WASHINGTON

GEOLOGICAL SURVEY.

HENRY LANDES, STATE GEOLOGIST.

VOLUME I.

ANNUAL REPORT FOR 1901.

OLYMPIA, WASH.:
GWIN HICKS, . . . STATE PRINTER,
1902.

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Late Professor of Mining Engineering and Metallurgy, University of Washington.

LETTER OF TRANSMITTAL.

To His Excellency, HENRY MCBRIDE, *Governor of the State of Washington and President of the Board of Geological Survey:*

SIR — I have the honor to present herewith the annual report of the State Geological Survey for the year 1901. It embraces a preliminary account of the geology and mineral resources of the state, to which is added a bibliography of the literature referring to Washington geology. It is hoped that this report, while very general in its nature, may serve as a basis for more elaborate and detailed reports in future years.

Very respectfully,

HENRY LANDES, *State Geologist.*

UNIVERSITY OF WASHINGTON,
SEATTLE, March, 1902.

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PREFACE.

In the Creation of a State Geological Survey, which constitutes the first chapter of Part I of this report, after some mention is made of the causes leading up to the inauguration of a Survey, a copy of the law is then given. This law is modeled after that of older states where geological surveys have been in progress, and emphasizes the economic rather than any other side of geology. Some mention is also made of the organization of the Board of Geological Survey and the selection of a survey staff to whom the actual work of the Survey is entrusted. An account of the field work of the first season is included, together with some statements concerning the office work of the State Geologist, and a word in regard to the expenses of the Survey.

In An Outline of the Geology of Washington, or the concluding chapter of Part I, a resume is given of the present knowledge of the geology of the state. It is planned to afford a sort of bird's-eye view of the topography and the geological formations, in order that the detailed work of the future may be planned with intelligence. It is thought worth the while to include a map upon which an attempt has been made to outline the larger geological formations. The boundaries of the different formations have, as a rule, been accurately determined only in a few places, and between these points the lines of separation are mainly conjectural. Nevertheless it is believed that the geological map will prove of help to all those whose work brings them in contact with the state's geology.

In the article on the METALLIFEROUS RESOURCES OF WASHINGTON, EXCEPT IRON, which comprises Part II of this volume, only an outline or sketch of the subject is attempted, preparatory to detailed descriptions of the various mining districts that will be given in later reports. Some of the representative or typical metalliferous deposits are described, selected here and there from the large area in which the metallic minerals are known to occur. No attempt is made to classify the ore deposits according to their mineral contents, but the usual products such as gold, silver, copper, lead, etc., are all described together. This is done because of the peculiar intimate association of these minerals, one with another, in the veins of ore.

The geographical classification of the metalliferous deposits is that by counties, districts and mines. The district boundaries as given in this report are largely those of convenience, and they may vary considerably from those established by law or custom. The proper outlines of the districts will be given when these are later described in detail. In this article the name of the writer of each section is placed at the beginning of it, except that the State Geologist has been responsible for the preparation of the article as a whole, and all unsigned sections have been written by him. The names of the persons who have given the information contained in the minor parts are placed in brackets at the end of the paragraph.

The NON-METALLIFEROUS RESOURCES OF WASHINGTON, EXCEPT COAL, or Part III, contains a brief discussion of six mineral products, viz.: building and ornamental stones, clay materials, limestone, soils, road-making materials, and petroleum.

In the few pages devoted to building and ornamental stones, some reference is made to the geographical distribution of these products, and the best developed quarries are hastily described. While the building and ornamental stones of the state are of great importance, but scant attention is given them in this report because it is planned that they shall be the subject of an extended and exhaustive article in the report for 1902.

While clay is an important resource, the matter pertaining to it is chiefly limited to descriptions of a few of the leading plants concerned in the manufacture of clay products. As in the case of building stone a complete account of the clay resources of the state will be given in the next annual report.

Limestone for lime-making is one of the state's leading mineral resources. Large deposits of excellent limestone occur at many places in Washington. The lime-burning industry is already well developed, and at the present time large quantities of lime are exported from Washington to all the neighboring states, to California and to Hawaii.

Soils come under the head of non-metalliferous, or mineral resources, because they are derived directly from rocks. In this article soils are treated from the geological standpoint, and the close connections between the rock formations and the different varieties of soils is shown.

Road-making materials are valuable resources wherever they occur, and Washington is fortunate in possessing throughout the state road metals of superior quality. Road construction on the most scientific basis is receiving a great deal of attention now-a-days in the older states, and Washington with her splendid materials should be a leader in the grand movement toward good roads.

Petroleum, at the present time, is not one of the state's determined mineral resources. The subject receives some consideration in this report because of the wide-spread interest in oil prospecting, and because of the many inquiries as to whether or not there is any possibility of oil being found in different parts of the state. There are some parts of Washington where the correspondence in age, composition and structure between the rocks here and those of the oil-bearing districts of California is very striking. In such localities of the state, especially where there are good surface indications, prospecting for oil may be looked upon as well worth the while.

In the IRON ORES OF WASHINGTON, by S. Shedd, which embraces the first chapter of Part IV, the subject is treated more exhaustively than is the case with any other part of this report. A description is given of all the known occurrences of iron in the state, together with complete analyses and comparisons with ores found elsewhere. In the field work necessary to the preparation of the article on iron ores, two seasons were occupied by Professor Shedd and his assistants. The field work was all done prior to the inauguration of the State Geological Survey, and the entire expense of it was borne by the State Agricltuural College and School of Science.

The article on the COAL DEPOSITS OF WASHINGTON, by Henry Landes, which concludes Part IV, is a brief description of the coal fields and coal mines of the state. While the general geology of the subject is touched upon, along with the extent of the coal areas, etc., the commercial phase of the subject receives the most emphasis. At the present time coal constitutes by far the most important mineral resource of the state, and the treatment accorded it in this report is regarded as wholly inadequate. The present article is but a temporary treatment which it is planned to replace by a thorough and extended one a little later.

The WATER RESOURCES OF WASHINGTON, or Part V of this report, deals with the potable and mineral waters, artesian waters and the water power of the state.

In POTABLE AND MINERAL WATER, by H. G. Byers, some statements are made concerning drinking water in general, followed by a discussion and the analyses of the drinking water of the various cities of the state. Comparisons are made with certain potable waters found elsewhere. Descriptions are given of the principal mineral springs, including analyses of their waters, temperature, etc. At the time this article was written some of the mineral springs were inaccessible, and hence cannot be described until a later report. A partial study was made of the alkali lakes in the hope that the water might be sufficiently concentrated to be of economic value. From the analyses such does not appear to be the case.

In Artesian Water, by C. A. Ruddy, after some general statements concerning artesian basins, the leading artesian districts of eastern Washington are described. In any arid district the possibility of artesian water is a matter of great interest because of the necessity of water for irrigating purposes. It is hoped that there will be an opportunity for investigations throughout the arid and semi-arid portions of central Washington, so that all the artesian basins may be discovered and described, in order that their storehouses of water may be unlocked.

In Water-Power, by R. E. Heine, after some introductory statements concerning the latent water-power of the state, brief descriptions are given of the best known water-power plants. All of these plants have been only lately put in operation, and it is thought that they but mark the beginning of a development which will prove a tremendous factor in the commercial advancement of the state.

The Bibliography of the Literature Referring to the Geology of Washington, which comprises Part VI of this report, was written chiefly by Mr. Ralph Arnold, of Stanford University. After the manuscript was received from Mr. Arnold, a number of references were added by Professor Milnor Roberts. This bibliograpy has been prepared with great thoroughness and care, and it is believed to be practically complete. While many of the articles are out of print, or else are to be found only in the larger libraries, it will be noticed that the most important papers mentioned are of a late date and as a rule easily procured. Professor Roberts has prepared brief notes upon some of the articles, stating the substance of their contents, where they may be secured, cost, etc. It is hoped that this bibliography of Washington geology, the first to be prepared, may be found useful to all students of the subject.

PART I.

CREATION OF A STATE GEOLOGICAL SURVEY.

AND

AN OUTLINE OF THE GEOLOGY OF WASHINGTON.

BY

HENRY LANDES.

CREATION OF A STATE GEOLOGICAL SURVEY.

INTRODUCTION.

In her gifts to the State of Washington, Nature has been exceedingly generous. She has endowed the young commonwealth with resources many and varied, and already our citizens are coming to a realization of the material wealth which surrounds them. The fertile soil with which a large portion of the state is blessed is leading to a great development along agricultural lines; the extensive and magnificent forests of evergreens are conducive to lumbering and manufacturing on a large scale; the many fine harbors, advantageously located, point to a large and increasing commerce; the waters teeming with fish hold within their depths great riches; while the large mountainous area in which useful and precious metals abound contains in itself enough to make Washington a wealthy state, if correct and accurate knowledge of its mineral resources is made accessible to the public. In order that these resources lying hidden in the earth may be made known to our own citizens, and to any others who may wish to take a part in the building up of the state, it is necessary that a careful and systematic study should be made of our economic minerals. Thus it came about that, in response to a general demand of those interested in the development of the mineral resources of the state, the Legislature of 1901 passed a law providing for a Geological Survey of Washington, and appropriated money for the carrying on of the same. Following the plans of some of the older states in which geological surveys have been of great utility and benefit it was provided that the work of the survey for the present at least should be as practical as possible; that the economic minerals should be studied first of all; and that the results of the survey work should be embodied in reports and bulletins from time to time and disseminated among the people.

THE LAW ESTABLISHING THE SURVEY.

Be it enacted by the Legislature of the State of Washington:

SECTION 1. There is hereby established a State Geological Survey of the State of Washington, which shall be under the direction of the Board of Geological Survey of the State of Washington, which is hereby established, composed of the Governor, the Lieutenant Governor, the State Treasurer, the President of the University of Washington, and the President of the Washington Agricultural College and School of Science, who shall serve without compensation, but shall be reimbursed for actual expenses incurred in the performance of their official duties, and the said board shall have general charge of the survey, and shall appoint as superintendent of the survey a geologist of established reputation, to be known as the State Geologist, and upon his nomination such assistants and employes as the said board may deem necessary, and the said board shall also determine the compensation of all persons employed by the survey, and may remove them at will.

SEC. 2. The said survey shall have for its object:

(1) An examination of the economic products of the state, viz., the gold, silver, copper, lead, and iron ores, as well as building stones, clays, coal and all mineral substances of value.

(2) An examination and classification of the soils, and the study of their adaptability to particular crops.

(3) The investigation and report upon water supplies, artesian wells, the water power of the state, gauging the streams, etc., with reference to their application for irrigation and other purposes.

(4) An examination and report upon the occurrence of different road building material.

(5) An examination of the physical features of the state with reference to their practical bearing upon the occupations of the people.

(6) The preparation of special geological and economic maps to illustrate the resources of the state.

(7) The preparation of special reports with necessary illustrations and maps, which shall embrace both the general and detailed description of the geology and natural resources of the state.

(8) The consideration of such other kindred scientific and economic questions as in the judgment of the board shall be deemed of value to the people of the state.

SEC. 3. The board shall cause to be prepared a report to the Legislature before each regular meeting of the same, showing the progress and condition of the survey, together with such other information as they may deem necessary and useful or as the Legislature may require.

SEC. 4. The regular and special reports of the survey, with proper illustrations and maps, shall be printed as the board may direct, and the reports shall be distributed or sold by the said board as the interests of the state and of science demand; and all money obtained by the sale of the reports shall be paid into the state treasury.

SEC. 5. All materials collected, after having served the purpose of the survey, shall be distributed by the board to the University of Washington, the Washington Agricultural College and School of Science, the normal schools, and the leading high schools of the state in such a manner as to be of the greatest advantage to the educational interests of the state.

SEC. 6. The Board of Geological Survey shall meet for organization within thirty days after the passage of this act. The regular meetings of the board shall be held on the first Wednesday in April and the first Wednesday in November of each year.

SEC. 7. The sum of five thousand dollars ($5,000) annually, or so much thereof as may be necessary, is hereby appropriated out of any funds out of the treasury not otherwise appropriated for the purpose of carrying out the provisions of this act.

SEC. 8. "An act to create a mining bureau, and to define its powers and duties, and declaring an emergency," approved February 25, 1890; also "An act to create the office of a State Geologist, prescribing his duties and compensation, and making an appropriation for the same, and declaring an emergency," approved February 28, 1890, are hereby repealed.

ORGANIZATION OF THE BOARD OF GEOLOGICAL SURVEY.

In accordance with the law, and at the call of the Governor, the following gentlemen: Governor Rogers, Lieutenant Governor McBride, State Treasurer Maynard, President Graves of the University of Washington, and President Bryan of the

Agricultural College and School of Science, met upon June 5, 1901, at Tacoma, and organized the Board of Geological Survey of the State of Washington. Permanent organization was effected by electing Governor Rogers as president of the Board, and State Treasurer Maynard as its secretary.

The first important business of the board was the selection of the survey staff. Professor Henry Landes, of the University of Washington, was chosen State Geologist, with Professors Solon Shedd and W. S. Thyng, of the Agricultural College and School of Science, and D. A. Lyon of the University of Washington, as geologists. Charles E. Gaches, George W. Evans, Louis Pohle and Lewis D. Ryan were appointed field assistants for the season of 1901.

The board voted that members of the survey staff should receive no salaries other than a small *per diem* allowance for time actually spent in the field work of the survey. The president and the secretary of the board were authorized to pass upon the accounts of the State Geologist and to draw upon the State Auditor for the payment of the bills approved by them.

FIELD WORK OF 1901.

In order that the citizens of the state may be informed as to what the survey attempted to do in its first field season, the general scheme of the summer's work is here set forth and somewhat elaborated. It was thought advisable to do first of all such field work as would be required in order to prepare a general statement of the mineral resources of the state. With this end in view, the major part of the season was spent in reconnaissance work, studying the geological formations, examing the mines of gold, silver and copper, making maps and sections of the coal fields, examining with care the building and ornamental stones, and collecting other data for the first report, which should be devoted chiefly to a description of the state's mineral resources. It was also planned to gather such data during the first season as would be needed in the preparation of some special bulletins on the coal fields, building and ornamental stones, clay materials, and on one or two of the most prominent mining districts of the state. In order to carry on the plans outlined above, three parties were placed in the field. These were equipped so that they might move with as great rapidity as possible and thus be able to cover a large part of the state in the time at their disposal. Necessarily the work was of a reconnaissance order, and only a little attention could be given to details. The personnel and scope of work of the three parties will now be mentioned.

The first party was composed of the State Geologist, D. A. Lyon, C. E. Gilman, Lewis Ryan, Charles Landes and J. W. P. Dunlap. About July 1st, after having provided themselves with the necessary horses and camp equipment, they began work at Republic. Here they remained about ten days, studying the mining geology of the district. The party then proceeded north to Curlew, visiting several properties on the way. The next move was to the Myers creek district and thence to Oroville and Loomis. At the latter place some time was spent visiting and studying the best developed mines in the Palmer mountain district. From this point the party proceeded to the Methow by way of Conconully. From the Methow they moved up the Twisp river, over Twisp pass to Bridge creek, and down the Stehekin to the head of Lake Chelan. From this point the mines on Railroad creek were visited. From Lake Chelan the party passed to the Horseshoe basin, thence over Cascade pass and down the Skagit to Marblemount. Barron was next visited and an examination was made of the mines on Slate and Thunder creeks and thereabouts. Returning down the Skagit to Hamilton, some time was spent in studying the coal field of that region. The boundaries of this field were approximately determined, as were those of the Cokedale field as well. Blue Canyon was next visited, and here some time was spent in determining the boundaries of that large coal field, and in studying the outcrops of coal which occur at several places northward and eastward of Lake Whatcom. While the party were camped at Keese a detachment under the leadership of D. A. Lyon visited the principal mines of the Mount Baker district. The last move of the party was to LaConner where the horses were to winter, and here the work of the party closed for the season.

The second party, consisting of Professor Solon Shedd as geologist and George Evans and Louis Pohle as field assistants, spent the season mainly in an examination of the building and ornamental stones of the state, paying some attention to the clay materials as well. They began work at Spokane in the last days of June by making an examination of the granite quarries about Spokane and Medical Lake. Then came an investigation of the marble and serpentine which is found at Valley station and elsewhere in Stevens county. Finishing their work here, they then moved to Western Washington, where the remainder of the summer was spent in a study of the building stones and clays of that region. Tenino, Wilkinson, Index, Chuckanut and Sucia Island were visited, as well as many other places where stone of desirable character for building purposes was known to exist.

Professor W. S. Thyng, who made studies upon several mining districts during the summer, began his work upon the mines in the districts about Silverton, Monte Cristo, Goat lake, Silver creek and Index. From Index he went to the Carbon river district to examine the copper mines located there. He finished his work by an examination of the Cedar canyon district in Stevens county.

OFFICE WORK.

It is a fact acknowledged by every one who has had any experience in the matter that the hardest and most exacting work of a Geological Survey is that of the office. It is here that the field notes must be most carefully elaborated, the minerals and rocks collected during the summer must be identified and described, and numerous analyses made of the same; maps and sections must be prepared for illustrating the subject matter of the bulletins and reports; and great care must be exercised in every direction in order that the reports may be complete and accurate in every respect.

Since the inauguration of the survey, a considerable portion of the time of the State Geologist has been taken in making replies to inquiries from our own citizens and from many outside the state, who desire information concerning our mineral resources. It is of course necessary that these replies be carefully prepared, so that the demands of our citizens and of outside capitalists may be fully met. While the correspondence has already reached large proportions, it will doubtless reach a greater volume when the fact that Washington has a Geological Survey becomes better known.

One important part of the work of the Geological Survey is the identification of minerals and rocks sent in by prospectors and mining men. Such specimens will be examined and promptly reported upon if the following rules are observed: 1st. A specimen should weigh not less than one-half pound and should be taken from as great a depth as possible. 2d. Each specimen must be accompanied by a statement of the exact location where it is found, and a description of the mass as a whole from which it came. 3d. The specimen must be sent prepaid, with the name of the sender plainly written upon the package, and addressed to the State Geologist, University Station, Seattle, Washington.

It must be patent to every citizen that no assays or chemical analyses can be expected from the office of the State Geologist. In the first place no provision is made for any such work in the law creating the Geological Survey. In the second place the sampling or selection of ores for assays or analyses is of the greatest importance, and usually an average sample is not taken, so that the assay or analysis indicates very little as to the real value of the mineral deposit. In the third place the cost of making such assays or analyses by the survey would be so very great that its resources would be largely consumed in this work alone, and the sender only would be benefited and not the state.

EXPENSES OF THE GEOLOGICAL SURVEY.

The amount appropriated by the Legislature of 1901 for the carrying on of the work of the Geological Survey was five thousand dollars per annum. For all moneys paid out in the prosecution of the work of the survey vouchers are taken in duplicate. These vouchers pass through the hands of a committee of the Board of Geological Survey, and upon their approval one set passes to the State Auditor, while the duplicate set is retained by the board. The appropriation above mentioned must provide for the entire expenses of the survey, not only for the field work but for the printing of all reports and the mailing of the same.

The cost of doing field work in Washington is probably fully as great, if not greater, than that of any other state in the Union, because of the extreme ruggedness of large parts of the state and the difficulties in the way of transportation. It is, therefore, only by practicing the most rigid economy and by getting a large amount of work done without any attendant compensation that it is possible to attain even moderate results.

RELIEF MAP OF WASHINGTON, BY SOLON SHEDD.

AN OUTLINE OF THE GEOLOGY OF WASHINGTON.

The following brief account of the geology of Washington must be regarded as general and at the same time provisional. It is thought desirable at this time to make some preliminary statements concerning the state as a whole, in order to pave the way for the detailed work of the future. Up to the present time it is only at a few points, often widely separated, that the geology of the state has been studied with thoroughness and with an attention to details. Not until all parts of the state have become readily accessible, and especially not until complete topographic maps have been made, will it be possible to carry on all of the investigations necessary to formulate a complete and detailed account of Washington geology.

The most important work on the geology of Washington has been done by the United States Geological Survey, mainly by Messrs. Bailey Willis, I. C. Russell, and George Otis Smith. In the Bibliography of Washington Geology, comprising part 6 of this volume, will be found a list of the contributions to the geology of the state that have been made by the above mentioned geologists and others. In the preparation of this article all printed reports on the geology of Washington that were accessible have been freely drawn upon, and an attempt has been made to give full credit in every case. The writer has been engaged for several seasons in geological field work in various parts of Washington, and much of the result of his work on the general geology of the state is embodied herein.

TOPOGRAPHY.

Before an intelligent discussion of the geology of Washington can be had, it is necessary that some statements concerning the topographic features of the state should be made. In time to come, when the geology is better known than it is now, the topographic features as a result will be much better understood; and consequently, when topographic maps shall have been made of the entire state, the details of its geology will be made out with much greater ease than is possible at the present time.

A visitor to Washington cannot but be immediately impressed by the very great diversity of physical features which the state possesses. From the low plains which are found along the 3,000 miles or more of coast line it is possible within a short space of time to ascend to heights on which the snow remains throughout the year. The far reaching influence of such great differences in the topography of the state are readily observable. Not only is a varied scenery produced, but of necessity there follows a great variation in the climate, rainfall, soil, vegetation, and occupations of the people in the different topographic provinces of the state.

A study of the relief map which accompanies this report will make it clear that the physical features of the state may be divided into six provinces. Passing from the Pacific ocean inland these divisions are: Olympic Mountains, Puget Sound Basin, Cascade Mountains, Okanogan Highlands, Columbia Plain, and Blue Mountains. It must be understood, of course, that no hard and fast lines separate these provinces. The border line is always arbitrary and difficult of exact location. Another fact to be noted is that without exception these provinces extend beyond the boundaries of the state, overlapping into the adjoining states. The provinces already noted are capable of subdivision into smaller and yet smaller areas which can receive but scant attention in these pages.

OLYMPIC MOUNTAINS.

These mountains should be regarded as merely a segment of the general coastal range which extends northward and southward beyond the confines of the state. They reach their greatest development in Washington in the triangular shaped area bordered by the ocean, the Straits of Fuca and the arms of Puget sound. Their highest peak is Olympus, which has an elevation of about 8,000 feet, and is the first point of land to be recognized by navigators when approaching the coast of Washington from the westward. The Olympics when seen from any point of view exhibit a labyrinth of serrated ridges and sharp peaks. Standing as they do in the path of the moist westerly winds, and rising to a considerable height above the sea, these mountains are visited by an excessive precipitation.

The Olympics have been but little explored and reliable information concerning them is very meager. It is known, however, that they are well nigh impassable because of their extremely broken and dissected character. The divides are exceedingly sharp and difficult to follow. The rivers flow in deep canyons with walls which in many instances can not be scaled. On the whole the streams of these mountains seem to be approaching the stage of maturity in their development.

The southern extension of the Olympics consists merely of hills or ridges rising as a rule not more than 1,500 feet above the sea. In fact so inconspicuous are they in the topography of the southwestern part of the state that the term mountains is not usually applied to them. They have been cut in two by the Chehalis and Columbia rivers.

PUGET SOUND BASIN.

The Puget Sound basin lies between the Olympic and Cascade mountains, its longer axis having a north and south direction. It has the form of a broad trough, its large central area being less than 100 feet above sea level, while its eastern and western sides rise gradually until they coalesce with the mountains.

The basin for the most part has a foundation of sedimentary rocks which have been thrown into folds. The inequalities produced by the folding of the strata have been largely reduced by erosion, so that the basin at the present time is a plain of low relief.

A late episode in the history of the basin was a subsidence of sufficient extent to cause the wide valleys of the northern portion to sink below sea level, whereby the rivers became "drowned" and Puget sound was produced. A still later episode was the advent of great glaciers from the mountains to the northward, eastward, and westward, whereby the northern part of the basin was overwhelmed and its rock foundation almost wholly hidden by a mantle of glacial sediments varying in thickness from 500 to 1,000 feet. The glacial sediments consist for the most part of plains of till, with local deposits of stratified clay, sand and gravel. About the southern end of Puget sound there are many level, barren plains of coarse sand and gravel, which were formed by the great streams of water which the melting glaciers produced. The southern part of the basin has a somewhat more hilly or broken character than the northern part, because of an absence of plains of glacial materials.

CASCADE MOUNTAINS.

On the southern border of Washington where the Cascade mountains enter the state they have a breadth of about fifty miles, which increases to 100 miles at the British Columbia line. The general height of the mountains is about 8,000 feet above the sea, although there are some peaks, usually old volcanoes, which rise to much greater heights. Only one of the volcanoes that are well known stands on the axis of the range, viz., Glacier Peak. The remaining volcanoes, Baker, Rainier, and St. Helens, stand on the western flank of the mountains, and Adams on the eastern side.

The northern half of the Cascades in Washington differs much in character from the southern half. In the southern portion igneous activity has been very great and much of the topography is due to the presence of volcanoes with their attendant lava flows. In the northern Cascades there is such a marked uniformity in the heights of the loftier peaks and ridges as to suggest very strongly that they are the remnants of a plateau. In other words, the northern Cascades have seemingly been carved out of a great plateau which was the result of the uplifting of a peneplain. The ruggedness of the topography, therefore, is not due primarily to the folding of the rocks, but to erosion. The streams have been, and are yet, large and well fed, so that the old plateau is now well dissected and transformed into mountains of extreme ruggedness. The main streams which flow out from the Cascades all have valleys noted for their depths, so that the flanking mountains stand alongside in great boldness. In ascending the principal mountain valleys, especially those on the western side of the Cascades, one notices that the grade is gentle, even into the heart of the mountains, and the ascent is nearly all made in the last few miles before the summit is attained.

Very many glaciers, some of large size, occur in the higher portions of the Cascade mountains. They once filled the larger mountain valleys and eroded and modified these very materially. Amphitheatres or cirques are found at the heads of many streams, and as these basins usually contain small lakes and parks, they afford some of the most beautiful scenery that the mountains possess.

OKANOGAN HIGHLANDS.

The Okanogan highlands occupy that portion of the state lying north of the Columbia and Spokane rivers and east of the Cascades. On their western border they merge insensibly into the latter mountains, and on the east they join the mountains of Idaho. In their geological characteristics they closely resemble the northern Cascades, but in their topographical aspects they are quite different. Instead of ruggedness they are characterized largely by beautiful rolling surfaces, with long gentle slopes leading down from the watersheds to the wide stream basins. The hills are low and broad and of a slope so slight that they are covered with a deep soil. The divides between the larger streams, although they reach heights of 5,000 or 6,000 feet above the sea, are gently rounding and not sharp or abrupt. The larger valleys were filled with glaciers at one time, and characteristic terraces or moraines are now found along the valley sides. Throughout the Okanogan highlands there is a close and easily observed relationship between the vegetation and the amount of rainfall. On the higher hills and ridges where the rainfall is greatest forests grow everywhere. On the lower hills and in the higher valleys the rainfall will not support a forest growth, but bunch grass grows luxuriantly. In the lower valleys of the larger streams, where the rainfall is least, bunch grass disappears and sage brush takes its place. The forests have an open character with practically no underbrush, the number of streams is large and the water excellent, so that the highlands have a remarkable park-like character.

COLUMBIA PLAIN.

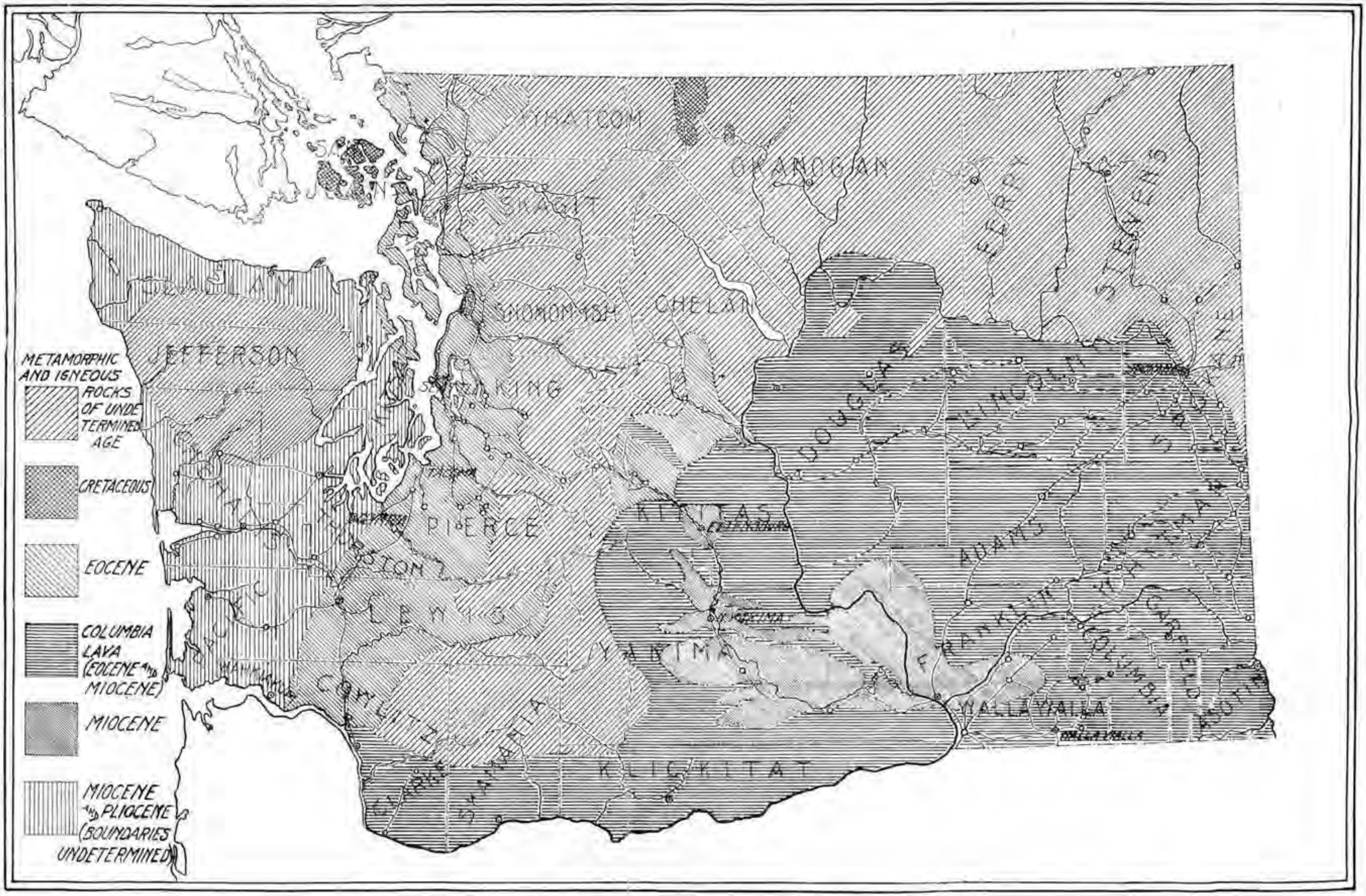
With the exception of the Blue mountains, described below, virtually all of that part of the state south of the Okanogan highlands and east of the Cascade mountains is embraced in the Columbia plain. From the Columbia river at a height of 500 or 600 feet above the sea, the plain rises rather rapidly to the westward until it merges into the piedmont plateau which borders the Cascades. To the eastward the plain rises slowly and does not reach an altitude of 2,000 feet until near the Idaho line. The area under discussion is really composed of a number of plains and plateaus which can not be differentiated with accuracy at this time.

While the Columbia plain as a whole is quite level and monotonous, there are some local irregularities which tend to give the plain a diversified appearance. In the region about North Yakima there are a number of sharp east and west ridges of a semi-mountainous character, which represent anticlines or arches in the sheets of lava. These ridges have occasionally risen athwart the stream courses, and some rivers, such as the Yakima, have cut deep gaps across them. In some parts of the plain, notably within the great bend of the Columbia river, the country is much cut up by old river courses, now wholly abandoned by streams, and known locally as coulees. Of these, Moses and Grand coulees are good types. The coulees are often 500 or 600 feet in depth, with precipitous walls, and represent the courses of streams which have now sought other channels, or which have withered away because of a decrease in the amount of rainfall. Each coulee now has within it usually a chain of small alkali lakes.

In the region drained by the Snake river and its tributaries deep canyons have been cut in the plain. From the Snake river northward toward Spokane, in what is known as the Palouse country, the plain (or more properly called here a plateau) is covered with hills having altitudes of from 400 to 600 feet, which possess the character of sand dunes. They are hills of æolian origin, made up of deposits of fine soil which was carried to its present position by the prevailing winds of the southwest. These wind-blown hills have long, gentle southwesterly slopes, with northeasterly ones that are somewhat abrupt. They must have been formed at a time when there was less precipitation than now and when the surface of the country had no vegetation upon it. Since the time when the hills were fashioned out of the wind-blown soil the streams have accomplished considerable erosion, and now have their drainage lines well established.

BLUE MOUNTAINS.

These mountains, situated on the border line between Washington and Oregon, represent merely a local uplift of promi-



A PRELIMINARY GEOLOGICAL MAP OF WASHINGTON.

nence in the great lava plain. A broad, dome-shaped area of lava was elevated here, rising about 7,000 feet above the sea. and about 5,000 feet above the surrounding plain. While the streams have cut deep canyons in the mountains, as a whole they still retain their even-topped appearance. The mountains are high enough to have sufficient precipitation to support a moderate forest growth, and in this way they afford a contrast to the surrounding prairies.

GEOLOGICAL FORMATIONS.

METAMORPHIC ROCKS.

Metamorphic rocks are those which have been acted upon by heat and pressure for the most part and as a result they have undergone certain changes from their original conditions. These changes are so great that the rocks are greatly altered in their structure, mineral composition, and physical aspects. Some common examples of metamorphism are the changes of ordinary limestone into marble, sandstone into quartzite, and clay-rock into slate.

It is generally believed that the metamorphic rocks are the oldest as far as known in Washington, while at the same time all efforts to determine their geological age have so far been unsuccessful. From their marked physical resemblance to Archæan rocks found in other parts of the United States some have been inclined to designate the metamorphic rocks of Washington as Archæan, but this cannot be done with assurance until further evidence is obtained. In many places it has been observed that the metamorphic rocks have sedimentaries lying unconformably upon them, and in fact it has been largely from the erosion of the former that the latter have been made.

It is known that metamorphic rocks occupy a large portion of the state, being very frequently met with throughout the Cascades, from Stampede pass northward to the British Columbia boundary, and from near Puget Sound eastward across the Cascade mountains and Okanogan highlands to the Idaho line. The ordinary varieties of metamorphic rocks in Washington are gneiss, schist, marble, slate, and quartzite. The most important of these are described below.

Gneiss.

Gneiss is a rock composed essentially of the same minerals as granite, and as a consequence is often mistaken for the latter. While a hand specimen of gneiss usually resembles closely a hand specimen of granite, in a ledge of gneiss a banded or stratified appearance is always displayed. Gneiss in general is a good building stone, and in Washington it oftentimes has within it mineral veins of economic importance.

The gneiss of Washington is generally associated with granite and schist, usually lying above the former and below the latter. The most important areas of gneiss observed by the writer are the following: A wide belt, having a north and south course, which is crossed by the road from Myers Falls to Republic; along the Kettle river, between Curlew and Midway, where many veins of pegmatite occur in the gneiss; along the Okanogan river between Johnson creek and Oroville; at several points along the Methow river, between its mouth and the Twisp river, notably near the mouth of Gold creek; along Bridge creek and the Stehekin river, from Twisp pass to Lake Chelan; and on the Columbia river between Chelan Falls and Wenatche.

Schist.

Schists are metamorphic rocks, possessing a clea· age which causes them to break into thin laminæ or folia. The parting along the cleavage planes is almost always wavy, although occasionally it is smooth. When derived from a sedimentary rock the cleavage of schist is at right angles to the original stratification, although all semblance of the latter has usually been wholly destroyed by metamorphism. Schists are recognized by their cleavage habit and by the greasy feel which they usually possess.

Schists are of various kinds and are usually classified according to the prominent minerals found within them. Mica is usually the most abundant mineral and mica schists are therefore of the most frequent occurrence. Chlorite, hornblende, and staurolite, with some others, also occur occasionally and give rise to chlorite schist, hornblende schist, etc., etc.

Russell * mentions a number of localities herein given where schists occur. A great escarpment occurs on the south side of Yakima valley two miles southwest of Clealum. The schists

* Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, pp. 102-3-4, 1900.

may be traced westward from this point for ten or twelve miles, with an increasing thickness exposed. Similar schistose rocks outcrop about the base of the Wenatche mountains, at various localities at the head of the Teanaway and on Nigger creek, and thence northward to beyond Leavenworth on the Great Northern Railway.

The mountains west of the Columbia and on the north side of the Wenatche valley, known as the Entiat range, are composed largely of mica and hornblende schist. Here the schist is cut by dikes of basalt and acid dikes as well and in some places quartz veins are found containing free gold. Another exposure of schist, thought by Russell to be a continuation of the last mentioned area, occurs in the mountains to the northward of Lake Wenatche between Chiwahwah and White creeks. Hornblende schist also occurs in the vicinity of Dirty Run peak, near the western end of Lake Wenatche, and along the crest of the ridge which extends northwest from it for about ten miles. This same rock forms the south wall of the valley of the west fork of White creek, and extends to the main Cascade divide near Glacier peak. The valley of Indian creek is almost surrounded by schists, which also crown Indian pass and cover most of the country from the region along the Sauk river to the mouth of Whitechuck creek. Schist is found in the region around Cascade pass and along Cascade creek for nearly its entire length. The most northern area of schist recorded by Russell occurs on the Skagit, extending from the mouth of Skaadle to beyond the mouth of Beaver creek. On the east side of the valley of the Skagit the same schist outcrops from Thunder creek to a point five miles up Ruby creek. Russell * also mentions schist as occurring under the lava in the Snake river canyon between Grande Ronde river and Wild Goose creek, and in the mountains along the western base of which runs the Washington-Idaho line. On the Snake river, at Buffalo rock, fifteen miles above Asotin another outcrop of schist occurs.

Other considerable areas of schist have been observed by the writer, usually associated with gneiss. Schist occurs commonly along the Methow between its mouth and that of Twisp river. Schist with gneiss occurs on Bridge creek and on the Stehekin between Twisp pass and the head of Lake Chelan. It occurs

* Russell: Water Supply and Irrigation Papers, U. S. Geol. Survey, No. 4, p. 36, 1897

occasionally on the borders of Lake Chelan and between the mouth of Chelan river and Wenatche. Large areas of schist occur on the Skagit from near Marblemount to Cokedale.

Near Hamilton the schist contains some important veins of magnetic iron. West of Hamilton and about Cokedale are two areas where schist is the enclosing rock of some coal basins to be described later on. Upon the eastern and southern boundaries of the large Blue Canyon coal field mica schist constitutes the rim rock. Schist is found in isolated outcrops about La Conner. It also occurs on the Great Northern Railway near Madison, and for a number of miles from Berne to the eastward. Four miles east of Cheney along the Northern Pacific Railway there are several outcrops of mica schist where the overlying basalt, thin at this place, has been wholly removed.

Crystalline Limestone.

In the metamorphic area above described, crystalline limestone occurs in a large number of localities. Originally a common limestone, it has become crystalline or marbleized through the influence of heat and pressure which was at some time exerted upon it. From an economic standpoint the best crystalline limestone, as far as now known, occurs in Stevens county where commercial marble is found at several places and is extensively quarried. A long, narrow belt of limestone extends north and south across Ferry county, lying at the western foot of the granite divide which separates the Columbia and Kettle rivers from the streams to the westward. Near the head of Lambert creek and in the vicinity of the town of Curlew the limestone forms hills which show quite prominently because of their white color. Crystalline limestone occurs midway between Republic and Wauconda. It also occurs near Johnson creek on the Okanogan river and on the eastern slope of Palmer mountain. On the western slope of the Cascade mountains crystalline limestone occurs at many places from Snoqualmie Pass northward, notably near the Denny iron mines, along the Stillaguamish river near Granite Falls, along the Skagit river between Baker and Marblemount, and near Kendall in Whatcom county. Important areas of the same rock occur on the San Juan islands, where the limestone is intimately associated with some basic eruptive rocks. It occurs here in isolated masses varying in

YAKIMA CANYON, BETWEEN NORTH YAKIMA AND ELLLENSBURG.

size from a few feet in diameter to one-fourth of a mile or so. This limestone doubtless belonged to some sedimentary beds from which fragments were torn by the eruptive rocks in their ascent from their former position below the surface.

Quartzite.

Quartzite is a metamorphic rock which has been derived from sandstone by the cementing of the sand grains by silica. It is practically, therefore, entirely composed of silica, and is of course very hard and resistant.

In a country where gneiss, schist, and crystalline limestone occur it would be very exceptional if quartzite did not occur also. In Washington, however, as far as the metamorphic area has been studied, quartzite has been noted in only a few places. It has been observed by the writer on the Similkameen river, a few miles directly north of Loomis. It is here interstratified with beds of gneiss. Russell* mentions quartzite as occuring at several places north of the Snake river and near the Idaho line, where islands of quartzite appear in the sea of lava. Kamiack and Steptoe Buttes in Whitman county are two very prominent examples of quartzite. The first of these rises over 500 feet, and the second over 1,000 feet, above the surface of the surrounding basalt plateau.

IGNEOUS ROCKS.

The igneous or heat rocks are those which have solidified from a fused condition. An igneous rock may be formed by the fusion of a sedimentary rock, or it may represent merely the final stage in metamorphism. Two kinds of igneous rocks may be noted — the plutonic and the volcanic. The plutonic or deep seated rocks are those which, cooling at a distance beneath the surface and under great pressure, solidify slowly, attaining a coarse granular structure, except near their borders where they come in contact with the cooler rocks. In Washington the plutonic rocks are well represented by granite, syenite, diorite, etc., but as detailed studies have not been made in regard to the particular areas where these different varieties occur, it will be convenient to group them all under the head of granite.

Volcanic rocks are those which are brought to the surface or

*Russell: Water Supply and Irrigation Papers, U. S. Geol. Survey, No. 4, pp. 37-38, 1897.

near to the surface by volcanic action and are either spread out in layers, intruded into fissures as dikes, or accumulated as fragments of lava. On account of their sudden cooling, many volcanic rocks are glassy or only partly crystalline. Others are wholly crystalline, the crystals generally, but not always, being of a small size. Examples of volcanic rocks are to be found throughout Washington, notably the great lava plains of southeastern Washington, and within and about the great volcanoes of the Cascade mountains.

Granite.

Granite occurs at very many places and in very large quantities in Washington. Throughout the metamorphic area of the state above described granite is perhaps the most common rock. It is the belief of the writer that further study will make it clear that there are in the state two kinds of granite—one representing a final stage in metamorphism, or in other words, a metamorphic granite—the other variety an intrusive granite which was forced into the rocks above it. It is possible that these varieties are both shown along the line of the Great Northern Railway in the Cascade mountains. At Index a light colored granite occurs composed mainly of feldspar and quartz, with comparatively small amounts of mica and hornblende. Although the writer has observed this granite over a considerable area about Index, at no place has any evidence of intrusion been noted. At the point where the railway crosses the mountain summit there is another large area of granite, composed mainly of mica and hornblende with a proportionally small amount of quartz and feldspar. This granite is very plainly intrusive, for it shows within it embedded masses of mica schist which it broke off in its ascent.

Granite occurs about Spokane and Medical Lake, where important quarries have been developed. In Ferry county a long narrow belt of granite is found on the summit of the divide between the streams flowing east into the Kettle and Columbia rivers, and those flowing west into Curlew creek and the San Poil river. A similar belt running north and south is crossed on the road from Republic to Wauconda.

Mount Bonaparte, in Okanogan county, stands at the center of a large granite area. It is probable that this area continues southward along the summit between the streams flowing eastward into the San Poil river and those flowing westward to join the Okanogan. There is a granite area of unknown width, extending southward from Loomis by way of Conconully and Ruby to the Columbia river. The central portion of this area extends in an east and west direction virtually from the Okanogan river to the Methow, making it one of the largest granite areas of the state. Near Ruby and elsewhere the granite contains a pinkish feldspar, which gives it a beautiful appearance. Granite occurs for two miles east and about eight miles west of Twisp pass, and it is not improbable that this granite continues northwest and southeast forming the divide between the drainage of the Methow and Lake Chelan. Granite occurs along the whole course of Railroad creek, which heads on the summit of the Cascades and which empties into Lake Chelan near its northern end.

Russell* gives several localities in the Cascades where granite and related rocks occur. There is a very large area of granite around Mount Stewart, known as the Mount Stewart granite. All of the high peaks of the Wenatche mountains are composed of this rock, and an area of granite extends from a point about five miles northwest of Blewett to beyond the summit of the Cascades at the point crossed by the Great Northern Railway. Ingall creek, for its whole length to within four miles of its junction with the Peshastin, forms a border of this area. Here the boundary turns and runs nearly due north to seven or eight miles beyond Leavenworth, where it again turns and goes toward the west.

The drainage basin of the north fork of White creek is nearly all in granite, and this area probably connects with that of Cascade pass. Similar granite is found along Indian creek and on Glacier peak. Between the two latter localities a part of the granite branches off from the main mass and in the form of dikes is intruded into the schists to the south. Granite has also been noted along the Sauk river, where schistose rocks are the prevailing type. Another granite area, noted by both Willis† and Russell‡, occurs along the Skagit river from Marblemount to Thunder creek.

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* Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, pp. 105-108, 1900.

† Willis: 10th Census U. S., Vol. XV, p. 761, 1886.

‡ Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, p. 107, 1900.

Little is known of the granite in the southern part of the Cascades. According to Smith*, granite forms an elevated platform on which stands the volcanic cone of Mount Rainier. Granite has been observed by the writer at the foot of Silver Star mountain, fifteen miles northeast of Washougal on the Columbia river. It is very probable that granite occurs at intervals along the axis of the Cascade mountains from the British Columbia line to a point within a few miles of the Columbia river. Mr. Charles A. Ruddy has informed the writer that a few miles from the mouth of the Dosewallips river on Hood's Canal large boulders of granite are found, which have beyond any doubt been brought from the Olympic mountains adjoining.

Basalt.

The most important volcanic rock of the state is represented by the series of basaltic outflows known as the Columbia lava.† The Columbia lava not only extends over a good portion of Washington, but covers all of Southern Idaho, Eastern Oregon, and extends into California as well. It is doubtless the largest lava flow in the world, covering nearly 250,000 square miles and displaying a thickness in some places in excess of 4,000 feet. Along the margin of the basaltic flow the lava becomes comparatively thin, as is shown near the big bend of the Columbia river, where the granite beneath the lava shows in canyons at depths of 300 or 400 feet. It is generally conceded that the basalt came to the surface through great fissures of considerable linear extent rather than through the usual volcanic vents. In other words the basalt is of a composition which is characterized by a low melting point, and consequently the molten lava would flow for long distances before cooling. Throughout the Columbia lava plain there are no indications of true volcanoes, as far as observed.

The floor upon which the Columbia lava was outpoured was quite uneven. It was a floor composed as far as known of granite, schist, gneiss, and other metamorphic rocks not dissimilar in character, perhaps, from the Okanogan highlands which lie

*Smith: 18th Ann. Rep. U. S. Geol. Survey, Part II, p. 423, 1898.

†This formation is discussed in the papers by Russell, Smith, LeConte, Gibbs, Richthofen, and Symons, which are mentioned in the Bibliography of Washington Geology at the close of this volume.

Photograph by Dr. U. M. Lauman. MOUNT ST. HELENS AND SPIRIT LAKE.

to the north, or the mountains along the Idaho-Washington line. Some of the bolder hills of the former floor were never covered, as in the case of Kamiack and Steptoe Buttes and others. Other hills, although finally covered by lava, are yet known to have reached heights of 2,500 feet above the surrounding valleys. Such instances are to be seen in the canyon of Snake river.

Wherever the rivers, such as the Snake, have cut deeply into the basalt, the individual lava flows may be readily made out. The number of lava flows presumably varies in different parts of the lava field. According to Russell,* in the canyon of Snake river, where perhaps there is the greatest exposure of lava, eight distinct lava sheets may be seen. Smith † says that ten or more separate flows can be counted in the canyon of Yakima river, and that individual flows may be traced for great distances. The surface of the basalt in some places is yet characterized by the ropy appearance which is always observed upon recent unweathered lava flows. In appearance the basalt is usually black in color, but various tints of brown, red, gray, and green may easily be found. It is observed that the lava varies somewhat in character in the successive flows, and that from the surface of a flow toward the center some differences may be noted. In some of the flows the basalt is very compact and heavy, while in other cases it presents rough and scoriaceous surfaces, caused by the small cellular cavities which were produced by the steam when the rock was molten. In some instances where the molten rock cooled with great rapidity the minerals did not have time to form and the basalt is therefore glassy, but in the central part of the thicker flows where cooling took place with great slowness the rock is crystalline in structure and the crystals can readily be seen by the naked eye. The composition of the basalt from a mineralogical standpoint is that of plagioclase feldspar, augite, olivine, and magnetite, in a glassy ground mass composed of silicates of alumina, magnesia, soda, potash, lime, iron, etc. According to Russell, "chemical analyses of basalt show that in general it contains from 46 to 47 per cent. of silica and from 11 to 22 per cent. of alumina, together with lime, magnesia, potash, etc., in proportions varying from a small fraction of one per cent. to over ten per cent. It is the presence of

*Russell: Water Supply and Irrigation Papers, U. S. Geol. Survey, No. 4, p. 48, 1898.

†Smith: Water Supply and Irrigation Papers, U. S. Geol. Survey, No. 55, p. 15, 1901.

lime, potash and phosphoric acid in basalt that gives the soils formed from its decay much of their richness for agricultural purposes."

Everywhere that the basalt is seen in a vertical section the columnar structure is very apparent. By the columnar structure is meant the parting of the lava into long colonnades or prismatic columns. These columns vary greatly in thickness and height; in the latter dimension they often reach thirty feet or more and in breadth they may be from three to four feet. In cross section the columns are usually hexagonal, although sometimes very irregular, with sides ranging in number from three to eight. As a rule the smaller columns are more perfect than the larger ones, and it is also noted that in the smaller lava flows the columns may be limited to the central portions of the sheet. A rock such as basalt necessarily shrinks a great deal upon cooling. When the shrinkage is quite regular, symmetrical breaks in the rocks are found which are known as joints. It is because of the great network of joints which extend through the mass of rock that origin is given to the basaltic columns.

When the basalt was outpoured in the form of fiery inundations, it of course filled the valleys first of all, and rose by successive additions to greater and greater heights. It is known that in some cases there was considerable time intervening between successive flows, for extensive layers of gravel and the charred remnants of forest growth often occur between the lava beds.

At the time of its eruption the lava must have assumed a position practically flat or horizontal. That position continues to the present time in some parts of the lava field. In other places, however, the lava beds have suffered great deformation in the way of faulting and folding, and we now find these beds tilted at various angles. The Blue mountains represent a moderate arching of the lava so that here a broad dome has been produced, which rises four or five thousand feet above the surrounding plain. The Badger mountains, located in the great bend of the Columbia, probably had a similar origin. In the western portion of the lava field, as the Cascade mountains are approached, the structure of the lava and of the mountains is closely identical. In other words the basalt has been folded into arches and troughs, or anticlines and synclines, which are plainly evident to anyone passing through that region. The larger streams, such as the Yakima, have held tenaciously to their courses, even though the arches of lava have arisen across them and deep canyons, such as the striking Yakima canyon, have been produced.

In age the Columbia lava belongs chiefly to the Eocene Tertiary, but the final flows did not cease until Miocene Tertiary time.

Andesite.

Andesite is a volcanic rock composed essentially of plagioclase feldspar and one or more of the following: hornblende, augite, and biotite. It resembles basalt in some respects, but fuses with more difficulty, and is generally of a lighter color. It occurs commonly in Washington, both as intrusive sheets, or dikes, and as extrusive sheets in the form of flows from volcanoes.

The rocks of Mount Rainier have been studied by Smith,* who reports the cone as being composed for the most part of flows of andesite, with occasional layers of basalt. Russell† mentions andesite as forming the summit of Glacier peak, and also dikes or old lava flows that radiate from it in different directions.

Andesite rocks are also said to form the summit of Goat mountain‡, west of the Clealum river, and to be immediately associated with the formations in the region drained by the headwaters of the Yakima river.

Serpentine.

Serpentine is not an unusual rock in Washington, especially in the central and northern Cascades, and its presence has been noted by several observers. In composition serpentine closely resembles talc, both being hydrous silicates of magnesium. Serpentine is generally a soft mineral or rock, some shade of green in color, usually massive in form, although occasionally very fibrous. It is always formed by the metamorphism of some other rock, and hence is secondary. The peridotites, rocks composed essentially of olivine and pyroxene, are particularly liable to alteration whereby serpentines are the result.

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*Smith: 18th Ann. Rep. U. S. Geol. Survey, Part II, p. 416-23, 1898.

†Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, p. 134, 1900.

‡Willis and Smith: Clealum Iron Ores, Trans. Am. Inst. Min. Eng., February, 1900

The best known serpentine area in the state is that which encircles the Mt. Stuart granite and which has been described by Russell*. Here the serpentine occurs at many places, notably on the headwaters of the south fork of Icicle creek, on Fortune creek, middle and north forks of the Teanaway river, south of Ingall creek, throughout the drainage basin of Nigger creek, on the ridges to the east of Fish lake and the upper waters of the Clealum river, and in the region around Blewett. In all of these cases the serpentine seems to have been derived from peridotite, and the degree of alteration varies in different portions of the field. Mineral veins are a common accompaniment of the serpentine, and in the region about Blewett, Fish lake, and other localities within the serpentine belt, valuable ores of copper, silver, and gold are found.

In Stevens county several areas of serpentine have been discovered, the best known probably being the one at Valley, on the Spokane Falls and Northern Railway. The serpentine here is a valuable ornamental stone, and the quarrying of it has become an important industry. It has a pleasing color, may be obtained in large masses, and possesses other desirable qualities.

SEDIMENTARY ROCKS.

Sedimentary or stratified rocks are those which are made from the sediments or fragments derived from older rocks. These fragments may be produced along the sea shore by the work of the waves, or they may be produced upon the land by the forces of air and water. Sediments are transported usually by water and deposited upon the ocean floor, in estuaries, or in lakes. Thus we have rocks of marine, brackish water, and fresh water origin. Rocks are also divided according to composition or the kind of sediment which has entered into them, so that we have limestones, clay rocks, sandstones, etc. Another classification that may be made of sedimentary rocks is one according to the geological age in which they were made.

The sedimentary rocks of Washington cover a large portion of the state and are of great importance. At the present stage of knowledge concerning Washington geology the sedimentary rocks are better known than are the other divisions. From their irregular line of contact with the metamorphic and volcanic

*Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, page 109, *et seq.*, 1900.

LAKE OF THE MOUNTAINS, NEAR CASCADE PASS, CASCADE MOUNTAINS.

rocks on the western flank of the Cascades, the sedimentary rocks extend continuously to the coast with the exception of the higher central portion of the Olympics. In the northern Cascades and over the Okanogan highlands, sedimentary formations occur at many places, usually in comparatively small isolated areas. They represent of course the remnants of previous areas of larger size which in the course of time have been greatly reduced by erosion. Many of the areas now separated were at one time connected. These isolated areas are often found where least expected, and so small are they that a great amount of detailed work will be necessary before they are all made known. On the eastern slope of the Cascades in the central part of the range there are some fields of sedimentary rocks of considerable extent. Some outlying areas, disconnected by erosion, reach down to the Columbia river and a little way beyond. The only part of Washington which seems to be quite free from sedimentary rocks is that part of the state which lies to the eastward of the Columbia river and to the southward of the Columbia and Spokane rivers. In the following discussion the different formations will be taken up in the order of their supposed geological position, or geological age, beginning with the oldest.

PRE-CRETACEOUS PERIOD.

A limestone which bears fossils that are supposed to be the remains of crinoid stems lies beneath the iron-bearing schists along Skagit river. Upon evidence offered by these fossils, Willis* ventures the opinion that the limestones are of Carboniferous age. If so, they are the oldest rocks so far identified in the state. In this same article Willis mentions black slates, conglomerates, and limestones from the Monte Cristo district which he thinks may be of Mesozoic age.

Russell† describes a series of sandstones, shales and conglomerates, of a distinct reddish-brown color which outcrop in the mountains bordering Methow river near the old mining camp of Ventura. He calls the series the Ventura formation, and suggests that it may be of Pre-Cretaceous age. He bases his correlation on the stratigraphic relationship of this formation with the two Cretaceous formations that adjoin it—the Similkameen

*Willis: 17th Ann. Rep. U. S. Geol. Survey, Part I, p. 55, 1896.

† Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, p. 193, 1900.

sandstone on the north and west, and the Winthrop sandstone on the east.

CRETACEOUS PERIOD.

As far as known, the Cretaceous age is but little represented among the sedimentary rocks of the state. The oldest and probably the best known locality is that of Sucia Island and a few other small adjoining islands of the San Juan group, lying between the island of Vancouver and the mainland. These rocks have been designated the Vancouver formation because of their splendid development upon the large island of that name. Sucia Island has yielded about fifty species that are common to the Chico group of California, which is of upper Cretaceous origin.

Another locality, widely separated from this, is on the Snoqualmie river about three miles below Snoqualmie Falls, where from an outcrop of rocks characteristic marine fossils have been obtained.*

A third area yet further separated from the other two, located upon the headwaters of the Similkameen and Methow rivers, is described by Russell.† The Similkameen formation consists chiefly of sandstone, shale, and limestone with smaller quantities of conglomerate, quartzite, and breccia, the whole forming a series which is 4,000 or 5,000 feet thick. The mollusks obtained from the limestone, and the well-preserved ferns found in the blue sandstone at the base of Gold Ridge, establish the Cretaceous age of this formation.

To the southeastward of the area just described, on the Methow river near Winthrop there is to be found a series of coarse sandstones and light grey sandy shales having a thickness of about 2,000 feet. From the abundant plant remains found in the shaly layers the Cretaceous age was cleary established. This group of rocks has been termed by Russell the Winthrop sandstone.

TERTIARY PERIOD.

The Tertiary rocks have been studied for a number of years, and beyond a doubt are the best known rocks of the state. They are of great economic importance because they contain within them large deposits of coal and valuable ledges of building stone.

*Kimball: Am. Geol., Vol. XIX, p. 305, 1897.

†Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, p. 114, *et seq.*, 1900.

As was the case in other parts of the United States, Tertiary time in Washington was characterized by the presence of many lakes, in which sediments of great thickness were deposited. In the early part of Tertiary time, or during the Eocene epoch, vegetation grew with great luxuriance about the lake shores, and upon the lake floors vegetal matter was deposited in thick beds between the layers of sand and clay. After an average accumulation in these lakes of several thousand feet of mechanical sediments and vegetal matter, the strata were elevated, folded, and sometimes faulted, the vegetal accumulations were compressed and metamorphosed and converted into coal seams. The lakes above mentioned were located along the eastern and western borders of the Cascade mountains, and in the northeastern part of the state, in what is now Okanogan, Ferry and Stevens counties. They had their best development west of the Cascades, along the eastern side of the present Puget Sound basin, but in this region the Tertiary sedimentary rocks have been largely covered by lava flows from the mountains nearby, and by the sediments from the great glaciers which later passed over them.

A little way to the westward of the chain of lakes just described was the sea coast of that time which was somewhat parallel to the present ocean border. Upon the floor of the shallow ocean sediments accumulated, consisting mostly of clay, sand, and gravel, with thin layers of limestone. The marine deposits were made almost wholly in middle and later Tertiary; or in the Miocene and Pliocene epochs. As far as known there is no unconformity in the Tertiary period between any epoch and the one following. The Eocene rocks have received more study than those of the Miocene and Pliocene epochs because of their economic importance. The rocks of the latter epochs lie in the southwestern part of the state and have received practically no attention from geologists.

Eocene Epoch.

The Eocene rocks of Washington are nearly all coal-bearing and so a reference to the map of the coal fields, herein, will give one an idea of the approximate extent of the rocks of this period. In some instances the areas are very small and the thickness of the rocks not very great. In other cases, as in the Blue Canyon coal field, an area of more than 360 square miles is represented and the rocks are not less than 10,000 feet in thickness. The geological characteristics of each Eocene area is described in more detail in the article on the coal fields of Washington, which is a part of this volume.

During the field season of 1901 the writer collected from a few new localities some plant remains which were submitted for examination to Professor F. H. Knowlton of the United States Geological Survey, and his report is here given:

Preliminary Report on Fossil Plants from the State of Washington, Collected by Henry Landes, 1901.

By F. H. Knowlton.

This material consists of seven small lots of specimens, from as many separate localities, all, with a single exception, being in the northwestern part of the state. The species afforded by the various localities are as follows:

Day creek, near Hamilton, Skagit county, Wash.:

Quercus banksiæfolia Newberry.
Quercus sp.

Coal creek, near Hamilton, Skagit county, Wash.:

Quercus banksiæfolia Newberry.
Quercus coriacea Newberry.
Thuja interrupta Newberry.
Glyptostrobus Europæus (Brongn.) Heer.

Cokedale, Skagit county, Wash.:

Quercus banksiæfolia Newberry.
Nyssa ? cuneata ? Newberry.
Cinnamomum n. sp.?

These three localities, being evidently of the same horizon, are best considered together. The most abundant and unmistakable species is *Quercus banksiæfolia* of Newberry. It occurs at all the localities and is a very beautiful species. It was originally described by Newberry,* from Chuckanut, near Bellingham bay, and so far as I now know has been found but once since, namely, by myself at the coal mines at Blue Canyon on the east side of Lake Whatcom. The history of *Quercus coriacea* and *Nyssa ? cuneata* is the same, and the conifer identified as *Glyptostrobus Europæus* was found at the same place.

Thuja interrupta was described originally from the Fort Union group near old Fort Union, North Dakota. I found it also on Blue Canyon, and it is present in the material from Coal creek.

The locality at Chuckanut was referred by Newberry to the Cretaceous, and this was nearly fifty years ago when much less was known of the geology of this region than now, and I do not think it should be so

* Bost. Jour. Nat. Hist., Vol. VII, p. 522, 1863; Extinct Floras of North America, p. 69, pl. xviii, figs. 2–5, 1898.

regarded. From the general appearance of the plants alone I should incline to place the age as somewhere near the Middle Tertiary, certainly younger than beds at Carbonado, etc. In any case these three localities represent an age similar to that of the beds at Blue Canyon.

Coal Creek, near Keese, Whatcom county, Wash,:

Sequoia Langsdorfii (Brongn.) Heer.
Sabal similar to *Sabal* n. sp., from Liberty, Wash.
Cinnamomum n. sp. of vein XII, Franklin, Wash.
Cinnamomum sp.
Pipu n. sp.
Phyllites n. sp. of vein XII, Franklin, Wash.
Populus n. sp. of vein XII, Franklin, Wash.

This collection contains beautifully preserved and very interesting material, some of which is undoubtedly new, and much of which is identical with, or similar to, forms from vein XII at Franklin, Wash. On this ground I should regard the age as similar to that at Franklin. I have not given the names of the new species in advance of their publication in my proposed monograph.

Skykomish, Snohomish county, Wash.:

Anemia n. sp., as found at Carbonado.
Glyptostrobus sp., as found at Roslyn.
Ficus n. sp., as found at Carbonado.
Ficus n. sp., as found at Liberty.
Celastrus n. sp., as found at Carbonado.

The age of this locality would seem to be the same as that at Carbonado and Roslyn, the beds at Liberty being a little lower. In any case it is probably not greatly different from the age at Carbonado.

Black River Junction, King county, Wash.:

Acer n. sp.
Cinnamomum n. sp.
Ficus ? n. sp.

This material is the same as that obtained at Steel's Crossing and, judging from the matrix as well as the plant impressions, came from the identical beds. There is no evidence tending to change my opinions on the age.

Republic, Ferry county, Wash.:

Thuja interrupta Newberry.
Sequoia Langsdorfii ? (Brongn.) Heer.
Cinnamomum sp.

There is too little of this material to base a very definite conclusion on, but it would seem to be similar or identical with the beds in Skagit county.

Miocene Epoch.

Marine Miocene strata which have been correlated with the Astoria beds, outcrop along the shore from Port Blakely to

Pleasant Beach, on Puget Sound. The formation at this locality consists of several thousand feet of sandstone, shale, and conglomerate, all tilted at a high angle. Dall* mentions rocks of this age as occurring at Shoalwater Bay (Willapa Harbor), Bruceport, and Bellingham Bay. Willis† mentions a fresh water formation in the southeastern portion of the New Castle hills which he correlates with the Miocene.

The Ellensburg sandstone, as described by Russell‡, is the largest fresh water deposit of known Miocene age yet discovered in Washington. The formation is well exposed along the Yakima river between Dudley and Ellensburg, and consists of strata of sandstone, volcanic dust, and conglomerates, both consolidated and unconsolidated. This formation lies immediately above the Columbia basalt, and reaches a thickness of about 1,500 feet in the North Yakima area.§ The Ellensburg formation was deposited in a large lake which covered much of central Washington, the exact boundaries of the lake being as yet unknown. The lacustrine sediments, being as a rule quite incoherent, have been largely removed by erosion.

Pliocene Epoch.

It is not improbable that future study will disclose rocks of this age among the sedimentary formations which make up the southwestern part of the state. Dall‖ mentions the occurrence of a "mytilus bed" at Bruceport which he thinks is of Pliocene age.

QUATERNARY PERIOD.

Pleistocene Epoch.

Marine Pleistocene deposits within the state are confined chiefly to raised beaches. Dall¶ writes of the occurrence of beds 30 to 40 feet thick which lie uncomformably upon the Pliocene at Bruceport. Raised beaches of Pleistocene age occur at Alki and Restoration Points and elsewhere about Puget Sound wherever the beach is made up of bed rock. Pleistocene sediments in the nature of glacial deposits occupy a large portion of

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* Dall: Bull. 84 U. S. Geol. Survey, p. 228, 1892.

† Willis: 18th Ann. Rep. U. S. Geol. Survey, Part III, p. 414, 1898.

‡ Russell: 20th Ann. Rep. U. S. Geol. Survey, Part II, p. 127, 1900.

§ Smith: Water Supply and Irrigation Papers, No. 55, p. 17, U. S. Geol. Survey, 1901.

‖ Dall: Bull. 84, U. S. Geol. Survey, p. 228, 1892.

¶ Dall: Bull. 84, U. S. Geol. Survey, p. 227, 1892.

the state. In all of the mountain districts, except in the Blue mountains, glaciers once covered the mountain tops and filled the valleys, and the latter are now partially occupied by terraces, boulders, and moraines. The region about Puget Sound was occupied by great ice masses which came from British Columbia, the Cascades, and the Olympics. The sediments left by these glaciers consist of till, with stratified sand, clay, and gravel, in all averaging in thickness not less than five hundred feet.