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J. B. FINK, Acting Director

DIVISION OF GEOLOGY
HAROLD E. CULVER, Supervisor

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THE GEOLOGY OF WASHINGTON

PART I

GENERAL FEATURES OF WASHINGTON GEOLOGY

(To accompany the preliminary geologic map, 1936)

By
HAROLD E. CULVER

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LETTER OF TRANSMITTAL

Hon. J. B. Fink, Acting Director,
Department of Conservation and Development,
Olympia, Washington.

Dear Sir:

I have the honor to present a report of the "General Features of Washington Geology" with the recommendation that it be published as Part I of Bulletin 32 of the Geological series.

Respectfully yours,

HAROLD E. CULVER,
Supervisor of Geology.

November 16, 1936.
Pullman, Washington.

THE GEOLOGY OF WASHINGTON

PART I
GENERAL FEATURES OF WASHINGTON GEOLOGY

By HAROLD E. CULVER

INTRODUCTION

This brief pamphlet, Part I of a comprehensive report on the Geology of Washington, has been written with the double purpose of presenting the generalized geologic features of Washington and of explaining the mode of their presentation on the accompanying geologic map. The great mass of stratigraphic and structural data on which the generalizations were based find no place in this summary. They are presented and discussed in some detail in Part II of this report, "Index to the Stratigraphy of Washington."

The preparation of areal maps showing the distribution of rock formations is the culmination of a great amount of field and office work and constitutes the one satisfactory way of representing what is known of the rocks of specific regions. To the layman, there may be some confusion in the multiplicity of colors, the variation in pattern, and the extreme irregularity in shape exhibited on the map. Hence it will be advantageous to note some of the conventions which have been developed for the presentation of geologic information on a map. Some of these are extremely simple; all are more or less technical.

The reader will readily recognize that the violet color shown in the area about Mount Baker represents the volcanic rocks making up this cone. Immediately to the east is Mount Shuksan, shown by two different colors which mean that rocks of two different formations make up this mountain peak. A total of twenty-five different rock formations is shown on the map by means of the several colors and patterns, and, in addition, each is given a printed symbol composed of two or more letters. It will be noted by reference to the time scale presented subsequently that the first letter, usually a capital, refers to the major time period to which the rock in question belongs. Thus, the

formation making up Mount Baker has the designation Qv, an abbreviation for *Quaternary volcanic rocks.*

Another convention is in the mapping of rock formations without regard to the cover of loose material which conceals most of the bedrock below. Glacial drift, for example, covers a large part of the bedrock in the northern counties but is mapped only where it is so thick that the bedrock beneath is not known or where its presence is significant.

It will be noted further that igneous rocks, whether intrusive or extrusive, are always shown with a pattern of triangles or rhombs. Rocks of sedimentary origin, consolidated in character, are shown with straight ruling on the background color, while all loose mantle rocks are shown with an all-over pattern of dots or circles. This convention introduces a difficulty in representing the geology of Washington, for it so happens that here, particularly in the eastern part of the state, are sedimentary formations locally loose and unconsolidated but distinctly different from the true mantle rock which generally conceals them. They are therefore classed with the sedimentary formations and given the symbol Qc but are presented with the all-over pattern which is used to designate all loose surficial material.

Boundaries between formations are commonly marked by solid lines where the position is well established and by broken lines where it is less certain. On a map of as small a scale as eight miles to the inch, it is extremely difficult to place such boundaries accurately even where their true position is known. A measure of generalization is necessitated and so it has seemed best to show all boundaries with solid lines. In some instances, however, the limits of adjacent formations are not well enough known to warrant presenting a boundary. Along the west coast of the Olympics, for example, no line separates the marine Mesozoic area from the Tertiary marine area to the west. This is a convention indicating a quite indefinite boundary.

THE PLAN OF THE GEOLOGIC MAP

An areal geologic map not only records the observations made in the field but shows also the interpretations of these observations in the light of present geologic knowledge. As the general geologic concepts are modified on the basis of new discoveries, all interpretations of locally observed data will be subjected to alterations. Different observers reflecting differences in training and experience originally make different interpretations of observed facts. These factors in the compilation of a general map for the State of Washington necessitated the formulation of a definite plan of operation to obviate as far as

possible the contradictions appearing in the records of previous workers. It is thought that an understanding of the essential features of this plan will make clear just what is represented and what is not, and aid materially in the use of the map.

The data used in the compilation have come from widely different sources, and with few exceptions relate to small separated areas. Some are from completed detailed studies; others from work equally detailed but far from complete, and hence largely fragmentary. Considerable information has come from reconnaissance studies of more or less satisfactory character but largely not available in the form presented. Some of this work is of high reliability; some reveals lack of discrimination both in the field observations and in inferences recorded. This factor necessitated great care in the final selection of data used on the map.

To one acquainted with the thousands of articles and reports that have been written on the geology and mineral resources of the State of Washington, it may be surprising to learn that they present the geology of less than 40 per cent of the total area of the state. The remainder, over 40,000 square miles, has been mapped during the past decade by the staff of the Division of Geology. To provide results of requisite accuracy, a considerable amount of detailed stratigraphic and structural work was undertaken and this supplemented by careful reconnaissance. There was the additional task of tying in these results with the work done by those unconnected with the State Division.

Not infrequently reports from adjacent areas show marked discrepancy in the stratigraphic position of several formations. In most cases, special reconnaissance studies served to clear up the difficulty, but in a few instances this could not be done without more field work than was possible and the discrepancy is shown on the map. An example of this appears in Snohomish County west of Monte Cristo, where a series of beds in the Monte Cristo area appears as "Tertiary." Beds which appear to be extensions of these sediments to the west and south have been mapped by other workers as Mesozoic and Paleozoic, respectively. Future work will reveal whether all these rocks are of the same age or whether two or all three groups are represented. There is reason to believe the designation of each unit is correct; hence on the present map the boundaries are drawn as straight lines indicating that they have been arbitrarily placed.

Perhaps the most difficult feature of the compilation lies in the fact that in few cases were the formations in one area correlated successfully with those of any other or with a Statewide column. A total of more than two hundred formations has

been more or less satisfactorily described within the boundaries of the State. In very large part, the mapping of these formations has been restricted to small areas and in but few instances have entire boundaries been presented. In order to produce a more generally useful map as well as to bring the production within the limitations of the printer's art and reasonable cost, it was necessary to reduce the total number of map units by almost 90 per cent.

This drastic cut has necessitated a careful examination of practically all of the available information on the geology of the State. It has been necessary to examine every description of rock formations, every assignment to a position in the stratigraphic column, and, finally, each proposed extension outside the original type locality. Only on the basis of such scrutiny could any change from the previously completed work be considered.

In the main, the needed reduction has been accomplished by generalization applied in the case of both sedimentary and igneous rocks. Examples will appear in the ensuing discussion of the mapped units but the principle will be made clear with a single illustration. The Stevens series has long been recognized as comprising a score of geographically distinct units whose mutual stratigraphic relations were not yet determined. On the present map all of this large group was placed in one unit and there were added to this several other formations mapped and described by different workers. By this means, the probable stratigraphic relation of previously uncorrelated formations was indicated and the whole brought into a single mappable unit.

Some modification of existing distribution of rock formations has been necessitated by the scale of the map, which does not permit the representation of small areas of rock. For example, the volcanic rocks designated by Tmv in the Colville Indian Reservation actually appear in a great number of small areas isolated by erosion. Some of these have been omitted, others united, and still others enlarged to mappable proportions. By this procedure, the essential distribution of the formation is indicated, although the precise details are not shown.

THE BASIS FOR MAKING UP MAP UNITS

Use of the map will be enhanced if the basis used in the formulation of the map units is clearly understood. Each unit presents its own peculiarities, but the principles used in making up the groups are the same in all instances. For example, in the "Explanation" column it will be noted that the formation unit marked Tmc is designated "Miocene continental deposits."

The rocks so mapped are all considered to be of "Tertiary" age and to be of continental origin. Most of the beds so designated are Miocene, that is, approximately mid-Tertiary in age. Prominent among such formations already recognized are the Ellensburg, the Latah, and some interbasalt beds of lesser importance; but, in addition to these beds, the map unit has been made to include the so-called "Lake beds" of several areas of eastern Washington which are continental in character and believed to be Tertiary in age but not yet assigned to the Miocene or, indeed, to any other epoch.

Practically each of the map units has such inclusions. A little care in examination of both the "Explanation" and the text of the accompanying bulletin will make the mapping procedure clear and prevent misinterpretation.

THE TIME SCALE FOR WASHINGTON

For the convenience of the reader, there is inserted here a statement regarding the standard time scale and its application in Washington. The subdivision of all geologic time into eras, periods, and epochs is, of course, based upon studies carried on throughout the world. It will be at once clear that no one place will have rock formations representing all of these subdivisions. As a matter of fact, only a few will be represented at any one place, the whole geologic column having been built up from the correlated fragments found in many parts of the globe. For North America a rather complete column has been constructed to which all local geologic sections have been referred. In California, a great amount of study has already resulted in the construction of a column which is especially complete in the two later eras, and it is customary to consider it the standard section for the Pacific Coast.

There are recognized in Washington one or more formations representative of each of the four major divisions of geologic time, the Cenozoic, Mesozoic, Paleozoic, and the Proterozoic eras. In the following table will be found the more important subdivisions of time, together with a single formation of Washington which is illustrative of each. It should be understood that these rock masses, although selected to represent each unit of time, are in no sense typical, and that a number of other formations would serve the present purpose equally well.

STANDARD GEOLOGIC TIME SCALE WITH ILLUSTRATIVE WASHINGTON FORMATIONS

Time Scale			Illustrative Washington formations
Era	Period	Epoch	
Cenozoic	Quaternary	Recent	Alluvium
		Pleistocene	Glacial drift
	Tertiary	Pliocene	Howson andesite
		Miocene	Montesano, Astoria
		Oligocene	Lincoln-Blakely
		Eocene	Cowlitz
Mesozoic	Cretaceous	Upper	Nanaimo
		Lower	Spieden
	Jurassic	Upper, Middle, Lower	Mt. Stuart granodiorite
	Triassic	Upper	Haro
		Middle, Lower	Fidalgo (?)
Paleozoic	Carboniferous	Permian, Pennsylvanian, Mississippian	Peshastin
	Devonian	Upper, Middle, Lower	Stevens
	Silurian		Stevens
	Ordovician	Upper, Middle, Lower	Stevens
	Cambrian	Upper, Middle, Lower	Stevens
Proterozoic (Pre-Cambrian)			Priest River terrane

General inspection of the foregoing table will show that a surprising number of the recognized time units are represented by rock formations in Washington. This, indeed, is one of the complicating factors in the solution of problems of geology in this State.

Reference to the "Explanation" column on the margin of the map will show four formations of the Quaternary period and ten of the Tertiary period. It will be noted, however, that these are not referred to each of the several accepted time units of these two periods. A vast amount of additional work remains to be done before this assignment to detailed position can be made. Comparison of the Mesozoic and the Paleozoic units in the "Explanation" column with the foregoing time scale will reveal an even greater discrepancy. Here again insufficient work makes the assignment to individual periods inadvisable. As explained in some detail in the discussion of the various rock units, the Tertiary and Recent formations are much more accessible, more easily interpreted, and, in general, better known than those of earlier time which are not only generally concealed but have suffered great metamorphic changes, making their interpretation a matter of the greatest difficulty.

ACKNOWLEDGMENTS

A complete list of writings consulted in the compilation of the map and report on the Geology of Washington would be equivalent to a comprehensive bibliography of the geology and mineral resources of the State. The writer wishes to acknowledge free use of much published material, but in addition is particularly happy to record here the very gratifying and wholehearted response from geologists and others to requests for data. He acknowledges gratefully permission to examine private maps and notes of many writers in the Northwest. Some use has been made of unpublished dissertations submitted to the faculties of the University of Washington and of the State College of Washington. Especial thanks are due H. A. Coombs, Walter C. Warren, and W. A. G. Bennett for permission to use data gained from their private studies in the Mount Rainier, Mount Aix, and Colville areas, respectively, prior to their presentation as doctoral dissertations.

An attempt will be made in the body of the report to indicate what data have come from outside sources, and it must suffice here to record a recognition of debt to a large number of workers. The writer enjoyed an extra measure of cooperation from Charles E. Weaver on the boundaries of the Tertiary marine formations in western Washington and from Richard F. Flint on the boundaries for the ice in the latest glaciation in

eastern Washington. Valuable suggestions as to certain phases of Tertiary stratigraphy have been made during field conferences by many who have been primarily interested in oil and gas studies. Prominent in this group have been the late Marcel Daly, Irvine E. Stewart, and Charles S. B. Henry.

While the writer assumes full responsibility for decisions as to correlations and stratigraphic relations presented, he is glad to acknowledge the invaluable aid of members of the staff of the Division of Geology. It is difficult to overestimate the importance and value of this assistance, which brought the results of direct observation in all parts of the State to bear on the problems of correlation. Especial thanks for aid in transferring published material, checking maps, and proof reading the final map and manuscript are due Everett Hougland, W. A. G. Bennett, and Sheldon L. Glover.

THE PHYSIOGRAPHIC PROVINCES

The simplest approach to an understanding of the essential features of the geology of Washington is through its physiographic aspects. Although exceedingly complicated in detail, the physiography of the State is superficially simple.

During the past half century many students have given attention to the physiographic features of the State. As a result of this work, certain natural physiographic provinces have come to be recognized and the following discussion is based on this division.

A group of seven provinces comprises the whole. On the west are two facing the Pacific, the Olympic Mountains at the north, and the Willapa Hills at the south. Just east lies the Puget Sound Trough, a structural depression occupied at the north by Puget Sound and adjacent lowlands, while southward it includes a part of the Nisqually, Chehalis, and Cowlitz drainages, as well as that portion of the Columbia from the vicinity of Vancouver to below Longview. Immediately east lies the extensive Cascade Mountain province which, although breached by prominent drainage lines, nevertheless constitutes a north-south geographic barrier across the State. Still farther east is the Okanogan Highland province, lying north of the Spokane and Columbia rivers and having much in common with the Cascade Mountain province. South of the Okanogan Highlands, the Columbia Lava Plateau occupies the rest of eastern Washington except for the small portion east of Walla Walla where an uplifted mass constitutes an extension of the Blue Mountains of Oregon and has been called the Blue Mountains province.

There the simplicity of the distinctions between the provinces stops. Even so prominent a feature as the Columbia River Valley does not provide an adequate boundary between the Columbia Lava Plateau and the Cascade Mountain province on the west. Although the Okanogan Highland province is sharply delimited in the vicinity of Grand Coulee, it merges into the Columbia Lava Plateau to the east, and to the west no semblance of a physiographic break can be detected on the contoured map. Arbitrarily, the Okanogan Valley is frequently used as the west limit of the Okanogan Highland province. Bounded on three sides by salt water, the Olympic Mountains province shows no well-defined boundary on the south. It must be borne in mind that the designations for the physiographic provinces are generalizations and subject to correction for details; that all boundaries are essentially arbitrary, these departures from strict accuracy being necessitated by a desire to acquaint the

reader with the outstanding features stripped of all complicating detail.

The Olympic Mountains province.—The Olympic Mountains province lies between the Puget Sound area and the Pacific and is separated from the Willapa Hills area to the south by the valley of the Chehalis. The relief is slightly over 8,000 feet, roughness characterizing the central portion where stream and glacial erosion have worn the sharply folded sandstones and slaty rocks into a series of rugged peaks and steep-walled valleys. Many streams take the upland water to the sea, the Skokomish, Duckabush, and Dosewallips leading eastward to Hood Canal, the Dungeness and Elwha northward to the Strait of Juan de Fuca, while the Soleduck, Queets, Hoh, and Quinault empty into the Pacific. The Humptulips and Wynooche lead south but have limited drainage areas in the Olympic upland. Essentially all of Clallam and Jefferson counties lies within the province, which includes also adjacent parts of Grays Harbor and Mason counties. Climatically, great variation is exhibited with maximum rainfall on the west of 160 inches and a minimum of less than 10 inches in the Dungeness zone. Water is abundant, soils are extremely fertile, and vegetation is rank below the timber line, fixed at approximately 6,000 feet.

The Willapa Hills province.—Although characterized as an extension of the Oregon Coast Range by some, there seems little in the Willapa province to justify this relationship. This area of Tertiary rock formations, both sedimentary and igneous, is one of low relief with the maximum elevation well below 3,000 feet. It comprises rather rough country, nevertheless, where the short streams have cut sharp gashes in the upturned lava flows and associated sandstones. Relatively abrupt where they face the Columbia, the hills merge into the lowlands at the north almost imperceptibly. This area is largely within Pacific and Wahkiakum counties but includes part of adjacent Grays Harbor, Lewis and Cowlitz counties. Less water falls here than in the province to the north, yet it is plentiful and furnishes flow for a large number of streams. The Chehalis, Willapa, and Naselle rivers carry most of this water to the sea while a number of smaller streams enter the Columbia drainage or empty directly into Willapa Bay. As in the Olympic province, vegetation here is rank, a result that would be expected from the combination of abundant water and rich soil.

The Puget Sound province.—This well-defined area appears to constitute a structural downwarp, since it is underlain almost everywhere by Cenozoic rocks and is probably related to corresponding depression zones both in British Columbia and Ore-

gon. From north to south, this province has an irregular but fairly definite boundary separating it from the Cascade Mountains on the east, although at the north the province includes some island-like masses ranging well above the general level. To the south, this relationship is replaced by a sharper line of demarkation which is broken only by a few ridges leading onto the lowlands of the trough zone.

With minor exceptions, the Puget Sound province lies below the 1,000-foot level. It comprises a slightly sinuous belt which is readily divisible into (1) a north section extending through Island County in which most of the province is below sea level; (2) a broader mid-section extending nearly across Thurston County in which the land masses predominate; and (3) a southern section, very narrow in Cowlitz County but spreading southward to include a strip on either side of Columbia River above Longview. The Puget Sound province is one of moderate rainfall, and in spite of its proximity to the sea, is, in the main, well-drained so that the fertile soils have given rise to a widespread vegetal cover.

The Cascade Mountains province.—A belt of elevated land trending slightly west of south crosses the State just east of the Puget Sound province and comprises the Cascade Mountains province. Its east boundary at the north is arbitrarily placed at the Chewack Valley, whence it spreads westward for nearly one hundred miles. In the mid-section, it is about half as wide but reaches full width again at the south.

It is marked by the presence of the five volcanic cones: Baker, Rainier, Glacier Peak, Adams, and St. Helens. Aside from these, it reveals some outstanding characteristics. There is, first, the remarkably even summit level of the peaks and ridges. Above this surface, which has been taken to represent an early planation of the rocks of this region, rise the isolated volcanic cones. There is, second, the sharp incision of the upland by such streams as the Skagit and Methow at the north, the Yakima and Snoqualmie in the mid-section, and the Cowlitz and the Klickitat at the south. And, finally, there is the irregularity of the crest line which progresses in a series of zigzag sections from the Canadian line to as far as Mount Rainier. Prominent divides coalescing with the main crest lead off southeasterly in Sawtooth Ridge, Entiat Mountains, Wenatchee Mountains, and others, producing in the area north and east of Mount Rainier a striking elongation of valleys and ridges in the northwest-southeast direction. Southward, in the lower and less rugged portion of the Cascade province, this control is absent, leaving a widespread upland without apparent orientation although north-south structural elements are present.

Even without the volcanic peaks, the total relief of the Cascade belt is high, a large number of peaks and ridge crests standing well above the highest of the Olympic peaks. With such relief, great variation in precipitation is to be expected with resultant and concomitant climatic features. This combination of factors results in a wide range of features in which the Cascade province shows great variation. Both sides share in excellent soils with the necessarily greater vegetation on the west.

The Okanogan Highlands province.—The Okanogan province, sometimes arbitrarily delimited on the west by the Okanogan Valley, is here, with equal propriety, extended westward to the Chewack and the lower Methow valleys. The Columbia and Spokane channels make an acceptable physiographic boundary at the south, while, so far as Washington is concerned, the State boundary north and east constitutes a limiting line. The outstanding characteristic of the province is perhaps its division by north-south lowland areas of considerable breadth. These are, from west to east: the Okanogan, San Poil, Kettle-Columbia, Colville, and Clark Fork valleys. This trenching results in an equally prominent series of north-south uplands. Lacking marked continuity except in Ferry County, they are generally not separately designated, although some more elevated tracts have well-recognized names. Among these are the Priest River, Pend Oreille, Kettle, San Poil, and Okanogan ranges.

Topographically, the region is varied, having relief of well over 7,000 feet but showing little of the roughness that might be expected. Smooth gentle slopes are dominant, so that much of the area carries a thick soil cover.

The moderate annual precipitation, ranging from nearly 25 inches at the Idaho line to about 15 inches in the drier section of the western part, is so distributed during the year as to provide an adequate supply of water for vegetation generally throughout the province.

The Columbia Lava Plateau province.—This extensive area is so anomalous in its topographic character as to defy classification as a basin, plain, or plateau. It is, mainly, within the circle of the Spokane, Columbia, and Snake rivers, although topographically and structurally extending beyond these borders on the south and west. Lying below the 2,000-foot level with little exception, its total relief is slight, almost as low as that of the Puget Sound Trough, and it exhibits greater monotony in all characteristics than any other province in the State. It comprises all of Whitman, Adams, Franklin, Benton, Grant,

Douglas, and Lincoln counties, and includes parts of adjacent Spokane, Kittitas, Yakima, Walla Walla, Columbia, and Garfield counties. Climatically dry, in the south semi-arid, this region is one of sparse vegetation, showing the temperature extremes expected in such situations. The outstanding feature is the drainage, which is away from the center of the area toward the Spokane, Columbia, and Snake, in spite of the marked channels extending across the area from the northeast toward the Columbia. Another characteristic is the presence of a series of uplifts which, while neither identical in character nor parallel in position, nevertheless show common features suggesting a common genesis. These hills are progressively less prominent from south to north and include the Horse Heaven Hills of Benton County, the Rattlesnake Hills of Yakima and Benton counties, the Saddle Mountains and Frenchman Hills of Grant County. These are sharp local uplift ridges of essentially east-west trend which, while not continuous with the northwest trending ridges of the Cascade belt, yet seem to merge into them.

The Blue Mountains province.—As previously noted, this extremely limited area, mainly in Asotin, Garfield, and Columbia counties, constitutes an extension of the Blue Mountains of Oregon, and only deserves special mention as a province in Washington on account of its dissimilarity from the Columbia Plateau province which lies north and west of it. Elevations here rise to above 5,000 feet, giving a relief of half that much. The elongate shape of the upland mass does not suggest the sharp character of the incision by present streams which have cut most of this region into a series of excessively steep gorges, separated by flat-topped irregular, narrow ridges.

THE GEOLOGIC FORMATIONS

There follows here a section dealing with the many rock formations that have been recognized in Washington. As indicated in the introductory section, the large number of these described by different workers has made it necessary to combine them in map units. These units are presented in the "Explanation" column on the margin of the geologic map accompanying this bulletin and are discussed here in the same chronologic order beginning with the most recent.

Under group headings, such as "Tertiary Formations," are given the general characteristics of the group together with a list of the included map units. This is followed by a description of each of the separate map units giving the designation and symbol which appear in the "Explanation" column, a tabulated list of the formations making up the units, and then some notations on the distribution, stratigraphy, and structure of the rocks in the unit.

QUATERNARY FORMATIONS

Four groups of Quaternary rocks are distinguished on the present map. These are: (1) the alluvial deposits of recent formation whose relations to the Glacial deposits and to one another are only partly understood; (2) certain late volcanic rocks such as the Tieton andesite; (3) deposits of the Glacial epoch; and (4) other sedimentary formations whose relations to the Glacial deposits and to one another are not yet clearly understood.

Alluvium, Quaternary, Recent Qa

(Marine sands of Weaver and probably some glacial drift and other sediments included.)

Under this designation are included the post-Glacial beds present in all parts of the State but mainly confined to flood plains of present streams. Off-shore deposits also belong here, but these are not shown since mapping stops at the shore line.

In general, alluvium is not shown on the preliminary geologic map. It does appear where the nature of the underlying rocks is not known, where separation from other Quaternary deposits is desirable, and locally where it is of especial importance for agriculture.

Included with the alluvium are the marine terrace sands of southwest Washington from Moclips to the Columbia River and the terraces near Clarkston on the Snake. In the Tacoma quadrangle are included swamp deposits, possibly of glacial origin.

Much more detailed work is necessary to provide an accurate separation of alluvium from the Pleistocene deposits; hence in

places glacial drift, or possibly older Pleistocene formations may be found mapped as alluvium. Similarly, alluvial flats of Okanogan Valley are not separated from drift, being mapped entirely with the latter formation.

Volcanic rocks, Pleistocene and Recent Qv

(Tieton andesite, Mt. Rainier lavas, and other flows of the Cascade belt. Some Pliocene, Howson andesite, included.)

DESCRIBED FORMATIONS INCLUDED UNDER Qv

Formation	*Region*	*Authority*
Carson lava	Skamania County	Williams, I. A. 69*a*
Glacier Peak volcanics	Snohomish County	Russell, I. C. 46
Later andesite	Monte Cristo	Spurr, J. E. 54
Mt. Rainier lavas	Mt. Rainier National Park	Coombs, H. A. 17
Tieton	Ellensburg	Smith, G. O. 49
Howson	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
Rhyolite	Mt. Stuart	Smith, G. O. 50

a Numbers refer to items in Appendix I.

The rock formations grouped under this heading are restricted to the Cascade belt and, with certain notable exceptions, appear to have been derived from the prominent volcanic cones Adams, St. Helens, Rainier, Glacier Peak, and Baker. An extensive area of andesitic rock between Lewis and Yakima counties has been mapped with the Tieton andesite of Smith in the Ellensburg quadrangle. A still larger expanse of volcanic rock in similar relations is to be found southwest of Mount Adams where it appears on the Hood River topographic sheet as the Big Lava Bed. The outstanding characteristic of all these rocks is their freshness and their superposition on most other rock formations. They have been affected by little, if any, diastrophic movement and are surprisingly free from evidence of erosion. Locally covered by forest trees, the rock surface shows essentially no weathering, and the vegetation has apparently been developed on wind-blown silts which cover the volcanic rocks. When more detailed mapping in the Cascade belt has been completed, there is no doubt that considerably larger areas of these relatively young volcanic rocks will be found. Indeed, some additional areas of these rocks, too small in extent to warrant inclusion on a map of this scale, are now known.

The inclusion of two formations which are not definitely Quaternary in this unit needs explanation. A rhyolite in the Mount Stuart area and the Howson andesite in the Snoqualmie quadrangle are both recorded as distinctly post-Eocene and probably post-Miocene. They might properly be placed in the Pliocene epoch but rather than introduce a Pliocene unit into the geologic column for formations of uncertain dimensions and importance, they have been mapped with the group of Quaternary

volcanics, exactly as has been done for the sedimentary rocks provisionally classed as Pliocene.

Glacial drift, Quaternary, Pleistocene Qg

(Some nonglacial beds included.)

Accurate mapping of the deposits formed in conjunction with the great ice invasions of Washington will show a very large part of the State to have been more or less covered. While in places these still unconsolidated gravels, sands, silts, and clays are piled up in considerable thickness, a reasonably accurate determination of the underlying bedrock is generally possible. The latter is shown wherever it is known except locally where the glacial deposits are of economic importance. In general, the drift is mapped where it conceals bedrock in complex relations as in the Colville Valley. In northern Douglas County, a wide area of glacial drift is shown over the Columbia River basalt to emphasize the southern limit of the glacial ice, where an inconspicuous end moraine separates the drift from other Quaternary sedimentary formations. Outwash sands and gravels over an extensive area in the vicinity of Moses Lake are likewise mapped with the glacial beds.

In certain areas, very detailed work has resulted in the identification of several distinct glacial formations. In the Tacoma quadrangle, for example, Willis described nine mappable deposits of which eight have been combined in the geologic map of the State under this one stratigraphic unit.

Included here intentionally are the materials composing terraces along Lake Chelan in the vicinity of Wenatchee and along the Okanogan River. Unintentionally, through the lack of detailed Pleistocene studies over most of the State, nonglacial beds have probably been included. This is perhaps more commonly the case west of the Cascade Mountains. The margin of the latest continental ice sheet is shown on the present map with a heavy blue line across eastern Washington, through the courtesy of R. F. Flint and with permission of the Geological Society of America. It will be apparent at once that this glacial ice is not thought to have completely covered the higher ridges and peaks of the Okanogan region.

West of the Cascade Mountains equally careful study by J Harlen Bretz has given us a similar limit for the ice mass that moved southward in the Puget Sound region. This is shown in detail between Olympia and Eatonville in Bulletin 8 of the Washington Geological Survey, but is not reproduced on the present map because of the limited extent of the mapped boundary.

Continental sediments, Quaternary, Pleistocene **Qc**

(Nespelem silt, Ringold formation, Cowiche gravels, and Satsop of Grays Harbor area. Palouse formation and miscellaneous deposits included.)

DESCRIBED FORMATIONS INCLUDED UNDER Qc

Formation	*Region*	*Authority*
Cowiche gravels	Ellensburg	Smith, G. O. 49
"Lake beds"	Klickitat County	Hodge, E. T. 29
Nespelem	Upper Columbia and Spokane Valleys	Pardee, J. T., 43 and Flint, R. F. 24
Palouse	Scabland	Bretz, J H. 9
	Oakesdale	Barnes, V. E. 5
	Chelan	Waters, A. C. 64
	Pullman	Treasher, R. C. 55
Post-basalt channeled sedimentary rocks	Scabland	Bretz, J H. 9
Ringold	White Bluffs	Merriam, J. C., and Buwalda, J. P. 39
Satsop	Grays Harbor	Bretz, J H. 7

The deposits here included are mainly older than those mapped as Alluvium and also older than those referable to the latest glaciation. What relationship they may have to the earliest glaciation is problematical. Except for a limited distribution in the lower Chehalis Valley and a more extensive area in Clark County, these deposits are restricted to eastern Washington. Examination of the area south of the Okanogan Highland province reveals wide areas in which these deposits are uninterrupted except by the deep incisions of the channeled scabland.

Much less uniformity either as to character or genesis is exhibited by the beds than is suggested by their combination under one stratigraphic designation. Prominent among these deposits are the Ringold and Palouse formations, the former comprising the notable cliffs of White Bluffs on the Columbia, the latter making up at least the upper portion of the low, rounded hills characterizing the Palouse country. The separation between these two extensive deposits is everywhere in doubt, but they are alike in their relations to both the underlying basalt and the later glacial beds, and hence are placed in a single stratigraphic unit for mapping purposes. To them are added the Nespelem silts along Columbia and Spokane valleys as well as the still less extensive Cowiche gravels in the Yakima area.

TERTIARY FORMATIONS

Distribution.—Tertiary rocks are found in all counties except Island and San Juan, both igneous and sedimentary being present in most areas. The least area is to be found in the Okanogan Highlands, while to the south these rocks underlie the entire area. So far as known, the marine formations are restricted to the West Side. The continental beds lie mostly in the

central Cascade belt, where they are broadly exposed, only smaller masses being known elsewhere. None are reported in the Olympic or Willapa provinces, yet they are commn in the adjacent Puget Sound province, particularly in its southern portion.

Lithology.—The Tertiary rocks show an extreme range from fine-grained fossiliferous limestone through mudstones and sandstones to coarse conglomerate. A corresponding range from highly siliceous to distinctly basic composition is exhibited by the igneous rocks both in the intrusive and extrusive masses. They show perhaps fewer intergradational types than do the sedimentary formations.

Structure.—The bedded rocks of the Tertiary, either igneous or sedimentary, show considerable deformation. Warping is universal, and in many areas folding is sharp, dips above 45° being very common. Many of the Tertiary plutonic rocks appear to be free from any well-defined gneissoid banding, such as results from internal shearing under great pressure. In this respect, separation of Tertiary from older plutonic masses seems practicable in some areas.

Mapped units.—The size and importance of the formations assigned to the Tertiary is suggested by the presentation of ten Tertiary units on the preliminary geologic map of the State; nor does this even approximate the number of recognized formations. The continental sediments of Eocene age, for example, include more than twenty formations whose character and boundaries are known in greater or less detail. The other map units of the Tertiary involve similar combinations in order to bring out the fundamental relations of the large number of formations in this group.

In the class of sedimentary rocks, four groups are designated to separate the Miocene and Oligocene from the Eocene marine strata and the continental beds of each group from the others. The Miocene and Oligocene marine strata make up one unit to separate them from the Eocene beds of similar origin. Two other units separate the continental sedimentary equivalents of the two marine groups. All four of these are shown with a yellow color. Most of the igneous rocks are placed in three units for mapping: one for volcanics of Miocene time; one for "undifferentiated" volcanics; and a third for Tertiary intrusives. The second group includes rocks much older than Tertiary as well as the Tertiary lavas, since the nondescript character of volcanic rocks makes their precise separation difficult. The Kachess rhyolite and Teanaway basalt, presumably Eocene in

age, are also mapped separately from other Tertiary igneous masses.

Miocene and Oligocene, marine strata, Tertiary **Tm**

(Tm, undifferentiated Miocene and Oligocene; Tma, Astoria; Tmm, Montesano; Tmo, Oligocene.)

DESCRIBED FORMATIONS INCLUDED UNDER Tm

Formation	*Region*	*Authority*
Astoria	Chehalis Valley	Etherington, T. J. 22
Blakeley	Western Washington	Weaver, C. E. 67
Chehalis	Western Washington	Weaver, C. E. 66
Clallam	Olympic Coast	Arnold, R. 1
	Western Washington	Weaver, C. E. 67
Hoh	Olympic Coast	Weaver, C. E. 67
Lincoln	Chehalis Valley	Weaver, C. E. 66
Lincoln-Blakeley	Chehalis Valley	Etherington, T. J. 22
Montesano	Western Washington	Weaver, C. E. 67
		Etherington, T. J. 22
Porter	Western Washington	Weaver, C. E. 66
San Lorenzo	Olympic Coast	Arnold, R., and Hannibal, H. 2
Seattle	Olympic Coast	Arnold, R., and Hannibal, H. 2
Twin River	Olympic Coast	Arnold, R., and Hannibal, H. 2
Wahkiakum	Western Washington	Weaver, C. E. 66

More has been written on the marine beds of the Miocene-Oligocene group than on any other similar series in the State of Washington. The interest in these beds has both a scientific and an economic aspect.

Distribution.—The beds are entirely restricted to the West Side, where they are exposed throughout Wahkiakum and Pacific counties as well as in parts of Cowlitz, Lewis, Grays Harbor, Jefferson, Clallam, and Kitsap counties. They are not widely exposed in the Puget Sound country where, if present over extensive areas, they are covered with glacial drift.

Stratigraphy.—The stratigraphic relations of these beds have been the object of a great amount of field study and the subject of numberless discussions, both written and oral. The importance of the scientific aspect of these beds is better understood when the implications of the marine origin are recognized.

Marine beds furnish an exceptionally firm basis for geologic work, since they constitute the calendar by which geologic events are dated. In addition, the presence of marine beds serve to suggest the position and shape of shore lines, to indicate depth and temperature of shore waters, to suggest the topography and even the climate and life conditions of the inland country. Small wonder, then, that these beds have been studied so carefully or that they continue to attract interest of geologists.

In general, these marine strata are abundantly fossiliferous and, while rather extensive lists of species not known elsewhere

have been compiled, there are still certain marked affinities with stratigraphic units of the standard California section which have made possible some suggestive, if not final correlations.

Nothing short of a detailed discussion of each formation will serve to make clear the complexity of the Tertiary marine stratigraphy for one not already in touch with problems of that sort. Only a few points will be touched on here, so that the reader may not lose sight of the primary features in a maze of details. In the first place, it should be remembered that reference of any beds to this group is on the basis of fossils they contain. It should also be kept in mind that these formations have been studied in many parts of western Washington and that, as a result, local names have been introduced into the geologic column, frequently with little suggestion as to their correlatives elsewhere. As the paleontologic details are worked out, these local formation names will be extended or restricted; some will be eliminated, and doubtless new names will be added to meet stratigraphic needs not now known.

The present mapping of Miocene and Oligocene marine beds serves to indicate the major subdivisions. The uniformity of pattern with a designation by letter indicates not only the physical continuity of the formations, but the ease with which they can be confused. It is unlikely that the boundaries here shown will be final. Examination of printed descriptions of the several formations shows that we are dealing with distinct stratigraphic units and, quite obviously, the combination of these district units under the one head involves a measure of inaccuracy. To relieve this situation, four stratigraphic subunits are presented: two for the Miocene, the *Montesano* (Tmm) and the stratigraphically older *Astoria* (Tma); one for the *Oligocene* (Tmo); and, finally, one for the *"Undifferentiated" Miocene and Oligocene* (Tm).

In the present areal distribution, beds mapped as Miocene include some strata that have been differently classed by workers in this field. The published and unpublished results of study by Weaver, Etherington, and Lupher have been used.

Montesano (Tmm).—The Montesano subunit has been recognized in extensive areas along the lower Chehalis Valley between Elma and Grays Harbor. Smaller patches have been identified along the coast near Mora and Cape Elizabeth. Etherington estimates the thickness of the Montesano in the Chehalis Valley at between 4,000 and 4,500 feet.

Astoria (Tma).—As now recognized, the Astoria formation shows a wider distribution than the Montesano. At the north there is a small coastal area on either side of Clallam Bay. Two

areas appear on the south side of Chehalis Valley, Montesano to Elma, and west of Grand Mound. A third area extends as a strip from east of Chehalis River nearly to Raymond and there is a rather extensive area north of the Columbia between Kelso and Skamakawa. In the Chehalis area Etherington estimates the Astoria section at 2,500 feet.

Although the beds assigned to the Miocene are, in general, strictly marine sedimentary rocks, mainly sandstones, it should be noted that the Astoria subunit includes several lava flows and probably some strata of continental origin. This is particularly true in the Willapa Hills province.

This introduces a lithologic similarity of Miocene to the Eocene rocks of this region which is but another of the confusing elements in the stratigraphy of the Tertiary of western Washington.

Oligocene (Tmo).—The present map shows Oligocene as widely distributed as are the Miocene beds. A broad band constitutes a margin of the Olympics on the north and east where the Tertiary overlies the Mesozoic rocks of the Olympic Mountains. At the south, smaller areas lie on either side of the Willapa Hills, which are largely composed of Eocene rocks, and patches of Oligocene are in similar relation to the Eocene along the Chehalis between Centralia and Elma. Sedimentary rocks exposed over a few square miles south of Snohomish and near Seattle have also been classed as Oligocene by Weaver. Lithologically, nearly all beds of this group are composed of clastic sediments. Shales predominate, although some well-defined sandstone zones have been recorded. As in the case of the Astoria group, the rocks assigned to the marine Oligocene include some igneous rock, which is apparently confined to dikes. The Oligocene, as now recognized, is by far the thickest of the Tertiary marine formations. In 1916, Weaver recorded 15,000 feet for the Oligocene with 4,000 feet of lower Miocene overlying in the Cape Flattery-Juan de Fuca area. Subsequently, Etherington has stated that 19,000 feet of beds in the Cape Flattery area may be referred to the Oligocene. As at present recorded, the thickness is less farther south. Nearly 9,000 feet have been measured by Weaver in the Blakeley area, while in the Chehalis and lower Columbia valleys, the total thickness is less than 3,000 feet.

Undifferentiated strata.—Brief mention of the formations mapped with the designation "Undifferentiated Miocene and Oligocene" (Tm) will make clear the basis for the introduction of this subunit. The application of the term "undifferentiated" connotes a lack of sufficient information to permit assignment

of the beds to a stratagraphic unit of known position in the geologic column. The strata so designated are mainly confined to three areas: (a) an east-west strip roughly defined by the valley of North River (along the Grays Harbor-Pacific County line); (b) a broader belt along the west side of the Olympic province; and (c) an extension of this area to the southeast into Mason County. Two small areas in western Snohomish County are included with the undifferentiated beds. Without doubt, considerable thickness of strata totaling several thousand feet are included in this group. Since so little is known of thickness, fossils, or stratigraphic relations, it is futile to attempt generalizations for this mapped subunit, which is a sort of scrap bag for the unidentified Tertiary marine formations.

Miocene volcanics Tmv

(Columbia River lavas, Keechelus andesite, and other Miocene extrusives. Some undifferentiated Tertiary rocks included.)

DESCRIBED FORMATIONS INCLUDED UNDER Tmv

Formation	*Region*	*Authority*
Andesite flows	Republic	Umpleby, J. B. 57
Basalt	Republic	Umpleby, J. B. 57
Basalt	Spokane	Pardee, J. T. and Bryan, Kirk 44
Basalt	Colville Ind. Res.	Pardee, J. T. 43
Camas basalt	Stevens County	Weaver, C. E. 68
Columbia lavas	Central Washington	Russell, I. C. 45
Diabase	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
Early andesite	Monte Cristo	Spurr, J. E. 54
Enumclaw	Western Washington	Weaver, C. E. 67
Gerome	Stevens County	Weaver, C. E. 67
	Chewelah	Jones, R. H. B. 36
Keechelus	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
	Skykomish	Smith, W. S. 53
	Cedar Lake	Fuller, R. F. 25
	Mt Aix	Warren, W. C. 62
Latite porphyry	Republic	Umpleby, J. B. 57
Midway	49th Parallel	Daly, R. A. 20
Pyroxene andesite	Pierce County	Daniels, J. 21
Taneum	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
Tertiary andesite	Colville Ind. Res.	Pardee, J. T. 43
Tertiary porphyry	Colville Ind. Res.	Pardee, J. T. 43
Tieton andesite (pars)	NW. corner Ellensburg quadrangle	Warren, W. C. 62
Wenas	Ellensburg	Smith, G. O. 49
West Index andesite	Index	Weaver, C. E. 65
Yakima	Ellensburg	Smith, G. O. 49
	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
	Mount Stuart	Smith, G. O. 50

Distribution.—This is by far the most widespread unit appearing on the preliminary geologic map. The total area covered by rocks of this designation probably is in excess of half

the area of the State. Below a cover of Pleistocene and Recent sedimentary beds, it blankets practically every square mile of the ten southeastern counties, a total of over 15,000 square miles. Similar relations obtain in four more counties in the southern Cascades, adding some 10,000 square miles to the area. This practically continuous lava blanket extends westward to cover much of Cowlitz, and the eastern part of Lewis, Pierce, and King counties. In addition, the older rocks of more than half of Kittitas County and an equal part of Spokane County are concealed beneath the widespread basalt. Besides these more or less continuous masses, there are a number of beds assigned to this unit in the northern tier of counties from the vicinity of Mount Baker to beyond the Columbia River. None of the volcanic rocks of the Olympic Peninsula are here assigned to this unit, although further study may show some of the basic volcanic flows to be as late as mid-Tertiary.

Stratigraphy.—The major formation of the Miocene volcanic unit, far exceeding all others combined, is the series of Columbia River lavas. Under this term, Russell originally included flows of Eocene as well as Miocene age. The whole series from Asotin County to the Big Bend region, together with Smith's Yakima and Wenas groups of Miocene age, is combined under the one designation Miocene volcanics (Tmv). These flows, constituting the northern extension of an area of some 200,000 square miles from southern Idaho over eastern Oregon and into California, are found over the crest of the Cascades south of Mount Rainier and farther west merge into similar rocks of uncertain age in West Side counties between the Cowlitz and Columbia rivers.

A large area of these volcanic rocks, mainly of basic composition, exposed in Clark, Cowlitz, and Lewis counties, is mapped provisionally with the Miocene volcanics. These have not been adequately studied to determine either their relations to the Columbia River lavas, or to similar rocks known to be interbedded with the Eocene in the Cowlitz Valley. Much remains to be done with the volcanic series in this southern Cascade belt; it is certain that within the area now mapped as Miocene volcanics there will be found not only extensions of the Quaternary lavas, but also additional exposures of pre-Miocene sedimentary and igneous rocks. This procedure will modify greatly the continuity of the Tmv pattern as now shown.

Elsewhere in the Cascades, additional areas of volcanic rocks, almost certainly Tertiary but not belonging to the Columbia River lavas, are included in this group. Perhaps the most extensive is the Keechelus series mapped in the Snoqualmie area

by Smith and subsequently in the Skykomish and Cedar Lake quadrangles by W. S. Smith, and Fuller, respectively. There are also included the Taneum andesite and a diabase of the Snoqualmie area. To the west is a rather extensive area of volcanics of andesitic character described by Weaver under the name "Enumclaw" volcanics. This formation is also incorporated in this stratigraphic unit. In Pierce County a pyroxene andesite was doubtfully referred by Daniels to the Mount Rainier lavas, presumably of Pleistocene age. Subsequent work by Coombs, taken in conjunction with the distribution of the Enumclaw series, makes it likely that only a very small amount of Daniels' pyroxene andesite is to be correlated with the Rainier lavas. The larger part being almost certainly of Miocene age, the whole formation is placed with the Miocene volcanic unit. To the north, the west Index andesite series, a relatively small area mapped by Weaver, is included as is also Spurr's Early andesite in the Monte Cristo district.

In the northwest part of the Ellensburg quadrangle, a portion of Smith's Tieton andesite has been correlated with his Keechelus of the Snoqualmie area to the northwest through the Mount Aix region by Warren. This part of the Pleistocene of Smith is, therefore, moved into the Miocene volcanic unit. In eastern Washington there is also included a group of Tertiary volcanics of the Colville Reservation, comprising Pardee's Tertiary andesite and Tertiary porphyry. To the north, Umpleby's Latite porphyry, basalt, and andesite flows in the Republic area are also included, as is the Midway volcanics of Daly at the Canadian boundary, together with extensions of this series to the south in Ferry County. Limited to an area in Stevens County, the Camas basalt and Gerome andesite constitute the only other described formations included with the Miocene volcanics.

Descriptions.—The Miocene volcanic stratigraphic unit comprises nearly a score of formations which are here combined for mapping purposes. The one common characteristic is their volcanic origin. In addition to that, they are predominantly flows of lava and also predominantly basic in composition. Aside from these features, it is quite obvious that there can be no uniformity in physical character or in chemical composition. A few of the formations, such as the Camas basalt, show probable affinity with the great Columbia River lavas. A number of the others, such as the west Index andesite series, reveal no hint as to their proper correlation. So far as can be determined from all bases, all of these formations here grouped together are either definitely Miocene in age or more probably Miocene than belonging in any other part of the geologic column.

This not being a single stratigraphic unit in the ordinary sense of the term, no useful purpose can be served by discussion of the thickness of the group. For purposes of comparison, nevertheless, it is well to note that the Enumclaw volcanics, among the lesser groups, is one of the thickest, Weaver reporting more than 1,000 feet in the Pierce County area. East of the mountains, Smith records more than 2,000 feet of Yakima flows, pointing out that this includes neither the top nor the bottom of the series. Within the central portion of the great Columbia Lava plateau is found the greatest thickness of this vast series, which ranges to a minimum at the eastern margin near the Idaho line. No very reliable figures are at hand for maximum thickness of the Columbia River lavas. A number of holes in excess of 2,000 feet have been drilled without penetrating the sub-basalt rocks. It seems probable that a maximum thickness of 4,000 or 5,000 feet will probably be found over the lowest point in the pre-basalt surface. The absence of any horizon markers in the basalt series makes it impossible to tie up sections obtained in different localities, as is so commonly done in the case of sedimentary rocks. Hence the maximum thickness recorded must be measured in a single area. Perhaps the outstanding characteristic of the Columbia River lavas is their monotonous uniformity, although any section may show much variation in texture and structure.

Some of the other groups, such as the Enumclaw volcanics, show in addition to these variations the introduction of pyroclastic beds, layers of dust, and volcanic tuff. Other groups show even the introduction of coarse sedimentary rocks.

Structure.—As would be anticipated in a composite group such as that making up the Miocene volcanics, the structural aspect shows extreme variation. While over much of the Columbia Plateau the beds show but slightly the effect of deformation, broad, gentle warping has been common, and locally more severe movements have resulted in the formation of relatively sharp folds together with some marked faulting. The major deformation involving these beds is, of course, that of the Cascade Range itself. Prominent among the subordinate deformative movements have been those which resulted in the series of east-west ridges which are particularly prominent east of the mountains. A series of up-warps from the Horse Heaven Hills on the south to the Frenchman Hills at the north show progressively less uplift. Faulting of the surficial portion of the series is apparent in the Saddle Mountains, Rattlesnake Hills, and Horse Heaven Hills. The amount of displacement has been estimated at nearly 1,000 feet in some instances, although it is unlikely that the deformation is generally excessive.

Miocene continental deposits Tmc

(Ellensburg, Latah, and some interbasalt sedimentary rocks. Eagle Creek, Madras, and undifferentiated "Tertiary Lake Beds" in eastern Washington included.)

DESCRIBED FORMATIONS INCLUDED UNDER Tmc

Formation	*Region*	*Authority*
Beverly	Saddle Mountains	Twiss, S. N. 56
The Dalles	Lower Columbia Valley	Buwalda, J. P., and Moore, B. N. 13
Eagle Creek	Skamania County	Williams, I. A. 69
Ellensburg	Ellensburg	Smith, G. O. 49
	Mt. Stuart	Smith, G. O. 50
	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
	Prosser	Shedd, S. 48
	Chelan	Waters, A. C. 64
Guye	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
Howard	Index	Weaver, C. E. 65
Latah	Spokane	Pardee, J. T., and Bryan, Kirk 44
Madras	Klickitat County	Hodge, E. T. 29
Tertiary Lake beds	Republic	Umpleby, J. B. 57
	Oroville	Umpleby, J. B. 59

Distribution.—The rocks of this group are relatively inconspicuous areally, although in a few places they are prominently exposed and well known. They are important from a scientific point of view for the light they throw on certain phases of the stratigraphy of the Tertiary. Locally, they have a certain economic importance, since they include some commercially valuable clays and beds of pure diatomaceous earth. Beds assigned to the Miocene continental group are largely, but not exclusively, found on the east side of the Cascade Range. The largest area appears in the Yakima Valley, only small patches appearing elsewhere although widely distributed from the Oregon line to the Canadian boundary. On the preliminary geologic map, only the larger and better known beds have been shown. A still larger number of less conspicuous strata are to be found; indeed, thick sections of the Columbia River lavas usually include more or less of sediments referable to this series.

In addition to the formally described formations listed above, there have been included and mapped a number of formations such as the interbasalt beds appearing in Klickitat County in the vicinity of Roosevelt and to the northwest along Rock Creek. Farther north, interbasalt beds are mapped for the Horse Heaven Hills north of Bickleton and Toppenish Ridge. Interbasalt sediments also appear along Columbia River between Vantage and Rock Island, together with similar beds in Douglas County near Waterville, south of Bridgeport, and at the head of Grand Coulee. Beds farther north in the Okanogan

Valley which appear to have approximately the same stratigraphic position are also placed with this unit, as are the coal-bearing beds in the Spokane Valley near Sand Creek. In Pend Oreille County a rather extensive area of coarse gravels and sands in the vicinity of Ione, together with small patches on either side of Clark Fork north of Usk, are similarly mapped.

Stratigraphy.—Not all of these beds occupy an interbasalt position which is characteristic of the majority of strata here included. Thus, the Ellensburg formation as mapped by Smith in the Ellensburg area lies near the top of the basalt flows, much of the recorded thickness being post-basalt. On the other hand, the thick Latah beds of Bryan and Pardee in the Spokane district are reported to lie wholly below the Columbia River lavas. The beds of Douglas County and those along Columbia River in Kittitas and Grant, as well as those appearing in the upwarps of Toppenish and Horse Heaven ridges are strictly interbasalt in position.

This situation raises some doubt as to the contemporaneity of the interbasalt sediments, recent studies indicating that the Miocene continental sediments were probably deposited in a series of fresh-water areas which were geographically separated and probably in process of formation intermittently throughout the period of extrusion of the Columbia River lavas.

While the rocks assigned to the Miocene continental sedimentary group (Tmc) are largely related to the Columbia River basalts, if not interbedded with them, there are outside of the Columbia Plateau a number of small areas of similar rocks whose age has been designated as Miocene, at least tentatively.

In this group comes the Howard arkose of the Index area and the Guye formation of the Snoqualmie district. Both groups are fossiliferous, the Guye showing particularly abundant leaf forms in the more shaly parts. In the case of the Guye, the degree of compaction and a slight tendency toward slatiness have suggested to some workers that the formation may be older than Miocene.[1]

Description.—The beds here included, as would be expected from their diverse geographic distribution and lack of continuity, comprise silts, sands, and gravels, in large part derived from the surrounding lava flows through the ordinary process of erosion, and in part derived from wind-blown material which lodged in the lakes or rivers where deposition was taking place. Under these conditions, the material composing these sediments is in

[1]The Howard arkose is designated Tm on the geologic map of the State. This should be changed to Tmc.

part completely weathered and in part represents the less decomposed fragments of the consolidated lavas. The occasional beds of diatomite are rarely continuous for any great distance, but show deposition of remarkably pure material, in thickness ranging from a few inches to more than 15 feet. A conspicuous feature of the diatomite beds is the presence of concretions up to several feet in diameter of a yellowish-green opal. In numerous instances, both the diatomite and other sedimentary beds of this series show the effect of contemporaneous outpouring of lavas. Locally, these are injected in the form of short sills or dikes into the sediments. Among the gravels, particularly those of interbasalt position in the Yakima Valley, are to be found large numbers of pebbles of white glassy andesite or of pumice. These are by no means widespread over the State and presumably represent local additions from nearby sources.

The extreme variation in thickness of the sedimentary beds included with the Miocene volcanics is a direct reflection of the variety of sites and conditions of deposition. The interbasalt beds of the lower Columbia area, for example, are largely less than 100 feet thick. Those farther north, as in the Saddle Mountains, range up to 200 feet in thickness. A total of 1500 feet assigned to these beds was recorded by Smith in the Ellensburg area, while in the Latah, near Spokane, a thickness of more than 800 feet was recorded by Pardee and Bryan. Except where these beds are well exposed, figures as to thickness have to be considered approximations and subject to the correction which more detailed investigation may provide.

Being largely interbasalt in position, the Miocene continental sediments are involved in all of the movements which have deformed the basalts. Thus, over most of the Columbia Plateau the beds show relatively little deformation, although in the uplifted zones such as the Rattlesnake Hills, the displacement is marked. Gentle dips are the rule throughout the Yakima Valley, only rarely rising above 35°, and the same situation obtains in the series of "Lake Beds" in Okanogan County.

Fossils.—Even the most brief discussion of the Miocene continental beds would be incomplete without mention of the fossil plants which are characteristic of a majority of these rocks. By far the greatest collection has been made in the Latah beds in the vicinity of Spokane, and these have been given careful study, first by Knowlton and subsequently by Berry. Relatively few plants have been found in the type Ellensburg, but those beds in Moses Coulee and at the head of Grand Coulee have yielded excellent and abundant forms. Equally productive of well-preserved plant fossils are the similar beds in the lower Clearwater Valley of Idaho. Beds presumably correlatives of these in the

bluffs above Asotin have not as yet yielded good fossil plants. The flora of Williams' Eagle Creek was among the first of these to be studied and the work of Chaney on this material resulted in valuable suggestions as to conditions at the time these beds were laid down.

Tertiary intrusives **Ti**

(Snoqualmie granodiorite and other intrusives of ascertained Tertiary age.)

DESCRIBED FORMATIONS INCLUDED UNDER Ti

Formation	*Region*	*Authority*
Andesite porphyry	Mount Stuart	Smith, G. O. 50
Castle Peak	49th Parallel	Daly, R. A. 20
Diorite	Colville Ind. Res.	Pardee, J. T. 43
Gabbro	Mount Stuart	Smith, G. O. 50
Lightning Creek	49th Parallel	Daly, R. A. 20
Pyroxene diorite	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
Sheppard granite	49th Parallel	Daly, R. A. 20
	Stevens County	Weaver, C. E. 68
Snoqualmie granodiorite	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
	Skykomish Basin	Smith, W. S. 53
	Cedar Lake	Fuller, R. E. 25
	Mt. Rainier Park	Coombs, H. A. 17

General considerations.—Rather generally throughout the State, but particularly prevalent in the northern half of the State, are great masses of granitic and related rocks injected into the sedimentary and other rocks previously formed there. In the main, these rocks are associated with large-scale intrusion. By far the most complete and comprehensive investigation of these intrusive masses was made more than a quarter of a century ago by Daly for the Geological Survey of Canada. Until equally detailed studies are made of this vast series of intrusive rocks in the northern tier of counties, it will not be possible to indicate with any assurance either the areas occupied by the various masses or their interrelations.

Enough has been done, however, to show that these intrusive rocks belong to at least three major groups separated by appreciable time intervals. The latest of these three is that referred to the Cenozoic era.

Much study has already been devoted to these Tertiary injections and many features of them are now being investigated. Present data are insufficient, nevertheless, to separate these masses from those of earlier eras in most parts of the State. The areas which appear on the present geologic map with the designation Ti include only those masses for which a Tertiary age has been indicated and for which approximate boundaries can be drawn from data available at this time.

It should be borne in mind, therefore, that the Ti areas now mapped not only do not include all of the known Tertiary in-

trusives but probably do not include even a majority of these rocks. Many omissions are recognized, but information is not available to permit correction. A particularly good example of such omissions is found by comparing the intrusive formations mapped by Daly in the Cascade belt with those appearing on the map of Washington. Daly's Chilliwack, Cathedral Peak, and Similkameen stocks and batholiths are all represented as of Tertiary age. Quite obviously, these extend to a greater or less distance south of the Forty-ninth Parallel. Their relations to the older, Mesozoic, masses are presumably intrusive, possibly intricately so. Reconnaissance studies south of the line have not made these items clear, and rather than introduce arbitrarily any fictitious boundaries between unrecognized granitic masses, these areas have been mapped with the similar rocks of Mesozoic age.

Distribution.—Bearing these restrictions in mind, it may be noted that the largest of the Tertiary intrusive areas is that of the Snoqualmie granodiorite of eastern King County, the only other large mass being Pardee's diorite in the San Poil Valley of Ferry County. A few fairly well-defined masses appear in southern Lewis and Skamania counties, but elsewhere intrusives assigned to this group appear as inconspicuous masses.

Lithologically, these rocks are of coarse texture, contrasting sharply with the Tertiary volcanic rocks in this regard. While by no means all granites, they are, nevertheless, predominantly of granitic type and comprise only the "granites" of the layman.

As indicated in the preliminary discussion of this group of rocks, great scientific interest attaches to the study of them. They are, however, not less important from the standpoint of their relation to economically important deposits. The genesis of the ore deposits in the Mt. St. Helens mining district is definitely tied up with the Tertiary intrusive diorite of that region. Presumably, to an equal if not now definable extent, many deposits of the northern half of the State are related to the Tertiary intrusives there present.

The importance of detailed geological investigations of these granitic masses by which it may be possible to separate the Tertiary from the older intrusions is fully realized by those interested in the development of the deposits of metallic minerals in the State. The origin of these minerals in the intrusions is beyond question. It becomes necessary, therefore, to determine which of the intrusive masses have been responsible for the introduction of the metallic content. As indicated in the preliminary paragraph on the structure of the Tertiary formations, these injected granitic rocks are relatively free from any banding or other indications of dynamic alteration. While not

yet demonstrated as an infallible rule or guide, it appears likely that this characteristic will be of increasing service in making the distinctions between intrusions of the three major groups.

Eocene marine strata and intercalated basalt lavas Te

(Tejon of Weaver, Cowlitz, and other Eocene rocks.)

DESCRIBED FORMATIONS INCLUDED UNDER Te

Formation	*Region*	*Authority*
Cowlitz	Chehalis Valley	Etherington, T. J. 22
	Western Washington	Weaver, C. E. 66
Crescent	Clallam County	Arnold, R. 1
Tejon	Pacific Coast	Arnold, R., and Hannibal, H. 2
	Western Washington	Weaver, C. E. 67

Distribution.—Like the Miocene and Oligocene group of marine beds, these rocks of Eocene time derive no little importance from the fact that they were laid down in the sea and hence serve as part of the basic geologic record of the State. Much study has already been devoted to this group. During the past twenty-five years, many changes have been made in the stratigraphic column. In the main, these changes have been slight as to names of formations, but the upper and lower stratigraphic limits have been shifted appreciably as new and more complete fossil collections provided data for more accurate correlation with the type section of California. It should be recognized that a rather extended list of members of one of these marine formations, such as the Tejon, can be prepared from the several groups of fossil remains obtainable at different zones within the series.

Like the younger Tertiary marine beds, those of Eocene time are restricted to the West Side and, indeed, are found in none of the mountainous areas. Except for a few small patches between Everett and Tacoma, the rocks assigned to the Eocene marine group are found west of the axis of the Puget Sound depression. Throughout much of this area the Eocene rocks occupy the regions comprising the low divides between drainage basins. The outstanding example of this is the elongate belt of Eocene reaching from the south shore of Grays Harbor to the Cowlitz River and comprising most of the upland of the Willapa Hills province. A similar physiographic position is seen for the Eocene in the headwaters of Lincoln Creek, northwestern Lewis County, in the Shelton-Olympia divide between the Chehalis and Puget Sound waters, and to the north in the uplands practically surrounded by the hook of the south end of Hood Canal. A narrow belt of Eocene rocks crosses the drainage lines of the upper Satsop and Humptulips. This area has an arbi-

trary boundary at the north in the absence of any detailed information as to the exact position of the south margin of the Mesozoic (?) rocks making up the Olympic Mountain mass. At the north, just northeast of the Oligocene rocks bordering the Strait of Juan de Fuca, is a narrow belt of Eocene rocks between Port Ludlow and Washington Harbor, and another small marginal zone lies ten miles west of Port Angeles.

Description.—The Eocene marine beds include, mainly, clastic rocks in which shales predominate, although sandstones comprise a not unimportant portion. In rare instances is the Eocene marine section free from intercalated beds of continental origin. This relation between the sediments of fresh and salt water is indicated, also, by the presence of conspicuous masses of basalt and andesite. While some tuffaceous beds appear, the flows predominate. Weaver's type section in southern Lewis County includes nearly 5,000 feet of Eocene of which little more than one-fourth is of continental origin and none is of igneous origin. An estimated thickness, not accurately measured, brings the total Eocene in the type area up to more than 10,000 feet. A considerable amount of tuff and lava beds is included. In but few places are the Eocene beds exposed in contact with the underlying rocks. The upper limit of the Eocene in many instances, however, is marked by the overlying marine strata of the Oligocene or Miocene. The margins on the west are largely concealed beneath Quaternary deposits. Eastward, although the relations at the north are largely concealed by glacial drift, farther south in Lewis and Cowlitz counties the marine beds appear to grade eastward into continental correlatives, which are mapped separately (Tec) on the preliminary geologic map of the State. As demonstrated in the type section in southern Lewis County, the interfingering of marine and continental beds rather generally in the Eocene areas makes clear that this was a time of fluctuating sea level, with the shore line now advancing and now retreating over a zone several miles wide.

The Eocene marine beds have been deformed more extensively than the corresponding beds of Miocene age and are found in rather extensive folds, some of which show dips as high as 60°. In the main, the beds lie with gentle undulations, and the absence of much faulting makes it clear they have been subjected to no great deformative stress.

Eocene continental strata **Tec**

(Puget, Swauk, and other Eocene beds. Tev, *Kachess, Rhyolite, and Teanaway basalt.)*

DESCRIBED FORMATIONS INCLUDED UNDER Tec and Tev

Formation	*Region*	*Authority*
Arkose	Monte Cristo	Spurr, J. E. 54
Bayne	Green River	Evans, G. W. 23
Burnett	Tacoma	Willis, B., and Smith, G. O. 70
	Pierce County	Daniels, J. 21
Carbonado	Tacoma	Willis, B., and Smith, G. O. 70
	Pierce County	Daniels, J. 21
Carbon river series	Pierce County	Daniels, J. 21
Chuckanut	San Juan Islands	McLellan, R. D. 38
	Whatcom County	Jenkins, O. P. 33
	Skagit County	Jenkins, O. P. 34
	Whatcom County	Crickmay, C. H. 18 Glover, S. L. 26
Eocene volcanics	Chelan	Waters, A. C. 64
Fairfax	Pierce County	Daniels, J. 21
Franklin	Green River	Evans, G. W. 23
Kachess rhyolite	Snoqualmie	Smith, G. O. and Calkins, F. C. 52
Kummer	Green River	Evans, G. W. 23
Manastash	Mt. Stuart	Smith, G. O. 50
Melmont	Pierce	Daniels, J. 21
Naches	Snoqualmie	Smith, G. O. and Calkins, F. C. 52
Natapoc	Chiwaukum	Hougland, E. 31
Pittsburg	Pierce County	Daniels, J. 21
Puget	Tacoma	Willis, B. 70
	Southwestern Wash.	Culver, H. E. 19
Roslyn	Mt. Stuart	Smith, G. O. 50
South Prairie	Pierce County	Daniels, J. 21
Swauk	Mount Stuart	Smith, G. O. 50
	Chelan quadrangle	Waters, A. C. 64
	Skykomish Basin	Smith, W. S. 53
Teanaway	Mt. Stuart	Smith, G. O. 50
	Snoqualmie	Smith, G. O. and Calkins, F. C. 52
Wilkeson	Tacoma	Willis, B. 70
	Pierce	Daniels, J. 21

The Eocene of continental origin in Washington is primarily of interest for its economic importance and only secondarily for its scientific aspect. Essentially all of the commercial deposits of coal and a large fraction of those of clay of Washington belong among the continental beds of Eocene age. The Swauk sediments, with the included Teanaway basalt, were also the source of the important gold-placer gravels of Swauk Creek in Kittitas County.

Distribution.—Beds belonging in this group are found along the east margin of the Puget Sound depression, to the south in Lewis and Cowlitz counties, and to a limited extent at the crest of the Cascades in eastern Lewis and King counties; but the

greatest expanse of these beds is found just east of the crest of the Cascades in Kittitas County, where the Swauk formation extends over several hundred square miles in a horseshoe loop around Mount Stuart. Marginal to this area on the south and east are remnants of formerly more extensive areas of rocks of similar character and essentially contemporaneous. Except for the continuous Swauk formation, these continental Eocene beds are mainly separated masses of strata. The present separation is in part due to original deposition in distinct basins and in part to subsequent deformation followed by erosion of the intervening or connecting portions. Whatever the cause, the separation has been a source of considerable difficulty in stratigraphic work and has resulted in the application of the rather large number of names given to members of this group. The economic importance of the coal-bearing strata has, of course, been the prime reason for designation of certain members within the group.

Description.—In general, it is recognized that all of the Eocene continental beds of northwestern Washington may properly be placed in the Chuckanut group. Those in the southern Puget Sound and southwestern Washington areas can properly be designated the Puget group, while those along the crest and to the east of the Cascades can be combined under the general designation Swauk.

The sedimentary rocks belonging to this map unit are almost exclusively coarse clastics. Sandstones and sandy shales with a large percentage of conglomerates make up the bulk of the series in all parts of the State. Locally, appreciable thicknesses of clean shale are recognized, this being particularly true in those beds of the southern Puget Sound area which are referred to the Puget formation. Some relatively massive and resistant sandstones make prominent markers on the landscape not only in the Puget Sound region, but also in the Swauk area of Kittitas and Chelan counties. The other strata are in general less resistant and commonly outcrop only in stream valleys.

In addition to the sediments, there are included with the Eocene continental group of rocks three igneous formations. This combination is for stratigraphic purposes and the igneous rocks are shown with separate pattern and color (Tev) on the geologic map. In the Mount Stuart and Snoqualmie areas, the Swauk sandstone has been penetrated by hundreds of dikes of basalt and diabase which have been interpreted as mainly feeders for the overlying Teanaway basalt. As would be expected under this relation, the Teanaway basalt lies, roughly, in a marginal position with reference to the Swauk area. The Kachess rhyolite in the Snoqualmie area, which is classed by

Smith as of Eocene age, is likewise placed with the Eocene continental group. The third igneous mass included with this continental group comprises the Eocene volcanic rocks of the Chelan quadrangle mapped by Waters.

The rocks of the Eocene continental group show considerably greater deformation than the Eocene marine in general. This would be expected from their position with reference to the uplifted Cascade belt. High dips, approaching verticality, are found, and beds at angles of less than 25° are rare.

Undifferentiated volcanics, Carboniferous to Tertiary uv

(Rossland, Chilliwack, and miscellaneous volcanic rocks of undetermined age. Some associated metamorphic sedimentary rocks included.)

DESCRIBED FORMATIONS INCLUDED UNDER uv

Formation	*Region*	*Authority*
Chilliwack	49th Parallel	Daly, R. A. 20
Jumbo volcanics	Stevens County	Weaver, C. E. 68
Palmer volcanics	Stevens County	Weaver, C. E. 68
Phalen Lake volcanics	Stevens County	Weaver, C. E. 68
Rossland	49th Parallel	Daly, R. A. 20
	Stevens County	Weaver, C. E. 68
Slollicum	Whatcom County	Crickmay, C. H. 18
Vedder greenstone	49th Parallel	Daly, R. A. 20

This group has been given an explanatory description. Volcanic rocks, in general, while showing considerable local variation, infrequently reveal associations or peculiarities by which their position in the stratigraphic column can be definitely determined. This is particularly the case if the rocks, subsequent to their extrusion, have been involved in deformation.

In most parts of the State the volcanic rocks can be referred to a specific zone in the stratigraphic column on the basis of the associated sedimentary beds. To take care of cases where this has not been possible on data available at present, this special group of rocks has been set aside.

In addition to those listed above, a rather large area of volcanics in east-central Skagit County is included. These are the rocks which are found on Sauk Mountain. The rhyolitic masses of small size southwest of Wenatchee are similarly incorporated in this group. Rarely is a series of volcanics free from intercalated clastic sediments of known volcanic origin. In some instances these are marine beds, but much more commonly they were deposited under subaerial conditions. In several instances it is probable that not only the interbedded sediments but other beds deposited before or after the extrusion of the volcanic material will be found within the area assigned to the undifferentiated volcanics. Usually the separation is a simple matter, although frequently the assignment of the sedimentary beds to any specific zone in the stratagraphic column is impossible without extensive detailed field studies.

Description.—Most of the rocks here included are of basic composition, although some of the rocks, like those in the vicinity of Wenatchee, are rhyolitic. Similarly, most of these rocks, whether of Tertiary or earlier beds, have been more or less metamorphosed so as to produce both physical and chemical changes. Some of them approach the character of the volcanics assigned to the Paleozoic, but in the absence of any specific evidence of such relation, they are incorporated with this group.

Most of these masses are of limited extent and do not represent great stratigraphic thicknesses. The Rossland volcanics and those in the vicinity of Sauk Mountain are probably among the thickest of the series.

Structurally, as indicated by the notations on metamorphism, these rocks show extreme variation. In some instances, they are practically undeformed and appear as nearly horizontal flows. In general more or less deformation is obvious, and in some instances folding under considerable pressure has resulted in the formation of a series of greenstones which may even show lines of shearing.

MESOZOIC FORMATIONS

The rocks assigned to this stratigraphic group cover large areas in the State but are almost entirely restricted to the northern counties. Some of the Mesozoic formations are closely related to the metalliferous ore deposits. Four subdivisions of Mesozoic rocks are represented on the geologic map: two are of sedimentary formations and two are of igneous. These four are by no means of equal importance, although three are so closely tied to commercially important ore deposits as to stand in a class by themselves in comparison with any other of the stratigraphic units shown on the geologic map.

Considered from an areal standpoint, the Mesozoic marine and the Mesozoic acidic intrusives are formations of large size, while the Mesozoic continental sediments and the basic intrusives of this age are relatively insignificant. A number of interesting and important scientific problems are connected with the Mesozoic formations, both those of the sedimentary group and those of intrusive type. Not even the Tertiary marine beds exceed these Mesozoic rocks in either scientific or commercial importance. They have not received much attention from geologists, nevertheless, perhaps largely on account of two factors: first, their occurrence in areas that are relatively inaccessible, and, second, the inherent difficulty of determining the geologic characteristics and relations of rocks which are greatly deformed by mountain-building forces and somewhat metamorphosed.

Mesozoic marine strata Mm

(Pasayten series, Hoh formation, and miscellaneous marine and continental sedimentary rocks of probable Mesozoic age. Includes volcanic rocks in the Olympic area.)

DESCRIBED FORMATIONS INCLUDED UNDER Mm

Formation	*Region*	*Authority*
Haro	San Juan Islands	McLellan, R. D. 38
Nanaimo	San Juan Islands	McLellan, R. D. 38
Newaukum	Lewis County	Culver, H. E. 19
Pasayten	49th Parallel	Smith, G. O., and Calkins, F. C. 51 Daly, R. A. 20
Spieden	San Juan Islands	McLellan, R. D. 38
Tamihy	49th Parallel	Daly, R. A. 20
Undivided Mesozoic	Whatcom County	Crickmay, C. H. 18

Distribution.—The rocks belonging to this stratigraphic unit are found on the West Side or relatively near the crest line east of the Cascades. The largest area is that making up the central portion of the Olympic Mountains, which are almost exclusively formed of this group. The next largest mass is along the crest of the Cascades at the Forty-ninth Parallel. Minor areas are in northeastern Whatcom, western San Juan, central Snohomish, central and eastern Lewis, and western Yakima counties.

Stratigraphy.—No attempt has been made to indicate the stratigraphic relations existing between the marine sedimentary groups of Mesozoic age. Such assignment can only be made on the basis of adequate collections of fossils, together with detailed study of the field relations existing between these rocks and those of recognized stratigraphic position. Only in the case of the San Juan Islands strata, the Pasayten formation, and the sedimentary rocks in north-central Whatcom County has the paleontologic work been adequate to permit the assignment of at least part of these beds to a definite stratigraphic position. It has long been recognized that rocks of Cretaceous age occur in the Church Mountain area of Whatcom County and in the Pasayten formation near the Canadian boundary. It has not yet been demonstrated beyond question whether the beds are to be assigned to early or late Cretaceous and it is entirely possible that both epochs are represented. Except in the San Juan Islands no assignment on adequate basis has yet been made of any of these marine beds to pre-Cretaceous zones in the Mesozoic. In the Olympic Peninsula the inclusion of the Hoh formation introduces an anomalous situation. The term Hoh was originally assigned by Weaver to unfossiliferous, probably pre-Tertiary beds along the west coast of the Olympic Peninsula, where they were mapped along a wide belt parallel to the shore. Subsequent study has shown that probably much of the coastal belt is not

only fossiliferous but definitely Tertiary in age. An inland portion of the original Hoh area has been left with the Mesozoic and to it has been added the main mass of the Olympic Mountain tract, rather careful reconnaissance having shown that only rocks which can be so assigned are exposed there. At present a lithologic criterion, together with the absence of fossils, constitutes the only means of separating the Mesozoic beds in the Olympic area. Assignment of sedimentary rocks in the Sultan Basin, as well as in Lewis and Yakima counties, is based on their relations to the Tertiary and the absence of such extensive metamorphism as is apparently prevalent, if not universal, in rocks of the Paleozoic. While there is perhaps little doubt that these rocks belong somewhere in the Mesozoic, the absence of marine fossils permits the suggestion that the beds may be continental.

Within the beds assigned to the Mesozoic marine group, certainly in the case of the Pasayten and the Olympic areas, beds of nonmarine character are included. Interbedded stringers of coaly matter suggest short-lived swamps of small area and with these the presence of land plants suggests continental conditions but does not eliminate the possibility of their being marine. Within the Newaukum group in Lewis County, certain limestones have been classed tentatively as fresh-water in origin on the basis of the fauna enclosed.

In the Olympic Peninsula, the occurrence, if not the genesis, of the important manganese deposits is closely connected with the rocks assigned to the Mesozoic marine group. Near the outer margin of the Olympic area, and to a much less extent in the interior of the mass, are greenstones which represent the slightly metamorphosed equivalent of basic flows of Mesozoic time. The occurrence of ore near the contact of these basic igneous rocks with the marine sediments is characteristic of most, if not all, of the important deposits of manganese on the Peninsula. Quite clearly, the results obtained from further scientific study of the stratigraphy and structure of these rocks with special reference to their mode of deposition will be immediately applicable to the manganese deposits. It should be possible not only to determine the mode of origin of these interesting ores, but to work out, also, methods by which exploration for any deposits can be effectively prosecuted.

In the absence of any detailed stratigraphic studies of the beds of the Olympic Mountains, it is impossible to calculate with any satisfaction the probable thickness of this group. That it runs into several thousands of feet is obvious to the casual observer. It must be remembered that the repetition of beds either by folding or by faulting makes possible the calculation of

extreme thickness which may be found to be many times that actually present.

Lithologically, the rocks assigned to the Mesozoic marine group show relatively few types. In the Olympic Mountains, an excessively monotonous series of interbedded sandstones and sandy shales shows some variation in the content of sand, but rarely approaches a pure sandstone on the one hand or a clean shale on the other. The more carbonaceous phases commonly show some development of slaty cleavage. The coarser clastic zones include occasional but not abundant conglomerate phases. Near the margin of the Mesozoic area limestones are widespread but appear to be nearly confined to this zone, which may be stratigraphically high in the series. The igneous phases of this group already mentioned include greenstone, some of which exhibits excellent ellipsoidal structure, although this character is not universal. The presence of ellipsoidal greenstone suggests the outpouring of lavas into water in which the sediments were being deposited. This common interpretation, however, is subject to correction since it has not been demonstrated that the structure is developed only in subaqueous situations. As suggested by their position in the mountainous parts of the State, these Mesozoic beds are involved in relatively complex structures. Apparently all of the deformation to which they have been subjected was under conditions of relatively light load, so that the resulting structures are not complicated by internal deformation of the beds. Faulting is common, but in the absence of stratigraphic details, it is impossible to even estimate the amount of the displacements. In the Pasayten area, the lithologic character of the rocks is more varying than in the Olympic belt. Here the outstanding characteristics are great thicknesses of coarse conglomerates and even greater thicknesses of fine clastic sediments more or less carbonaceous, which give whole mountain slopes of black slaty rocks. Sandy shales are less common, although some even-grained beds have been recorded.

Mesozoic (?) acidic intrusives Mi

(Mount Stuart granodiorite, Chelan and Colville batholiths, and Loon Lake granite. Mig, *older gneissoid rocks, generally not separable, locally mapped. Possibly some later intrusives included.)*

DESCRIBED FORMATIONS INCLUDED UNDER Mi

Formation	*Region*	*Authority*
Cascade batholith	49th Parallel	Daly, R. A. 20
Cathedral granite	49th Parallel	Daly, R. A. 20
Chelan granodiorite	Chelan	Waters, A. C. 64
Chilliwack batholith	49th Parallel	Daly, R. A. 20
Colville batholith	Colville Ind. Res.	Pardee, J. T. 43
Contact breccia	Chelan	Waters, A. C. 64
Custer granite-gneiss	49th Parallel	Daly, R. A. 20
Granite porphyry	Stevens County	Weaver, C. E. 68
Granodiorite	Republic	Umpleby, J. B. 57
Index granodiorite	Snohomish County	Weaver, C. E. 65
	Skykomish	Smith, W. S. 53
Kruger alkaline body	49th Parallel	Daly, R. A. 20
Loon Lake granite	Stevens County	Weaver, C. E. 68
	Chewelah	Jones, R. H. B. 36
Meteor granodiorite	49th Parallel	Daly, R. A. 20
Mount Stuart	Mount Stuart	Smith, G. O. 50
Orient gneiss	Stevens County	Weaver, C. E. 68
Osoyoos granodiorite	49th Parallel	Daly, R. A. 20
Park granite	49th Parallel	Daly, R. A. 20
Quartz-diorite	Snoqualmie	Smith, G. O., and Calkins, F. C. 52
Remmel	49th Parallel	Daly, R. A. 20
Rock Creek granodiorite	49th Parallel	Daly, R. A. 20
Rock Creek gabbro-diorite	49th Parallel	Daly, R. A. 20
Similkameen granite	49th Parallel	Daly, R. A. 20
Swakane	Chelan	Waters, A. C. 64
Tye soda-granite	Skykomish	Smith, W. S. 53

Description.—In this group belong the great mass of "granites" of the State of Washington which show granitic characteristics, coarse texture and relatively light-color, although but rarely is the true petrologic character of a granite exhibited by these rocks. With the few true granites, therefore, are the great masses of related rocks of similar origin; the granodiorites, monzonites, syenites, and diorites. Only the most basic of the intrusive rocks are separately shown on the preliminary geologic map. The granitic rocks are of great importance, not only because they are found over so great an extent in the northern counties, but because they are closely related to almost all of the known deposits of ores. A glance at the geologic map shows that rocks of this group predominate from the Idaho line westward to beyond the crest of the Cascades. It should be pointed out that, as indicated in the discussion of Tertiary intrusives, there are presumably included in this area a great many masses of variable size of Tertiary injections whose relations to the Mesozoic granitic mass, while recognized, have not been worked out in sufficient detail to permit their separation on the geologic map. Indeed, it seems probable that in some instances the

interfingering of these two intrusives is so intricate as to defy mapping on any practicable scale whatsoever.

The outstanding characteristic of these acidic intrusives is perhaps their size. Although individual outcrops are frequently small, the obvious continuity beneath a relatively thin cover, as shown by structural and chemical characters, brings out sharply that we are here dealing with masses of unusual dimensions. The Loon Lake granite, for example, a name assigned to these rocks in southern Stevens County, is found to extend not only throughout much of Stevens County, but eastward indefinitely into Pend Oreille County, southward into Spokane, and westward into Ferry, where it does not appear on present data to be distinguishable from some phases of the Colville batholith. This Colville mass, in turn, not only has no recognized division on the east to separate it from the Loon Lake granite, but is not readily distinguished from phases of the Cascade batholith and related rocks to the north in Ferry County, and has in the wide stretches of Okanogan County to the west only the most vague semblance of a boundary between it and Swakane and Chelan batholiths of Chelan County. The same situation obtains still farther west and north where batholithic masses of diorite are found from the vicinity of Palmer Lake westward over the Cascades and into the upper Skagit Valley. It is not intended to suggest that the batholithic masses with which we are dealing are not distinct nor that they are all phases of one tremendous intrusion. Rather, it is to be pointed out that the rocks are of such similarity in their individual lithologic and structural variations that nothing short of extremely comprehensive as well as detailed study will serve to separate them into the igneous units which presumably compose them. The list of names of intrusive bodies given above is, therefore, to be taken largely as a list of the regions in which rocks of this general type have been found. It will be some time before the detailed relations will be understood, since the study of these rocks constitutes one of the most difficult phases of geology.

For identical reasons the separation of the Mesozoic from the later intrusive masses will be delayed until much detailed work has been completed. As indicated under the description of Tertiary intrusive masses, it has seemed better to introduce into this group those southern extensions of certain stocks and batholiths which were quite definitely placed in the Tertiary along the Canadian boundary by Daly. Present data do not permit the separation of these rocks from the older intrusives, and no good end would be attained by the introduction of arbitrarily placed boundaries.

Structure.—Discussion of the structure of the Mesozoic acidic intrusives involves a series of more or less theoretical considerations for which there is no place in the present report. It has already been pointed out that, in the main, there seems to be some basis for distinguishing the Tertiary from earlier intrusives on the basis of the presence of banding in the earlier rocks. It can probably be shown that there are exceptions to this generalization, both in the presence of banded Tertiary intrusives and in the occurrence of Mesozoic acidic intrusives in which no banding is apparent. In general, nevertheless, as would be expected from their greater age, the rocks assigned to this group appear to have been subjected to extensive deformative stress under sufficient load to have produced an internal rearrangement of the mineral constituents, which has resulted in a more or less definite regular banding of light and dark constituents. In the less metamorphosed phase, the banding is practically an alignment of the dark minerals, mica, biotite, and hornblende. In the more extremely metamorphosed phase, the light-colored constituents have, likewise, been reorganized, thus providing a more striking banded effect. The tremendous size of these masses, particularly below the surface at which they are exposed, precludes the possibility of their being involved in the ordinary warping or folding which affects sedimentary rocks. On the contrary, they have usually served as buffers in regional deformation, thereby concentrating the effect of stresses in the sedimentary rocks associated with them.

Mesozoic continental strata Mc

(Winthrop, Sheep Creek and other sedimentary rocks of reported Mesozoic age.)

DESCRIBED FORMATIONS INCLUDED UNDER Mc

Formation	*Region*	*Authority*
Sheep Creek	Stevens County	Weaver, C. E. 68
Ventura	Methow Valley	Russell, I. C. 46
Winthrop	Methow Valley	Russell, I. C. 46

Only three previously described formations are included in the beds assigned to this stratigraphic unit. In addition, certain beds in Ferry and Stevens counties have been tentatively assigned to this group. It should be kept in mind that these few formations are not all of the continental beds of Mesozoic age in Washington. Most groups of rocks designated as Mesozoic marine formations in the State are known to have some continental strata interbedded with them. Only where the boundaries of the continental beds have been mapped in sufficient detail do they appear on the present geologic map of the State.

This constitutes by far the smallest stratigraphic group of all those mapped in Washington. It is, also, of less importance

than any others. There is, indeed, some question about the propriety of including some of these few beds in the group. For example, the Sheep Creek conglomerate appears to be contemporaneous with part of the Rossland volcanics. Elsewhere, other similar beds known to be contemporaneous with the Rossland group are included with the volcanic rocks for mapping purposes. While some of these formations are locally as much as 500 feet thick, they are not extensive at the present time and may never have been. It seems not unlikely, therefore, that future work will reveal the desirability of placing the Sheep Creek beds with their correlative volcanic rocks in the Rossland series.

The Winthrop formation, placed in the Cretaceous on the work of Knowlton on fairly adequate collection of plant remains, can without hesitancy be assigned to this unit, there being no evidence of marine origin. Russell's Ventura beds, "lithologically and structurally distinct" from his Winthrop on the east, are also included.

Two small areas east of Curlew Lake in Ferry County have been tentatively assigned to the Mesozoic. The evidence for this designation is merely suggestive and quite inadequate when carefully scrutinized. The relation of these rocks to the Paleozoic sediments is not known. They are, however, clearly older than some of the andesitic beds assigned to the Miocene volcanic group.

Little more secure is the designation of Mesozoic for certain beds shown on the State map in the Colville quadrangle. No fossils have been discovered in these beds. They are not readily assigned either to the Tertiary on the one hand or to the Carboniferous on the other, and hence are tentatively placed with the Mesozoic continental strata.

The foregoing qualifications make it clear that the beds included in this map unit do not constitute a clearly defined stratigraphic unit and that, therefore, considerable variation is to be expected. As a matter of fact, neither variation nor uniformity can be held of significance for these formations. The clastics are generally coarse, although the beds near Curlew Lake include some limestones and argillites. The Winthrop beds are predominately arkose, while the Sheep Creek is almost entirely a water-worn gravel. An association with the volcanic rocks, which is at least geographical if not genetic, appears to be the one common characteristic of all of the beds assigned to this unit.

Mesozoic (?)basic intrusives Mbi

(Peridotite, dunite, and serpentine; pre-Tertiary.)

DESCRIBED FORMATIONS INCLUDED UNDER Mbi

Formation	*Region*	*Authority*
Ashnola gabbro	49th Parallel	Daly, R. A. 20
Basic complex	49th Parallel	Daly, R. A. 20
Basic intrusives	Chopaka	Smith, G. O. and Calkins, F. C. 51
Eagle Cliff	San Juan Islands	McLellan, R. D. 38
Fidalgo	San Juan Islands	McLellan, R. D. 38
Gabbro	Palmer Lake	Umpleby, J. B. 59
Peridotite	Mount Stuart	Smith, G. O. 50
	Snoqualmie	Smith, G. O. and Calkins, F. C. 52
Serpentine	Stevens County	Weaver, C. E. 68
Turtleback complex	San Juan Islands	McLellan, R. D. 38

Formations assigned to this group occupy a small total area in the rocks of the State, although not less common in occurrence than is usual in relation to the abundance of intrusions of acidic type. The smallness of area, however, is no indication of the relative importance of these rocks. As is usual in such cases, the interest has both scientific and economic aspects. The scientific interest is, of course, with reference to the mode of formation of these rocks of relatively rare chemical composition. Their economic importance is in connection with the substances which they may contain. Platinum, nickel, and chromite are genetically related to these rocks and hence lend importance to them. Dunite, the high-olivine variety of the basic intrusives, is valuable in itself. In addition, serpentines of many types, talc, and such rare minerals as meerschaum are derived by alteration of certain of these rocks. All of these substances are commercially valuable.

Distribution.—The recorded occurrences are confined to six localities: Mount Stuart area, San Juan Islands, Mount Baker area, the Ashnola area, including both the gabbro and the basic complex, Chopaka, together with the Palmer Lake gabbro, and the Kettle River area at the Canadian line. Of these occurrences, only that on Sumas Mountain in Whatcom County is unmapped, its small size precluding its introduction. There is, also, an unmapped extension of the Chopaka intrusive area on the east side of the Similkameen near Ruby. It is, perhaps, unlikely that any large mass of rocks which belongs in this group has escaped notice. It is entirely probable that small ones yet remain to be reported.

Such rocks comprise the darker, chemically basic phases of the intrusives. They are composed predominantly of iron and magnesium minerals, augite, hornblende, olivine, and associates. In the case of gabbro, such feldspars as appear are of the high-lime type. The metallic content is an important feature. The

more basic rocks may carry magnetite or other iron oxides with or without platinum, chromite, or nickel.

Alteration produces characteristic rock masses in which talc and serpentine with other magnesium minerals, like meerschaum, are associated with the iron and other metallic alteration products.

The relations of these basic formations to other intrusives is not always clear. They are definitely not considered to be related to the immediately adjacent granitic intrusions in the case of the rocks in the Chopaka, Ashnola, Mount Baker, or Mount Stuart regions. For some of these basic masses, their pre-Tertiary age seems to be the only relation definitely established.

Structure.—There are no structures which may be considered characteristic of these basic intrusives. Mount Stuart serpentinous masses show abundant shearing which produces glistening surfaces on fresh fragments. Elsewhere, the rocks are not so prominently sheared, and in the Ashnola gabbro, particularly, the basic rock seems to have resisted deformation more successfully than the adjacent clastic rocks.

PALEOZOIC FORMATIONS

The rocks of this era are presented in three groups, two of sedimentary formations and one of volcanics. Although very widely distributed over the State and known since the earliest of geologic work was undertaken, their structural and stratigraphic complexity is so great that study of them has been left generally in favor of the more readily understood Tertiary and Mesozoic formations. Nor is this surprising in view of the fact that in the beginning none of these groups were known; and it is commendable that the earliest detailed studies were, in a majority of instances, confined to the sedimentary and associated igneous rocks, so that the study of the complicated features of the Paleozoic rocks might be aided by that information.

There is ample evidence that there are present, within the State, rocks representing most of the larger subdivisions of the Paleozoic from Cambrian to Permian. Distinctions between these groups are largely dependent on the evidence of marine fossils. The difficulties in the way of paleontologic work in these beds are indicated by the fact that in 1920 Weaver characterized all of the formations of the Stevens series as "certainly nonfossiliferous." Within the past decade an excellent start has been made in the discovery of diagnostic types, and fossils have been identified from at least forty-four localities within the Stevens series and its extension into the Metaline district. These collections, important as they are, still do not serve to define the subdivisions of the Paleozoic sedimentary formations. These

must still be supplemented by painstaking detailed field studies before any of the separate stratigraphic units can be mapped satisfactorily.

Because of this situation, Paleozoic sediments have been placed in two divisions which are mutually inclusive.

There is only one older sedimentary unit mapped in Washington, and it is of such limited extent that for most of the State these Paleozoic strata are the oldest rocks from the San Juan Islands to the most southeastern township of Asotin County.

The most common distinguishing mark by which these beds are recognized is the degree of dynamic metamorphism they exhibit. The original sands, silts, and muds are now completely solidified and to a large extent recrystallized to form quartzites, argillites, slates, and marbles, with many more highly sheared phases, properly classed as schists.

In noting the three larger areas into which these Paleozoic sedimentary formations may be geographically grouped, the hundreds of smaller areas, many too small to be shown on the State map, must not be lost sight of. Inspection of the map shows one of these larger areas extending from San Juan Islands east and south over the crest of the Cascades at Snoqualmie Pass. A second occurrence occupies a medial position in northern Okanogan County. A third area, the largest but least continuous, may be drawn to include the region from the San Poil Valley to the Idaho line.

Carboniferous and older Paleozoic sedimentary rocks Pe

(Peshastin, San Juan series, and Gunn Peak. Some metamorphosed sediments and volcanics of Mesozoic (?) age included.)

DESCRIBED FORMATIONS INCLUDED UNDER Pe

Formation	*Region*	*Authority*
Anarchist series	49th Parallel	Daly, R. A. 20
Atwood	49th Parallel	Daly, R. A. 20
Chilliwack	49th Parallel	Daly, R. A. 20
	Whatcom County	Crickmay, C. H. 18
Cultus	49th Parallel	Daly, R. A. 20
Gunn Peak	Index	Weaver, C. E. 65
Hozameen	49th Parallel	Daly, R. A. 20
Paleozoic metamorphics	Okanogan County	Umpleby, J. B. 58, 59
Peshastin	Mount Stuart	Smith, G. O. 50
	Skykomish	Smith, W. S. 53
San Juan series	San Juan Islands	McLellan, R. D. 38
Twin Falls	Cedar Lake	Fuller, R. E. 25

Cambrian, Ordovician, and younger Paleozoic sedimentary rocks Poe

(Stevens, Covada, Metaline, and miscellaneous Paleozoic strata. Some pre-Cambrian rocks may be included.)

DESCRIBED FORMATIONS INCLUDED UNDER Poe

Formation	*Region*	*Authority*
Covada	Colville Ind. Res.	Weaver, C. E. 66A
		Pardee, J. T. 43
Pend Oreille schist	49th Parallel	Daly, R. A. 20
Pend Oreille limestone	49th Parallel	Daly, R. A. 20
Stevens series	Stevens County	Weaver, C. E. 68

In the absence of the recognition of mappable groups of strata belonging to specific periods within the Paleozoic, it has been found helpful to suggest the position of these rocks in all parts of the State by classifying them either as Carboniferous and older or as Cambrian, Ordovision, and younger. Admittedly a temporary expedient, this procedure has the advantage of taking into consideration the results of all paleontologic work to date. In a large number of instances, some diagnostic fossils have been identified from one or more beds exposed within a given area.

Reference to the map shows that the majority of the early Paleozoic strata are in the eastern part of the State, while those in the western part are largely referred to the group Carboniferous and older. This may be roughly accurate, but stratigraphic data already available indicate clearly the probability that each of these groups as now mapped will be found to include not only mid-Paleozoic strata but those of both early and late periods as well.

Familiarity with the rudiments of stratigraphic and structural work will make clear that no accurate estimate of thickness of these beds can be formulated on present information. It cannot be doubted that several thousands of feet of strata are present.

Structurally, the rocks of these two units are the most highly complex of any in the State. While the dips exhibited are commonly low over considerable areas, as in Ferry and Stevens counties, the close association of these with areas of localized but intense dynamic alteration makes it clear that as a group these beds have been deformed under high pressures. These were presumably induced by the very thick overburden of rocks long since removed by erosion. Indeed, it is proper to regard all of these masses of Paleozoic rocks as remnants of thick and geographically extensive sedimentary and volcanic series. In this connection, it should be noted that the wide areas of granitic rock spotted with scattered small areas of Paleozoic sedimentary rocks characteristic of the Okanogan Highlands province has resulted from the stripping of the sedimentary cover from the intrusives by the ordinary processes of erosion.

Paleozoic volcanics Pv

(Hawkins formation and undifferentiated greenstones of Stevens series.)

DESCRIBED FORMATIONS INCLUDED UNDER Pv

Formation	*Region*	*Authority*
Chewelah argillite, greenstone phase	Chewelah	Jones, R. H. B. 36
Hawkins	Mount Stuart	Smith, G. O. 50
	Snoqualmie	Smith, G. O., and Calkins, F. C. 52

The rocks of this stratigraphic unit are insignificant in area and importance. Here included are rocks of two areas only: the Mount Stuart quadrangle in the Cascades and the Chewelah quadrangle of Stevens County. These formations in both instances have been studied in considerable detail and have been placed rather definitely with the rocks of the Paleozoic era. Otherwise, they could as well be classed with the unit of Undifferentiated volcanics (uv) which presumably already includes some Carboniferous volcanics which have been neither recognized nor areally delimited.

The Hawkins formation is in the Mount Stuart region, where it appears comformable with the Peshastin formation, the two being referred on a lithologic basis to the Carboniferous. Of small extent areally, and of undetermined thickness, the Hawkins seems, on present data, to be an unimportant part of the Paleozoic section. It shows the usual deformation of the Paleozoic rocks of the Mount Stuart area and is intimately intermingled with the Peshastin beds. The Stevens County area of these rocks is of about the same importance. Here volcanic beds are considered as a phase of the Chewelah argillite which, as mapped by Jones, constitutes an important unit of the Stevens series and presumably belongs well down in the Paleozoic section. Quite obviously, there is no possibility of suggesting a reasonable correlation between the Hawkins and the Chewelah greenstones, although the latter is the more definitely fixed of the two.

PROTEROZOIC FORMATIONS

(Pre-Cambrian)

These, the oldest formations of all, include only a limited number of rock masses. Although early work in Washington indicated the presence of rather extensive areas of such rocks, later studies have shown that, in spite of apparent antiquity suggested by a high degree of metamorphism, practically all of the rocks so designated are actually younger.

Highly metamorphosed rocks, undifferentiated p-€

(May include some Paleozoic rocks.)

DESCRIBED FORMATIONS INCLUDED UNDER p-€

Formation	*Region*	*Authority*
Ripple Beehive Dewdney Wolf Monk Irene volcanics	49th Parallel	Daly, R. A. 20

The description of this stratigraphic group is self-explanatory as to the character of rock formations included. The beds

placed here comprise only those rocks whose degree of metamorphism is such that they can hardly be classed with the Paleozoic rocks. In general, their relations to the Paleozoic sedimentary series are obscure.

Distribution.—Only the northeast part of Pend Oreille County shows rocks of this age. Here they constitute a southern extension of rocks mapped by Daly along the Forty-ninth parallel near the Washington-Idaho line. The Summit series, of which these formations are a part, Daly considered essentially equivalent to the early Cambrian and the late pre-Cambrian or Belt of Montana. Walker, working in the area north of the Forty-ninth parallel, has subsequently reached the conclusion that all of this group of beds is to be considered pre-Cambrian. This accords with the results obtained in preliminary studies south of the line, and these metamorphic sedimentary rocks are, therefore, mapped as pre-Cambrian.

The area here included extends from the extreme northeast corner of Pend Oreille County past Sullivan Lake to the flood plain of Clark Fork west of Molybdenite Mountain. Outside of this limited area there are probably additional masses of quartzitic and schistose rocks which study will show are to be classed with the pre-Cambrian unit. It is recognized that the Paleozoic group of rocks lies in a marginal position with reference to pre-Cambrian rocks reported in northern Idaho. In view of the extreme deformation to which these Paleozoic rocks have been subjected, it is reasonable to expect that pre-Cambrian rocks will be found not only in places along the east margin of the Paleozoics, but also within the main mass where they may have been brought up by folding and exposed at the present surface by erosion.

East of the Washington-Idaho line, Daly mapped the Irene conglomerate, the oldest of his Summit series. Unconformably below the Summit series, on the east he mapped his pre-Belt group, which he named the Priest River terrane. No corresponding subdivision of the pre-Cambrian rocks into Belt and pre-Belt has been attempted on the present map, although the accumulated data show that such subdivision is entirely practicable on maps of larger scale. Indeed, in the southeastern portion of this pre-Cambrian area are beds which presumably constitute southwestern extensions of both the Irene conglomerate and the Priest River terrane of Daly.

Description.—In general, the rocks of this unit are similar to those assigned to the Paleozoic groups. In so far as they are referable to a sedimentary origin, the original characteristics have all but been eliminated by recrystallization and by the

development of platy structures. In so far as an igneous origin for certain masses is indicated, the original features are largely concealed by the secondary structures always developed under conditions of extreme metamorphism. The schistose rocks of the series are particularly striking with the abundance of mica which gives them a glittering aspect not presented by any other rock type. Thicknesses have not been satisfactorily estimated in the boundary area, but certainly several thousands of feet of beds are included.

Structure.—Determination of details of structure is totally dependent on the stratigraphic determinations and can, therefore, be suggested in only the most general terms. Needless to say, these ancient rocks have been subjected to all of the folding which has affected rocks of younger age and have undergone earlier deformation besides. This has resulted in the high degree of metamorphism shown and introduces many complicating factors which interfere with the satisfactory working out of both stratigraphy and structure. Relatively late in their history, it seems probable that these rocks were subjected to severe faulting, but here again, details must await further field investigation.

SUMMARY OF GEOLOGIC HISTORY

In considering the historical geology of Washington, the reader should keep in mind certain basic ideas. There are just three of these: (1) that all land masses are subject to very slow changes in level which at times bring them below sea level and later may bring them above sea level; (2) lands above sea level are universally eroded by rivers, winds, and other agencies; (3) lands submerged beneath the sea are invariably the site of deposition of sediments carried from the adjacent lands.

It will be recognized that changes in level are rarely confined to areas within political boundaries and hence that if all of what is now eastern Washington was submerged, adjacent parts of Oregon, Idaho, and British Columbia were also submerged. The geologic record is thus one of slow erosion of land masses with accompanying deposition of sediments in marine waters while they are spread over the land. Accompanying both phases may be the introduction of igneous rocks either as surface volcanic formations or as intrusives from below in masses of extreme variation in shape and size.

It follows that the more complete the depositional record, the better is known the detailed series of geologic events. On the other hand, while the erosional phase leaves a record of the wearing away of the land, at the same time it causes a loss of some of the pre-existent rock record.

Deciphering the geologic record of an area as large as the State of Washington is itself no small undertaking. When there is introduced the wide variety of geologic features in different parts of the State, the difficulty of the task is greatly increased. If there be considered the additional serious factor of inadequate records, of missing pages in the geologic book, so to speak, the real formidability of the task becomes apparent.

It is with these points firmly in mind that this brief historical summary is prepared, and the reader is forewarned as to the character of the chronicle which must be evolved under these conditions. A surprising number of facts are definitely established, but there are many for which search is still being made, and this situation interferes with the presentation of the history as a continuous series of events. The reader will, therefore, anticipate gaps in the record which cannot now be bridged.

In order that essentially related sequences will not be lost in a maze of discussion, controversial points will be touched upon only lightly. This procedure, advantageous though it is, still must be recognized as relatively inaccurate, since it is not possible to avoid a certain amount of arbitrary interpretation.

It will be helpful in obtaining a clear understanding of the geologic history of Washington to have the time relations well in mind; hence frequent reference to the time scale presented in the introduction will aid those whose memory of the geologic column is inadequate.

As was noted in the section on the rock formations mapped in Washington, all four major time units are represented by one or more formations. There are many more formations known for the later than for the earlier of these four time units. This is not because of any greater number of geologic events in later eras, but simply because our knowledge is greater in regard to the more recent happenings, while those of more ancient time are clouded in obscurity. Since the nature and character of later events were determined by those which preceded them, it will be advantageous to begin with the earliest part of the record, coming on down through geologic time to the present. So we start with the oldest era, usually known as the Proterozoic.

PROTEROZOIC ERA

As might be expected, the record of this very early time in geologic history is not only incomplete but only interpretable with difficulty. It appears almost certain that two epochs are recorded: one by the rocks referred to the Priest River terrane; the other by those referred to the Belt, a later section of the pre-Cambrian column. Both names come from rocks of similar character and age to the east in Idaho and Montana, respectively. From the Priest River group, it is recognized that both sedimentary and igneous rocks were being formed in that ancient time. Presumably, the area which furnished the sedimentary materials lay east of the Idaho line, and all of northeastern Washington was beneath marine waters. When more is known of the geology of this ancient time, it may be found that another land mass lay off to the west, possibly in the zone now covered by the Pacific.

During the subsequent epoch, the Beltian, the sea was also over the area of Washington, perhaps with land masses similarly situated to the east and to the west. Between these two epochs, however, was a long period of time during which the sedimentary rocks of Priest River time were consolidated, uplifted, and subjected to erosion. This interval is suggested by the unconformable relations which appear to exist between the two groups of rocks. During each of these epochs, in addition to the formation of sedimentary deposits, it appears there was intrusion of granitic masses. These rocks are now altered to gneisses, just as the earlier sedimentary rocks of both epochs are metamorphosed to highly sheared forms, the schists of the

Pend Oreille region. These changes in the formations are so great that it is by no means clear in some instances whether the rock originally was sedimentary or igneous.

Briefly, then, our knowledge of these early times suggests, therefore, that during at least two epochs the sea spread over the land and permitted the accompanying formation of sediments brought down from still older land masses nearby. In each epoch there appear to have been granitic intrusions, also.

It should be noted in passing that this simple sequence of events demands a tremendous lapse of time. As will be more clearly seen in later sections of our geologic history, these events involve not only long periods of erosion of pre-existent lands with accompanying deposition of great thicknesses of sediments, but the subsequent elevation of these formations into land masses and the later wearing down of them in turn. Many millions of years and a vast number of geologic events, inferred but unchronicled, are necessarily involved. All this took place, so far as we know, before the earliest rock formations bearing known traces of life were formed. It is certain, nevertheless, that life had its beginning in this early time, and we may confidently look forward to the discovery and recognition of some of these early forms.

PALEOZOIC ERA

For this era the record in Washington is not only more abundant, but it is much clearer than in the preceding or pre-Cambrian era; and while the record for the Proterozoic is confined to a very small area in Pend Oreille County, that for the Paleozoic is spread over at least the north half of the State from the Idaho line to the San Juan Islands. There is definite evidence that in the Cambrian period and again in the Carboniferous period marine conditions obtained over large areas, if not over all of the northern part of the State. Whether these waters covered the area to the south is problematical. There is, certainly, no reason to think that they did not, particularly since there are many exposures of these rocks along the whole eastern boundary of the State. Yet all rocks which would have been formed farther west in these seas are, if existent, buried below great thicknesses of younger beds.

When the vast extent of time represented by the Paleozoic rocks is taken into consideration, it is readily understood why it is not possible to indicate briefly the conditions existing during the Paleozoic; nor is it possible to present the geography of the era. Quite clearly, conditions changed during these hundreds of millions of years, what was land at one period being submerged by salt water at another. Much more detailed knowl-

edge of these formations will be necessary before even a good beginning on the geographic changes can be made.

Meanwhile, it is of value to note that there is at least a suggestion that during the earlier part of the Paleozoic, sediments were being deposited in marine waters in the northeastern quarter of the State. Later in the era similar sediments were being deposited in marine waters west of the present Cascades. In mid-Paleozoic the record is not so clear, and it is at least possible that there was a wide-spread emergence of the land during some part of Silurian or Devonian time.

Until much more adequate record of the fossils contained in these beds has been made, it will be quite impossible to determine whether the submergence during the early or later Paleozoic represented a marine invasion from north, southwest, or west; but it is not unlikely, in view of our knowledge of the geographic changes in North America as a whole, that the invasions were from the north rather than from the west in both instances. Discussion of the evidence for this and other similar generalizations has no place in this report and will be considered in Part II. As indicated above, the record of life of the Paleozoic is entirely marine. Such fossils as have been found, including a considerable variety of trilobites, graptolites, crinoids, bryozoa, corals, and less well-known forms, record the presence of waters which were in places clear, in others muddy, probably generally temperate, and rarely if ever of any great depth. Reef-building forms appeared from time to time during the Paleozoic, leaving their structures incorporated in the massive limestone formations from one side of the State to the other. Abundant as they are, the paleontologic data are still inadequate for the formulation of any general conclusions as to the land-sea relations during the several periods of the Paleozoic era.

The rocks of the Paleozoic appear on the geologic map in relatively small patches except in western Skagit and Snohomish counties. The many isolated rock masses standing as prominent hills on the lowland flats in western Skagit County, together with a considerable number of the outstanding ridges, have remnants of these Paleozoic sediments making up a large part of them. The large limestone mass in Okanogan County north of Riverside and the ridge in Stevens County known as Huckleberry Mountain, together with Stensgar Mountain, Old Dominion Mountain, and Mount Abercrombie, are all composed of these Paleozoic rocks. In many another situation, however, they are much less conspicuous, occupying valleys where they are exposed only through active stream erosion.

During the later part of the Paleozoic era, much, if not all, of the area of Washington was submerged beneath marine

waters, Carboniferous limestone and related rocks being found rather generally in the northern half of Washington as well as in adjacent parts of British Columbia and Idaho.

MESOZOIC ERA

During the early part of the ensuing Mesozoic era, all of this region was probably mountainous land. Only at the western margin was there any continuous marine deposition. The absence of great areas of marine sedimentation does not leave us without a record of some important geologic events in the early Mesozoic. Sometime after the last of the Paleozoic sedimentation in the Okanogan and Cascade provinces came the intrusion of great batholithic masses into the Paleozoic rocks. Coming to rest after working their way up from depths of many miles, these intrusions did not reach to within several thousand feet of the surface. Under a thick cover of the sedimentary beds they cooled slowly enough to permit crystallization into the granitic rocks so common in northern Washington.

It is only through the later erosion of this great thickness of rock cover that the presence of the granitic mass beneath has been revealed. Such areas of these older sediments, now quartzites, slates, schists, and marbles, as are to be found throughout most of the Okanogan province should be recognized as being the last remnants of this cover. In reality, they are parts of the roof of these molten masses which were intruded from below at this time.

Further encroachment by the sea occurred rather late in the Mesozoic era. There resulted deposition of great thicknesses of sediments, mainly muds and sands, with little limestone. This Cretaceous deposition was apparently confined to the western half of the State but is known definitely to have occurred in what is now the northern Cascades area, the San Juan region, and adjacent lands to an indefinite distance southward. Probably the rocks making up the central Olympic mountains province were formed at this time. Here, too, is recorded the extrusion of some flows of basaltic lava.

In eastern Washington, while most of the region was being eroded, there was, presumably, some continental deposition such as that recorded by the Sheep Creek conglomerate and other beds in Stevens County.

Both in the Olympic and the Cascade areas marine conditions, although generally maintained, were interrupted by short periods when the land was slightly above the sea level, giving rise to deposits in swamps and rivers. The carbonaceous interbeds of both these regions record such conditions.

The Mesozoic era seems to have been closed by a general elevation of at least those parts of the State which had been the site of marine deposition during the Cretaceous period. To what extent the uplift affected the rest of the State can only be conjectured. This part of the history is written in the sedimentation, both marine and continental, which took place in the succeeding period, the Tertiary.

It seems entirely possible that the essential features of the physiographic provinces as we know them today in Washington were initiated before the opening of the Cenozoic; but this cannot be substantiated until the record of Tertiary events is better known.

The record of Mesozoic life is apparently scanty. A few marine fossils and locally abundant ferns and related plants comprise the forms known to date. What little information is available suggests a range in climate from humid in the west half to distinctly more arid in the east. This indicates faintly a barrier of mountains in the Okanogan region which provided a control of climate similar to that exercised by the present Cascade belt.

CENOZOIC ERA

The Cenozoic era includes all geologic time from the Mesozoic down to and including the present. Although there is some slight disagreement as to nomenclature for the subdivisions of this era, it is generally agreed that there are two major periods, the Tertiary and the Quaternary. The earlier period is subdivided into the Eocene, Oligocene, Miocene, and Pliocene epochs, while the latter is resolved into the Quaternary and the Recent.

The marine beds of the Tertiary are apparently restricted to the first three epochs, none having been discovered that are assignable to the Pliocene. The continental beds of the Tertiary are less definitely placed stratigraphically, being generally referred to the Eocene and to the Miocene epochs. It is wholly probable that the final story, when worked out, will reveal that deposition was taking place during all four epochs more or less continuously both beneath marine waters and on the adjacent lands.

In the Eocene, the sea encroached upon the land area of Washington from the west, extending eastward at least to the central part of the Puget Sound province. It covered practically all of this area except perhaps the central part of the Olympic Mountains province where the uplifted Mesozoic beds may have formed an island in the advancing seas. Upon this submerged area was deposited a considerable thickness of richly fossiliferous sands, silts, and muds.

East of this shore the land was apparently low. This is indicated, first, by the presence of many swamp deposits with workable coal beds, and second, by the frequent incursions by the sea for short distances inland giving a series of marine beds interstratified with continental beds. This shifting of the shore line, of course, gave rise to the same sort of interbedding in the seaward region, where the marine beds predominated. Typical Eocene marine sections show as much as 25 per cent of these continental beds.

An interesting feature of the events of this time was the introduction of sheets of basaltic igneous rock into the sedimentary series both as flows on the surface and as sills intruded into the series after their deposition. This appears to have been the case particularly in the coastal zone, but certainly took place in the interior region as well. The prominent hills of the Willapa province are largely made up of the basalts which were poured out at this time.

In the northeastern part of the State are a few small areas of sandstones and shales which may have been laid down during the early part of the Cenozoic. They have tentatively been assigned to a time somewhat later than the Puget epoch but belong in the Tertiary period rather than later in the Cenozoic.

The submergence of the western part of the State was a matter of slow progression, the earlier beds lying farther west, the later, nearer the ultimate shore line in the Puget Sound depression. In the same way the beds of the Puget series seem not to have been exactly contemporaneous with the Chuckanut beds farther north. The fossil evidence for this is not conclusive and the relations cannot be stated with certainty. It may be noted that there seem to be fewer masses of basaltic lava included in the early Tertiary sections of the northern counties than in those nearer the Columbia River.

During the Oligocene epoch, marine waters continued over the major part of western Washington, again with the exception of the Olympic Mountains. The eastern margin was about the same as during the earlier epoch, but it probably continued to show slight variations in position. Probably the higher land masses continued to be subject to erosion, but no strata of this epoch have been recognized among the continental beds of the State.

Of particular interest are the fossil plants and animals of these first two epochs of the Tertiary. The marine beds of the Chehalis Valley are abundantly fossiliferous as are those along the Cowlitz River in the vicinity of Vader.

Most sections of the coal-bearing formations of Washington include some beds carrying abundant fossil plants representing

the Eocene epoch. The shales and sandstones along Chuckanut Drive in Whatcom County and others on Swauk Creek in Kittitas County show superlatively fine examples of fossil ferns and palms.

During the Eocene, also, were deposited most of the valuable shales in King County as well as the sandstones quarried in Thurston and Pierce counties.

It appears probable that about mid-Tertiary there was an uplift of some parts if not all of Washington. At this time the Eocene and Oligocene beds were elevated and somewhat folded both in the Willapa Hills province and in the belt of the Cascade Mountains. It should be noted, however, that the Cascades, at least, were not brought to their full height at this time.

Subsequently, during the Miocene epoch, marine deposition continued in somewhat restricted areas of western Washington, giving rise to a belt of fossiliferous strata entirely surrounding the Olympic Peninsula except, perhaps, for a wide neck connecting this region with the mainland in the latitude of Tacoma.

On the mainland, however, conditions changed markedly from those existing during the early Tertiary. Over all the Columbia plateau and the adjacent area now occupied by the southern Cascades was being formed a vast series of flows of basaltic rocks, which covered the land from north of Spokane to beyond the Oregon line. During this epoch the erosional surface of this entire region, showing thousands of feet of relief, was concealed beneath a great series of flows to make up the great Columbia lava plateau. This was only the northern portion of a still greater area including eastern Oregon and southwestern Idaho and even extending into parts of Nevada and California. Only one other comparable outpouring of lava has been recorded in the history of the earth, the great Deccan flow area of India being of the same order of magnitude.

An outstanding feature of this event was that the lava seems to have come, not from a series of volcanic centers such as developed later on to form the great cones of the Mount Rainier type, but from a series of elongate vents, or fissures, which opened at scores of places throughout the region. Nor should it be imagined that the flows came out all at once. On the contrary, single flows covered only relatively small areas of irregular shape, subsequent flows being poured out promiscuously over the former ones and over adjacent land. A great amount of time was involved in this process, and while flows were spreading over some parts of the region other parts were being weathered and eroded just as they are today. This destructive process resulted in the formation of soils and beds of sands and

clays on which vegetation was developed, in some instances in great luxuriance. This seems to have been taking place generally over the plateau during its formation, so that scarcely a section of the basalt but shows the interbedded sediments. To this origin are assigned the trees of the Ginkgo forest east of Ellensburg, the shale beds at the head of Grand Coulee, the sediments of the Ellensburg area, and all of the diatomite beds, so important commercially, of the Columbia plateau.

During the succeeding epoch, there was a general deformation of most of the land area of Washington as we know it today. Two features of the deformation are particularly noteworthy. An elevation of the coastal zone practically closed the record of marine deposition in the State. Coincident with this, or later, there appears to have been further uplift of the Cascade belt. This may reasonably be taken to mark the close of the Tertiary period; but since the record of the Pliocene appears to be so largely one of deformation and erosion, it is not possible to state, on present information, just what event opened the subsequent period.

It is clear that the Miocene and earlier rocks were first deformed and uplifted and then subjected, during the Pliocene, to a sufficiently long period of erosion to permit the development of rather extensive peneplane areas particularly noticeable in the Cascade belt and apparently recognizable elsewhere. Still later, and more satisfactorily marking the close of the Tertiary period, the erosion surface referred to Pliocene time was itself elevated. The elevation of this surface, which gives us the remarkably uniform summit levels characteristic of the present Cascades, seems to have been progressively greater toward the north. Although the general level is approximately 5,000 feet in the southern Cascades, it is nearly 3,000 feet higher near the Canadian boundary. There is more than a suggestion, also, that the greater elevation in the north was accompanied by marked faulting, probably of the block type.

Events of the next period, the Quaternary, are so recent that the record is relatively complete and therefore less difficult to decipher. For some parts of the State, a portion of the Quaternary record has been well worked out. The State-wide conditions, however, cannot be outlined in any detail until other critical areas in the State have received the same careful study.

Quaternary history in Washington reveals events of extremely varied character. From the great mass of details already accumulated by investigators, it is apparent that there were three events of outstanding character to which the whole history of the Quaternary can probably be related.

Sometime early in the Pleistocene epoch were opened the vents from which issued the great volume of volcanic material making up the immense cones of Baker, Glacier Peak, Rainier, Adams, and St. Helens, in Washington, Hood and many others, in Oregon. Both lava flows and beds of volcanic clastic material accumulated on top of the elevated erosion surface, which has been referred to the Pliocene epoch. Elsewhere in the Cascade province were extensive extrusions of lava not clearly connected with the volcanic vents. Similar in character and form to the flows of mid-Tertiary time, these are distinct because of their close relation to the physiographic features of the Pleistocene epoch.

Later, accompanying a change to cooler climate, came the great accumulations of ice in the region north of Washington, from which enormous tongues flowed steadily southward to cover the northern counties in an almost solid blanket of ice and snow. On the newly uplifted Cascade Mountains, particularly on the towering volcanic peaks, changed climatic conditions provided a great number of alpine glaciers which flowed down the mountain valleys and out onto the adjacent lowlands. In the Okanogan province to the east, the great continental ice sheet is believed to have covered all but the higher land masses, as shown on the geologic map of the State. Its melting furnished great quantities of water to flood the valleys leading southward.

A third major event of the Pleistocene is not separated from the glacial history in time but is distinct because it applies to that portion of the State lying south of the margin of the glaciers. This comprised the depositions of sedimentary materials over a wide area, partly in lakes, partly in stream valleys, and very possibly in some part piled up by the winds in the more arid portions of the State. At the time of their greatest development in eastern Washington, practically all of the wide expanse of the Columbia River lavas was concealed by these deposits, which locally were several hundred feet thick. Stripping of these deposits over wide areas proceeded as the meltwater from the north streamed southward. Casual inspection of the geologic map reveals the characteristic continuity of these stripped regions known in eastern Washington as the scablands.

Much remains to be learned of the details of all three of these major events, but a few features stand out clearly. The volcanic eruptions included those of both quiet and explosive type, the former giving rise to flows extending to some distance from the vents, the latter to great thicknesses of tuffs and volcanic dust. The Glacial epoch included the advance and subsequent retreat

of the glacial ice front during each of at least two substages, with a considerable time interval between them. The concomitant deposition of sediments over the Columbia Lava plateau came before the latest of the ice advances and may have occurred in the interglacial stage.

Details of the glacial history in the Puget Sound region have been well worked out and constitute a chapter too long for insertion here. It includes an early glaciation, a long interglacial epoch when great thicknesses of sediments were formed, followed by a re-advance of the ice. Marked changes of sea level occurred during these substages, giving rise to the development of an extensive system of river valleys, which were later submerged to form the irregular bodies of water which comprise Puget Sound.

The final wasting away of the continental ice sheet, accompanied by a corresponding shrinkage of the mountain glaciers throughout the Cascade and Olympic provinces, marked the close of the Glacial epoch and initiated the Recent. Since that time there has been no important change in the topographic features of the State. The geologic record is primarily one of erosion, although deposition both on the land surface and in the sea has, of course, taken place. Although there is some reason to think that the Pleistocene igneous activity may have continued until late in the Glacial epoch, it appears unlikely that it extended into the Recent.

APPENDIX I

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