

**GEOLOGIC HISTORY AND  
ROCKS AND MINERALS OF WASHINGTON**



**By VAUGHN E. LIVINGSTON, JR.**

**Washington Department of Natural Resources  
Division of Mines and Geology**

**Information Circular No. 45**

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#### COVER PHOTO

Mount Rainier, the snowclad monarch of the Cascade Range. Standing 14,408 feet above sea level, the dormant stratovolcano Mount Rainier is the tallest mountain in Washington, and dwarfs the adjacent 5,000-to-6,000-foot peaks of the Cascade Range.

Known as Tahoma to the Indians, the mountain was named Rainier by Captain George Vancouver in 1792 in honor of Admiral Peter Rainier of the British navy. The mountain was first climbed by General Hazard Stevens and P. B. Van Trump in August of 1870. The mountain and part of the surrounding area was established as a national park in 1899.

(Photo courtesy of Rainier Brewing Co.)

State of Washington  
Department of Natural Resources  
BERT L. COLE, Commissioner of Public Lands  
DON LEE FRASER, Supervisor

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DIVISION OF MINES AND GEOLOGY  
MARSHALL T. HUNTTING, Supervisor

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By  
VAUGHN E. LIVINGSTON, JR.



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## FOREWORD

For many years the Washington Division of Mines and Geology has been receiving requests, especially from students, for a geologic history of our state. This report was prepared to help supply this need.

The report includes a general geologic history of Washington, and it gives information on the rocks and minerals that have played a part in the history of the state's mineral economy.

We thank Professor Norman Anderson of the University of Puget Sound and Professor Frank Scott of Washington State University, both of whom reviewed the manuscript and made helpful suggestions on how it could be improved. Thanks are also due W. A. G. Bennett and W. W. Rau of the Division staff for helpful comments and advice.

MARSHALL T. HUNTING, Supervisor  
Division of Mines and Geology

November 20, 1969



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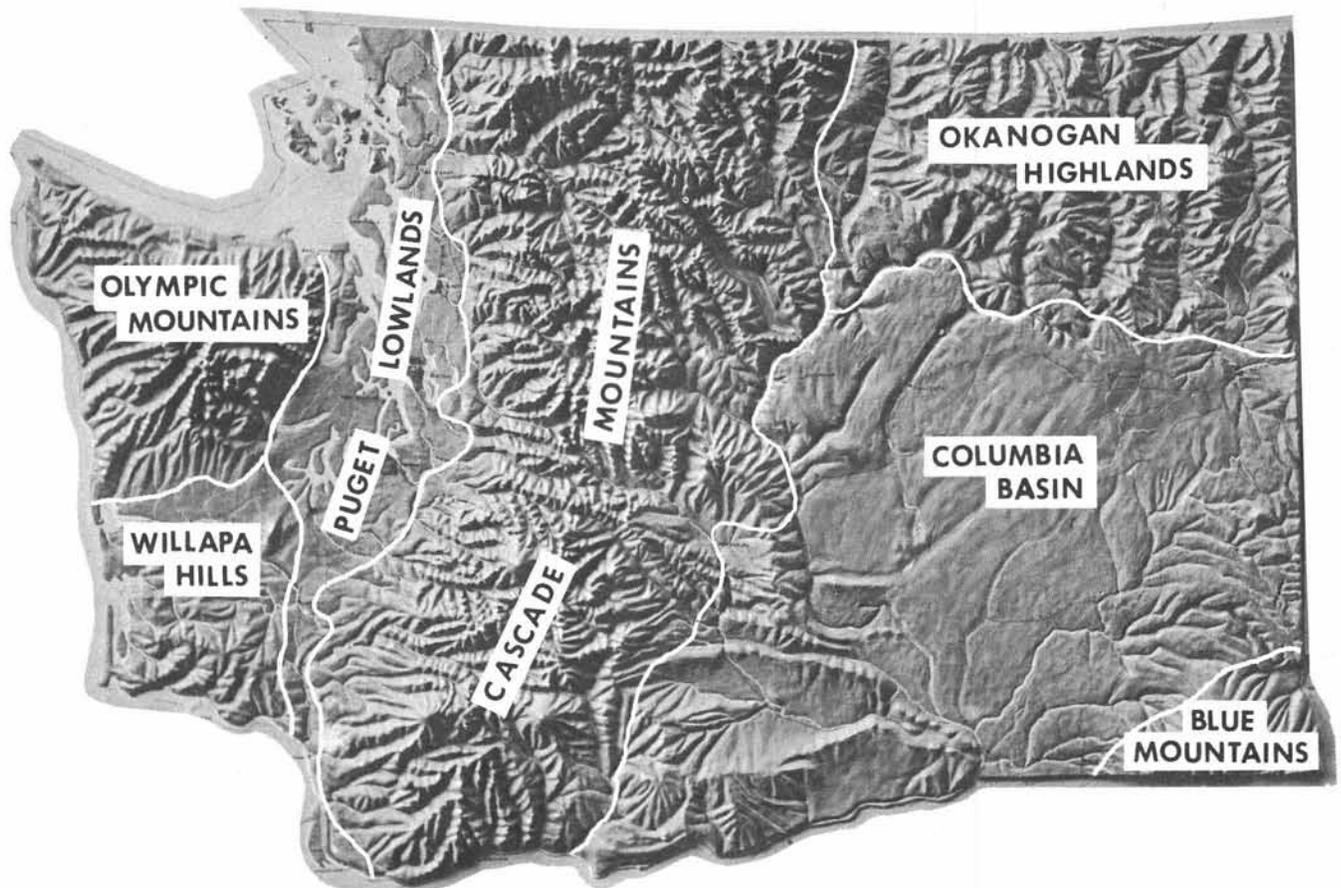
# GEOLOGIC HISTORY AND ROCKS AND MINERALS OF WASHINGTON

BY VAUGHN E. LIVINGSTON, JR.

## INTRODUCTION

The complex geology of Washington is responsible for many contrasts within the state. The Cascade Mountains form a barrier that limits rainfall in some parts of eastern Washington to less than 10 inches per year, in contrast with some areas in the western part of the state that receive as much as 200 inches of rain annually. The rugged Cascades, with their majestic snow-

capped volcanic peaks, contrast sharply with the lowlands of the Puget Sound area, the coulee-divided mesas of central Washington, and the rolling hills of the Palouse country. The towering Olympic Mountain Range stands as a sentinel to the Strait of Juan de Fuca and contrasts sharply with the flat ocean beaches and the less rugged mountains of the Coast Range to the south.



*Physiographic provinces of Washington. Figure 1.*

## PHYSIOGRAPHIC PROVINCES OF WASHINGTON

Washington is divided into seven physiographic provinces or areas that have distinctive landforms. They are: the Blue Mountains, Columbia Basin, Okanogan Highlands, Cascade Mountains, Puget Lowlands, Olympic Mountains, and Willapa Hills, all shown on Figure 1. Each of these provinces has a distinct topography. Unlike the states that border the Atlantic Ocean, Washington has no broad flatland or coastal plain adjacent to the sea, and, unlike some of the southern states, Washington has no extensive swamplands, but almost all other physiographic forms are represented in the state.

The climate, topography, and mineral resources differ from one province to another. These differences result from the varied geologic histories of the provinces. It is apparent that the geology of an area has a great effect on economic conditions and on the physical environment of the people who live there. The relatively flat Puget Lowlands have excellent industrial sites, an abundance of industrial minerals, and agricultural lands; the rugged Cascade and Olympic Mountains provide timber, metallic and nonmetallic minerals, recreational opportunities, and scenery unsurpassed; the Okanogan Highlands are well known for their metallic and non-metallic mineral deposits, timber resources, recreation potential, and livestock range; the Willapa Hills provide timber; the Columbia Basin is a great agricultural region and has many lakes that provide year-round hunting and fishing recreation; and the Blue Mountains are known for stock raising, timber, and recreation.

### BLUE MOUNTAINS

The Blue Mountains province is in the extreme southeastern part of the state and constitutes the northeastern end of a mountain range that trends southwestward into central Oregon. It is bounded by the Columbia Basin province on the north and west; it extends into Idaho on the east, into Oregon on the south, and almost to Walla Walla on the west. The rocks that make up the province are predominantly basalt flows that are a continuation of those of the Columbia Basin, and the boundary between the two provinces is indefinite. The area is deeply and complexly dissected by streams and rivers, some having valleys more than 2,000 feet deep. Streams have cut deeply into the mountains in some places in the extreme southeast corner of Asotin County, so that rocks older than the plateau-type basalts have been exposed. Ridges between drainage systems are mostly broad and flat; some are almost 6,000 feet above sea level. Generally, the area slopes north and west and drains into the Snake and Columbia Rivers. In the southeastern part, however, the streams drain north and south into the Grande Ronde River, which empties into the Snake River near Rogersburg, in the southeastern corner of Asotin County.

### COLUMBIA BASIN

The Columbia Basin province is bordered on the north by the Okanogan Highlands and merges to the west with the Cascade Mountains. This province is often called the Columbia Plateau, but it is really a basin, being surrounded on all sides by mountains. The Columbia Basin has not been as thoroughly dissected by erosion as have the other provinces of the state, although where large streams crossed the area they have dug deep, almost vertical-walled valleys. The Columbia and Snake Rivers have cut trench-like valleys that in some places are almost 2,000 feet deep. Generally, however, the province has a gently rolling, almost plain-like topography, although there are some ridges that reach about 2,500 feet above the basin floor.

The province has several distinct subprovinces, which are: the Waterville Plateau, Quincy Basin, Pasco Basin, Channeled Scablands, and Palouse Hills. Probably the most interesting of these subprovinces is the Channeled Scablands. The landforms that make up this subprovince were carved when torrents of water, which were derived from the melting of the continental glacier, flooded the area, stripping the soil cover and cutting numerous southwest-trending channels in the basalt.



*Subprovinces of the Columbia Basin physiographic province. Figure 2.*

Other interesting features of the Columbia Basin are the east- to southeast-trending ridges—the Frenchman Hills, Saddle Mountains, Horse Heaven Hills, Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Manastash Ridge, and Toppenish Ridge. All these

ridges are surface expressions of anticlinal folds; they begin along the east edge of the Cascade Mountains and die away toward the center of the basin. Still other interesting features of the area are the tremendous coulees, Grand Coulee and Moses Coulee, that rivers cut into the thick basalt flows during the ice age.

### OKANOGAN HIGHLANDS

The Okanogan Highlands, in the northeastern part of the state, are bordered on the south by the Columbia Basin and on the west by the Cascade Mountains. The province slopes generally toward the south, and all major streams drain in that direction except the Pend Oreille River, which flows north through Pend Oreille County. The area has been thoroughly dissected by streams whose valley walls are comparatively smooth and gentle, being broken only occasionally by cliffs. The highest mountain peaks are over 7,000 feet in elevation, but, in spite of their heights, the terrain is not as rough as might be expected. Probably the continental ice sheet that once covered the area was responsible for this — as it moved southward it beveled and ground off the jagged protrusions in its path, leaving the valley walls rounded and smooth.

### CASCADE MOUNTAINS

The Cascade Mountains province forms a long spine from the Canadian border to the Columbia River, dividing the state into an eastern and a western part. The mountains are bounded on the east by the Okanogan Highlands and the Columbia Basin, and on the west by the Puget Lowlands.

This province can be considered in two parts, the northern Cascades and the southern Cascades. The dividing line between the two is approximately at Snoqualmie Pass. The northern Cascades have been subjected to extensive alpine glaciation, and many of the higher peaks still have active glaciers on them. The valleys are deep, U-shaped, and commonly have cirque basins at their heads. The rocks that compose the northern Cascades are granitic intrusives, old metamorphosed sedimentary and volcanic rocks (phyllite, marble, greenstone, greenschist, gneiss, etc.), and scattered patches of younger volcanic extrusive rocks. The southern Cascades are composed of Tertiary and Quaternary volcanic rocks and a few sedimentary and igneous intrusive rocks.

Probably the most spectacular features of the Cascade Mountains are the five dormant volcanoes: Mount Baker, Glacier Peak, Mount Rainier, Mount Adams, and Mount St. Helens. These five cones were formed during Pleistocene to Recent time, but we cannot be sure one or more of them will not erupt again some time in the future. In fact, the latest eruption of Mount St. Helens

occurred about 1854, and Mount Rainier and Mount Baker both have active gas vents at their summits.

### PUGET LOWLANDS

The Puget Lowlands extend from the Canadian border to the Columbia River and are bounded on the east by the Cascade Mountains and on the west by the Olympic Mountains and the Willapa Hills. The part of the province north of Tenino was repeatedly covered by continental glaciers during part of the Pleistocene Epoch, so that most of the area is now covered with a layer of glacial till and outwash gravel, leaving very little bedrock exposed. In many places rivers have cut channels in the glacial drift plains, leaving the areas between drainages as low flat-topped platforms. Lake Washington, Sammamish Lake, Lake Whatcom, and a multitude of smaller lakes scattered over the drift plain owe their existence to some phase of glaciation. The southern part of the Puget Lowlands province has been sculptured mostly by stream action; it is much narrower than the northern part, and bedrock exposures are much more abundant.

### OLYMPIC MOUNTAINS

The Olympic Mountains rise from sea level to almost 8,000 feet in elevation. They are bordered on the east by the Puget Lowlands, on the north by the Strait of Juan de Fuca, the west by the Pacific Ocean, and the south by the Willapa Hills. The core of the Olympic Mountain range consists of slightly metamorphosed sedimentary rocks bounded on the north, east, and south by a band of volcanic rocks. The rocks along the Pacific Coast, the Strait of Juan de Fuca, and Puget Sound are Tertiary sandstone, siltstone, conglomerate, and volcanics. Most of the Tertiary rocks in low-lying parts of the province have been mantled with Pleistocene glacial drift. Stream drainage radiates in all directions from the center of the range. The interior highlands of the province have been extensively sculptured by alpine glaciation; the heads of valleys end in cirque basins; and the valleys are deep and U-shaped.

### WILLAPA HILLS

The Willapa Hills province is bounded on the east by the Puget Lowlands, on the west by the Pacific Ocean, the north by the Olympic Mountains, and the south by the Columbia River. It is composed of low mountains, few of which rise more than 2,000 feet above sea level. These mountains are cut by many crooked valleys, which have fairly steep walls. Flat sand ocean beaches border the province on the west from the Columbia River north to Grays Harbor.

## GEOLOGIC HISTORY OF WASHINGTON

Historical geology is the study of the succession of events through which the earth has passed. This history is deciphered by studying rocks and the fossils they might contain, and interpreting the evidence through a knowledge of observable conditions that exist today. We assume that certain processes have remained unchanged down through time; for instance, rains have always fallen, water has always run downhill, sediment has always settled to the bottom of lakes and seas, winds have always blown, and waves have always pounded the shorelines. By making these assumptions and observing the effects of these different processes today, we can use the present as a general key to the past.

Washington has a long and diversified geologic history. Rocks in the state range in age from Precambrian to Recent, and fossils representing almost every geologic period have been found.

Some generalizations can be made about Washington's geologic past that will help us to understand its history:

1. The area that is now Washington has always been part of an area of the earth's crust that has been unstable

compared with the central part of the United States.

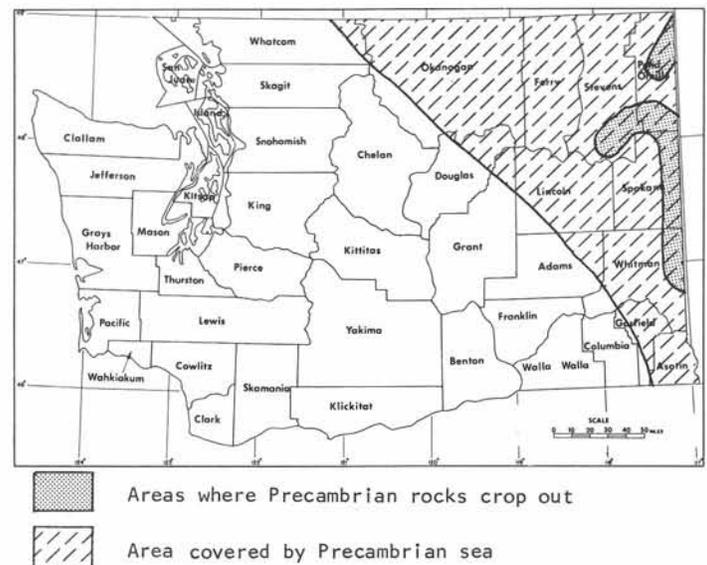
2. This area has always been near the sea or bordered by it, and frequently has been covered by a shallow sea.
3. The area has often been subjected to much volcanic activity.

Because only small areas of rocks of most ages are available for study, only an incomplete history can be deduced from them. Therefore, this description of the geologic history of Washington is based partly on what was happening in other areas at the same time. In discussing this history, we start at the beginning, or at least the beginning as we can recognize it from the rocks that are exposed in the state. The distribution of these rocks in the state is shown by the geologic map on page 23. Table 1, on page 24, summarizes the geologic history of the state, and our discussion reviews the geologic events of each era, period, or epoch as they are shown in the table.

### PRECAMBRIAN TIME

Precambrian rocks have been recognized in Stevens, Pend Oreille, Spokane, Lincoln, and Whitman Counties. Rocks of this age consist mostly of bedded, slightly metamorphosed sedimentary and volcanic rocks in Stevens and Pend Oreille Counties, and of smaller areas of metamorphosed rocks in Spokane and Whitman Counties. The metamorphosed sedimentary rocks were originally deposited in a shallow sea as lime, clay, sand, and sand and gravel. After burial they were compacted and hardened to limestone, shale, sandstone, and conglomerate, respectively. Still later, after being subjected to a moderate temperature and pressure increase, the limestone was changed to marble and dolomite, the shale became argillite and phyllite, the sandstone became quartzite, and the conglomerate became metaconglomerate. The volcanic rocks were metamorphosed to greenstone and amphibolite. (See Tables 2, 3, and 4, on pages 39, 40, and 41, respectively.) The volcanic rocks are thought to be ancient submarine lava flows, as they are interbedded with rocks of marine sedimentary origin. Gneiss, schist, migmatite, and amphibolite have been found in Spokane and Whitman Counties, where many of the rocks were metamorphosed more than those in Pend Oreille and Stevens Counties.

Some geologists believe that somewhere to the east of northeastern Washington there was a landmass that supplied some of the sand and silt that accumulated in the area. Just where that landmass was situated is not known, except that it was probably somewhere in northern Montana or in Canada. Another source of sediments was a series of volcanoes that are thought to have existed in what is now western Washington.



*Area covered by the sea during Precambrian time, and distribution of Precambrian sedimentary and volcanic rocks and their metamorphic equivalents. Figure 3.*

Judging from the distribution and kinds of Precambrian rocks, we can say that at least the eastern part of the state was covered by the sea during Precambrian time. By considering the distribution of Precambrian rocks in Washington, Idaho, Montana, and British Columbia, it appears that a seaway extended north-

westward from the interior of the United States across the north-eastern part of Washington and on into Canada. To find out when the Precambrian seaway existed, geologists have studied certain radioactive minerals that decay at a constant rate and that are present in the Precambrian rocks. According to the scientists' estimates, the sea covered the area about 1.6 to 1.4 billion years ago.

Interpretation of the climate of Washington during Precambrian time is largely a matter of guesswork. The only rocks that give a hint as to climate are the limestone, marble, and dolomite. If these rocks were deposited under conditions similar to those under which such sediments are accumulating today, they were deposited in a warm sea where the climate was mild and warm.

The Precambrian sea had animal and plant life in it, but during Precambrian time very few species of organisms had hard parts that could be fossilized. No Precambrian fossils have been found in Washington, although such things as algae, worm tracks and tubes, and bacteria have been found at other places.

Two Precambrian rock sequences are present in Washington. The older beds were uplifted above sea level, folded, eroded, and then submerged again by a broad subsidence of the earth's crust. The younger beds were then deposited over the older ones. At the end of Precambrian time both rock sequences were uplifted slightly and gently folded in southern Stevens County. In other areas of the state where Precambrian and Cambrian rocks are exposed together, it appears that there was no uplift of the sea floor at the end of Precambrian time.

## PALEOZOIC ERA

### Cambrian Period

During Early Cambrian time the land surface again sank beneath a sea, which probably encroached slowly from west to east across the entire state, although its rock record is today preserved only in Stevens, Pend Oreille, and possibly Ferry Counties. The distribution and kinds of Cambrian rocks in adjacent states show that during this period a Cambrian seaway developed over the old Precambrian seaway rocks. It extended far to the east and also northward into what is now the arctic region. Cambrian rocks in Washington are predominantly quartzite, phyllite, limestone, and some dolomite, argillite, and schist. As far as can be determined,

the sediments that were deposited in the Cambrian sea were laid down without major interruption in sedimentation. Between Middle Cambrian and Ordovician time there occurred some sort of crustal uplift that prevented Upper Cambrian strata from being deposited. This crustal movement was not intense, however, because the Ordovician rocks appear to have been deposited as a continuous series with the Middle Cambrian rocks, even though a long time period separated the two periods of deposition.

The Cambrian sea had abundant life in it, and fossil remains are common in some of the rocks. The limestone beds contain trilobites, brachiopods, and a strange cone-shaped fossil, distantly related to sponges and corals, called an archaeocyathid. The archaeocyathids lived together in colonies and commonly built reefs something like present-day coral reefs; they are important to the geologist because they are found only in the oldest Cambrian rocks and thus their appearance marks the beginning of Cambrian time. Most of the fossils found in the Cambrian of Washington are in limestone; however, a few are found in quartzite and phyllite.

There is little evidence to indicate what the climate in the Washington area was like during the Cambrian Period, but abundant limestone and the presence of fossils of reef-building creatures are suggestive of warm, stable conditions during at least part of this time.

Radiometric studies of Cambrian rocks show that these rocks range between 570 million and 500 million years in age (the Cambrian Period was about 70 million years long). These ages have been determined by studying the decay of certain radioactive minerals.



Area where Cambrian rocks crop out



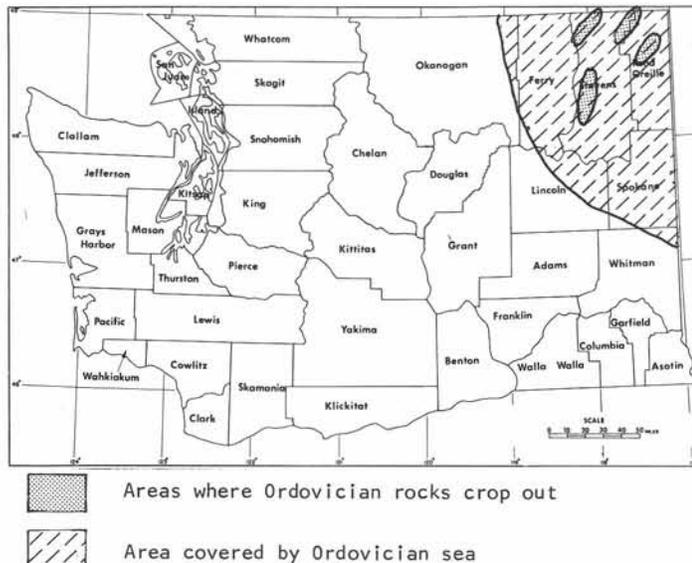
Area covered by Cambrian sea

Area covered by the sea during Cambrian time, and distribution of Cambrian sedimentary rocks and their metamorphic equivalents. Figure 4.

### Ordovician Period

There is no evidence showing a physical break in the deposition of sediments into the sea at the end of Cambrian time; however, as discussed previously, there is a considerable amount

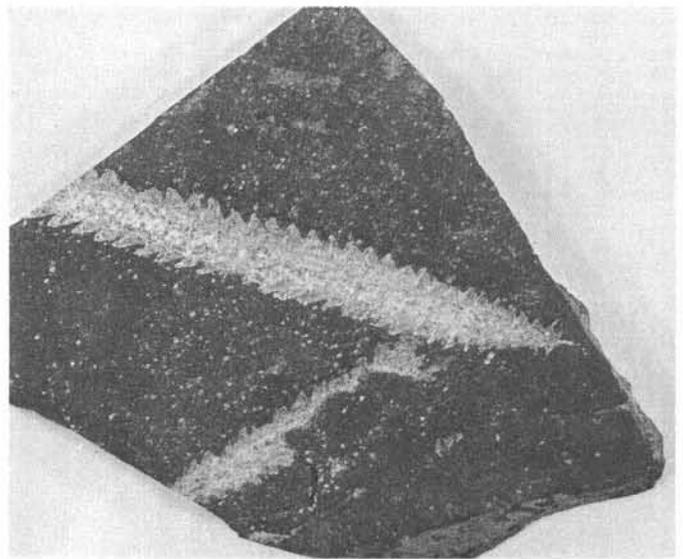
of time not represented by the rock record. Ordovician fossils seem to be in unbroken sequence with those of Cambrian age. The sea during Ordovician time probably covered about the same area as had the Cambrian sea, although rocks containing Ordovician fossils have been found only in Stevens and Pend Oreille Counties.



*Area covered by the sea during Ordovician time, and distribution of Ordovician sedimentary rocks and their metamorphic equivalents. Figure 5.*

The sediments laid down during Ordovician time in what is now the state of Washington show a gradual change of sedimentary environment. The earliest of the Ordovician sediments consisted predominantly of clay-size material rich in organic matter. As time went on, conditions slowly changed so that more lime was deposited. The original sedimentary material has undergone slight metamorphism, so the Ordovician rocks are now mostly argillite and some limestone and quartzite. The limestone occurs in the upper part of the Ordovician sequence of rocks.

Ordovician fossils include brachiopods, crustaceans, and graptolites. The graptolites are especially valuable fossils to the geologist, because they are restricted almost entirely to the Ordovician. They first appeared in the geologic column during Late Cambrian time, and the creatures had become extinct by Early Carboniferous time, leaving a fossil record that covers a little more than 155 million years. Most of the species, or different kinds, of graptolites lived during the Ordovician Period, which is generally considered to be the classic age of graptolites. It is these Ordovician types that have been found in Stevens and Pend Oreille Counties. Graptolite fossils are similar in appearance to leaf or twig fossils, but the graptolite actually was a type of animal that secreted a saw-blade-looking skeleton around the out-



*Graptolite from the Ledbetter Formation of Ordovician age. Natural size. Figure 6.*

side of its soft parts. What we see as the fossil is either an impression of the whole creature or is the carbonized remains of its exoskeleton.

The climate in the Washington area during the Ordovician Period was probably warm and mild. Geologists have concluded that climate zones as we know them today did not exist during Ordovician time. They visualize large expanses of sea and a few very low-lying lands with no mountains, which would have a moderating effect on the climate and would prevent well-defined climatic zones.

Geologists have determined that the youngest Ordovician rocks in Washington are Middle Ordovician in age. This indicates that before the Silurian sediments were deposited there was a period of time during which either no Ordovician sediments were deposited or, if they were deposited, the area was later uplifted above sea level and they were eroded away. Ordovician rocks are estimated by radiometric studies to range between 500 million and 440 million years in age, or, in other words, the period lasted about 60 million years.

### Silurian Period

Silurian rocks in Washington have been found only in a very small area in northern Pend Oreille County. The Silurian sea probably covered a greater area than is indicated by the few rocks that are present, but it seems likely that the sea covered only part of the state. If the sea had been more widespread, one would expect to find Silurian rocks associated with the older Ordovician and younger Carboniferous rocks that crop out in Stevens and Pend Oreille Counties. The distribution of Silurian rocks in the



Area where Silurian rocks crop out

Area covered by Silurian sea

Area covered by the sea during Silurian time, and distribution of Silurian sedimentary rocks and their metamorphic equivalents. Figure 7.

western United States and Canada indicates that the seaway was smaller in Silurian time than it was during the Cambrian and Ordovician Periods. The known Silurian rocks are argillite and limestone; other rocks that may be Silurian in age are conglomerate and sandstone. If the conglomerate is Silurian in age, the seashore was probably close by, because this is generally thought of as a nearshore deposit.

Coral, crinoid, brachiopod, and bryozoan fossils have been found in the Silurian rocks. Some of the corals are of colonial type; that is, they grew together, and some of them in such large numbers that they built reefs.

As reef-building organisms are usually found in warm water, the presence of these fossil corals in Silurian rocks is evidence for a warm, mild, nearly uniform climate during the Silurian Period. In other parts of the United States, Silurian rocks indicate an arid, or warm dry climate.

Judging from the Silurian rocks that are present in Washington, it appears that there was not much movement of the earth's crust during Silurian time. In fact, it is impossible at present to differentiate some of the Silurian rocks from Devonian rocks where they occur together in one area, indicating a long period of uniform geologic conditions. The length of the Silurian Period is estimated to have been about 45 million years.

### Devonian Period

Devonian rocks occur in Pend Oreille, Stevens, and Whatcom Counties, and on Orcas Island in San Juan County. In eastern Washington the rocks are argillite, limestone, sandstone, and conglomerate. In western Washington they are argillite, cherty quartzite, and smaller amounts of limestone, conglomerate, graywacke sandstone, and volcanic rocks. As all these rocks were deposited in the sea, we can assume that at least the northern part

of the state was below sea level during part of Devonian time. The Silurian seaway had been uplifted during Early Devonian and later resubmerged and broadened during Late Devonian time, when it stretched from the southwestern United States northward into the



Areas where Devonian rocks crop out

Area covered by Devonian sea

Area covered by the sea during Devonian time, and distribution of Devonian sedimentary rocks and their metamorphic equivalents. Figure 8.

arctic region. The distribution of Devonian rocks indicates that a lobe or arm of this seaway extended southward through the centers of Washington, Oregon, and California, to where it connected with the main seaway. The graywacke sandstone and conglomerate constitute evidence of a nearby landmass that was being rapidly eroded. The volcanic rocks of the Devonian Period indicate that there were some strong local movements taking place in the earth's crust during part of that time. It is possible that an archipelago, or a chain of volcanic islands, extended along the west border of the seaway and by their erosion supplied most of the sediments mentioned above.

Fossil corals, bryozoans, brachiopods, algae, and snails have been found in rocks of Devonian age in Washington. All these fossils are remains of animals that had lived in the sea.

Geologists have found no evidence that climatic belts such as we have today existed during Devonian time. Plants and animals that lived during the Devonian are the types that required for their existence a warm, humid, and stable climate.

The known outcrops of Devonian rocks in Washington do not reveal their relation to the younger Carboniferous rocks, so geologists are unable to draw any definite conclusions as to folding or faulting of the earth's crust that might have taken place at the end of the Devonian Period. In other areas of the western United States, however, there is evidence that the whole western part of the continent was uplifted above sea level before the end of Devo-

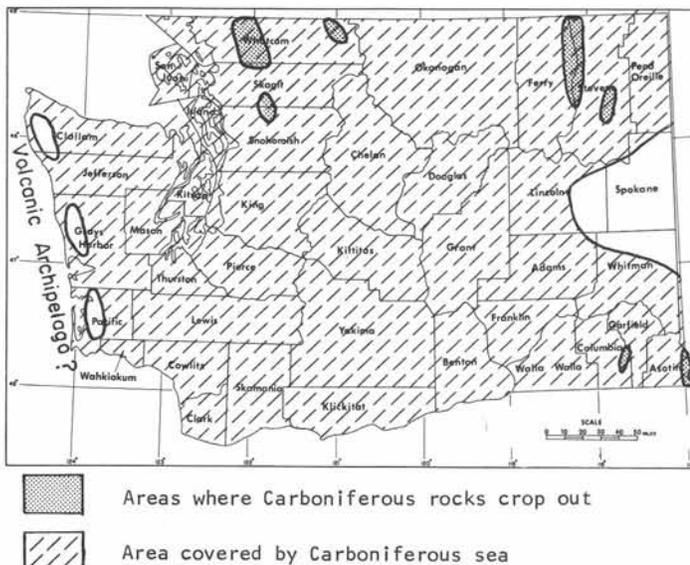
nian time, leaving the land surface exposed to erosion. Widespread erosion took place in the western United States during Early Devonian time. It was during this erosional interval that many of the Cambrian, Ordovician, Silurian, and Devonian rocks were eroded enough to expose the older underlying Precambrian strata.

The Devonian Period is estimated to have lasted about 50 million years.

### Carboniferous Period

Carboniferous rocks crop out in Stevens, Whatcom, Skagit, Snohomish, San Juan, Columbia, Asotin, and probably Ferry Counties. Most rocks of this age in western Washington are slightly metamorphosed and consist of shale, argillite, slate, gritstone, conglomerate, limestone, graywacke sandstone, and volcanic breccia. In northeastern Washington, Carboniferous rocks are limestone, dolomite, graywacke, limy argillite, and volcanic rocks. In Columbia and Asotin Counties they are argillite, graywacke sandstone, cherty slate, and volcanic rocks of various kinds.

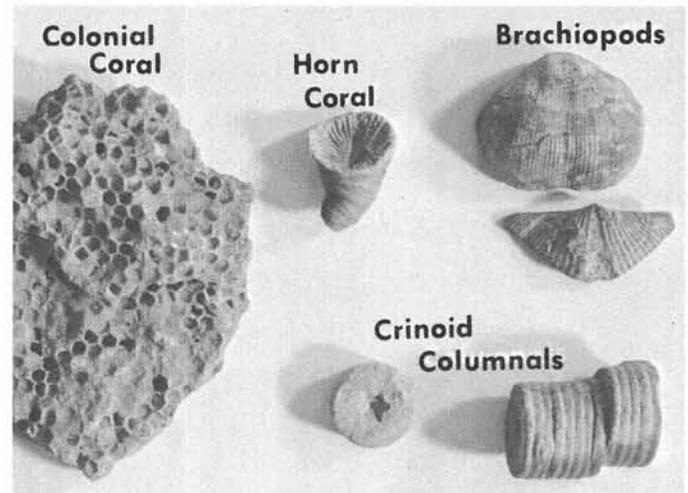
The sedimentary rocks were deposited in a shallow sea bordered by a landmass in the area that is now western Montana



*Area covered by the sea during Carboniferous time, and distribution of Carboniferous sedimentary and volcanic rocks and their metamorphic equivalents. Figure 9.*

and possibly by a volcanic archipelago on the west. The graywacke and conglomerate indicate a nearshore depositional environment. The volcanic rocks are indicators of crustal unrest during Carboniferous time. A broad general uplift took place about the middle of the period, raising the area above sea level. Toward the end of the period the land sank again, so that by Permian time the sea covered a larger area than it had during most of the Carboniferous Period.

Carboniferous fossils that have been found in Washington consist of corals, bryozoans, brachiopods, crinoids, fusulinids,



*Some typical fossils of the Paleozoic Era. Three-fourths natural size. Figure 10.*

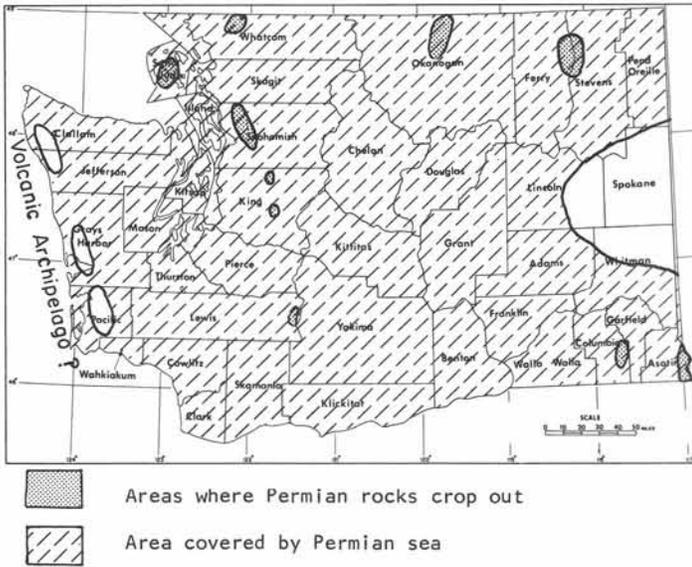
and foraminifers. In Oregon, plant fossils of this age have been found. The marine fossils indicate warm water conditions, and plant fossils of this age found in other states are indicative of a warm, moist climate that produced lush vegetation. This is the period of time when the great coal measures of the eastern part of the United States and of Europe were laid down, but the coal deposits of Washington and other western states originated at a much later time.

Using radiometric dating, scientists estimate that the Carboniferous Period lasted 65 million years. In Washington there were no obvious mountain-building movements in the earth's crust at the end of Carboniferous time. In most areas of the state where Carboniferous and Permian rocks crop out it is impossible to determine the boundary between them.

### Permian Period

Permian rocks have been recognized in Stevens, Ferry, Whatcom, San Juan, Skagit, Snohomish, King, Lewis, and Okanogan Counties and are thought to occur in Asotin and Columbia Counties. The sea probably covered most of the state during Permian time. There may have been a landmass protruding into the state from the east, and also a volcanic archipelago occupying about the same area in western Washington that it had during Carboniferous time.

Permian fossils that have been found in Washington include fusulinids, bryozoans, crinoids, gastropods, pelecypods, scaphopods, brachiopods, and corals. The fusulinid is an interesting fossil protozoan that first appeared in the geologic column



Area covered by the sea during Permian time, and distribution of Permian sedimentary and volcanic rocks and their metamorphic equivalents. Figure 11.

their fossil remains are important in recognizing Carboniferous and Permian rocks.

Permian rocks that crop out in Washington are limestone, quartzite, graywacke, argillite, chert, conglomerate, greenstone, and volcanic rocks. The graywacke and conglomerate indicate the nearness of a landmass. Chert, which is a fine-grained variety of quartz, probably was formed when silica was precipitated from the sea water.

The climate during Permian time was drier than during Carboniferous time. Evidence for this is revealed by the many different types of plant fossils that occur in Permian rocks the world over. Unlike the Carboniferous Period, when the plants were more or less the same worldwide, during Permian time there was a wide variation representing many different types of climate. In North America the plant fossils are typical of plants found in dry climates. Permian marine fossils indicate warm, temperate water conditions.

Scientists estimate that the Permian Period lasted 55 million years. There was widespread uplift in eastern North America and also in Europe near the end of the Permian. Whether or not there was an uplift in the northwestern United States is not obvious from examination of Permian rocks in Washington, because they have been so intensely folded and faulted that their relation to Triassic rocks is poorly understood.

during Carboniferous time. It is commonly "wheat" or "spindle" shaped and ranges in length from 1/16 inch to more than an inch. Fusulinids became extinct by the end of the Permian Period, so

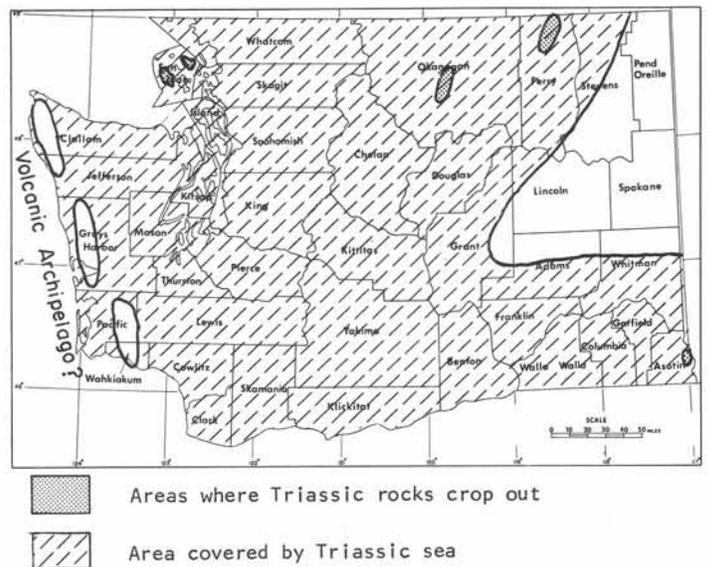
MESOZOIC ERA

Triassic Period

Triassic rocks occur in Asotin, Ferry, Okanogan, Whatcom, and San Juan Counties. Rocks of this age consist of limestone, dolomite, conglomerate, shale, graywacke, greenstone, argillite, chert, and volcanic rocks. A shallow sea probably covered most of the state during the Triassic. Landmasses are thought to have existed just east of the present Washington-Idaho boundary and as a volcanic island archipelago in the western part of the state. The seaway served as an accumulation basin for sediments and volcanic material being poured in from both sides.

Most of the Triassic fossils that have been found in Washington are pelecypods and cephalopods. The climate was arid or semiarid and had alternate wet and dry seasons. Geologists find evidence for this in areas outside the state, where many Triassic rocks are continental in origin. These formations show a predominantly red color, resulting from the oxidation of iron minerals; this oxidation is promoted by alternate wetting and drying.

At the end of Triassic time an uplift of the sea floor caused the sea to retreat. The Triassic beds were folded and eroded in



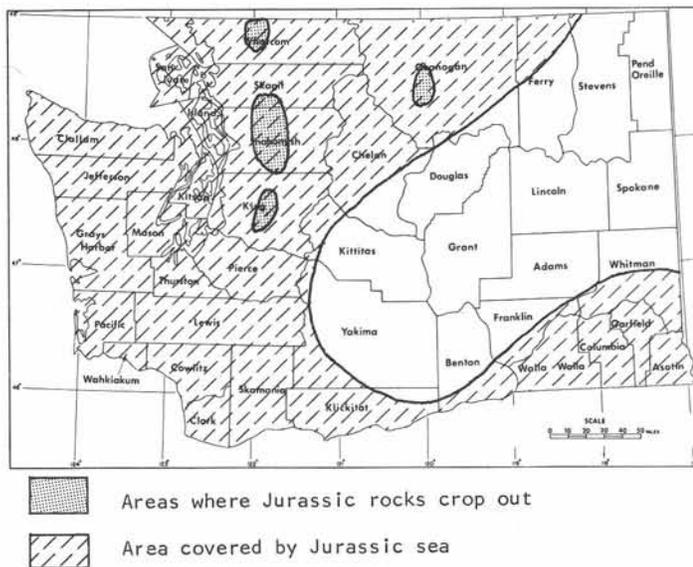
Area covered by the sea during Triassic time, and distribution of Triassic sedimentary and volcanic rocks and their metamorphic equivalents. Figure 12.

Washington before the area was again submerged during Jurassic time.

The Triassic Period is estimated to have lasted 30 million years. One of the most significant developments during this time was the rapid evolution of the dinosaurs. No dinosaur remains have been found in Washington, but elsewhere in the world, including the western part of the United States, they have been found in great abundance.

### Jurassic Period

Jurassic rocks occur in Whatcom, Skagit, Snohomish, King, and Okanogan Counties. These rocks consist of argillite, siltstone, shale, limestone, graywacke, phyllite, greenschist, greenstone, ribbon chert, and volcanic rocks. The Jurassic seaway covered



*Area covered by the sea during Jurassic time, and distribution of Jurassic sedimentary and volcanic rocks and their metamorphic equivalents. Figure 13.*

almost the same area as did the Triassic seaway except that it probably was somewhat narrower. Sediment was deposited in the seaway at a rapid rate from both east and west. The periods of sedimentation were punctuated by explosive volcanic activity, and thick layers of volcanic rocks accumulated. In many areas the volcanics are interbedded with sedimentary rocks, indicating that the lavas flowed out onto the sea floor.

Fossils that have been found in Jurassic rocks are cephalopods, pelecypods, radiolarians, and crinoids.

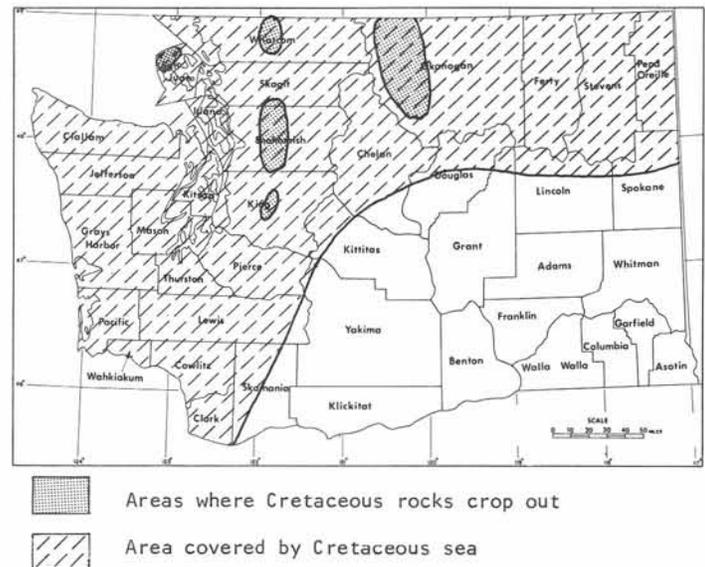
The climate during this period was warm and arid in the Early Jurassic, becoming mild with no well-defined climatic belts in the Late Jurassic.

The Jurassic Period is estimated to have lasted 59 million years. Strong mountain-building forces became active in the crustal

rock layers toward the end of the period, and the whole state was probably raised above sea level.

### Cretaceous Period

Sedimentary and volcanic rocks of Cretaceous age are exposed in San Juan, Whatcom, Skagit, Snohomish, King, and Okanogan Counties. The rocks include sandstone, limestone, shale, conglomerate, and volcanic flows. Their distribution, plus the



*Area covered by the sea during Cretaceous time, and distribution of Cretaceous sedimentary and volcanic rocks. Figure 14.*

distribution of rocks of similar age in other states and in Canada, indicates that a narrow seaway extended from about the southern tip of Alaska southward through British Columbia, Washington, Oregon, and California. The seaway was shallow and received sediments principally from the east. Toward the end of the period the seaway was filled with sediments and the area was slightly uplifted so that continental sediments were deposited in Okanogan County.

Fossils that have been found in Cretaceous rocks include gastropods, pelecypods, cephalopods, and leaf imprints. The leaf fossils are especially interesting, because they were deposited in fresh-water sediments.

The mountain-building forces that exist in the earth's crust were very active during this time. Rocks of all types that had been buried during the Paleozoic Era and earlier periods of the Mesozoic were subjected to terrific heat and pressure—so much so that many of them were converted to metamorphic rocks, such as schist and gneiss, whereas others were melted or were otherwise converted to intrusive igneous rocks such as granite. These igneous

rocks are interspersed with older rocks throughout the northern counties of the state. They include the Mount Stuart igneous complex in Kittitas, King, Snohomish, and Chelan Counties; the Chelan batholith in Chelan and Okanogan Counties; the Okanogan batholith in Okanogan County; the Colville batholith in Ferry and Stevens Counties; the Kaniksu batholith of Pend Oreille and Spokane Counties; and the other granitic rocks in Whitman, Okanogan, and Skagit Counties. In some areas these batholiths have associated with them satellite dikes (see Fig. 15) that intrude the surrounding country rock. These are very conspicuous in Pine Canyon, near Waterville, in Douglas County.

Mountain-building movements became intense by the end of the Cretaceous (the period lasted about 71 million years), and the uplift of the land forced the sea out of what is now eastern Washington. Red beds in Okanogan County indicate an alternately wet and dry climate and oxidizing conditions similar to those of the Triassic Period. The end of the Cretaceous Period also marked the end of the age of the dinosaurs, as the last of these great beasts died and their kind joined the list of extinct animals. It was also during this period that the flowering plants or "angiosperms" that dominate the plant world today began to flourish.



Satellite dikes in Pine Canyon, Douglas County. The dikes consist of rock that is more resistant to erosion than the country rock, thus they stand out as cockscomb ridges. Figure 15.

CENOZOIC ERA

Tertiary Period

Paleocene Epoch

Paleocene rocks crop out in Chelan, Kittitas, King, Snohomish, Douglas, Skagit, Okanogan, and Whatcom Counties. They consist of shale, conglomerate, arkosic sandstone, and coal.



Areas where Paleocene rocks crop out  
 Distribution of Paleocene sedimentary rocks. Figure 16.

In western and central Washington these rocks were deposited in a mountain-flanked low-lying troughlike area that may have ex-



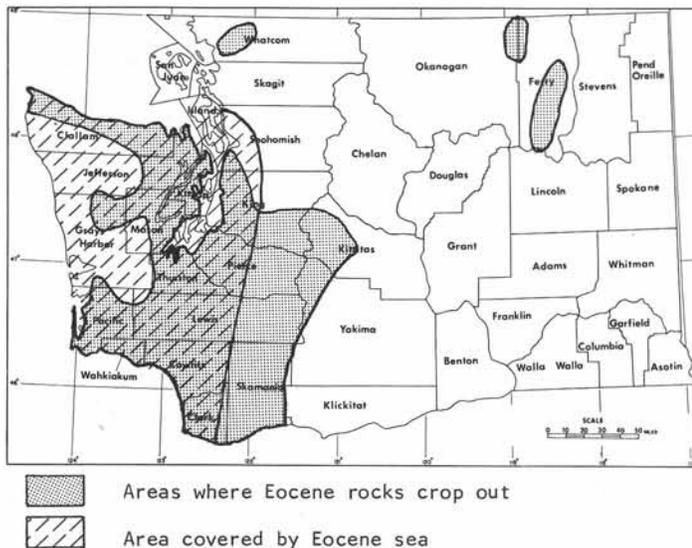
Fragment of a fossil palm frond from the Chuckanut Formation near Bellingham, in Whatcom County. (Note ball-point pen for scale.) Figure 17.

tended continuously from the vicinity of Bellingham southeastward into Chelan County near Wenatchee. The rock types indicate that they were deposited in stream channels, lakes, flood plains, and alluvial fans. The old Cretaceous mountains were being eroded rapidly during this time, and streams were carrying a tremendous amount of sediment into the trough. In the Bellingham area, swampy conditions developed periodically, causing the accumulation of peat that was later converted to coal.

This epoch of geologic time is estimated to have lasted about 10 million years. Its climate was tropical to subtropical, and numerous leaf fossils have been found in rocks deposited during this time. Among the most interesting of these leaf fossils are those of palm leaves that have been found at many locations, especially near Bellingham, and in the Liberty area of Kittitas County. By the end of Paleocene time the Cretaceous mountains had been pretty well worn down, and the long trough that extended south-eastward into the state was uplifted enough so that no additional sediments were being deposited in it.

### Eocene Epoch

Eocene rocks are exposed in all counties of western Washington and in the southern Cascades. Interfingering marine and nonmarine shales, sandstones, and siltstones indicate that the sea-



Area covered by the sea during Eocene time, and distribution of Eocene sedimentary and volcanic rocks. Figure 18.

shore extended south through the Puget Lowlands. Landward from the seashore were low-lying swamplands in which vegetal matter accumulated. This material was later converted to coal. These swamplands were periodically inundated by the sea, and as a result we find marine fossils in beds alternating with the coal seams in



Sandstone showing ripple marks that were originally formed on the sandy floor of the Eocene sea. Near Wilkeson, Pierce County. Figure 19.

some areas. Offshore, to the west of the coastline, a series of volcanic centers were pouring lava and volcanic debris into the sea. Also, much volcanic material was being deposited in the sea from volcanoes along the shore. These volcanic rocks can be seen in Cowlitz, Wahkiakum, Lewis, Grays Harbor, Thurston, Jefferson, Kitsap, and King Counties.

A considerable amount of volcanic activity also took place in the area of the central and southern Cascade Mountains. During Eocene time a large fresh-water lake in the central part of the state extended from about the location of Snoqualmie Pass to the present border between Washington and Oregon, and many of the volcanic eruptions had their beginnings on the bed of the lake.

A large lake developed in the area of Cle Elum during part of the Eocene. Apparently it was shallow and swampy, because several coal seams are associated with the sedimentary rocks that were formed in the lake. In this same area, but before the deposition of the coal-bearing sediments, a dike swarm composed of thousands of basalt dikes was intruded into the Paleocene sedimentary rocks. Many of these dikes are exposed along the Swauk Pass Highway.

Marine life was abundant during the Eocene. Fossil clams, oysters, snails, cephalopods, scaphopods, barnacles, and foraminifers have been found in marine rocks of this age. Fossil remains of vertebrate animals have been found in the nonmarine sedimentary rocks of central Washington. The angiosperms had become the dominant plant life, and their fossil remains show marked similarities to existing floras. The ancestries of many of the vertebrate

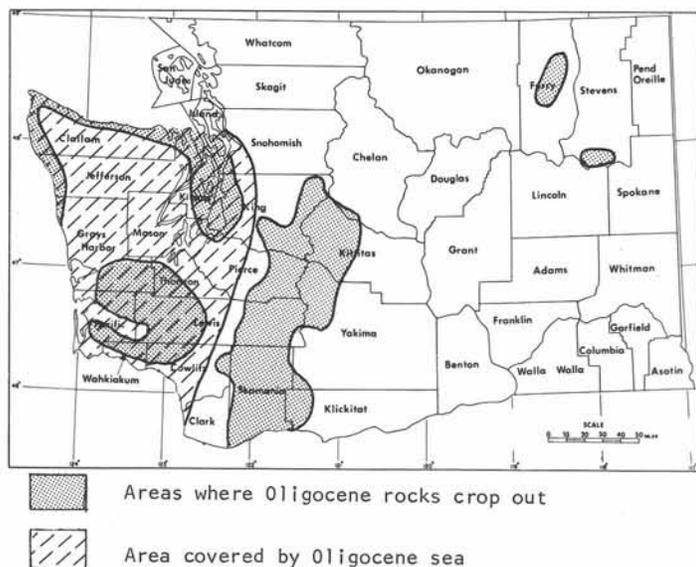
animals living today had their beginnings during the Eocene. The mammals had become the dominant animals, replacing the then extinct dinosaurs.

The climate was warm temperate, probably similar to that of the middle Atlantic Coast states today.

The Eocene Epoch lasted about 16 million years. During that time the old Cretaceous mountains, which were not very high at the beginning of the epoch, were leveled by erosion, and the seashore was pushed steadily westward by sedimentation and a slowly rising continental landmass to the east. A tremendous thickness of volcanic rocks buried the pre-Eocene terrain in the western and central parts of the state; these rocks are exposed in a belt partly surrounding the Olympic Mountains. The volcanic eruptions along the coast were basaltic, and those in the central part of the state were andesitic. Andesitic eruptions are usually explosive and commonly build up cones similar to the big volcanic peaks of the present-day Cascades.

### Oligocene Epoch

During Oligocene time the seashore was pushed farther west by the slowly rising continental landmass. Marine rocks of



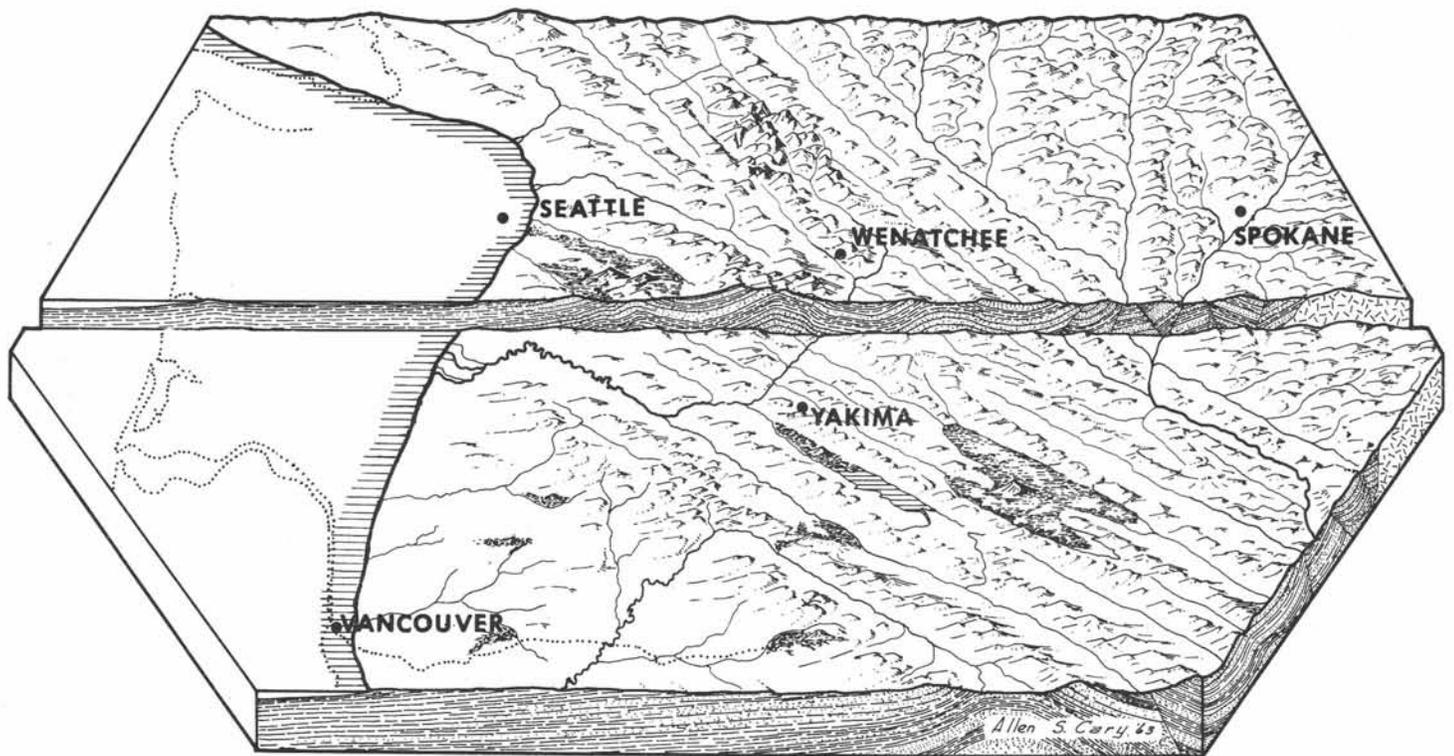
Area covered by the sea during Oligocene time, and distribution of Oligocene sedimentary and volcanic rocks. Figure 20.

this age have been found as far east as Seattle, Chehalis, and Kelso. The sea was shallow and was being filled by mud, silt, and some sand and gravel, which were later compacted to form mudstone, shale, siltstone, sandstone, and conglomerate. Volcanic activity along the coast had diminished after Eocene time, but volcanoes were very active in the area of the present-day Cascade Mountains. Great thicknesses of pyroclastic and flow rocks accumulated during Oligocene time. Two large lakes existed—in the Republic and southern Stevens County areas—during part of the Oligocene. Excellent fossil leaves and insects have been found in the tuffs and shales that accumulated in the Republic area lake. Sediments deposited in the lake in southern Stevens County contain enough uranium minerals so that mining of them will probably be undertaken. The uranium minerals were weathered from older rocks that surrounded the lake. The abundant andesitic volcanic rocks associated with the Oligocene sedimentary rocks in both areas indicate explosive volcanic activity during the existence of the lakes.

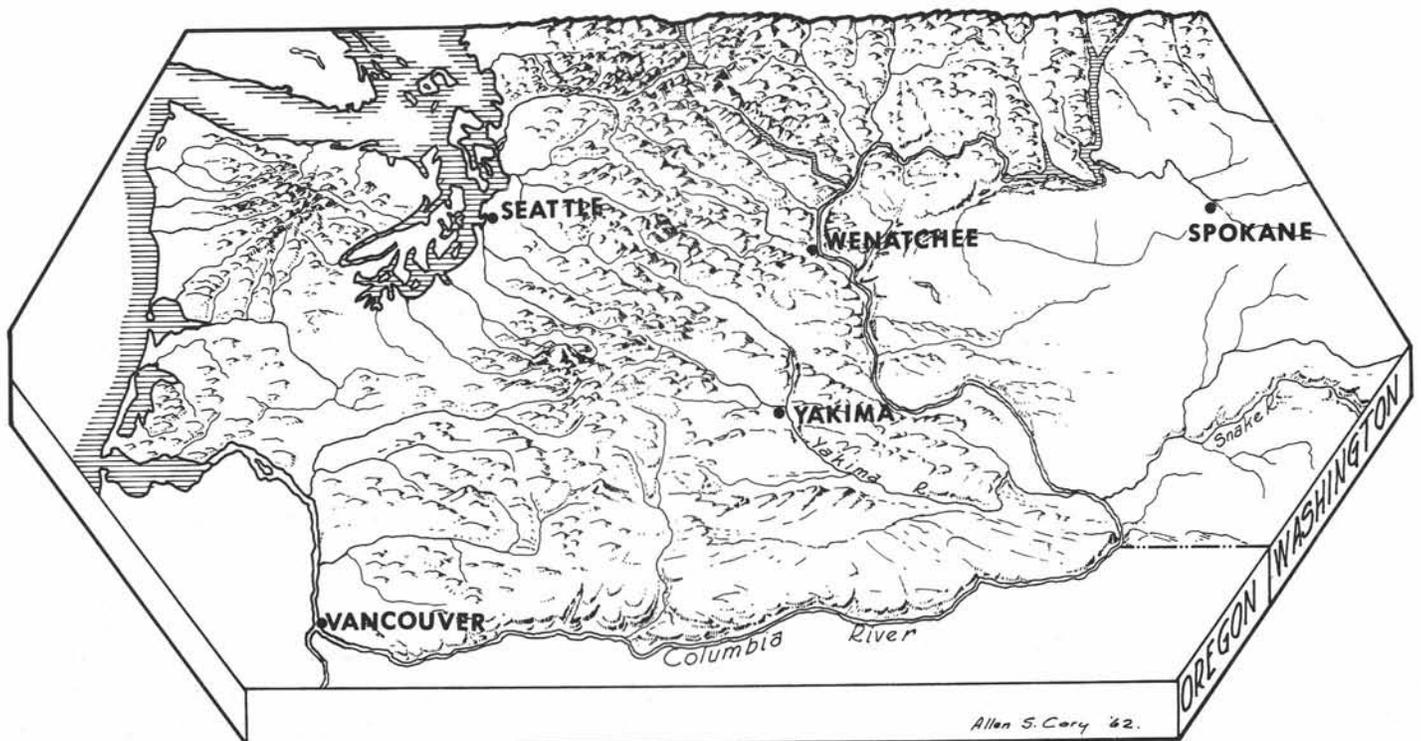
Marine Oligocene sedimentary rocks occur in Clallam, Jefferson, Kitsap, King, Grays Harbor, Lewis, Pacific, Wahkiakum, Cowlitz, and Thurston Counties. Continental sedimentary rocks have been found in Ferry, Skamania, Klickitat, Stevens, Lewis, and Cowlitz Counties. Oligocene volcanic rocks occur in King, Ferry, Yakima, Kittitas, Lewis, Skamania, Cowlitz, and Clark Counties.

Oligocene marine fossils are similar to those found in Eocene rocks; however, certain warm-water species had disappeared, indicating that the temperature of the ocean had become cooler. Land fossils, particularly plant fossils, indicate a temperate climate somewhat similar to that of the middle Atlantic Coast states.

The Oligocene Epoch lasted 12 million years, and during that time a low northwest-trending mountain range was formed by folding and faulting of the earth's crust. The mountains were probably nowhere near the size of our present-day Cascades, but they were sufficiently large and were raised rapidly enough to change the drainage pattern of rivers from essentially east-west during Eocene to northwest-southeast. This drainage pattern, established during the Oligocene, still persists today in the Cascades. On a map of Washington one can see that most of the major rivers in the Cascade Mountains physiographic province flow northwest or southeast. During the time of mountain building, a tremendous thickness of volcanic rock both flowed and was blown out onto the earth's surface from eruptive centers scattered over the southern part of the



*Drainage pattern and structural grain during the Oligocene Epoch. Note that streams and ridges trend northwest-southeast. (From Mackin and Cary, 1965.) Figure 21.*

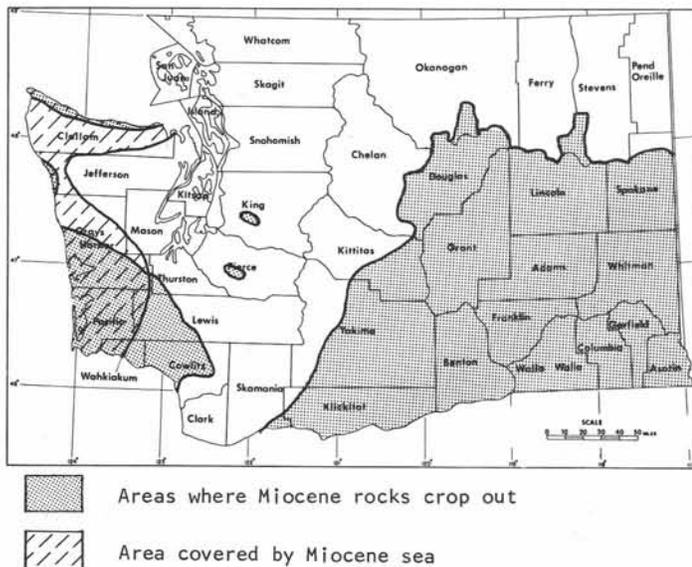


Drainage pattern today. Note that the northwest-southeast structural grain established during the Oligocene still controls many of the large streams flowing out of the Cascade Mountains. (From Mackin and Cary, 1965.) Figure 22.

state. Still recognizable in the central and southern Cascade Mountains are some of the old strata cones; that is, volcanic peaks that were built up of layers of ash and lava flows.

### Miocene Epoch

By Miocene time the seashore had been pushed westward almost to the present coastline along the west side of the Olympic Peninsula. However, there was an embayment that extended from



Area covered by the sea during Miocene time, and distribution of Miocene sedimentary and volcanic rocks. Figure 23.

about the south flank of the Olympic Mountains to the Oregon border. Invertebrate marine fossils such as clams, oysters, scaphopods, snails, echinoids, and foraminifers have been found in the marine rocks. An area several square miles in extent in northern Cowlitz County and south-central Lewis County is underlain by sedimentary rocks originally laid down in fresh or brackish water. These continental sedimentary rocks interfinger with the marine sedimentary rocks to the west, so no definite boundary between them can be drawn. Sandstone and shale are the main types of sedimentary rocks that were deposited during the Miocene; however, conglomerate was laid down also.

In eastern Washington and extending into southwestern Washington along the Columbia Gorge, great volcanic eruptions took place during Miocene time. Unlike the explosive eruptions that took place during the Oligocene, the Miocene volcanoes were the quiet type. This type of eruption was described eloquently by Mark Twain in "Roughing It," written when he visited the volcano Mauna Loa in Hawaii. He reported,

. . . the noise made by the bubbling lava is not great, heard as we heard it from our lofty perch. It made three

distinct sounds—a rushing, a hissing, and a coughing or puffing sound, and if you stand on the brink and close your eyes it is no trick at all to imagine that you are sweeping down a river on a large low-pressure steamer, and that you hear the hissing of the steam about her boilers, the puffing from her escape pipes, and the churning rush of the water abaft her wheels. The smell of sulfur is strong but not unpleasant to a sinner.

More than 25,000 cubic miles of highly fluid lava welled up from the mantle of the earth through great fissures and flowed out onto the earth's crust almost like water, forming great lakes of molten rock. Successive flows followed one after another. The exact thickness of the basalt that fills the Columbia Basin and constitutes part of the Blue Mountains is unknown, but geologists working in Oregon have measured one section that is 6,000 feet thick in the Blue Mountains. Oil and gas test wells drilled in Washington have penetrated more than 4,000 feet of basalt before reaching pre-Miocene rocks. The lava flows spread out over a terrain having a considerable amount of relief. Along the eastern edge of Washington, tops of the pre-Miocene mountains protrude above the lava plain as steptoes. The lava filled many valleys and dammed streams, forming lakes. As time passed, the lakes eventually overflowed and the streams circumvented the lava dams and found new courses, only to be redammed and pushed out of their channels by new floods of lava. This constant battle between the streams of water and the lava floods continued until the streams were more or less consolidated into the ancestral Columbia River and forced to skirt the northern edge of the lava field. The abundant lake deposits of silt, sand, and clay; the foreset-bedded palagonite (a yellow glassy rock that forms when lava flows into water) layers that occur between different basalt flows; along with the ancient lava-filled stream channels that are exposed in many of the coulee walls, all bear mute witness to the struggle that continued between the opposing streams of water and of lava.

The lakes that were formed by the lava dams served as accumulation centers for the remains of plants and animals that lived during the Miocene. Fossil leaf impressions, petrified wood (see Fig. 24), fossil insects, and bones of vertebrate animals have been found in, or associated with, these ancient lakes. Three of these lakes are of particular interest. Two of them, one in Kittitas County between Ellensburg and Yakima and the other between Vantage and Quincy in Grant County, had the right conditions for rapid growth of diatoms, for on the beds of the two mentioned lakes the skeletal remains of these microscopic plants accumulated in deposits as much as 15 feet thick. The third lake, which was in the Spokane area, has yielded from its sediments some fossil leaf collections that have been important in establishing the age of the basalt flows in the Columbia Basin. These fossils include many of swamp cypress and also of the ginkgo and dawn redwood, which today are native only to interior China.

One of the most unusual fossils ever found associated with the Miocene basalt flows is a mold, containing a few bones, of a small rhinoceros. The mold is preserved in pillow basalt and palag-



*Petrified log that has been exposed by weathering and erosion. Ginkgo Petrified Forest State Park near Vantage, Kittitas County. At the time it was covered by basalt, the log was probably lying at the bottom of a pond or in a swamp. During the millions of years it was covered, the wood was gradually replaced by silica to form petrified wood. Figure 24.*

onite that overlies a thin sand bed. The rhino, which was dead and bloated at the time, was lying in a small pond, and as the molten lava flowed into the pond the lava was chilled, forming basalt pillows and palagonite that covered the dead rhino, as well as several water-soaked logs, without cremating them. The pillows were formed around the beast in such a way as to preserve its shape.

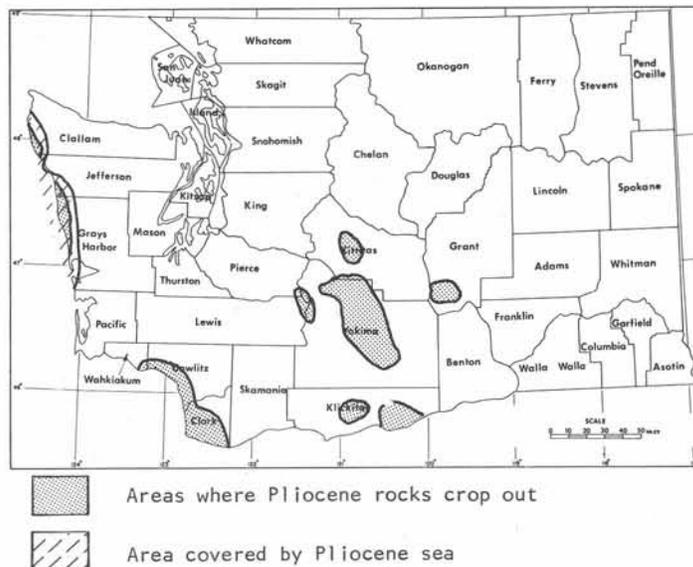
During the time the volcanic activity was taking place, the basin was slowly subsiding or sagging. The sag may have been brought about in part by the weight of the millions of cubic feet of basalt being spread onto the earth's surface by continual eruptions.

The Miocene Epoch lasted about 20 million years, and as it drew to a close the fissure eruptions became fewer and fewer until all volcanic activity in the basin stopped. At the same time, compressional forces in the earth's crust were beginning to slowly upfold parts of the Columbia Basin into long narrow northwest- to west-trending ridges called anticlines.

The climate during Miocene time was temperate. Such trees as bald cypress, ginkgo, chestnut, beech, fig, sycamore, tulip, magnolia, sassafras, hickory, poplar, birch, elm, and maple flourished.

#### Pliocene Epoch

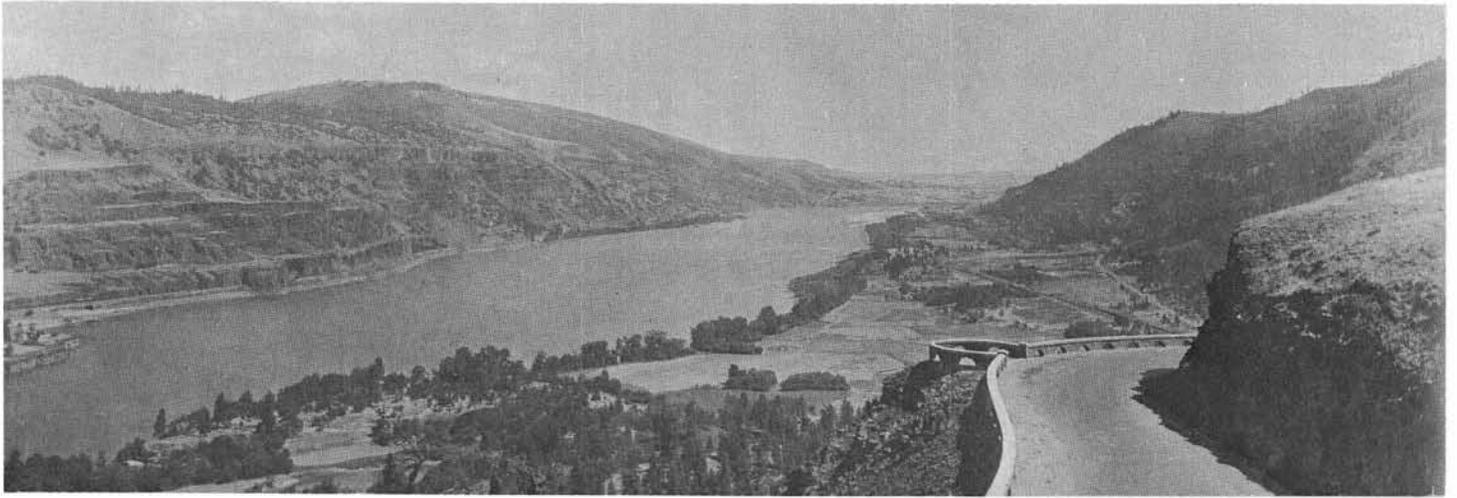
By the beginning of Pliocene time the seashore had been pushed to within a few miles of its present location, with the ex-



*Area covered by the sea during Pliocene time, and distribution of Pliocene sedimentary and volcanic rocks. Figure 25.*

ception of a large embayment in the Grays Harbor area. Pliocene rocks consist mainly of shale, sandstone, mudstone, conglomerate, and beds of ash. At one time during early Pliocene the Columbia River valley from Vancouver to the sea was choked with coarse gravel deposits. The river has since removed practically all of the old valley fill, but remnants can still be seen as bold outcrops of conglomerate along the valley walls between Vancouver and Kelso. An apron of coarse sediments derived from the erosion of the volcanic upland was laid down along the east flank of the up-rising Cascades. Volcanic activity was considerably less than during the Miocene, but a few volcanoes were still erupting in the southern part of the state.

The Pliocene Epoch lasted about  $5\frac{1}{2}$  million years, which is shorter than other epochs of the Tertiary Period. This short duration may account for the small amount of sedimentation and volcanic rock accumulation in comparison with the older epochs. It appears to have been a time of mountain building. The forces that had begun during the Miocene continued to push up the great anticlinal ridges in the Columbia Basin. The rate of uplift was slow enough, however, so that the large streams, such as the Yakima, Columbia, and Snake Rivers, flowing across the basin could down-cut their channels at a rate equal to the uplift. Thus, water gaps now exist through the Ahtanum Ridge-Rattlesnake Hills, Saddle Mountains, Frenchman Hills, Horse Heaven Hills, Manastash Ridge, and Umtanum Ridge. Toward the end of the Pliocene, the mountain-building forces in the earth's crust changed direction and the Cascade Mountains began to rise. Scientists estimate that the uplift of these mountains took only about 6 million years,  $4\frac{1}{2}$  million of which were during the Pliocene. Their rise was slow enough so that the Columbia River was able to maintain its channel and cut



Looking east through the Columbia River Gorge. The Columbia River was able to downcut its channel at a rate equal to the uplift of the Cascade Mountains, thus forming this deep notch through the Cascades. (Photo by Cross and Dimmitt.) Figure 26.



Entrenched meanders of the Grande Ronde River in Asotin County. The layer-cake effect along the valley walls is caused by flat-lying basalt flows cropping out in dark bands. (Photo courtesy Washington Department of Commerce and Economic Development.) Figure 27.

the Columbia Gorge. The uplift of the Blue Mountains took place during this time also. Again, as elsewhere, the uplift was slow, and the Grande Ronde River, which had been meandering over a lowland surface, was able to incise or downcut its channel at a rate comparable to the uplift.

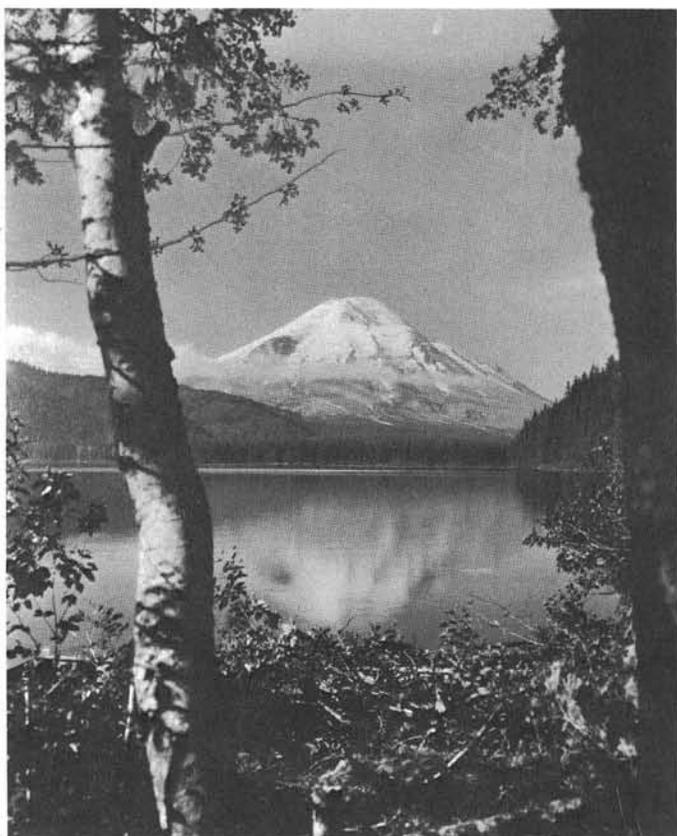
The climate during the Pliocene Epoch was similar to that of the Miocene. Camel bones have been found in sediments of Pliocene age, as have a number of different kinds of leaf fossils.

### Quaternary Period

#### Pleistocene Epoch

The Pleistocene was the age of ice in Washington, as it was in many other places in the world. The Cascade Mountains continued to be uplifted, and the five great volcanic strata cones, Mount Rainier, Mount Adams, Mount St. Helens, Mount Baker, and Glacier Peak, were formed during that time. The sea occupied about the same area it does today, except during the time when the Pleistocene glaciers forced it out of Puget Sound and the Strait of Juan de Fuca.

Early in Pleistocene time the Yakima and Columbia Rivers had wide flood plains upon which silt- and clay-size sediments were deposited each time the rivers overflowed their banks. After the floodwaters had receded, the fine sediments dried and were picked up by prevailing winds from the southwest and blown out over the Columbia Basin. These sediments were eventually dropped by the moving air currents as a blanket of silt over much of the basin, where they formed the famous Palouse soil that produces Washington's bounteous wheat crops.



Mount St. Helens, one of five very large dormant strato-volcanoes in Washington. Mount St. Helens last erupted in 1854. Figure 28.

At least three, and possibly four, times during the Pleistocene Epoch a continental ice sheet invaded Washington from the north. The first advance was during the early Pleistocene; recession of the last glacier began about 15,000 years ago.

In western Washington the ice reached into the Puget Lowlands as far south as Tenino. The Olympic Mountains acted as a buttress that split the ice sheet, forcing one lobe to go around the west side of the Peninsula, where the ice melted in the sea. The Puget Sound lobe pushed southward, completely filling the Puget Lowlands and forming an ice dam across all the river valleys that opened out of the Cascades as far south as Tenino. As a result, meltwater draining off the glacier formed up-valley lakes behind the ice dam and partly filled them with outwash sand, gravel, and silt. As the glacier moved southward, it scoured out depressions that later were filled and became Lake Whatcom, Lake Washington, and Sammamish Lake. When the ice melted, it left the area coated with a veneer of sand, gravel, and till. A very interesting topographic phenomenon that was probably developed as a result of the glaciation is the group of hummocks called "Mima Mounds," in southern Thurston County. Scientists have speculated that they might be pocket gopher cities, large ant hills, giant fish nests, or Indian burial mounds. None of these theories seems wholly acceptable, and it is more likely that the mound formation was related to ground ice, or permafrost.



Mima Mounds, on Mima Prairie, Thurston County. (Photo by Arthur M. Ritchie.) Figure 30.



Limits of continental glaciation in Washington during the Pleistocene Epoch. Figure 29.

In eastern Washington the ice sheet pushed south out of Canada, across the Okanogan Highlands, and into the northern part of the Columbia Basin. One lobe advanced as far south as Coulee City, forming an ice dam across the Columbia River at the present site of the Grand Coulee Dam. At this position, the ice remained stagnant for many years; that is, the rate of melt was equal to the rate of advance. Evidence for this is the large terminal moraine (a more or less sinuous ridge of boulders, gravel, sand, and mud) that formed at the ice front. This moraine stretches southeastward from the lower end of Lake Chelan across the Big Bend country



*Coulee City monoclinial fold at Park Lake, Douglas County. Note that the basalt flows are flat lying on the right and tilted on the left of the picture. (Photo by L. D. Lindsley.) Figure 31.*

almost to Coulee City, then turns toward the northeast and parallels the west rim of the Upper Coulee to the site of Grand Coulee Dam, and then turns eastward. As the great ice sheet lay stagnant and as it began to retreat, tremendous meltwater streams poured down from its icy surface. These streams, and the Columbia River drainage



*Grand Coulee Dam. The continental ice sheet dammed the Columbia River at this point during part of the Pleistocene Epoch, and the channelway—the Grand Coulee—cut by the diverted river can be seen in the background. Figure 32.*

from other glacial areas to the east, quickly filled the lake behind the Grand Coulee ice dam to overflowing; the water spilled over the valley rim to the south; and the stage was set for the excavation of the Upper and Lower Coulees of the Grand Coulee.

The waters that overflowed the Columbia Valley at the present site of Grand Coulee Dam formed a river that flowed along the edge of the glacier, picking up additional water from the many meltwater streams that were pouring off the ice lobe to as far south as Coulee City. Here the river roared down the steep south-sloping Coulee City monocline, forming a wild cascade 800 feet from top to bottom. The folding of the monocline had spread open the joint systems of the columnar basalt flows at the crest of the fold, and now the tremendous meltwater river began to attack this weakness. The surging torrent began to pluck columnar chunks of basalt from the face of the fold, and a cataract developed that would dwarf any presently existing waterfall. This waterfall eroded its rim and retreated some 20 miles back to the site of Grand Coulee Dam and into the Columbia River valley before the ice dam broke, allowing the Columbia River to return to its old course, thus ending the flow in the coulee.

At the time Upper Grand Coulee was being excavated by the diverted Columbia River flowing over its retreating waterfall, the river spread out below the Coulee monocline and ran along the toe of the fold to about the present site of Soap Lake, where it went raging over the brink of the Soap Lake anticline, forming another foaming torrent. Here also the folding had produced a

weakness in the basalt that the turbulent river was quick to take advantage of, and soon a roaring cataract 400 feet high developed. This cataract retreated back upstream to the present site of Dry



*Dry Falls as it may have appeared during the latter part of the Pleistocene Epoch, when meltwater was roaring over the falls. (From a painting by Dee Molenaar.)* Figure 33.

Falls before the original channel of the Columbia River was freed of ice, allowing the river to return to its normal stream course. When this happened, the once magnificent falls became a series of sheer cliffs; and small lakes, such as Dry Falls Lake, Alkali Lake, and Deep Lake, filled the plunge pools at their bases (a plunge pool is the large deep pool that develops at the base of a falls). When the river abandoned the Grand Coulee stream course, it left a series of lakes—Park Lake, Blue Lake, Lenore Lake, and Soap Lake—in the Lower Coulee. An interesting feature of these lakes that were formed during Pleistocene time is that they become progressively more saline down the coulee, so that Soap Lake, which is at the lower end, is quite salty.

At the time the Grand Coulee was being cut, another southwest-flowing meltwater stream was cutting Moses Coulee. Meltwater streams flowing off the ice sheet east of Grand Coulee and floodwater being discharged from a large ice-dammed lake in Montana were cutting the famous "channeled scablands." The scabland channels start at the Spokane River and extend southwestward as far as the Snake River. The ancient glacial lake that existed in the valley of the Clark Fork of the Flathead River in Montana is called Lake Missoula. The valley was dammed by ice near Lake Pend Oreille in Idaho. The ice dam broke periodically, spilling tremendous quantities of water through the scabland channels, cutting them deeper each time. The Columbia River also was periodically ponded during Pleistocene time, in the vicinity of Walla Walla, possibly by ice-jamming of the Wallula water gap. Evidence for the ponding can be seen in the fine-grained cyclic-bedded sediments in the Walla Walla-Richland area.



*Channeled scablands and the Palouse River upstream from Palouse Falls, in Adams and Whitman Counties. Most of the soil has been stripped off the area, leaving the bedrock exposed. Notice the channels that have been gouged into the bedrock by glacial floodwaters. (Photo by John T. Whetten.)* Figure 34.

Valley glaciers were abundant in the northern and central Cascade Mountains during part of the Pleistocene. A valley that has had a glacier in it is easy to recognize by its U-shaped cross section, smooth steep walls, and straightness. Lake Chelan occu-



*Broad straight U-shaped valleys of the Chiwawa River (to the right) and Buck Creek (to the left) in Chelan County, which are typical glaciated valleys. (Photo courtesy U. S. Forest Service.)* Figure 35.

pies a valley that was deepened considerably by glaciation. Other Cascade river valleys that were glaciated along their upper reaches are the Cowlitz, Yakima, Snoqualmie, Skykomish, Wenatchee, Entiat, Methow, Nooksack, Skagit, and Stillaguamish. Probably all major river valleys in the Olympic Mountains were occupied by glaciers also.

Bison, caribou, and mammoth remains have been found in Pleistocene deposits. The climate was colder than it is now, but by the end of the Pleistocene Epoch, about 10,000 years ago, it was beginning to warm up. The great ice sheet melted, the rivers resumed their old courses or dug new ones, and the topography of the state was approximately what it is today.

#### Recent Epoch

Recent time, which began about 10,000 years ago, has produced little in the way of change on the earth's surface in Washington. Some dramatic events have taken place within the past 10,000 years, but they have affected only small areas. About 4,500 years ago a very large mudflow slid off the north slope of

Mount Rainier, continued down the White River valley, spread out over the glacial plain around Enumclaw, and even flowed down into the Duwamish Valley. In 1947 a similar, but very much smaller, mudflow came down Kautz Creek, on the south side of the mountain. One can see the results of its destructive force where the Longmire road crosses Kautz Creek.

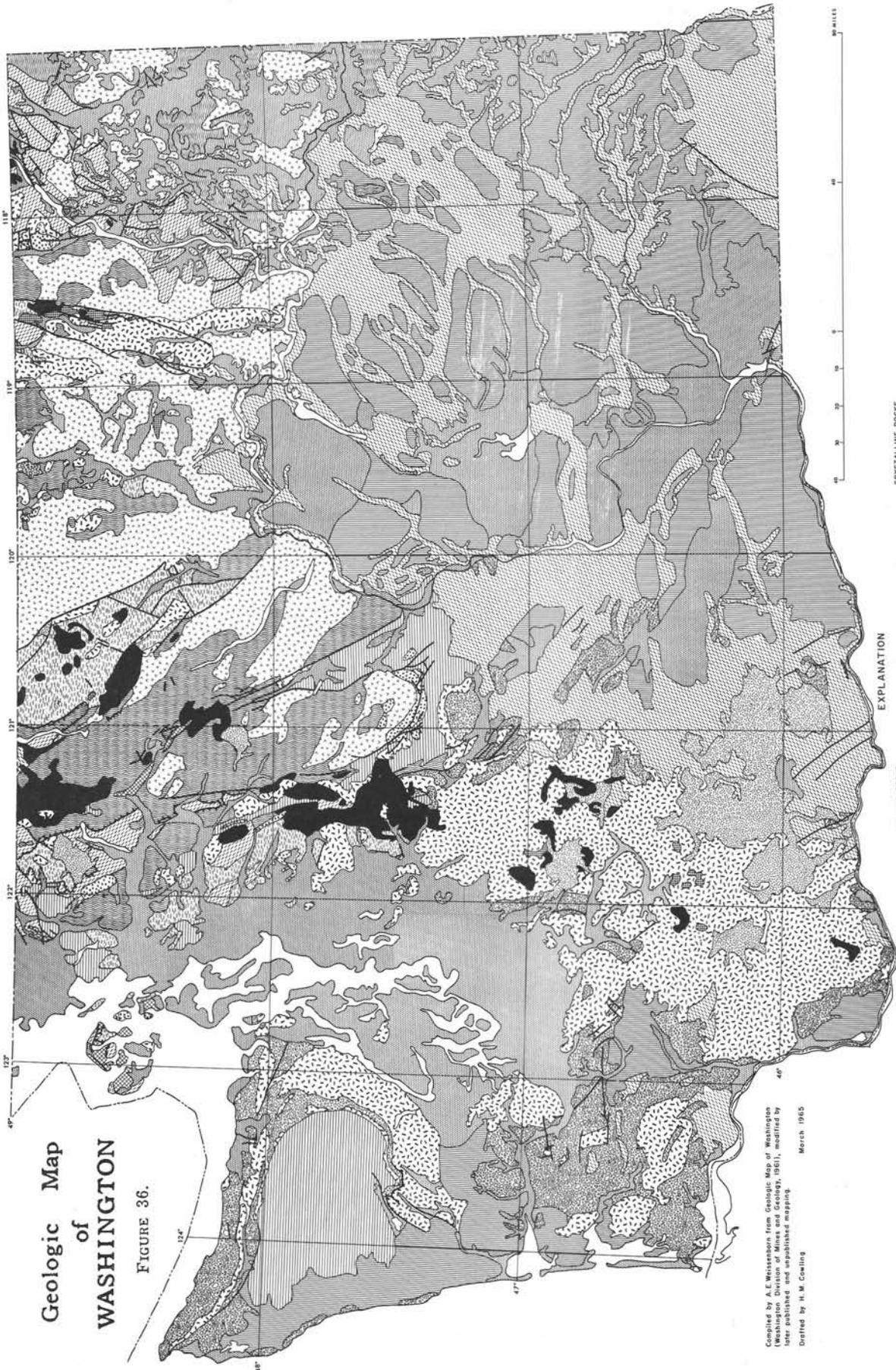
During Recent time there have been several volcanic eruptions, some of which have been observed by the white man. The last was the pumice eruption of Mount St. Helens in the 1850's.

We are still in the Recent Epoch. We stand as spectators to geologic events as they happen around us, and the thing that is most striking is how extremely slow are the changes brought about by these processes. The steady erosion of the landmass is so very slow as to be almost imperceptible. Only when we experience a disaster, such as a volcanic eruption, earthquake, landslide, or flood, is there any dramatic change.

The geologic history of Washington has been related in condensed form here. As more geologic studies are completed in the future, new and better ideas will modify this story, and so it is left to the individual to pursue the subject and unravel the story that is yet untold.

# Geologic Map of WASHINGTON

FIGURE 36.



Compiled by A. E. Weissborn from Geologic Map of Washington (Washington Division of Mines and Geology, 1961), modified by later publishers' and unpublished mapping.  
 Drafted by H. M. Cowling  
 March, 1965

## EXPLANATION

- SEDIMENTARY ROCKS**
- Glacial deposits and Recent alluvium.
  - Quaternary glacial till, terrace deposits in Washington, terrace deposits west of the Cascades, includes some older alluvium in Clark County.
  - Tertiary continental and marine deposits.
  - Cretaceous and Paleocene continental deposits. In central Olympic Mountains includes some marine sedimentary rocks, some younger Tertiary rocks, and may include some older rocks.
  - Mesozoic sedimentary rocks.
  - Paleozoic sedimentary rocks.
  - Pre-Cambrian sedimentary rocks.
  - Pre-Cambrian volcanic rocks. Includes lava, volcanic and gneissic rock east of Mt. Spokane.
- VOLCANIC ROCKS**
- Recent volcanic rocks, volcanic spicula from Mt. Baker, Mt. St. Helens, Mt. Adams, and Glacier Peak.
  - Miocene volcanic rocks, includes modified sedimentary rocks south of Columbia River Group. Includes some Miocene and Pliocene andesite and rhyolite in Puget Sound area, mostly in southwestern Washington.
  - Pre-Miocene volcanic rocks.
- CRYSTALLINE ROCKS**
- Small Tertiary intrusive bodies, mostly of andesitic and diabasic composition. Many small bodies not shown.
  - Tertiary granitic rocks. Includes the Chilliwack, Skagit, and Skamania groups, and the Tolt and other small plutons.
  - Mesozoic and early Tertiary granitic rocks includes the Coville, Kanim, Simulmneston, and Mt. Stuart intrusions. Includes some rocks of probable later age.
  - Tertiary and pre-Tertiary mafic and ultramafic rocks.
  - Pre-Devonian granitic rocks. Restricted to Cascade Mountains and San Juan Islands.
  - Metamorphic rocks, mostly pre-Jurassic but includes some rocks of probable later age.
- FAULTS**
- Thrust fault, saw-tooth on upper plate.

Geologic map of Washington. Figure 36.

TABLE 1.—Geologic time, rocks, and fossils in Washington

TIME UNITS				ROCKS AND FOSSILS
Era	Period	Epoch	Age (million years)	
CENOZOIC	Quaternary	Recent		Recent deposits and rocks include the alluvial deposits that occur along streams, landslide debris, and very young lava flows and volcanic breccia and ash. They are present in one form or another in every county in the state.
		Pleistocene	.01	Pleistocene rocks and deposits occur in almost every county of the state. Fossils of animals such as mammoth, bison, and caribou have been found in both western and eastern Washington. In the western part of the state, fossil clams have been found. Rocks are basalt, loess, till, sand, and gravel. The seashore was about where it is today. The outstanding geologic event during this time was the advance and retreat of the great continental ice sheet. The land surface was greatly changed by glacial erosion, especially in the northern Cascades where valley glaciers were active. Mount Rainier, Mount St. Helens, Mount Adams, Mount Baker, and Glacier Peak, which are all volcanic cones, probably had most of their eruptive activity during this time. The most important rocks of Pleistocene time are the sand and gravel deposits, which serve as aggregate for concrete, as road metal, etc. Some interesting rocks that were deposited during this time are the huge "haystack" rocks, or glacial erratics, that the continental ice sheet pushed out onto the Waterville Plateau.
	Tertiary	Pliocene	1.5	Pliocene rocks occur in Clark, Cowlitz, Grays Harbor, Skamania, Yakima, Klickitat, Kittitas, Douglas, Grant, and Benton Counties. Marine clam and snail fossils have been found in Pliocene rocks in Grays Harbor County. Elsewhere, leaf fossils have been found. The Pliocene seashore was slightly east of the present shore. Rocks are sandstone, conglomerate, siltstone, and basalt. The Cascade Mountains, Olympic Mountains, Coast Range, and Blue Mountains were pushed up during this time. The large ridges—Saddle Mountains, Frenchman Hills, Rattlesnake Hills, Horse Heaven Hills—were upfolded in the Columbia Basin. The northern part of the Cascade Range was uplifted more than the southern part, so that the overall structure of the range might be thought of as a south-plunging anticline.
		Miocene	7	Every county in the state except San Juan, Island, Skagit, and Pend Oreille has rocks of Miocene age. Marine clam, snail, oyster, and fish fossils have been found in western Washington. Vertebrate, wood, and leaf fossils have been found in the eastern part of the state. One of the most famous fossil localities is in the Ginkgo petrified forest, near Ellensburg. Miocene rocks are basalt, granite, sandstone, siltstone, shale, palagonite, and diatomite. During Miocene time the seashore was slightly west of the present Highway 99 from Oregon to Centralia. In eastern Washington there were several large lakes that formed in conjunction with the outpouring of the flood basalts of the Columbia Basin. Many of the granite bodies in the Cascade Mountains were formed during this time. A point of interest is that most of the metallic ore deposits in the Cascades are associated with Miocene age granitic rocks. The diatomite and basalt are both economically important rocks in the state.
				27

TABLE 1.—Geologic time, rocks, and fossils in Washington—Continued

Time units				Rocks and fossils
Era	Period	Epoch	Age (million years)	
CENOZOIC	Tertiary	Oligocene	27	Oligocene rocks occur in all counties west of the Cascade Mountains except Whatcom, Island, and San Juan. They are present also in Yakima, Klickitat, Kittitas, Spokane, Lincoln, Stevens, and Ferry Counties. Fossils of marine clams, snails, cephalopods, crinoids, and fish have been found in western Washington. In the eastern part of the state, leaf fossils have been found. Rocks are sandstone, siltstone, shale, basalt, andesite, breccia, and tuff. During Oligocene time the seacoast was slightly west of the Cascade foothills, and large fresh-water lakes existed in Ferry County near Republic and in southern Stevens County; other lakes existed in areas in the eastern part of the state.
		Eocene	39	Eocene rocks occur in all but San Juan, Skagit, and Island Counties west of the Cascade Mountains. East of the mountains they occur in Okanogan, Ferry, Yakima, Kittitas, and Klickitat Counties. The sea during Eocene time covered most of the western part of the state, the shore being about where the Cascade foothills are today. Large lakes existed in the Cle Elum area and other areas to the south. Marine fossils (clams, snails, and barnacles) have been found in marine sandstone, siltstone, and shale in western Washington. Fossil leaves have been found in nonmarine sandstone and shale. Basalt, andesite, flow breccia, and pyroclastic rocks of Eocene age are abundant in the Cascade Mountains, the Coast Range in southwest Washington, and the Olympic Peninsula. Coal, which occurs in the nonmarine rocks, has been mined extensively in Kittitas, King, Lewis, Thurston, Pierce, and Cowlitz Counties.
		Paleocene	55	Paleocene rocks crop out in a discontinuous belt from Wenatchee, in Chelan County, to Bellingham, in Whatcom County. Fossils of palm fronds and other leaf types have been found in these rocks. Rocks include sandstone, shale, conglomerate, and coal. The coal has been mined near Bellingham.
MESOZOIC	Cretaceous		65	Cretaceous rocks crop out in Okanogan, Whatcom, Skagit, Snohomish, King, and San Juan Counties. Rocks of marine origin, such as sandstone, limestone, and shale that contain fossil clams, snails, and cephalopods, indicate that a shallow sea covered the northern part of the state. Fossil leaves have been found in nonmarine sedimentary rocks of the Methow River area. In addition to the rocks mentioned above, conglomerate and volcanic flow rocks were laid down during this time. Much of the granite in Kittitas, Chelan, Okanogan, Ferry, Stevens, Pend Oreille, Spokane, and Whitman Counties was emplaced during Cretaceous time. The Okanogan Highlands began to be uplifted. This mountain-building movement continued into the Tertiary Period and was accompanied by major faulting.
	Jurassic		136	Jurassic rocks occur in northwestern Whatcom County, in the Methow River drainage area of Okanogan County, and along the west margin of the Cascade Mountains in Skagit, Snohomish, and King Counties. The marine rocks indicate that at this time a shallow sea probably covered most of the northwestern part of the state. Much of the state east of the Columbia River may have been above sea level. Fossil clams and cephalopods have been found in Jurassic rocks of Washington. Rocks are argillite, siltstone, shale, limestone, and volcanic rocks.
			195	

TABLE 1.—Geologic time, rocks, and fossils in Washington—Continued

Time units				Rocks and fossils
Era	Period	Epoch	Age (million years)	
MESOZOIC	Triassic		195	Triassic rocks occur in southeastern Asotin County, northern Ferry County, the San Juan Islands, northwestern Whatcom County, and near Riverside in Okanogan County. The Triassic sea may have covered a large part of the state. Rocks are limestone, dolomite, conglomerate, shale, graywacke, greenstone, argillite, chert, and volcanic rocks. Clams are the commonest of the Triassic fossils. The dolomite in Okanogan County has been used as a metallurgical flux.
			225	Permian rocks occur in northern Stevens and Ferry Counties, in the San Juan Islands, and in Whatcom, Skagit, Snohomish, King, Lewis, Okanogan, Asotin, and Columbia Counties. The sea may have covered most of the state during Permian time. The rocks are graywacke, limestone, quartzite, argillite, chert, conglomerate, and greenstone. Fusulinid and bryozoan fossils are common in the limestone rocks. Economically, limestone is the most important Permian rock; it is used to make cement.
PALEOZOIC	Carboniferous		280	Carboniferous (sometimes called Mississippian-Pennsylvanian) rocks crop out in Stevens County, the northern Cascades, and the San Juan Islands. The sea covered at least the northern part of the state. The rocks are graywacke, shale, argillite, slate, schist, conglomerate, volcanics, and limestone. Brachiopod, coral, bryozoan, and crinoid fossils have been found. Economically, the limestone is the most important of the Mississippian-Pennsylvanian rocks. It has been mined extensively in the northern Cascades for making cement.
			345	Devonian rocks occur in northern Pend Oreille, Stevens, and Whatcom Counties, and on Orcas Island in the San Juan Islands. The rocks are mostly argillite in eastern Washington and cherty quartzite, argillite, and some limestone and graywacke beds and lenses in western Washington. Coral fossils have been found in eastern Washington.
	Silurian		395	Silurian rocks occur in northern Pend Oreille and Stevens Counties. The rocks, which are predominantly argillite and some thin beds of limestone, conglomerate, quartzite, and dolomite, conformably overlie the older Ordovician rocks. Graptolite, brachiopod, bryozoan, and coral fossils have been found.
		Ordovician		440
	Cambrian			500

TABLE 1.—Geologic time, rocks, and fossils in Washington—Continued

Time units				Rocks and fossils
Era	Period	Epoch	Age (million years)	
PALEOZOIC	Cambrian		570	and archaeocyathid fossils have been found in the Cambrian rocks, mostly in the limestone. Economically, the Cambrian limestone is very important because of the associated lead-zinc deposits and also because of its use in the manufacture of cement. Some of the quartzite is mined for its high silica content, and for building stone.
PRECAMBRIAN			3,300±	Precambrian rocks have been identified only in Stevens, Pend Oreille, Spokane, Lincoln, and Whitman Counties. Northeastern Washington was below sea level at that time. Two rock sequences are present; the older beds were folded and eroded before the younger deposits were laid down. Phyllite is the most abundant rock type, but conglomerate, quartzite, carbonate rocks, schist, gneiss, and argillite are all common. Volcanic rocks occur in Stevens and northern Pend Oreille Counties. Intrusive rocks occur in southern Pend Oreille County. Economically, the Precambrian rocks are important; rich uranium and magnesite deposits occur in phyllite and dolomite, respectively. Precambrian rocks were folded and eroded before deposition of Paleozoic sediments.

## MINERAL RESOURCES OF WASHINGTON

Washington is fortunate in having a wide variety of mineral resources that support the overall economy of the state. Through the years the use of our valuable raw materials has been steadily increasing, keeping pace with the ever-rising standard of living. Everything we do and all our industries, in some way or another, are tied into the mineral industry. We must have bricks made from clay to build homes, metals obtained from ores for manufacturing automobiles and for other industrial uses, crushed rock for asphalt road paving, various minerals for medicinal and other chemical uses, and so forth. If one were to try to list all the uses minerals have, the list would be endless, because new uses are being developed every day.

The mineral deposits, which are so necessary to our existence, were formed on the surface of, and deep within, the earth by slow natural processes during the long geologic past. Most of

the valuable minerals occur in small isolated deposits and, of course, are found only where they formed. Because mineral deposits are nonrenewable and cannot be grown like crops, nor can they be shifted from one location to another, it is important to keep potential mineral-producing areas open to prospecting and possible future production. As our population increases, the demand for mineral products of course will increase also. It is in the interest of every citizen of the state to make sure that land-management practices are such that maximum use of our mineral resources will be possible. It should be kept in mind that a mine, stone quarry, or gravel pit is a temporary thing. As soon as the deposit is depleted, the land is available or can be reclaimed for other uses. Examples are the abandoned coal strip mines of the Middle West that have been reclaimed as lakes and parks. In our own state, the old Holden mining property has been converted to an attractive summer retreat for religious groups.

## CONSERVATION OF MINERAL RESOURCES

Is it possible for people in the mineral industry to practice conservation? The dictionary defines conservation as "preserving or protecting; a keeping in a safe or entire state." Once a mineral or stone is mined, it is lost from its natural setting. How then is it possible for an industry whose existence depends on the depletion of its raw materials to practice conservation? Should a part of each mineral deposit be set aside and saved, to be mined at some future date? Or should certain specific mineral deposits be saved for generations to come? Neither of these two suggestions is practical, so if the mineral industry is to practice conservation, it must be done in some other way. One of the simplest ways for a miner or mining company to practice conservation is to make sure that all material that can be mined at a profit is utilized. In some instances in the past, miners who were short-sighted mined out high-grade mineral deposits in such a way as to render valueless untold tons of lower grade mineralized material remaining in the deposit. Improved mining practices might have made it possible to use this low-grade ore. In mining, the quality of the ore is very commonly the restricting factor. A deposit may have tremendous tonnages of mineralized material that cannot be profitably mined because, for instance, the value of the material may be \$15 per ton and the cost of mining and processing it may be \$16 per ton. If a deposit has zones of high-grade ore (zones that are very rich in the mineral to be mined) associated with the low-

grade material, the high-grade ore may be mined out and stockpiled. Later it can be mixed with the low-grade material in such a way that the quality of the lean ore is raised to commercial grade. Through blending the rich and the poor ores, the miner is able to realize a profit from material that otherwise would be wasted.

This is only one way that conservation is applied in the mineral industry. Mining men are always experimenting with new and different methods of mining, milling, and transporting in the hope of finding cheaper ways of handling ore, thus enabling them to mine lower grade material. Metallurgists are continually looking for new methods of extracting metals from ore, to find ways in which to utilize presently worthless minerals. Because our planet is made up of minerals, the whole earth represents a vast potential ore deposit. The only thing that restricts the commercial use of many of these minerals is our technical ability.

Conservation is practiced in the mining industry not by leaving the minerals in the ground to save them but by mining them properly so as to recover the largest quantity possible with the least waste and by increasing our technical knowledge of mineral recovery. In so doing, we increase the mineral reserves of our state and nation. Conservation is also practiced by restoring the surface of a depleted mineral deposit to a usable condition wherever it is possible.

## ROCKS AND MINERALS THAT HAVE BEEN MINED IN WASHINGTON

Washington has a great variety of mineral deposits, and mineral production and processing is one of the major industries of the state. Mineral deposits are distributed throughout the state, but most are concentrated in the northern counties. Many of the deposits, as in other areas, are either too small, too inaccessible, or too low in grade to be mined commercially at the present time, but increased prices and improved mining and processing methods undoubtedly will make it feasible to mine some of these deposits in the future. The following minerals have been or are now being mined in Washington.<sup>1/</sup>

Antimony

In Washington, antimony probably was first discovered in 1892 in King County. Since that time, small production has also been reported from Stevens and Okanogan Counties. Antimony is used chiefly in lead alloys for storage battery plates, bearing metal, linotype metal, and cable covering. Other uses are in making paints, ceramics, colored glass, and flame-proof textiles. The most common antimony mineral is stibnite.

Arsenic

Arsenic usually is more of a nuisance than a value to the miner. It commonly occurs with other minerals and is a definite hindrance in the milling and smelting of some of them. Washington began producing arsenic commercially during the early part of the century and still produces some as a smelter byproduct of other ores. At the present time (1969) there are no deposits in the state that are being worked for their arsenic content.

Arsenic is used mainly to make poison compounds for insecticides and weed killers. Other uses are in making glass, paint, drugs, dyes, and lead and copper alloys. The principal arsenic minerals are arsenopyrite, realgar, and orpiment. Arsenic minerals are found in most of the mining districts of the state.

Barite

Small shipments of barite have been made from several deposits in Washington. Almost all of this production was used for industrial purposes rather than as an ore of barium metal. The principal barium mineral is barite. Most of the deposits are in the northeastern part of the state.

The chief use of barite is in preparing the heavy mud used in drilling oil wells. Other uses are in the sugar refining industry, for flux in the glass industry, and in adding weight and color (white) in the paper and rubber industries. Metallic barium is used as a lubricant, in X-ray tubes, and is alloyed with magnesium and aluminum as a getter (a material that removes the last traces of gas from vacuum tubes) in electronic tubes.

Barite occurs as pods, large veins, and as beds in sedimentary rocks. In some places it is the cementing agent in sandstone. It is a common gangue mineral associated with other, more valuable minerals.

Basalt and Other Volcanic Rocks

Basalt is one of the most abundant rocks in Washington. It covers most of the southeastern part of the state, as well as large areas west of the Cascade Mountains.

Much of the basalt in the state, particularly in western Washington, has no value because many of the original mineral constituents have been altered to clay or chlorite, which makes the rock soft and easily broken down. The fresh hard unaltered varieties, however, are excellent for road-building material and for riprap and breakwater construction. Road builders prefer the brickbat or hackly jointed basalt because it crushes easily. For



*Columnar basalt near Longview, in Cowlitz County. The columns are quarried out in large blocks, which are used as riprap and in building jetties. Figure 37.*

riprap and breakwaters, the massive columnar jointed material is usually preferred. There are a few volcanic rock quarries in the state that yield a slabby flagstone type of rock that is used as an ornamental stone.

Almost every county in the state has at least one basalt

<sup>1/</sup> Most of the information given about these minerals has been condensed from Washington Division of Mines and Geology Bulletin 27, Inventory of Washington Minerals, Part I—Nonmetallic Minerals, and Part II—Metallic Minerals.

quarry that is presently producing or has in the past produced basalt. The rock's most common use is as a road surfacing material.

### Chromium

Small shipments of the principal chromium mineral, chromite, have been made from Washington. Some of the most promising areas for its occurrence are on Cypress Island in the San Juan Islands, Twin Sisters Mountain in the northern Cascade Mountains, and Mount Chopaka in Okanogan County.

Chromium is used mostly in special steel alloys such as stainless steel. It adds hardness, strength, and ductility to the steel. Chromite is also an excellent refractory and is ground up and molded into brick for use in metallurgical furnaces. It is also used in the manufacture of paint.

Chromite occurs as pods, layers, and placers, and in lateritic iron deposits. Pod or lenslike deposits are most common in Washington.

### Clay

There are two main types of clay deposits: residual, those that were formed in place; and transported, those that were moved from their place of origin by wind, water, or ice.

Most of the clay that occurs in Washington is the transported type; that is, it was not formed where it now occurs but was transported by glaciers, streams, or wind and deposited at its present location. Most of the state's deposits yield a clay that is used to make common brick and tile.

Twenty-three counties in Washington have had recorded clay production, but in 1960 there were only 10 counties that had operating clay pits. Most of the production goes into the manufacture of building brick. Other uses are in making refractory brick, earthenware, and tile.

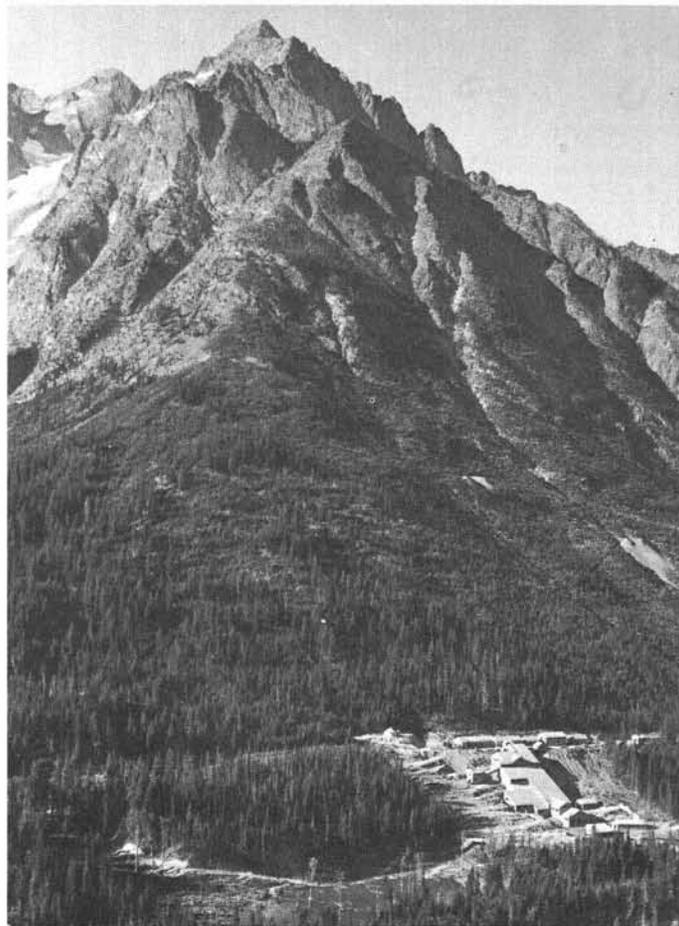


Old-fashioned beehive-like downdraft brick kilns formerly operated at Granger, in Yakima County. Most modern brick plants use continuously fired tunnel kilns to produce bricks. (Photo by Simmer.) Figure 38.

A special kind of clay called bentonite is found near Tieton, in Yakima County. The principal value of bentonite lies in its quality of expanding when immersed in water. It is mixed with water to make a circulating fluid to carry rock chips to the surface in the drilling of oil wells. It is also used in the bleaching and filtering of fats and oils, in oil refining, in special water-proofing compounds, and as a filler in soap and paper. It can also be used to prevent seepage from irrigation ditches and ponds and as a forest fire retardant.

### Copper

Copper is the most abundant base metal. It was first mined in Washington in 1894, and since that time production has been almost continuous. Between the years 1939 and 1956, Washington ranked among the top 10 copper-producing states in the United States. Production fell sharply in 1957, when the Holden mine in Chelan County was closed.



Holden mine buildings nestled at the base of Copper Peak, in Chelan County. This mine produced more copper than any other mine in the state. It also produced substantial amounts of gold, silver, and zinc. The mine was worked out and closed in 1957, and a church took over the property and converted it to a recreation area. Figure 39.

Copper has many uses, most of which are related to its ability to conduct electricity and heat, and to the ease with which it can be worked. Most of the copper produced is used in the electrical industry. Other uses are for wire, cable, automobile parts, building materials, household appliances, ammunition, as an alloy with zinc to make brass, as an alloy with tin to make bronze, as a coloring agent in glass and ceramic glazes, and in antiseptics and insecticides.

The most important copper mineral is chalcopyrite. Other copper minerals that occur in Washington are chalcocite, azurite, malachite, and native copper. These minerals, with the exception of native copper, are found in all of the state's mining districts. Native copper occurs as small masses in the Tertiary volcanic rock of the Olympic Peninsula. Copper may occur in veins, but most deposits are irregular-shaped bodies that were formed by copper being precipitated out of hot mineral-bearing solutions given off by magmas.

#### Diatomite

Diatomite, or diatomaceous earth, is material composed primarily of the siliceous skeletons of microscopic aquatic plants known as diatoms. As these minute plants die, their skeletons sink to the bottom of the body of water in which they lived, where they accumulate as diatomite beds. In Washington, diatomite has been produced from Grant, Adams, Kittitas, and Klickitat Counties and is known to occur in at least 15 other counties.



White diatomite overlain by dark palagonite and basalt near Quincy, in Grant County. Figure 40.

Diatomite is used as a filtering agent in manufacturing antibiotics and liquors, to clean dry cleaning fluid, in water purification, and in the chemical industry. It is also used as an insecticide carrier, a filler in paper and rubber, a fine abrasive, and as an insulating agent.

#### Dolomite

Dolomite is a name that is applied to both a rock and a mineral. The chemical formula for the mineral is  $MgCa(CO_3)_2$  (magnesium calcium carbonate). The rock form, however, usually contains impurities such as iron, silica, and alumina. With an increase in calcium and corresponding decrease in magnesium, dolomite grades into limestone. With an increase in magnesium and a decrease in calcium, it grades into magnesite. All the known occurrences of dolomite in Washington are in Okanogan, Stevens, Pend Oreille, and Lincoln Counties; Stevens County, however, produces the most.

Dolomite is calcined to make dolomitic lime, which is used as a refractory in patching open-hearth furnaces and in paper mills as a digesting agent. Other uses are in producing magnesium metal, as a soil conditioner, an insecticide carrier, and for roofing chips.

#### Gold

Finding of gold in Washington was first reported by Captain George B. McClellan, of the United States Army, in 1853. Captain McClellan was investigating possible routes through the Cascade Mountains when members of his party found traces of gold in the Yakima River. Later, in 1855, gold was reported at Fort Colville, in what is now Stevens County. The first production of gold came from the Similkameen River in Okanogan County in 1859. In succeeding years gold was found in the Slate Creek



Mill building of the Knob Hill gold mine near Republic, in Ferry County. This mine is one of the larger lode gold mines in the United States. (Photo by Simmer.) Figure 41.

district of Whatcom County, the Peshastin Creek district of Chelan County, the Liberty district of Kittitas County, and the Republic district of Ferry County. In 1966 two important gold producers were the Knob Hill mine at Republic and the Gold King mine at Wenatchee.

There are many streams in the state along which one can pan gold. One of the most productive is Swauk Creek in Kittitas County. The hills around Swauk Creek are still being worked intermittently by "old timers" and "weekend prospectors." In 1956 two brothers working their claim on weekends mined 45 pounds of wire gold from a small pocket. At \$35 per ounce, this gold would have a value of \$18,900. The largest nugget weighed 5 pounds. Large masses of gold such as this are unusual; in most gold ore the gold is so finely divided or disseminated in the rock that it cannot be seen.

Gold occurs most commonly as a native metal and is usually in a natural alloy with silver. It occurs in particles that range from minute, submicroscopic size to nuggets that weigh several pounds. More rarely it occurs as crystals that have grown together end to end to form wire gold.

Gold's greatest use is as the base of our country's monetary system. Other uses are in jewelry, dental work, sign painting, and medicine. The principal gold mineral is native gold.

### Granitic Rocks

Most of the granitic rocks in the state are situated east of the crest of the Cascade Mountains and in the northern part of the state.

Granite is used as riprap, road-building material, chicken grit, and roofing chips. Some varieties are used in monumental and architectural work.

### Gypsum

The gypsum that is mined in Washington is an impure granular earthy variety called gypsite. It is mined from a saline lake in Okanogan County.

Pure gypsum is used mostly as a plaster base. The gypsite mined in Washington is used as a soil conditioner. In the soil it helps plants assimilate potassium.

### Iron

Iron was first smelted in Washington at Irondale, near Port Townsend, in 1881, using limonite as ore. Since then, production has been nearly continuous but never large. For several years the iron ores of the state were used primarily as ship ballast. Smaller quantities have been used in calcining magnesite, as heavy concrete aggregate, in the production of mineral pigments such as ochre and sienna, and in special portland cement. Na-

tionally, most of the iron mined is used in the steel industry.

Two of the better known iron deposits in Washington are the Cle Elum deposit in Kittitas County and the Buckhorn deposit in Okanogan County. The Buckhorn deposit has produced some ore, and both it and the Cle Elum deposit have been extensively explored. A small deposit in Stevens County, the Kulzer property, periodically supplies a small amount of ore to cement companies for special cements. Black magnetite sand deposits may also be of value as sources of iron; two such deposits are at the mouth of the Columbia River and at the mouth of Grays Harbor. The magnetite grains were derived from the weathering and erosion of rocks farther inland and were transported and concentrated into placer deposits by the action of water and wind.

Iron is present in hundreds of minerals, but it can be extracted commercially from only a very few. The most important iron ore minerals are hematite, magnetite, and limonite. Pyrite, an iron sulfide mineral, is sometimes used as sulfur ore. The sinter that remains after the sulfur has been roasted off has been used as an iron ore.

Iron ore may occur as small grains of magnetite disseminated or scattered through igneous rocks, as a body of magnetite associated with metamorphic rocks, as massive hematite bodies that have replaced the country rock, and as sedimentary deposits of hematite and magnetite sand.

### Lead

Lead was first mined in Washington during 1898 and has been produced continuously ever since. It has been mined from 10 of the state's 39 counties, but most of the production has come from the Metaline district in Pend Oreille County and the Northport, Bossburg, and Leadpoint districts in Stevens County.

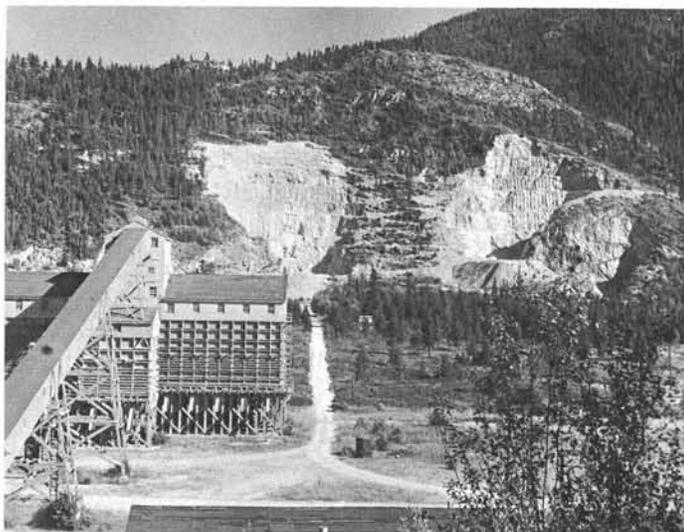
Most of the lead produced in the United States is used in making batteries, cable covering, and as an additive in making high-octane gasoline. Other uses are in making dyes, medicine, ceramic glazes, in lead plating, in manufacturing ammunition, lead sheeting, weights, pipes, containers, paint, and, in recent years, lead glass for use in atomic energy plants.

The principal lead mineral is galena. There are, however, many other lead minerals; in fact, lead occurs as an important constituent in over 150 minerals. Lead is commonly associated with zinc and silver minerals.

Lead minerals commonly occur in limestone and dolomite rocks, generally as disseminated replacement deposits. They are also found in veins.

### Limestone and Marble

Limestone and its metamorphic equivalent, marble, have been reported from 17 counties in Washington and mined commercially in 11 counties.



*Limestone quarries near Northport, in Stevens County. Limestone is used to make cement. Figure 42.*

They are used in greatest quantity in the manufacture of portland cement and of paper. They are also used in making building mortar, as a flux in the steel industry, in water purification, in the chemical industry, and as a soil conditioner. Marble is commonly used as an ornamental and building stone, and for roofing chips.

#### Magnesium Minerals

The magnesium minerals that are mined in Washington are more important for their physical properties than for their elemental magnesium content. Magnesite, which has been quarried near Chewelah in Stevens County, was used to make refractory linings for metallurgical furnaces. Other things that magnesite is used for are the production of magnesium metal, oxychloride cement, and synthetic rubber. It is added to fertilizers to help plants assimilate phosphorus, and it is used as an ultrafine abrasive.

Magnesite is found as a replacement of dolomite or limestone, as veins in serpentine, and as a chemical precipitate.

Another important magnesium mineral that is quarried in Washington is olivine. It is produced from the Twin Sisters Mountain area of the northern Cascade Mountains. It is used mainly as a molding sand for metal castings. Olivine molding sand does not shrink, as does silica sand, when it is heated, thus producing a smoother casting that requires less polishing to finish. Olivine is also used as a sandblasting material. It has eliminated the danger of silicosis that was always present when silica was used for sandblasting. A possible new use for olivine is as a source of magnesium metal.

In the Twin Sisters Mountain, olivine occurs as large pure masses and as intermixtures with other minerals in an intrusive ultrabasic rock.

Washington has the largest deposits of both magnesite and olivine in the United States.

#### Manganese

Manganese was first mined commercially in Washington during 1916. Since that time production has been intermittent. Grays Harbor, Mason, Jefferson, and Okanogan Counties have all had limited production, but most of the state's output has come from Clallam County. The Crescent mine, at the west end of Lake Crescent, has been the largest producer.

Manganese is essential in making all grades of commercial steel, being used as an oxidizer and desulfurizer in the manufacturing process. When it is added to steel in larger amounts it increases the hardness, toughness, and strength, and allows the steel to be more easily fabricated. It is also alloyed with copper, nickel, aluminum, and magnesium. Other uses are in making dry cell batteries and in the chemical industry.

Common manganese minerals are pyrolusite, rhodochrosite, and rhodonite. Rhodonite commonly is cut and polished for gem stone use because of its hardness and attractive pink color.

Most of the commercial manganese deposits are either sedimentary or residual in origin. The Olympic Peninsula deposits were probably derived from submarine lava flows and were deposited on the ocean floor, probably as gel which later hardened.

#### Mercury

Mercury was first produced in Washington in 1916 from the Morton district, in Lewis County. It has been found in 13 of the state's 39 counties, but the principal production has come from Lewis County.

Mercury is used in electrical apparatus, primarily for switches. It is also used in pharmaceutical supplies, paint, dentistry, recovery of gold and silver, and in atomic power plants.

The principal mercury mineral is cinnabar. To recover the mercury, the ore is heated in a special furnace. The mercury vaporizes and is piped into a cooling system, where it condenses into the familiar liquid quicksilver form. Native mercury has been found in small quantities in Washington.

Some of the mercury deposits of western Washington have arsenic minerals associated with them. Great care must be taken when handling or working with any of these minerals, because their fumes or vapors are poisonous.

Mercury is found in rocks of all ages. It occurs in veins and irregular-shaped bodies. It was deposited in open spaces, such as cracks and fissures in the rock.

#### Molybdenum

Molybdenum has been found in 16 counties in the state, but Washington has had very little production; the first is reported to have come from Whatcom County.

Molybdenum's greatest use is as an alloy with steel. It makes the steel stronger and renders it easily worked. Molybdenum steel is used in rifle barrels, auto parts, tools, propeller

shafts, and boiler plates. Other uses for molybdenum are in the manufacture of electric lights, radio tubes, X-ray tubes, printer's ink; in tanning leather; and in enameling iron and steel.

The principal molybdenum mineral is molybdenite. Molybdenite is almost always associated with granitic igneous rocks. It occurs as disseminated replacement deposits, veins, and in contact metamorphic zones.

#### Peat

Peat consists of the partially decomposed remains of plants that have accumulated in water. In some kinds of peat, parts of plants can be recognized with the unaided eye. In other kinds, decay has reduced the plants to an earthy material called humus. Peat is the ancestor of coal; through the action of certain chemical and physical agents the peat is broken down, compacted, and eventually converted to coal.

Peat occurs in 29 of the state's counties, only 9 of which are east of the Cascade Mountains. Because it accumulates best in areas that are relatively flat, Washington's most extensive deposits are in the Puget Lowlands.

In Europe, peat is used as a domestic fuel; however, in the United States it is used almost exclusively as a soil conditioner. It has the ability to absorb and hold large quantities of water, thus keeping the soil moist.

#### Pumice and Pumicite

Pumice is a finely vesicular, fibrous volcanic glass, usually of rhyolitic composition. Pumicite has the same composition as pumice but occurs as a dust or powder, usually referred to as volcanic ash. Because the wind can carry the pumicite more easily, it is usually found farther from the source volcano than is pumice. Pumice and pumicite have been produced from 11 counties in the state. Most of the material occurs in two regions; one extends northeast from Mount St. Helens; the other extends southeast from Glacier Peak nearly to Ephrata. The main commercial deposits are in Yakima, Grant, and Chelan Counties.

Pumicite is used primarily as an abrasive in such things as scouring powder, mechanic's soap, metal polish, and rubber erasers. The largest uses for pumice are as a lightweight concrete aggregate and as an insulating material.

#### Sand and Gravel

Sand and gravel is one of the most widespread and important resources of the state. Because of the tremendous quantity that is mined, it is the state's most valuable mineral product. Every county has pits that are producing or are capable of producing pit-run or crushed material.

Sand and gravel is used as concrete aggregate, in road surfacing, as fill material, mortar and plaster sand, and in drain fields.



Gravel being loaded on a barge at Pioneer Sand and Gravel Company's Steilacoom gravel pit. Sand and gravel is shipped to several places around Puget Sound that do not have local sources of good gravel. (Photo by Simmer.) Figure 43.



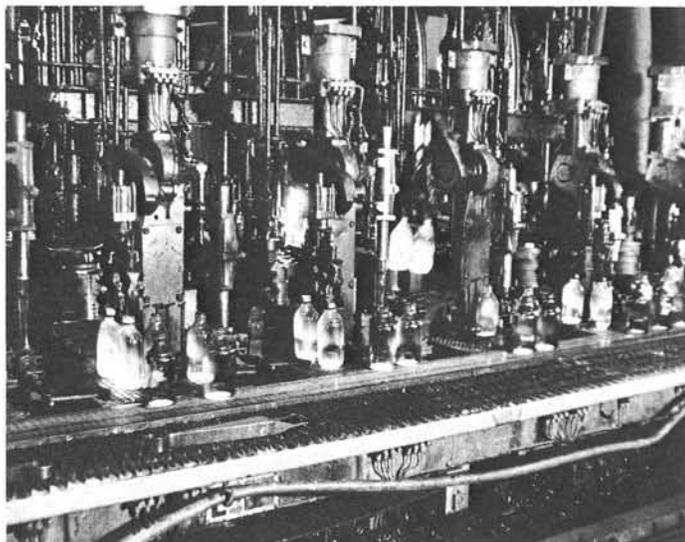
The Wilkeson stone quarry near Wilkeson, in Pierce County. Upper photo shows the working face of the quarry; note the man in the lower right-hand corner of the picture. Lower picture shows a large block of sandstone being cut by a gang saw. Figure 44.

### Sandstone and Quartzite

In 1960, sandstone and quartzite were being quarried in four counties: Pierce, Kittitas, Ferry, and King. These operations produced dimension stone, flagstone, and rubble. Most of the buildings on the State Capitol grounds in Olympia are faced with sandstone mined from the Wilkeson quarry, in Pierce County. An abandoned sandstone quarry that has some historical interest is the one at Tenino, in southern Thurston County. It was from this quarry that the rock was obtained to build the old capitol building in downtown Olympia.

### Silica

Washington has been a producer of silica for many years. Most of it has been mined from Stevens, Spokane, King, and Chelan Counties.



*Bottle-making machine at Northwestern Glass Company, in Seattle. Bottles are red hot, which is why they glow. (Photo courtesy of Northwestern Glass Company.) Figure 45.*

Silica sand is used as blast sand, engine sand, molding sand, furnace sand, and in making glass and abrasives.

The element silicon, which is derived from silica, is used mostly as a deoxidizer and a degasifier in the production of steel. Sometimes it is used as an alloy with steel, copper, and aluminum. Very pure material is used in the manufacture of transistors, rectifiers, and other electrical equipment.

The important silica ores in Washington are quartz, quartzite, and sandstone.

### Silver

It has been many years since Washington has had a producing mine in which silver was the principal product. However, almost every gold, copper, lead, and zinc mine produces silver as a byproduct. Areas that were notable silver producers in the past are the Colville area in Stevens County and the Nespelem, Nighthawk, and Ruby-Conconully districts of Okanogan County. Most of the production now comes from the gold mines at Republic and Wenatchee.

Silver is used chiefly in coins. Other uses are in jewelry, trophies, sterling ware, photography, dentistry, electrical equipment, mirror coatings, and in alloys with other metals for special uses.

The principal minerals in which silver occurs in Washington are not silver minerals but minerals of other metals that have silver associated with them. They are galena, sphalerite, chalcopyrite, and gold.

Most silver minerals occur in veins or as irregular-shaped deposits in which the ores have been deposited in open spaces in the rock.

### Sulfur

Sulfur has not been mined commercially in Washington, but there is a deposit in the state that is so unusual that it is worthy of mention. This deposit occurs in the crater of the dormant volcano, Mount Adams. A few years ago a group of people explored this deposit, using horses to carry their equipment to the top of the mountain. The operation ran into so many difficulties that it was abandoned, temporarily, at least.

### Talc and Soapstone

Talc and soapstone have been mined in Washington for many years. Impure varieties of talc are called soapstone. Talc and soapstone have been reported from seven counties, but most of the commercial production has come from Skagit County.

Talc in its purest form is used in cosmetics and for ornamental carvings. Because of its resistance to acids and other chemicals it is used to manufacture sinks for use in laboratories. It is also used as a furnace liner; as a filler in textiles, paper, and soap; for greaseless pancake griddles; for table tops, steel marking pencils, tailor's chalk; and as an insecticide carrier.

Talc and soapstone occur as massive and lenslike deposits associated with metamorphic and igneous rocks.

### Tungsten

Tungsten was first produced in Washington from the Germania mine in southern Stevens County in 1904. Since that time

there has been irregular small production from a number of mines. Tungsten minerals are known to occur in 14 counties in the state. However, most of the occurrences are in Okanogan, Ferry, and Stevens Counties.

Tungsten is used mostly as an alloy with steel. It imparts toughness, elasticity, and strength to the steel. Probably its greatest value as an alloying element in steel is its remarkable property of making the steel hard, even when heated to red-hot temperatures. Other uses are in making tungsten carbide, which is very hard and is used to face cutting tools; in the manufacture of electric light filaments, for which no satisfactory substitute material has been found; and for various other, minor uses in the electrical and chemical industries.

The two most common tungsten minerals found in Washington are wolframite and scheelite. Most commonly, they are found near the contacts of granite intrusions.

Tungsten occurs in veins, as replacements, and along the contact metamorphic zones around igneous intrusions. Tungsten is always associated with silica-rich granitic rocks.

### Uranium

In Washington, uranium was first discovered in commercial quantities in 1954. During 1955 the state underwent a uranium prospecting boom similar to that of the Colorado Plateau. Uranium has been found in nearly every county in the northern part of the state. The Midnite mine, in southern Stevens County, has been the state's largest producer.

The most important use of uranium is as a source of atomic energy. This energy, when released explosively, is used in atomic bombs, but the same kind of energy, when released at a controlled rate, is a valuable source of power for productive use. Uranium is also used in the ceramic industry, as a coloring agent in glass and to control the coefficient of thermal expansion of the glass. It has been used in luminous paint, electrical equipment, and as an alloy with steel for special uses.

The most important uranium minerals that occur in Washington are the secondary minerals, the most common of which is the flaky, green to yellow, green-fluorescing autunite. The heavy black primary mineral pitchblende, or uraninite, is found also.

Uranium is known to occur in all three principal rock types. It is commonly found in veins or as disseminated deposits. In the "four corners" area of Colorado, Utah, Arizona, and New Mexico it occurs in sedimentary rocks. In Washington the most important deposits have been found in or near the contact zone between granite and the intruded country rock.

### Zinc

The first recorded production of zinc in Washington was in 1911 from the Oriole mine, in the Metaline district in Pend



*Loading of a 12-ton truck by a front-end loader underground in the Pend Oreille Mines & Metals Co. mine at Metaline Falls, Pend Oreille County. (Photo courtesy of Pend Oreille Mines & Metals Co.) Figure 46.*

Oreille County. Since that time, zinc has been mined continuously and has become Washington's most valuable metal. Zinc minerals have been reported to occur in 18 of the state's counties. Most of the production, however, has been from Stevens and Pend Oreille Counties.

Almost half of all the zinc produced is used in the galvanizing industry, in which a thin coating of metallic zinc is placed on another metal to combat corrosion. Other uses are in manufacturing wet-cell batteries, in light-metal alloys, as pigments, as a filler in rubber, in making medicines, and many other, minor uses.

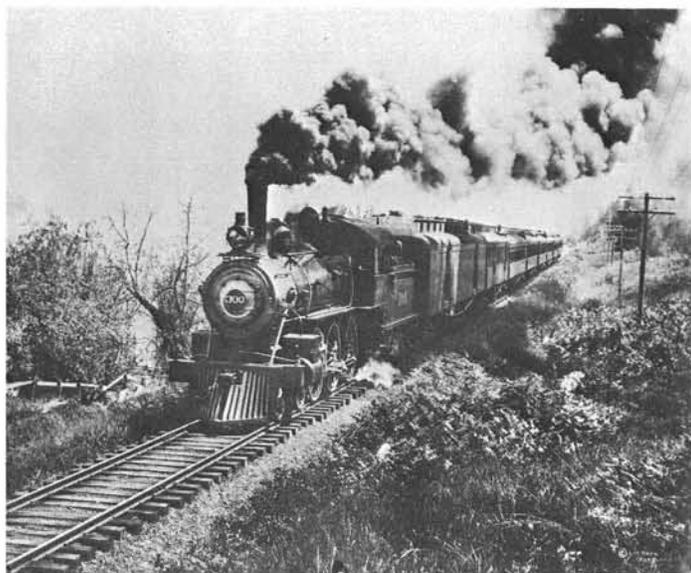
The most common and important zinc mineral is sphalerite. It commonly occurs with lead and copper minerals.

Zinc minerals occur as open-space fillings, in veins, and as massive irregular-shaped replacement bodies. The massive deposits are usually found in limestone or dolomite country rocks.

## MINERAL FUELS OF WASHINGTON

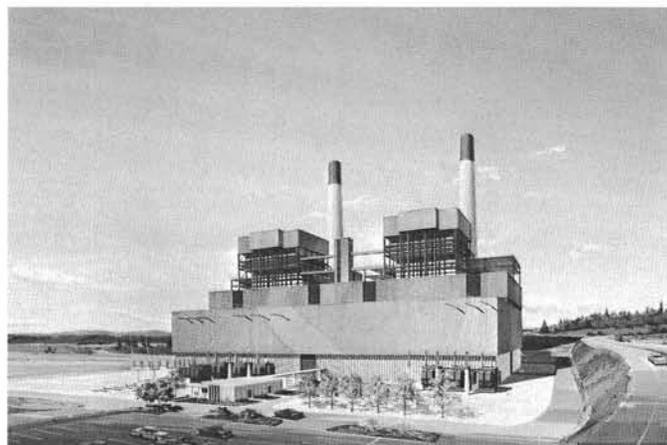
Coal

Coal was first discovered in Washington in 1833, along the Toutle River near where it empties into the Cowlitz River. Since that time, coal has been found in Whatcom, Skagit, King, Pierce, Kittitas, Thurston, Cowlitz, and Clallam Counties. Although Washington has substantial reserves of coal, most of it is subbituminous in grade and has a high ash content. This makes the coal relatively undesirable as a domestic fuel but is not a serious drawback for some other uses. The coal from some of the deposits near Wilkeson, in Pierce County, can be coked; that is, the volatile materials can be driven off by heating the coal in large ovens, leaving a porous material called coke, which is important as blast furnace fuel. Most of the coal produced in Washington has been used for domestic and locomotive fuel.



*Years ago, one of the most important uses of coal in Washington was producing steam to power locomotives. (Photo courtesy Northern Pacific Railway.)* Figure 47.

A use that is being developed for Washington coal is as a fuel to produce steam to operate electric generators. Power companies have undertaken research programs in Kittitas County, King County, and Whatcom County, and in the Tono area of Lewis and Thurston Counties, to determine if the coal in those districts can be used for power generation at a cost that will compete with presently available hydroelectric power. In 1967 a combination of power companies started to move ahead with construction of a huge power plant near Centralia, using the Tono coal. When completed, the plant will produce 1,400,000 kilowatts of electricity per year and will consume more than 6 million tons of coal per year (about 350 railroad carloads per day).



*Today, coal is still used to make steam. The steam in turn spins generators that produce electricity in plants such as this one, situated near Centralia, in Lewis County. (Artist's concept photo courtesy Pacific Power and Light Co.)* Figure 48.

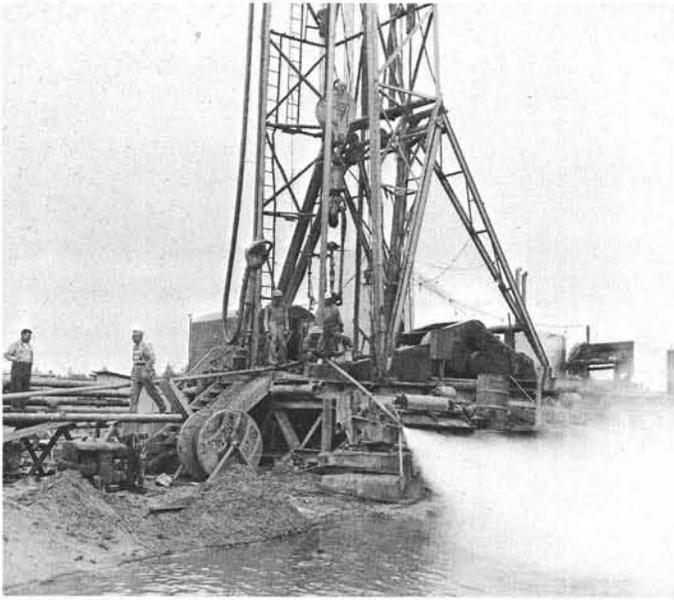
Oil and Natural Gas

Oil was first discovered in Washington about 1893 along the ocean beaches of the western side of the Olympic Peninsula. It was found seeping from certain sandy shale beds that had a distinct kerosene odor. The Indians called these beds "smell muds." The first actual test wells are reported to have been drilled in Snohomish County between 1900 and 1902. Many test wells drilled since that time have had good showings of oil and gas, but it was not until 1957 that the first commercial producer was drilled. This well was drilled by Sunshine Mining Company at Ocean City, in Grays Harbor County, and produced about 12,000 barrels of oil before the well was abandoned in 1960.

Oil has been found only in marine sedimentary rocks of Tertiary age in western Washington. No oil has been found east of the Cascade Mountains, where the rocks are mostly volcanic and metamorphic.

Oil is formed by the accumulation of minute droplets of animal cell fluids. These are set free after the organism dies and is buried in the mud at the bottom of the sea. The billions upon billions of tiny animals that live in the sea, such as plankton and necton, are probably the major source of crude oil.

In 1893, natural gas was discovered in Whatcom County, in a water well that was being dug. The discovery was made when the well digger lit a match to light his pipe, causing the gas to explode. Gas found in Whatcom County has not been in large enough quantity to be used commercially. It has, however, been used to heat the homes and farm buildings of people on whose property it has been found.



*Testing of the Sunshine Mining Company-Medina No. 1 oil well, near Ocean City, Grays Harbor County. The spray coming from the pipe is a mixture of crude oil and natural gas. Figure 49.*

In 1913, natural gas was discovered in Benton County. This field produced gas commercially, supplying several lower

Yakima Valley towns from 1929 to 1941. The field is now depleted and abandoned.

Most of the natural gas that has been found in the state has been methane, and was probably derived from coal formations rather than from crude oil. In 1959, however, the Sunshine Mining Company drilled a well near Ocean City, in Grays Harbor County, that has produced a small amount of the type of gas that is associated with crude oil.

Near Marys Corner, in Lewis County, is a natural gas field that is unusual in that the sandstone storage beds have been filled artificially. Gas that is delivered from the southwestern United States by a pipeline is pumped into a subsurface storage reservoir during summer months. During winter months, when the demand for natural gas is higher than the pipeline can deliver, gas is taken out of the reservoir and supplied to the consumers. The capacity of this reservoir is about 13 billion cubic feet, and its function is to supplement normal gas flow during times of high demand.

Oil and natural gas usually occur in sandstone beds that have been arched up into what geologists call anticlines. The gas and oil accumulate in layers at the tops of these archlike folds. The gas is on top of the oil, which, in turn, is usually above a water layer in the sandstone.

TABLE 2. — Igneous rock classification chart

Mode of occurrence	Texture	Light-colored minerals predominate	Light- and dark-colored minerals about equal	Dark minerals predominate
		Orthoclase is chief feldspar; minor plagioclase. Quartz present. Biotite or amphibole may be present.	Plagioclase is chief feldspar; minor orthoclase. Biotite or amphibole may be present.	Feldspar present. Plagioclase is chief feldspar; pyroxene, amphibole, or olivine may be present.
Batholiths, stocks, dikes, and sills	Phaneritic	Granite	Diorite	Gabbro
	Phaneritic porphyry (has phenocrysts)	Granite porphyry	Diorite porphyry	Gabbro porphyry
Dikes, sills, and surface flows	Aphanitic porphyry (has phenocrysts)	Rhyolite porphyry	Andesite porphyry	Basalt porphyry
	Aphanitic	Rhyolite	Andesite	Basalt
Surface flows, dikes, and sills	Aphanitic	Felsite (light-colored lava)		Trap (dark-colored lava)
		Dense—obsidian Coarsely vesicular—scoria Finely vesicular, fibrous—pumice	Basalt glass	
Flow surfaces, volcanic cones, areas around cones	Glassy			
Crudely to well-stratified layers; volcanic cones	Fragmental	Fine fragments—tuff and ash Coarse fragments—breccia and cinders		

TABLE 3. — Sedimentary rock classification chart

Origin	Texture	Composition	Remarks	Loose, uncompacted form	Rock name				
Detrital	Coarse grained; most fragments over 2 mm. in diameter	Fragments of other rocks	Usually poorly stratified	Gravel	Conglomerate				
			Chaotic, heterogeneous mixture of clay, sand, and gravel	Till	Tillite				
	Medium grained; 1/16 to 2 mm. in diameter. Grains can be seen with unaided eye.	Quartz, feldspar, or rock fragments	Well stratified; may have ripple marks and cross-bedding. Occasionally contains fossils.	Sand	Sandstone, (if mostly quartz grains, quartzose sandstone) (if mostly feldspar grains, arkosic sandstone)				
Chemical	Fine to coarse grained. Made up of crystals, usually less than 1 mm. in diameter.	Very fine particles of quartz, clay, and mica	Stratified in thick massive beds to thin platy beds. Often contains fossils.	Mud or clay	Siltstone (if gritty)				
					Shale (if not gritty and in thin platy beds)				
		Calcite	Effervesces with acid; often contains fossils	Lime mud	Lime mud	Limestone			
						Dolomite	Effervesces with acid only when powdered	Lime mud	Dolomite
									Quartz
Organic	Coarse to fine grained	Plant remains	Black; burns	Peat	Jasper (usually red)				
					Calcite seashells	Mass of broken and unbroken shells cemented together; fine to coarse grained.	Shell bed	Flint (usually brown)	
								Opaline diatom skeletons	Chalklike, white, fine grained
Agate (banded)	Coal	Coal	Black; burns	Peat	Agate (banded)				
					Coal	Coal	Coal		
Organic	Coarse to fine grained	Calcite seashells	Mass of broken and unbroken shells cemented together; fine to coarse grained.	Shell bed	Coquina				
					Opaline diatom skeletons	Chalklike, white, fine grained	Siliceous mud		

TABLE 4. — Metamorphic rock classification chart

Texture	Mineral composition	Outstanding feature	Original rock	Metamorphic rock
Fragmental	Varied, any rock or mineral fragments	Rock breaks through the grains as well as through the cementing material. Usually composed mostly of quartz and has hardness of 7.	Sandstone Conglomerate	Quartzite (medium-grained fragments) Metaconglomerate (coarse-grained fragments)
Dense	Clay, mica, quartz, chlorite, and other minerals. Minerals are not identifiable with the unaided eye.	Commonly dark colored; hard, showing conchoidal fracture	Claystone and siltstone	Argillite
Granular	Calcite or dolomite	Effervesces with acid in either solid or powdered form. Formed by recrystallization of limestone or dolomite. Has a hardness of 3 to slightly more.	Limestone and dolomite	Marble
Slaty	Clay, mica, quartz, chlorite, and other minerals. Minerals are not identifiable with the unaided eye.	Has very good rock cleavage. Breaks into thin flat plates or slabs. When struck with a hammer it has a ring to it.	Shale, siltstone, and claystone	Slate
	Clay, mica, quartz, chlorite, and other minerals. Mica, which gives a sheen to the rock cleavage surfaces, is the only mineral that can be identified with the unaided eye.	Same as slate except that the rock cleavage surfaces have a mica coating or sheen.	Shale, siltstone, and claystone	Phyllite
Foliated	Mica, chlorite, talc, amphibole, quartz, and others	Platy minerals are all oriented in one direction. Minerals are packed together like a shuffled deck of cards; that is, they overlap one another.	Shale, siltstone, sandstone, claystone, basalt, and others	Schist (rock name prefixed by most abundant or characteristic mineral; for example, mica schist, garnet schist)
	Quartz, plagioclase, orthoclase, biotite, muscovite, amphibole, and others	The minerals are banded into alternating light and dark bands. Good crystalline texture; appears very much like an igneous intrusive rock. Commonly the bands are contorted or twisted.	Sandstone, shale, conglomerate, claystone, granite, basalt, and others	Gneiss

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