

WASHINGTON GEOLOGICAL SURVEY

HENRY LANDES, State Geologist

BULLETIN No. 13

The Tertiary Formations of
Western Washington

By CHARLES E. WEAVER



OLYMPIA, WASH.

FRANK M. LAMBORN  PUBLIC PRINTER

1916

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LETTER OF TRANSMITTAL.

*Governor Ernest Lister, Chairman, and Members of the Board
of Geological Survey.*

GENTLEMEN: I have the honor to submit herewith a report entitled "The Tertiary Formations of Western Washington," by Charles E. Weaver, with the recommendation that it be printed as Bulletin No. 13 of the Survey reports.

Very respectfully,

HENRY LANDES,

State Geologist.

University Station, Seattle, June 15, 1916.

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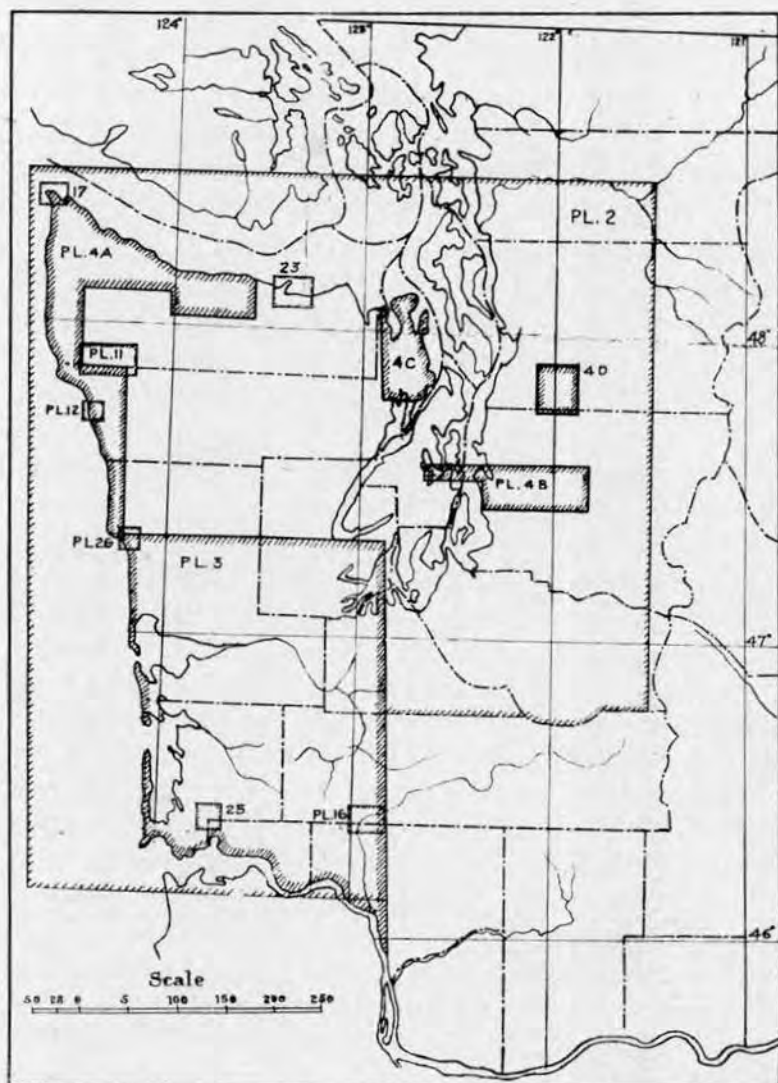
INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

The purpose of this report is to set forth the results of certain geological and palaeontological investigations of the Tertiary formations of Western Washington, carried on by the writer from 1907 to 1914. An attempt has been made to subdivide the Tertiary deposits upon a stratigraphical and palaeontological basis and in a preliminary manner to determine their areal distribution. A study has been made of the strata entering into each formation, the conditions under which they were deposited, the character of the fauna contained therein, and the structural conditions under which they appear. Geological maps accompany this report, upon which the larger part of the data has been assembled.

The area embraced in this report extends from the western foothills of the Cascade Mountains westerly to the Pacific Ocean and from Columbia River northward to the Strait of Juan de Fuca. The central portion of the Olympic Peninsula is excluded since only a hasty reconnoissance of this region has been made. Large portions of Western Washington have been examined in only a preliminary manner but other portions have been studied in minute detail. Survey traverses have been carried from Grays Harbor northward along the ocean shoreline to Cape Flattery and from that point easterly along the Strait to Dungeness River. Similar traverses have been made along all the more important streams where there were sufficient rock exposures to warrant such. Observations on the strike and dip of the sedimentary rocks were taken wherever possible and these were definitely tied into stations on the lines of traverse. Detailed measurements were made in feet of each stratum exposed for the purpose of constructing stratigraphic sections.

Wherever possible collections of fossils were made and their exact localities tied into traverse survey lines. An effort was made to record the position of each individual stratum from



Outline Map of Western Washington.

which fossils were taken and refer each to some point on the line of traverse.

One large areal geological map of the western part of the state has been constructed on the scale of one inch to seven and one-half miles. Upon this the geographical distribution of the several formations involved have been represented by colors. In those places where the contact between formations can be definitely determined, the positions of the contact lines, as drawn on the map, are correct. In the intervening areas where the contact relations are obscure or entirely concealed, the contact lines have been drawn from the best evidence obtainable. In those regions where the pre-Pleistocene formations are concealed beneath a great thickness of glacial deposits, the surface geology has been designated as Pleistocene. However, where occasional outcrops of older formations project through the drift so as to indicate the probable age of the underlying formation, the pre-Pleistocene formations have been given the preference in mapping.

The area involved in southwestern Washington, from the south flanks of the Olympic Mountains to the Columbia, was mapped on a scale of one-half inch to the mile. A belt bordering the Olympic Peninsula from Grays Harbor northward around Cape Flattery and easterly to Port Angeles has been mapped on a similar scale. Another map has been constructed on the scale of one inch to the mile, extending west to east from Kitsap County across Seattle to the foothills of the Cascades. Upon this have been located all observations taken upon strike and dip, as well as contact lines between formations. The probable positions of all anticlines and synclines, where they can be determined, have been inserted. Where the contacts are definite they are represented by continuous lines; where only proximate, by broken lines.

Altogether about twenty months were spent in the field in areal mapping. The remaining time at odd intervals has been devoted to office work in preparing the maps and report. The writer has been assisted in the field work by Messrs. Charles R.

Fettke, Donald Ross, Olaf Stromme and T. A. Bonser in 1911, and by Charles Landes in 1913.

The collections of fossils have been identified and may be found in the Palaeontology collections of the University of Washington.

HISTORICAL REVIEW

The earliest records concerning the Tertiary formations of western Washington are to be found in the reports of the Wilkes Exploring Expedition, published in the year 1849. Examinations were made of the Tertiary formations along Columbia River by James D. Dana. Other members of his party examined the small valleys entering the Columbia from the north side, including the Cowlitz. Records were made of the occurrence of Tertiary strata along the shores of Puget Sound and in the vicinity of Bellingham. Collections of fossils were made at the town of Astoria. These were determined and described by T. A. Conrad, who recognized in them a very close relationship to the Miocene faunas of Maryland and Virginia.

After the appearance of this report very little was written concerning the geology or palaeontology of this region until 1867, when W. P. Blake published several articles on the coal formations of Washington Territory. In 1870 Dr. Robert Brown in a paper on the coal fields of the north Pacific coast describes coal deposits as appearing at Clallam Bay, Bellingham Bay, Cowlitz Valley, Issaquah, and Stillaguamish River. He regarded these as being of Tertiary age and also recognized the existence of Pleistocene lignite seams in the sea-cliffs of Puget Sound.

From 1870 to 1888 numerous short papers appeared referring to the geological conditions in the Cascade Mountains and along Columbia River, but are confined chiefly to a description of the basaltic lavas. In 1888 a report appeared by C. A. White on the Puget Group of Washington Territory, which was intended to include the coal bearing formation of King, Pierce and Whatcom counties. Collections of the brackish water fauna were made from the vicinity of Newcastle and Carbonado.

This formation was thought to bear a close relation to the Laramie. A collection of marine invertebrate fossils was made and reported as occurring in bluffs along the shores of Duwamish Valley. A list of these was given and they were referred to the Tejon horizon of the Eocene.

In 1892, in the Correlation Papers on the Eocene and Neocene of the United States, by Wm. B. Clark, W. H. Dall and G. D. Harris, reference was made to the Tertiary horizons of western Washington. The coal bearing horizon of the Puget Group was placed in the Eocene. It was suggested however that it might be in part of Cretaceous age. Miocene deposits were recognized as the equivalent of those at Astoria.

In 1906, reports in considerable detail were published by Bailey Willis on the Tertiary coal fields of King, Pierce and Whatcom counties. Detailed areal geologic mapping was begun and the structure of the formations in part worked out. Mr. Willis recognized the Puget Group as of Eocene age based on palaeobotanical determinations made by F. H. Knowlton. The Puget Group was described as having been deposited under estuarine conditions and to possess a thickness of over 12,000 feet. Marine Miocene deposits were referred to as resting unconformably upon the Eocene. In 1897 a report was published by J. P. Kimball on the physiographic geology of Puget Sound Basin. The larger part of this paper was devoted to a description of the glacial deposits: several localities were referred to where Eocene and Miocene outcrops were examined. In 1898 the volcanic rocks upon and around Mt. Rainier were described by George Otis Smith.

The older Mesozoic and Palaeozoic rocks of the western slope of the northern Cascades were described in a preliminary manner by I. C. Russell. These formations are of interest because they form the basement complex upon which the Tertiary strata rest.

In 1901 and 1902 the State Geological Survey of Washington was organized and field work was carried on for two years. The coal bearing horizons of the western part of the state were

described and their approximate areal extent represented upon a geological map. The distribution of all formations in the western part of the state as they were known at that time were shown upon this map.

A geological reconnoissance around the coast of the Olympic peninsula was made by Ralph Arnold in 1904. The results were published in 1906, in which he recognized the existence of an old series of partly metamorphosed sediments constituting the interior of the Olympic Mountains and the presence of Eocene, Oligocene and Miocene formations around its border. The Oligocene-Miocene strata were not differentiated and were referred to as the Clallam formation. On the Pacific coast of the Olympic peninsula certain fossiliferous deposits were noted on the Bogachiel and farther south at the mouth of the Quenault River. He regarded these as of upper Miocene or Pliocene age.

In the same year a paper appeared by the same author on the Pectens of the Pacific Coast, in which several new species were described from Washington. Reference was made to several fossiliferous deposits in Cowlitz and Chehalis valleys, as well as along the Strait of Juan de Fuca and in Puget Sound Basin across from Seattle. Later in 1909 Dr. Arnold published a paper on the environment of the Tertiary faunas of the Pacific Coast of the United States, in which the several Tertiary horizons of Washington were correlated with those in Oregon and California. Eocene, Oligocene, Miocene and Pliocene formations were recognized. In the same year Albert B. Reagan described the geologic formations in the vicinity of Bogachiel and Soleduck rivers and listed collections of fossils made there and along the Strait of Juan de Fuca. A considerable number of new species were placed on record.

In 1911 a paper published by W. H. Dall on the Miocene of Astoria and Coos Bay described several new species of marine invertebrates from Washington and a list of the fossils associated with them. These records are of great assistance in comparing the faunal zones of Washington with those of Oregon. During 1912 a paper appeared by Charles H. Clapp on the

geology of the southern end of Vancouver Island in which the geology of the Miocene deposits on the north shore of the Strait of Juan de Fuca were described.

In 1912 a paper was issued by the writer on the Tertiary Palaeontology of Western Washington, in which a considerable number of new species were described and figured. The geological horizons of the Tertiary, as recognized at that time, were given as well as a list of the characteristic fauna.

In 1912 a paper was issued by Arnold and Hannibal on the stratigraphy of the Tertiary formations of the Pacific Northwest. The formations of Oregon and Washington were correlated with one another and a new classification of the Tertiary horizons was set forth.

BIBLIOGRAPHY.

In the following list of references to the literature concerning the geology and palaeontology of western Washington only those papers have been quoted which have contributed some direct information concerning the Tertiary rocks. Numerous papers are in existence which refer to the topographical features or economic products of this part of the state, but which add no facts to Tertiary geology problems. The following references are regarded as important in a historical review of previous literature:

1845. Wilkes, Charles. Narrative of the United States Exploring Expedition. Vol. 4, pp. 313, 415, 424.

The only notes referring to western Washington geology are the "trap dikes" encountered on Cowlitz River and the basaltic flows on the banks of the Columbia.

1845. Greenhow, Robert. Geography of Oregon and Washington.

This work deals chiefly with the historical development and colonization of Oregon and Washington. A description is given of the geography of the western part of Washington as known at that time.

1849. Dana, James D. Notes on the geology of Washington Territory. Wilkes Exploring Expedition, volume X, pp. 616-623, 626-628, 658.

In this report a description is given of some of the geological features of Washington which was then a part of Oregon Territory. Basalt was observed as occurring in places along both sides of Columbia River. Tertiary sedimentaries are described at Astoria and across on the Washington side of the Columbia and are said to have a thickness of 1000 to 1200 feet. Similar strata are mentioned in Cowlitz River valley and along the shores of Puget Sound. Collections of fossils made by Dana have been described and figured by T. A. Conrad. Mr. Conrad's conclusions concerning the Miocene age of these faunas may well be quoted here:

"From the investigation of the fossils previously received from Mr. Townsend, I had arrived at the conclusion that they were of the geological era of the Miocene, and the specimens you sent confirm the opinion. I do not recognize, it is true, any recent species of the coast of California or elsewhere, but neither is there any shell of the Eocene period, nor has the group any resemblance to that of the Eocene. On the contrary, the forms are decidedly approximate to those of the Miocene period which occur in Great Britain and the United States. *Nucula divaricata*, for instance, closely resembles *N. cobboldiae* (Sowerby) of the English Miocene, and *Lucina acutilineata* can scarcely be distinguished from *L. contracta* (Say), a recent species of the Atlantic coast and fossil in the Miocene beds of Virginia. *Natica heros*, a shell of similar range, is quite as nearly related to the *N. saxea*. A similar number of species might be obtained from some of the Miocene localities of Maryland or Virginia and yet no recent species be observed among them. In the Eocene, and also in the Miocene strata, there are peculiar forms which obtain in Europe and America, and although the species differ, yet they are so nearly allied that this character alone, independent of the percentage of extinct forms, is quite a safe guide to the relative ages of remote fossiliferous rocks. On this foundation, I speak with confidence when I assign the fossils of the Columbia River to the era of the Miocene."

Gibbs, George. A reconnaissance of the country lying upon Shoalwater Bay and Puget Sound; upon the geology of the central portion of Washington Territory.—Pacific Railroad Reports, volume 1, pp. 465-486.

A general reconnaissance report on the geography of the region. Trachyte rocks are referred to as occurring about Mt. Rainier and St. Helens and gravels and sands in the Puget Sound region.

1856. Blake, William P. Review of a portion of the geological map of the United States and British Provinces.—American Journal of Science, second series, volume 22, pp. 383-388.

Reference is made to the fact that on Marcou's geological map of the United States the coal fields of Puget Sound are represented as upper Carboniferous. Mr. Blake states that "all the evidence that can be produced concerning the age of these deposits shows them to be Tertiary."

1857. Newberry, J. S. Coal of Bellingham Bay.—Pacific Railroad Reports, volume 6, part 2, pp. 53-68.

A section measured in the Bellingham Bay region gave "2000 feet of shales, sandstones and coal of which the coal presents the enormous aggregate of 110 feet." The strata of Bellingham Bay are believed to be of Miocene age and closely related to the shales of the Columbia and Coos Bay. Mention is made of the occurrence of fossil plants.

1857. Meek, F. B. On Cretaceous fossils from Vancouver and Suquia Islands.—Transactions, Albany Institute, volume 4, pp. 37-39.

1858. Shumard, B. F. Description of new fossils from the Tertiary formations of Oregon and Washington territories and the cretaceous of Vancouver Island. Transactions of the St. Louis Academy of Science, volume 1, pp. 120-125.

1859. Lesquereux, Leo. Species of fossil plants from Bellingham Bay, etc.—American Journal of Science, second series, volume 27, pp. 360-363.

This article describes several species of fossil plants collected by Dr. John Evans at Nanaimo and at Bellingham Bay. Those at the latter place are from the coal measures and are regarded as of Tertiary age.

1859. Heer, Oswald. Fossil plants of Vancouver and Bellingham Bay.—*American Journal of Science*, second series, volume 28, pp. 85-89.

Certain species of fossil leaves from the Tertiary strata at Bellingham Bay have a very close relationship to species of the same geological horizon in Europe.

1861. Meek, F. B. Descriptions of new Cretaceous fossils from Vancouver and Suia islands.—*Proceedings Academy of Natural Science*, Philadelphia, volume 13, pp. 314-318.
1863. Newberry, J. S. Description of fossil plants from Orcas Island, Bellingham Bay, etc.—*Boston Journal of Natural History*, volume 7, pp. 506-524.
1867. Blake, William P. Notes on the brown coal formation of Washington Territory and Oregon.—*California Academy of Science, Proceedings*, volume 3, p. 347.

A brief description of the coal measures at Bellingham Bay. They are said to dip at an angle of 70° and strike East 15° North, and to have a thickness of about two thousand feet. He reports ten workable coal seams interstratified with six or seven heavy beds of sandstones and numerous strata of bituminous shale, slate, clay, ironstone, and thin beds of sandstone. Two well preserved shells of the genus *Pecten* are said to have been collected. Reference is made to the occurrence of coal on the banks of the Cowlitz River.

1870. Brown, Dr. Robert. Glacial scratches near Bellingham Bay, Washington.—*American Journal of Science*, volume 50, p. 323.

Reference is made to the presence of fluting and grooving as evidences of glacial action at Sehome near Bellingham Bay.

1871. King, Clarence. On the discovery of actual glaciers on the mountains of the Pacific slope.—*American Journal of Science*, volume 101, pp. 157-167.

Describes the general character of the glaciers on Mt. Rainier and states that they are the principal source of the following rivers, viz., Cowlitz, Nisqually, Puyallup and White.

1876. Meek, F. B. Descriptions and illustrations of fossils from Vancouver and Suia islands, and other northwestern localities.—*Bulletin United States Geological Survey, Territories*, volume 2, pp. 351-374.

1870. Brown, Dr. Robert. On the geographical distribution and physical characteristics of the coal fields of the North Pacific Coast. *Transactions Edinburgh Geological Society*, volume 1, part 3, pp. 305-325.
1879. Donald, J. T. Elephant remains of southwestern part of Washington Territory.—*American Journal of Science*, volume 118, p. 79.
1880. Willis, Bailey. Report on the coal fields of Washington Territory.—*Tenth Census of the United States*, volume XV, pp. 759-771.

The coal bearing strata are described as extending up the Cowlitz valley into Puget Sound and as far as the foothills of the Olympic Mountains around the north border to Cape Flattery. Those of the Puget Sound region are referred to as the "Laramie."

"The coal measures of the Puget Sound basin consist of alternating beds of yellow and gray fine-grained sandstones and very fine gray arenaceous shales interstratified with many beds of carbonaceous shale and coal; the individual strata of sandstone and shale, from 20 to 200 feet thick, maintain the same general character wherever observed, and no well-defined horizon has been found which might serve as an index to correlate the widely-separated exposures. Leaf impressions occur in both shales and sandstones associated with unios.

"The best sections are those obtained in the Wilkeson and Green River fields, and described in detail in their proper connection, though even they are incomplete; of these one gives a minimum of 13,200 feet, with a probable maximum of 14,500 feet; a second, still less complete, measures 7,700 feet; and the third, on Green River, lies between 6,200 and 8,200 feet; and these sections do not in either case reach the limits of the coal measures, as the base of each is an anticlinal axis and the top the highest exposure, geologically speaking, beneath the volcanic flows or drift-beds. Such figures challenge confirmation, but they are the result of accurate surveys and careful observation, and are only invalidated by the possibility of undiscovered faults, of which the sections have yielded no proof under close examination.

"The fossils indicate the maintenance of fresh and brackish water conditions through this long period of deposition, implying that the general rate of this profound subsidence was the same as that of accumulation of sediments."

1881. Brockett, L. P. Our Western Empire.—San Francisco, pp. 1189-1213.

The following statement is made concerning the geology of Washington:

“The shores of the Pacific, the lower valley of the Columbia, and the great valley drained by Puget Sound, are Tertiary and Quaternary; the islands west of the Canal de Haro in the Gulf of Georgia are Cretaceous; the vicinity of Bellingham Bay is Carboniferous; the Coast Range is Eozoic; the Cascade Mountains to about 47° 40' and the Great Plains of the Columbia River in central and eastern Washington, south of the Spokane River, are volcanic.”

1888. White, C. A. On the Puget Group of Washington Territory.—*American Journal of Science*, third series, volume 36, pp. 443-450.

This paper deals with a collection of fossil mollusca from the Puget Group of Washington made by Prof. J. S. Newberry. The species are of brackish water origin. Two species were thought to be closely related to the Laramie of the Rocky Mountain region. Several other genera were not known to occur at any other place in North America. Mention is made of strata containing a Tejon fauna in the Duwamish valley. These strata were correlated with the upper portion of the Puget Group. The strata of the Puget Group were considered to have been deposited in estuaries.

1889. White, C. A. On invertebrate fossils from the Pacific Coast.—*United States Geological Survey, Bulletin No. 51.*

In this report reference is made to a collection of fossils said to come from “Fossil Bluff, Duwamish River.” The region referred to is probably in the vicinity of Duwamish Station. The following is a list of the species collected: “*Cylichna costata* Gabb, *Conus hornii* Gabb, *Lunatia nuciformis* Gabb, *Leda protecta* Gabb, *Euspira alveata* Gabb, *Fusus diaboli* Gabb, *Turritella wasana* Gabb, *Tellina* sp.” The formation in this particular region was regarded as the “Tejon portion of the Chico-Tejon Series.” The sedimentaries in King and Pierce counties were regarded as of estuarine origin. The brackish water fos-

sils occurring in those strata were described. To a certain extent they have a close similarity to the Laramie. There are many forms, however, which have never been observed in the Laramie and which are peculiar to the Puget Group. The term "Puget Group" is here applied to this brackish water deposit.

1891. Clark, Wm. B. *Correlation Papers: Eocene*.—United States Geological Survey, Bulletin No. 83, pp. 100-110.

An historical review is given concerning the literature on the Puget Group in Washington. It is suggested that the Puget Group may be in part Cretaceous and in part Eocene.

1891. White, C. A. *Correlation Papers: The Cretaceous*.—United States Geological Survey, Bulletin No. 82.

The upper Cretaceous or Chico formation is the coal bearing formation on the north of Vancouver Island. The same formation is known to appear in the San Juan Islands in the State of Washington.

1892. Dall, Wm. H. and Harris, G. D. *Correlation Papers: Neocene*.—United States Geological Survey, Bulletin 84, p. 228.

At the time this report was written very little was known concerning the occurrence of marine Miocene deposits within the state. It is stated (p. 228) "Siliceous casts of molluscan fossils have been collected at various points on Shoalwater Bay, which show a synchronism of the deposits in which they are found with both the Eocene and the Miocene clay shales of Astoria. The Astoria bed outcrops at Bruceport and elsewhere. A Pliocene deposit has been observed by Dr. Condon in this vicinity which, from its most characteristic fossil may be called the *Mytilus* bed. It furnished specimens of *Buccinum cyaneum*, *Mytilus condoni*, *Crepidula*, *Pecten*, and *Panopaea*; this is overlain by a Pleistocene formation, the level of which is from 30 to 40 feet above the sea." On page 271, marine Pliocene is referred to as occurring at Shoalwater Bay, 35 feet above sea level. The fossils exhibit a boreal facies.

1893. Corey, T. B. The coal fields of western Washington.—Journal Illinois Mining Institute, May, 1893, volume 11, No. 1, pp. 14-30.

This paper describes briefly some of the coal seams in Whatcom, Skagit, King, Pierce and Chehalis counties. A number of geologic cross sections are inserted.

1893. Diller, J. S. Notes on palaeontology referring to Washington.—Bulletin Geological Society of America, volume 4, p. 217.

A well preserved specimen determined by Mr. Stanton to be *Baculites* was given to Mr. Diller by Mr. W. P. Guye. It is said to have come from Snoqualmie River, three miles below the falls. Mr. Diller states: "It shows the presence of the Chico at that point. The rock is unaltered and lies between the Puget Group and the metamorphics." Careful areal geological studies have been made in that region and no strata have been found which could be assigned to the Cretaceous. It was undoubtedly derived as a fragment from the glacial drift which in that region heavily veneers the country.

1894. Diller, J. S. Tertiary revolution in the topography of the Pacific Coast.—Eighth Annual Report, United States Geological Survey. (Powell), part 2, pp. 401-434, 8 plates, 4 figures.

1895. Diller, J. S. A geological reconnaissance in Northwestern Oregon.—United States Geological Survey, 17th Annual Report, part 1, pp. 441-520.

The paper discusses the geology of northwestern Oregon. Notes are given concerning the geology on the north shore of Columbia River across from Astoria. Reference is made to the occurrence of the very lowest Oligocene strata at Knappton on the Washington side of Columbia River. The raised beach at Ilwaco in Washington is described. A drawing is added to illustrate the unconformity between the older Oligocene and the overlying Pleistocene. He states:

"At Ilwaco, on the north bank of the Columbia near its mouth, is an exposure of which a sketch is shown in figure 8. The upturned edges of the Astoria shales make the mass of the hill, and these shales are unconformably overlain about 30 feet above sea level by a series of gravel, sand, and clay layers 14 feet thick. The material in these layers is incoherent and contains occasional fresh fragments of shells belonging to species

yet living on the coast. Near the middle of the deposit is a dark seam of vegetal matter, and the character of the stratification is such as to indicate that the deposit is waterlaid and not of eolian origin.

“At the base of the hill the upturned edges of the shales have been cut off to an even surface by the waves, and this wave-cut terrace extends more than 100 yards toward the river. The top of the shales, in the hill immediately beneath the Pleistocene layer is planed off in the same way, and it is evident that when this was accomplished the shale in the hill top was then at the sea level and the waves rolled over it as they now roll over the lower wave-cut terrace to reach the beach.

“The Pleistocene capping of the hill was laid down when the ancient wave-cut terrace was below the sea level deep enough to receive the deposits we now find there. Since then, of course, it has been raised to its present elevation by a general, perhaps more or less unequal, uplifting of the land along the coast.”

Mr. Diller's views concerning the Pleistocene history of Northwestern Oregon are of particular interest inasmuch as it must apply in part at least to Southwestern Washington. Extensive nearly horizontally bedded sands and clays rest unconformably upon older strata up to elevations above 600 feet. Remnants of peneplains are recognized up to elevations of 2000 feet, indicating that all of Northwestern Oregon has been submerged perhaps that amount. A great sound is thought to have existed, perhaps similar to Puget Sound. Afterwards the region was again uplifted to an elevation somewhat higher than at present. The most recent movement was a subsidence sufficient to partially drown the lower Columbia and Willamette river valleys, allowing the tide to extend up a considerable distance above their mouths.

1896. Gilman, S. C. Olympic country. *National Geographic Magazine*, volume 7, pp. 133-141.

The paper deals primarily with explorations carried on in the Olympics. The general topographic features are described and reference is made to the occurrence of sandstones and shales in the bluffs at the mouth of Queniult River. A map of the Olympic Peninsula accompanies the report.

1896. Stanton, Timothy William. Contributions to the Cretaceous paleontology of the Pacific Coast: the fauna of the Knoxville beds.—United States Geological Survey, Bulletin 133, 132 pages, 20 plates.

The following reference is made concerning the occurrence of Knoxville strata in the State of Washington: "The presence of Knoxville beds in Washington is inferred from the occurrence of boulders containing *Aucella crassicollis* near Seattle and Tacoma and also from the fact that *Aucella* beds are well developed in British Columbia immediately north of Washington." The facts are that these boulders are of glacial origin and may have been brought down from British Columbia by glaciers.

1896. Willis, Bailey. Geology of the Cascade Mountains.—Johns Hopkins University Circular, volume 15, p. 90.

Mr. Willis states:

"In the Cretaceous period Puget Sound and adjacent areas of Washington and Oregon of indeterminable extent were beneath a sea in which limestone was the principal formation. It is probable that toward the north or northeast in northern Washington and British Columbia, there was a low land area consisting largely of granitic and metamorphosed crystalline rocks. There gradually ensued a change by which Puget Sound and the area where the southern Cascades now extend from the 48th parallel southward through Oregon became an extensive estuary, in whose waters deposits of sand and mud were laid down, and around whose changing shores there were many marshy lagoons in which a rank vegetation flourished. The conditions of estuarine deposition, which perhaps can be best exemplified by pointing to our southern Atlantic coast, endured throughout Eocene and Miocene times, and we know that in the Miocene the climate was tropical and the place of the Cascade Range was a swampy lowland near sea level. The thickness of sandstones, shales, and coal beds of the Puget Group is 7,000 to 12,000 feet or more."

1897. Dall, W. H. A table of the North American Tertiary horizons correlated with one another and with those of western Europe, with annotations.—United States Geological Survey, 18th Annual Report, Part 2, pp. 323-349.

In this paper the various Tertiary formations on the Pacific coast are briefly described and correlated with one another. He

states concerning the Puget Group of Washington: "The conditions continued through the Eocene and possibly into Miocene time. If so, the Puget Group may eventually be differentiated into several members."

1897. Kimball, James P. Physiographic geology of the Puget Sound basin.—*American Geologist*, volume 19, pp. 225-237, 304-322, plates 12 and 19.

In this paper numerous outcrops of pre-Pleistocene strata occurring at various points in the Puget Sound basin are described.

1897. Smith, George Otis. Rocks of Mount Rainier.—United States Geological Survey, 18th Annual Report, part 2, pp. 416-423.

Mr. Smith states:

"The volcanic rocks of Mount Rainier include both lavas and pyroclastics. The breccias, agglomerates, and tuffs, although of striking appearance, are, perhaps, less important elements in the construction of the composite cone.

"The lavas vary much in color and texture, but these megascopic differences are referable rather to the degree of crystallization of the magma than to its chemical character. The variation in the chemical composition of the lavas expresses itself in mineralogical differences, and thus four rock types are distinguished—hypersthene-andesite, pyroxene-andesite, augite-andesite, and basalt. The distribution of these types indicates a radial arrangement of lava streams, and hypersthene-andesite is the more abundant variety of lava.

"Granite is exposed on the slopes of Rainier where erosion has cut away the overlying lava, and it is plain that the volcanic cone rests upon an elevated platform of older rock, approximately 8,000 feet above sea level."

1897. Willis, Bailey. Glaciation in the Puget Sound region.—*American Geologist*, volume 19, pp. 144-145.

1897. Willis, Bailey. Stratigraphy and structure of the Puget group.—*Bulletin Geological Society of America*, volume 9, pp. 2-6.

Abstract of a paper presented to the Society August 10, 1897. A description is given of the coal bearing formations in King and Pierce counties. He states: "They are prevailing sandstones of variable composition, texture and color, thinly interbedded, and a typical arkose consisting of slightly washed



Summit of Cascade Range Showing Characteristic Topography.

granitic minerals, to siliceous clays. Beds of concentrated quartz sands or conglomerates have not been observed. Carbonaceous materials are generally present as fragments of plants, as vegetal ooze in greater or less proportion to the other constituents and as distinct coal beds. In color they are, when fresh, generally bluish gray, shading to brownish black. They weather to buff tints, which are usually dull. Most prominent among the rocks associated with the Puget Group are eruptives of Tertiary or later age. They occur as dikes and flows in various forms of intruded and extruded igneous rocks. The measured sections of the Puget series exhibit total thicknesses of 5,800 feet on Green River, 5,500 feet on South Prairie Creek, and 5,480 feet in Carbon River canyon. None of these measures are complete. In each instance the lowest stratum is of the Eocene outcropping on an anticline and the highest is the limit of exposure where the rocks pass under later formations. The strata of the Puget Series were deposited upon the slowly subsiding bottom of the geosyncline between the axes of the present Cascade and Olympic ranges. As strata of similar composition and age are involved in the mass of the Cascade Range, and probably also of the Olympics, the uplift of these mountains was to a greater or lesser extent accomplished after the Puget Epoch." These strata have been folded. In general the axes of these folds trend north and south parallel to the axis of the antecedent geosyncline, but there are evidences in local structures which show that the forces of compression were exerted also at right angles to the greater pressure.

1898. Lawson, Andrew C. Note on the Chehalis sandstone. *American Geologist*, volume 13, pp. 436-437.

Note is made of some fossil bearing sandstones in the hill at Chehalis, Washington. The rock "is a sandstone of variable character. For the most part it is soft and friable. It is generally clayey and its color varies from bluish gray to yellowish, according to the stage of oxidation." Fossils collected were determined by Mr. T. W. Stanton as *Solen*, *Leda*, *Tellina*, *Venus*,

Fusus, *Dentalium* and others. They are of marine origin and the strata were considered to be of "Eocene or Miocene age."

1898. Merriam, J. C. Note on two tertiary faunas from the rocks of the southern coast of Vancouver Island.—University of California, Bulletin, Dept. of Geology, volume 2, No. 3, pp. 101-108.

This paper deals with two collections of marine invertebrate fossils from the south coast of Vancouver Island. One of these is from Carmanah Point and the other from the vicinity of Sooke Bay. Altogether twenty-four species were collected at Carmanah Point. He states: "The fauna of the Carmanah Point beds seems on the whole to be the same as that of Conrad's Astoria Miocene, excluding, however, the lower portion of the latter series, which has been supposed to be of Eocene age." Of the fauna collected at Sooke fifty-five per cent are extinct. Eight or nine species are living. He states: "Comparing the Sooke fauna with that of well-known Tertiary and post-Tertiary horizons on the Pacific Coast, we find that six or seven of the species are known from the Miocene and about an equal number from the Pliocene, nine species are found in the Quaternary and Recent, and seven or eight are not known to occur elsewhere, either recent or fossil." Dr. Merriam also says: "The evidence at our command indicates that the Sooke beds are of middle Neocene age, and that the time of their deposition was considerably later than that of the Carmanah Point beds."

1898. Russell, I. C. A preliminary paper on the Geology of the Cascade Mountains in Northern Washington.—United States Geological Survey, 20th Annual Report, pt. 2, pp. 83-210.

This report deals chiefly with the geology of the Cascade Mountains proper. A series of old metamorphic formations consisting of slates and schists of unknown age are intruded by granite. The Cretaceous is recognized in the extreme northern portion of the Cascades and is locally referred to as the Similkameen and Winthrop formations. The Tertiary formations which are described are confined to the eastern side of the Cascades. They consist of the Swauk, Roslyn, Ellensburg and Columbia River lava. In late Tertiary times the Cascade Mountains were reduced to a peneplain.

1898. Willis, Bailey. Some coal fields of Puget Sound.—United States Geological Survey, Eighteenth Annual Report, part 3, pp. 399-436, plates 52-68, figures 26-31.

In this report a detailed description of the geology of the coal bearing formations of Pierce and King counties is presented. Special consideration is given to the geologic structure. The preceding paper which was presented as an abstract covers the principal points in this. (1897. Willis, Bailey. Stratigraphy and structure of the Puget group.)

1899. Willis, Bailey, and Smith, George Otis. Tacoma Folio.—United States Geological Survey, Geologic Atlas, Folio No. 54.

This report describes the geology of an area involving parts of King and parts of Pierce County. The oldest formations are of Eocene age and are represented by the Puget Group. The Puget formation in this area is described as consisting "of interbedded sandstones, shales, and coal beds aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture and color, and are frequently cross stratified. Their composition ranges from a typical arkose consisting of slightly washed granitic minerals to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. In general the strata are similar and are similarly interbedded from top to bottom. The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron and generally more or less carbonaceous matter which varies in character from finely divided organic material to large leaves and stems. They accordingly range in color from rather light gray and blue to black. The lighter tints weather out brown through oxidation of the iron. The proportion of coal beds is extraordinary. Carefully measured sections show that the Puget formation contains more than 125 beds. The valuable coal is found in the lower 3,000 feet of the formation. The physical history which is recorded in the Puget formation is one of persistent but frequently interrupted subsidence of the area within which the sediments were deposited. Throughout these changes the

waters appear to have remained fresh or brackish. The fossils other than plants are prevailingly unios or other fresh water forms."

The flora is known to contain over 100 species, a very large number of which are new. The plant remains in the lower beds give evidence of a tropical climate while those in the upper are more closely related to those of the present day.

"The condition of subsidence which characterized the Puget Sound Basin during the Eocene period continued into the next, the Neocene. There is apparently no interruption or change in the sedimentary sequence to mark the transition, but plants collected from the upper part of the Puget formation differ from those taken from lower portions, and are of Neocene types.

"In the northern Duwamish Valley, in the vicinity of Steels, is an isolated area of brown sandstone containing fossil plants which are younger than any collected from the recognized Puget formation, and which may belong to a later epoch of the Neocene period. A little farther northwest in the same vicinity are outcrops of green sand in which occur marine fossils of early Neocene (Miocene) age."

1899. Diller, J. S. Latest volcanic eruption on the Pacific Coast.—*Science*, new series, volume 9, pp. 639-640.

Certain evidence is presented to show that Mt. St. Helens and Mt. Baker were in eruption during the early part of the 19th century.

1902. Landes, Henry. Coal deposits of Washington.—*Washington Geological Survey*, volume 1, Annual Report for 1901, pp. 257-281.

This report describes the coal bearing formations of the Puget Sound and Cowlitz Basin regions. The strata were believed to have been deposited under estuarine conditions during the Eocene.

1902. Landes, Henry. An outline of the geology of Washington.—*Washington Geological Survey*, volume 1, Annual Report for 1901, pp. 11-35.

In this report the state is divided into five topographic provinces. A preliminary geological map of the state is inserted, showing the areal distribution of formations as known at that

time. The coal measures of Puget Sound are recognized as of Eocene age. The sedimentaries in Kitsap County are referred to as Miocene, as well as the belt bordering the south side of the Strait of Juan de Fuca and the larger part of southwestern Washington.

1902. Landes, Henry, and Ruddy, C. A. Coal deposits of Washington. —Washington Geological Survey, volume 2, pp. 167-275.

A more detailed discussion is entered into concerning the coal bearing formations than in the previous report. The following generalized statement is made:

“The coal measures of Washington belong to the early part of the Tertiary period or the Eocene epoch. In only a very few instances has the base of the coal measures been found. In the coal fields of Whatcom and Skagit counties the lowest strata of the coal measures lie upon a metamorphic rock, a mica schist of unknown age. At the Blue Canyon and Cokedale mines the largest coal seams lie but a few inches or at the most, but a few feet, above the schists. In general in the different fields the principal seams of coal lie well toward the bottom of the coal series and hence belong to the earlier portion of the epoch. In Washington, during Eocene time, the shore line was somewhere in the vicinity of the eastern border of Puget Sound, and extending southward beyond the present boundary of the state. The Olympic Mountains formed a large island immediately off the coast. The region of the Cascade Mountains was in general one of low relief.

In the northern portion of the state, however, the Cascades were doubtless of considerable height and the streams flowing from them possessed of great strength, as shown by the coarse character of the sediments deposited at that time. The hills were composed of granite rocks as shown by the character of the sediments derived from them. The fossil contents and character of the sediments of the coal fields of Roslyn-Clealum and those of Whatcom and Skagit counties show that these fields represent lake deposits. In the case of the Whatcom coal field the sediments reach an approximate thickness of 20,000 feet and are made up of massive sandstones and coarse conglomerates. In the remaining coal fields as far as known, the coal swamps were in estuaries along the shore where brackish water conditions prevailed.”

1903. Smith, George Otis. *Geology and Physiography of Central Washington*.—United States Geological Survey, Professional Paper No. 19, pp. 1-44.

The area involved in this paper lies in the east central part of the Cascade Mountains. The deformational movements are of importance because of their possible influence on the western side of the mountains. Concerning the geologic history of central Washington, it is stated:

“The oldest rocks, probably of Paleozoic age, furnish a record of sedimentation and volcanism, but this record has been greatly obscured by the altered condition of these rocks. This metamorphism in turn tells of the orogenic movements to which the rocks have been subjected and of the action of intrusive magmas.

“The great intrusions of peridotite and granodiorite probably belong to the Mesozoic, and were events of the first importance in the history of this portion of the Cascade Range. The period of erosion subsequent to these intrusions was of sufficient length to allow these deep-seated bodies to be uncovered and deeply dissected.

“From these eroded older rocks was derived the material for the Eocene sediments, and the process of sedimentation appears to have been a rapid one within this area, since several thousand feet of granitic sands and other sediments were deposited in early Eocene time, before uplift again inaugurated erosive activity. Then began the first basaltic eruptions, the forerunners of the greater volcanism of the Miocene. This volcanic activity was succeeded by the quieter processes of sedimentation, by which the Roslyn sandstone was deposited in middle Eocene time. Somewhat later, in an adjacent area, the deposition of the Manastash sediments took place, and the Eocene period closed with the uplift and folding of all of these Eocene formations.

“Erosion continued well into the Miocene within this area, but ceased with the beginning of the great eruption of basalt, the many flows of which covered the greater part of central Washington like a molten sea. Immediately succeeding this epoch of volcanism came the deposition of the Ellensburg formation, thick deposits of stream sands and gravels, brought down from a volcanic area to the west.

“Mountain building movements followed this sedimentation of the later Miocene, and again erosion began to cut away what had been uplifted.”

During the Neocene the region was extensively peneplained. Concerning its uplift later, he states:

“The ultimate deduction is that, whatever the relative proportion of antecedent and consequent character in the drainage system, the main divide for the greater portion of its length in this area neither coincides with nor parallels the axes of most marked deformation of the preexistent surface. The uplift to which the Cascade Range owes its origin was not simple in type but complex, and within this area, can be resolved into three well defined upwarps, which, moreover, are transverse to the main trend or major axis of the range considered over the large area to the north.”

1905. Arnold, Ralph. Gold placers of the coast of Washington.—United States Geological Survey, Bulletin No. 260, pp. 154-157.

Certain bluffs of Pleistocene sands and gravels occurring along the ocean south from Cape Flattery contain small amounts of placer gold. These Pleistocene deposits rest upon the upturned edges of the older shales and sandstones.

1905. Arnold, Ralph. Coal in Clallam County, Washington.—United States Geological Survey, Bulletin No. 260, pp. 413-421.

This report describes the coal-bearing Miocene formations east of Clallam Bay, Washington. Mention is made of the Eocene basalts in the vicinity of Port Crescent and also of the pre-Oligocene formations south of Cape Flattery. The Oligocene-Miocene strata occurring along the Strait of Juan de Fuca are described as well as their thickness, composition and structure. Special mention is made of the coal deposits found in these strata. The more important geologic results are to be found in Mr. Arnold's paper on the Olympic Peninsula published the following year.

1905. Diller, J. S. Coal in Washington, near Portland.—United States Geological Survey, Bulletin No. 260, pp. 411-412.

Reference is made to the occurrence of coal on Coal Creek in Cowlitz County, 12 miles west of Kelso. The coal seam is 6

feet to 7 feet thick with two small partings of sand. It is overlain by soft sandstone. He states: "The bed of coal is interstratified with a lot of shales and shaly sandstones well exposed along Coal Creek near the mine. The strike of these beds near the mine is northwest-southeast with a dip of about 15° S. W. There are igneous rocks cutting the coal bearing beds in that region and the strata are faulted locally. Marine shells occur in the strata 3 feet above the coal. Among them is the ribbed *Venericardia planicosta*, which is characteristic of the Eocene. The coal is essentially of the same age as that farther north in Washington."

1906. Arnold, Ralph. Geological reconnaissance of the coast of the Olympic Peninsula, Washington.—Geological Society of America, Bulletin 17, pp. 451-468, 4 plates, 4 figures.

This paper contains a description of the topographic and physical features of the Olympic Mountains, as well as the geologic formations and their structure. The following statement is made concerning the geologic formations:

"The formations involved in the geology of the coastal region of the Olympic peninsula include serpentine, old diabase or greenstone, metamorphosed sandstone and quartzite, probably of Jurassic age; 6,000 feet of gray sandstone with minor quantities of carbonaceous shales, supposed to represent the lower part of the Puget group and of Cretaceous age; 1,200 feet of basalt and conglomerate, sandstone and shale; 2,260 feet of Pliocene conglomerate, clay and gravel. In addition to this the Oligocene-Miocene breccia contains large quantities of angular fragments of hard black slate, indicating a probable widespread formation of this type of rock somewhere in the general region. Nothing is known of the age of the slate, except that it is pre-Oligocene."

Five recognizable faunas are described as occurring in the Clallam formation along the Strait of Juan de Fuca: 1st, Lowest clay shale (Oligocene); 2nd, "above the clay-shale horizon is a series of medium bedded to fine massive sandstones in which are found a fauna apparently transitional from the clay-shales to the coarse sandstones"; 3rd, a horizon of Miocene sandstone occurring east of Clallam Bay; 4th, the fourth fauna is found

near the top of the Clallam formation in sandstone layers interbedded with conglomerates; 5th, "The fifth fauna of the Oligocene-Miocene is that found at the mouth of the Sekiu River in beds the equivalent of the uppermost strata of the Cape Flattery section."

The Pliocene is described as occurring in a synclinal trough at the mouth of Queniult River. The term Queniult formation is applied to these strata. The following statement is made concerning the geologic structure:

"As indicated by the exposures along the coast, the structural lines in the region from Port Angeles to Gettysburg average approximately parallel to the trend of the Olympics, north 70° west, south 70° east; those in the Gettysburg-Clallam Bay territory almost perpendicular to this, or a little east of north, and those in the Clallam Bay-Cape Flattery stretch north 30° west, south 30° east, or again parallel with the ridges which extend along the coast in this region. A syncline, with its southern limb resting against the sandstones south of Lake Crescent and its northern one truncated by the waters of the strait of Fuca, is the major structural feature of the Port Crescent-Gettysburg region. From Gettysburg westward to the mouth of the Pysht River the structural features are not pronounced, the rocks in general, however, having a westward dip. A rather broad syncline, with its axis extending in a northeasterly-southwesterly direction, occupies most of the territory between the Pysht River and Clallam Bay. This syncline is complicated in its southeastern portion by sharp local folding and some faulting. The region between Clallam Bay and Cape Flattery is formed by a great northeast-dipping monocline, the beds of which appear to have a total thickness of over 15,000 feet.

"South of the Clallam Bay-Cape Flattery monocline is the western extension of the axis of the Olympic Mountains. The structure in the region about this line of disturbance is quite complex, but as one goes away from it toward the south the structure becomes simpler. Several determinable folds with northwest-southeast axes were noted along the coast between the Ozette and Hoh rivers, and in the vicinity of the mouth of the Queniult there is a very prominent syncline developed in the Pliocene, with its axis parallel to those just mentioned.

"A great uplift in the Olympic Peninsula region appears to have taken place at or near the close of the Miocene epoch and still another lesser one during the late Pliocene. That orogenic movements are still taking place, or have occurred since the deposition of the Pleistocene, is evidenced by the very gently folded and tilted clays, sands, and gravels in the vicinity of Port Angeles."

1906. Arnold, Ralph. The Tertiary and Quaternary pectens of California.—United States Geological Survey, Professional Paper No. 47.

This paper consists primarily of descriptions of *Pecten*s occurring on the Pacific Coast. The majority of the forms are from California, although several new species are from the Eocene and Miocene of Washington. Lists of other associated species occurring with the *Pecten*s are given. Among the more important localities in Washington are Little Falls, where the Eocene strata occur, and the Oligocene-Miocene along the north coast of Clallam County.

1906. Smith, Geo. Otis, and Calkins, Frank C. Description of the Snoqualmie Quadrangle.—United States Geological Survey, Geologic Atlas, Folio No. 139, 14 pages, 3 maps, 1 columnar section.

The area involved in this report is confined to the central part of the Cascade Range. The western portion of the quadrangle is largely covered with the *Keechelus* volcanic series which is of importance because of its probable extension westward to the Puget Sound region.

1907. Reagan, Albert B. Some geological studies of northwestern Washington and adjacent British territory.—Kansas Academy of Science, Transactions, volume 20, part 2, pp. 95-121.

The larger part of the area involved is covered with glacial drift. The pre-Glacial sediments at Bellingham are mapped as Eocene as are the metamorphics on Lummi Island. Basalts are said to outcrop in places just north of the international boundary line.

1907. Weaver, Charles E. Notes on the bed-rock geology of the Olympic Peninsula.—Mountaineer, pp. 58-64.

This paper was written from a popular standpoint. It records some geological data collected on a trip up the Elwha



View of Cascade Range, Taken From Mt. Rainier, Looking South Toward Mt. Adams.

Basin on the way to Mt. Olympus. The central portion of the Olympic Range is composed of slates and quartzites possessing an enormous thickness and having a general trend of North 60° West.

1909. Arnold, Ralph. Environment of the Tertiary faunas of the Pacific Coast of the United States.—*Journal of Geology*, volume 17, No. 6, pp. 509-533.

The general relations of the Tertiary on the Pacific Coast are discussed, including that of Washington. He states: "Immediately preceding the Eocene period practically all of Washington, all of Oregon, excepting a small area along the southern border, the Sierra and desert region, and certain portions of the coastal belt of California were dry land." During the Eocene continuous oscillations of the sea floor were taking place, allowing the deposition of alternating deposits of estuarine and marine origin. In the Oligocene, strata "consisting largely of sandy to clayey shales and carrying a characteristic marine fauna are found at many localities throughout Puget Sound region. Wherever their relations are known these beds lie conformably with the Eocene below and lower Miocene above; they therefore mark areas of persistent subsidence."

1909. Arnold, Ralph. Notes on some rocks from the Sawtooth Range of the Olympic Mountains, Washington.—*American Journal of Science*, fourth series, volume 28, pp. 9-14.

Describes some rock specimens collected from the Olympic Mountains west of Lake Cushman. They are quartzites and associated metamorphics of pre-Tertiary age.

1909. Dall, William Healey. The Miocene of Astoria and Coos Bay, Oregon.—*Professional Paper No. 59, U. S. Geological Survey*.

This paper is primarily a description of the Tertiary fauna from Coos Bay and Astoria. A number of new species from the Tertiary of Washington are described. The discussion of the geological conditions at Astoria is of especial interest as the fossils are closely related to similar forms in Washington. He states:

"No proper Eocene is exposed at Astoria, but the rocks may occur below the water level. The *Aturia* bed, of Oligocene age, in which *Aturia angustata*, *Mioleiona indurata*, *Marcia oregonensis*, *Trophosycon oregonensis*, and *Scapharca devincta* appear to be characteristic species, as already explained, is no longer accessible, its outcrop having been close to the water's edge under the most elevated part of the high bluff behind the town, which is strung along on a narrow talus or built out on piles over the river, there being hardly any level land between the bluffs and the water. At Smith's Point, west of the town, the shales are very low, the vertical face not exceeding 15 feet. They dip about 16° in a southeasterly direction and are composed of thin layers of chiefly bluish-gray shale with numerous fractures lined with peroxide of iron which develop more numerous as the surface dries, while the iron causes the face to weather into a brownish color. Most of the layers contain a little sand, but some do not show any. The fluctuations seem to succeed each other with a certain regularity.

"Here and there a little gravel is mixed in one of the layers and in these gravelly layers are also small fragments of bivalve shells, the most perfect and numerous being valves of *Pecten (Pseudamusium) peckhami* Gabb, *Acila conradi* Meek, and fragments of a species of *Terebratalia*.

"At some places in the upper layers of the shale the clayey parts form along a bedding plane lines of concretions, partly fossiliferous and containing most commonly specimens of *Macomma calcarea* in a bad state of preservation.

"Above the shales at this point is a bed 8 to 20 feet in thickness of a yellowish clayey sand with irregular, mostly rounded fragments of a harder sandstone, maculated with peroxide of iron, with a few traces of marine fossils, and more or less gravel not regularly bedded and penetrating into fissures in the shaly rock below, in the form of dikes. The beach in this vicinity is composed of the pebbles, nodules, and small boulders of the hard sandstone washed out of this layer mixed with a few fragments of volcanic tufa.

"Near Tongue Point, at the other end of the town, two miles away, the same beds were recognized, but the gravelly layer seemed thicker and the shale much broken up. The same beds appear to compose the bluffs between Tongue and Smith's points, though owing to the way the town is built they are difficult of access. These bluffs at their highest point, near the high-school

building, rise perhaps 150 feet. Here a fine section shows 30 to 40 feet of the shales exposed at an angle of 40° to 60° , dipping about 26° S. E., though the dip is not invariable. The yellowish sandstone gravel overlies the shales of an equal thickness and descends into them in dikes here and there. The upper margin of the shales is in places indistinguishable, the clayey and sandy layers merging into each other and being similar in color.

"It is notable that in the upper part of the shales some of the shells seem to have been fossilized in sandstone, washed out and reembedded in the clays. Between the valves or on one side of a single valve of a bivalve shell, there will be a remnant of soft coarse sandstone, while the fossil is otherwise embedded in a dark waxy clay shale.

"These sandstones and shales have much similarity to Miocene deposits occurring in various localities along the coast from California to Alaska and part of the fossils are of identical species.

"The *Aturia* bed and the superincumbent Astoria group occur on the north bank of the Columbia in a good many places, apparently more elevated than on the Oregon side.

"From a preliminary examination of Miocene beds examined by Ralph Arnold under my instructions at Clallam Bay, Washington, it would seem that the species agree more generally with those of Astoria; but the difficulty of correlating in the present state of our knowledge is indicated by the fact that no trace of Sooke Miocene fauna, profusely developed on the Vancouver Island shore of Juna de Fuca Strait has yet been found after careful search on the opposite coast of Washington."

1909. Darton, Nelson Horatio. Structural materials in parts of Oregon and Washington.—United States Geological Survey, Bulletin No. 387.

In this report brief descriptions are given of those rocks which are of importance as structural materials. In the vicinity of Portland the areal distribution of basalts are shown upon a topographic map. No age is assigned to them. They may possibly be Eocene.

1909. Reagan, Albert B. Some notes on the Olympic Peninsula, Washington.—Kansas Academy of Science, Transactions, volume 22, pp. 131-238.

This paper records the results of some geologic studies along the shore of the Strait of Juan de Fuca in Clallam County and

in the valleys of the Bogachiel and Soleduck rivers. Collections of fossils were made at numerous points and from these several new species are described. The principal formations involved are the Oligocene-Miocene and some Pliocene strata outcropping near the mouth of the Bogachiel and Soleduck rivers. Many of the molluscan species in the Miocene are characteristic of strata of the same age in many parts of western Washington.

1910. Bretz, J. Harlan. Glacial lakes of Puget Sound.—*Journal of Geology*, volume 18, No. 5, pp. 448-458.

This paper deals exclusively with certain phases of the glacial history of the Puget Sound region. Pre-Pleistocene deposits are not discussed. During the Glacial epoch the ice field is said to have filled the Puget Sound region. As it retreated it left ponded water in front forming a large glacial lake, which was not drained off until the front of the ice sheet had passed north of the junction of Puget Sound and Strait of Juan de Fuca.

1911. Bretz, J. Harlan. Terminal moraine of the Puget Sound glacier.—*Journal of Geology*, volume 19, No. 2, pp. 161-174.

This paper deals entirely with Pleistocene deposits of glacial origin in the Puget Sound basin. Mention is made of bed rock formations resting beneath the glacial deposits.

1911. Smith, E. Eggleston. Coals of the State of Washington.—United States Geological Survey, Bulletin No. 474.

This paper deals chiefly with the analyses of coals from Washington coal fields. However, record is made of stratigraphic and structural data collected at those points where coal samples were taken.

1912. Clapp, Charles H. Southern Vancouver Island.—*Geological Survey of Canada*, Memoir No. 13.

The area reported upon is entirely outside of the state of Washington, but the formations involved are so closely related, both structurally and physiographically, that it should be included.

The pre-Cretaceous complex has apparently had a history in common with that of the Olympics. During the Cretaceous, parts of the region were submerged, allowing deposition of Chico sediments. During the Miocene the southern coast of the island was submerged and the sediments of the Carmanah and Sooke formations deposited. During late Miocene and Pliocene the entire southeastern part of the island is believed to have been reduced to a peneplain. Late in the Pliocene or early in the Pleistocene the peneplain was uplifted and maturely dissected and then later somewhat depressed, forming the present drowned valley topography.

“On the retreat of the earliest and largest glaciers, the land stood some 200 to 400 feet lower than at present, and on the lowlands developed by the pre-Glacial erosion cycle, marine sediments were deposited, while large rivers flowing from the retreating glaciers formed extensive fluviatile and delta deposits. A second period of glaciation is recorded by the till overlying these deposits, but it was far less intense than the first period, and merely eroded portions of the stratified deposits. Soon after, or possibly before the retreat of the later glaciers, an uplift of some 200 to 400 feet took place, uplifting the stratified deposits, which have been submaturely retrograded during the present marine cycle.”

1912. Evans, George Watkin. The coal fields of King County.—Washington Geological Survey, Bulletin No. 3.

In the investigation of the King County coal fields, detailed observations were taken on surface outcrops wherever possible. This information has been platted upon a map. The rocks as exposed in Green River are of Eocene age and have been divided into three groups: the Bayne, Franklin and Kummer.

1912. Weaver, Charles E. Geology and Ore deposits of the Index Mining District, Washington.—Washington Geological Survey, Bulletin No. 7.

The area involved in this report lies in the western foothills of the Cascade Mountains in Snohomish County. The formations are chiefly pre-Tertiary in age and consist of metamorphics intruded by granodiorites. They represent, however, the basement complex upon which the Tertiary of Puget Sound

rests. At Index these old formations occur at elevations ranging from five hundred to five thousand feet above sea level.

1912. Weaver, Charles E. Preliminary report on the Tertiary Palaeontology of western Washington.—Washington Geological Survey, Bulletin No. 15.

A preliminary outline is presented of the areal distribution of the pre-Tertiary and Tertiary formations in the western part of the state. The following subdivisions were made of the Tertiary:

Pleistocene—		
Pliocene—wanting		
Miocene.....	} Upper.....	Montesano formation
		Lower.....
Oligocene.....	Lincoln formation	
Eocene.....	} Upper.....	{ Tejon formation.. } Puget
		{ Cowlitz formation, } Brackish-
	Lower.....	Wanting.
		{ water group

The Cowlitz formation was regarded as provisional with the understanding that it might represent a part of the Tejon. A partial list of the marine fauna was included and eighty-four new species of invertebrates were figured and described.

1913. Arnold, Ralph, and Hannibal, Harold. The marine Tertiary Stratigraphy of the North Pacific Coast of America.—Proceedings of the American Philosophical Society, volume LII, No. 212, pp. 559-605.

This paper presents the ideas of the authors concerning the correlation of the marine Tertiary deposits of Oregon and Washington and gives a list of the fauna found in each division. The following stratigraphic column is submitted for the North Pacific Coast:

<i>Age—</i>	<i>Formation</i>
Pleistocene.....	{ Saanich Vashon Drift
Pliocene.....	{ Admiralty Till Elk River Merced
Miocene.....	{ Empire Monterey (Clallam)

Oligocene.....	{ Astoria..... } { Sooke }	{ Twin River } { Seattle } { San Lorenzo }
Eocene.....		

1913. Bretz, J. Harlan. Glaciation of the Puget Sound Region.—Washington State Geological Survey, Bulletin No. 8.

This paper is confined almost entirely to a discussion of the glacial deposits and history of the Puget Sound region. Concerning the Pliocene he states:

“For this region the Pliocene was primarily a time of diastrophic movement and erosion. The Eocene and Miocene beds were domed and folded, the whole area was lifted higher than at present, and subaerial erosion developed great relief in the weak Tertiary rocks already deposited.”

The following three epochs of Pleistocene glaciation are recorded as “Admiralty (glacial), Puyallup (interglacial) and Vashon (glacial).”

Concerning diastrophism during the Pleistocene, he states:

“The land was high during the Pliocene, presumably higher than at any subsequent time. At the time of the retreat of the Admiralty ice, however, the region was slightly lower than at present; marine organisms in the Admiralty sediments having been found *in situ* a few feet above present high tide. Early in the Puyallup interglacial epoch, the region was probably a thousand feet higher than now. At the maximum of Vashon glaciation outwash gravels were poured westward down the Chehalis as far as the present head of Grays Harbor, where they now lie 35 feet above tide, with stream bedding. From this we may conclude that the land had lowered from its high interglacial portion to one near that of the present.”

As the Vashon began to retreat a lake developed in front to the south. After Vashon retreat opened the Strait of Juan de Fuca the waters of the lake were replaced by marine waters. From the presence of marine shells at elevations as high as 280 feet, it is thought that there was a post-glacial submergence of the Puget Sound region of that amount.

"When the submergence was 120 feet or more in excess of the present, Grays Harbor and Puget Sound were connected by tide water across the site of Lake Russell's discharge-way and the Olympic Mountains constituted an island."

After this submergence the Puget Sound region was re-elevated to approximately its "immediately post-glacial position."

1913. Collier, A. J. Coal Resources of Cowlitz River Valley, Cowlitz and Lewis counties, Washington.—Bulletin No. 531, U. S. Geological Survey, pt. 2, pp. 323-330.

This paper contains results of a brief investigation of coal resources of the southern part of the Cowlitz River valley in Washington. He states:

"Along Cowlitz River northward from its junction with the Columbia lies an area of coal land 30 miles long and 15 miles wide. Probably a large part of this area is not underlain by coal, but beds are exposed at so many places in the field that all of it is considered possible coal land. This field is probably continuous with that about Centralia and Chehalis, although for a few miles south from Chehalis no outcrops of coal have been found. The prevailing rocks are soft sandstones, which lie approximately horizontal and which locally contain beds of coal. Fossils of Eocene age are found in the sandstones. Besides the sedimentary rocks there are a great many bodies of igneous rocks, some of which are known to be of the same age as the sedimentary beds, whereas others are of later intrusion or extrusion. For example, a few miles north of Castle Rock an old lava flow, overlain by the later Eocene sediments, outcrops. Near Kelso there are several masses of rock, which cut through the sedimentary formation in the form of dikes, and on the east side the coal field is limited by later eruptive rocks, presumably of the Miocene series, which forms a large part of the Cascade Mountains farther south.

"The structure of the sedimentary rocks consists of open folds, in which the dips are low. Faults do not appear on the surface, but they have been encountered in some mines, causing abandonment. The structure in this field appears to be decidedly different from that about Chehalis and Centralia. In that field the coal beds dip as high as 70°, whereas in this field the beds nowhere dip more than 25°."



Mount Rainier Looking North From Tatoosh Range.

1913. Landes, Henry. Notes on Glacier coal field.—Pacific Mining Journal, volume 2, No. 4.

This area involved is situated in Whatcom County northeast of Bellingham and northwest of Mt. Baker. Sandstones and shales outcrop and within them seams of anthracite coal are found interbedded.

Throughout the Glacier field the strike of the formations is approximately east and west with some small local variations. The dip of the strata is almost universally to the northward, thus giving to the field as a whole a monoclinical structure. The persistency of the dip northward is something remarkable. Not only is it true between Discovery tunnel and Glacier, but as far north as Church Mountain, which is located about three miles northeast of Glacier, the same northward dip persists. How much farther to the northward of Church mountain the monoclinical structure continues is unknown at the present time. The angle of dip varies greatly throughout the field. On the steep mountain sides the amount of dip seems to be greater than that in the valleys or where the slopes are not so precipitous. It is interesting to note that the slope of the mountain and the dip of the formations are in the same direction. It is very clear that as a result the rocks near the surface have settled forward so that they have a greater apparent angle at the surface than they have at a depth below the limit of surface influence.

1914. Lupton, Charles T. Oil and Gas in the western part of the Olympic Peninsula, Washington.—U. S. Geological Survey, Bulletin 581-B, pp. 23-80.

This paper presents the results of a geological examination of the region on the western side of the Olympic Peninsula and south of the Cape Flattery axis. A record is given of numerous observations taken on the strikes and dips as well as a description of all occurrences of oil and gas.

1914. Washburn, Chester W. Reconnaissance of the Geology and Oil Deposits of Northwestern Oregon.—U. S. Geological Survey. Bulletin 590, pp. 1-111.

In this report a record is made of the occurrences of Tertiary strata in the coast ranges of northwestern Oregon and also along the north shore of Columbia River in Pacific County, Washington. The strata outcropping along the north shore of Columbia River between Megler and Fort Columbia tunnel are described as being of Eocene age on the basis of a partly worn hinge of *Venericardia planicosta*.

1915. Dickerson, R. E. Fauna of the Type Tejon: Its Relation to the Cowlitz Phase of the Tejon Group of Washington.—Proceedings of the California Academy of Sciences, Fourth Series, volume 5, No. 3, pp. 33-98, plates 1-11.

A list is given of fossils collected one and one-half miles east of the town of Vader, Lewis County, Washington, in the shales outcropping in the banks of Cowlitz River. This fauna is regarded as representing the same faunal facies of the fauna of the type Tejon of California, *i. e.*, the Rimella simplex Zone.

1915. Clark, Bruce L. The Occurrence of Oligocene in the Contra Costa Hills of Middle California.—University of California, Publ. Bull. Geol., volume 9, pp. 1, 16-21.

Studies made in the Coast Ranges of California show the *Agasoma gravidum* zone to be unconformable beneath the *Arca montereyana* zone. This unconformity is believed to be of wide extent. The faunal break between the Oligocene and Miocene in Oregon and Washington appears to be as great as in California.

1915. Weaver, C. E. The Possible Occurrence of Oil and Gas Fields in Washington.—Transactions American Institute of Mining Engineers, Bulletin No. 103, pp. 1419-1427.

A short description is given of the formations in the western part of the state and the structural conditions in their relation to the possible occurrence of oil and gas.

1916. Weaver, C. E. Tertiary Faunal Horizons of Western Washington.—University of Washington, Publ. Geol., volume 1, No. 1, pp. 1-67, plates 1-5.

The report describes several new species of Tertiary Mollusca from western Washington. A list is given of the species known to occur in the Eocene, Oligocene, and Miocene formations of Washington. The Tertiary deposits of the western part of the state are divided into five divisions on a faunal basis. The Eocene is represented by the Tejon as known in California. The Oligocene is divided into three faunal zones. The lower Miocene corresponds to the Arca montereyana zone and the upper may be the equivalent of the Empire formation of Oregon.

CHAPTER I. TOPOGRAPHY AND DRAINAGE.

GENERAL STATEMENT.

The western half of the North American continent, embracing the entire area west of the Rocky Mountain divide as far as the Pacific Ocean, is commonly recognized as divisible into five distinct provinces, all of which have a general elongation parallel to the western margin of the continent. From east to west these provinces are generally referred to as the Rocky Mountain system; the elevated plateaus of the interior; the Sierra Nevada and Cascade ranges; the structural downfold involving the great valleys of California, the Willamette Valley of Oregon, the lower Cowlitz Valley and the Puget Sound Basin of Washington; and the Coast Ranges of California, Oregon and Washington.

With the exception of the Rocky Mountain province these extend north and south across the state of Washington. The topographic features within the state may be grouped into seven divisions: Cascade Mountains, Okanogan Highlands, Columbia Plateau, Blue Mountains, Puget Sound Basin, including the lower Cowlitz Valley, Olympic Mountains and the Coast Ranges of southwestern Washington.

The Cascade Mountains extend from the Oregon line almost due north to the Canadian boundary. The northern portion is approximately 100 miles in width. To the south the range gradually narrows and in the central part has a width of only 75 miles. The crest line from north to south is somewhat sinuous in outline due to the differential resistance to erosion and difference in erosional power of streams heading on the eastern and western slopes. The general surface of the Cascades when viewed from any of the higher peaks gives the impression of a deeply dissected, slightly undulating plain. The summits of the ridges seem to constitute the remnants of a former peneplain the surface of which averages 6,000 feet above sea level.

Located upon this strongly dissected plateau surface are five high volcanic cones, the remnants of former active volcanoes. Mt. Baker in Whatcom County, attaining an elevation of 10,750 feet, is situated forty miles west of the main divide of the Cascades. About 70 miles to the southeast of Baker, in eastern Snohomish County, is Glacier Peak, having an elevation of 10,436 feet, and situated ten miles west of the summit of the range. A little distance south of the middle of the Cascades, in southeastern Pierce County is Mt. Rainier, the highest peak within the state, attaining an elevation of 14,408 feet. It is situated twelve miles west of the summit of the range. Mt. Adams, 12,307 feet high, is located 35 miles north of Columbia River on the main divide of the Cascades. Thirty miles due west of Mt. Adams is Mt. St. Helens, with an elevation of 9,750 feet. The slopes of the cones are the gathering grounds of permanent snow fields or glaciers, feeding the streams issuing from their base, so that they have as a rule been partly dissected by erosion. The topography of the northern portion of the range is much more rugged than the southern part. The western slope of the Cascades is a maturely dissected mass of strong relief modified by glacial erosion. At the heads of the valleys on both sides of the summit are glacial amphitheatres or cirques many of which contain small alpine glaciers or rock-rimmed lakes.

The Okanogan Highlands are situated in the northeastern portion of the state and extend from the northern Cascades easterly to Idaho. They terminate abruptly on the south along Columbia and Spokane rivers and extend on the north across the international line into the great interior plateaus of British Columbia. These mountains are much less rugged than the Cascades and rise only to elevations of 6,000 feet or less.

The Columbia Plateau lies east of Columbia River and south of the Okanogan Highlands. It consists of several plains grading into one another which range in elevation from 500 to 2,000 feet. It is crossed by numerous anticlinal ridges and its surface is scarred by several abandoned stream channels.

The Olympic Mountains occupy the northwestern portion of the state and when viewed from an elevation suggest an uplifted and deeply dissected peneplain at an average elevation of 5,000 feet. The surface of this plain appears as an axial up-warp with a low angle slope to the southwest and northeast. Rising above the surface are numerous residual monadnocks such as Mt. Olympus, Mt. Angeles, Mt. Eleanor, Mt. Constance, The Brothers and Mt. Church. These mountains attain elevations up to 8,250 feet. Volcanic peaks are absent from the range. The main divide of the range trends from Hood Canal in the area between Duckabush and Skokomish rivers northwesterly to Cape Flattery. The main stream valleys bear away from the axis of the range to the northeast and southwest. The sides of the valleys are bold and rugged and near their heads are small alpine glaciers and snow fields. Bordering the Olympic Mountains on the north and west is a low coastal plain averaging 600 feet in elevation and deeply covered with deposits of glacial drift, river gravels and sand. This low plain is also dissected by the streams flowing across it. The eastern slope of the mountains descend abruptly to Hood Canal while the southern side gradually merges into the low lying hills of southwestern Washington.

The Coast Ranges of southwestern Washington lie between Columbia River on the south and the Chehalis Valley on the north. They extend from the Puget Sound Basin-lower Cowlitz Valley depression westerly to the Ocean. They are composed of low-lying heavily timbered hills attaining a maximum elevation of 3,000 feet. The average elevation is approximately 500 feet. The area involved is about 5,500 square miles. The western part of this area is marked by two irregular shaped embayments namely, Grays Harbor and Willapa Harbor. One prominent range of hills with several lateral spurs extends across this area diagonally from northwestern Cowlitz County, through southwestern Lewis County, and terminates at Willapa Harbor. A second less important one trends from Chehalis northwesterly to Grays Harbor, with lateral spurs.

In the northeastern portion of this province, in Thurston and southeastern Grays Harbor counties, there is a dome shaped group of hills, composed almost entirely of andesitic lavas, known as the Black Hills. They attain an elevation of 2,000 feet and structurally constitute a spur trending southeasterly from the Olympic Mountains. From the standpoint of origin it connects with the spur of the Cascades between Nisqually and Cowlitz rivers.

The Puget Sound Basin lies between the Olympic and Cascade mountains. It is limited on the north by the San Juan Archipelago and on the south by the low divide between Chehalis River and Puget Sound. The larger part of this basin is an undulating gravel surfaced plain, having an average elevation of approximately 500 feet. This plain is dissected by deep and partially submerged valleys elongated in a north and south direction. The eastern side of the basin rises gradually and merges into the western foothills of the Cascades while the western border terminates abruptly against the Olympic Mountains. The southern continuation of this province is to be found in the lower Cowlitz Valley.

Immediately north of the Puget Sound Basin there is a group of islands which constitutes part of an extensively eroded, glaciated and partially submerged mountain range connecting a spur of the Cascades with Vancouver Island. These islands are known as the San Juan Archipelago. This group, consisting of several large and many small islands, is about 50 miles in length and 25 miles in width. The islands are separated by winding marine channels of varying depth. The largest islands of the group are San Juan, Orcas and Lopez. Mt. Constitution with an elevation of 2,400 feet is the highest peak within the group.

The entire drainage of Washington is ultimately into the Pacific Ocean. The coastal margin is drained directly to the ocean but other portions of the state are drained first to several trunk channels and through these to the ocean. Three large drainage areas are recognized within the state west of the sum-



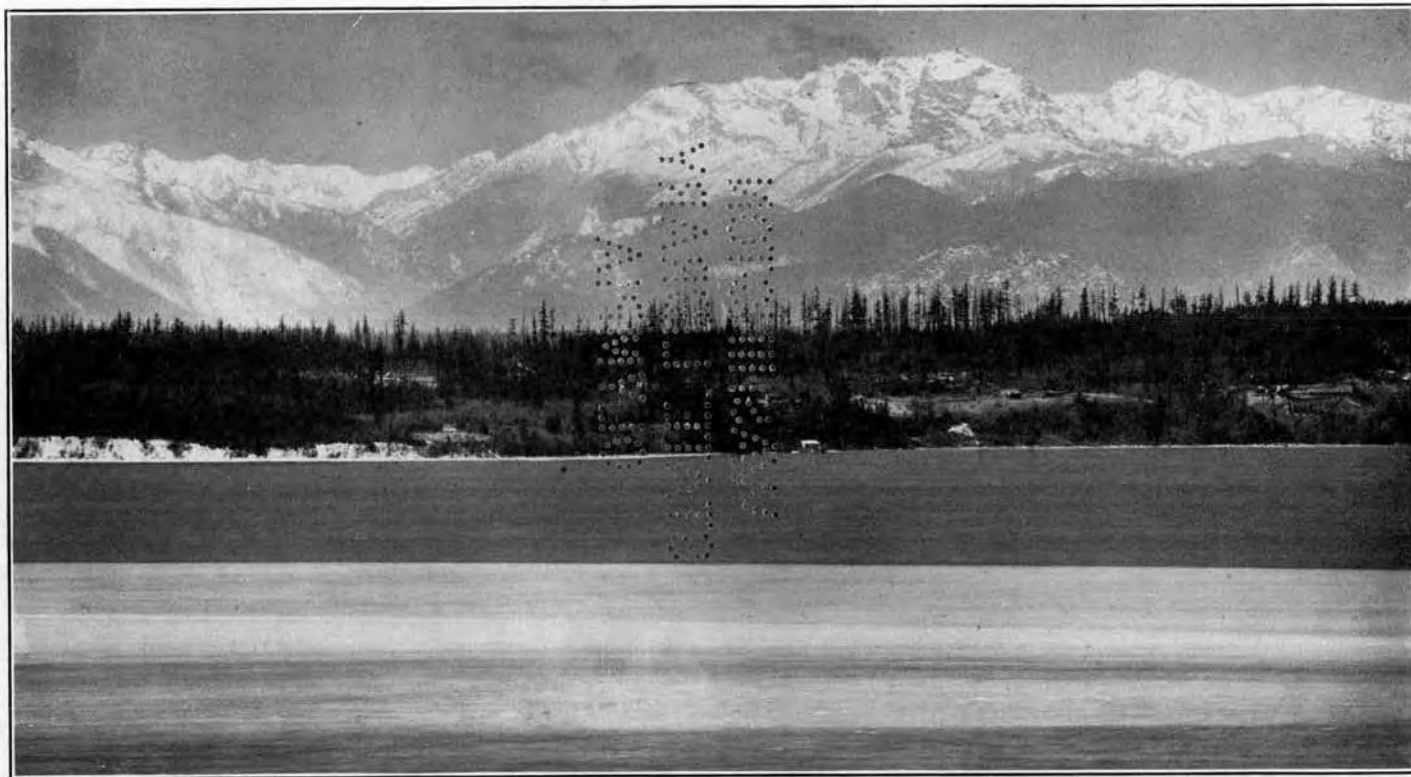
Tatoosh Range in the Cascade Mountains Showing Characteristic Topography of the Western Slope.

mit of the Cascade Mountains: Puget Sound, Columbia River and the Pacific Ocean. The largest of these is the Puget Sound area, which includes Hood Canal, Admiralty Inlet, Haro Strait, Rosario Strait and the larger part of the Strait of Juan de Fuca. These embayments receive the entire drainage from the western slope of the Cascade Mountains north of Cowlitz River including that of the Skagit, Stillaguamish, Skykomish, Snoqualmie, Cedar, Green, White and Nisqually rivers, together with numerous smaller ones. It also receives the drainage from the east and north slopes of the Olympic Peninsula. The more important streams involved are the Skokomish, Hamahama, Duckabush, Docewallips, Quilecene, Dungeness and Elwha rivers.

Nearly all of eastern Washington as well as the western slope of the Cascade Mountains south of Cowlitz River is a part of the Columbia River drainage. The more important streams within this area draining the western slope of the Cascade Mountains include the Cowlitz, Toutle, Kalama, and Lewis rivers. In addition there are several small streams in western Cowlitz and Wahkiakum counties which drain directly into the lower Columbia River.

The western border of the state from Cape Flattery southward to the mouth of Columbia River is drained through numerous small streams directly to the ocean. The more important of these streams on the Olympic Peninsula are the Soleduck, Hoh, Queets, and Queniult rivers. To the South, Grays Harbor receives the drainage from Chehalis River and all its numerous tributaries including Hoquaim, Wishkah, Wynoochee, Satsop, Skookumchuck and Newaukum rivers. Willapa Harbor and Shoalwater Bay receive the drainage from the low coastal hills of southwestern Washington. The more important of these streams are North, Nasel and Bear rivers.

The rainfall in the western portion of the state is exceedingly heavy and the amount of water carried to the ocean correspondingly great. Many of these streams have their sources in the high mountainous areas where they are fed by small glaciers or lakes which mark the sites of past glaciers. The upper por-



Olympic Range as Viewed From Seattle, Showing Low Glacial Plain of Puget Sound in the Foreground and Mt. Constance in Background.

tions of their courses are characterized by numerous small lateral streams many of which cascade down steep slopes to the main streams. In their middle stretches they have reduced their valleys to a grade with well defined floodplains in which the channels shift their position from year to year. In many instances their lower courses become sluggish and meander, resulting in the development of alluvial plains and deltas.

Numerous small lakes exist in various parts of western Washington. The majority of these owe their origin to some phase of glaciation. In the Puget Sound Basin and along the north coast of the Olympic Peninsula the majority of the lakes are associated with moraines formed during the occupation of the region by ice. Among the more important of these are lakes Washington, Sammamish, Whatcom and Crescent together with numerous smaller lakes including those on the gravel prairies south of Tacoma.

In the higher mountainous areas at the heads of the small tributaries there are commonly small rock rimmed lakes which occupy cirques or the basins of glacial amphitheatres. They usually lie in short hanging valleys and the streams issuing from them cascade to the main streams below.

On the western side of the Olympic Peninsula there are two medium sized lakes, namely: Queniult and Ozette. Lake Queniult is about five miles long and three miles wide and lies in the valley of Queniult River. Above the lake the river descends rapidly from the heart of the Olympics, while below it meanders with a fall of about 300 feet through a distance of thirty-five miles to the ocean. The lake appears to have been formed by a local damming of the river.

Lake Ozette, situated in western Clallam County on the western side of the Olympic Peninsula, is approximately eight miles long and three miles wide. It has an elevation of 50 feet above sea level and is drained directly to the ocean through Ozette River. It is situated on the gravel covered plain bordering the western side of the Olympic Mountains and owes its origin, in part at least, to glacial action.

CHAPTER II. PRE-TERTIARY FORMATIONS.

GENERAL STATEMENT.

A large portion of the formations exposed at the surface in Western Washington is of Pleistocene age and consists of deposits of either glacial or fluvial origin. Where the pre-Pleistocene formations are not covered, they are often so badly disintegrated and weathered that their extent, character, and structure cannot be determined. These formations may be grouped under two broad divisions. The older consists of deposits of Palaeozoic or Mesozoic age while the younger belong to the Tertiary. In this report, their description will be considered under the two broad divisions just mentioned.

It is not the object of this paper to deal very extensively with the pre-Tertiary formations. In the course of field investigations a considerable amount of detailed information concerning their extent, character, and structural relations was obtained. Inasmuch as these older rocks form the basement upon which the younger formations rest and to a certain extent have influenced their mode of accumulation, it seems best to outline a few of their more essential characteristics. An old series of sediments and volcanic materials, which have been more or less metamorphosed, occur in the Olympic and Cascade mountains and also in the San Juan Islands. These range over several periods in age, but for general purposes of description are grouped together under the broad term OLD METAMORPHIC SERIES. Intrusive into these are plutonic rocks, largely of intermediate chemical composition. They are described as the INDEX GRANODIORITES. On the western side of the Olympic Mountains there is an extensive series of sandstones, shales and conglomerates which are sometimes partially metamorphosed. The term HOH FORMATION has been applied to these deposits. On the north side of the San Juan Islands and in northern Whatcom County, the upper Cretaceous or Chico formation is present.

OLD METAMORPHIC SERIES.

GEOGRAPHIC DISTRIBUTION.

This series of late Palaeozoic and early Mesozoic age which have been more or less metamorphosed undoubtedly underlie nearly all of the younger formations of western Washington. In the southwestern part of the state and in the Puget Sound Basin they are covered over with later Tertiary strata. They do, however, constitute the surface rocks in three distinct geographical areas. The largest of these involves the western slope of the northern Cascades in Whatcom, Skagit, Snohomish, King and Pierce counties. To the west, almost the entire area of the San Juan Islands is composed of these metamorphic rocks. The central core of the Olympic Mountains forms the third area.

WESTERN SLOPE OF NORTHERN CASCADES.

From the summit of the northern Cascades westerly to the gravel covered plains of the Puget Sound Basin are high mountain ridges composed of quartzites, slates, schists and igneous rocks. These have been examined only in limited areas. In the valley of Skagit River north of its junction with the Sauk are exposures of partially metamorphosed sandstones interbedded with chert, breccias and slates. Along with these are lenticular bodies of crystalline limestone. The general trend of the strata is North 70° West, with a dip to the southwest, varying from 45° to vertical. Similar exposures occur northward along Baker River. In the high mountainous region between the Skagit and the north fork of Stillaguamish River and also south of Darrington, similar formations are exposed, but showing more intense metamorphism. Farther south, along the south fork of the Stillaguamish and east of Granite Falls, quartzites with interbedded metamorphosed volcanic rocks and slates are exposed. From this region they constitute a belt extending southeasterly toward Gold Bar and after crossing Skykomish River swing around to the east, past Index Mountain. In the vicinity of the town of Index these metamorphic rocks have been described as the Gunn Peak formation. In this particular region the formation consists of quartzites showing various stages of

metamorphism and interbedded with these are schists, slates, crystalline limestones and cherts together with intercalated metamorphosed lava flows.

The quartzites as a rule form units of considerable thickness. They vary in color ranging from a pure white to a dark gray. Occasionally they exhibit well defined banding but more commonly are massive. In the near vicinity of large masses of granite or diorite they show the effects of intrusive action and are sometimes twisted and gnarled in such a way that the structure is difficult to determine. In some localities they have been extensively fractured and the intersecting cracks or openings are filled with quartz in the nature of small gash veins.

Because of the great disturbances which these rocks have undergone, it is difficult to estimate their original thickness. In the area east of Index a detailed examination was made of these rocks and a minimum thickness of at least 10,000 feet was established. Three fourths of this amount is composed of quartzite and the remainder is made up of slates and schists.

In King County excellent exposures of the quartzites and schists may be seen in the valleys of the North, South and Middle forks of Snoqualmie River. These rocks have been extensively invaded by granodiorite magmas and the metamorphic rocks occur largely in the form of residuals. In many places the original shaly phases have been converted into mica schists. Both the quartzites and schists extend northeasterly into the Skykomish Quadrangle and may possibly connect with the southern extension of the Gunn Peak formation.

In western Snohomish County mica schists and quartzites extend from the Cascade Mountains and suddenly disappear beneath the alluvium of Skagit River flats. Kultus Mountain, as well as the small rock hills projecting up through the alluvium, is composed of these rock types. Westerly they become more prominent again and constitute the bulk of Fidalgo Island as well as the major portion of the San Juan Island group. They continue on westerly from the San Juan Islands into the central core of Vancouver Island.

OLYMPIC MOUNTAINS.

Quartzites and slates occur in the central part of the Olympic Mountains. Outcrops of these rocks may be seen along the canyon of Elwha River as well as along the main crest of the range leading up to Mount Olympus. Similar exposures occur at the headwaters of the Queets, Queniult and Hoh rivers. These formations may be the equivalent of those occurring in the northern Cascades or possibly younger than these. Future detailed studies will be required to determine these points.

INDEX GRANODIORITE.

AREAL DISTRIBUTION.

The Index granodiorite outcrops typically near the town of Index in Snohomish County about thirty-six miles east of Everett (Plate X). Its continuation may be traced northwesterly where it is exposed at intervals as far as Granite Falls. At the latter place it outcrops in the hills just east of the town as well as to the north in the canyon of Stillaguamish River. It has been intruded into an older series of metamorphic rocks which in the vicinity of Index have been referred to as the Gunn Peak formation. In the vicinity of Granite Falls it is also intrusive into quartzites and slates which are presumably of the same age as the Gunn Peak formation. It is quite probable that the intrusion of these magmas has in part produced metamorphism. Over a large part of the intervening country between Index and Granite Falls erosion has not as yet completely removed the overlying quartzites so as to expose the granodiorite. To the south and southwest of Index the granodiorites are unconformably overlain with a series of volcanic lavas of Tertiary age.

CHARACTER OF OUTCROPS.

The granodiorites are resistant to erosion and form high rugged mountain ridges with great talus slopes fringing their sides. They have been vigorously scoured by glacial action. Cirques and glacial lakes have been produced as a result in the higher elevated portions of the granodiorite outcrops. In the

vicinity of Granite Falls the exposures do not occur very much elevated above sea level. In the San Juan Islands small isolated patches of granodiorite may be seen intrusive into the older metamorphics. These may possibly be contemporaneous with the Index granodiorites.

PETROGRAPHIC DESCRIPTION.

The granodiorite varies much in general appearance in different parts of the country and is locally referred to by the miners as granite. The most typical phase of this rock is well exposed in the Soderberg quarry, about one mile west of Index in Snohomish County on the Great Northern Railway. The entire mass is here seen to be uniform in character in contrast to the mottled appearance which it possesses in many other parts of the district. Specimens collected from different parts of the quarry show a uniformity in texture, mineral composition and color. Megascopically the rock is holocrystalline, medium grained, dense, of a light gray color and breaks in large blocks with a slight tendency to a conchoidal fracture. When carefully examined the hand specimens are seen to be composed of light colored feldspars, hornblende, and varying amounts of biotite and quartz. Occasionally small crystals of apatite may be seen. A more detailed study of the feldspar crystals proves them to be plagioclase with only a very small amount of orthoclase. When examined microscopically these specimens are found to be composed of about 40% plagioclase, 10% orthoclase, 30% hornblende and biotite and 20% of quartz, together with occasional crystals of apatite and titanite.

CORRELATION.

The exact time during which the Index granodiorite was injected into the earth's crust cannot be absolutely determined. If the metamorphic series into which it is intruded is of Carboniferous or Triassic age, which appears most probable, it certainly must have been intruded at some time later than the Triassic. It is overlain unconformably by Tertiary volcanics.

Granodiorites of similar character occur to the southeast in the vicinity of Mt. Stuart and are found to be intrusive into an old series of metamorphic rocks of presumably Carboniferous or Triassic age. It is overlain unconformably by early Eocene sediments locally known as the Swauk formation.

Both in the Index and the Mt. Stuart region the granodiorite is younger than the metamorphic series and older than the Tertiary formations. Thus the only possible time for its intrusion was during the Jurassic or Cretaceous.

HOH FORMATION.

GEOGRAPHIC DISTRIBUTION.

Along the western coast of the Olympic peninsula in Jefferson and Clallam counties there are extensive outcrops of sedimentary rocks possessing certain characteristics differing somewhat from the other sedimentary formations within the state.

To this assemblage of strata the general term Hoh formation is applied. Areally these rocks constitute the surface outcrops over a belt approximately 60 miles in length by 15 miles in width and trending parallel to the coast. The northern limit of this belt lies on the south side of the divide extending from the central portion of the Olympics northwesterly toward Cape Flattery. It crosses the wagon road from Clallam to Forks in the vicinity of Beaver Lake and trends northwesterly in a direction approximately North 50° West and intersects the ocean shore line about two miles south of the Point of the Arches, or ten miles south of Cape Flattery. North of this line no outcrops of this formation have been recognized within the state of Washington, although it is possible that they may be represented on Vancouver Island. From the Point of the Arches southward along the ocean, exposures of the Hoh formation are almost continuously present in the bluffs. In the vicinity of Quillayute River a small local area of the Montesano formation of Upper Miocene age is found resting upon the Hoh formation. With this exception the latter continues predominately southward to a point three miles below the mouth of Queets River. Here another small area of the Montesano formation is found

resting upon the Hoh, or possibly faulted down into it. Southward from Raft River for a distance of three miles the Hoh formation is exposed along the beach and then to the south is again covered with the Miocene formations. At a point about one and one-half miles north of Cape Elizabeth, in the cliff along the ocean, outcrops of the Hoh formation are exposed for a distance of about one thousand feet. Apparently here they have been brought to the surface by faulting. This fault has caused the Hoh strata to appear in the south bank of Queniult River about four miles above its mouth in Section 6, Township 21 North, Range 12 West. South of Queniult River no outcrops are known which may be definitely assigned to the Hoh formation with a possible exception of some sandstones outcropping at the water's edge near the mouth of Copalis River. If they are again found to reappear southward it must be at some point in the coast ranges of Oregon.

The areal extent of the Hoh formation easterly into the Olympic Mountains has not been definitely determined. Examinations have been made of the rock exposures along the Queets, Hoh, and Soleduck rivers for a distance of over twenty miles from the ocean and the only formation encountered was the Hoh. From the close resemblance of certain strata outcropping along the course of Elwha River and the headwaters of the Queets and Queniult rivers in the vicinity of Mt. Olympus, it is possible that the Hoh formation extends into the heart of the Olympic range.

CHARACTER OF OUTCROPS.

The most important topographic feature of the western side of the Olympic peninsula is an uplifted coastal plain ranging from 15 to 20 miles in width and trending from Grays Harbor northwesterly to the Cape Flattery axis. This plain ranges in elevation from 250 to 600 feet above sea level. Easterly it gradually rises and merges into the Olympic Mountains. To the south it becomes a part of the plain bordering Grays Harbor. Its surface is undulating in character and across it trend



Index Mountain Situated on Western Slope of Cascade Range. Skykomish River in Foreground.

several river valleys such as the Queniult, Queets, Hoh and Quillayute. The bed rock or pre-Pleistocene surface of this area consisting almost entirely of the Hoh formation has been unevenly veneered over with sands, clays and gravels of fluvial origin, all of which are resting approximately horizontal.

Over a large part of this coastal plain the Pleistocene gravels and sands constitute the surface outcrops. It is only where the rivers have carved their channels through this covering and down into the underlying bedrock, that the strata of the Hoh formation are exposed. Sometimes these exposures consist of outcrops exposed only a few feet above the water's edge. In other cases they stand as high, bold bluffs and in a number of instances form rocky gorges through which the streams flow. Wherever the bed rock exposures outcrop away from the main stream courses they appear to represent prominent topographical features in the nature of monadnocks as related to the Pleistocene gravels.

Along the ocean shore line excellent exposures of the various strata composing the Hoh formation may be seen almost continuously. Occasionally, however, their upper surface passes down below sea level and the overlying Pleistocene sands and gravels form the ocean bluffs. The cliffs along the ocean, where composed of outcrops of the Hoh formation, range from a few feet to over three hundred feet above sea level and sometimes project out into the ocean as bold headlands so as to be impassable even at the lowest tides. The character of the outcrops are such that excellent exposures of the Hoh formation may be obtained at intervals over a large part of the western portion of the Olympic peninsula. Observations have been recorded in the field wherever possible. These observations have been tied into a continuous tape and compass traverse extended along the ocean shore line and up the more important streams. From these observations it has been possible to determine the lithologic character of the formation and to a certain extent the geologic structure which it now assumes.

LITHOLOGY.

The materials composing the Hoh formation are almost entirely of sedimentary origin although these in places have been subjected to slight metamorphism. If the assumption be correct that the quartzites and slates comprising the central portion of the Olympics also belong to the Hoh formation, the series as a whole may be regarded as having undergone differential metamorphism. The lithologic appearance of all the strata along the western border of the peninsula is typical throughout the entire area and generally can be easily distinguished from strata composing any of the formations in western Washington. They consist chiefly of sandstones, shaly sandstones, sandy shales, shales and conglomerates. The sandstones are commonly medium to coarse grained with a somewhat gritty appearance. They are nearly always firmly consolidated and possess a grayish brown color. Generally small angular fragments of black slate may be seen in them. These sandstone layers are often six or seven hundred feet thick and contain occasional lenticular layers of conglomerates. Often these massive sandstone belts, in a very short distance along their strike, rapidly grade over into conglomerates. Another characteristic phase of this formation is a bluish gray, coarse grained, gritty sandstone which when examined carefully is generally found to contain a considerable amount of muscovite, sometimes in sufficient amount to give the sandstone a somewhat banded and scaly appearance. It is generally in this type of sandstones that indications of petroleum are found. This sandstone sometimes becomes more or less shaly and is often interbedded with very narrow bands of dark brown shale. Upon weathering such outcrops are rapidly converted into mud banks so that the original geologic structure cannot be determined. Typical examples of this may be seen between the mouth of Hoh River and Hoh Head as well as at numerous other places northward along the shore line.

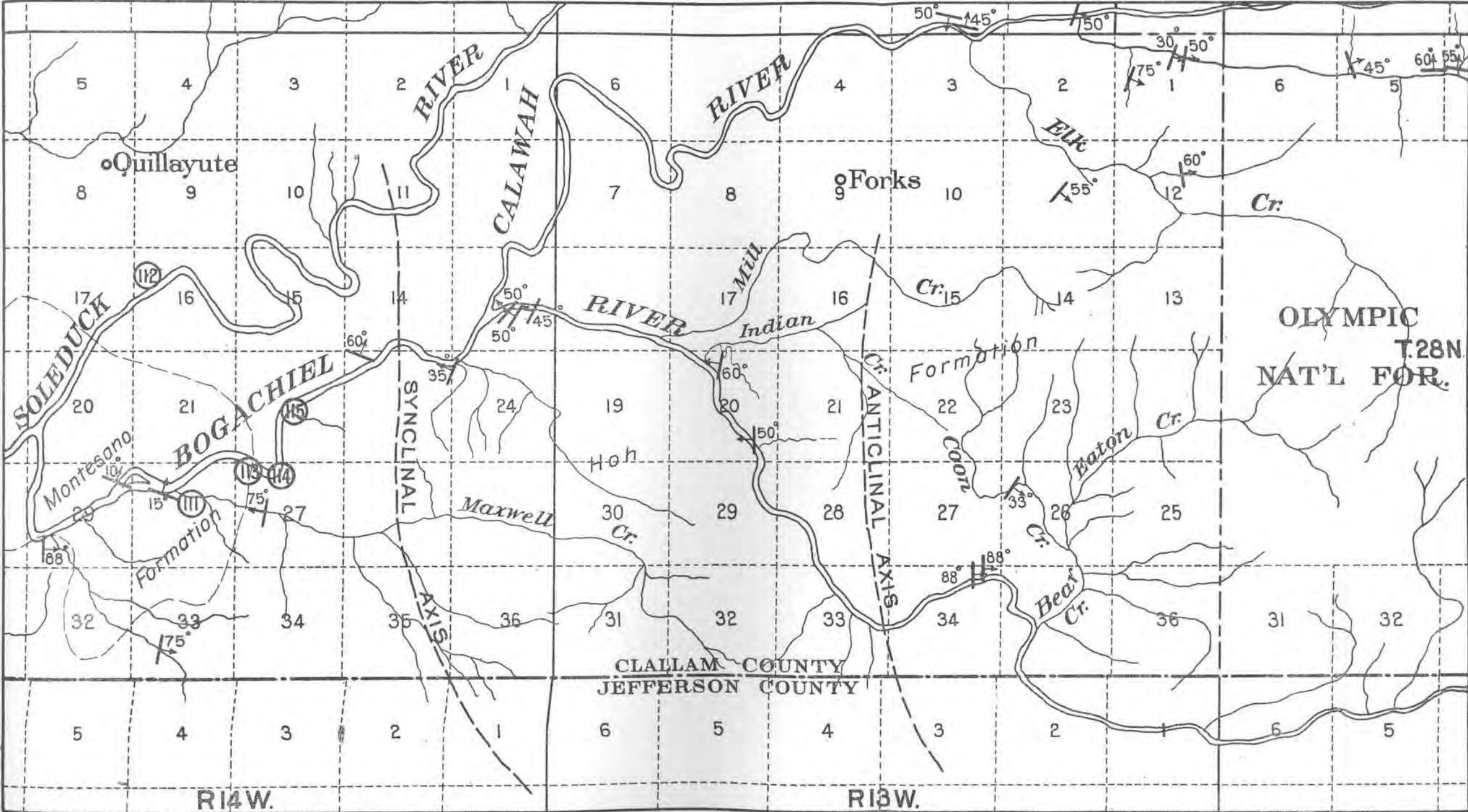
Certain sandstones in the Hoh formation have a laminated appearance so that they may be easily broken into huge slabs

each of which will average four or five inches in thickness. Good examples of this type are illustrated on Salmon River about two miles south of its junction with the Queets.

The shales range from a gray to a chocolate brown. They are sometimes massive but often occur in narrow bands alternating with more sandy material. Sometimes small lenticular masses of hard, flinty limestone are interspersed among the shales. These vary from three feet to fifteen feet in length and weather out in nodular form. As a rule the shales disintegrate much more easily than the sandstones and it is in this phase of the formation that the valleys and gullies have been largely carved. Along the beach the coves are almost invariably developed in the shaly phase of the formation and the higher headlands in the sandstone.

GEOLOGIC STRUCTURE.

During the course of field investigations observations were taken on the strike and dip at as many points as possible. These have been platted upon Map A, Plate IV. The structure has been definitely worked out along the coast but inland sufficient data are not at hand to determine the continuation of the coast structure. In the vicinity of Forks in Clallam County an anticlinal axis trends nearly south, crossing Bogachiel River in Section 33, Township 28 North, Range 13 West. (Plate XI.) This may continue southward as far as Hoh River and if so would cross it in Township 26 North, Range 12 West. More detailed data must be obtained in order to establish this point. A well defined syncline trending nearly north and south crosses Bogachiel River in Section 23, Township 28 North, Range 14 West. This has been traced as far as the Clallam-Jefferson County line, but has not been established farther to the south. Along the coast from Queets River northward to Point of Arches at least eighteen anticlinal and synclinal axes exist. With two or three exceptions these possess a northeast-southwest strike extending diagonally to the coast. In only a few instances have they been traced more than two miles inland. In many cases they have the appearance of minor warps developed on the limb



Geologic and Structural Map of a Portion of Southwestern Clallam County.

of a supposed large sub-marine anticlinal axis lying west of the present coast line. On the south side of Queets River an anticlinal axis crosses Salmon Creek about two miles south of its mouth and trends southwesterly into the Queniult Indian Reservation. A similar axis crosses Queets river about two miles from its mouth. Two miles north of Cape Elizabeth the bluffs composed of low-dipping Miocene sandstones are suddenly replaced by dark chocolate colored shales. While no actual contact between the two may be seen, yet the sharp discordance between the strike and dip give direct evidence of faulting. About one thousand feet north of this fault the shales are replaced by Miocene sandstones. Four miles east of Queniult River, in the southern portion of the big bend, a fault may be detected whose trend is North 45° West. The intervening area is heavily covered with fluviatile deposits so that the underlying bed-rock is entirely concealed. It is probable, however, that a narrow fault block of the Hoh formation has been thrust into the upper Miocene.

Along the coast between the mouth of the Hoh River and Hoh Head excellent exposures of the Hoh formation may be observed. (Plate XII). Hoh Head itself is composed largely of massive brown sandstone. At its western end a small cove has been developed and a synclinal axis trending nearly east and west has folded down a few hundred feet of overlying shale. Because of the non-resistance of the shales to erosion a cove has been formed at this point. Immediately south of Hoh Head and north of the high conglomerate point just north of the mouth of Hoh River a synclinal axis trends North 30° East. Where this axis intersects the coastline a cove has been developed in an extensive series of sandy shales underlying the massive sandstone of Hoh Head. From Hoh Head northward along the coast for a distance of ten miles an anticlinal axis appears to lie just off the shore beneath the waters of the ocean. It passes inland again in Section 1, Township 27 North, Range 15 West and crosses Quillayute River about one-half mile east of Mora. Northward from the mouth of the Quillayute the Hoh forma-

tion is involved in several synclines and anticlines and finally passes beneath the Eocene(?) basaltic formation exposed at Point of Arches. The formation is exposed in places along Dickey River east of Ozette Lake but insufficient data have been obtained to determine its structure. The eastward continuation of this formation has been traced into Township 29 North, Range 12 West, where it is found to be badly broken and shows the effect of greater metamorphism. Whether it extends eastward into the heart of the Olympic Mountains from present evidence cannot be determined.

STRATIGRAPHY.

Wherever possible along the coast, detailed stratigraphic measurements of the strata in the Hoh formation were made. In every case such sections have been tied into traverse surveys. A continuous traverse was run from Moclips to Cape Flattery and the station numbers referred to in the following sections are points upon that traverse. There are insufficient data at present to determine in which particular portion of the Hoh formation each of these sections belongs. Inland from the ocean shore line the exposures are so limited that it is impossible to correlate one with another. Faulting has also complicated the structure.

The following section represents partial measurements from Station No. 133 at a point north of the mouth of Kalaloch River to a point at the mouth of Cedar River:

Top of Section	<i>Feet</i>
Massive brown sandstone.....	110
Massive sandstone	180
Covered	120
Banded sandstone with intercalated shale bands.....	36
Interbedded shale and sandstone, sandstone predominating	22
Covered	400
Massive sandstone	200
Covered—but where exposed mostly shale.....	500
Massive sandstone	60
Massive sandstone	53
Banded sandstone	6
Massive sandstone	28
Banded sandstone	2
Massive sandstone	6
Banded sandstone	5
Massive sandstone	7

Top of Section	<i>Feet</i>
Shale	1
Massive sandstone	7
Covered—probably shale	150
Shale	150
Massive sandstone	100
Banded sandstone	2
Massive sandstone	6
Banded sandstone	9
Massive sandstone	25
Banded sandstone	6
Alternating bands of shale and sandstone.....	24
Shale	36
Chocolate colored shale	50
Massive sandstone	20
Shale—At station No. 170.....	20
Mostly covered—where exposed a massive gray sandstone	400
Covered—where exposed hard conglomerate and meta- morphitic rock—largely determined from stacks located at intervals along the coast. This region may repre- sent the true base of the Hoh formation.	
Base of Section	---
Total	2741

The following section was measured along the coast from Station No. 360 to No. 407. The base of this section is at Station No. 360. The line along which the section was measured is approximately five miles north of the mouth of Quillayute River, in southwestern Clallam County.

Top of Section	<i>Feet</i>
Brown massive sandstone	100
Massive brownish gray sandstone with some conglom- erate	1500
Gray sandstone	200
Interbedded gray sandstone and shale.....	300
Sandy shale	600
Base of section	---
Total	2700

CONDITIONS OF DEPOSITION.

The Hoh formation was laid down either on the coastal margin of the ocean direct or in an extensive embayment of the ocean. The fact that massive conglomerates and coarse-grained gritty sandstones alternate with enormous thicknesses of shale suggest oscillations in the depth of the sea-floor. Occasionally fragments of carbonized wood or small lenticular seams of lignite occur interbedded with gravel or conglomerates. These conglomerates may represent deposits formed along former beaches or even along the lower portions of stream

valleys. A microscopic examination of the shale phases of the formation indicate the presence of marine diatoms and foraminifera. These forms of life may have thrived in the deeper waters. Because of the total absence of marine invertebrate fossils other than those just mentioned and the absence of plant remains, it is impossible to arrive at any conclusion concerning climatic conditions.

FOSSILS.

Although a careful search has been made for fossil Molluscan remains within the Hoh formation, not a single fragment has as yet been found. A portion of a small leaf of undetermined species was collected from the first headland south of Raft River. In the vicinity of Hoh Head brownish colored shales outcrop which upon microscopic examination are found to contain numerous remains of diatoms. Nearly all the shale exposures which show the presence of diatom remains possess the odor of petroleum. Fragments of shale brought up from a depth of seventeen hundred feet in the oil well at Forks contain the remains of numerous foraminifera. These shales also have a pronounced odor of petroleum.

CORRELATION.

The exact age of the Hoh formation is not certain. It is certainly older than the Miocene and apparently older than the Eocene (?) basalts as exposed south of Cape Flattery. It is less metamorphosed than the older Carboniferous and Triassic rocks of the San Juan Islands and northern Cascades. It might possibly be of the same age as those just mentioned but have undergone a lesser degree of metamorphism. As far as known no massive intrusive rocks occur within the Olympics. If they are present they are of minor importance. This fact might account for the difference in degree of metamorphism and still allow them to be of Carboniferous or Triassic age. They do not, however, contain the large limestone masses that are so commonly associated with those older formations in the northern Cascades, San Juan and Vancouver islands. They do not bear any resemblance to the upper Cretaceous rocks as ex-

posed along the northeast coast of Vancouver Island. They are presumably older. It is quite possible that they may be of Jurassic age. These suggestions are based entirely upon lithological evidence which forms a very insecure basis for correlation.

CHICO FORMATION.

GENERAL STATEMENT.

The Cretaceous deposits of the Pacific Coast have been divided into three divisions. These are referred to as the Knoxville or lower Cretaceous, the Horsetown or middle Cretaceous, and the Chico or upper Cretaceous. With the exception of the possible occurrence of the Knoxville in Whatcom County, the Chico formation is the only Cretaceous deposit known within the western half of the state.

Chico strata are known to occur in the Queen Charlotte group, as well as on the northeast side of Vancouver Island.*

GEOGRAPHIC DISTRIBUTION.

In western Washington strata of Cretaceous age are found in the northern portion of the San Juan Islands and in the northern portion of Whatcom County. With the exception of these localities, rocks of Cretaceous age are unknown in western Washington. However, they may possibly exist deeply buried beneath an enormous overburden of Tertiary strata. The upper Cretaceous or Chico strata as exposed in the San Juan Islands are the southeastern extension of a thick series of sedimentary rocks exposed along the northeast coast of Vancouver Island. They disappear to the east in Sucia Island, but may possibly exist beneath the glacial covered plains north of Bellingham.

In the San Juan group, the Chico formation composes all of Sucia Island, Patos Island, the extreme northern part of Orcas Island, all of Waldron Island, Stuart Island and several smaller unnamed islands off the north end of San Juan Island

* Descriptions of new Cretaceous fossils from Vancouver and Sucia islands. Proceedings, Academy of Natural Science, Philadelphia, vol. 13, pp. 313-314. 1861.

proper. To the northwest these outcrops continue to Saturna, Mayne, Pender, and Galiano islands on the British side.

CHARACTER OF OUTCROPS.

The general character of the outcrops has been largely determined from the structure which the strata assume. The harder conglomerates and sandstones constitute the higher hills and mountains while the valleys and sub-marine channels have for the most part been developed in the softer shale members. On Orcas Island the softer Cretaceous rocks form low hills compared with the harder metamorphosed formations just south as represented in Turtle Back Mountain and Mt. Constitution. Suquia Island is nearly divided by an east-west embayment which has been carved into the soft shales leaving the harder rock to form the north and south portions of the island. Waldron Island is more nearly circular and owes its general form to the resistant character of the conglomerates and sandstones which so largely compose it.

LITHOLOGY.

The Chico formation as exposed in the San Juan Island group is composed of massive and bedded shales, and extensive belts of alternating beds of shales and sandstones. The series, as a whole, has not been metamorphosed. The pebbles composing the conglomerates have nearly all been derived from the underlying metamorphic formations. They are composed of quartzites, granite, diorite and gabbro gneisses. The pebbles range in size from that of a marble to boulders over five feet in diameter. Probably from 4 to 6 inches in diameter is the average size. These conglomerate masses resist weathering and constitute the more important topographic features of the formation. Interbedded with these conglomerates are irregular shaped bands of grit and sandstone. Commonly these widen out so as to allow the conglomerate belt to develop into an alternating series of sandstones and conglomerates. Sometimes they grade over into massive sandstones which contain small cross-bedded lenses of conglomerate and then back again into conglomerate proper.

The sandstones are most commonly coarse-grained, of a light brownish gray color and sometimes showing cross-bedding. The shales vary from a light gray to a predominating chocolate brown. They are often distinctly bedded, although sometimes massive. On the north side of Orcas Island they alternate as very narrow bands with sandstone.

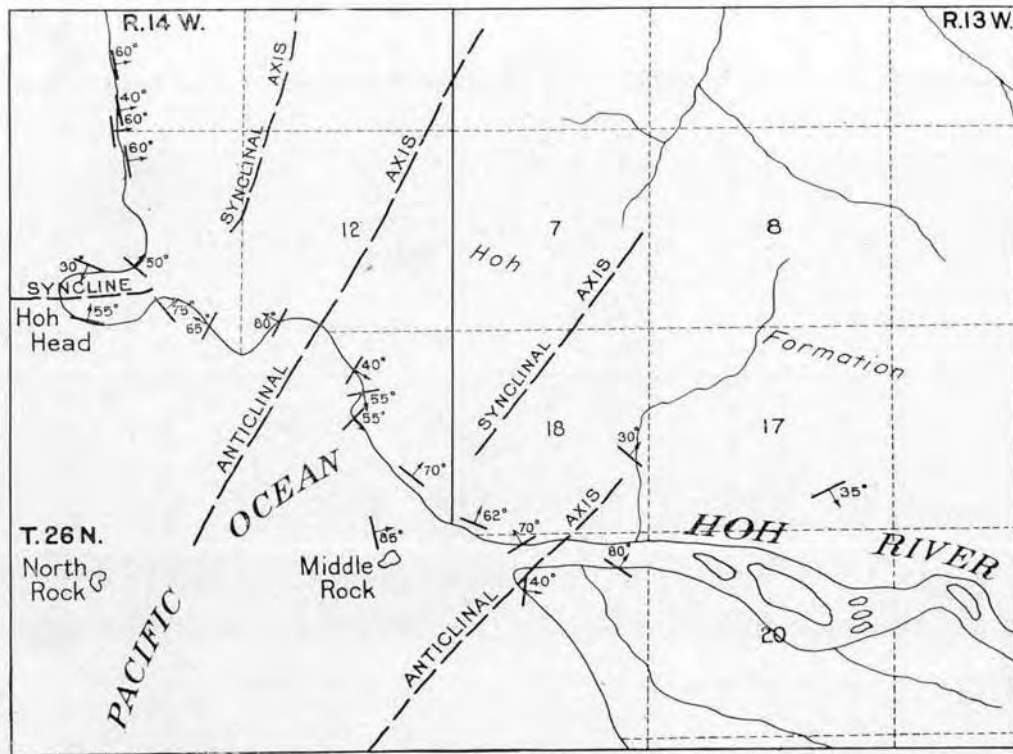
No igneous rocks, either extrusive or intrusive, have been found associated with the Chico formation in the San Juan Island group.

CONDITIONS OF DEPOSITION.

The Chico formation as represented in the northern part of the San Juan Islands in common with that of the east coast of Vancouver Island was deposited in an embayment of the ocean formed between the main axis of Vancouver Island and the British Columbia mainland. This arm appears to have been cut off at the south of the Straits of Rosario by a mountainous mass extending from the present site of the Cascades, through the San Juan Island group into Vancouver Island. The lower portion of the formation appears to have been formed under comparatively shallow water conditions, the middle portion of the formation in deeper water, and the upper portion under shallow water and in part under fluvial conditions. The latter is evidenced by the extensive series of non-fossiliferous interbedded conglomerates and sandstones.

GEOLOGIC STRUCTURE.

The strata involved in the Chico formation in the northern portion of the San Juan group in common with those along the northeast coast of Vancouver Island have been folded into a series of northwest to southeast anticlines and synclines. On the north side of Orcas Island the strata rest unconformably upon the older metamorphic formations and dip at an average angle of 60° to the northeast. On Waldron Island the formation has been folded back so as to form the nose of a syncline.



Geologic and Structural Map of the Region from Hoh Head South ward to the Mouth of Hoh River.

CHAPTER III.

EOCENE FORMATIONS.

GENERAL STATEMENT REGARDING THE TERTIARY AS A WHOLE.

West of the crest line of the Cascade Mountains within the state there are extensive deposits of Tertiary age. These deposits consist of rocks of sedimentary and igneous origin. The sedimentary materials are composed of sandstones, shaly sandstones, shales and conglomerates. The igneous rocks consist of lava flows of varying texture, volcanic tuffs, dikes, sills and intrusive plutonic rocks. The formations of surface origin possess a maximum aggregate thickness of over 35,000 feet not all of which is present in any one particular locality. For the most part they are firmly indurated but have not been metamorphosed. The basement complex upon which they rest is composed of quartzites, slates, schists, gneisses and various types of intrusive rocks all of which have been subjected to more or less deformation and erosion. Formations of Tertiary age are largely absent from the central portion of the Olympic Peninsula, the San Juan Islands and portions of the Cascade Mountains.

The following subdivisions of the Tertiary have been made within the western portion of the state upon a basis of the information obtained in this investigation:

QUATERNARY.....	}	Diastrophism, volcanism, glaciation and erosion. Development of the present Cascade Range.
PLIOCENE.....	}	Largely a record of diastrophism and erosion. Igneous activity in eastern Washington. The upper portion of the Montesano formation may in part belong here.
MIOCENE.....	{	Upper Miocene. Montesano formation containing Yoldia strigata Zone. Unconformity— Lower Miocene. Wabkiakum Horizon containing Arca montereyana Zone.
OLIGOCENE.....	{	BLAKELEY HORIZON. Characterized by <i>Acila gettysburgensis</i> Zone. PORTER HORIZON. Characterized by <i>Turritella portersensis</i> Zone. LINCOLN HORIZON. Characterized by <i>Molopophorus lincolnsensis</i> Zone.
EOCENE.....	}	Upper Eocene Tejon formation. Igneous, estuarine marine and lacustrine phases. Lower Eocene Martinez formation. Wanting. Basement complex of Palaeozoic and Mesozoic rocks largely metamorphosed.

Deposits containing a fauna representative of the Martinez epoch or lower Eocene have not as yet been recognized within the state. It is possible, although not certain, that the Swauk formation of eastern Washington may in part be the equivalent of the Martinez. Deposits of marine, estuarine and fresh water origin together with intercalated flows of lava and tuff are well developed and possess a maximum thickness of 15,000 feet. The marine sedimentary phases of these deposits contain a rich marine invertebrate fauna characteristic of the Tejon epoch or upper Eocene of the Pacific Coast. The lacustrine or fresh water phase of the formation is best developed in the central and eastern portion of the Cascade Mountains. The estuarine phase occurs in the western foothills of the Cascades and in the form of small lenses interbedded with the predominating marine phase of southwestern Washington. The volcanic phase, which consists of lavas ranging in composition from basic andesites to acidic basalts, occurs in the form of flows of varying thicknesses intercalated with the marine and estuarine sediments. These lavas range in texture from typical volcanic ash and flow breccias to microcrystalline and glassy types. The materials have in part at least escaped to the surface through fissures and accumulated both on the land surfaces as well as upon the floor of the upper Eocene embayments. Faunal and floral evidences indicate the existence of a tropical to sub-tropical climate during the entire Tejon epoch.

During the Oligocene epoch marine embayments were much more widely extended throughout Washington west of the present site of the Cascades than during the Eocene. The deposits formed in these embayments attained a maximum aggregate thickness of 14,000 feet. They are almost entirely of marine origin and contain abundant and in many cases excellently preserved invertebrate faunas. Three distinct faunal zones can be recognized. The strata identified by each of these zones are referred to as horizons. The oldest Oligocene within the western portion of the state is identified as the Lincoln Horizon and contains the *Molopophorous lincolnensis* Zone. The middle di-

vision is known as the Porter Horizon or *Turritella porterensis* Zone and the upper division as the Blakeley Horizon or *Acila gettysburgensis* Zone. The materials deposited in the Oligocene embayments consist largely of shaly sandstones and sandy shales together with minor amounts of conglomerate, sandstones and shale. Volcanic lava flows are almost entirely absent from the Oligocene formations with the exception of certain areas north of Columbia River in Pacific County. Many of the shales and sandstones are derived from rock of volcanic origin. The principal areas where deposits of Oligocene age now form surface outcrops are along the north border of the Olympic Peninsula, the Puget Sound Basin and southwestern Washington.

During the lower Miocene the marine embayments became much more restricted than during the Oligocene and the deposits formed are now found outcropping in the vicinity of Clallam Bay on the south shore of the Strait of Juan de Fuca, in the Grays Harbor region and on the north side of Columbia River in Wahkiakum County. The maximum thickness in the region of Clallam Bay as well as at Grays Harbor is approximately 4,000 feet. The materials are predominately coarse-grained sandstones, shales and conglomerates. They contain a fairly abundant fauna which is quite distinct from the older Oligocene faunas as well as the younger upper Miocene faunas. One of the most common and characteristic species occurring in this fauna is *Arca montereyana* Osmont. The fauna occurring within these deposits is referred to as the *Arca montereyana* Zone and the strata containing the fauna as the Wahkiakum Horizon. Future studies may determine that this horizon is the equivalent of the Monterey formation of California. Sufficient evidence is not now available to warrant such a direct correlation.

At the close of the lower Miocene the Pacific Coast was subjected to intense deformational movements. A large part of the former sea floor was elevated above sea level. Sediments

formerly deposited were folded and faulted. The newly elevated land areas were attacked by erosional agencies and the newly derived sediments were during the course of upper Miocene time deposited in newly developed embayments. In Washington nearly all of the western portion of the state was elevated during the middle Miocene. During the upper Miocene two small embayments were formed. One of these embayments was situated on the western side of the Olympic Peninsula near the mouth of Quillayute River and the other to the north and east of Grays Harbor. Apparently the land area during the upper Miocene extended much farther to the west than at present. The upper Miocene sediments in western Washington consist of sandstones, conglomerates, and shales of marine, shallow water origin and possess a thickness of 2,000 feet. Marine invertebrate faunas are abundant and are closely related to the Empire fauna of Oregon and the San Pablo of California. Sufficient evidence is not as yet available to warrant making correlation of the upper Miocene of Washington with the Empire or San Pablo formations. The upper Miocene fauna of Washington is referred to as the *Yoldia strigata* Zone from the presence of this most characteristic species. The strata containing this fauna are termed the Montesano Horizon. Montesano formation might appropriately be used.

Along the western slopes of the Cascade Mountains there are extensive deposits of andesitic lavas and interbedded tuffs and clays. The older Eocene deposits pass beneath these lavas along the western margin of the foothills of the Cascades. Exposures are well defined from Enumclaw to Cedar Lake in King County and the name Enumclaw volcanic series is provisionally applied to them. They are at least two thousand feet in thickness in the region studied. They may be the western extension of the Keechelus Volcanic Series which have been mapped in the Snoqualmie Folio by George Otis Smith and F. C. Calkins.*

* Smith, G. O., and Calkins, F. C. Snoqualmie Quadrangle, U. S. Geol. Surv. Folio 139, 1906.

In eastern King County, north of Cedar Lake, there are exposures of granodiorites which are intrusive into a series of old metamorphic quartzites, slates and schists. These intrusive rocks may be traced easterly to the summit of the Cascade Mountains where they have been mapped in the Snoqualmie quadrangle as the Snoqualmie Granodiorite and are regarded as being of Pliocene age. In the vicinity of Cedar Lake they are also covered with the Enumclaw andesites.

No marine deposits of Pliocene age have as yet been recognized within the state of Washington. It is possible that they may exist and be buried beneath a mantle of glacial drift. It is more probable that they were never formed and that the western part of the state as well as the eastern was a land area. The geological record of the Pliocene in western Washington with the exception of the Cascade Mountains must be sought in terms of diastrophism and erosion.

Early in the Quaternary or possibly in late Pliocene time the western coast of North America was again subjected to deformational movements which caused for a second time the uplift of the Sierra Nevadas and Cascades. The present Cascade Mountains of Washington were developed by a series of differential uplifts. The original peneplained surface of the present site of the Cascades was warped during the uplift and the broad features of the drainage adjusted themselves to the structure. Volcanic energies became concentrated at certain points beneath the surface of the uplifted peneplain and upon it as a base prominent volcanic cones were developed.

GENERAL STATEMENT OF THE EOCENE.

No record is available of the geologic history of western Washington during the early Eocene epoch. The region was presumably a land area not much elevated above sea level. The geological history of Washington during the upper Eocene can be partially interpreted from a fairly complete record as exhibited in the surface rock exposures. Marine, estuarine and brackish water faunas are abundant as well as land floras. An examination of the marine invertebrate species occurring within

these faunas indicates a very close relationship to the upper Eocene of California, in fact so close as to warrant a direct correlation with the Tejon. The basement upon which the upper Eocene sediments were deposited is in most localities concealed. In Skagit, Whatcom and Snohomish counties estuarine deposits are resting directly upon schists and slates of Palaeozoic or Mesozoic age. In the central and eastern portions of the Cascade Mountains lacustrine deposits of Eocene age are resting upon extensively eroded peridotites and granodiorites as well as slates and quartzites of Mesozoic age. In the southwestern portion of the state as well as in the Puget Sound Basin the basal contact relations cannot be determined as they are nowhere exposed at the surface. During the upper Eocene the Cascades as a range did not exist. The central and southern portions of the range within the state were presumably not greatly elevated above sea level while the northern portion may have possessed some relief. The regions now involved within the San Juan Islands as well as the central portion of the Olympic Mountains were apparently land areas which had been uplifted at the close of the Jurassic. Differential oscillations of the land areas as well as the sea floor were taking place during the upper Eocene or Tejon epoch. Coincident with these movements the embayments of the ocean were shifting both in area and depth. There was a consequent change in the environmental conditions under which the marine invertebrate fauna was existing. A record of these conditions is in part preserved in the character and distribution of the fossil faunas as well as the lithologic character of the sediments in which the faunas were buried. On the present site of the Cascade Mountains fresh water lakes of considerable size were in existence. These basins were continuously changing in size and may at times have had direct or indirect connections with the estuaries to the west in central King, Pierce and Lewis counties.

GEOGRAPHICAL DISTRIBUTION.

Surface outcrops of upper Eocene age occur in the western foothills of the Cascades, in the Puget Sound Basin, on the

north flanks of the Olympic Mountains, on the southeastern portion of Vancouver Island, in the lower Cowlitz Valley and in the hills of southwestern Washington. Over considerable portions of these areas they are more or less obscured by later lavas or tuffs or by deposits of glacial drift. As a result the surface exposures of the Eocene formations appear in the form of isolated outcrops. In some cases it is possible to determine definitely that the intervening covered areas are underlain with strata of Eocene age. In other instances their presence is only conjectural. On the maps accompanying this report an effort has been made to represent the distribution of the preglacial formations. Those areas where the surface exposures are of Pleistocene age but where there is some evidence to indicate that the underlying bedrock formations are Eocene have been mapped as Eocene. Where the contacts between Eocene and other bedrock formations are covered the probable approximate position of the contact lines have been inserted upon the maps. These facts should be borne in mind whenever detailed use is made of the maps.

The surface distribution of the marine, estuarine and basaltic phases of the Eocene are also designated upon the maps. Usually they are interbedded with one another but one phase predominates over the other. In every case the predominating phase has been mapped.

Along the north side of the Olympic Peninsula, Eocene basalts together with interbedded tuffs and shales trend from Port Discovery Bay westerly to the Point of the Arches south of Cape Flattery. Between Port Angeles and Port Crescent a tongue like mass extends northerly to the Strait of Juan de Fuca. This belt of lava rests upon the older Mesozoic sedimentaries of the Olympic mountains and in turn forms the basement for the overlying marine Oligocene deposits.

The basalts just described extend southerly around the east and south flanks of the Olympic mountains and are also exposed in the Bald Hills of central Kitsap County in the Puget Sound Basin. If all the overlying deposits of glacial drift were re-

moved exposures of basalt would presumably occupy the entire southern portion of the Puget Sound Basin from the Olympic mountains to the western margin of the Cascades. Outcrops of basaltic lava and interbedded sandstones and shales occur in the hills south and southeast of Seattle in King and Pierce counties. Similar deposits are present in Thurston, Lewis and Cowlitz counties. In Pacific, Wahkiakum and Grays Harbor counties extensive exposures occur intimately associated with younger marine deposits of Oligocene, lower Miocene and upper Miocene age.

In the foothills of the Cascades in western Skagit and Whatcom counties there are small local deposits of sandstones and shales of probable lacustrine origin formed contemporaneously with the estuarine and marine deposits farther south.

The southeastern portion of Vancouver Island from Albert Head westerly to Sambrio River is composed of Eocene basalts and basaltic tuffs. Interbedded with the tuffs are shales containing typical marine fossil invertebrates.

LITHOLOGY.

The Eocene sedimentary rocks consist of medium to coarse grained sandstones, thinly bedded and massive shales, alternating thinly bedded shales and sandstones, sandy shales, shaly sandstones, carbonaceous shales and coal seams. The coarse grained sandstones are often arkosic in composition and show no well defined bedding planes. Occasionally they exhibit cross bedding and contain fragments of carbonized wood. When examined microscopically they are found to be composed of small rounded grains of quartz together with angular and rounded grains of badly altered feldspar and fragments of biotite and hornblende. The cementing material consists of silica and iron oxide. The sandstones when fresh possess a gray color but where exposed to weathering range from brownish gray to brownish yellow.

The shales range from a fine grained fissile condition to a thinly bedded and laminated condition. Other varieties are mas-

sive and show no indications of stratification. They break with a distinct conchoidal fracture. Still other varieties are carbonaceous and grade from that condition to an impure shaly lignite. Very commonly the shales are sandy and pass to a condition where they would be classed as a shaly sandstone. The shales range in color from a light gray to a dark chocolate. Certain of the shales upon microscopic examination are found to be composed of fine volcanic products. Some of the coarser sandstones are composed of reworked volcanic tuffs.

Commonly the lavas are composed of flow breccias intermixed with coarse pumice and ash. These have been subjected to the action of running water at the time of deposition. Extending upward from the contact, the sorting action of water becomes more pronounced. Illustrations of this phase of deposit may be seen in the small rock outliers south of Seattle at Duwamish Station. They were probably formed during an epoch of volcanic activity in close proximity to a region where streams were emptying into a marine embayment as marine fossils are often associated with deposits only a short distance away.

The thickness of these several phases varies from place to place. Sandstone belts exist having a thickness of nearly 1,000 feet. There are numerous belts ranging in thickness from 25 to 300 feet. These belts vary in thickness as well as lithologic composition when traced along their strike. Extensive belts composed of alternating layers of shale and sandstone of varying thickness are very characteristic and make up a considerable portion of the upper Eocene deposits.

Andesitic lavas and tuffs in certain areas constitute a large part of the Eocene of western Washington. Exposures may be seen along Columbia River, Cowlitz River, in the Puget Sound Basin and along the north flanks of the Olympic Mountains. In nearly all instances they are interbedded with the marine or estuarine sediments. In many places they might be mistaken for flows of Pliocene or Pleistocene age but areal mapping tends to show that marine Eocene strata lie either above them or interbedded with them. The shales below them are commonly baked

near the contact. Occasionally the sedimentary rocks above and below certain flows show the action of heat. Such belts of andesite were presumably intruded in the form of sills contemporaneously with the andesitic extrusions. Instances of this condition may be seen in the rock hill outliers at Duwamish Station south of Seattle as well as in the rock exposures in Cowlitz County.

The volcanic materials range in mineralogical composition from basic andesites to acidic basalts. They grade in texture from dense glassy lavas to coarse grained granular types and from fine grained volcanic ash to coarse ejectamenta. These several types are often intricately mixed. In certain localities as along Columbia River individual flows may be seen resting upon one another. Between the different flows there are occasionally deposits of light colored or yellow clay ranging from a few inches to a foot or more in thickness. Carbonaceous material is often included within the clay indicating the probable existence of vegetation during the intervals between the outpouring of lava. Commonly deposits of light colored volcanic tuff of considerable thickness are intercalated with the lava flows.

It very often happens that thick layers of tuff breccia have thin tongues of glassy lava intercalated. During the accumulation of the series quantities of ash and boulders were in contact with liquid lava and were in part mixed and carried along with it. In certain areas these deposits were forming on tidal flats or estuarine basins and much of the finer material was sorted and partially stratified. Marine fossils are occasionally found within these partially baked shales and tuffs.

Within the lower Cowlitz Valley and in King and Pierce counties narrow andesitic dikes and sills are of common occurrence. They range in thickness from a few inches to over fifty feet. In several places as at Coal Creek in Cowlitz County they are clearly feeders for the interbedded andesite flows.

Thin sections of all these various phases were examined microscopically. Partial chemical analyses as well as mineral analyses place them in the rock classification at the boundary

between andesites and basalts. A number of specimens were without question typical basic andesites, while other samples proved to be basalts.

THICKNESS.

Presumably large amounts of the total sediments deposited during the upper Eocene have been removed by erosion. The Eocene strata have been folded and in part covered so that at no locality can the entire thickness be observed. In King County detailed stratigraphic surveys have been made along Green River. The base of the formation was not found at any point. From a series of careful measurements made in the canyon of Green River the Eocene deposits exposed were estimated to have an approximate thickness of 8,000 feet. In the vicinity of New Castle and Issaquah the Eocene sedimentary rocks have a thickness of 2,000 feet and rest upon andesites which are also of probable Eocene age. They are overlain by marine Oligocene sediments.

In Pierce County in the region of Carbon River and southward the Eocene strata attain a thickness of 14,000 feet. Here the base of the formation is also unknown. In Thurston County Eocene rock outcrops occur as isolated exposures. In the region between Tenino and Centralia interbedded sediments and lavas are dipping to the south at low angles and possess an estimated thickness of at least 2,000 feet.

In northern Cowlitz and southern Lewis counties sedimentary and igneous rocks of Eocene age occur at intervals from the town of Winlock in the north to Castle Rock in the south. The lowermost beds are exposed near the town of Castle Rock. Successively higher strata are encountered to the north and the uppermost beds are exposed near Winlock. Approximately 8,000 feet of strata are involved in this section.

In northern Clallam County in the vicinity of Port Crescent Eocene lavas and shales possess a total thickness of about 4,000 feet. In the central and eastern Cascade Mountains the Swauk, Teanaway and Roslyn formations, all of Eocene age, have a total maximum thickness of 12,000 feet.

STRATIGRAPHY.

The details of the stratigraphy are given in the descriptions of each area. The most complete sections have been measured in portions of King, Pierce and Lewis counties. In the other areas the exposures are so scattered that only fragmentary sections can be made. The type marine section for western Washington is the one just described as occurring between Winlock and Castle Rock. The following lithologic subdivisions are recorded:

Top of Section	Feet
Massive clay shale, grading in places into sandy shale, as exposed along the banks of Olequa Creek south of Winlock and also in the banks of Cowlitz River in Section 5, Township 11 North, Range 2 West, at locality 239. These strata constitute the basal member of the Oligocene.....	600
Chiefly sandy shale grading into massive clay shale of a dark brownish gray color. Exposures of this member are not very abundant but contain occasional specimens of <i>Venericardia planicosta</i> and <i>Turritella uvasana</i> . This is the uppermost marine Eocene as yet recognized within the state.....	960
Shaly sandstone	100
Slightly banded sandy shale.....	130
Slightly carbonaceous sandy shale.....	50
Sandy shale	430
Laminated sandstone and sandy shale.....	150
Shale slightly sandy. The upper portion of this member contains an abundant marine Tejon fauna	340
Massive clay shale. The equivalent of the shales occurring in the bank of Cowlitz River in Section 25, Township 11 North, Range 2 West.....	50
Sandy clay shale. Base of upper marine division.....	70
Yellowish brown sandstone with interbedded lignitic layers. These sandstones often grade into carbonaceous sandy layers. The fauna occurring within these strata are entirely of brackish water origin.....	520
Fresh water beds. Light gray massive clay shales, containing numerous fresh water Eocene invertebrate fossils. Fossil localities 295 and 303 occur in these beds.	130
Brackish water beds. Sandy shales and shaly sandstones grading into brownish yellow coarse grained sandstone all of which is more or less carbonaceous. Faunas at localities 231, 234 and 300 occur in these beds.....	550
Marine beds. Sandy clay shales grading into shaly sandstones. Faunas at localities 240, 240b, 299, 241, 238, 236, 298, 294 and 294a occur in these strata. The basal portion of this belt grades into beds of brackish water origin. Below this zone no detailed measurements have been made. The underlying strata are those involved in the area between Castle Rock and Olequa. Just below, andesite and tuffs are intercalated with the sedimentaries	390
Total thickness of measured Eocene strata.....	4470
Possible thickness of unmeasured strata involved in area between Castle Rock and Olequa.....	6000
Possible total thickness of Eocene as exposed in the lower Cowlitz Valley.....	10,470

The above section is involved in a continuous northeasterly pitching monocline. The lower portion of the section consists

of alternating belts of lava, tuff, shale and sandstone. The upper portion is entirely composed of sediments, having a thickness of nearly 4,000 feet as indicated above. The lower beds of the upper measured portion are of marine origin. Above these in sequence are brackish water strata, fresh water, brackish water and finally marine at the top. Resting upon the uppermost Eocene beds are sandy shales containing a fauna of lower Oligocene age. The contact relations suggest an unconformity.

FAUNA.

A total of 130 species of invertebrate fossils are known to occur within the upper Eocene strata of western Washington. Of these 52 are Pelecypods and 77 are Gasteropods. In addition there are two species belonging to the Scaphapoda and two species to the Cephalopoda. The following table includes a list of the upper Eocene fauna of the state as known up to the present time as well as the localities at which the different species occur.

EOCENE.

LIST OF SPECIES	1	2	3	4	5	6	7	8	11	17	17	18
PELECYPODA												
1 Avicula pellucida Gabb.....	*											
2 Barbatia morsei Gabb.....					*							
3 Cardium breweri Gabb.....	*				*	*	*				*	
4 Cardium cooperi Gabb.....	*				*							
5 Cardium olequahensis Weaver.....												
6 Corbula hornii Gabb.....	*											
7 Corbula n. sp.....	*											
8 Crassatellites washingtonensis Weaver.....					*							
9 Crassatellites grandis Gabb.....	*				*							
10 Crassatellites merriami Weaver.....												
11 Crassatellites dalli Weaver.....												
12 Crassatellites cowlitzensis Weaver.....												
13 Crassatellites compacta Gabb.....	*				*							
14 Cyrena brevidens White.....		*	*						*			*
15 Corbicula cowlitzensis Weaver.....								*				
16 Corbicula eufaulaensis Weaver.....								*				
17 Diplodonta polita (Gabb).....	*											
18 Glycimeris sagittata (Gabb).....								*				
19 Glycimeris eocenica (Weaver).....								*				
20 Glycimeris eocenica var landesi (Weaver).....								*				
21 Leda vaderensis Dickerson.....	*											
22 Leda gabbi Conrad.....			*				*					
23 Leda sp.....												
24 Meretrix hornii Gabb.....					*	*	*					
25 Meretrix urvasana Conrad.....	*					*						
26 Meretrix ovalis Gabb.....					*		*					
27 Meretrix olequahensis Weaver.....							*					
28 Meretrix longa? Gabb.....	*											
29 Marcia quadrata (Gabb).....							*					
30 Marcia conradana (Gabb).....							*					
31 Macrocallista andersoni Dickerson.....	*											
32 Macrocallista vaderensis Dickerson.....	*											
33 Modiolus ornatus Gabb.....							*					
34 Ostrea idriaensis Gabb.....			*				*					
35 Ostrea olequahensis Weaver.....	*						*				*	
36 Ostrea fettkei Weaver.....	*											
37 Pecten cowlitzensis Weaver.....												
38 Pecten landesi Arnold.....												
39 Placunanomia inornata Gabb.....	*						*					
40 Psammobia hornii (Gabb).....	*											
41 Semele diaboli Dickerson.....	*											
42 Solen parallelus Gabb.....	*		*			*	*			*		
43 Septifer dichotomus Gabb.....	*											
44 Thracia dilleri Dall.....	*		*									
45 Tellina sutterensis Dickerson.....	*											
46 Tellina longa Gabb.....	*											
47 Tellina hornii Gabb.....	*				*							
48 Tellina ooides? Gabb.....	*											
49 Tellina cowlitzensis Weaver.....	*											
50 Teredo sp.....	*											
51 Unio transpacificus Arn & Hann.....	*											
52 Venericardia planicosta Gabb.....	*		*		*	*	*					
GASTEROPODA												
53 Amauropsis alveata Conrad.....	*											
54 Ancellaria bretzli Weaver.....	*											
55 Ambloxyus olequahensis Arn & Hann.....	*											
56 Amphissa eocenica (Weaver).....	*											
57 Amphissa packardii (Weaver).....	*											
58 Bursa washingtoniana (Weaver).....	*	*										
59 Bursa cowlitzensis (Weaver).....	*											
60 Brachysphingus clarki Weaver.....	*											
61 Calyptraea excentricus Gabb.....	*					*						
62 Crepidula pilea Gabb.....	*											
63 Cyliehna costata Gabb.....	*											
64 Cancellaria stantoni Dickerson.....	*											
65 Conus hornii Gabb.....	*				*							

Marine invertebrate Tejon fossils are confined entirely to the western part of the state. None occur in the Swank or Roslyn formations of the central Cascades. Fossil plant remains occur both in the fresh water and estuarine deposits. In many cases the plant bearing estuarine beds are interbedded with the marine strata. Such evidence indicates that the fossil plants of the western portion of the state are of the same age as the marine invertebrates, namely upper Eocene. Insufficient work has been done on the fossil flora of the lacustrine beds of the Cascades to show their relations to the fossil flora west of the Cascades.

Near Duwamish Station, south of Seattle, marine beds containing marine invertebrate fossils occur associated with the lignite bearing strata which are the equivalent of the coal bearing strata of New Castle and Renton. Presumably the estuarine beds of King and Pierce counties are of Tejon or upper Eocene age.

The upper Eocene marine faunas of western Washington show close similarities at all localities. Marine and estuarine strata are interbedded but the former occur near the base as well as at the top of the series. At the present time there seems to be no sufficient evidence to warrant subdividing the Tejon into formations. Several faunal zones may ultimately be recognized. In the type section between Olequa and Winlock the marine faunas have their closest relationship to the *Siphonalia suterensis* Zone of the Tejon of California.*

The fossil flora varies somewhat at different localities but the stratigraphic relations in those localities where collections have been made are not in all cases known. A large number of the species are new and undescribed and their range unknown.

CONDITIONS OF DEPOSITION.

The bathymetric conditions under which the upper Eocene deposits of western Washington accumulated ranged from very shallow depths in the estuarine basins to possibly a maximum

* Dickerson, Roy E., Fauna of the Eocene at Marysville Buttes, California, Univ. Calif. Publ. Bull. Dept. Geol. vol. 7, pp. 257-298, p. 13, 11-14, 1913.

depth of 100 fathoms. Corals are unknown as fossils in these deposits. Glauconite which is common in portions of the Eocene of California has not been recognized in the Eocene of Washington. The majority of the genera belonging to the Pelecypoda and Gasteropoda are forms whose environment is in the littoral or sublittoral zones. Differential subsidence and elevation characterized the sea floor during the Tejon epoch. In those portions of King, Pierce and Lewis counties where estuarine conditions prevailed oscillations of the embayment floors must have been frequent. Over 100 coal or carbonaceous seams are interstratified with sandstone and shale members and each represents an interval of time during which vegetation flourished under possible swampy conditions. The sandstones or shales above each seam are water laid and indicate subsidence and a burial of the former swamp areas. Wherever the strata contain marine fossils there is evidence that the subsidence has been sufficiently great to cause the marine waters to transgress over former estuaries.

The arkosic character of many of the massive sandstone members in King and Pierce counties indicates nearby land areas composed largely of granitic or dioritic rocks which were being vigorously subjected to erosion. Presumably portions of the Index, Mt. Stuart and Snoqualmie granodiorites were in part supplying this material. Many of the clay shales show ripple marks indicating the presence of extensive tidal flats presumably situated near the shores of the estuaries. The simultaneous outpouring of lavas and the deposition of volcanic tuffs have already been referred to.

CLIMATIC CONDITIONS.

The climate of the Eocene in Washington as well as in California and Oregon was tropical. The marine invertebrates belong to genera which are found for the most part at the present time in the waters of the tropics. The fossil flora tells the same story. Palms and other closely allied groups predominate. In the upper beds of King and Pierce counties as well as in the

Olequa-Winlock region the flora indicates the presence of species of sycamores and birches. Apparently towards the close of the Tejon epoch the climate became somewhat cooler and certain austral types of plants began to develop. This climatic change is evidenced in the flora rather than in the fauna.

NEWCASTLE HILLS—GRAND RIDGE AREA.

GEOGRAPHIC DISTRIBUTION.

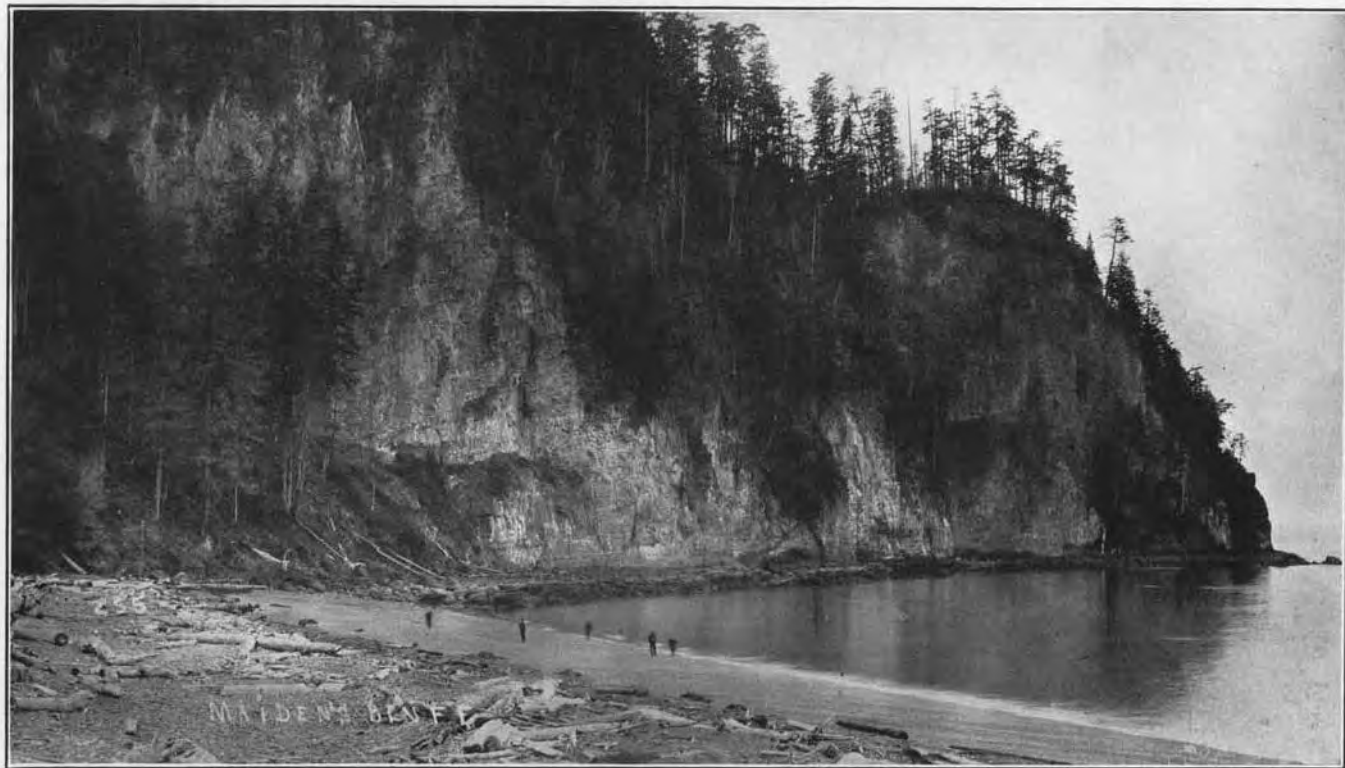
The Newcastle Hills are the westerly extension of a spur from the Cascade Mountains, situated between Snoqualmie Valley on the north and Cedar River on the south. They range in elevation from 3,000 feet, south of Grand Ridge, to sea level at Lake Washington. Both Eocene and Miocene formations occur within them. The Eocene, consisting of both sedimentary and volcanic rocks, occupies an area about two miles in width near Lake Washington, but increases easterly in the vicinity of Grand Ridge to over four miles. This belt of outcrops trends approximately east and west. The western end swings slightly to the northwest and the eastern end to the northeast in the vicinity of Grand Ridge.

CHARACTER OF OUTCROPS.

To the north of, and fringing the belt of Eocene outcrops just described, are marine sediments of Oligocene age. To the north of these, for a distance of over fifteen miles, no outcrops of formations older than Pleistocene glacial drift deposits are known to appear at the surface at any locality. Bed rock undoubtedly exists at various depths below the thick covering of glacial drift. Glacial drift of varying thickness mantles the Newcastle Hills, but in many places it has been removed by erosion exposing bold outcrops of bed rock such as Squak Mountain and Tiger Mountain immediately east of Issaquah Creek. The hills just north of May Creek are somewhat rugged and show the effects of glacial scouring.

LITHOLOGY.

The Eocene formation in the Newcastle Hills is composed of sedimentary and igneous rocks, the former resting strati-



Interbedded Tuffs and Shale in the Eocene Basalt Series at Port Crescent, Washington.

graphically above the latter. The sedimentary division is composed of coarse grained sandstones, shales, sandy shales, shaly sandstones, and carbonaceous seams. These several phases of the formation vary in thickness and are interbedded with one another. The sandstones are commonly coarse grained and appear to be largely composed of materials derived in part from volcanic lavas and tuffs and in part from granite and granodiorite. Cross-bedding is generally very pronounced in this phase of the formation. Often small seams of a chocolate-brown colored very fine grained shale occur interbedded in the form of lenses within the sandstone. Near the upper and lower portions of the thicker beds of sandstone at the contacts with the shale bands there are commonly very thin layers of shale less than one inch in thickness interbedded with narrow seams of sandstone averaging less than one-half inch in thickness, giving this type of rock a banded or laminated appearance. The sandstone masses are sometimes as much as one hundred and fifty feet in thickness. The shales are commonly massive without very distinct bedding planes. They break with a conchoidal fracture and occasionally possess considerable thickness. The sandy shales and shaly sandstones are generally harder and possess well-defined bedding planes. Within these are often found remains of fossil leaves, especially in the vicinity of the carbonaceous seams.

In the Coal Creek mine hundreds of fossil trees occur standing at right angles to the bedding planes of the coal seams and projecting upwards into the shales and sandstones above. Many of these trees have a diameter of four or five feet.

The strata outcropping along Coal Creek and in the underground workings of the Coal Creek mines are lithologically very similar to those on Tibbetts Creek in Section 32, and to those at Issaquah in Sections 26 and 33. Some minor variations, however, may be noted along the strike of individual beds or coal seams, as in the case of the Bagley coal seam in the Coal Creek mine.

The belt of igneous rock which underlies the sedimentary phase of the Eocene is composed of a series of lava flows with interbedded volcanic tuffs apparently derived from small fissures and vents in the immediate vicinity. None of this material, however, is found interbedded with the sedimentary portions of the formation above. The base of the sedimentary formation is composed of conglomerates made up of pebbles and boulders firmly cemented and derived directly from the various phases of this lava and tuff. A careful examination of the lava areas along the anticlinal belt shows the presence of much intrusive material of the same nature indicating that vents were continuously being opened through the earlier consolidated portions of the flow, allowing fresh material to well out over the surface. Many of these flows show the effects of movement just prior to consolidation and contain irregular shaped angular blocks of hardened lava which they have carried along with them. The tuff beds contain various sized fragments of pumice which have been firmly indurated. Some phases of the lava are very porphyritic showing large crystals of feldspar imbedded in a fine grained groundmass. Other phases possess a distinctly fine grained basaltic appearance; some individual flows are completely honeycombed with steam cavities.

GEOLOGIC STRUCTURE.

The principal structural feature of the Newcastle-Issaquah area is a broad anticline trending along the direction of the Newcastle Hills. Between lakes Washington and Sammamish it trends North 45° West. In the vicinity of the town of Issaquah and Squak Mountain it trends nearly east and west and then turns North 45° East in the vicinity of Grand Ridge. The north limb of the anticline between the Newcastle Hills and Grand Ridge develops into a broad syncline the axis of which trends nearly due north through Lake Sammamish. The western extension of the anticline can be traced to the eastern shores of Lake Washington in the vicinity of Newcastle Landing. From Newcastle Landing it crosses Lake Washington and passes through the south central part of Mercer Island. This

island is almost entirely composed of glacial drift, but on its western side in Section 24, Township 24 North, Range 4 East, huge broken boulders of basic igneous rock outcrop at the water's edge, which may possibly be a part of the core of the anticline. Immediately west on the Bailey Peninsula and just south toward Brighton Beach well defined outcrops of Oligocene shales and sandstones outcrop. These strata have a northeast-southwest strike with a very steep dip to the north. They are a continuation of similar strata occurring in the Newcastle Hills just north of Coal Creek. This, together with further evidence in the Rainier and Duwamish valleys, show conclusively that the anticline occurring in the Newcastle Hills crosses Lake Washington and then turns south toward Duwamish Station.

Along the course of Coal Creek from its mouth to its headwaters, numerous outcrops occur upon which observations for strike and dip can be obtained. These show the strike to range from North 45° West to North 70° West, the latter prevailing near the headwaters of the creek at the town of Coal Creek. The dips range between 40° and 70° . The general average is between 45° and 50° to the northeast. Similar observations were taken farther to the northeast along logging and wagon road cuts in the overlying Oligocene formations. From Coal Creek these same strata cross the mountain ridge and reappear on the north slope of Squak Mountain between Tibbetts and Issaquah creeks. Excellent observations on strike and dip may be taken in the vicinity of the Superior Coal Mine on Tibbetts Creek in Section 32, Township 24 North, Range 6 East and also in Section 33, same township and range, in the vicinity of the Issaquah coal mine at the town of Issaquah. The strike in both of these localities is nearly east and west with an average dip of 40° to the north. In the vicinity of Grand Ridge in Section 26 the strike swings to the northeast. Numerous observations were recorded both on the surface and in the underground workings of the Grand Ridge Mine. About two miles northeast of Grand Ridge in Section 13, Township 24 North, Range 6

East, several openings have been made in the bed rock strata along the courses of small creeks, exposing coal seams as well as sandstone and shale strata. The strike averages North 45° East with a dip of 65° to the northwest.

To the north and east of these outcrops the Eocene rocks are no longer exposed, but are covered with a very thick mantle of glacial drift. About four miles southeast of Section 13, in Section 28, Township 24 North, Range 7 East, outcrops of sandstone and shale are exposed in a railroad cut just west of the point where the Northern Pacific railway crosses Raging River. The strike of these beds is North 45° West and the dip ranges between 55° and 75° to the northeast. Although there is no absolute certainty that these are a continuation of the exposures in Section 13, yet it is probable that they are such an extension and are a part of the north limb of the Newcastle Hills anticline. The main axis of the anticline has been indicated upon Map B, Plate IV, and consists of almost continuous outcrops of basaltic lavas and tuff lying stratigraphically below the Eocene sandstones and shales.

From such evidence as can be obtained on May Creek along the south side of this anticline, the probabilities are very strong that the strata on the north slope formerly arched over the lava and dipping southward, extended under what is now May Creek Valley. The evidence pointing toward this conclusion may be found in Section 2, Township 23 North, Range 5 East, along the May Creek wagon road. Several exposures of sandstone and shale appear on the north side of May Creek close to the wagon road and near the surface are dipping almost vertical with a strike of North 75° West which is approximately parallel to the anticlinal axis just described. At this point on May Creek, a seam of coal has been discovered and a shaft sunk upon it to a depth of 325 feet. At the foot of the shaft a crosscut has been driven to the south for a distance of 450 feet. Along this crosscut several seams of coal were encountered as well as sandstone and shale strata which lithologically resemble very closely those in the Coal Creek and Newcastle mines on the

north side of the anticline. At the depth of the crosscut below the surface the strata are no longer pitching vertical, but assume a dip of 64° to the southwest. Outcrops of sandstone and shale on the south side of the anticline are only known in sections 1 and 2. To the west, toward Lake Washington, the country is almost entirely covered with deposits of glacial drift and the only pre-glacial outcrops exposed at the surface are occasional masses of basaltic lava and tuff. To the east of sections 1 and 2 no sedimentary rocks are exposed for a distance of six miles. Throughout this distance the south limit of the lavas which is indicated upon Map B, Plate IV, is in direct contact with very thick deposits of glacial drift. In Sections 12 and 13, Township 23 North, Range 6 East, numerous exposures of Eocene sandstones and shales containing coal may be seen along one of the branches of Issaquah Creek. This belt is about one-third mile in width and two miles in length. On both the northwest and southeast sides of this small belt are large areas of andesitic lava which should stratigraphically underlie the sediments. These sediments are presumably a remnant of those which at one time arched the anticline and have been dropped into their present position as a fault block.

The vertical and even overturned position of the strata along May Creek strongly suggests a slightly overturned anticline and also a possible fault approximately parallel to the strike. Along the sedimentary igneous contact in a number of places as may be seen near the May Creek coal shaft there are slickensided walls on the lava. If such a fault exists it quite possibly extends southeasterly into the Sherwood-Taylor region which will be described later.

From May Creek southward to Cedar Creek no outcrops of Eocene strata have been found to indicate the intervening structure. The northward pitching attitude of the strata at Renton and Cedar Mountain suggests a possible synclinal basin of Eocene strata trending parallel to and lying between Cedar River and May Creek.

STRATIGRAPHY.

The following stratigraphic section was measured from the base of the coal series on Coal Creek to the top of the productive coal measures. Unmeasured Eocene strata extend above this.

Top of Section	<i>Feet</i>
Massive brownish gray sandstone and interbedded shales.....	3004
Banded gray shale	25
Massive brown sandstone.....	115
Coal seam	8
Massive brownish gray sandstone.....	54
Dark gray shale	5
Banded shale	21
Light gray coarse sandstone.....	10
Thick bedded gray shale.....	28
Coal seam	17
Shale	9
Coal	1
Light gray sandstone	67
Gray shale	6
Gray sandstone	17
Dark gray shale	4
Massive brown sandstone	10
Clay	3
Massive brown sandstone.....	13
Banded shale and sandstone.....	37
Black shale	8
Coal and shale bands.....	25
Shale	3
Massive brownish gray sandstone.....	38
Dark gray shale	13
Coal seam	6
Sandy clay	9
Banded sandstone	17
Banded shale	36
Coal	14
Dark gray shale	8
Coarse brownish gray sandstone.....	36
Massive gray shale	14
Coal	17
Massive sandstone	4
Sandy shale	23
Sandstone	9
Interbedded sandstone and shale.....	8
Coarse brownish gray sandstone.....	19
Gray shale	30
Coal seam	20
Massive brownish gray sandstone.....	50
Coal seam	6
Massive brownish gray sandstone.....	9
Shaly sandstone	13
Massive brownish gray sandstone.....	126
Coal seam	10
Massive brownish gray coarse grained sandstone.....	30
Base of Section	
Total.....	4055

GREEN RIVER AREA.

GEOGRAPHIC DISTRIBUTION.

The region involved in this area comprises nearly all of Township 21 North, Range 7 East, the eastern half of Township 21 North, Range 6 East, the south half of Township 22 North, Range 7 East and the southeastern quarter of Township 22 North, Range 6 East. This territory is drained by Green River in the central portion, Cedar River on the north, and White River on the south. It extends easterly to the foothills of the Cascades and includes the low glacial hills of the east part of the Puget Sound Basin. In places the glacial covering has been in part removed by erosion and the underlying Eocene sandstones and shales exposed. The most extensive outcrops are along the canyon of Green River and in the smaller streams emptying into it. Tiger Mountain at Bayne and Sugar Loaf Mountain near Durham are bedrock hills of sandstone surrounded by deposits of drift. At the eastern margin of the region the Eocene sedimentaries pass beneath the Miocene and Pliocene lavas and tuffs. The contact roughly follows the western escarpment of the foothills of the Cascade Mountains.

LITHOLOGY.

The Eocene formation exposed within this area is almost exclusively of sedimentary origin. Minor amounts of igneous material occur in the form of dikes and sills which are probably post-Eocene in origin. They may have been feeders to the Enumclaw lavas which undoubtedly at a former time covered this area.

The sedimentaries consist of sandstones and shales of varying characteristics. The sandstones are usually massive and thick bedded with a brownish gray color when fresh. Often they exhibit cross-bedding. Certain phases are very coarse grained and arkosic. One of these beds, as exposed near Franklin in the canyon of Green River, is almost 600 feet in thickness and is persistent in lithologic character throughout this area. This belt is medium grained and hard. When weathered it assumes a

light brown color and forms almost vertical canyon walls. These massive sandstones occasionally pass into shaly sandstones and from that condition into sandy shales. The shales range from a dark gray to a brown and from a massive condition to a distinctly laminated phase. Narrow bands of all these types occur interbedded with one another. All phases may be seen in the exposures along Green River.

Interbedded with this series of sediments are numerous coal seams and carbonaceous shale beds. They vary in thickness from a few inches to fifty feet. The character of the coal ranges from a bituminous to a low grade lignite. Within each seam there are variations in character from the base to the top. The different lithologic members of the formation including the carbonaceous seams often change in composition when followed along the strike of the beds indicating different conditions on the sea bottom at the time of their deposition.

The intrusive dikes and sills are narrow and usually intercalated with the sedimentary beds. They range from a foot to 80 feet in thickness. When fresh specimens can be obtained they are found to be very fine grained and composed of labradorite feldspar and augite. The minerals are always more or less altered and the phenocrysts are only slightly larger than the microlites of the ground mass. The rock would be classed as a basic andesite.

Twelve of these dikes occur in the canyon of Green River between Kummer and Palmer Junction. Six others are on Coal Creek south of Bayne. One of the largest dikes occurs in the western half of Sections 18 and 19, Township 21 North, Range 7 East. It crosses the Columbia and Puget Sound R. R. near the center of Section 18 and trends nearly due north for a distance of one mile. It is overlain and underlain with Eocene shales and pitches with them to the west at an angle of 40°.

STRATIGRAPHY.

The excellent exposures of the Eocene formation in the canyon of Green River afford opportunities for constructing stratigraphic sections of the series. In the underground workings of

the coal mines as well as at many localities both to the north and south of Green River partial sections may be measured which in many cases can be directly referred to their true position within the complete section as exposed along Green River. As a result of such field studies it is possible to subdivide the Green River Eocene into three lithologic units. The terms Bayne, Franklin and Kummer series have been applied. These subdivisions can be recognized only locally and cannot be used for lithologic correlation purposes. For this reason it would seem best to regard them as members and not formations. Detailed surveys have been made in Green River canyon and the lithologic variations from the base to top of each member have been determined.

The lowest division, or Bayne member, consists of a predominating series of shales together with subordinate amounts of sandstone, shaly sandstone and carbonaceous beds. It has a thickness of over 3,000 feet as measured along the canyon of Green River from the center of Section 17 up the river to the east line of Section 8, Township 21 North, Range 7 East. The top of this member appears at the Franklin wagon bridge at the contact with the Franklin sandstone member. The following section was in part measured by the writer in connection with an investigation of the King County coal fields:

STRATIGRAPHIC SECTION OF BAYNE MEMBER.

Top of Section.	Feet
Brownish gray sandstone, somewhat banded.....	135
Gray sandy shale	14
Coal and carbonaceous material.....	35
Gray sandy shale.....	19
Covered	40
Alternating beds of shale carbonaceous shale and sandy shale.	128
Massive grayish brown sandstone.....	52
Interbedded sandy shales and carbonaceous seams.....	30
Massive brownish gray coarse grained sandstone.....	45
Carbonaceous seam	7
Gray sandy shale	27
Carbonaceous seam	9
Alternating beds of sandy shale and carbonaceous seams.....	55
Sandy shale	82
Brownish gray banded sandstone.....	22
Gray sandy shale.....	51
Carbonaceous seam	34
Sandy shale	24

Top of Section.	Feet
Massive brownish gray sandstone.....	11
Gray banded sandy shale.....	30
Massive brownish gray coarse grained sandstone.....	21
Shale and carbonaceous seams.....	26
Massive brownish gray sandstone.....	10
Interbedded banded gray shale and carbonaceous seams.....	81
Massive grayish brown coarse grained sandstone.....	85
Interbedded shaly sandstone and carbonaceous seams.....	22
Massive brownish gray coarse grained sandstone.....	120
Sandy shale and carbonaceous seams.....	26
Coarse massive brownish gray sandstone.....	117
Banded gray sandy shale.....	50
Carbonaceous seam.....	40
Banded sandy shale.....	16
Brownish gray coarse grained sandstone.....	40
Interbedded sandy shale and carbonaceous seams.....	106
Massive brownish gray coarse grained sandstone.....	190
Carbonaceous seam and sandy shale.....	30
Massive brownish gray sandstone.....	94
Stratified sandy shale.....	44
Massive brownish gray sandstone.....	60
Interbedded sandy shale and carbonaceous seams.....	43
Massive brownish gray coarse grained sandstone.....	123
Banded sandy shale and carbonaceous seams.....	157
Banded gray sandstone.....	83
Interbedded shale, sandy shales and coal seams.....	246
Massive brownish gray sandstones.....	55
Coal seam.....	6
Brown gray banded sandstone.....	27
Coal seam.....	5
Massive gray sandstone.....	21
Banded gray sandy shale.....	11
Banded gray sandstone.....	29
Interbedded gray shale and carbonaceous seams.....	30
Brownish gray sandstone.....	13
Carbonaceous seam.....	5
Massive brownish gray sandstone.....	35
Slightly metamorphosed sandstone.....	21
Andesite and baked sandstone.....	26
Massive but somewhat baked sandstone.....	45
Base of Section	
Total.....	3009

The Franklin member is composed of massive sandstones with interbedded shales and carbonaceous seams possessing a thickness of over thirty-six hundred feet. The basal portion of the series consists of a belt of massive coarse grained brownish gray sandstone having a thickness of 600 feet. It is typically exposed at the Franklin bridge. The upper portion of the Franklin series contains the most important seams of coal mined in the district. The following stratigraphic measurements of this series have been made:

Stratigraphic Section of Franklin Member as measured on Green River, King County.		<i>Feet</i>
Bony coal		16
Stratified sandy shale.....		20
Shaly gray sandstone.....		52
Inter-stratified shale and carbonaceous shale.....		9
Brown massive sandstone.....		7
Gray shale		8
Hard shaly carbonaceous bed.....		6
Nodular sandy shale.....		4
Interbedded shale and carbonaceous shale.....		37
Laminated sandstone		10
Nodular gray shale.....		5
Banded gray sandstone.....		22
Banded gray sandy shale.....		13
Banded gray shale.....		10
Carbonaceous seam		10
Carbonaceous shale		12
Banded sandy shale.....		30
Massive brownish gray sandstone.....		23
Carbonaceous shale		15
Massive sandstone		6
Nodular gray shale.....		7
Banded gray sandstone.....		30
Light-brown medium-grained sandstone.....		150
Massive brownish gray sandstone.....		205
Covered		204
Massive gray sandstone.....		58
Intrusive sill of andesite.....		10
Carbonaceous seam		13
Banded nodular gray shale.....		6
Interbedded carbonaceous seams and shale.....		24
Banded gray sandy shale.....		15
Brownish gray massive sandstone.....		23
Banded gray sandy shale.....		12
Carbonaceous seam and shale.....		17
Massive brownish gray medium-grained sandstone.....		83
Interbedded sandy and carbonaceous shale.....		25
Massive brownish gray sandstone.....		74
Carbonaceous seam		2
Massive brownish gray sandstone.....		3
Gray shale		17
Carbonaceous shale		6
Banded gray shale.....		5
Massive brownish gray sandstone.....		6
Banded gray sandy shale.....		23
Carbonaceous shale		6
Massive brownish gray sandstone.....		13
Banded gray sandy shale.....		45
Brownish gray massive sandstone.....		92
Banded brownish gray sandstone.....		12
Banded gray shale.....		11
Intrusive sill of andesite.....		10
Covered		35
Massive brownish gray sandstone.....		24
Banded brownish gray sandstone.....		17
Banded gray sandy shale.....		12
Covered		37

	<i>Fect</i>
Banded brownish gray sandstone.....	12
Covered	24
Banded brownish gray sandstone.....	20
Banded gray sandy shale.....	30
Covered	20
Banded gray sandstone.....	26
Banded gray sandy shale.....	58
Gray sandy shale.....	18
Banded gray sandstone.....	28
Banded sandy shale.....	16
Coal seam	11
Interbedded layers of shale, sandy shale, carbonaceous seams and thin bands of shaly sandstone.....	191
Massive brownish gray sandstone.....	26
Banded gray sandy shale.....	7
Medium grained brownish gray sandstone.....	44
Coal seam	7
Banded nodular gray sandy shale.....	58
Carbonaceous bed	38
Gray shaly sandstone.....	8
Massive gray brownish sandstone.....	25
Interbedded sandy shale and shaly sandstone.....	79
Gray banded sandy shale.....	78
Intrusive sill of andesite.....	7
Slightly metamorphosed shale.....	32
Intrusive sill of badly altered andesite.....	118
Banded gray sandy shale.....	35
Banded brownish gray sandstone.....	24
Banded sandy shale.....	10
Banded brownish gray sandstone.....	16
Massive brownish gray sandstone.....	37
Banded gray sandy shale.....	23
Interbedded carbonaceous seam with sandy shales.....	78
Banded gray sandy shale.....	14
Massive brownish gray sandstone.....	46
Carbonaceous seam	10
Banded gray sandy shale.....	30
Covered	22
Carbonaceous seam	5
Banded gray sandy shale.....	23
Covered	47
Massive brownish gray sandstone.....	44
Carbonaceous seam	6
Banded gray sandy shale.....	15
Banded brownish gray sandstone with interbedded layers of shaly sandstone	119
Covered	107
Banded gray sandy shale.....	10
Franklin sandstone light grayish brown color and medium grained	210
Base	
Total.....	3558

The uppermost division of the Eocene sedimentaries as exposed in Green River canyon consists of a predominating series

of coarse grained light colored sandstones together with numerous intercalated strata of shale and carbonaceous beds. They possess a thickness of about 1800 feet and are described as the Kummer member. At the base of this series there is a light colored massive sandstone having a thickness of 475 feet. The entire Kummer member is involved in a syncline with the basal sandstone of the western limb resting in the eastern half of Section 26, Township 21 North, Range 6 East. The following stratigraphic section has been measured:

Stratigraphic Section of the Kummer Member.

Top of Section	<i>Feet</i>
Banded sandstone	10
Alternating beds of shale, sandy shale and carbonaceous seams	91
Massive, brown, coarse grained sandstone.....	540
Covered	35
Coal	2
Massive, brown, coarse grained sandstone.....	30
Dark gray shaly sandstone.....	12
Massive, brown, medium grained sandstone.....	100
Coal and carbonaceous shales.....	8
Gray sandy shale.....	60
Gray shale	113
Coal seam	2
Massive brown gray coarse grained sandstone.....	165
Coal seam	3
Shale	30
Coal seam	5
Dark gray shale.....	55
Coal seam	4
Brownish gray sandstone.....	7
Fire clay	5
Coal seam	6
Massive brownish gray coarse grained sandstone.....	475
Base of Section	—
Total.....	1758

No strata of purely marine origin have been found in the Green River area. In the Bayne member, species of brackish water mollusca are occasionally found. They are in a bad state of preservation but belong mostly to the genus *Corbicula*. No subdivisions of the Green River Eocene can be formed on a basis of the brackish water molluscan fauna. The species occurring here are common in all the brackish water zones interbedded with the marine Tejon occurring farther to the southwest. Fossil plant remains are abundant at many localities along Green River but there is insufficient knowledge con-

cerning the species to warrant using them for correlation purposes.

GEOLOGIC STRUCTURE.

The geologic structure of this area is very complex. Detailed traverses tied in by transit surveys were made along Green River from Section 28, Township 21 North, Range 6 East to Section 13, Township 21 North, Range 7 East, a distance of over seventeen miles. Stratigraphic sections were made throughout this entire traverse. All the variations in strike and dip were recorded in their exact position along this traverse line. This line and all observations tied into it have been platted and may be referred to in the report on the King County coal fields.*

Observations on the strikes and dips have been taken at all points where outcrops were found to occur, either above or below ground. From the results of such data it has been possible to determine the approximate structure which the Eocene sedimentary formations now assume.

The broad general features of the structure consist of a series of nearly parallel anticlines and synclines pitching to the south. Their average trend is North 20° East. One broad syncline begins on the boundary line between Ranges 6 and 7, Township 21 North, in the vicinity of Sections 7 and 12. This syncline averages about two miles in width and at least six miles in length. At least six parallel anticlines and as many synclines lie on the east side. One anticline and one syncline lie on the west. What the structure may be beyond, to the west, cannot be determined because of the absolute disappearance of the Eocene formations beneath a very thick covering of glacial drift. These anticlines and synclines in the vicinity of Cedar River, to the north, also disappear below a very thick covering of drift and only reappear in the vicinity of Taylor and Raging River.

* A part of the work was undertaken by the writer during the season of 1909 and the details are to be found in the maps accompanying a report on the coal field of King County, Bulletin No. 3, Washington Geol. Survey 1912.

In addition to folding, the strata have been cut by numerous faults, the most prominent of which trends in a sinuous manner nearly east and west and has dislocated the strata nearly at right angles to their strike. This fault appears to begin in Section 21 and to extend westerly through Sections 20 and 19 of Township 21 North, Range 7 East, into Sections 24, 13, 14 and 15 of the township immediately west. The dislocation along this fault plane has been definitely shown in the underground workings of the Franklin mine and in the dislocated positions of the big heavy massive Franklin sandstone adjacent to the fault plane. Numerous minor faults occur in this region.

CONDITIONS OF DEPOSITION.

The Eocene sedimentaries of the Green River area as well as those in the Pierce County coal field are of shallow water origin. They were deposited in an estuarine basin which during the progress of Eocene time was in a state of differential oscillation. The results of these diastrophic movements are to be observed in the alternating character of the sediments and in the numerous interbedded coal seams. Some of the lower grade seams attain a thickness as great as fifty feet.

CEDAR MOUNTAIN AREA.

GEOGRAPHIC DISTRIBUTION.

This area is situated within Cedar River Valley in Sections 29 and 30, Township 23 North, Range 6 East. The surrounding country is very heavily covered with glacial drift. Three miles to the north, the basalts of the Newcastle anticline outcrop and five miles to the west the Renton coal measures appear. Exposures of this formation are well developed in the banks of Cedar River in Section 29. In Section 30 the strata are well developed along the county road and in the hill just south. A number of coal seams occur interbedded with sandstones and shales and these have been opened up by a series of underground tunnels.

STRATIGRAPHY.

The Eocene formations in this region are composed almost entirely of sedimentary rocks, consisting of sandstones, shales and carbonaceous beds. The total thickness of the strata as measured upon the surface is over two thousand feet. The lower eight hundred feet of the section contain the coal seams. The upper half of the section is predominantly shaly. The section as a whole is lithologically somewhat similar to that exposed at Renton. The following stratigraphic section has been measured:

Stratigraphic section as measured at Cedar Mountain along county road.

Top of Section	<i>Feet</i>
Banded gray shales.....	120
Brown concretionary shale.....	570
Interbedded shale and sandy shale.....	400
Brown sandstone.....	8
Interbedded sandstone and shale.....	30
Banded sandstone and shale.....	82
Coal.....	12
Light gray massive sandstone.....	45
Covered.....	18
Banded sandy shale.....	60
Covered.....	62
Banded brownish gray shale.....	28
Brownish gray coarse grained sandstone.....	23
Banded brownish gray shale.....	12
Massive brownish gray sandstone.....	22
Total.....	1492

GEOLOGIC STRUCTURE.

In Section 20, Township 23 North, Range 6 East, the strata have a strike of North 20° West and dip to the northeast. In this particular locality they may represent the southwest limb of a syncline whose axis lies somewhere southwest of May Creek and trends northwest to southeast. If so, the north limb of the syncline should reach the surface along the valley of May Creek.

South from Section 20 at Cedar Mountain the strike swings and becomes more nearly north and south and in Section 30 becomes North 45° East with a southeasterly dip. The strata of Cedar Mountain are possibly involved in the nose of a southeasterly pitching anticline, and are more or less dislocated by faulting.

RAGING RIVER AREA.

GEOGRAPHIC DISTRIBUTION.

Eocene deposits occurring within this area are confined almost entirely to Township 23 North, Range 7 East and the north half of Township 22 North, Range 7 East. Raging River Valley heads in the southern part of Township 23 North, Range 7 East and extends nearly due north to the valley of Snoqualmie River. A few surface exposures of sandstones and shales occur but the greater part of the area is deeply covered with glacial sand and gravels. The rock outcrops are confined chiefly to the small canyons along the valley slopes. The floor of the valley is entirely covered with drift. Elevations in this region range from 1,000 to 3,500 feet. The entire area is covered with a dense growth of forest and underbrush.

STRATIGRAPHY.

Exposures of Eocene rocks occur as a rule in small disconnected patches rendering it difficult to determine the relation of one outcrop to another. Sandstones and shales outcrop in the beds of the creeks west of Raging River between Preston and Kerriston. Low grade coal and carbonaceous bands are interbedded with the sediments and several years ago were prospected. All of these materials have been invaded by dikes of andesite and rhyolite. Nearly all the coal seams are more or less disrupted and in places baked. Such exposures as occur along the divide between Raging River and Issaquah Creek are composed of a brownish yellow badly altered igneous rock. Some of the fresher specimens upon examination are found to be a rhyolite intrusive. To the north of Taylor the dikes are andesitic in character. It is possible that these intrusives may be in part contemporaneous with the Eocene deposits but presumably the greater proportion of such outcrops are a part of the igneous materials which were intruded in the near vicinity during the upper Miocene or lower Pliocene. The greater portion of the ridge between Raging and Snoqualmie valleys is composed of andesite and tuffs belonging to the Enumclaw Volcanic Series. These lavas cover extensive areas from the foot-

hills of the Cascades to the summit of the range. It is quite possible that these dikes are remnants of feeders to these late Miocene flows.

The sandstones are brownish gray in color, medium grained and in places cross bedded. The shales grade from a clayey condition to a banded sandy shale. They are best exposed in Sections 9, 16, 21 and 26. They also outcrop in Sections 32 and 33 and continue into the township immediately south where they are well developed in the vicinity of the Taylor coal mine in Sections 2, 4 and 5. Shales and sandstones with interbedded coal seams occur on the divide between Snoqualmie and Raging River valleys in Sections 1 and 12, Township 23 North, Range 7 East. No very detailed stratigraphic sections can be measured with the exception of those exposures occurring within the Taylor mine. In the main crosscut tunnel of the mine a cross-section of the strata is as follows:

Top	<i>Feet</i>
Massive coarse grained sandstone.....	92
Coal seam	10
Hard gray clay shale.....	2
Massive shaly sandstone.....	63
Carbonaceous sandy shale.....	3
Hard massive sandy shale.....	27
Coal seam	7
Massive sandstone	5
Coal seam number seven.....	55
Shale	3
Massive coarse grained sandstone.....	187
Sandy shale	3
Igneous dike	6
Carbonaceous seam	2
Igneous dike	2
Coal seam	21
Shale	91
Coal seam	13
Shale containing brackish water fossils.....	23
Coal seam	12
Brown shale	8
Hard massive sandstone.....	8
Banded sandy shale.....	50
Light colored plastic clay.....	10
Dark gray shale.....	6
Coal seam, cut by igneous dike.....	11
Light gray massive sandstone.....	143
Coal seam	36
Dark gray shale.....	16
Coal seam	24

Top	Feet
Massive sandstone	95
Dark gray shale.....	1
Massive sandstone	2
Coal seam	4
Igneous dike	22
Shaly sandstone	23
Coal seam	9
Massive dark gray sandy shale.....	10
Banded sandy shale.....	6
Massive sandy shale.....	37
Shale	11
Sandy shale	12
Carbonaceous seam	10
Sandy shale	7
Massive shaly sandstone	9
Massive gray shale.....	2
Thinly bedded shale.....	7
Massive gray shale.....	6
Thinly bedded shale.....	12
Shale	15
Massive sandy shale.....	175
Total.....	1414

The sedimentary strata are of brackish water origin. No marine fossils are known. The most common species are *Batissa newberryi* White, *Cyrena brevidens* White and *Corbicula pugetensis* White. These species are characteristic of the estuarine Eocene of western Washington but give no clue as to what particular portion of the upper Eocene they represent.

GEOLOGIC STRUCTURE.

The well defined anticline extending easterly from Lake Washington past Issaquah to Grand Ridge apparently flattens out in the region between Issaquah and Taylor and develops into a complex series of small anticlines and synclines. This complex folding has been further complicated by much faulting and the strata have been badly dislocated as the result of numerous igneous intrusions. In Township 23 North, Range 7 East, the strata have been so badly disrupted as to make it impossible to determine any well defined structure. The western limb of an anticlinal axis appears to trend about North 35° West through Sections 22, 16, 9, 8, 5 and 6. Numerous strikes and dips have been recorded; many of them are at variance with one another, but the majority of those taken on

outcrops that appear to be least disturbed, possess a south-westerly dip averaging 35° . To the west of the sedimentary outcrops just mentioned, the only pre-glacial formations exposed are a few scattered outcrops of badly altered igneous rocks occurring in Sections 17, 18, 19 and 20. The areal distribution of these has been indicated upon the accompanying map and while no definite statement can be made, yet the relations of the sedimentaries to the igneous suggest a fault trending North 15° West. If such a fault exists the sediments along the western slope of Raging River Valley have been dropped down to the northeast. The central portion of Raging River Valley contains no outcrops. It is deeply filled with deposits of glacial drift. In Sections 1 and 12 in the northeast corner of Township 23 North, Range 7 East, the Eocene sediments have a prevailing strike of North 35° West and a dip of 62° to the southwest. They are isolated from any of the surrounding outcrops and may possibly represent the western limb of a second anticline lying parallel to, and to the northeast of, the one previously mentioned in Sections 9, 16 and 22. If so, a broad synclinal trough must lie along the present position of Raging River or a little to the east of it. The strata as exposed in the underground mine workings in Sections 1 and 12 are badly dislocated as the result of faulting.

In the southeastern corner of Township 23 North, Range 7 East, a number of rock exposures outcrop in Section 26, about one-half mile west of Kerriston. These strata assume a nearly east-west strike with an average dip of about 46° to the south. They are presumably a part of the southwestern flank of the anticline referred to as trending through Sections 16, 21 and 22 on the west side of Raging River.

In Sections 2, 3, 4, Township 22 North, Range 7 East in the vicinity of the Taylor mine the strata have been folded into a well defined syncline trending North 45° West and approximately parallel to the other two anticlines just mentioned and lying to the southwest of them. The maximum width of this

syncline is a little over one mile and it may be traced northwesterly into the northwest quarter of Section 33, Township 23 North, Range 7 East. No pre-glacial outcrops have been found between this syncline and those exposures occurring in Section 26, Township 23 North, Range 7 East, just south of Kerriston.

The strata at Kerriston have a southwest dip in common with those on the northeast flank of the syncline at Taylor. It is possible that the strata at Taylor are the basal portion of those occurring on the east side of the Taylor syncline. There is also a possibility that there may be an anticline trending northwest to southeast somewhere between Taylor and Kerriston along the divide between Rock Creek and the head of Raging River. There is no direct evidence to support either view.

About three-quarters of a mile southwest of the Taylor syncline another anticline has been developed which trends North 45° West through the centers of Sections 4 and 10, Township 22 North, Range 7 East, into Sections 32 and 31 of the township immediately north. The position of this anticline has been largely determined from strikes and dips occurring at isolated points along its course.

In the discussion of the Newcastle-Issaquah anticline reference has been made to sedimentary outcrops containing coal seams, lying along Guy Creek in Sections 12 and 13, Township 23 North, Range 6 East. They may represent a block of Eocene sediments formerly resting upon the underlying basalts and which were dropped into their present position as a fault block between Tiger and Issaquah mountains. Observations taken on the strike and dip in Section 12, on Guy Creek, show an average strike of North 16° East and a dip of 45° to the northwest. Just south, in Section 13, the strike of these same strata appears to swing around to the northwest and assume a position almost due east and west. The dip is southwesterly and some minor faulting is indicated in places. In Section 12 these strata rest unconformably upon igneous rocks. The contact is not an intrusive one but rather one of sedimentation.

About one and one-half miles southwest of Preston a number of small local outcrops of shale containing carbonaceous seams project through the glacial drift. They are badly broken and dislocated and no definite structure could be determined. The prevailing strike is North 50° West and the dip very steep to the northeast.

QUIMPER PENINSULA AREA.

GEOGRAPHIC DISTRIBUTION.

The Quimper Peninsula forms the extreme northeastern corner of the Olympic Peninsula. The surface distribution of the Eocene deposits within this area is confined to two belts. One of these belts trends northwesterly from Hood Head and Olele Point to the south end of Discovery Bay and thence to Sequim Bay. The other belt lies to the southwest of Quilcene and extends along the western margin of Hood Canal to Mason County. Between these two belts and on the north side of the first belt, there are deposits of shale and sandstone of Oligocene age. Both the Eocene and Oligocene rocks are thickly covered with glacial drift. Such outcrops as occur are mostly along the shores of the Canal and its inlets.

The Eocene rocks in this region consist largely of basic andesites and intercalated bands of tuff, a part of which have been deposited in water. Exposures of these rocks occur along the shore line most of the distance from Olele Point to Hood Head. The contact between the Eocene and the overlying Oligocene sedimentaries appears in a low cliff immediately north of Olele Point. Shales rest directly upon basaltic andesites. No basal conglomerate is present at this locality and it is possible that the contact may be a fault plane rather than one of deposition. The rocks at Olele Point are distinctly tuffaceous and noticeably stratified. One-half mile south of the Point there is a long narrow channel extending inland a distance of about one mile to the small Indian village of Mats Mats and along the shores of this inlet the rocks may be studied in detail. To the south of this locality and towards Hood Head, the igneous

materials become more dense and occur as lava flows. Hood Head is a rock outlier of andesite and the country to the west of it is composed of glacial drift. The contact as mapped between Olele Point and Port Discovery Bay is only approximate since exposures of bedrock occur at only a very few localities. Andesite may be seen in contact with the overlying Oligocene conglomerates in a small creek near Anderson's Lake in Section 10, Township 29 North, Range 1 West. At this point the outcrops are at the falls and along the gorge of the creek just mentioned. Exposures of Eocene andesite occur in cliffs nearly 100 feet high along the east shore of Port Discovery Bay, between its head and Woodman Station. One-third mile north of Woodman Station Oligocene sandstones outcrop at the water's edge and dip at a very low angle to the north. Two miles south of Woodman Station conglomerates rest upon the igneous rocks. The contact on the north side of this belt of andesite may be traced from the western shore of Port Discovery Bay westerly to Sequim Bay. From the south end of Port Discovery Bay to the head of Dabop Bay at Quilcene the only bed rock exposures are shales and sandstones of Oligocene age. A high hill lies to the southwest of Quilcene, the central portion of which is composed of basic andesite. High upon its slopes it is thickly mantled with glacial gravels and sands. Similar igneous rocks form the hills bordering Hood Canal from Quilcene southward to Dosewallips River. These andesites, although disconnected by surface deposits of drift and the waters of Hood Canal, are in reality an extension of those in central Kitsap County. The contact between the igneous rocks and the Oligocene sedimentaries in the vicinity of Quilcene is very indefinite. Exposures of shale occur in the railway cuts two miles north of the town and exposures of andesite three miles to the southwest.

LITHOLOGY.

The textural and mineralogical characters of the rock vary considerably in different localities. On the east shore of Port Discovery Bay, south of Woodman Station, the formation is in

part a flow breccia. Large sized blocks of vesicular rounded masses of andesite occur embedded in a fine grained matrix of hardened tuff and lava exhibiting flow structure. Intercalated with this phase there are tongues of typical andesitic lava flows. A microscopic examination of the plagioclase crystals shows them to belong to the basic labradorite variety. Augite and minor amounts of hornblende compose the dark minerals. A few sections revealed the presence of a small amount of olivine. The surface exposures of the rock are deeply weathered and fresh specimens are difficult to obtain.

The tuffaceous phases are banded and often have thin layers of shale and clay interbedded. In the vicinity of Olele Point bands of tuff averaging two or three feet in thickness are interbedded with lava flows of about the same thickness. They are stratified and occasionally contain marine Eocene fossils.

GEOLOGIC STRUCTURE.

The main structural features involving the pre-glacial formations of the Quimper Peninsula consist of an anticline and syncline parallel to each other and trending southeast to northwest. The axis of the anticline lies along the area designated upon Plate IV as Tejon lavas. The banded phases of the lavas near Olele Point have a prevailing strike of east and west and a dip of 40° to the north. The overlying Oligocene sedimentaries exposed along the shores of Oak, Scow, Port Townsend and Port Discovery bays have an average east to west strike with a northerly dip ranging from 15° to 45° . An examination of the strikes and dips as platted upon the maps around the shores of Port Townsend and Scow bays indicates minor transverse folding of the strata on the north limb of the anticline.

Between Port Discovery Bay and Quilcene, Eocene rocks do not outcrop at the surface. There are a few exposures of the overlying Oligocene sandstones and shales. These have been folded so as to form a synclinal trough which also presumably involves the underlying lavas. Observations on strike and dip at the south end of Port Discovery Bay indicate that the nose



Eocene Basalts Exposed on the West Side of Cape Disappointment North of Entrance to Columbia River.

of the synclinal trough is not far to the southwest. It presumably extends easterly into Kitsap County but this cannot be proved on account of the lack of surface exposures. The anticline referred to may extend westerly past the south end of Sequim Bay.

PORT CRESCENT AREA.

GEOGRAPHIC DISTRIBUTION.

The type occurrence of the Eocene in this area is along the cliffs in the vicinity of Crescent Bay and Observatory Point on the south side of the Strait of Juan de Fuca. The region for some distance south of the shore is heavily covered with deposits of glacial drift but judging from such outcrops of Eocene rocks as are available they probably occupy the entire area southward from the shore line to the east-west center line of Township 30, Ranges 7 and 8 West. The western limit of these outcrops has been designated upon the geological map as extending from Section 16, Township 30 North, Range 8 West in a north-westerly direction to a point on the shore line on the Strait about two miles west of Port Crescent. This contact has been approximately drawn. To the south, the Eocene rocks extend into the northern ridges of the Olympic Mountains. To the east they may be seen outcropping in the canyon of Elwha River and presumably they underlie the glacial drift still farther east as far as Dungeness River.

The outcrops are conspicuous as bold rugged sea-cliffs ranging from ten to over one hundred feet in elevation and extending along the Strait from a point two miles west of Port Crescent to a point one mile east of Observatory Point in Freshwater Bay. Plate XIII.

Immediately south from the shore line, the entire region is so thickly covered with drift that all of the bed rock formations are deeply buried. The first reappear in the cuts along the county road in Section 16, Township 30 North, Range 8 West on the north side of Lake Sutherland. Immediately west of this point strata composed of sandstones and shales outcrop which overlie the Eocene and are believed to be of Oligocene age. To

the south of the valley formed by Lake Sutherland and Lake Crescent the Eocene rocks extend into the foothills of the Olympics. About six miles east of Lake Sutherland they are well exposed in the canyon of Elwha River. From that point eastward careful examination has not been made to determine their extent. About four miles south from Port Angeles they may be seen in Frazier Creek where they rest beneath the Oligocene sandstones and shales.

LITHOLOGY.

The rocks entering into the Eocene formations in the Port Crescent area are composed for the most part of basic igneous lavas of a basaltic character. Sandstones and shales are occasionally interbedded. The basaltic rocks vary in character, ranging from dark, fine-grained, dense lavas to vesicular and fragmental material. In many places the vesicular cavities are filled with secondary radiating crystals of natrolite which often attain a size of two inches in diameter. In a number of instances the flow lines are well exhibited in the cliffs along the shore. Often these are abruptly cut by small intrusive bodies of basalt which have forced their way up from below through the already consolidated surface flows giving the rock a much contorted appearance.

The interbedded sedimentary materials and water-worn tuffaceous materials vary considerably. The tuffaceous materials are sometimes distinctly bedded and show evidences of marine deposition. Interbedded with these there are often small lenticular bands of sandstone and shale. Sometimes the tuffs consist of a consolidated mass of heterogeneous materials ranging in size from that of a pea up to irregular sized blocks several feet in diameter. Many of the sandstones, shales, and stratified tuffaceous layers contain marine molluscan remains. These are quite numerous along the shore cliffs about one-half mile east of Tongue Point.

STRATIGRAPHY.

The contact between the Eocene formation and the overlying Oligocene sedimentaries occurs on the south shore of the

Strait of Juan de Fuca near the mouth of Whiskey Creek. From the mouth of this creek, Eocene rocks are exposed almost continuously easterly to Freshwater Bay. The upper portion of the Eocene section as exposed between the contact at Whiskey Creek and a point two miles east of Port Crescent consists of alternating marine sediments together with basaltic tuffs and flows all of which dip to the southwest. These rest upon basaltic flows of an unknown thickness. That portion of the Eocene formation in this region which can be measured is approximately 4,000 feet thick. The top of the section occurs at Whiskey Creek and the base is situated two miles east of Port Crescent.

Top of Section	Feet
Chiefly shale	380
Sandstone and small amounts of interbedded shale.....	200
Black fine grained tuff.....	130
Coarse grained massive sandstone and conglomerate.....	210
Massive agglomerate	280
Dark shale and thinly bedded sandstone.....	200
Basalt	410
Sandstone	700
Basalt	800
Basalt of unknown thickness.....	780
Base of Section	
Total.....	4090

FAUNA.

In the tuffaceous shales just east of Crescent Bay and in the sandstone layers interbedded with the tuffs at the east end of the bay are marine Tejon fossils. The following fauna has been collected:

- Anomia subcostata* Conrad
- Cardium breweri* Gabb
- Modiolus ornatus* Gabb
- Venericardia planicosta* Gabb
- Calyptrea excentrica* Gabb
- Turritella wasana* Conrad.

The same fauna occurs in a similar tuffaceous material on the southeast coast of Vancouver Island at Albert Head. The fauna is typically Tejon and of the same age as faunas in Lewis and Cowlitz counties.

GEOLOGIC STRUCTURE.

The structure of this area may be regarded as consisting of the northeast limb of a northwesterly pitching syncline. To the west of Port Crescent for a distance of twelve miles a traverse was run along the beach and careful observations made on the strike and dip at various points. These were tied in to the traverse line. The axis of this syncline intersects the shore line near Twin Post Office. Along the road from Port Crescent to Lake Crescent at a point about two miles north of Fairview Post Office outcrops of sandstones and shales are well defined. Observations made on the strike and dip in this vicinity indicate the presence of the southeastern extension of this same synclinal axis. Near the center of the north side of Lake Sutherland the Eocene basalts appear, apparently resting unconformably below Oligocene sediments. This point is assumed to be approximately the keel of the synclinal axis. The outcrop of the basaltic rocks cannot be traced on the surface northward to the coast line. The same contact, however, does occur on the coast-line about two miles west of Port Crescent and the overlying Oligocene sediments possess a northwest strike and southwest dip. The interbedded Eocene sandstones and shales have an average strike of North 70° West and an average dip of 30° to the southwest toward the axis of the syncline. This condition holds true as far east as Freshwater Bay. At one or two places in Crescent Bay, as may be seen upon the map, there are exceptions, but these may be explained as due to local faulting and slipping.

A synclinal trough trends southeasterly from Freshwater Bay and crosses Frazier or Tumwater Creek about three miles south of Port Angeles. The axis of this syncline crosses Morse Creek in Section 29, Township 30 North, Range 5 West.

In this portion of Washington during the Eocene eruptions of igneous materials were taking place almost continuously. The region around Crescent Bay was an embayment of the Eocene sea and basaltic lava flows were poured out on to the sea floor. At intervals ashes were ejected and these were afterwards worked over by the waves and redeposited as tuffaceous shales.

Similar conditions appear to have taken place as far north as Vancouver Island.

BALD HILLS AREA.

GEOGRAPHIC DISTRIBUTION.

The Bald Hills constitute a prominent topographic feature of central Kitsap County. When viewed from a distance they stand in marked contrast to the prevailing level bench topography so common to the greater portion of the Puget Sound Basin. These hills are composed of basic andesitic lavas together with small amounts of shale and sandstone all of which are of Eocene age. Outcrops of the formation are best exposed in the west central portion of the county to the south and west of Bremerton in Townships 23 and 24 North, Ranges 1 and 2 West. Accessible exposures may be seen along the shores of Sinclair Inlet immediately southwest of Bremerton.

If the glacial drift which covers the greater portion of the county were removed presumably the surface exposures of the entire southern half of the county would be composed of Eocene andesites and sediments. The lavas of the Bald Hills would directly connect with the same rocks of the Black Hills of Thurston and Mason counties as well as those of eastern Jefferson County.

CHARACTER OF OUTCROPS.

The surface exposures of the northern half of Kitsap County are entirely of glacial origin. The average elevation of the surface of this portion of the county is 500 feet above sea level. The monadnock-like ridges forming the Bald Hills have an elevation of 1,000 feet. They form the drainage divide between Hood Canal on the west and Admiralty Inlet on the east. Surrounding the Hills on all sides are very thick deposits of glacial drift. They are much thicker on the west than on the east. The Eocene formations pass beneath the drift and presumably form a part of the floor of Hood Canal and connect with the lavas near the mouth of Dosewallips River. Because of the heavy overburden of glacial deposits along the western slopes of the Bald Hills no surface outcrops of the Eocene formations occur along the eastern shore of Hood Canal in Kitsap County.

Bald Mountain ridge possesses a general trend of North 45° East, approximately parallel to Hood Canal. No exposures of basalt occur north of Bremerton. In Dyes Inlet which extends east from Bremerton to Silverdale, outcrops of the overlying Oligocene strata may be seen outcropping in the cliffs along the water's edge. To the north of this inlet no strata older than the Pleistocene glacial deposits are known to exist either in the cliffs along the shore line or inland.

On the eastern side of Bald Mountain ridge outcrops of basalt may be seen in places even as far as Sinclair's Inlet where the glacial drift has been removed by erosion. On the shores of this inlet, about two miles southwest of Bremerton in Sections 28 and 33, Township 24 North, Range 1 East, excellent exposures of the basalt may be seen. It outcrops along the shore for a distance of over one mile. At the north end of the exposure, it appears only a few feet above sea level and is overlain with glacial gravels and sand. The contact surface between the basalt and the glacial deposits exhibits fine examples of glacial grooving and scouring. Further to the southwest along the shore and near the head of the inlet a large quarry has been opened in the basaltic cliff. Here flow structure and the vesicular character of the basalt may be studied.

Southeast of Sinclair Inlet no outcrops of basalt have been noted at any point within Kitsap County. The only rocks observed are the various phases of glacial drift. To the southwest of Bremerton, towards Clifton and from there on to Dewatto the only exposures observed are of glacial origin. Basaltic lavas undoubtedly exist in this region below sea level but are so deeply buried with glacial deposits that no exposures outcrop at the surface.

LITHOLOGY.

Nearly all of the Eocene formations occurring within the Bald Hills area are composed of basaltic and andesitic lavas. Interbedded with these in a few places are narrow bands of sandstone. The prevailing lithologic character of the rock is of the typical black, fine but even-grained basalt. Associated

with this are numerous layers having a vesicular structure. The steam holes range in size from the head of a pin to over one inch in diameter. Commonly these are filled with secondary minerals such as natrolite. In a number of places and especially in Section 30, Township 24 North, Range 1 East, these amygdaloids of natrolite are very conspicuous. They are commonly referred to by the people living in that vicinity as fossil shells. In the exposures along Sinclair Inlet, southwest of Bremerton, both the fine-grained dense variety as well as the vesicular may be seen in the cliff. In those localities near the quarry where the fresher rock is continuously being exposed, these types may be studied to advantage. Here much jointing and fracturing has occurred and along these joint and fracture planes, secondary alteration is in evidence. The faces of the joint planes are commonly covered with a coating of red iron oxide. In the Bald Mountain ridge jointing is very prominent, giving rise to columnar structure. These columns are roughly hexagonal in shape and stand nearly vertical being at right angles to the lava flows. Interbedded with the basalts are occasional bands of fragmental material composed of rough angular blocks of basalt imbedded in finer tuffaceous materials. These are not, however, characteristic of the Eocene igneous materials of Kitsap County. Such sedimentary rocks as occur interbedded with the Eocene lavas are not very prominent. They have been observed only in a very few places. On the north side of Bald Hill ridge about three miles southwest of Chico in Section 12, Township 24 North, Range 1 West, sandstones may be seen in a small creek.

At this point they are cut by diabase dikes which were probably the feeders for some of the basaltic layers lying above this particular sandstone stratum. No fossils were seen in this sandstone but in so much as it is interbedded with the basaltic layers and since eruptions of basaltic lavas seem to have ended at the close of the Eocene, the sandstone may be also considered as belonging to this period.

GEOLOGIC STRUCTURE.

No very important details concerning the structure of the Eocene formations in Kitsap County can be determined. In the southern part of the county the lava flows appear to lie nearly horizontal or perhaps in gentle undulations. Extending in a direction a few degrees north of west from the entrance to Bremerton Inlet westward to Chico, there is evidence of a well-defined monocline or possibly the north limb of an anticline. This evidence is obtained from observations taken on the strike and dip of the Oligocene sandstones and shales at Restoration Point, Orchard Point and along the shores of Dyes Inlet. At least 9,000 feet of Oligocene strata are exposed and assume a persistent average strike of North 85° West with a dip ranging from 45° to 88° to the northeast. The basal beds which stratigraphically lie nearest to the Eocene basalts and which presumably rest unconformably upon the basalts are dipping nearly vertical. The actual contact between the overlying Miocene sediments and the underlying Eocene basalts is everywhere covered over with glacial drift. It seems probable that just south of this contact the basaltic layers have been folded downwards in accordance with the overlying Oligocene formations. It is possible, although there is no direct evidence to support such a view, that a nearly vertical fault plane may exist parallel with the contact. Between Quilcene and Discovery Bay in the eastern part of Jefferson County a syncline has been referred to which extends southeasterly in a general direction of South 45° East. The central part of this syncline is composed of Oligocene sandstones and shales. On the northeast and southwest flanks and lying beneath the sediments are Eocene basalts. The south limb appears to be a continuation of the Bald Hill basalts although its areal continuity is interrupted by the glacial deposits along Hood Canal. The basalts on the north side of this syncline outcrop at Hood Head and near Port Ludlow. If these outcrops were extended southeasterly they would diagonally cross the north end of Kitsap County from Port Gamble to Kingston. Because of the very thick covering of

glacial drift in this region, however, no pre-glacial rocks have been seen. It is to be presumed that they do underlie this portion of the county, though perhaps below sea-level, and if so, represent the reappearance on the north limb of the syncline of the same basaltic layers outcropping in the Bald Hills and forming the south limb of the syncline. The axis of such a syncline would extend through Township 26 North, Range 1 East, southeasterly through the north part of Bainbridge Island and thence across Puget Sound into the north part of Seattle.

BLACK HILLS AREA.

GEOGRAPHIC DISTRIBUTION.

The Black Hills are situated in the northwestern portion of Thurston County and extend into the extreme eastern part of Grays Harbor County. They involve a large part of Townships 16, 17, and 18, Ranges 3 and 4 West. They form a group of hills attaining an elevation of over 1,500 feet. They are composed almost entirely of basaltic lavas which are flanked on all sides by deposits of glacial drift.

To the north of the Black Hills, in Mason County, the surface formations are largely of glacial origin, but here and there projecting through the drift are rounded knobs of basalt exhibiting glacial scouring. It seems best to include these with the Black Hills for discussion. The north limits would then extend as far as Hoodspout on Hood Canal. The western limits would extend from Hoodspout southwesterly to Matlock and thence to McCleary in Section 11, Township 18 North, Range 5 West. From McCleary the contact between the Eocene formation and the Oligocene can be fairly determined from exposures in the creeks. It extends to Section 1, Township 17 North, Range 5 West, where it may be seen in the banks of Porter Creek. From Porter Creek it passes through Sections 12, 14, 23, 26, and 35 of the same township and range and thence due southeast to a point one mile west of Oakville where it may be seen in a Northern Pacific Railway cut. From Oakville the eastern limits of the basaltic area follow the line of

the railway past Gate to Little Rock. It then crosses the glacial outwash prairie of Thurston County to a point north of Plumb Station on the Port Townsend and Southern Railway. The basalts occurring at Tumwater Falls south of Olympia are included within this area. The northeastern limits of the area cannot be definitely determined because of the heavy overburden of glacial drift.

CHARACTER OF OUTCROPS.

Within the Black Hills the basaltic masses outcrop as high rounded hills which form the divide between those streams flowing northeasterly to Puget Sound and those flowing southwest-erly into Chehalis River and thence direct to the Ocean. This divide varies in elevation. Between Little Rock and Gate along Black River it rises abruptly from an elevation of about 200 feet to an elevation of 800 feet. It extends due north as a ridge between Bordeaux Creek and Cedar Creek into the corner where Townships 17 and 18, Ranges 3 and 4, meet. In these hills the small creeks head and flow outwards through steep canyons. Extending up Bordeaux Creek through the lumbering town of Bordeaux there is a logging railroad, along whose grade many rock cuts have been made. In these the contact between the overlying glacial drift and the surface of the basalt may be seen. These surfaces always show the effect of glacial scouring in the form of grooves and polishing. On the higher slopes of the hills west of Delphi Post Office the vegetation is very heavy, but sufficient exposures exist to indicate that they are composed exclusively of Eocene basalt. In the smaller valleys leading out from these hills the soil is always of a typical reddish color due to the oxidation of the iron bearing minerals in the basalt below.

Extending from Little Rock to Gate on the west side of the Northern Pacific railway the basaltic rock forms a very steep escarpment in contrast to the level glacial outwash prairies immediately to the southeast. From Gate this escarpment swings around and extends in a direction North 20° West ap-

proximately parallel to the Northern Pacific railway and is three or four miles to the northeast of it.

About fifteen miles northwest of Gate the general elevation of the Black Hills gradually becomes much lower and in the vicinity of Matlock they form a low divide between the Puget Sound basin and Grays Harbor. From Matlock the elevation of this divide gradually increases and soon merges into a high rugged spur of the Olympic Mountains, which passes up the south side of the south fork of Skokomish River. The elevation of the gap at Matlock is 400 feet. This broad gap lying between the Olympics and the Black Hills is thickly veneered with glacial drift, but at numerous points projecting through it are outcrops of basalt always more or less rounded and scoured. The more important outcrops are located between the railroad extending from Shelton to Cloquallam and the branch extending from Kamilchie to McCleary. These outcrops are never over five or six acres in extent. The surrounding soil is generally of a deep red color. Many of the pebbles in the glacial gravels surrounding them are composed of the same material. These knobs are often at an elevation of twenty-five feet above the surrounding glacial drift. Numerous outcrops of these basaltic areas may be seen along the old logging railway track and also along the county road extending from Shelton to McCleary.

If the glacial drift of the Black Hills and the area northward to Hoodspport were completely removed it is very probable that the basalt would continue northward and directly connect with that occurring from Hoodspport northward to Quilcene and also with that in the Bald Mountain area of Kitsap County.

In Tumwater Canyon just south of Olympia the Des Chutes River has cut its canyon down through the drift and into the basaltic rock. This basalt, while not areally connected with that in the Black Hills to the west, is a continuation of it, the intervening area being covered with glacial gravel and sands.

Occasionally basalt may be seen outcropping in the eastern part of Thurston County and in the valley of Nisqually

River, as well as along the divide between the head waters of the Des Chutes and Skookumchuck rivers. These eastern basaltic areas are probably in reality the eastward extension of those in the Black Hills. The two areas are separated by the glacial outwash prairies south of Olympia.

To the northeast of the Black Hills among the inlets at the head of Puget Sound no basaltic formations outcrop at the surface. The only surface formations are glacial drift. Eocene basaltic masses may underlie Hartstine Island, McNeil Island, Carr Inlet and Tacoma, but there is no means of obtaining information concerning their character or structure. No deep well borings are available to determine how far below sea-level the upper surface of the basalt exists.

LITHOLOGY.

The Eocene formations within the Black Hills area are for the most part composed of igneous material. Occasionally interbedded sandstones and shales containing carbonaceous seams occur. The igneous materials consist of dense fine grained black basalt together with basaltic tuffs and vesicular layers, many of which are filled with amygdules of secondary natrolite. In places basaltic material of diabasic structure may be seen in the form of dikes cutting through the basaltic layers illustrating the methods by which the molten lavas reached the surface. These amygdaloidal phases of the basalt outcrop just north of the county road at Delphi, about seven miles southwest of Olympia. In the Black Hills proper and in the hills surrounding Bordeaux the basalt is of the fine grained, black, dense variety, ringing when struck with a hammer and breaking with a conchoidal fracture. In the exposures between Little Rock and Gate along the Northern Pacific Railway the basalt is often coarse grained and vesicular. In places in the ridge between Bordeaux and Gate, pyroclastic materials are interbedded with basaltic flows. These, however, are not a very conspicuous feature among the basalts of the Black Hills area.

The basaltic rock in Tumwater canyon south of Olympia is of the typical variety, ranging from fine to medium grained.

In the northern part of the area, in the vicinity of New Kamilchie, Cloquallam and thence northward to Shelton, the small knobs of basalt which outcrop are nearly always very fine grained and dense in appearance, and usually much weathered and altered. Extending into the rock several inches from the joint plains are masses of soft red material, largely composed of iron oxide. The rock itself is usually, even in the fresher portions, more or less altered.

About 1,000 feet west of Gate City in one of the small creek canyons leading up into the Black Hills, are exposures of sandstone and shale, containing low-grade coal seams. The sandstones are coarse grained, and have a yellowish brown color. They commonly show cross bedding and are presumably of estuarine origin. The shales are thinly bedded, of a brown color not very hard. In places there are beds of slightly carbonaceous shales interbedded with the sandstones. In Section 26, Township 16 North, Range 4 West, a seam of impure coal outcrops in the banks of a small creek which at this point has carved its canyon down through the sandstone leaving the igneous rock on either side. The sedimentary rocks are distinctly interbedded with basalts.

GEOLOGIC STRUCTURE.

Because of the absence of interbedded sedimentary rocks or stratified tuffaceous materials it is very difficult to determine the structure over the larger part of the Black Hills area. In the northern part of this district the basaltic outcrops form only isolated knobs, the intervening country being heavily covered over with glacial drift, thus rendering it impossible to actually connect any suggested structure from one outcrop to another. At the locality just west of Gate City where observations on the strike and dip of interbedded sandstones have been taken, the basalts along with the sedimentaries appear to be folded into a northwest-southeast direction. It is possible that the Black Hills, which trend northwest to southeast, may represent an anticlinal fold or warp, or possibly a series of closely folded

anticlines and synclines. Although there is no conclusive evidence on this point, the former is the more probable.

Along the western contact of the basalt in the Black Hills area, sandstones and shales of Oligocene age are resting unconformably upon the former. The sediments have a strike approximately parallel to the contact. This is nearly north and south with a low dip to the west ranging from 9 to 11 degrees. These Oligocene sandstones and shales constitute the east limb of the syncline whose axis trends nearly parallel to Chehalis River between Oakville and Elma. The basalt lying along the western margin of the Black Hills must form a part of this eastern synclinal limb. To the northeast of Olympia such structural relations as may exist among the basaltic flows are entirely obscured by the very heavy overburden of glacial drift. The lava formations are below sea-level. To the southwest of the high ridge exposed between Little Rock and Gate the greater part of the country is involved in glacial outwash prairies. In places along railroad, stream, or wagon road cuts the older bed-rock Eocene formations are exposed. The Eocene formations here contain a larger amount of sedimentary material in which igneous flows are interbedded.

ELK CREEK AND CHEHALIS RIVER AREA

GEOGRAPHIC DISTRIBUTION.

This area is situated in the southwestern corner of Lewis County in Townships 13 and 14 North, Range 6 West. It embraces the drainage area of the south branch of Chehalis River and Elk Creek. The belt is traversed by the Willapa Harbor branch of the Northern Pacific Railway. The areal boundary lines of the formation have in certain places been definitely established. In many other localities because of insufficient outcrops the contact has been only approximately drawn. The bed-rock formations of the entire drainage area of Elk Creek are almost entirely composed of basaltic rock. Beginning at a point one mile west of Pluvius on the railway in Section 3, Township 12 North, Range 6 West, the contact between the Eocene and Oligocene swings about North 45° West and follows along the

high ridge which forms the divide between Elk Creek on the east and Mill Creek, Wilson Creek and the head waters of North River on the west. At the head of Martin Creek, one of the tributaries to North River, the contact swings northeasterly, crosses the Lewis-Chehalis County line in the southeast quarter of Section 7, Township 15 North, Range 5 West and appears in the railway cut of the Grays Harbor branch of the O.-W. R. R. & N. Co. in Section 5 of the same township and range. It passes thence into the Black Hills area already described. The south boundary of the area may be arbitrarily chosen as the Lewis-Cowlitz County line. The areal outcrops of this formation extend much farther south, but for purposes of description they will be considered in connection with the Columbia River area. The eastern contact of this belt is very indefinite. Along the south branch of Chehalis River and from Pe Ell southward, basaltic rock outcrops. These exposures are conspicuous in the high ridge immediately east of the river. On the eastern side of this ridge in the valley of the headwaters of the main branch of Chehalis River the bedrock formations disappear from view. The entire country is covered with very thick deposits of non-consolidated sands and clays. The last bed-rock outcrops to appear are basalts. In the intervening area between the valley of the main branch of Chehalis River from Ceres to Wildwood on the west and the main line of the Northern Pacific on the east, occasional outcrops of bed-rock formations may be seen in the small canyons. These outcrops are partly of Eocene sedimentary origin and partly of Oligocene and will be described in the Cowlitz River area. It seems best to construct the eastern areal contact of the Elk Creek-Chehalis area on the eastern side of the valley of the main Chehalis River from Wildwood northward to Boistfort and from thence to a point on the Willapa Harbor branch of the Northern Pacific two miles west of Adna. From Adna the contact extends northwesterly along the divide between Bunker Creek and Chehalis River. Sedimentary rocks probably of Eocene age outcrop on Bunker Creek and contain carbonaceous seams. From the head of Bunker Creek the con-

tact extends about North 10° West past the head waters of Lincoln and Independence creeks and on the north side of the latter in Section 26, Township 15 North, Range 5 West, swings northeasterly and appears in the railway cut of the Oregon-Washington Railway and Navigation Co., in Section 10, Township 15 North, Range 4 West. It then passes under the alluvium of Chehalis River Valley and connects with the basaltic area at Gate in the Black Hills area.

CHARACTER OF OUTCROPS.

That part of the area under consideration south of the Willapa Harbor branch of the Northern Pacific Railway is mountainous in character and very inaccessible. It is densely timbered and logging has not been attempted on any large scale. Along the south branch of the Chehalis River due south from Pe Ell rock outcrops are abundant. They are almost entirely composed of basalt. Occasional bands of sandy shale are interbedded. In Section 10, Township 11 North, Range 5 West, quartz veins occur in the basalt. These are said to carry low values in gold and have been mined on a very small scale.

Along the line of the Willapa Harbor branch of the Northern Pacific Railway in the canyons of Chehalis River, outcrops of basalt are very common. Along the divide in the vicinity of Pluvius, Rock Creek and McCormick, the river has cut its channel into bed-rock. The surface exposures, however, are more commonly composed of thick deposits of Pleistocene clays and sands. At various intervals from Pe Ell to Doty and from Doty to Meskill, basalt with occasional interbedded layers of sandstone and shale are very conspicuous.

A traverse line was run from Doty westerly to the head waters of Elk Creek. The surface rocks in this drainage basin are for the most part composed of gravels, sands, and clays. Through these, Elk Creek has carved its course and exposed along its bed outcrops of basalt. These are exposed in places along the creek for a distance of six miles west of Doty. From there westerly to the head of the smaller branches of the creek the boulders along its course are composed of basalt. On the

headwaters of North River in the north half of Township 14 North, and the southeast quarter of Township 15 North, Range 6 West, basaltic outcrops make their appearance.

DIVIDE BETWEEN COLUMBIA AND WILLAPA RIVERS AREA.

GEOGRAPHIC DISTRIBUTION.

The Eocene formations occurring within this area involve a belt approximately twelve miles in width and thirty miles in length. The belt extends diagonally from Willapa Harbor across Pacific County southeasterly to the point where Lewis, Cowlitz, Wahkiakum and Pacific counties meet. Its northeastern contact with the Oligocene sedimentaries crosses North River in Section 31, Township 16 North, Range 9 West. It continues southeasterly through a country where rock outcrops are very scarce and consequently the line as drawn upon the maps is only approximate. Between the towns of Raymond and South Bend its position is more definite. A quarry has been opened in the Eocene basalts one and one-half miles northeast of South Bend in Section 23, Township 14 North, Range 9 West, and one-half mile east of this locality Oligocene sandstones and shales form prominent outcrops. From South Bend the contact trends about South 40° East and crosses Trap Creek two miles south of Holcomb Station in Section 11, Township 12 North, Range 8 West. It continues more nearly east along the west-east center line of Township 12 North, Range 7 West and then turns north crossing the railway about one mile west of Pluvius Station.

The southwestern contact of this belt is near the north end of Shoalwater Bay. From this point it trends nearly South 40° East. It passes through Sections 26, 27 and 28, Township 11 North, Range 9 West, and nearly due east across the center of Township 11 North, Range 8 West, and finally enters Wahkiakum County. It can be observed on the left fork of Grays River and near the head of Fossil Creek.

In Section 11, Township 10 North, Range 7 West, a small tongue shaped spur trends southwesterly for a distance of five miles. This narrow band is about one and one-half miles in width. In the south part of Section 13, same township and



Eocene Basalts on East Side of Cape Disappointment as Viewed From Ilwaco.

range, the contact extends nearly due east through the center of the township just east, and crosses the head waters of the several branches of Skamokawa River. It crosses the left and right branches of Alockaman River in Sections 21 and 23, Township 10 North, Range 5 West, and extends into Cowlitz County.

CHARACTER OF OUTCROPS.

This broad belt of the Eocene formation, whose areal limits have just been defined, occupies the divide between the drainage flowing northerly to the Willapa River basin and that flowing southerly to the Nasel and Columbia River basins. This divide ranges in elevation from two hundred to fifteen hundred feet above sea-level. It is very heavily timbered and in places at the headwaters of the several creeks there are steep escarpments. Disintegration of the rock formations has produced a very thick covering of soil which, together with the accumulations of vegetable material, render rock exposures difficult to find. In addition to these deposits produced by weathering there are formations of clays and sandy clays, together with gravels somewhat bedded and very loosely consolidated. These vary in thickness, ranging from a few feet to over 100 feet. No fossils are found in these and they undoubtedly represent river deposits formerly laid down over this region when it possessed a much lower elevation than it has today.

As this divide gradually approaches Shoalwater Bay and Willapa Harbor the Eocene formations become thickly covered with Pliocene or Pleistocene sands, gravels and clays. Along the shore at Bay Center, the mouth of Nemah River, and at Bruceport, the young horizontally bedded sediments are well developed and only in a few places back from the shore do the bed-rock formations outcrop.

Exposures of Eocene basalt may be seen in the city of South Bend and just south of town on the trail to Nemah. One of these outcrops, within the city limits, is being quarried for road material. In the several street cuts of the city the nearly horizontal Pleistocene clays may be seen overlying the basalt.

From South Bend a wagon road extends almost due south for a distance of five miles and then continues as a trail on to Nemah River. For the first three or four miles south of the city limits, the country is comparatively flat and about two hundred feet above sea level. Numerous small creeks have cut their canyons into this flat surfaced country and where the trail passes along the walls of these small valleys exposures of bed-rock may be seen. In every case these are of basalt. At the point where the trail crosses the north fork of Nemah River outcrops of sandy shale may be seen in its bed and along its banks. The material is massive in character and no strike and dip could be obtained. These are believed to be interbedded with the basalts. From Nemah postoffice a road extends up the middle fork of Nemah River for a distance of five miles. At several points along the river the same sandy shale outcrops. In the northwest corner of Section 30, Township 12 North, Range 9 West the road crosses from the south to the north side of the river. In the road cut about 500 feet south from the bridge, exposures of sandy shales and shaly sandstones are well developed. Observations on the strike and dip were taken at this point and yielded the following data: Strike North 20° West, dip 30° to the southwest. Thence the road continues on for some distance and then becomes a trail which has become grown over so as to be no longer usable. Observations were made on the character of the rock up to the head of the river and such exposures as could be seen were of sandy shale.

From South Bend a road extends southwesterly to the Palix River. The greater part of this distance is covered with late Pleistocene sands and shales. In several places, however, the bedrock, consisting of basalt, is exposed.

In the high ridge extending from Nemah Harbor southeasterly and lying between South Nemah and Nasel rivers there are exposures of basalt. These are usually heavily covered with sands and clays. The majority of the exposures occurring along the banks of Nasel River are of Oligocene age. On a small creek in Section 33, Township 11 North, Range 9

West, basaltic outcrops are well developed, and interbedded with these are sandstones. In Section 20, Township 11 North, Range 8 West, the contact between the basalts and overlying sandstones and shales crosses Nasel River. From this point northward the river flows through a gorge with steep rocky slopes. A second gorge is well developed from the junction of the north fork of Nasel River and the main stream. This continues easterly a little over one mile to the point where Alder Creek enters Nasel River. About 500 feet up Alder Creek north from its junction with the main Nasel River, volcanic tuffs, together with shales, are interbedded with volcanic lavas. They have been much disturbed by faulting and contain marine fossils. A traverse line was run to the head waters of Alder Creek over the main divide and thence down to Trap Creek. Along the Alder Creek portion of the traverse such exposures of bedrock as were seen were composed entirely of basalts. All the boulders and stream pebbles were of the same material. Along the main divide the bedrocks are heavily covered with sands and clays and a dense growth of forest. In places boulders and blocks of hard, massive, brown, coarse grained sandstone were occasionally seen. They seem to be portions of interbedded layers of sedimentary rocks between the basaltic flows.

On the north side of the divide in the valley of Trap Creek very few exposures of bedrock occur. The boulders in the streams are almost entirely composed of basalt. The hill slopes are thickly covered with residual soil in addition to the Pliocene sands and clays. Small outcrops of basalt were seen on the north side of Trap Creek about three miles south of Willapa River. In Section 3, Township 12 North, Range 8 West, at a point where the main trail crosses Trap Creek, sandy shales outcrop in the bank of the river. They have a strike of North 20° East and dip 30° to the northwest. Further observations were taken on sandstones and shales in Sections 1 and 12, same township and range, and from their lithological character they were thought to be of Oligocene age and the basaltic contact has been drawn just south. The sandy shale mentioned as occur-

ring in Section 3 is probably a sedimentary layer interbedded within the basalts.

About one mile west of Holcomb basalts form prominent outcrops along the Northern Pacific Railway grade and continue over the Willapa-Chehalis divide to Pe Ell. West of the contact rock exposures are not well developed, but such as do occur are a part of the overlying Oligocene formation.

A traverse line was run from the Northern Pacific Railway at Raymond southward, up the south fork of Willapa River and detailed observations made on the various outcrops along the traverse. In the north half of Section 6, Township 13 North, Range 8 West, the basalt contact was found to cross the river, to extend southeasterly and again recross it in the west half of Section 8, the same township and range. On the northeast side of the contact marine fossiliferous sandstones and shales of Oligocene age were seen dipping at an angle of 35° to the northeast. Within the basaltic areas extending southwesterly from the contact, numerous bands of sandstones and shale occur interbedded with the basaltic layers. No fossils could be found within these. Stratigraphically downwards from the Eocene-Oligocene contact the interbedded sedimentaries become less numerous and much thinner, and ultimately entirely disappear. In every case the upper limit of the basalt has been chosen as the contact between the Eocene and Oligocene formations. The interbedded sandstones and shales are regarded as belonging to the Eocene. Future detailed studies may prove that a part of the basalt belongs to the Oligocene.

On the left fork of Grays River, Oligocene sandstone and shales were found to outcrop as far as the boundary line between Pacific and Wahkiakum counties. The basaltic contact occurs approximately on the line between Section 5, Township 10 North, Range 7 West, and Section 32, Township 11 North, Range 7 West. Near the contact, layers of basalt interbedded with sandstones and shales begin to outcrop. In places layers of tuffaceous material are interstratified. For a distance of one-half mile north of the contact the sediments are quite commonly interbed-

ed with the basalts. Beyond that point basalt predominates. About one-half mile north of the junction of the left fork of Grays River and the main branch, on the former, the contact may again be seen. South of this contact the lower Oligocene shales and sandstones are well developed in the river banks, dipping southerly away from the basalt. Just north of the contact sandstones are interbedded with the basaltic layers. At this point, on the east bank of the river, a small diabase dike cuts the sedimentary rocks. Along the upper branches of the left fork of Grays River tuffaceous layers are very conspicuously interbedded with the basaltic flows. On the main branch of Grays River in Section 20, Township 11 North, Range 6 West, about two miles north of Blaney Creek the tuffaceous and shaly layers outcrop very prominently. Marine fossils are very common in the shales. The shales are somewhat baked and never exceed over 100 feet in thickness. The creek flows through a very narrow valley and at a point near the junction of Blaney Creek flows through a gorge of basaltic rock. The headwaters of the several branches of Grays River lie entirely in basaltic areas. The fossiliferous shales above mentioned are lower Oligocene.

The contact between the basalts on the east and the overlying fossiliferous sandstones on the west occur in Section 11, Township 10 North, Range 7 West. The basaltic hills trend southwesterly and form the divide between Grays River on the north and the west fork of Skamokawa River on the south. This divide is about 500 feet in elevation and thickly covered with Pliocene sands and clays, although basalt outcrops in places.

On the main fork of Skamokawa River, basalts occur in the hillside throughout the north half of Township 10 North, Range 6 West. The creek valleys are commonly filled in with gravel and sand, but the basalts outcrop on the divides. The exact position of the contact could not be determined, but has been approximately drawn midway between the last outcrops of sedimentary rocks and the first outcrops of basalt.

On Wilson Creek, which enters the main branch of Skamokawa River in Section 29, Township 10 North, Range 6 West, exposures of sedimentary formations occur at various points up to the basalt contact which lies in Section 24, Township 10 North, Range 6 West. The sedimentary rocks consist of isolated exposures along the river banks until the river valley flattens out and no more outcrops are seen. From that point northward the boulders in the creek are composed entirely of basalt and such exposures in the hills as are not covered with Pliocene sands and clays are also composed of basaltic rock. The contact has been drawn at this point as may be seen upon the accompanying maps. To the east of Wilson Creek in Township 10 North, Range 5 West, outcrops of basalt are common. The contact between this formation and the marine Miocene rock to the south crosses the left fork of Alockaman River in the south half of Section 22, Township 10 North, Range 5 West. Near the contact in the basalt some mining development work has been done upon small quartz veins said to carry low values in gold. This contact crosses the right fork of the river about two miles due east. To the north on the headwaters of the Alockaman River and on the divide leading over the headwaters of the south branch of Chehalis River the rock formations are entirely of basalt. The divide has an elevation of over 1,500 feet and the several branches of both rivers flow through deep gorges cut into the basalt.

LITHOLOGY.

The Eocene formations along the divide between Willapa River and the Columbia are composed for the most part of basaltic lavas and tuffs. Interbedded with these are shales, sandy shales, shaly sandstones, and sandstones. The basaltic lavas appear in various phases, ranging from the fine-grained, dense black specimens to the highly vesicular types. Mixed with these are fragmental layers in which huge angular blocks range in size from a few inches to several feet in diameter. These are imbedded in the finer grained basalts and all show the effects of flow action. The sandstones are coarse-grained,

of a grayish brown color and fairly hard, but not widely distributed.

GEOLOGIC STRUCTURE.

The structure of the area under consideration is very complex. In its broad general features there is an anticline trending approximately North 40° West from Willapa Harbor, but in the vicinity of the headwaters of Grays River it turns and extends nearly due east along the divide between the headwaters of the Alockaman and the south branch of Chehalis River. Along Willapa River on the northeast side of the anticline the overlying Miocene rocks are dipping to the northeast at angles ranging from 7° to 35° . On the south side of the anticline on Salmon and Nasel, Gray and Alockaman rivers, the average angle is 30° to the southwest, but ranges from 3° to 60° in various places.

CATHLAMET-GERMANY CREEK AREA.

GEOGRAPHIC DISTRIBUTION.

The area involved in this district lies on the north side of Columbia River in the southeastern part of Wahkiakum County and southwestern Cowlitz County. It embraces the northwest corner of Township 8 North, Range 3 West, and the north halves of Townships 8 North, Ranges 4, 5, and 6 West, the west half of Township 9 North, Range 3 West, and the lower two-thirds of Townships 9 North, Ranges 4, 5, and 6 West. The south limits of the district are defined by Columbia River and the north limits by an east-west belt of marine Oligocene sedimentary rocks. The north contact between the Eocene basalts and the Oligocene sedimentaries begins about one mile north of Skamokawa. From this point it extends nearly due east for three miles and then turns southeasterly and crosses Alockaman River in the north half of Section 32, Township 9 North, Range 5 West. Here it swings around on the east side of Alockaman River, and in Section 10 swings back again to the west side of the river, and then recrosses in Section 2 of the same township and range. It crosses from Wahkiakum into Cowlitz

County and may be traced across the head waters of Abernathy and Germany creeks. In Section 18, Township 9 North, Range 3 West the overlying Oligocene sediments thin out and disappear and the basalts are areally connected with those in the Coal Creek and Arkansas Creek areas which lie to the east and northeast.

CHARACTER OF OUTCROPS.

Almost the entire area of this district is composed of basaltic rock. It is not always exposed at the surface, however, because of the extensive covering of Pleistocene sands and clays. The elevations range from a few feet to 1500 feet above sea level. The area is dissected by several streams heading to the north near the Cowlitz-Lewis County line and flowing southward into the Columbia. These streams have developed valleys varying from a few hundred feet to over two miles in width. In most instances, however, the valley floors are covered with alluvium. Here and there exposures of basalt may be seen in the stream banks.

Detailed traverses were run along Alockaman, Skamokawa, Cameron, Abernathy, Germany and Mosquito creeks and from observation taken along these traverse lines the areal geological data as shown on the maps accompanying this report, have been obtained.

From Oak Point a logging railway owned by the Oak Point Piling Company extends up Cameron Creek for a distance of seven miles from its mouth. For the first two miles outcrops of basalt are very numerous. The valley here is very narrow with steep slopes on either side composed of basaltic cliffs.

For the next three miles the basalt exposures are not so prominent but may be seen wherever any grading has been attempted along the railway track. The basalts in the hills back from the track are covered with clay. At a point five miles up the creek a basalt cliff, having an elevation of 50 feet, occurs on the east side of the track. At this point on the surface there is about two feet of yellowish clay followed by several inches of black bituminous material which is in turn covered with a sandy clay. From the results of examinations made to

the west, this appears to lie between two basaltic flows, the upper one of which in this particular place has been removed by erosion. The soil in the vicinity of the creek is of a reddish color and is clearly derived from the underlying basalts. The traverse was extended up the creek two miles further and no more outcrops of basalt were seen. Such exposures as occur in the banks of the creek or around upturned tree trunks show a light colored clay. From the general appearance of the soil, however, the underlying bedrock is undoubtedly basalt to the head waters of the creek.

From the mouth of Abernathy Creek the Wisconsin Logging and Lumber Company's railroad extends up the stream for a distance of nine miles to the forks of the creek in Section 6, Township 9 North, Range 4 West. At this point the main track leaves the creek and veers off in a northwesterly direction for a distance of three miles. Frequent exposures of basalt occur over the entire distance to the forks of the creek. In a number of places there are steep basaltic cliffs showing well developed columnar jointing. From the forks of the river northwesterly in Wahkiakum County no further exposures of basalt were seen. However, there are numerous cuts along the track in which clays appear. These are a bright reddish-yellow, white and cream color. At a point about two and a half miles west of the river in Section 1, Township 9 North, Range 5 West, this clay is underlain with a bed of yellow sand, massive in character and with no bedding plains. These may be a part of the interbedded Eocene sedimentary formations, or possibly of late Pliocene or Pleistocene origin. In many places these are directly overlain by basaltic flows.

At a point about one-half mile west of the forks of the creek already referred to the same characteristic clay occurs, included in which are angular fragments of light pinkish colored rock which when closely examined is found to be a distinctly altered vesicular basalt. In places these clays appear to be tuffaceous.

An examination was made of the upper branches of the creek to their headwaters. Only one outcrop of basaltic rock

was seen in place. However the pebbles and boulders in the creek are composed of fine-grained black basalt which occasionally is vesicular.

A detailed traverse was made along Germany Creek from the point where it empties into Columbia River at the town of Stella to its headwaters in the center of Township 10, Range 4 West. At a point about one-fourth mile northwest of Stella along the wagon road on the east side of the creek the basaltic rock is well exposed. Two distinct flows appear at this place. The upper is a hard dense black rock, the lower is soft, much decomposed and in places distinctly tuffaceous, often assuming a yellow to creamish color.

The county wagon road extends up Germany Creek for a distance of four miles. Examinations made along this road, except in the immediate vicinity of Columbia River, yielded very few outcrops of bed rock. Wherever exposures were seen, however, they were entirely composed of basalt. In those localities where bedrock was not observed the surface soils were very heavily iron-stained and the pebbles and fragments found in them were composed of very badly weathered basalt.

Farther north in Section 1, Township 9 North, Range 4 West, at a point where a small creek comes in from the west, a massive brown sandstone outcrops. No observations on strike and dip could be obtained here. Further examinations made up the creek near its headwaters, indicate the bed rock to be basaltic in character.

LITHOLOGY.

The Eocene formations in the area just described are almost entirely composed of basaltic and andesitic lavas. Such sedimentary rocks as occur with them consist of very narrow bands of shale or sandstone intercalated between the flows. These are commonly more or less carbonaceous. The basalt as seen along Columbia River present a series of horizontal layers resting one above the other. The contact surfaces between these layers are slightly undulating. These layers vary considerably in general appearance, some being light and others dark, some

having been extensively weathered and others appearing hard, dense and fresh. Some of these bands are distinctly tuffaceous, others are vesicular and still others show well-defined flow structure. In numerous places along the river cliffs there are seams of clay between the individual lava flows often over two feet in thickness and in these there are sometimes very thin seams of carbonaceous materials. These facts indicate that the different bands represent individual lava flows. The clays lying between the different flows indicate that a considerable length of time intervened between the outpouring of each successive flow sufficient to allow extensive weathering of the rock prior to the outpouring of the next lava sheet. The presence of carbonaceous material between these layers indicates the growth of vegetation during the quiescent periods.

GEOLOGIC STRUCTURE.

Very little detailed information is at hand concerning the structure of the Eocene formations within this area. Such data as have been collected suggest that the formations have not been greatly disturbed since their deposition. They lie nearly horizontal with very gentle undulations. These undulations are not sufficiently prominent to be regarded as minor synclines and anticlines. On the north side of the belt an east-west synclinal trough has been developed. In the center of it the Miocene sedimentary rocks are also folded. These latter lie to the north of the district and will be considered in the discussion of the Oligocene areas.

Because of the very thick veneer of Pleistocene sands, clays and gravels which overlie the bed rock Eocene formations, faulting is very difficult to detect. Minor fault plains ranging from a few inches to two or three feet are common, but are local in character. They have no prevailing direction.

ILWACO AREA.

GEOGRAPHIC DISTRIBUTION.

Eocene formations outcrop prominently in the high rugged rocky point at the north entrance to Columbia River. About three square miles of territory are involved.

The rocks outcropping in the point south of Ilwaco attain an elevation of 200 feet above sea level. The west side of this headland is directly exposed to the waves of the Pacific Ocean. Two points jut out into the ocean, namely North Head and McKenzie Head. Even at the lowest tides it is impossible to pass around these points but between them are coves with broad gravelly beaches and back of these beaches the elevations are comparatively low, forming shallow divides with the area on the eastern side of the cape. The eastern shore is more or less protected from the action of the ocean and in recent years shoaling has occurred to such an extent as to build up prominent sand spits. This high rocky cape ends abruptly immediately west of the town of Ilwaco and the country from that point northward is largely composed of low hills of Pleistocene gravels. Near the ocean a sandbar has been developed to the north for a distance of fifteen miles.

LITHOLOGY.

The rocks involved in Cape Disappointment are entirely of Eocene age and composed of varied types of lava flows, interbedded shales and sandstones, tuffaceous layers and fragmental material. The surface of the cliffs are covered with polygonal shaped blocks, due possibly to contraction at the time of cooling. A similar condition prevails on the north side of McKenzie Head. Along the eastern shore of Ilwaco Point about one-half mile south of the town of Ilwaco, shales and sandstones are interbedded with the lava. On their upper surfaces where they come in contact with other basaltic flows they are baked and slightly metamorphosed. In places, especially at a point one mile north of Fort Canby barracks, both the volcanic layers as well as the sandstones and shales are cut by diabase dikes. On the opposite side of Ilwaco Point north of McKenzie Head similar shales appear interbedded with basalt. Here they are badly baked, twisted and squeezed as on the eastern side. About one-half of the entire assemblage of volcanic materials occurring in this area is composed of tuffaceous and fragmental rocks.

These are firmly cemented and always show considerable alteration. (Plates XIV and XV.)

GEOLOGIC STRUCTURE.

Because of the crushing which the Eocene rocks in Ilwaco Point have undergone, the detailed structure is difficult to determine. Observations taken on strike and dip of the interbedded shales on the eastern side of the point show an average strike of nearly north and south with a dip ranging between thirty and fifty degrees to the east. Just east of this point and one-half mile east of Ilwaco prominent exposures of interbedded shales and sandstones outcrop on the beach. These have an average strike of North 30° East, and dip about 57° West. There are no volcanic materials in this locality and they are presumably younger than the Eocene. If so, there would appear to be a fault trending nearly north and south through the town of Ilwaco which has thrown the strata on the eastern side of Ilwaco Point downwards.

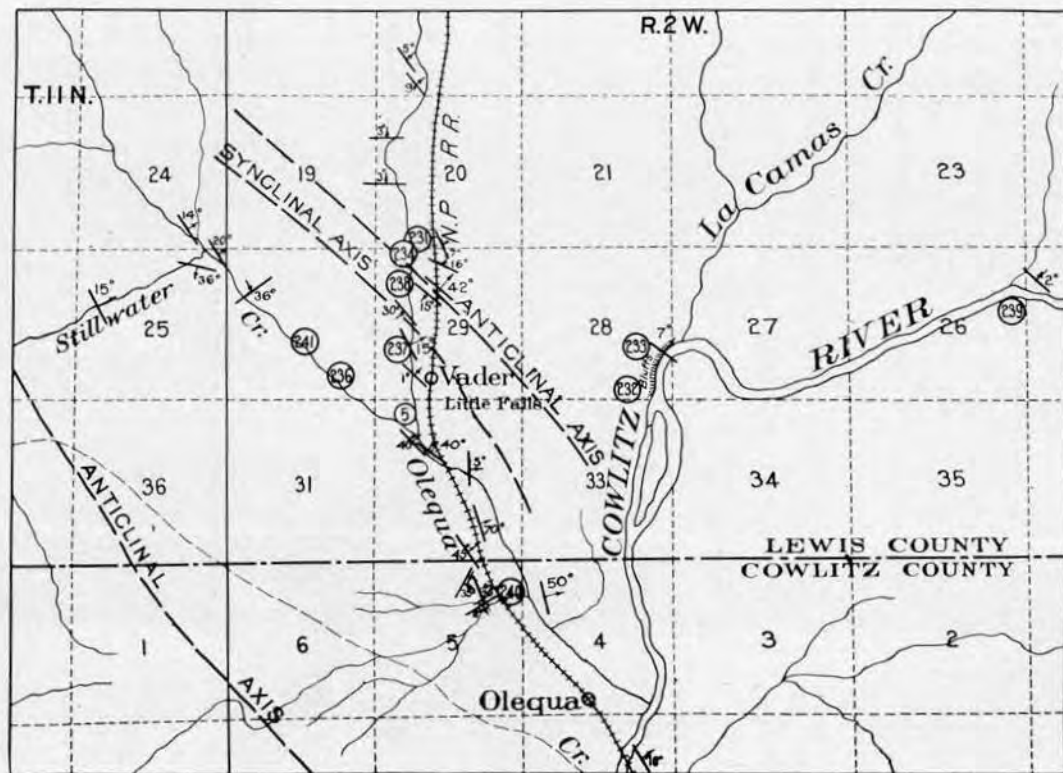
LOWER COWLITZ VALLEY AREA.

GEOGRAPHIC DISTRIBUTION.

The area involved in this particular district is situated in the Cowlitz River valley and extends from the town of Castle Rock northward to Winlock, a distance of about fifteen miles. The larger part of this distance is traversed by Cowlitz river which trends nearly north and south, but in Section 28, Township 11 North, Range 2 West, it turns abruptly and extends nearly due east toward the summit of the Cascades. At the town of Winlock, Olequah Creek occupies a wide valley, trending a little west of south to the town of Vader where it joins Stillwater Creek. Farther south the latter creek empties into Cowlitz River.

CHARACTER OF OUTCROPS.

Both sides of the valleys just mentioned are bordered by low wooded hills. The entire region has been more or less heavily covered with Pleistocene gravels and sands. These have in part been subsequently cut into and removed by the existing streams. Along the banks of Cowlitz River and also along those of Still-



Geological and Structural Map of the Region at the Junction of Olequa and Stillwater Creeks, Lewis County.

water and Olequah creeks there are occasional outcrops of Eocene formations. The Northern Pacific Railway grade from Castle Rock to Winlock lies very close to Cowlitz River and also to Olequah Creek. At a number of localities the railway cuts have exposed the Eocene strata. A traverse line has been extended along the railway track and also along both Stillwater and Olequah creeks. All of the Eocene exposures have been tied in so that their exact position has been located. Observations have been taken on strike and dip at every point possible and tied into the traverse line, as may be seen on Plate XVI.

Beginning at the town of Castle Rock and extending northward for a distance of two miles the only rock exposures are horizontally bedded gravels, clays and sands of Pleistocene age. Near the junction of Toutle and Cowlitz rivers basalts and sandy shales are found interbedded. The basalts occur distinctly as flows and exhibit well-defined columnar structure. Near the base of these flows the lava is somewhat tuffaceous and agglomeratic. From Toutle River northward for two miles the Eocene formations are not exposed. The first outcrops encountered, however, are interbedded basaltic flows and shales. Immediately south of the railway crossing of Cowlitz River an extensive basaltic flow appears having a strike of North 30° West and a dip of 10° to the northeast. After crossing Cowlitz River the Northern Pacific Railway grade extends along the west side of Stillwater Creek to the town of Vader. Exposures of Eocene rock are to be found in the railway cuts for a considerable part of this distance. The formation as here exposed consists of interbedded marine and brackish water sandstones and shales together with interbedded basalt flows. The prevailing strike of the formation in this vicinity is North 30° West with dips to the northeast ranging from 20° to 80° . This portion of the formation is stratigraphically higher than that just mentioned on the railway crossing on the Cowlitz and Toutle rivers. It lies stratigraphically below the Eocene ex-

posures extending up Stillwater Creek from its junction with Olequah Creek.

From the junction of Olequah and Stillwater creeks exposures of the Eocene formation extend almost continuously up the former creek to Winlock. No igneous rocks of any nature were found in this portion of the series. The prevailing type of rock is a shale or sandy shale, partly marine and partly of brackish water origin. The strata have a predominate northwesterly strike with a very low average dip to the northeast. In section 28, Township 11 North, Range 2 West at the big bend in Cowlitz River, steep cliffs of shale are exposed for a distance of one-half mile. These contain an extremely rich marine Tejon fauna represented by fossil localities Nos. 232 and 233. The strata at this locality have a strike of 45° to the west and dip at an angle of 8° to the northeast. The intervening area between this locality and Olequah Creek is entirely covered with Pleistocene gravels and sand. The same strata, however, appear to cross Olequah Creek in Section 8, Township 11 North, Range 2 West. At this point on Olequah Creek a similar, although not so complete, marine Eocene fauna occurs. At a point about one mile south of Winlock station in the banks of Olequah Creek shales are exposed, containing a marine invertebrate fauna somewhat different from the underlying Tejon. A number of Oligocene species occur, such as *Nucula dalli* n. sp., *Solen parallelus*, and *Macrocallista pittsburgensis* Dall. The strike of the strata at this point is North 20° West and the dip 4° to the northeast. Just north of Winlock station similar strata are exposed having a strike of North 75° West and a dip of 22° to the northeast. These shales contain a fauna having Miocene characteristics.

STRATIGRAPHY.

The lowest Eocene beds exposed in the area under discussion are to be found in the railroad cuts at the Toutle River railway crossing. The strata outcropping from this point northward to the Cowlitz river railway crossing are successively stratigraphically higher. The same condition holds true from

Olequah northward to Winlock. Altogether approximately eight thousand feet of strata are involved. The contact between the Eocene and Miocene is at a point about one and one-half miles south of Winlock. Whether the two formations are unconformable or not, could not be determined. The strike and dip of the two are approximately the same. It is possible that deposition went on continuously from Eocene to Miocene and that the non-fossiliferous shales intervening may be Oligocene.

GEOLOGIC STRUCTURE.

The predominant structure in the Cowlitz Valley region is that of a northeasterly pitching monocline. From Castle Rock northward to the railway crossing at Cowlitz River the prevailing strike is nearly east and west with a low dip ranging from 4° to 12° to the north. At a point several hundred feet south of the Cowlitz River railway crossing, the Eocene strata make a sharp turn and strike to the northwest in a direction approximately North 30° West, with a low dip to the northeast. At a point about 1,000 feet north of Vader there is a slight buckling of the strata in the flank of this northeasterly pitching monocline. The buckling is sufficient to form a very shallow anticline, trending North 40° West and crossing Olequah Creek about three-fourths of a mile north of Vader. The strata exposed at the axis of this buckle or anticline reappear at the surface on Olequah Creek near its junction with the Stillwater.

North of Winlock Eocene exposures are heavily covered with Pleistocene sands and gravels. Occasional outcrops of sandstone occur resting horizontal. They first reappear highly tilted and pitching to the south in the vicinity of Chehalis. It is probable that a broad synclinal trough trending northwest and southeast occupies the intervening area between Winlock and Chehalis and that the extreme lower portion of the Oligocene may lie in this depression.

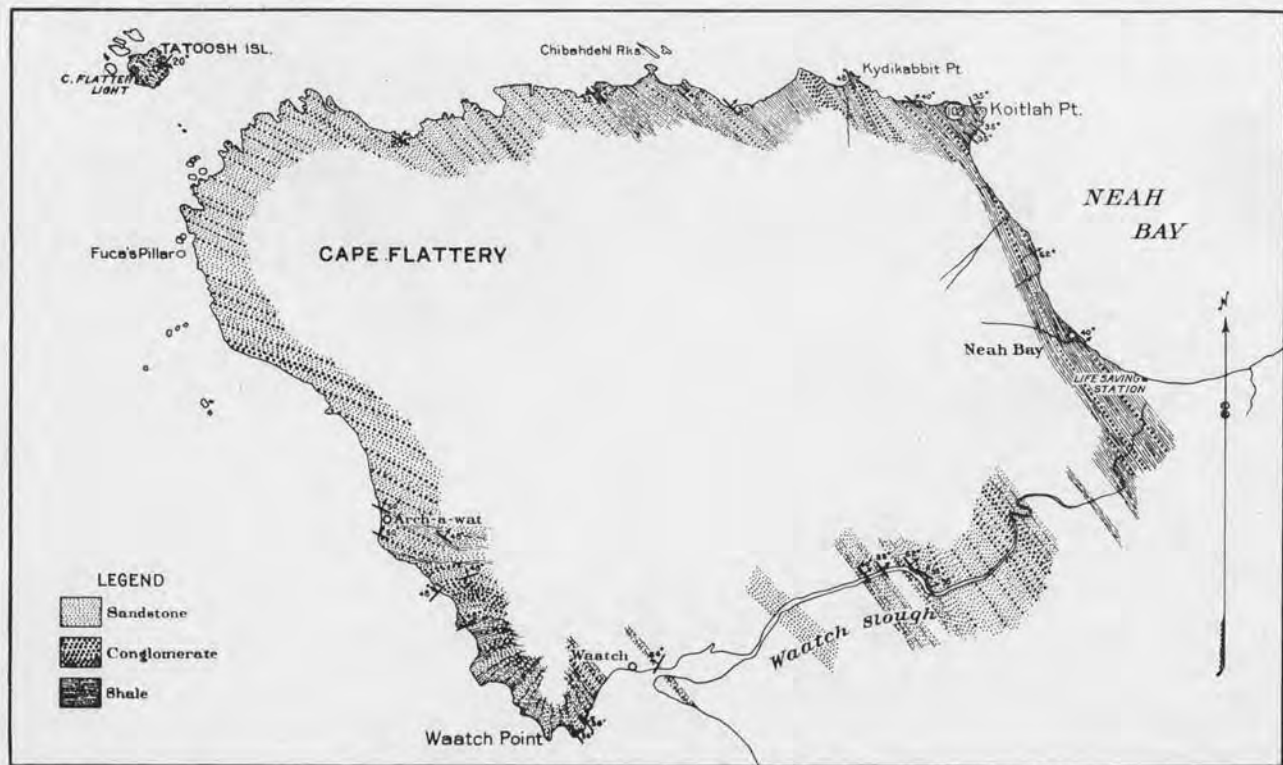
CHAPTER 4. OLIGOCENE FORMATIONS.

GENERAL STATEMENT.

The use of the term Oligocene as applied to marine formations of the Pacific Coast is involved in controversy. Early investigators of west coast geology divided the Tertiary into the Eocene, Miocene and Pliocene periods. Later studies showed that a well defined and widely spread unconformity existed in the middle Miocene. Certain deposits which had formerly been regarded as Miocene were found to contain a fauna possessing Eocene as well as Miocene characteristics. Such deposits were finally regarded as being the same age as the Oligocene of Europe. At the present time there is no general agreement on the west coast as to where the line between the Oligocene and lower Miocene shall be drawn.

In the western portion of North America extensive lacustrine and land deposits were in existence during the Oligocene epoch. From these deposits a rich fossil mammalian fauna has been collected. Detailed studies have been made on the evolutionary development of these forms of life and as a result it is possible to recognize several divisions of the Oligocene. Unfortunately up to the present time it has not been possible to correlate the Oligocene land deposits of the Great Basin and Rocky Mountain regions with the deposits of marine origin in western California, Oregon and Washington.

During the past twenty years certain fossiliferous strata occurring at Astoria, Oregon, have been recognized as Oligocene. The shales and sandstones exposed along the south shores of the Strait of Juan de Fuca and at the entrance to the Bremerton Navy Yard have in part been referred to as Oligocene. Poorly preserved faunas have been found in shales in the Coast Ranges south of San Francisco and have been described as the San Lorenzo formation. This formation is regarded as Oligocene and the Oligocene strata of Washington and Oregon have in part been correlated with it.



Geological and Structural Map of Cape Flattery.

Oligocene deposits of western Washington are for the most part of marine origin. They have a total aggregate thickness of 15,000 feet and occur along the south side of the Strait of Juan de Fuca, in the Puget Sound Basin and in southwestern Washington. Marine faunas are abundant and constitute several faunal zones. The term Clallam formation is applied to these strata.

FAUNAL ZONES.

Three faunal zones are recognized in the Oligocene of western Washington. The strata containing each of these faunas are referred to as horizons. The faunal zones beginning with the oldest are the *Molopophorous lincolnensis* Zone, the *Turritella porterensis* Zone and the *Acila gettysburgensis* Zone. The corresponding sedimentary horizons identified by these zones are designated as the Lincoln, Porter and Blakeley. The faunas occurring in each of the above zones are distinct and many of the species do not range into the zones above or below. There does not seem to be sufficient evidence at the present time to warrant subdividing the Oligocene into three formations.

MOLOPOPHOROUS LINCOLNENSIS ZONE.

The type section in which this zone occurs is situated in southwestern Thurston and northwestern Lewis counties, and occupies an area of about 40 square miles. The distribution as indicated upon Plate III is only approximate. The contact lines have been drawn upon the basis of very poor field evidence. It is quite possible that certain shales occurring in Chehalis County on Porter Creek in Sections 11 and 14, Township 17 North, Range 5 West, may contain a fauna belonging to this zone. The sandy shales outcropping in the banks of Olequah Creek in Sections 28, 29, 30, 31, 32 and 33, Township 12 North, Range 2 West, near Winlock, are presumably a part of the Lincoln Horizon.* The surface outcrops are limited and are included on Plate III with the Tejon formation. The covered area in Kitsap County, between the Eocene basalts exposed at Charleston and the shales

*After the printing of the maps Oligocene fossils were discovered.

and conglomerates at Rich Passage, may also in part belong to this horizon.

The most characteristic species of this zone are: *Acila schumardi* Dall, *Cardium lorenzanum* (Arnold), *Crassatellites washingtonensis* Weaver, *Glycimeris chehalisensis* Weaver, *Pitaria dalli* Weaver, *Macrocallista pittsburgensis* Dall, *Dentalium substramineum* Conrad, *Calyptraea excentrica* (Gabb), *Exilia dickersoni* (Weaver), *Exilia lincolnensis* Weaver, *Hemifusus washingtonensis* Weaver, *Drillia hecoxi* (Arnold), *Natica lincolnensis* Weaver, *Molopophorous lincolnensis* Weaver, *Strepsidura washingtonensis* Weaver, and *Turris thurstonensis* Weaver.

The following species are common to the marine Tejon occurring at locality 1 on Cowlitz River east of Vader and the *Molopophorous lincolnensis* Zone: *Crassatellites washingtonensis* Weaver, *Leda gabbi* Conrad, *Solen parallelus* Gabb, *Dentalium substramineum* Gabb, *Calyptraea excentrica* (Gabb), *Exilia dickersoni* (Weaver), *Hemifusus washingtonensis* Weaver, and *Strepsidura oregonensis* Dall.

The following species are common to the *Molopophorous lincolnensis* Zone and the *Turritella porterensis* Zone: *Cardium lorenzanum* (Arnold), *Crenella porterensis* Weaver, *Dentalium substramineum* Gabb, *Drillia hecoxi* (Arnold), and *Natica washingtonensis* Weaver.

Such forms as *Marcia oregonensis* Conrad, *Phacoides acutilineatus* Conrad, *Thyasira bisecta* (Conrad), and *Thracia trapezoidea* Conrad are entirely absent from the *Molopophorous lincolnensis* Zone, although they are among the most characteristic species in the *Turritella porterensis* Zone at Porter. The fauna as a whole is distinct from the Tejon fauna below and the *Turritella porterensis* Zone above.

TURRITELLA PORTERENSIS ZONE.

The type locality in which the deposits containing this fauna occur is located in Grays Harbor County, in Township 17 North, Range 5 West. Fossiliferous marine strata occur along the bluffs of Chehalis River both east and west of the town of

Porter as well as on Porter Creek. Similar deposits occur at different localities on Lankner Creek to the south of Chehalis River in Township 17 North, Range 6 West. The faunas of this zone are distinctly different from the underlying Molopophorous lincolnensis Zone as well as the Acila gettysburgensis Zone of the Puget Sound region. The most common species occurring in this zone are: *Cardium lorenzanum* (Arnold), *Crenella porterensis* Weaver, *Malletia chehalisensis* Arnold, *Marcia oregonensis* (Conrad), *Thracia trapezoidea* Conrad, *Thyasira bisecta* (Conrad), *Phacoides acutilineatus* (Conrad), *Drillia hecoxi* (Arnold), *Exilia lincolensis* Weaver, and *Turritella porterensis* Weaver.

Those forms which are common to the Molopophorous lincolnensis Zone and to this zone have already been mentioned. Many of the species occurring in this zone are very common to the Acila gettysburgensis Zone and it is possible that the extreme lower portion of the stratigraphic section exposed at the entrance to the Bremerton Navy Yard may be the equivalent of the upper beds at Porter. Such species as *Acila gettysburgensis* Reagan, *Macrocallista vespertina* (Conrad), *Modiolus directus* Dall, *Panope generosa* (Gould), *Eudolium petrosum* Conrad, *Turricula washingtoniana* Dall, and *Turritella porterensis* Weaver which are very characteristic of the Acila gettysburgensis Zone are entirely absent from the Turritella porterensis Zone. The dark colored shales exposed three miles west of Port Crescent in Clallam County may belong to the Porter Horizon.

ACILA GETTYSBURGENSIS ZONE.

The type section of the Acila gettysburgensis Zone is to be found within the strata outcropping at the entrance to the Bremerton Navy Yard. Excellent exposures containing marine fossils occur at the south end of Bainbridge Island as well as on the opposite shore to the south. The deposits consist of interbedded massive conglomerates and medium grained sandy shales possessing a thickness of at least 9,000 feet. The lower-

most strata which are exposed outcrop at Orchard Point and the highest on the north shores of Blakeley Harbor. Detailed stratigraphic surveys show that the conglomerates at Orchard Point are below the sandstones and shales at Bean Point on Bainbridge Island and that the beds at Bean Point are about 2,000 feet below the fossiliferous strata at Restoration Point. The fauna occurring within the lower portion of the Bremer-ton Inlet section are identical with those at the well known locality just north of Restoration Point.

The *Acila gettysburgensis* Zone is represented within the city limits of Seattle, Newcastle Hills, Cathcart and along the Strait of Juan de Fuca from a point two miles west of Gettysburg westerly to a point halfway between Twin River and Pysht. The conglomerates and overlying shales exposed along the north portion of Cape Flattery and along the Strait of Juan de Fuca easterly to the mouth of Sekiu River also contain faunas belonging to this zone.

The species most common to this zone are: *Acila gettysburgensis* Reagan, *Macrocallista vespertina* (Conrad), *Marcia oregonensis* (Conrad), *Modiolus rectus* Dall, *Panope generosa* (Gould), *Phacoides acutilineatus* (Conrad), *Spisula albaria* (Conrad), *Solemya ventricosta* Conrad, *Tellina oregonensis* Conrad, *Thracia trapezoidea* Conrad, *Thyasira bisecta* (Conrad), *Crepidula praerupta* Conrad, *Eudolium petrosum* Conrad, *Miopleiona indurata* Conrad, *Turricula washingtoniana* Dall, and *Turritella blakeleyensis* Weaver.

A list of the species known to occur in the Oligocene and lower Miocene of western Washington follows. This table also includes a list of species occurring at the more important localities. A reference list of the localities may be referred to on page 299.