,980.0												x	x			x		x								
Palouse Falls State Park	180S	95.0												x	x				x									
Historic:																												
Garrison Bay State Historical Site [4]	14S	20.0											x		x													
American Camp State Historical Site [4 5]	16S	5.0											x		x													
Rothschild House State Historical Site	21S	1.0											x															
Peace Arch State Park	28S	10.0											x		x				x									
Fort Casey State Historical Site	31S	110.0											x		x				x									
Fort Okanogan State Historical Site	52S	49.0											x		x			x										
Ranald MacDonald's Grave State Historical Site	55S	.5											x		x													
St. Paul's Mission State Historical Site	60S	4.0											x		x													
St. Michael's Mission State Historical Site	72S	1.0											x		x													
Spokane House State Historical Site	74S	1.0											x		x													
Aubrey L. White Painted Rocks State Historical Site	74S	.5											x		x													
Spokane Battlefield State Historical Site	75S	1.0											x		x				x									
Chief Seattle State Historical Site	102S	1.0											x		x													
Old Man House State Historical Site	102S	.5											x		x													
Captain Wallace State Historical Site	103S	1.0											x		x													
Fort Columbia State Historical Site [5]	138S	1,001.0											x		x			x	x									
Lewis and Clark Campsite	138S	1.0											x		x			x										
Jackson House State Historical Site	143S	.5											x		x													
Monticello State Historical Site	146S	.5											x		x													
Fort Simcoe State Historical Site	160S	200.0											x		x				x									

Yakima Indian Painted Rocks State Historical Site	164S	.5												x		x												
Nature preserve: Federation Forest State Recreation Area	93S	588.0					x									x			x	x	x						x	
Beaches:																												
Dungeness Water Access Area	12S	1.0				x										x							x					
Jones Island Marine Park	13S	179.0				x										x				x		x	x	x				
Prevost Harbor State Marine Park	13S	38.0				x										x							x					
Reid Harbor State Marine Park	13S	37.0				x										x							x					
Matia Island State Marine Park	24S	145.0				x										x				x	x	x	x	x	x			
South Whidbey State Park	32S	100.0				x										x			x	x		x						
Camano Island State Park	33S	136.0				x										x				x		x		x	x			
Bayview State Park	35S	19.0				x										x				x		x		x	x			
Lake Chelan State Park [4]	85S	140.0	L	A											x	x				x		x	x	x	x			
Dash Point State Park	98S	192.0				x										x				x		x		x	x			
Blake Island Marine Park	99S	475.0				x										x				x		x	x	x	x			
Pleasant Harbor Marine Park	108S	4.0				x										x			x				x					
Gerald's Cove State Marine Park	109S	45.0				x										x				x		x	x	x	x			
Belfair State Park	110S	79.0				x										x				x		x		x	x			
Twanoh State Park	110S	211.0				x									x	x				x		x	x	x	x			
Ocean City State Park	123S	82.0				x										x				x		x		x	x			
Twin Harbors State Park [4]	130S	87.0				x									x	x	x			x		x		x	x			
Ilwaco State Recreation Area	134S	65.0				x									x					x		x		x	x			
MAJOR LOCAL																												
Parks:																												
Chiawana Park	174L	100.0			A										x					x		x	x	x	x			
Hood Park	176L	140.0	L	A											x			x		x		x	x	x	x			
Recreation areas:																												
Salt Creek Recreation Area	10L	115.0				x									x					x	x			x	x			
Steel Lake Park	96L	23.0	S	A											x			x		x				x				
Bruceport Park	137L	50.0				x									x			x		x	x	x	x	x	x			
Lewisville Park	149L	244.0			A										x					x				x				
Columbia Park	173L	417.0			A										x			x		x	x	x	x	x	x			
Beaches:																												
San Juan Park	15L	12.0				x									x					x			x	x	x			
Turn Island Marine Park	17L	35.0				x									x					x		x	x	x	x			
Juanita Beach and Park	95L	29.0	L	A											x					x				x				

[1] Where acreage not shown:
"S" indicates water surface under 500 acres.
"M" indicates water surface of 500 to 10,000 acres.
"L" indicates water surface over 10,000 acres.

[2] An "A" indicates all or major portions of water surface acreage is adjacent to area.
[3] Included in national forest acreage.
[4] Major additions recommended.
[5] Eligible for registered national historic landmark status.

Lumbering and the leasing of farm and grazing lands are the chief sources of income. Also, in the northeast corner of the State along the Pend Oreille River is the Kalispel Reservation. Cut-over timberland and some farm and grazing land make up the 4,629 acres of this reservation.

The following briefly presents the attractions, activities, recreation facilities, and potential of each of the above-mentioned reservations:

Colville Reservation

Attractions: Grand Coulee Dam, largest manmade structure in the world. Also site of Roosevelt Lake and Coulee Dam National Recreational Area; old Fort Okanogan, site of first American settlement in Washington Territory.

Activities: Annual Nez Perce Circle Ground Celebration near Nespelem (July); annual Soap Lake Indian Celebration, at Soap Lake (summer; no set date).

Recreation: Fishing on and near reservation; swimming, other water sports at Soap Lake, Rufus Woods Lake, and Coulee Dam National Recreational Area; hunting (migratory waterfowl and pheasant).

Facilities: Adequate overnight lodging, other facilities in towns and in recreational areas, both on and near the reservation.

Potential: Excellent sites for development of summer homes, resorts, etc., both on and adjacent to Reservation.

Kalispel Reservation

Recreation: Hunting (deer, elk, bear) and fishing.

Facilities: Lodging, restaurants, other facilities at Newport.

Potential: Recreational development along Box Canyon Dam Lake.

Lummi Reservation

Attraction: Annual Lummi Water Stommish, on reservation (June).

Recreation: Fishing, water sports, camping, migratory waterfowl and upland bird hunting.

Facilities: Camping facilities on reservation; overnight lodging, restaurants, other facilities at Bellingham.

Potential: Expansion of tourist facilities.

Makah Reservation

Attractions: Scenic recreational areas of Olympic Peninsula (Olympic National Park, Olympic National Forest, Vancouver Island, etc.)

Activities: Annual Indian celebration, at Neah Bay (August).

Recreation: Salmon salt water fishing, swimming.

Facilities: On-reservation accommodations at Neah Bay.

Potential: Development of lumber resources, tourist facilities.

Spokane Reservation

Attractions and activities: Old Fort Spokane, on reservation; annual Indian fair and rodeo, at Wellpinit (Labor Day).

Recreation: Fishing in Lake McCoy and Chamokane Creek. Extensive recreational activities at Coulee Dam Recreational Area.

Facilities: Tourist accommodations at nearby towns and recreational areas.

Potential: Development of recreational facilities along Roosevelt Lake.

Swinomish Reservation

Attractions and activities: Scenic Whidbey and Fidalgo Islands just west of reservation; Treaty Day Indian Celebrations, on reservation (no set date); annual Tulip Festival, at LaConner (May).

Recreation: Boating and salt water fishing (salmon); hunting of migratory waterfowl.

Facilities: Limited camping and motel accommodations on reservation. Adequate facilities at nearby towns.

Potential: Expansion of resorts and camping facilities.

Quillayute Reservation

Recreation: Fishing, camping, swimming, beachcombing along ocean beaches; trout fishing in nearby rivers and streams.

Facilities: Adequate facilities at Hoquiam, nearby towns.

Potential: Expansion of present tourist facilities.

Quinault Reservation

Attractions and activities: Indian village at Taholah; annual Lake Quinault Trout Derby (May or June); "Taholah Days" Indian celebration (July 4), at Taholah.

Recreation: Water sports, camping, hiking, horseback riding.

Potential: Development of resorts, lumber industry.

Tulalip Reservation

Attractions: Mission Beach Cemetery, burial ground of Indian chiefs; old Tribal Potlatch House, at Tulalip, now public meeting place.

Recreation: Boating and swimming; salt water fishing; camping and hiking; migratory waterfowl hunting.

Facilities: Ample accommodations at nearby towns.

Potential: Expansion of motels, restaurants, other tourist facilities.

Yakima Reservation

Attractions: Historic Fort Simcoe and Museum, in nearby Fort Simcoe State Park; Indian dip net fishing on Yakima River.

Activities: Annual Toppenish Rodeo and Pow Wow (July 4); annual Indian encampment and festivities (July) at White Swan. Other celebrations at nearby towns.

Recreation: Hunting (migratory fowl, upland waterfowl) and fishing throughout reservation; nearby big game hunting (deer, elk, bear); winter sports, camping, picnicking at Brooks Memorial State Park in Satus area, south of Toppenish.

Facilities: Ample tourist facilities at Toppenish and nearby towns.

Potential: Recreational development along proposed area reservoirs; development of health resort at Soda Springs.

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POTENTIAL WATER RESOURCE DEVELOPMENTS

The need for water resource developments in the State of Washington is a continuing one, and there is an ever-increasing interest in such projects. An expanding population, both local and national, with attendant demands on State and national resources, is a primary factor in generating the need for and interest in such developments.

Expansion of urban centers onto flood plain areas creates demands for flood protection and control. Concentration of more people in a given area creates demands for more water-oriented outdoor recreation opportunities. Modification of stream regimen impinges on fish and wildlife resources and affects water quality. Municipal and industrial water requirements continue to climb, and the conversion of high-quality agricultural lands to urban and other uses creates demands for compensating acreages or the provision of supplemental water for existing acreages, which more often than not can only be supplied if additional storage capacity and irrigation facilities are provided.

Neither the potential requirements and needs for water resource developments nor the potential resources to meet them have yet been inventoried within the framework of an integrated analysis for the entire State of Washington. For the purpose of this report, therefore, existing information on proposed projects, or projects under investigation by the principal Federal and State agencies, has been summarized and an estimate of acreage that has some potential for irrigation development has been made.

IRRIGATION

By 1985 the population of the State of Washington is expected to exceed 4 million. By the same date the population of the United States is expected to exceed 265 million. Thus an increase in agricultural products is expected. The increased demand for agricultural products will be met in several ways: (1) by increasing the acreage of land under cultivation, particularly through irrigation, (2) by higher yields of crops and increased livestock production rates through adoption of technical advances, (3) by more intensive use of cultivated land, (4) by a shift in the use of certain farm products, and (5) by changes in the volume of interstate shipments. Most of the major agricultural commodities raised in Washington are shipped to other states. Thus future production of various agricultural products in Washington will depend upon the comparative advantages of production in this State and competing states. Future production will be related more largely to the total national demand and to the increase in population in the West as a whole, rather than to the growth of population in the State.

It is anticipated that about 490,000 acres of agricultural land will succumb to urban development by conversion to such uses as housing,

industry, and highways. Approximately 516,000 acres of mostly public domain land will resolve to non-Federal ownership and continue to be used for timber production or range land.

The total acreage of cropland in the State is expected to increase nearly 5 percent by 1975. The acreage of cropland under irrigation is expected to more than double by that same year. This includes lands in the Columbia Basin Project, other Federal reclamation projects, and small-scale, private irrigation developments. Despite the conversion of some forest, range, and pastureland to cropland, the acreage of nonirrigated cropland will decline, due primarily to its conversion to irrigated land. Little abandonment of land which is now being cultivated is expected.

Extreme variations in topography and productivity within areas small enought to be included in a single farm yield another important characteristic of agriculture in Washington. Of the total land in farms—18,767,000 acres — listed in the 1960 census, only 7,946,000 acres, approximately 42 percent, were classed as cropland. The other 58 percent of the area in farms was divided among pastureland, woodland, and other land, including wasteland of no use as cropland or pasture, and all house lots, barn lots, lanes, roads, and ditches. Technological advances in crop productions, yields and expansion of varieties, plus the application of new factors regarding livestock and its associated products, will help to meet the growing demands for food. However, the primary factor to be used in easing the demands for food is the bringing of water to land.

More than 13 percent of the total cropland in the State of Washington was irrigated in 1959. Based on information published in the Washington Soil and Water Conservation Needs Inventory, it is estimated that Washington had a total of 1,123,000 acres irrigated in 1962. Generally, wherever irrigation development occurs east of the Cascades, the proportion of cropland increases because rangeland is developed for cultivation. The addition of lands under irrigation west of the Cascades is less likely to be accompanied by a change in total cropland.

It is estimated that some 8,540,000 acres of arable land in the State of Washington has some degree of potentiality for irrigation development. (See fig. 87.) Of this total, over 1,100,000 acres have been irrigated, leaving a residual of about 7,400,000 acres. This estimate is based largely on physical attributes of the land, with little knowledge as to what percent could be economically justified for development, or whether such development would be financially feasible. The following tabulation shows an acreage breakdown by subbasins of the irrigated and estimated potential for the State.

[Thousand acres]

Subbasin	Arable irrigated	Arable potential	Total
Pacific coast	9	110	119
Puget Sound	54	525	579
Upper Columbia River	412	3,768	4,180
Yakima River	577	348	925
Snake River	9	1,351	1,360
Lower Columbia River	62	1,315	1,377
Total	1,123	7,417	8,540

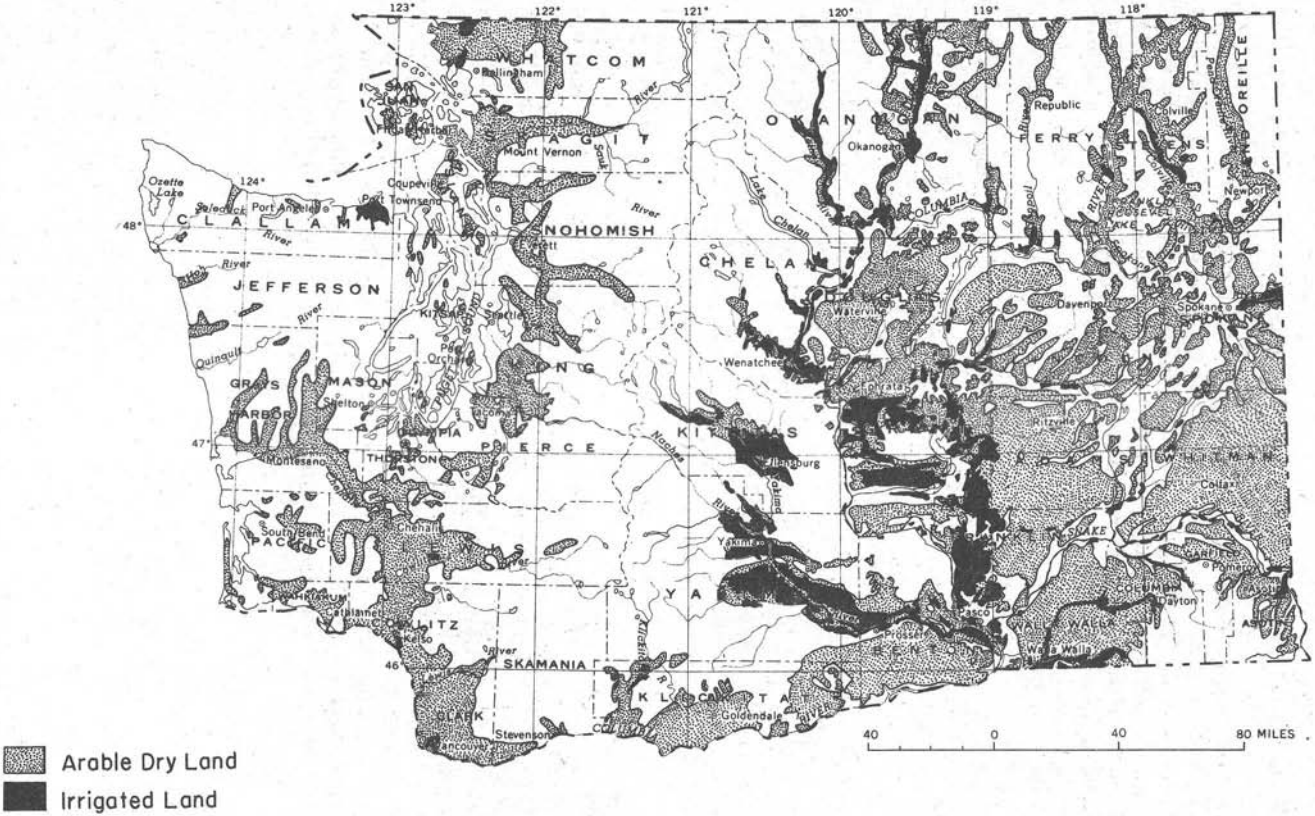

FIGURE 87.—Potential arable land.

SUBBASIN NO. 1 (PACIFIC COAST)

Of the 110,000 potential acres in this subbasin, the great majority lies along the Chehalis River and its tributaries in Grays Harbor, Mason and Lewis Counties. Other potential lands are located along the Willapa River in Pacific County, along the Humptulips River in Grays Harbor County, in the Queets-Clearwater and Hoh River basins in Jefferson County, and along the Pysht River and other smaller streams in Clallam County.

Farming is now practiced on the river bottomlands and the scattered prairies in the terraced uplands. Most of the arable lands in this subbasin are used primarily for the production of pasture, hay and grass silage. In areas where irrigation could be developed, it is expected that these crops would continue to be predominant either with or without development. Specialty crop production (fruits, berries, etc.,) would likely increase with irrigation development.

SUBBASIN NO. 2 (PUGET SOUND)

The Puget Sound subbasin is a 13,500-square-mile area located in all or a portion of 12 counties in the northwestern portion of the State. Irrigation is currently being practiced to some extent in the subbasin, and there is a large potential for additional development. The following tabulation shows the potential acreage for most of the major river basins in the Puget Sound:

	Total potential irrigable acreage		*Total potential irrigable acreage*
Nooksack	120, 000	Nisqually	70, 000
Skagit	90, 000	Deschutes	15, 000
Stillaguamish	30, 000	Dungeness	40, 000
Snohomish	30, 000	Other basins [1]	40, 000
Green-Cedar	20, 000		
Puyallup	70, 000	Total	525, 000

[1] Included in this category are the following river basins: Samish, Elwha, Dungeness, Big and Little Quilcene, Dosewallips, Duckabush, Hamma Hamma, Skokomish, Goldsborough, and Mill.

Nooksack River basin holds the most promise for project-type irrigation development of any in the entire Puget Sound area. Roughly 30 percent of the basin contains extensive agricultural areas of gently sloping or rolling lands. There are 120,000 acres of potentially arable lands that should be classified, to determine the location and amount of irrigable lands. The investigation would also determine whether the water supply would be obtained from surface or ground water.

Skagit River basin is the second largest agricultural area in the Puget Sound Basin. There are about 90,000 acres of potentially arable lands that should be classified. Although winter floods are a problem in the lower valley and delta area, construction of flood control projects would result in more intensive use of the land and increased interest in irrigation. The investigation would determine whether the water supply would be obtained from surface or ground water.

The main agricultural areas of the Stillaguamish River basin are on the flood plain, along the main stem and lower portions of the North and South Forks. About 30,000 acres of potentially arable lands should be classified. Lands on the flood plain and along the

main stem are leveed, but subject to flooding. Water for irrigation is now obtained from the river, but further development would probably require storage to accommodate multipurpose uses.

Snohomish River basin farmlands are along the downstream 19 miles of the Skykomish River and 35 miles of the Snoqualmie River. Some 30,000 acres of potentially arable lands should be classified. Of this total, about 17,000 acres were classified as irrigable in a reconnaissance survey made in the spring of 1963. There is some privately developed irrigation in the basin, but a large potential for additional development exists. The water supply could be obtained from the Skykomish and Snoqualmie Rivers. Although natural streamflows appear adequate for irrigation requirements, development of other multipurpose uses might require storage.

The Green River basin has some 20,000 acres of potentially arable lands that should be classified. The greater share of these lands border the downstream course of the Green River. Despite frequent flooding that has handicapped agricultural development, most of the farm units are small and intensively farmed. The city of Tacoma obtains its principal water supply from the Green River, and must plan for increased use. In total, the potential demands substantially exceed the available water supply. Additional irrigation would require additional storage, transbasin diversion, or a ground-water supply.

There are about 70,000 acres of potentially arable lands in the Puyallup River basin that could be classified. Most of these lands are along the lower reach of both forks and along the main stem of the river. This area is presently under cultivation and in competition with suburban encroachment. Eventually, to improve production on even less land, more intensive farming methods must be developed. Supplemental water during dry summer months would materially increase farm production. Also, natural streamflows are no longer adequate for all demands. The investigation would determine whether the water supply could be obtained from additional storage, pumping from ground water, or transbasin diversion.

Dairy and poultry farms dominate the economy of the Nisqually River basin. There are some 70,000 acres of potentially arable lands in the basin that should be classified. Included in the gross acreage is the former Yelm Project. The Yelm Irrigation District discontinued operations in 1950, and present irrigators pump from ground water to less than 2,000 acres. Chambers Prairie, downstream from the town of Yelm, is a 6,000-acre area that has an irrigation potential. The investigation would consider the Nisqually River or ground water as possible sources of water supply.

A large portion of the Deschutes River basin is relatively primitive, and has a limited agricultural potential. However, there are some 15,000 acres of potentially arable lands that should be classified. These lands are generally near and along the lower reaches of the river. The investigation would determine whether the water supply would be obtained from the river or ground water.

The Dungeness River basin is the only agricultural area of any significance in the northern part of the Olympic Peninsula. Commercial agriculture, representing the largest percent of the farmed land, is almost exclusively dairying. A total of 40,000 acres of potentially arable lands in the basin should be classified. Some 19,000

acres have already been classified as irrigable in a reconnaissance survey. Because the area lies in the rain shadow of the Olympics, summer rainfall is meager. The need to supplement the inadequate water supplies is accented by the duplication of facilities, excessive water losses, maldistribution of water, and deterioration of many of the facilities. Water is now obtained from the Dungeness River, minor streams, and ground water. Rehabilitation of the existing systems, surface storage, and ground water should be considered as possible means of obtaining an additional water supply.

The expansion of irrigation in the Puget Sound subbasin is expected to evolve through the existing and emerging trends in the technology and use of sprinkler irrigation. The long-range program for irrigation development would call for the protection of selected agricultural lands (and of the open space afforded) in the presence of the very strong urban and industrial advances anticipated in the Puget Sound area.

SUBBASIN NO. 3 (UPPER COLUMBIA RIVER)

The largest potential of any of the six subbasins, more than 3,750,000 acres, is located in the Upper Columbia River subbasin. A substantial amount of this total is located in or adjacent to the Columbia Basin Project.

In the northern portion of this subbasin the potential lands are found mostly along the major streams and their tributaries. There is a substantial amount of arable land on the Waterville Plateau in Douglas County and in the Quincy basin in Douglas and Grant Counties. Most of these lands could be served by pumping from the Columbia River.

It is anticipated that land use patterns for areas presently dry would, if these dry areas were irrigated, change to somewhat the same general use pattern of lands now being irrigated. The water users of the Columbia Basin Project have demonstrated the successfulness of irrigation in this area. The agricultural economy presently developed would provide the basic economic foundation for the potential lands. The soil and climate of this area permit a wide variety of crops to be grown with irrigation. These include forage crops, cereals, field crops, vegetables, seeds, and fruit. With further irrigation development it is anticipated that the area's economy would improve through expanded handling, marketing and processing facilities for these crops. Livestock production in the form of dairy products and beef production would also provide an important segment of the area's economy

SUBBASIN NO. 4 (YAKIMA RIVER)

With regard to irrigation, the most fully developed of the six subbasins is the Yakima River subbasin. Of the 925,000 total arable acres in this subbasin, 577,000 are presently under irrigation. Most of the potential lands are on the periphery of the large blocks of existing irrigated land. The largest single, contiguous, potentially irrigable land area lies north and west of the Kittitas Division of the Bureau of Reclamation's Yakima Project. Additional prospective irrigation developments lie within the Yakima Indian Reservation.

The development of irrigation on lands now dry is expected to create land-use patterns similar to that of the irrigated lands in the Yakima

Valley. This valley is the State's leader in the production of high value cash crops. The gentle slope of the valley sides and floor allow excellent air drainage; thus, orchards would continue to be most important. Expansion of handling and processing facilities along "Produce Row" in Yakima is anticipated with further irrigation development.

SUBBASIN NO. 5 (SNAKE RIVER)

As mentioned previously, irrigation development in the Snake River subbasin is restricted to individual developments. About 9,000 acres are irrigated. The potential of this subbasin is more than 1,350,000 acres. Much of this land is in the geographic section known as the Palouse Hills. Many of the potential areas lie at or near the lower end of tributaries. The bulk of the potential new acreage is in the Eureka Flats area in Walla Walla County. Several areas along the Snake River could be irrigated by pumping from the river.

On the benches above the rivers there is a potential for irrigated orchards. Other lands which could be irrigated would most likely develop a land-use pattern similar to the Columbia Basin Project. With irrigation development farm production would be materially increased. Hay and forage crops would provide feed for expanded livestock operations. Row crops such as sugarbeets, field beans, potatoes, and specialty crops, would also be produced.

SUBBASIN NO. 6 (LOWER COLUMBIA RIVER)

More than 1,300,000 acres are considered to be potential in this subbasin. The Bureau of Reclamation has examined areas in the Horse Heaven Hills area and in the Walla Walla valley. Storage of water for multipurpose development has been examined in the Walla Walla drainage; pumping from existing pools behind dams on the Columbia has been considered for the Horse Heaven Hills area. Storage is also being considered for sites in the drainage areas of the Klickitat and Cowlitz Rivers.

Because of the physical base of the Lower Columbia River subbasin land-use patterns developed under irrigation would be widely diversified. Crops would vary from intensive orchard developments in the Cowlitz area to forage and feed production for livestock production in the Touchet-Walla Walla area. Although agriculture has developed without irrigation in the lower part of this subbasin, it has been amply demonstrated that greater crop diversification can be obtained with the aid of irrigation.

INVESTIGATIONS

Studies are underway on various projects throughout the State. A brief description of each project in Washington under study by the Bureau of Reclamation follows:

SUBBASIN NO. 1 (PACIFIC COAST)

A'Chote Project.—This project is located in the Bear River Basin, Long Beach area of Pacific County. The results of a reconnaissance study now underway in the field will tentatively determine the feasibility of developing a multipurpose dam and reservoir on Bear River.

Functions served would be irrigation, municipal and industrial water supply, fish enhancement, and recreation. Plans for irrigating approximately 4,000 acres of peat lands will be investigated. The extent of other needs and facilities and water supply to meet such needs will also be determined in the investigation.

Chehalis Project.—A reconnaissance report was recently completed which presented findings regarding the Upper Chehalis River Basin. The study area includes lands lying upstream from the confluence of the Chehalis and Black Rivers in Grays Harbor County. The investigation encompasses some 300,000 acres of land and includes studies of 13 reservoir storage sites.

Willapa Project.—The Area Redevelopment Administration provided funds for the Bureau of Reclamation to devise a multipurpose development plan for the Willapa River Basin in Pacific County. The plan under consideration would provide water from a dam and reservoir constructed on the South Fork of the Willapa River for irrigation, municipal and industrial use, recreation, and enhancement of the fishery resource.

SUBBASIN NO. 2 (PUGET SOUND)

Puget Sound Basin.—This basin study area includes the 13,500-square-mile drainage areas of all the river systems draining into the Puget Sound from King, Snohomish, Skagit, and Whatcom Counties. Results of the survey will help to evaluate the irrigation potential along these rivers by determining the amount and location of arable lands, the best means of serving the lands, and the relative feasibility of the areas found to be suitable for multiple-purpose development. Various phases of this basin investigation are underway.

SUBBASIN NO. 3 (UPPER COLUMBIA RIVER)

Chief Joseph Dam Project.—The lands of the existing Okanogan Project lie along the Okanogan River in Okanogan County in the vicinity of Okanogan and Omak. Under consideration is a plan to provide additional irrigation water for 5,000 acres of these lands along Okanogan River which are presently inadequately irrigated. Several alternatives are being considered—one being the development of additional storage, another being the pumping from Okanogan River. Flood control, enhancement of fish and wildlife resources, and recreation will also be evaluated.

Columbia Basin Project.—Grand Coulee Dam is located on the Columbia River about 75 air miles north and west of Spokane. Feasibility studies for a third powerplant have been made to determine the feasibility of providing additional hydroelectric generating capacity at Grand Coulee Dam, now that anticipated future upstream development is to become a reality under terms of the United States-Canadian Treaty. The new powerplant would be located on the right bank of the river immediately downstream from the dam. Generating units of 300,000 kilowatts are planned, with a probable initial installation of 4 units and an ultimate installation of 12 units. The development plan has recently been sent to Congress.

Pend Oreille River Basin.—The Pend Oreille River Basin is in northern Idaho and northeastern Washington. The river actually is

a continuation of the Clark Fork, reaching from Lake Pend Oreille to the Columbia River just over the Canadian boundary. A reconnaissance survey to determine the areas of arable land which could be irrigated and to outline methods of serving these lands was recently completed. Approximately 37,000 acres of arable lands have been classified within the Washington portion of the basin.

SUBBASIN NO. 4 (YAKIMA RIVER)

Yakima Project.—The highly successful Yakima Project includes nearly half a million acres of irrigated land. It is a highly developed area in which several longstanding water supply problems, particularly those associated with fish, are growing to critical proportions. Development of additional storage is required to satisfy the basin's multipurpose requirements. Field work is underway on preliminary investigations of several multiple-purpose storage sites.

The existing Bumping Lake Dam and Reservoir, in the northwestern part of Yakima County, is one of the reservoirs currently serving the Yakima Project. It has been determined that a dam on Bumping River a short distance downstream from the existing structure could increase the storage capacity of Bumping Lake from the present 33,700 acre-feet to 458,000 acre-feet and provide increased flexibility in the storage system to meet the needs of several project purposes.

Ahtanum Division.—The Ahtanum Division is located in the Ahtanum Valley in Yakima County. The valley, which terminates only a few miles southwest of the city of Yakima, is 21 miles long. A 40,000 acre-foot reservoir on Ahtanum Creek could provide a sizable new water supply for arable lands in the Ahtanum Valley.

Kennewick Division Extension.—Approximately 6,300 acres of land lying between Richland and Benton City in Benton County would be irrigated with the development of the Kennewick Extension. Nearly all of the lands within the extension are presently dry, supporting only sagebrush and native grasses used for livestock grazing. With irrigation it is anticipated that most of the acreage would be devoted to feed and general row crops. The development plan has been presented to Congress.

SUBBASIN NO. 5 (SNAKE RIVER)

Eureka Flat Project.—The LeGrow Division of this project is located in western Walla Walla County. The purpose of this study is to establish the practicability of irrigating some 15,000 acres by pumping from the pool created behind Ice Harbor Dam on the Snake River. Irrigation water would be pumped into a main canal and pressure for sprinkler irrigation would be furnished by small relift plants.

Lower Snake River Basin.—The geographic area encompassed by this basin includes the drainage area from the river mouth at Pasco, to, but not including, the Grande Ronde River. Irrigation in this area is minor in nature, usually developed by individuals, and scattered along main streams. A few small tracts are irrigated from ground water. The basin survey will evaluate all water resource development possibilities, including irrigation, flood control, municipal and industrial water supplies, recreation, enhancement of the fishery resource, and water quality control.

SUBBASIN NO. 6 (LOWER COLUMBIA RIVER)

Lower Horse Heaven Project.—In southern Benton County, near the Columbia River, lies one of the large remaining areas of potential reclamation development in the State of Washington. A gross area of approximately 250,000 acres of land has been investigated. Water would be supplied to these lands by pumping from the Columbia River.

Walla Walla Project.—The drainage area of the lower Walla Walla River and its tributaries (except for the Touchet River Basin) in Walla Walla County comprise the Marcus Whitman Division. About 24,000 acres of land presently irrigated with an inadequate water supply and another 2,000 acres of dry land which could be irrigated, have been considered in this study. Storage on Mill Creek could provide for the multiple-purpose functions of irrigation, flood control, fishery enhancement, water quality control, recreation, and municipal and industrial water.

Also being considered for development are 9,960 acres of land in the narrow Touchet River Valley between the cities of Dayton and Touchet in Columbia and Walla Walla Counties. Features include the Dayton Dam and Reservoir on the East Fork of the Touchet River and fish passage facilities. The 52,600 acre-foot reservoir would provide an irrigation water supply, flood control, enhancement of the fishery resource, water quality control, recreation, and a municipal and industrial water supply for the city of Dayton.

The preceding presents in summary form a look at the irrigation potential in the State by subbasins and a brief look at the investigations conducted by the U.S. Bureau of Reclamation.

Many potential dam and reservoir sites are located within the State of Washington. Figure 88 shows the approximate location of 220 known damsites; table 44, which is coordinated with the map, presents the name and stream location of each site.

FLOOD CONTROL AND NAVIGATION

The State of Washington has thousands of miles of inland, as well as coastal, waterways which provide channels and berthing facilities for both deep-draft and shallow-draft vessels of every description and from every major port in the world. From Baline Harbor, at the United States-Canadian border, to the mouth of the Columbia River and throughout the inland waters of the State of Washington, inspection, improvement, and maintenance of the waterways is continuing to provide safe and efficient access to coastal and inland ports.

There is a continuing need of and potential for additional flood control and navigation projects in the State of Washington. Floods originating on the many small tributary streams frequently develop into devastating proportions in the larger rivers. At times towns, cities, and thousands of acres of fertile farm land are inundated, creating tremendous property losses. Hazards to navigation, such as silt or sand clogging or snags blocking a channel, and the perils of storms, present problems to the operators of steamships, fishing boats, and pleasure craft.

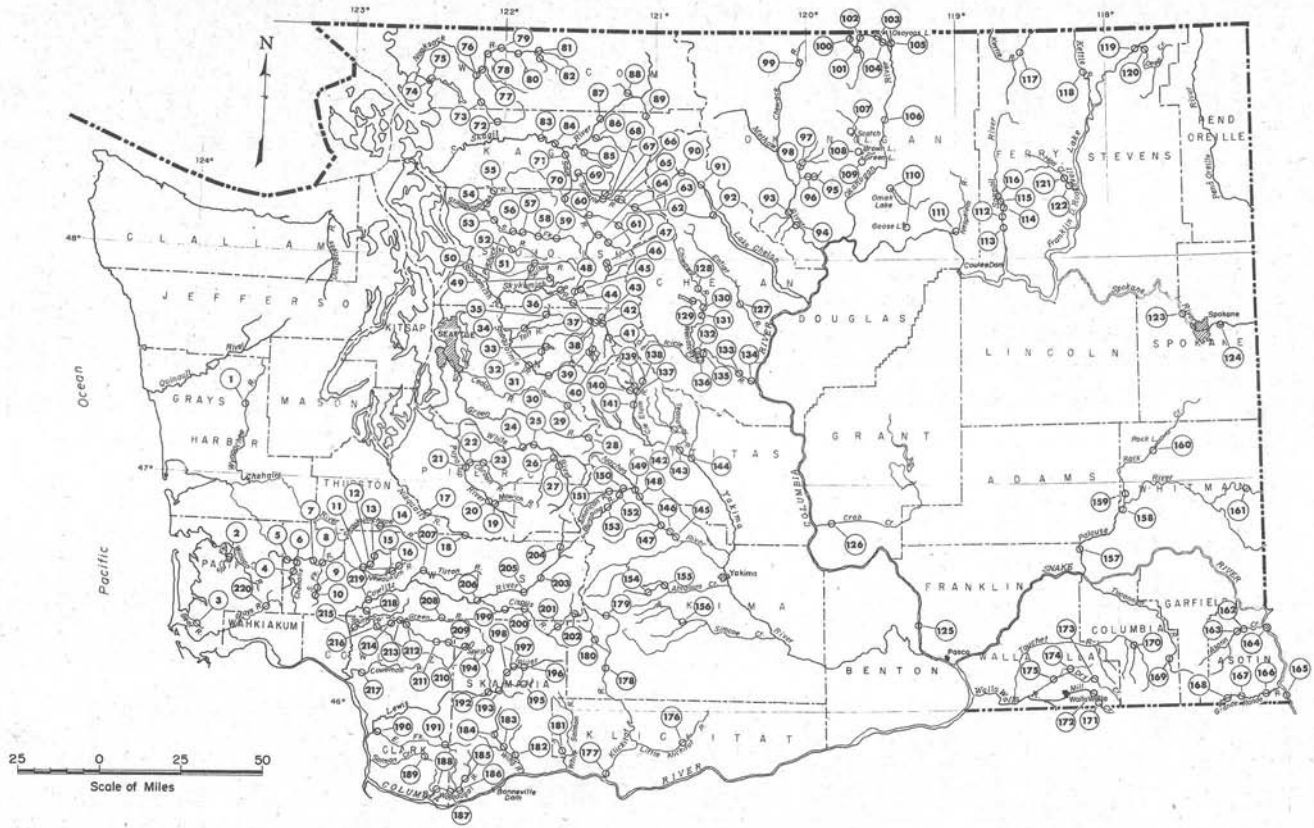

FIGURE 88.—Potential dam and reservoir sites. (Numbers refer to locations named in table 44.)

TABLE 44.—*Potential damsites, Washington*

Index No. on fig. 88	Damsite	Stream
	PACIFIC COAST SUB-BASIN	
1	Wynoochee	Wynoochee.
2	Raymond	South Fork Willapa.
3	A'Chote	Bear.
4	Pe Ell	Chehalis.
5	Doty	Elk Creek.
6	Dryad	Chehalis.
7	Meskill	Do.
8	Ruth	Do.
9	Boistfort	South Fork Chehalis.
10	Point Hill	Do.
11	Middle Fork	Middle Fork Newaukum.
12	Logan Hill	North Fork Newaukum.
13	Bear Creek	Do.
14	Bloody Run	Skookumchuck.
15	Onalaska	South Fork Newaukum.
16	Alpha	Do.
	PUGET SOUND SUB-BASIN	
17	Nisqually	Nisqually.
18	Park Junction	Do.
19	Mowich No. 1	Mowich.
20	Mowich No. 1a	Puyallup.
21	Orting	Do.
22	Mile 9.2	Carbon.
23	Fairfax	Do.
24	Deadman Flat	White and Greenwater.
25	Twin Creek	White.
26	West Fork Mouth	West Fork White.
27	Huckleberry	White.
28	Weston	Green.
29	Upper Cedar	Cedar.
30	Middle Fork Snoqualmie.	Middle Fork Snoqualmie.
31	Lower Site, Snoqualmie.	North and South Fork Snoqualmie.
32	Lower North Fork Snoqualmie.	North Fork Snoqualmie.
33	Calligan Creek	Hancock and Calligan Lakes.
34	Forks	Tolt.
35	Dry Creek	Do.
36	Lake Isabel	May Creek.
37	Miller Forks	Miller.
38	Upper South Fork	South Fork Skykomish.
39	Lake Dorothy	East Fork Miller.
40	East Fork Miller	Do.
41	Alturas Lake	East Fork Foss.
42	Tonga	Foss.
43	Beckler	Beckler.
44	Sunset Falls	South Fork Skykomish.
45	Trout Creek	Trout Creek.
46	Troublesome No. 2	Troublesome Creek.
47	Troublesome No. 1	Do.
48	Giddings Creek	North Fork Skykomish.
49	Wallace Lake	North Fork Wallace.
50	Lower Sultan	Sultan.
51	Middle Sultan	Do.
52	Pilchuck	Pilchuck.
53	Jorden	South Fork Stillaguamish.
54	Oso	North Fork Stillaguamish.
55	Chaplain Creek	Deer Creek.
	PUGET SOUND SUB-BASIN—continued	
56	Granite Falls	South Fork Stillaguamish.
57	Robe	Do.
58	Tyree	Do.
59	Silverton	Do.
60	Lower Whitechuck	Whitechuck.
61	Sloan Creek	Sauk.
62	Upper Whitechuck	Whitechuck.
63	Upper Suiattle	Suiattle.
64	North Fork Sauk	North Fork Sauk.
65	Downey Creek 1a	Suiattle.
66	Downey Creek	Do.
67	Buck Creek	Do.
68	Buck Creek No. 1a	Buck Creek.
69	Lower Suiattle	Suiattle.
70	Upper Sauk	Dry Creek.
71	Lower Sauk	Sauk.
72	Wanlick	South Fork Nooksack.
73	Skookum Creek	Do.
74	Whatcom Creek No. 1.	Whatcom Creek.
75	Whatcom Creek No. 2.	Do.
76	Deming	Nooksack.
77	Welcome	Do.
78	Maple Falls	Do.
79	Warnick	Do.
80	Glacier	Do.
81	Shuksan	Do.
82	Wells Creek	Wells Creek.
83	Dalles	Skagit.
84	Lower Faber	Do.
85	Illabot Creek	Illabot Creek.
86	Cascade	Cascade.
87	Copper Creek	Skagit.
88	Stetattle	Stetattle.
89	Thunder Creek	Thunder Creek.
	UPPER COLUMBIA RIVER	
90	Agnes Creek	Stehekin.
91	Stehekin	Do.
92	Railroad Creek	Railroad Creek.
93	Gold Creek	Methow.
94	McFarland Creek	Do.
95	Pipestone No. 1	Beaver Creek.
96	Pipestone No. 2	Do.
97	Batic Site No. 1	Do.
98	Batic Site No. 2	Do.
99	Chewack Creek	Chewack.
100	Nighthawk	Okanogan.
101	Palmer Lake	Palmer Creek.
102	Shankers Bend	Similkameen.
103	Similkameen	Do.
104	Below elevation 964, Similkameen.	Do.
105	Osoyoos Lake	Okanogan.
106	McLaughlin Falls	Do.
107	Scotch Lake	Scotch Creek.
108	Brown Lake	Johnson Creek.
109	Green Lake	Salmon Creek.
110	Omak Lake-Goose Lake.	Natural lakes.
111	Nespelem	Nespelem.
112	Iron Creek	Sanpoil.
113	Sanpoil	Do.
114	Louis Creek	Do.
115	Devils Elbow 1 and 2	Do.
116	Devils Elbow 3	Do.
117	Curlew	Kettle.
118	Orient	Do.

TABLE 44.—*Potential damsites, Washington*—Continued

Index No. on fig. 88	Damsite	Stream
	UPPER COLUMBIA RIVER—continued	
119	Deep Creek	Deep Creek.
120	Quarry	Do.
121	Hall Creek No. 2	Hall Creek.
122	Hall Creek No. 1	Do.
123	Bowl and Pitcher	Spokane.
124	Crossing	Do.
125	Ben Franklin	Columbia.
126	Crab Creek	Crab Creek.
127	Entiat	Entiat.
128	Chiwawa	Chiwawa.
129	Wenatchee	Wenatchee.
130	Beaver	Do.
131	Plain	Do.
132	Beaver Creek	Icicle Creek.
133	Above elevation 695, Wenatchee.	Wenatchee.
134	Elevation 612, Wenatchee.	Do.
135	Below elevation 1110, Icicle Creek.	Icicle Creek.
136	Icicle Creek	Do.
	YAKIMA RIVER SUBBASIN	
137	Elevation 2545, Cle Elum.	Cle Elum.
138	Fish Lake diversion	Fish Lake.
139	Waptus Lake diversion.	Waptus Lake.
140	Cooper Lake diversion.	Cooper Lake.
141	Below Big Salmon Le Sac.	Cle Elum.
142	Teanaway	Teanaway.
143	Yakima-Teanaway	Yakima.
144	Swauk	Do.
145	Elevation 1765, Naches.	Naches.
146	Rattlesnake Creek	Do.
147	Naches-Rattlesnake	Do.
148	Little Naches	Do.
149	Below American River.	Do.
150	Below Pleasant Valley.	American.
151	Pleasant Valley	Do.
152	Elevation 3165, Bumping River.	Bumping River.
153	Bumping River	Do.
154	Tampico	North Fork Ahtanum.
155	Pine Hollow	Do.
156	Simcoe	Simcoe Creek.
	SNAKE RIVER SUBBASIN	
157	Palouse	Palouse.
158	Wiedrich	Do.
159	Winona	Rock Creek.
160	Rock Lake	Do.
161	Hinchliff	North Fork Palouse.
	SNAKE RIVER SUBBASIN—continued	
162	Asotin Creek	Asotin Creek.
163	Rubenser	Do.
164	Asotin	Snake.
165	China Gardens	Do.
166	Narrows	Grande Ronde.
167	Rays Ferry	Do.
168	Wenaha	Do.
169	Panjab	Tucannon.
	LOWER COLUMBIA RIVER	
170	Dayton	Touchet.
171	Wickersham	Mill Creek.
172	Blue Creek	Do.
173	Dixie	Dry Creek.
174	Spring Valley	Do.
175	Pauls School	Do.
176	Hanging Rock	Little Klickitat.
177	Lyle No. 1	Klickitat.
178	Surveyors Creek	Do.
179	Klickitat	Do.
180	Glenwood	West Fork Klickitat.
181	Underwood	Moss Creek.
182	Panther Creek	Panther Creek.
183	Trout Creek	Wind.
184	Hollis Creek	Do.
185	Dougan Creek	Washougal.
186	Bobs Mountain	Do.
187	West Fork	Do.
188	Cougar Creek	Do.
189	Vernersburg	Salmon Creek.
190	Eddy Rock	East Fork Lewis.
191	Moulton	Do.
192	Eagle Cliff	Lewis.
193	Rush Creek	Do.
194	Paradise Falls	Muddy.
195	Big Meadows	Big Creek.
196	Steamboat Creek	Lewis.
197	Quartz Creek	Do.
198	Cascade Gorge	Do.
199	Greenhorn	Cispus.
200	Tower Rock	Do.
201	Muddy Fork	Do.
202	Walupt Lake	Do.
203	Backbone Lake	Cowlitz.
204	Silver Falls	Ohanapecash.
205	Cora Bridge	Cowlitz.
206	Cowlitz Falls	Do.
207	Tilton	Tilton.
208	Cascade Creek	Green.
209	Cold Water Creek	Toutle.
210	Spirit Lake	Do.
211	Elk Creek	Do.
212	St. Helens	Do.
213	Kid Valley	Do.
214	North Fork	Green.
215	Castle Rock	Toutle.
216	Tower	Do.
217	Kelso	Coveman.
218	Salmon Creek	Salmon Creek.
219	Toledo	Cowlitz.
220	Grays River	Grays.

On July 14, 1960, Congress enacted Public Law 86–645 (sec. 206, Flood Control Act of 1960) whereby the Corps of Engineers was authorized to—

compile and disseminate information on floods and flood damages, including identification of areas subject to inundation by floods of various magnitudes and frequencies, and general criteria for guidance in the use of flood plain areas; and to

provide engineering advice to local interests for their use in planning to ameliorate the flood hazard * * *

Figure 89 shows the location of the potential navigation and flood control projects in the State. The numbers on table 45 correspond with the numbers on the map.

Also within the State of Washington the Corps of Engineers has several projects in flood control work under special continuing authorities, including flood fighting, emergency protection of public works, channel clearing and snagging, and emergency flood control work.

RECREATION

Many existing areas are not suitable for intensive development for day and overnight use. The State park system could be expanded by additions to existing areas and acquisition of new areas near the major metropolitan centers; improvement of public access to suitable portions of the Pacific shoreline; and preservation of several free-flowing streams. Also, canoe and boat trails should be established, and increased protection should be given to archeological sites.

Existing State parks, recreation areas, beaches, and related areas provide 75,638 acres for recreation use. Potential State recreation lands as presently identified total 8,155 acres. Though these State acreages combined are short of 1976 needs, they are augmented by the presence of existing Federal recreation lands near the population centers. A similar situation exists in the local picture, where existing and potential acreages are short of 1976 needs. Further study is required to determine the location, type, and acreage for State and local areas to meet the future needs.

The following recommendations from a recent survey by the U.S. Department of the Interior, National Park Service (1964), were made to help provide needed outdoor recreation opportunities for public enjoyment and use:

State: Enlargement of the State park system to preserve significant resources by the addition of 3 State parks, 12 recreation areas, and 2 beaches, with major additions to 18 existing areas.

Local: Establishment of 3 recreation areas and 2 beaches, with further study of 8 recreation areas and 1 beach.

Supporting recommendations include:

(1) Study the feasibility of land acquisition and construction of a Pacific Coast scenic road.

(2) Bring U.S. 830, on the north side of the Columbia River Gorge, up to parkway standards.

(3) Designation and development of 13 potential canoe and boat trails, including facilities for stopover sites.

(4) Assistance to counties by providing technical aid for their recreation programs.

Figure 90 presents the potential recreation developments in the State. Table 46 is coordinated with the numbers on the maps. This table presents a breakdown of acreages, significant features, types of use, and activities by Federal, State, and local recreation areas.

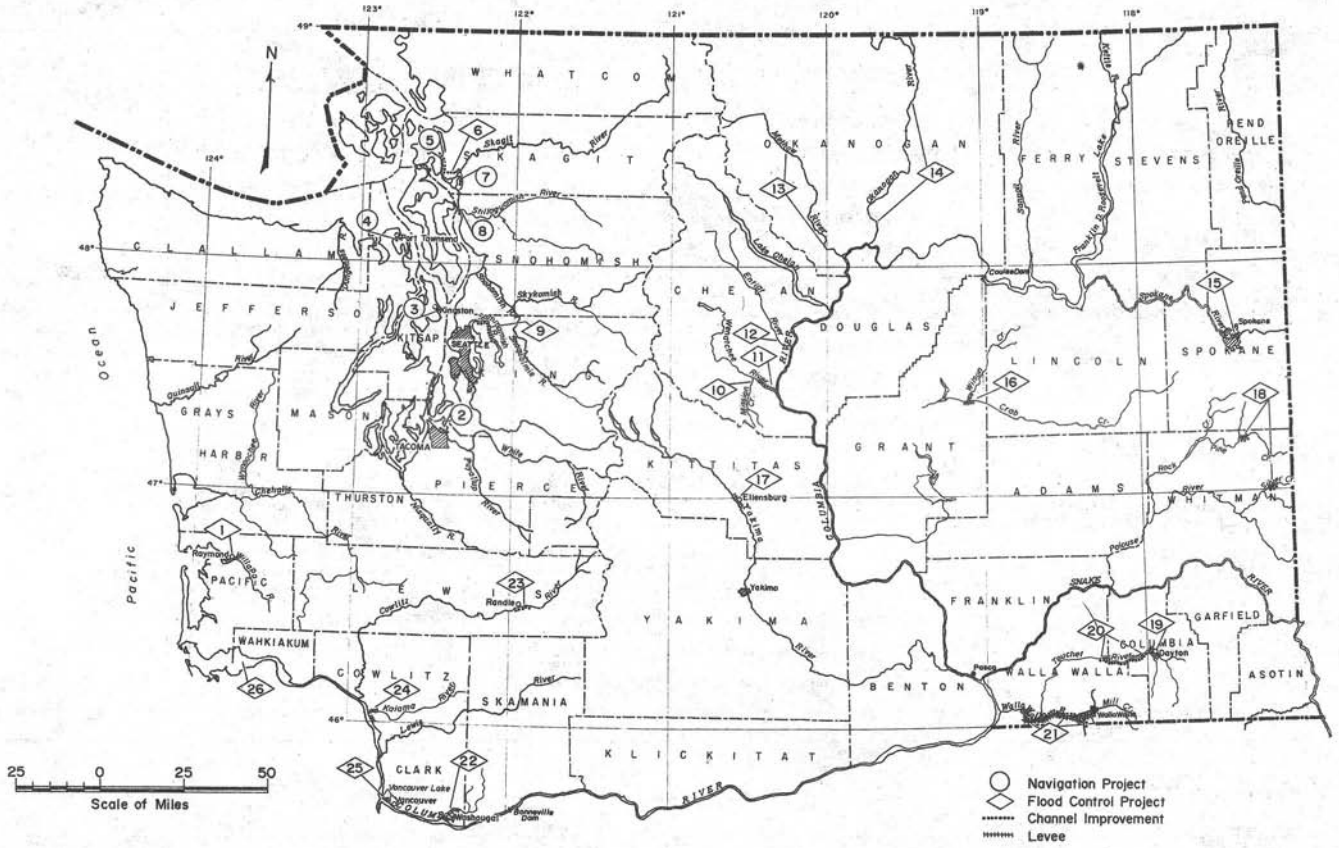

FIGURE 89.—Potential navigation and flood control developments. (Numbers refer to locations named in table 45.)

TABLE 45.—*Potential navigation and flood control projects other than storage*

Subbasin	Index No. on fig. 89	Name	Principal features	Status	Remarks
Pacific Coast	1	Raymond	Levee system	Authorized	Would protect Raymond from tidal floods.
Puget Sound	2	Tacoma Harbor	Extending existing waterways, widen channels and bends.	do	
	3	Kingston Harbor	Rubblemound, breakwater, dredging of entrance channel.	do	Local interests to provide recreation facilities.
	4	Port Townsend Harbor	Improve existing mooring basin, build breakwaters.	do	Local interests to furnish land, construct piers.
	5	Swinomish Channel	Removal of navigation hazards	do	
	6	Skagit River (flood control)	Diversion channel and control works	do	Inactive; no work has been done.
	7	Skagit River (navigation)	Channel improvements	Study underway.	Between Mount Vernon and Concrete.
	8	Stillaguamish River	do	Authorized	No construction has been done.
	9	Sammamish River	do	do	Would reduce overflow frequencies.
Upper Columbia River	10	Mission Creek	Straightening channel, constructing levees, bank protection.	do	Deferred status.
	11	Wenatchee River	Levees: bank protection	Conditional authorization.	Inactive; economic justification not established.
	12	Entiat River	Flood protection works	do	Do.
	13	Methow River	do	do	Do.
	14	Okanogan River	do	do	Do.
	15	Spokane	Levees and bulkhead on right bank of Spokane River.	Authorized	Inactive.
	16	Crab and Wilson Creeks	Channel improvement, levee construction	do	Do.
Yakima River	17	Yakima River, Ellensburg	Levees on both banks of river	do	Do.
Snake River	18	Palouse River, Pine and Silver Creeks.	Levees, floodwalls, channel rectification	Conditional authorization.	Economic justification to be determined.
Lower Columbia River	19	Touchet River at Dayton	Revetted levees, raise and strengthen existing levees.	Authorized	
	20	Touchet River	Provide protection to the river flood plain area	Study underway.	
	21	Lower Walla Walla River and Mill Creek.	Provide flood protection along Walla Walla River, levees, revetments.	do	
	22	Washougal	Levees, tide boxes, pumping plants, drainage ditches.	Authorized	Preconstruction planning is underway.
	23	Cowlitz River at Randle	Channel clearing and rectification, revetment	Conditional authorization.	Deferred for restudy.
	24	Kalama River	Levees, tide boxes, pumping plants, drainage ditches.	Authorized	
	25	Vancouver Lake	do	do	
	26	Lower Columbia River flood control projects.	Modification of 5 existing dike and drainage projects.	do	

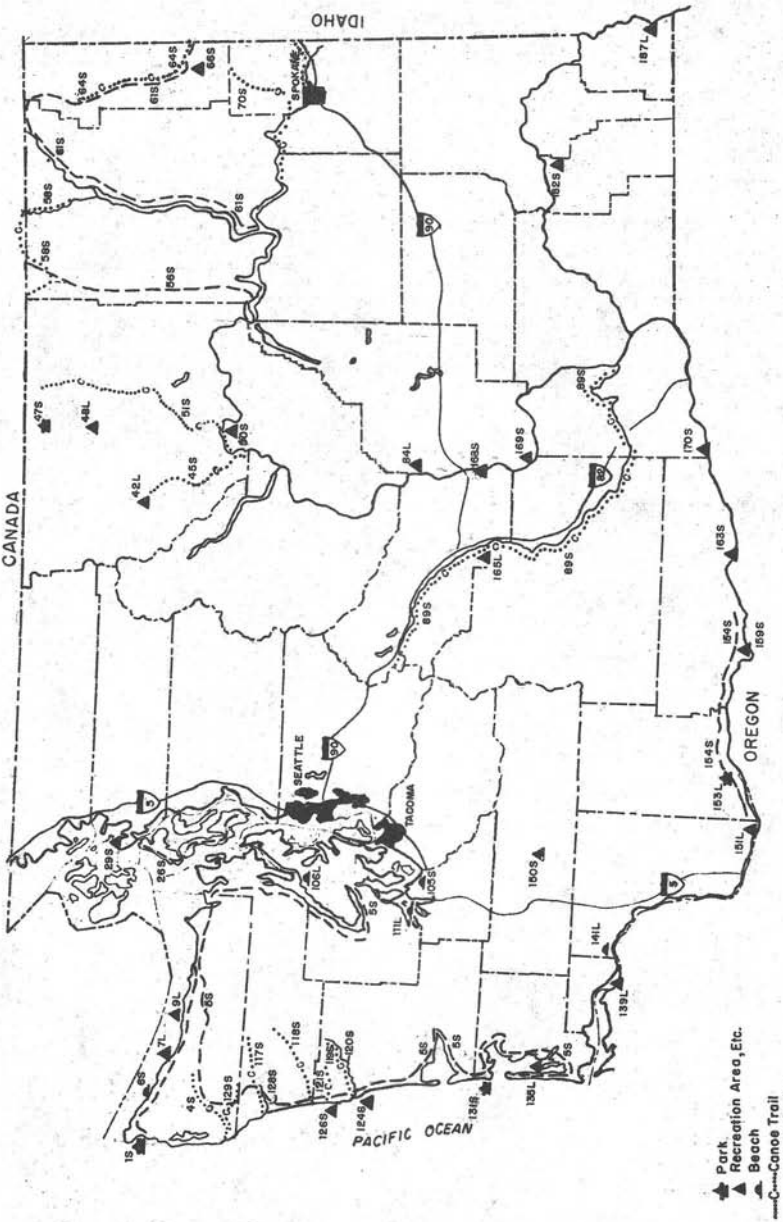

FIGURE 90.—Potential recreation developments. (Numbers refer to locations listed in table 46.)

TABLE 46.—*Potential recreation developments*

Washington potential areas	Index on fig. 90	Acreage		Significant features										Type of use				Activities										
		Total land and water within area	Water surface [1]	Lake [2]	Reservoir [2]	River [2]	Seashore	Forest	Prairie	Desert	Mountains	Biological	Historical or archeological	Geological	Day and weekend	Vacation	Out-of-State target	Tourist en route	Picnicking	Hiking and riding	Camping	Boating	Swimming	Fishing	Hunting	Nature study	Winter sports	Wilderness experience
STATE																												
Parks:		*Acres*																										
Shishi Beach	1S	1,000					x								x	x	x	x	x	x	x				x			
Chopaka Lake	47S	1,600	200	x							x				x	x	x		x		x	x	x		x			
Cape Shoalwater	131S	1,300					x					x			x	x	x	x	x	x	x	x	x		x			
Recreation areas:																												
Hart Lake	29S	100	S	A				x							x	x	x	x	x		x	x	x					
Bridgeport Bar	50S	300	M		A										x	x		x	x		x	x	x					
Newport	66S	160				A									x			x	x		x	x	x					
Grenville Bay	124S	160					x	x					x		x	x	x		x	x	x	x	x			x		
Raft River	126S	500					x								x				x	x								
Mayfield	150S	160	M		A										x			x	x		x	x	x					
Horse Thief Lake	159S	100	9,400		A								x	x	x			x	x		x	x	x					
Rock Creek	163S	100	52,000		A										x	x		x	x		x	x	x					
Wanapum Reservoir	168S	200	L		A										x			x	x		x	x	x					
Priest Rapids	169S	2,000	M		A										x			x	x		x	x	x					
Crow Butte	170S	100	52,000		A										x	x		x	x		x	x	x					
Lyons Ferry	182S	250	6,590		A									x	x		x	x	x		x	x	x					
Beaches:																												
Hoko Beach	6S	60					x								x	x			x	x	x	x	x					
Jones Beach	105S	95					x								x				x		x	x	x					
		Miles																										
Parkway: U.S. 830	154S	75			x						x			x														
Scenic roads:																												
State Route 9A	3S	60					x	x			x																	
State Route 12A, U.S. 101, State Route 13A, State Route 21	5S	350					x	x			x																	
State Route 1D	26S	52					x																					
State Routes 4, 4A	56S	95				x		x			x																	
State Routes 22, 22A, 6	61S	170				x		x			x			x														

Free-flowing streams:																															
Quinault River	120S	25				x		x				x																			
Hoh River	128S	14				x		x				x																			
Canoe trails:																															
Soleduck River	4S	25				x									x	x	x		x		x	x		x							
Methow River	45S	35				x									x	x			x		x	x		x							
Okanogan River	51S	70				x									x				x		x			x							
Kettle River	58S	52				x									x	x	x		x		x	x		x							
Pend Oreille River	64S	50				x									x	x	x		x		x	x		x							
Spokane River	69S	53				x									x	x			x		x	x		x							
Little Spokane River	70S	28				x									x	x			x		x	x		x							
Yakima River	89S	184				x									x	x	x		x		x	x		x							
Hoh River	117S	28				x									x	x	x		x		x	x		x							
Queets River	118S	21				x									x	x	x		x		x	x		x							
Quinault River	119S	26				x									x	x	x	x	x		x	x		x							x
Raft River	121S	15				x									x	x	x		x		x	x		x							
Bogachiel River	129S	18				x									x	x	x		x		x	x		x							
LOCAL																															
Recreation areas:		*Acres*																													
Juan de Fuca Strait	7L	1,000					x								x	x	x		x		x	x		x							
Crescent-Agate Beaches	9L	700					x					x	x		x	x			x	x	x	x	x	x		x					
Patterson Lake [3]	42L	160	80	A											x	x			x	x	x	x	x	x							
Blue Lake [3]	48L	80	20	A											x	x			x	x	x	x	x	x							
Crescent Bar	84L	200	L		A										x	x		x	x	x	x	x	x	x							
Willapa Bay	135L	80					x								x	x	x	x	x		x	x	x	x							
Puget Island [2]	139L	40				A									x				x				x	x							
Columbia River [3]	151L	62				A									x	x		x	x		x	x	x	x							
Bonneville [3]	153L	80	18,700		A										x				x		x	x	x	x							
Yakima River [3]	165L	80				A									x			x	x		x	x	x	x							
Grande Ronde [3]	187L	70				A									x		x		x		x	x	x	x							
Beaches:																															
Scenic Beach	106L	75					x								x		x		x		x	x	x	x							
Elde Inlet	111L	120					x								x		x		x		x	x	x	x							
Fishermen's Beach [3]	141L	100				A									x				x		x	x	x	x							

[1] Where acreage not shown:
"S" indicates water surface under 500 acres.
"M" indicates water surface of 500 to 10,000 acres.
"L" indicates water surface over 10,000 acres.

[2] An "A" indicates all or major portions of water surface acreage is adjacent to area.
[3] Suggested area—qualifications not wholly determined. Further study required.

SUMMARY

Washington is a land of contrasts. When the pioneers and early settlers pieced together a description of the area, it included windswept rain forests and arid desert country; snow-covered mountains and deep river gorges; sparkling, cold, tumbling streams and dry, dusty river beds.

The Evergreen State is rich in natural resources of land, water, timber, minerals, and fish and wildlife, and is tremendously endowed with scenic beauty and recreational opportunities. The geographic location of Washington's land and water resources, plus the temperate climate of the Northwest, have combined to make possible a diversity of resource use that is outstanding among areas of the United States.

The development of the water and related land resources of the Pacific Northwest, with the Columbia River System as its core, is one of the world's greater undertakings of its kind. The attention of planners, economists, engineers, politicians, and the general public of this and many other countries has been attracted for many years to this development.

A great amount of planning and study remains to be accomplished. There is a need for overall land use planning according to character, quality and location, and to the needs of people in their expanding urban and rural uses. The material needs are fundamental and real; regional land use planning should include: new cropland for the increase in population and for replacement of withdrawn lands; new areas for fish and wildlife; additional land for community, urban, and industrial uses; new areas for recreation and related purposes; land for mineral resources developemnt; land for forest and range; and areas for open space. Uses and demands for outdoor recreation, for example, under the cumulative effects of added population, disposable income, leisure time, and mobility, are expanding at rates far above those of population alone.

Of the approximately 8,500,000 acres of land having some degree of irrigation potential in Washington, only 1,123,000 acres, or 13 percent, are presently irrigated. There is a need of and potential for recreation areas at the State and local levels. Approximately 10,000 acres have been identified at the State and local level for potential outdoor recreation use; this, supplemented by developments on Federal lands, will help to meet the recreational demands of future generations.

Resource planners for the present and future are particularly concerned with the ramifications of more rational and efficient uses of available water in relation to arable land. Prospective means include: advancing technology in surface and underground water storage, transmission, and application; more efficient use of water; water transfers within and without local drainage basins and irrigation systems; and exchanges of water supplies to permit more efficient development and use of water and land resources.

Water resource development in the State will continue to progress. The people of Washington have learned the value of wise conservation, intelligent development, sustained management, and controlled use of the natural resources. Excellent cooperation among the various development and management agencies from all levels of public and private enterprise has helped to make the State a mecca for its citizens and for the thousands of tourists who visit each year.

Multiple-purpose planning is of primary importance for the most efficient use and preservation of the resources. The foremost determinant in the development and preservation of the natural resources is the well-being of all the people. The abundance of clean water, fertile land and timbered areas, plus technological advances, will help to meet the future demands for more diversified agricultural production, recreational activities, and employment opportunities in the State of Washington.

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