DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

# No. 108

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A GEOLOGICAL RECONNOISSANCE IN CENTRAL WASHINGTON

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WASHINGTON
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1893

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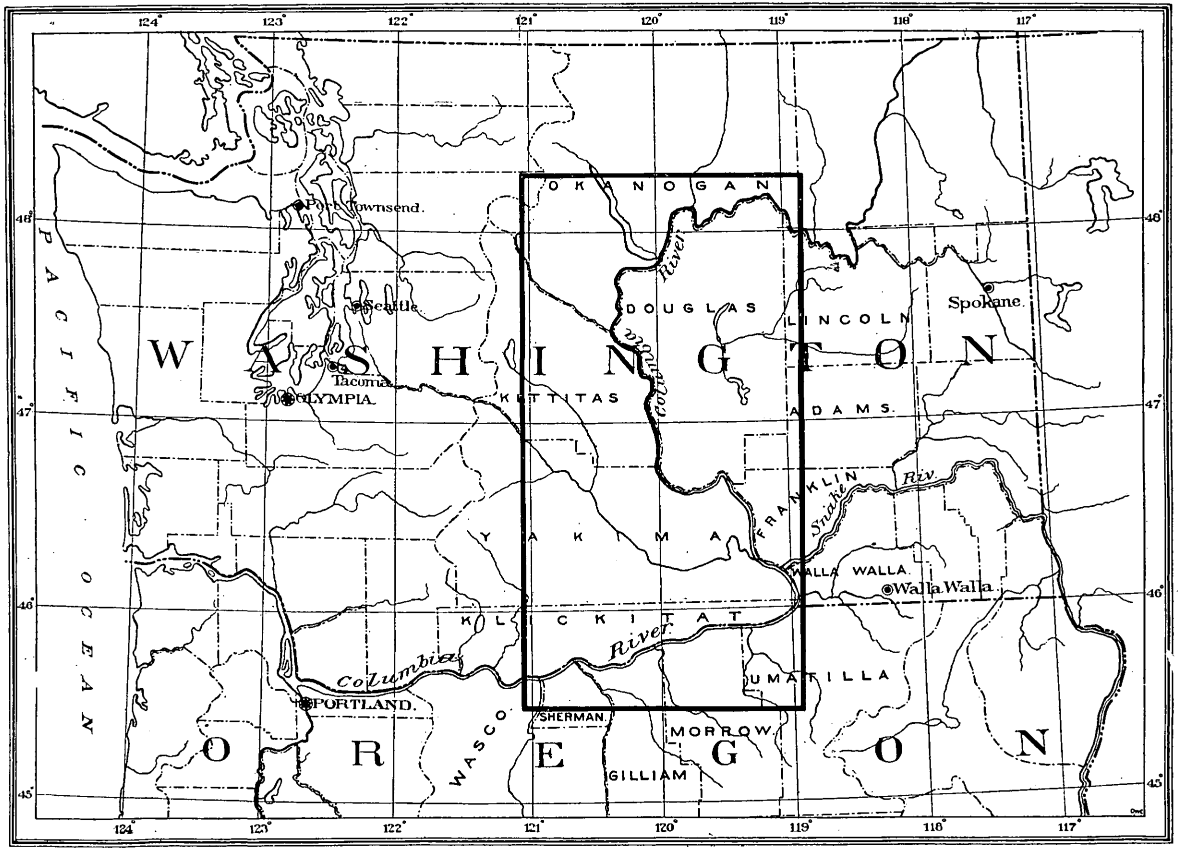

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DEPARTMENT OF THE INTERIOR

# BULLETIN

OF THE

# UNITED STATES

# GEOLOGICAL SURVEY

## No. 108

WASHINGTON
GOVERNMENT PRINTING OFFICE
1893

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

# A GEOLOGICAL RECONNOISSANCE IN CENTRAL WASHINGTON

BY

ISRAEL COOK RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1893

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# ILLUSTRATIONS.

# LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
*Washington, D. C., January, 5, 1893.*

Sir: I have the honor to transmit herewith for publication as a bulletin of the Geological Survey a paper entitled "A Geological Reconnoissance in Central Washington," by Israel C. Russell.

This work was initiated by your instructions of March 22, 1892, to investigate the vicinity of Yakima, Washington, with special reference to artesian resources. Mr. Russell was detailed as my assistant in this work and remained in the field until June 30. His studies were not limited to Yakima valley, but extended over a large portion of the country bordering upon the Great Bend of the Columbia, and have satisfactorily solved the artesian problems to which they were directed. In addition to this specially economic phase of the work he has made a large contribution to the knowledge of the structure and geologic history of that region.

While Mr. Russell was investigating artesian resources the writer, before going south to continue field work in Oregon and California, spent a few weeks of April and May making a preliminary examination of the coal-bearing metalliferous and other formations of Washington. The mines at Wenache, Pechastin, Roslyn, Carbonado, Wilkinson, Newcastle, Hamilton, and elsewhere were visited, and marine fossils were collected at Clallam bay, Snohomish, and near the Duwamish, to acquire the information necessary to properly direct future investigations within the state which will form the subject of a paper to be hereafter published.

On account of the important economic bearing of Mr. Russell's report I respectfully urge its immediate publication.

Very respectfully, your obedient servant,

J. S. Diller,
*Geologist in charge of Cascade Division.*

Mr. G. K. Gilbert,
*Chief Geologist, Washington, D. C.*

# OUTLINE OF THIS PAPER.

This is a report on a geological reconnoissance in the central part of the state of Washington, undertaken for the purpose of ascertaining to what extent the conditions there existing favor the project of obtaining artesian water for irrigation.

The region traversed embraced about 10,000 square miles, situated in the arid region east of the Cascade mountains, and draining to Columbia river. A sketch map of the geology of this region is presented on Pl. II.

## GEOLOGICAL FORMATIONS.

*Crystalline rocks.*—The oldest rocks in the area explored are schists, granites, and quartzites, occurring north of the Great Bend of the Columbia.

*Kittitas system.*—Resting on the eroded surfaces of the crystalline rocks is a series of sandstone and shales of early Tertiary age which contain valuable coal seams. These rocks occur at the surface to the west of the Columbia and adjacent to the Cascade mountains. The coal at Roslyn is in these rocks. The system is well exposed in the western part of Kittitas county, and hence is named provisionally the Kittitas system.

*Columbia lava.*—The principal formation in central Washington is a great series of lava sheets which have been outpoured in successive eruptions in such quantities as to completely conceal the relief of the land which was inundated by the fiery flood. This series of lava sheets is of such vast extent that it is the equivalent of some of the most important systems of sedimentary rocks. It extends south from Washington into Oregon and California, and east into Idaho. Its entire extent is unknown, but is thought to cover not less than 200,000 square miles to an average depth of about 2,000 feet. It is the greatest lava sheet now known. The rock is principally if not wholly basalt, which came to the surface through fissures and was spread out in successive flows at intervals throughout a long period of time, as is shown by fossil forests inclosed between the layers at a number of horizons.

*John Day system.*—This system consists for the most part of unconsolidated sand and clay, together with large quantities of lapilli and volcanic dust, and has a thickness in some localities of over 1, 000 feet. It is well reposed in the White bluffs on the Columbia, and in Moxee, Wenas, and Kittitas valleys. The strata composing the system were deposited in a great water body called Lake John Day which existed in late Tertiary times between the Cascade and Rocky mountains.

*Glacial records.*—After Lake John Day was drained and its sediments and the rocks on which they rest uplifted into mountains and deeply eroded, there came a climatic change which admitted of the existence of glaciėrs in the Cascade and Rocky mountains. A great glacier then filled the valley now occupied by Lake Chelan; another descended Okanogan valley, and crossing the Columbia spread out a sheet of morainal material and thousands of huge bowlders over the northern part of Douglas county. Columbia river was dammed by these glaciers and escaped southward through Grand Coulee.

*Lake Lewis.*—The glaciers from the north ended in a large lake, the northern shore of which crossed the central part of Douglas county, and is known as Lake Lewis. Icebergs floating on this lake carried their freight of bowlders over the Great Plain of the Columbia and into many valleys opening from it.

### GEOLOGICAL STRUCTURE.

After the deposition of the John Day system the rocks throughout central Washington and also over a vast region lying to the south were broken by a large number of fractures, some of them scores of miles in length, and the included blocks tilted in various directions so as to form monoclinal ridges or gently sloping tablelands. The displacement along many of these faults was between 2,000 and 3,000 feet.

Between the steep, narrow ridges there are level-floored valleys in which the John Day beds still retain their horizontal position. In a few instances the borders of the valleys have been raised so as to form artesian basins.

### GENERAL PRINCIPLES PERTAINING TO ARTESIAN WELLS.

In this section the conditions are briefly considered, under which subsurface water may exist under pressure, so as to rise to the surface when wells are drilled. Certain popular fallacies relating to artesian wells are also pointed out.

### GEOLOGY OF THE COUNTIES VISITED.

In this section a popular account is given of the geological formation and prevailing structure met with in each of the counties visited, and in each region the conditions bearing on the question of subsurface water supply are pointed out.

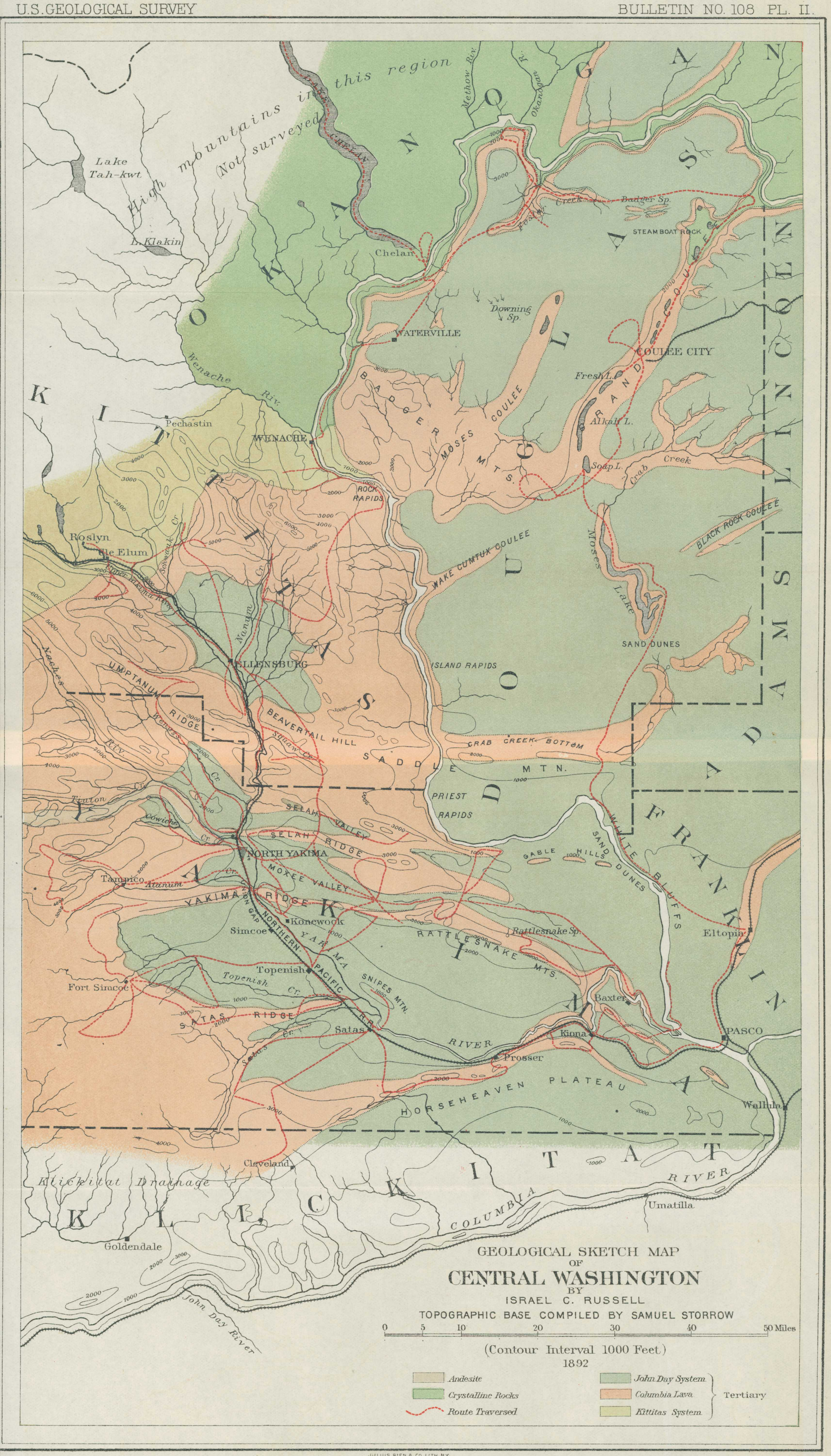
As the region explored is one of a few within the United States concerning which there is but little information to be obtained from books, our sketch has been given something of an itinerary character.

Some of the alkali lakes in Douglas county are described, and an analysis is given of the water of Soap lake. The deposition of calcium carbonate through the action of low forms of plant life, from waters far below saturation, is briefly considered.

### CONCLUSION.

The last section of the paper is devoted to a summary of the conclusions reached in reference to the probabilities of obtaining artesian water in the region traversed. In general the conditions are such as not to favor the drilling of more wells.

The appendix contains a report by F. H. Knowlton on fossil leaves from the John Day system.

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# A GEOLOGICAL RECONNOISSANCE IN CENTRAL WASHINGTON.

By Israel C. Russell.

## INTRODUCTION.

An examination of the country described in this paper was ordered by the Director of the U. S. Geological Survey at the request of persons interested in the development of the state of Washington, for the purpose of ascertaining how far the geological structure of the arid portion of the state favored the hope of obtaining artesian water for irrigation.

Flowing water had already been obtained at two wells in Moxee valley and several other wells were in progress when my examination began, but without a knowledge of the geology of the region over a wide area the success or failure of these enterprises depended upon chance. It was with the hope of being able to direct the search for artesian water so energetically begun that a geological examination was undertaken. The conclusions reached are in general not favorable to the view that a large portion of the central part of the state can be irrigated by artesian water, but it is hoped that by pointing out the unfavorable conditions a considerable waste both of capital and energy in drilling useless wells may be avoided.

During the reconnoissance I was accompanied by Mr. Samuel Storrow, civil engineer, residing in North Yakima, who is especially interested in the various problems connected with the irrigation of the adjacent region, and has a personal knowledge of several of the deep wells already drilled. I am indebted to Mr. Storrow for much general assistance, and especially for the topographic base of the map forming Pl. II, which was compiled and drawn after his connection with the Geological Survey had been discontinued.

Our work began on April 1 and ended June 30, 1892. The route traveled during this interval is shown on Pl. II, which will assist the reader in deciding to what extent the conclusions advanced in this paper are based on personal observations and will also serve in a measure to indicate the degree of confidence to be placed in them.

The region described embraces about 10,000 square miles situated east of the Cascade mountains in the central part of the state of Washington. Its relations to adjacent areas are shown on the index map, Pl. I, and its principal topographic features are represented, so far as the scale adopted will permit, on the geological sketch map, Pl. II. As may be seen from these maps, our field of study lies wholly within the hydrographic basin of Columbia river. A large portion is drained by Yakima river, the principal tributary of the Columbia from the west.

Our travels embraced the eastern portions of Yakima and Kittitas counties, the southern border of Okanogan county, nearly the whole of Douglas county, and small portions of the western borders of Adams and Franklin counties. The principal towns visited were Pasco, North Yakima, Ellensburg, Wenache, Waterville, Chelan, and Coulee city. The Northern Pacific railroad crosses the southern portion of the area examined, and the Great Northern railroad was being built across its central part during the season of our visit. Owing to the shortness of the time available for fieldwork and the great extent of territory that it was desirable to study, our examination was necessarily a reconnoissance and can not be considered as a survey. The region was previously almost entirely unknown geologically, and for this reason, at least, it is thought that the results reached will be of interest.

The main object of the present paper is to direct the attention of the people of central Washington to the features in the geology of their country which bear on the possibility of obtaining subsurface water under pressure. The better those interested in drilling wells are acquainted with the geology of the country in which they work, the more likely are they to avoid carrying on their search in unpromising localities. For this reason, as well as to make my report intelligible to a wide circle of readers, I have endeavored to avoid the use of technical terms and to tell the geological story in simple language.

In compiling the topographic base of the accompanying map, free use has been made of the published and unpublished work of the North Transcontinental Survey carried on under the direction of Prof. Raphael Pumpelly;[1] of the survey of Columbia river by Lieut. Thomas W. Symons;[2] and of maps published by the United States Land Survey. In writing the following pages the report of Lieut. Symons and a short paper by Bailey Willis,[3] geologist of the North Transcontinental Survey, on Changes in river courses in Washington territory due to glaciation, have been consulted.

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[1] Map bulletin No. 1. By E. W. Hilgard. New York; 1883.

[2] Report of an examination of the upper Columbia river, 47th Congress, 1st session. Senate Ex. Doc. No. 186. Washington; 1882.

[3] U. S. Geological Survey, Bulletin No. 40. Washington; 1887.

## GEOGRAPHY OF THE REGION TRAVERSED.

The geography of central Washington can not be fully understood until its geological structure is known. It is important, however, that the reader should keep in mind some of the more prominent topographic features of the State while studying its geology. The reasons why it has its present relief and marked diversity will appear as we proceed.

The Cascade mountains, trending north and south, divide the state of Washington into two strongly contrasted portions. On the west there is an excessively humid and densely forested country, sloping precipitously to the lowlands bordering Puget sound and the Pacific. On the east, the descent from the snow-clad summits of the mountains is equally abrupt at first, but the foothills extend far eastward and inclose many charming valleys, shaded by park-like groves of pine and carpeted with luxuriant grasses and flowers.

The Cascade mountains are largely composed of recent volcanic rocks, poured out as molten lava or ejected as scoria and ashes during times of violent eruption, as is testified by the great craters which give them dignity and prominence. The greatest of these volcanic cones, and at the same time the most conspicuous to the inhabitants of the region here described, is Mount Tacoma, the elevation of which, according to measurements by the United States Coast and Geodetic Survey, is 14,440 feet. Another remarkably attractive mountain, as seen from the low country to the east, is Mount Adams, nearly 10,000 feet high, situated 50 miles south of Mount Tacoma and rising as a massive truncated cone, white with snow, far above the densely wooded hills at its immediate base. This is also an ancient crater, and, like Mount Tacoma, has been considerably modified by the action of rain and glaciers, although its volcanic heat is not yet entirely dissipated.

The descent from the summit of the Cascade mountains to the Great Plain of the Columbia varies from 5,000 to nearly 14,000 feet. The general elevation of a large area in the eastern part of the state adjacent to the Columbia is from 600 to 1,000 feet.

There are several narrow mountain spurs from 50 to 75 miles in length, extending east from the immediate foothills of the Cascades, which divide the desert valleys as with a wall, and are among the most remarkable features in the relief of the land. These ridges frequently rise from 2,000 to 3,000 feet above the adjacent plains, and have a gentle slope on one side, conforming with the dip of the strata of which they are composed, but break off abruptly in bold scarps in the opposite direction. Numerous examples of these monoclinal ridges are furnished by east and west uplifts in the eastern part of Yakima and Kittitas counties. Nearly all of these terminate before reaching Columbia river, but one of the most typical, known as Saddle mountain, extends 25 miles east of the river, and forms a narrow, sharp-crested ridge, rising 1,500 feet above the adjacent desert. This ridge runs directly across the course of Columbia river, but the stream had its way established before the mountain was upraised, and has cut a deep notch through it at Sentinel bluffs. Other similar "gates" through narrow, precipitous ridges occur along Yakima river, which, like the Columbia, had its course established before the present topographic relief of the land was initiated.

None of the peculiar ridges referred to are due to the cooling of lava streams flowing away from the great volcanoes to the west, as has been suggested by certain writers. On the contrary, they are portions of a vast series of lava sheets which were at first horizontal, but have since been broken by fractures radiating in a general way from the main uplift to the west, and the edge of the strata on one side of a line of fracture upraised into a mountain ridge. Modifications of this structure where the displacement is small have produced long, narrow arches in the strata.

In the northern part of our field, in Okanogan county, the general relief is greater than in the remainder of the region shown on the accompanying map. The mountains are there composed of crystalline rock of greater age than the rocks in other portions of central Washington. This has also been a land surface for a long time, and the drainage system is well developed. The mountains on the upper courses of the rivers have rounded forms, and are separated by deep-stream channels, which divide and subdivide as one follows them upstream. Recent changes in the direction and character of the streams have been produced in many instances by the temporary occupation of their valleys by glaciers, and their lower courses have in several cases been given new direction or wholly obstructed by lava flows.

East of the Columbia there is a striking change in the topography. This is the lowest part of the great valley between the Cascade and the Rocky mountains, and resembles in many ways the continuation of the same great depression farther south, known as the Great Basin. An observer looking over this region from some commanding summit on its western border has spread before him a vast treeless plain, the general elevation of which at the south is 600 or 700 feet above the sea, and about 3,000 feet adjacent to the mountains bordering it on the north. The secondary relief of this region is but slight, and in a general view the desolate land appears to be a limitless plain. On clear days, when the prevailing desert haze is absent, the dim outlines of the Blue mountains in Oregon may be distinguished far away to the southeast. To the left of these may be seen the more prominent peaks in northern Idaho belonging to the Rocky mountain system. The summits of the distant ranges are white with snow during the winter and early spring, and it is with difficulty that they can be distinguished from cloud banks which float above them; in summer, if seen at all, they appear as shadowy mountains dimly outlined through the heated and much disturbed atmosphere above the desert.

The country east of the Columbia, which seems a plain in contrast with the rugged lands about it, is the northern extension of a vast lava-covered region, embracing part of Idaho, Oregon, and California, as well as hundreds of square miles in Washington. Portions of the cooled and hardened lava flood are still horizontal, but the greater part has been upheaved and much broken, as well as deeply eroded, since it was spread out in a molten condition. In central Washington, however, and particularly in Douglas county, the disturbances that have affected the lava are less conspicuous than in many other parts of the formation. In spite of numerous minor inequalities, this region has received the name of the "Great Plain of the Columbia;" more familiarly it is known as the "Big Bend country," from the fact that it is embraced in a great western curve of the Columbia river.

The Great Plain of the Columbia is treeless, except for a small area on the immediate brink of the canyon bounding it on the northwest, where there are small groves of pines. The lower, and by far the greater, part of its area is a sagebrush-covered desert, very similar to the desolate valleys between the desert ranges in Utah and Nevada. In its northwestern part, however, where the lava has been upraised so as to form a tableland nearly 3,000 feet in general elevation, the desert character is less strongly pronounced, sagebrush is absent, and the land is one vast prairie of waving bunch grass. The uplifts on the west side of the Columbia, formed also by the tilting of portions of the old lava sheets, are likewise remarkable for the luxuriance of their natural meadows. The richest of these smaller plateaus is known as Horseheaven, on account of the abundance of its pasturage.

The most southern of the swift, high-grade rivers draining the east slope of the Cascade mountains is the Klickitat, which flows south between the main uplift on the west and the upraised border of the basaltic plateau country to the east. This stream lies south and west of the country described in the following pages, and but little is known concerning it.

The Yakima river, next north of the Klickitat drainage, is the largest stream joining the Columbia from the west, and although too swift and too shallow to be navigated, it is of importance on account of the great amount of water it furnishes for irrigation and is a most interesting example of the way in which a powerful river can maintain its course in spite of pronounced changes in the topography of the country through which it flows. The ridges of basaltic rock through which the Yakima has cut deep canyons and gateways have all been upraised since that stream established its right of way. North of the Yakima drainage system, and individually of much smaller extent, are the Wenache, Chelan, and Methow rivers. These flow over granitic rocks and have witnessed fewer topographic changes than the main part of the Yakima. Their channels, although not broad, are deeply cut and show that they have suffered but little disturbance for a long period.

The Okanogan river has its principal source north of the Canadian boundary, and flowing south joins the Columbia. Its valley is broad, and is bounded on the west by rounded hills of granite; on the east there is a steep escarpment of basalt formed by the edge of an extruded sheet of basalt which probably filled the lowest portion of the old valley and forced the river to excavate a new channel.

Columbia river flows southward from beyond the Canadian boundary to its junction with Spokane river; it then turns abruptly westward on reaching the border of the basaltic rocks occupying the Big Bend country, and after cutting across a narrow northward prolongation of the lava fields, which, as already mentioned, filled the old channel of Okanogan river, followed the junction of the basalt with the granite to the north and west for about 75 miles. In this portion of its course the great river sweeps around an irregular bend, changing its course first to the south, then to the east, and then south again, until, on leaving the country shown on the accompanying map (Pl. II,) it takes a westerly course, which it holds to the sea.

On the east of the Columbia there are no streams tributary to it in the region here treated. In the winter a few small brooks find their way down the steep canyon wall bordering Douglas county on the west, but they disappear in early summer. A small, irregular brook flows out of Foster creek canyon in early summer, and another equally weak and uncertain rivulet is precipitated over the cliffs at the north of Grand Coulee and joins the Columbia, but precipitation is too scanty to support perennial streams.

Throughout central Washington agriculture is dependent upon irrigation. On portions of the plateaus near the Columbia, especially in the northwestern part of Douglas county and on Horseheaven plateau, in Yakima county, where the elevation approaches 3,000 feet, there is sufficient natural moisture to admit of the cultivation of wheat without irrigation. The crops are uncertain, however, being abundant on occasional wet years, but usually averaging not over 15 or 18 bushels to the acre.

The soil throughout central Washington is deep and rich, and, with the exception of precipitous mountain slopes and certain—and fortunately limited—portions of the valleys, where it is too alkaline, is well adapted to agriculture. Owing to the small rainfall, the general appearance of the country is barren and sterile, yet where irrigation is practicable the harvests are unusually abundant. The principal crops are hay, alfalfa, wheat, oats, potatoes, and hops, and fruits and vegetables of many kinds. The weeks and months of uninterrupted sunshine during the long, hot summers admit of an almost tropical luxuriance of plant growth when the requisite moisture is supplied. Only a small per cent of the entire area can be economically irrigated, however, from surface streams. On the higher plateaus, many of which have unusually rich soil derived from the decay of volcanic rocks, and on the lower and very gentle mountain slopes bordering many of the valleys, there are large areas of fine land which are beyond the reach of all ordinary irrigation methods, and must be reserved for grazing. The desire to cultivate these lands has led to the search for artesian water.

In general, the region embraced in this report may be divided into three strongly contrasted provinces: (1) The foothills of the Cascade, with bold relief, swift clear streams, deeply cut stream channels, and fine forests. (2) The region east of the foothills, limited on the east by the Columbia, where partially wooded ridges extending east and west inclose desert, sagebrush-covered valleys. The drainage originates principally in the more elevated province to the west, and flows eastward across the middle province to join the Columbia. (3) The great plateau region east of the Columbia, where the relief is low, trees are absent, streams are few and feeble, but deep canyons cut through slightly disturbed rocks, indicate a former period of more abundant precipitation. The land is desert-like, but produces luxuriant bunch grass.

## GEOLOGICAL FORMATIONS.

*Crystalline rocks.*—The oldest rocks seen by me in central Washington are granites, schists, quartzites, and allied rocks, which occur principally in Okanogan county. Only a small portion of this region about Lake Chelan and along the Columbia river was visited during our reconnoissance, but the information thus gained, together with what could be learned from miners and others, showed that probably the entire county, with the exception of a small area occupied by coal-bearing rocks near Wenache, is composed of crystalline rocks. These rocks were originally sand and clay, deposited by water in horizontal sheets, in the same way that the ocean is laying down sediments at the present time, but they have been deeply buried and metamorphosed, or changed by pressure and the passage of heated water through them, to such an extent that their minerals have been largely rearranged and separately crystallized, and the original horizontal stratification modified by extensive movements. The rocks forming the present surface have been long exposed to the action of frost, rain, and to glacial abrasion, which has resulted in their being sculptured into the multitudes of varying forms, to which the magnificent scenery of Lake Chelan and neighboring regions is due.

*Kittitas system.*—Resting on the upturned and eroded edges of the crystalline rocks belonging to the series briefly described above, there is an important system of sandstones and shales, with interbedded coal seams, which forms the surface of the country near Wenache, and extend with increasing breadth southwest through the western part of Kittitas county and probably also through the western part of Yakima county. The important coal mines at Roslyn are in this system. From the character of fossil leaves, occurring abundantly in the shale above the coal at Roslyn, it is known that the rocks are of early Tertiary age. The strata enumerated above form a well defined formation, which, for convenience, is named the "Kittitas system." It is limited below, at its junction with the upturned crystalline rock on which it rests, by a great unconformity, and is defined above by another unconformity at its contact with overlying basalt. Future study may show that this system should be subdivided, but as only a small portion of the region it occupies was traversed by me the classification here proposed will be sufficient for present needs.

*Columbia lava.*—Resting unconformably on the Kittitas system and overlapping it toward the north, there is a great series of lava sheets, composed principally of basaltic rocks, which extend with unbroken continuity, not only over the whole of Douglas county but the larger portion of Yakima and Kittitas counties, and besides are known to pass southward beyond the boundaries of Washington. Although this great series of lava sheets is irregular in many ways and of an entirely different origin from the sedimentary beds above and below it, yet it forms the most important geological series in the Northwest, and one which it will be convenient to designate by a specific name. As the region it occupies is drained almost entirely by the Columbia river, I venture to name it the "Columbia lava." So far as known this is the most extensive formation of its kind in the world. Its border, with the exception of the portion represented on the accompanying map, has never been traced, but it is known to occupy large portions of Oregon and Idaho, and to extend into northern California. Its area has been estimated at approximately 200,000 square miles, or as great as the area of France. It is traversed by Snake river throughout its entire course, and by the Columbia, from a locality near the mouth of Spokane river to where the Columbia breaks through the Cascade mountains, a distance of 800 miles. The streams tributary to the Columbia from the south, below the mouth of the Snake, also drain the same great lava field. The Columbia lava is not one vast flow, but is composed of many separate flows, sometimes separated by land surfaces, which frequently contain the stumps of large trees, or by sheets of lapilli. The time required for its accumulation must have been several centuries. The sheets of which it is composed overlap and supplement each other, so as to form one continuous but highly compound system. No single sheet can be traced over the entire field, but yet in the sides of the deep canyons that have been eroded in its surface, individual flows may be followed continuously for a score or more of miles. The entire series varies in thickness from 300 or 400 feet or less along the rim of the canyon of the Columbia, on the northwest border of Douglas county, to 3,700 feet, according to Le Conte, in the Cascade mountains at the Dalles.[1] Its average thickness is thought by Symons[2] to be not far from 2,000 feet. From my own observation this seems as fair an estimate as can be had until more extensive surveys have been made.

In the best sections of the Columbia lava exposed in the precipitous walls of the coulees or canyons, is Douglas county, and in the remarkable gates eroded by the Yakima river through ridges of the same material, there are frequently six or eight distinct layers of basalt exposed, which are from 50 to 150 feet thick. The rock is usually a compact bluish black basalt, with frequently a well defined columnar structure, but is also at times vesicular and scoriaceous, especially on the surfaces of the sheets. Many times the marked columnar structure recalls the finest of the basaltic columns so well known at the Giant's Causeway, and on the Isle of Staffa. The walls of the coulees in the Great Plain of the Columbia are similar to the Palisades of the Hudson, but are far more extensive, and composed of several distinct colonnades which may

[1] Am. Jour. Sci., ser. III, vol. 7, 1874, p. 168.

[2] Report of an examination of the upper Columbia river, p. 100.

be followed for many miles. While these architectural forms suggest the ruins of mighty temples, their extent and magnitude render the most impressive works of man insignificant. In the region traversed by me in central Washington there are no volcanic cones to which the lava sheets might be traced, and no important points of eruption have been reported from other portions of the lava-covered country. In central Oregon, as observed by myself during a former reconnoissance, there are small cones of scoriaceous material on the lava, but these instead of being points of eruption, seemed rather to be parasitic cones formed from the lava flows themselves. On the eroded western border of the system, some 20 miles north of Ellensburg, I saw large dikes of basalt which broke across much disturbed beds of the Kittitas system and connected with the overlying basalt. These prove that the basalt in part and probably to a great extent came from below through fissures and spread out in sheets over the land. The idea that the Columbia lava came to the surface through fissures, and did not originate in the mountains to the east or west, or from craters like Tacoma or Shasta, has been entertained by several writers, notably by Richthofen and Geikie, but even now I feel that much more study should be devoted to the subject before concluding that this was the mode of origin.

Near the upper surface of the Columbia lava, in the Yakima region, there is a thin layer of clay formed as a sediment in a Tertiary lake, and subsequently covered by a lava flow a hundred feet thick. Above this bed of basalt and resting evenly on its surface are gravels and fine, evenly bedded lacustral sediments, having a thickness of 125 feet: then comes an interstratified sheet of columnar basalt, from 40 to 100 feet thick which may be traced from the hills about Ellensburg eastward to Columbia river and appear again in the eastern portion of Saddle mountain. Above this layer there are other lacustral deposits forming the John Day system, described below. Besides the widely spread interstratified sheet of basalt there are other sheets more local and less well known; one of these was penetrated in the artesian wells in Moxee valley.

The records seen in many sections of lava and lake beds show that the period of extensive volcanic overflow ended in a lacustral period, during which the region from the present site of the Cascades eastward to the mountains of Idaho was occupied by a vast lake of Miocene age, in which many hundreds of feet of sediments were laid down. The presence of Miocene lake beds on the surface of the Columbia lava and the occurrence of the Kittitas system of probable Eocene age below it, show that the volcanic outbursts belong somewhere near the middle of the Tertiary, and can not be correlated with the period of general ice invasion known as the Glacial epoch, as some writers have supposed.

*John Day system.*—Before the Columbia lava was broken and tilted, or, in other instances, raised into long, narrow arches, its surface over the whole of central Washington and probably far into Idaho and

Oregon, was covered by the waters of a great lake into which streams washed mud and sand, and volcanoes, in times of violent eruption, strewed vast quantities of fine white dust and lapilli. The accumulation of fine sediment is at best a slow process, but in the instances before us it went on with but slight changes for a sufficient length of time for more than a thousand feet of evenly bedded strata to be laid down one above another. The lake beds thus accumulated have been upraised irregularly together with the underlying lava and greatly eroded. Over large areas nearly the entire series has been washed away, leaving the lava as the surface rock. Remnants of the John Day beds occur throughout our field of study, with the exception of the granitic areas at the north, but are best exposed in the White bluffs of the Columbia, and in Wenas and Naches valleys. Owing to the fact, however, that they occur mostly in the valleys and have been washed away more or less completely from the uplands, they are seldom conspicuous. The lava, owing to its frequent high relief, appears as the prevailing country rock, when in fact it only penetrates here and there through the general covering of superimposed lake beds.

This formation, as shown by its fossil leaves,[1] is of Middle Tertiary (Miocene) age, and is here designated as the John Day system, for the reason that it occurs along John Day river, Oregon, and was there first studied. The beds on John Day river have been described and their fossils referred to many times in geological treatises, and it will be found convenient to group under one name all of the sediments formed in the lake from which the strata on John Day river were deposited.[2] The lake in which these sediments were accumulated may be designated as "Lake John Day."

The John Day beds are usually light colored unconsolidated sediment. In the exposure at White bluffs, the beds are all friable and crumble to sand and clay between the fingers. Many of the strata in fact can not be said to have been consolidated at all, as they are fine loose sands with but little more coherence than the modern sand dunes, into which in some instances a portion of their material has been blown.

In Wenas and Naches valleys the beds are more compact and partake of the character of soft sandstone. In Kittitas valley they have been quarried for building stone, but are light and soft, although making a good appearance as may be seen in a bank building in Ellensburg. The quarry from which this rock was obtained at the south end of Kittitas valley, contains clays and sandstones which are charged with fossil leaves. Other leaf-bearing beds of the same

[1] A report on the fossil leaves of this system, by F. H. Knowlton, forms an Appendix to this paper.

[2] A summary of what has been written concerning this system and a list of papers pertaining to it have been given by Dall and Harris in Bulletin No. 84, U. S. Geol. Survey, pp. 280–282.

character occur at John Day river. It is by comparing the fossils from these two localities, as well as by practically tracing the beds from one exposure to the other, that the identity of the John Day system in general with the beds outcropping on John Day river has been established.

The John Day system will probably interest the reader more than any other series of rocks treated in this paper, for the reason that it is the one from which artesian water has been obtained.

The system is limited below by the Columbia lava, but there is no marked unconformity at this contact. As already mentioned, there are thin beds belonging to the John Day system interstratified with the upper layer of Columbia lava, and thin layers of lava interbedded with the lower layer of the John Day system.

The layers of sediment interbedded in the basalt have been baked and considerably altered by the heat of the inclosing rocks; and the sedimentary beds immediately below the sheets of basalt in the John Day system are also altered, while those above show no change.

The reader should bear in mind that the John Day system is composed of unconsolidated lacustral sediments, of middle Tertiary age, and that marked disturbances resulting in the formation of nearly all the mountains of Central Washington, possibly including the Cascades, have taken place since they were deposited; also that erosion has removed probably the greater part of the system and cut deep canyons in the hard basalt on which it rests. The time since Lake John Day existed is geologically not remote, but must be numbered even by the most conservative at tens of thousands of years. During this time many climatic changes occurred.

The foregoing account of the John Day system is somewhat at variance with previous descriptions of what is supposed to be a southern extension of the same formation. In describing the deposits of a Miocene lake in northern Oregon Prof. O. C. Marsh [1] says:

The Blue mountains formed the eastern and southern shores of this lake, but its other limits are difficult to ascertain, as this whole country has since been deeply buried by successive overflows of volcanic rock. It is only where the latter have been washed away that the lake deposits can be examined. The discovery and first explorations in this basin were made by Rev. Thomas Condon, the present state geologist of Oregon. The typical localities of this Miocene basin are along the John Day river, and this name may very properly be used to designate the lake basin. The strata in this basin are more or less inclined and of great thickness. One section near the John Day river, examined by the writer in 1871 and again in 1873, seems to indicate a thickness of not less than 5,000 feet. The upper beds alone of this series correspond to the deposits in the White river basin. The lower portion also is clearly Miocene, as shown by its vertebrate fauna, which differs in many respects from that above. Beneath these strata are seen, at a few localities, the Eocene beds containing fossil plants mentioned above. They are more highly inclined than the Miocene beds, and some of them show that they have been subjected to heat. The inferior strata elsewhere are Mesozoic, and apparently Cretaceous. Above the Miocene strata Pliocene beds are seen in a few places, but basalt covers nearly all.

[1] Am. Jour. Sci., ser. III, vol. 9, p. 52.

In the account quoted the John Day beds are stated to occur below great sheets of basalt, which I assume is the Columbia lava. In central Washington the John Day beds rest on the Columbia lava. The thickness of the strata in Oregon is nearly five times greater than the greatest thickness discovered in Washington. I see no way of explaining these discrepancies, and the records will have to stand as they are until a more comprehensive study of the region between the Cascade and Rocky mountains, in both Oregon and Washington, can be made.

*Glacial records.*—Long after Lake John Day was drained and its bottom upraised into mountains and ridges, and exposed to the action of rain and rivers until a very large part of its sediments had been carried to the Pacific and deep canyons eroded in the underlying basalt, another important entry was made in geological history of central Washington.

During the deposition of the John Day system the climate was mild and the shores of the great inland sea were clothed with a varied and beautiful flora similar to that of the southern Appalachians at the present time. But after the long interval mentioned above, there came a climatic change which affected the whole of the northern hemisphere. The climate was much colder than when the John Day system was laid down and also colder than at present. The higher valleys among the Cascades as well as all of the lower portions of Okanogan county, were occupied by glacial ice. The depression now holding Lake Chelan was filled from end to end by a magnificent glacier, which flowed southeast and joined another similar river of ice in the canyon of the Columbia. A great glacier flowed southward down the broad Okanogan valley, and reaching the Columbia, not only turned the river from its course but was of sufficient volume to fill its canyon there 2,400 feet deep, and to cross it without apparently being deflected from its general southern course. After crossing the canyon it continued southward on the Great Plain of the Columbia, grinding down and scoring the basaltic rock over which it passed and scattering thousands of huge bowlders over the plateau. The southern limit of this ice invasion was in the neighborhood of Coulee city, and its extension eastward was limited by Grand Coulee. At the south it ended in a great lake, known as Lake Lewis, briefly described below, on which icebergs floated and carried bowlders far and wide over the region to the south. These bowlders of granite, gneiss, basalt, etc., came from the north, some of them perhaps from Canada. They are the latest of all geological records in many portions of our field, and the one that, perhaps, claims the greatest amount of popular attention.

The region embraced in the present reconnoisance only touches the southern part of the glaciated area, and an extended study of the ice records will have to be postponed. The glaciers flowing east from the Cascades, in Yakima and Kittitas counties did not reach the country traversed by me, and hence does not claim attention.

*Lake Lewis.*—The lake into which the ice invasion from the north terminated covered a large area on the Great Plain of the Columbia, but was by no means so extensive as the great Tertiary lake which preceded it. Its northern limit crossed Douglas county from east to west in the neighborhood of Coulee city, and bent northward in Lincoln county, but its course to the east had not been traced. On the west its shores were irregular, owing to Badger and Saddle mountains which projected into it, forming long capes or islands, about which terraces, showing the water level of the lake, were traced at an horizon of about 1,400 feet above sea level, or about 700 feet above Columbia river.

Lake Lewis was first recognized so far as I am aware by Lieut. T. W. Symons and named by him in honor of Capt. Merriweather Lewis, whose name is inseparably connected with that of Capt. Clark in the early explorations of the Great Northwest. On a map in Symons's report,[1] the region covered by the former lake is roughly indicated. Apparently the beds forming the Johnday system were supposed by Symons to be sediments of the younger lake, which probably led him to extend its boundary much farther west than now appears to have been correct. On the map referred to the southern shore of Lake Lewis is represented as following a general east and west course through Walla Walla and Wallula. Present information concerning the topography of this region indicates that the boundary is much farther south than is indicated by Symons, but even its approximate position can not yet be stated.

The relief of central Washington has changed so little since Lake Lewis was in existence, that if we had a good contour map of the country we could trace with a considerable degree of accuracy the outline of its shore. In the absence of such a map we can only say that its water extended far south into Oregon and probably far enough east to cross the present Washington-Idaho boundary The lake probably owed its existence to a dam at the Dalles—perhaps a glacier then obstructed the drainage—or else there was a subsidence sufficient to allow the ocean to enter the great central valley between the Cascades and Rocky mountains. The water body referred to has been called a lake, not because of the presence of fresh water fossils in its sediments, for no fossils that can be referred to that water body have been found, but from analogy with other great lakes which existed under similar conditions.

Lake Lewis, while of broad extent and nearly a thousand feet deep in the deepest portion, seems from the lack of strength in the beach line that it carved, and from the small amount of sediment it left, to have had but a brief existence. The terraces on the flanks of the mountain against which it washed are poorly defined and are many times wanting. The shore records so far as known were of the simplest kind, consisting of cut terraces, of little strength and without the usual accom-

[1] Report of an examination of the upper Columbia river. Pl. 26.

paniments of bars and embankments. No deltas built by streams flowing into the lake have been recognized, unless the heavy gravel deposits filling the canyon of the Columbia to the depth of 700 feet in the neighborhood of Lake Chelan be considered as of this nature.

It is to be noted, however, that the shores of the lake thus far examined are too steep and rugged to be favorable for the development of shore phenomena. When the less precipitous eastern and southern borders are studied they will perhaps reveal a more satisfactory history. The sediments that can be clearly referred to this lake are scanty and almost insignificant, but the surface of the great plain of the Columbia and in the smaller valleys opening from it, as in the Moxee-Yakima valley, there are many large bowlders dropped from floating bergs, and in places a thin layer of subangular gravel from the surface. Lake Lewis existed at the time of the greatest extension of the glaciers on neighboring mountains and was fed by their melting. It was a Pleistocene water body, and had many contemporaries in the now desert valley of the arid region between the Rocky mountains and Sierra Nevada.

## GEOLOGICAL STRUCTURE.

All of the formations mentioned in the preceding section were originally spread out in essentially horizontal sheets, but since the youngest member in the series was laid down they have been broken into blocks and the blocks tilted and upturned so as to form prominent mountain ridges with horizontally floored valleys between. A structure has thus been given to the beds on which depends nearly all of the present topographic diversity of the region.

*Monoclinal ridges.*—The prevailing and most typical structure has been produced by the breaking of the strata and the upturning of the beds on one side of the lines of fracture. The fragments, more or less regular, into which the rocks have been broken are termed orographic blocks. The elevation of the edges of some of these blocks has produced ridges which are steep on one side and form bluffs in which the broken edges of the strata outcrop and slope gently in the opposite direction, the surface slope corresponding in general with the inclination of the beds. The fractures referred to, along which adjacent blocks have been moved up or down in reference to each other, are known as faults. An ideal vertical section across such a fault is shown in the following diagram, which will serve to define some of the terms used by geologists in connection with such displacements:

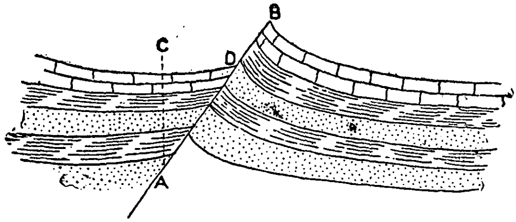



FIG. 1.—Ideal section showing a normal fault. The rocks to the left are a portion of the "thrown block;" those to the right belong to the "heaved block." The "hade" of the fault is the angle which the plane of fracture *a b* makes with a vertical plane *a c*. The fault scarp *b d* is the portion of the fault plane which projects above the thrown block. In a normal fault the fault plane hades toward the thrown block; in a reverse fault it hades toward the heaved block. All of the faults to be noted in this paper belong to the first type.

An example of the upturned edge of an orographic block is furnished by the northern escarpment of the sloping table-land known as Horseheaven, which is well exposed in the neighborhood of Kiona and Prosser. This long line of cliffs is a fault scarp from which the strata slope gently southeast toward the Columbia.

Rattlesnake mountain is another uplift of the same nature, but more abrupt and having its gentle slope in the opposite direction. The eastern face of Rattlesnake mountain is a fault scarp 2,500 feet high. Its crest line is sharp and its western slope conforms with the gentle dip of the beds with which the uplift is composed. The break, on the west side of which the mountain was upraised, may be traced for 50 miles toward the southeast by minor scarps, which form a range of low hills that reach the Columbia near Wallula.

Many other examples of the formation of prominent mountains in central Washington by the uplifting of the edges of great orographic blocks might be cited, but these will be described in the section of this paper devoted to local geology.

*Monoclinal folds.*—Besides monoclinal ridges there are other types of mountains in the region traversed which are not so simple in their structure. These are long narrow ridges which were formed by an arching of the strata without breaks. The arches were raised by a force acting from below upward, and not by lateral pressure which forced the strata into ridges and troughs, as is common especially in the Appalachian mountains.

A cross section of one of these folds is well exposed in Union gap, through which the Yakima river flows in escaping from the valley in which North Yakima is located. The ridge there cut through, runs eastward from the irregular high lands west of Tampico, and ends 5 or 6 miles east of Union gap. Throughout this distance it is a sharply defined, even crested uplift, rising 1,000 feet above the adjacent level floored valley, and has an arched structure throughout. At its east end it terminates in a low point curving south, but another ridge having a somewhat different structure immediately begins and extends 50 miles farther east, the gap between the two being so small that they are usually considered as a single range.

North of North Yakima there is another example of a similar nature, but in this instance the arch is broken longitudinally, and the ridge assumes the faulted character described in the preceding paragraph. The ridges due to an arching of the strata pass into folds that are very steep on one side and have a gentle slope in the opposite direction, and these change to faults.

Just what the action was which produced these arches it is difficult to determine. It is possible that volcanic rocks escaping in a molten state through fissures in lower beds raised the Columbia lava and superimposed beds into arches. In the continuation of the ridge cut through at Union gap, which forms the south wall of Moxee valley, molten rock forced up from below escaped through fissures in the Columbia lava, but raised the lighter beds above into a long narrow ridge. In this instance the intruded lava has been clearly exposed by the erosion of a longitudinal valley along portions of the crest of the uplift.

It seems to follow from such facts as are in hand that the fractures which allowed of the tilting of some of the orographic blocks, in other instances furnished a passage upward for molten matter which raised the superficial layers of the earth's crust into long narrow arches.

One of the popular impressions to be unlearned in reference to the peculiar east and west ridges of Yakima and Kittitas counties is the supposition that they are lava streams which flowed away from the Cascades and on cooling formed narrow precipitous ridges from 1,000 to 3,000 feet high. On the contrary, these ridges have been formed by the elevation, principally along lines of fracture, of the Columbia lava and of the overlying John Day beds, which were originally horizontal.

*North and south elevation.*—In the eastern portion of Yakima and Kittitas counties there are also gentle elevations which trend north and south across the much narrower and more prominent east and west ridges. These undulations, some of which are easily overlooked in the gentle relief, are difficult to trace to any definite dynamic action, but are of importance for the reason that, in connection with the east and west ridge, they take part in the formation of basins, of which Moxee valley is an example, having such a shape that they become reservoirs of artesian waters. The north and south elevation preceded the east and west breaks, as is shown by the continuation across them of the fault scarps produced by the east and west breaks. This is shown especially in the region of general uplifts bordering the Yakima hydrographic basin on the west, where the east and west ridges of the eastern part of Yakima county may be distinctly traced across a broad undulation trending north and south.

Too little is known of the structure of central Washington to warrant the framing of a comprehensive hypothesis to explain its structure, but the fact that the broad north and south uplifts follow the general direction of the Cascade mountains suggests that they were formed at the time the main mountain range was upheaved, and that subsequent movements produced cross fractures which radiate from the main elevation. It seems probable that the Cascades are formed to a large extent of tilted blocks of basalt which were originally horizontal, and belong to the same series as the Columbia lavas farther east, which have been, in comparison, only moderately disturbed. The Cascade mountains, at least in the State of Washington, do not seem to have been formed mainly by the piling up of erupted material as has been suggested in explanation of their origin farther south, but are due to the uplifting and tilting of previously consolidated lava sheets, as well as of granite and coal-bearing strata, which occur high up on each flank of the mountain, and even from portions of the main divide. The great volcanoes which appear so prominent along the general trend of the range are secondary to the main mountain-building. The lava sheets in central Washington have been separated from the Cascades by erosion, as is shown by the presence of the Kittitas system in the deeply dissected country at the eastern base of the range, dividing it from the the lava-covered country to the east.

*Mountains of denudation.*—In the northern part of our field especially in Okanogan county, there are lofty and exceedingly rugged mountains of crystalline rock, in which the diversity in relief is due to the sculpturing of a great uplifted mass of the earth's crust, by atmospheric agencies. The individual peaks and serrate ridges as well as all of the detail to which these mountains owe their picturesqueness, is due to the cutting out of the valley and canyons and not to the separate elevation of each towering summit. They are mountains of erosion, although the general relief is due to the elevating of a great mass of material which was formerly deeply buried in the earth's crust. In these mountains there is a structure not yet studied, which modified the action of the various erosive agencies, but scarcely render it necessary to qualify the statement that the topographic diversity is due to sculpture. In this respect the relief of the granite region differs from that of the younger rocks to the south, where the main features in the present topography are due to the upraising of the ridges and not to the down-cutting of the valleys.

In the Kittitas system there are folds probably due to lateral pressure, but these were produced before the outpouring of the Columbia lava and do not affect the topography of the surface where the lava occurs. West of the lava where the Kittitas system occupies the surface, the relief although modified by the structure, is due mainly to erosion which has removed material from the valleys and left the interstream spaces in relief.

*Volcanic mountains.*—The more prominent summits of the Cascade mountains, as already stated, have been formed by the piling up of volcanic rocks about the vents from which they came. There are no mountains of this type in the region described in this paper, but the prominence of the volcanoes of the Cascades, as yet scarcely extinct, renders them an attractive object-lesson to all who live in their vicinity.

*Level-floored valleys.*—The valleys between the ranges in Yakima and Kittitas counties, and over a large portion of the region east of the Columbia, have horizontal layers of John Day beds and Columbia lava beneath. The strata flooring the valley are horizontal and as far as we can judge, have remained so since they were deposited. These undisturbed regions form valleys for the reason that the ridges separating them have been upraised. These broad undisturbed areas, as well as the structure of the intervening ridges, show that there has been no lateral pressure of such a nature as to form anticlines and synclines. Much of the region in the Great Plain of the Columbia falls in this division.

*Summary.*—Briefly stated, the main structural features in our field are (1) narrow, sharp-crested ridges having a prevailing east and west trend, due to the upheaval of the borders of orographic blocks; (2) broad and comparatively gentle north and south elevation, produced apparently by an arching of the strata, parallel to and probably of the same date as the much greater uplift forming the Cascade mountains; (3) regions where the rocks have been but little disturbed and now form plains and valleys.

## GENERAL PRINCIPLES PERTAINING TO ARTESIAN WATER.[1]

The conditions on which the flow of water from artesian wells depend are simple and easily understood. To illustrate by an elementary example, suppose the following diagram to represent an east and west section of a valley 20 miles broad. A section north and south would show the same structure; that in the rocks form a basin. The rocks are in layers like a pile of saucers; some of the layers are composed of clay which is water-tight, while others are of sand through which water can percolate. Rain falling on the edges of the upturned layers of sand inclosed between layers of clay, penetrate them and fill them with water up to the lowest point on their rims, where it will leak out and form springs.

Let a hole be drilled through the upper layer of clay in the central part of the basin, say at D in the diagram, and the water which saturates the layer of sand below the clay will rise and overflow at the surface. If the well has a water-tight casing and an open tube be carried up from

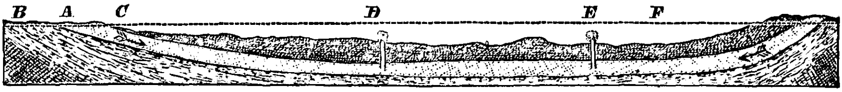



FIG. 2.—Ideal section illustrating the chief requisite conditions of artesian wells. A, a porous stratum; B and C, impervious beds below and above A, acting as confining strata; F, the height of the water level in the porous bed, A, or, in other words, the height of the reservoir or fountain head; D and E, flowing wells springing from the porous water-filled bed, A. (Chamberlin.)

it, the water will rise in the tube until it stands approximately on a level with the lowest point in the rim of the basin of sand.

The water rises in the tube because of the pressure of the water at a higher level in the sand. The layers of sand through which the water slowly flows, and the well connected with it, may be considered as a single tube. Everyone knows that water poured into a tube bent down in the center will rise to the same height in each arm. A teakettle filled with water is an illustration of this principle; the water in the kettle and in the spout will stand at the same level. The same simple principle governs the flow of artesian wells.

In the search for artesian water one finds many modifications of the conditions described above. Among these are changes in the character of the water-bearing beds, or of the impervious beds above or below. The water-bearing bed may change its character and have clay mingle with the sand in certain areas, thus obstructing or stopping the

[1] For a more complete discussion of the conditious limiting the existence of artesian water than is here practicable, see The requisite and qualifying conditions of artesian wells, by T. C. Chamberlin, U. S. Geological Survey, 5th Ann. Rept.

flow of water through it. When this happens, although the basin may have the requisite form and several alternating pervious and impervious strata about its margin, a well drilled in the central part may not be successful, while one near the border, which escapes the reigon where the sand is charged with clay, may give an abundant flow.

A change in the character of the pervious layer rendering it impervious sometimes makes it possible to obtain flowing water when the rocks do not form a basin but slope in one direction for a long distance. These conditions are sometimes produced in the deposition of sediments in the ocean or in lakes, owing to the fact that coarse material, such as gravel and sand, are deposited near shore, while finer sediments, as clay, may be carried a long distance before being dropped. The same bed thus changes from gravel to sand and then to sandy clay, and finally to clay as one follows it from the shore seaward. A peculiar modification of these conditions is illustrated in the following diagram, which should be of interest to those engaged in searching for flowing water in the desert valleys of the arid region.

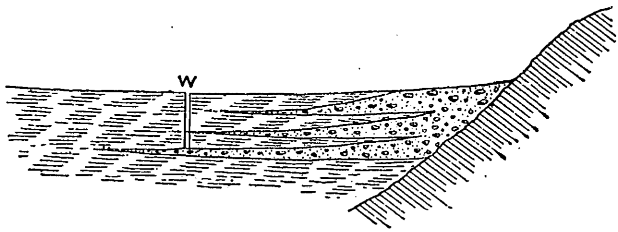



FIG. 3.—Ideal section of the border of a basin deposit.

The diagram represents a vertical section of the superficial deposits in a valley adjacent to a mountain range. In arid regions the valleys in many instances have been occupied by lakes at a late geological period. During the existence of the lakes sands and gravels were deposited along their borders, and fine sediments in their deeper portions. When, owing to climatic changes, the lakes became shrunken, coarse material was carried farther and farther out from the mountains and either deposited about the border of the lake as alluvial material or spread out by their waters as sheets of sand and gravel. When the lakes again extended and were enabled to deposit clays over broader areas, the fringe of coarse material adjacent to the mountains became covered by an impervious layer. These varying conditions in many instances gave origin to extensive deposits of gravel and coarse debris, which are thick near the borders of the valleys and thin out toward their centers, and are interstratified, especially on their attenuated margins, with layers of fine, impervious material. The present scanty rainfall and the flow of streams across the outcropping borders of the coarse deposits tend to keep them saturated with water; but as they thin out and are replaced by impervious layers the water is unable to escape. Under these conditions a hole drilled in a position corresponding with W in

Fig. 3 will penetrate the water-bearing strata at a point below the level of the source of supply, and, in consequence of the hydrostatic pressure, water will rise and overflow at the surface. Many of the flowing wells in Utah, Nevada, and California depend on these conditions.

Failure to obtain flowing water even when an examination shows that a given region has the requisite structure may result from one or more of several causes.

In the arid region the rainfall on the outcropping surface of a porous stratum may not be sufficient to fill it, or if already completely charged when first penetrated, may not be sufficient to supply the drain made by one or more flowing wells.

The layer inclosing the water-bearing stratum may be broken so as

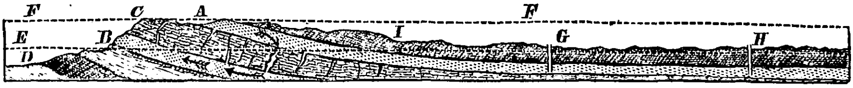



FIG. 4.—Ideal section illustrating the failure of an artesian well because of defects in the confining bed below a water-bearing stratum. A and B, porous beds; D and I, impervious beds; C, a defective confining bed; E, the water level of the stratum B; G and H, wells that do not flow. The bed A might give a flow at G and H but for the defect in C, which permits the water to descend into B and escape through its outcrop, which lies below the surface of G and H. (Chamberlin.)

to allow the water to escape. When an outlet is found through the layer below the porous stratum the water will escape and issue from a spring at some lower level, as shown in the following diagram:

When a break occurs in the overlying impervious layer the water will escape upward, thus relieving the pressure, and saturating superficial deposits percolate away and form springs in depressions.

Another source of failure when all the requisite conditions are present is sometimes experienced by beginning a well on ground that is higher than the artesian head, perhaps within the actual artesian basin, but more frequently on its border. To illustrate, if water stands at the horizon A A in the pervious layer, shown in the following diagram,

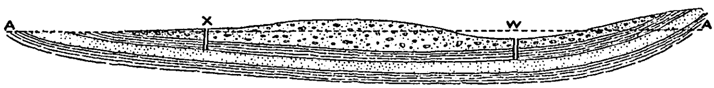



FIG. 5.—Ideal section showing the failure of wells in artesian basin.

because of an outlet somewhere at this horizon, and holes are drilled at X, the water will fail to reach the surface because the tube through which it would have to rise opens above the horizon at which the water stands in the reservoir.

The water would rise in wells at X, up to the horizon of the artesian head, but no farther. A well drilled at W would flow, because the surface at that point is below the horizon at which the water naturally escapes from the pervious layers.

The conditions shown in Fig. 5 illustrate the lack of consistency in confining the term "artesian" to wells that overflow. The water in the well at X is under the same pressure as in the well at W, but the tube is too long to allow it to rise to the surface.

In describing the conditions which combine to make an artesian basin, I have assumed that the water was supplied directly by the rain falling on the outcrops of the porous strata. While this is unquestionably the method by which water usually finds its way into artesian reservoirs, yet there is a modification of the process which sometimes makes artesian wells possible in unpromising situations. The pervious layer from which a well is supplied may be charged through fissures in the impervious layer beneath, either from the upward leakage of a lower basin or by fissure springs, such as exist in many regions where the rocks have been much disturbed.

The charging from below of a pervious bed, so shaped and inclosed as to form a basin, is a matter of interest to the readers of this report, since the Moxee basin, in which three successful wells are now flowing, seems to receive its water in this way. The manner in which a curved pervious sheet, inclosed in impervious beds, may be charged with water from below is shown in Fig. 7. Like several diagrams already printed this is a vertical cross section.

The shaded beds, forming the bottom of the basin, are rigid and have been faulted; the faults extend into the sands and clay above, and the displacement becomes a monoclinal fold, perhaps with some fracturing.

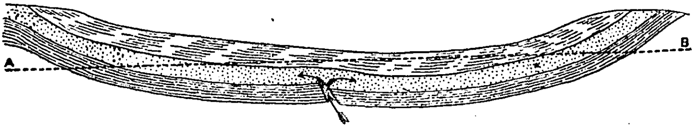



FIG. 6. Ideal section of a pervious bed charged with water rising through a fissure.

Water rising along the fault plane penetrates the overlying porous layers and saturates them to as great a height as the pressure of the water from below will allow, say to the horizon A B. A well drilled in the valley, so as to penetrate the water-charged strata below this horizon, would open a way for the water to reach the surface. The source of the water which rises along the fault in the bottom of the valley, as supposed above, may be far away and traverse irregular cracks or partially filled fissures for long distances. Water might also reach a basin not so situated as to receive a supply from surface outcrops, by the leaking upwards of a lower artesian basin.

There are a few popular fallacies which need to be disregarded by those searching for artesian water. One of these is that the water flowing from artesian wells is derived from open spaces or caves in the rocks, or else circulates as streams through underground channels. Such openings seldom exist, and, if they did, the search for them by drilling holes would be too uncertain and too expensive to be warranted. On the contrary, the water percolates through porous strata. The best water-bearing layers would be those of loose texture, like sheets of bowlders and coarse gravel, but commonally they are sandstone or loose unconsolidated sand.

Another mistake is that artesian water is looked for because there are highlands in the neighborhood, from which it is supposed to flow. This may be a favorable condition or the reverse. If the highlands are composed of stratified rocks, dipping towards the supposed location, all may be well; but if the elevated region is composed of strata dipping away from the site chosen, or if it is composed of volcanic rocks which break through sedimentary beds, its influence may be negative or decidedly adverse to the result desired.

Perhaps the most widely spread fallacy concerning artesian water, and one frequently advanced by those pecuniarily interested in having work done in a definite locality regardless of the result, is that, "if you go deep enough flowing water will be reached." The absurdity of this assumption will be shown, I think, even to the most sanguine, by inspecting Figs. 2 and 3. Plainly, if a well is carried through the pervious beds without reaching water, there is no hope of success in lower layers. In cases where there is no artesian basin it is plain that the deeper one sends his drill the worse he is off.

The depth to which artesian wells designed for irrigation can be carried is also limited commercially. Just as many large tracts of rich land can not now be advantageously irrigated, on account of the expense of bringing water to them in ditches, viaducts, etc., so an artesian basin may be so far below the surface, and the rocks to be passed through in reaching it so expensive to drill, that as a business enterprise it will not pay.

As will be shown in the following pages the rocks in the arid portion of central Washington which have yielded artesian water, and the only ones from which a supply for irrigation can be expected, are the John Day beds. These are composed of alternating layers of gravel, sand, clay, volcanic dust, etc., and over broad areas have sheets of basalt interstratified with them. Some of the layers are porous, while others are so fine and compact that water can not percolate through them. When this series has been bent upward in such a manner as to form basins, the condition for holding water so as to give an artesian head are obtained. When such basins are found it may still be a question whether the outcropping edges of the porous layers receive sufficient rainfall to fill them; and also whether in the formation of the basin the rocks have been fractured so as to allow the water to escape.

The John Day beds rest on a great thickness of stratified basalt, in which there are certain thin layers of porous lapilli, and old land surfaces now containing the remains of fossil forests. The basalt is not only difficult to penetrate with a drill, but is so thick and the chances of their containing water-bearing layers so slight, that although they may form basins, yet practically the search for artesian water is confined to the sedimentary beds resting upon them. When these occur in basins of sufficient depth and extent, further study is warranted in order to determine secondary conditions; but when they do not form basins, or when they have been eroded out of a valley, leaving the Columbia lava exposed, search for artesian water will be fruitless.

## GEOLOGY OF THE COUNTIES EXAMINED.

### YAKIMA COUNTY.

My reconnoissance covered about two-thirds of Yakima county, leaving unexplored an irregular belt, from 30 to 50 miles broad, extending eastward from the crest of the Cascade mountains. The recent discovery of anthracite coal at Cowlitz pass, in this unexplored tract, shows that an important chapter in the geological history of the county there awaits investigation. This region also contains much that is especially attractive to the general traveler in search of the picturesque and beautiful. It is a land of magnificent mountains and wild canyons, and is clothed with forests up to the beginning of the snow fields on the higher summits. Mount Tacoma, the loftiest peak in the state of Washington, stands near its western border, while Mount Adams, even more prominent as seen from many points of view to the eastward, is wholly within the limits of the county. Many mountain lakes, surrounded by rugged slopes still clothed with forests, all in the freshness and wildness of their natural beauty, occur along the eastern slope of the range. The streams flowing from these fountains have carved deep canyons through lava rocks, or where their task was less difficult, have spread out sediments so as to form natural meadows of great luxuriance. This mountain belt is without roads, and can be traversed only by following the few trails that penetrate it, thus adding the zest of exploration to the charm of the natural surroundings. From some of the secondary mountain crests to the eastward, I had most enticing glimpses into this attractive region, which tempted me to leave the arid lands which claimed my attention and enjoy the cool shade, clear, sweet water, and pleasant camp grounds of the forested uplands. The agricultural wealth of the county, however, is in the less picturesque central and eastern portions. The gray sagebrush plains separating the desert ranges become abundantly fruitful when they are nourished by irrigating waters, and it was in this region that our search for artesian basins was to be carried on.

The portion of Yakima county that was examined is drained almost entirely by Yakima river, and lies east of an irregular north and south line passing near Fort Simcoe, Tampico, and the junction of Tiaton creek with Naches river.

In this section of the county practically all of the rocks are black, compact Columbia lava and light colored sediment of Lake John Day which rests upon it. The attention of the reader will be occupied principally in tracing the deformations by faulting and arching that the Columbia lava has undergone and in noting the results of erosion which has removed the John Day beds from the uplands and in many instances cut deep trenches in the lava beneath. The mountains are composed essentially of basalt and many of the valleys are still deeply filled with lake beds. The mountains are the prominent topographic features and always claim their full share of attention, but the valleys are of even greater interest, as they contain the rich agricultural land for which water is needed.

*Lowlands along the Columbia.*—The country on the east border of Yakima county adjacent to the Columbia is low and forms a triangular area of about 50 miles long from northwest to southeast, and 20 miles broad at the north. The southern point of the triangle is a few miles north of Wallula; from there it widens northward and attains its greatest width opposite White bluffs. The elevation of the desert tract over large areas is less than a hundred feet above the Columbia, but increases in height toward the mountains bordering it on the west. The rocks beneath the plain are Columbia lava, mostly concealed by a thin covering of John Day beds. The amount of lake beds that have been removed from this area is indicated by the thickness of the same system in the bluffs forming the east bank of the Columbia. The beds now finely exposed on the east bank of the river formerly extended westward over the plain adjacent to the Columbia, and have been removed principally through the agency of rains and rills and by the Columbia itself, which is still working its way eastward, perhaps in obedience to the dip of the rocks beneath, which is possibly still undergoing change. The rocks beneath the plain dip gently eastward from a fault, as will be explained later; a slight movement along this fault, tending to raise the western edge of the thrown block, would have a direct effect on the course of the streams flowing over it.

On the surface of the plain there are broad areas occupied by drifting sand, which every breeze busies itself in building into new forms. The sand dunes present their steeper slopes to the east, thus showing the direction of the prevailing winds, and the course they themselves are traveling. In places they are encroaching on the river and adding to the material with which its brown current is already loaded.

Yakima river, flowing from the west, crosses the lowlands bordering the Columbia, and has sunk its channel through the John Day beds and into the basalt beneath to a depth regulated by the level of the Columbia. The lower portion of the stream, not being able to cut deeper, has begun to broaden its channel and to meander from side to side.

The west margin of the plain along the Columbia is determined for more than 40 miles by a displacement named "Rattlesnake fault," for the reason that its upheaved side forms Rattlesnake mountain. Besides Rattlesnake mountain there are several smaller uplifts situated on the same line of fracture toward the southeast, and reaching the Columbia about 3 miles north of Wallula. North of Rattlesnake mountain the border of the plain is less regular than farther south, and is formed by the ends of mountain ridges which trend east and west and terminate somewhat abruptly at their eastern extremities where they disappear beneath the desert. One of these ridges touches the Columbia at Priest's rapids, causing the river to change its course abruptly, and then passing beneath the level of the plain appears again some 6 or 8 miles to the east as a group of long narrow hills having a common east and west trend and rising from the plain like lost mountains. From the roof-like appearance of these uplifts they have been called the "Gable hills."

The Columbia plain is thus bounded on the west by a series of faults. The rocks beneath the plain do not form a single block, however, as is shown by a low fault scarp parallel with the great Rattlesnake fault and 3 or 4 miles east of it. This displacement forms a range of low hills running southeast past Baxter.

On the surface of the plain, where not covered with drifting sand, there are scattered bowlders of granite, gneiss, basalt, etc., dropped from icebergs floating in Lake Lewis, the shore lines of which are dimly shown on the lower scarps produced by the Rattlesnake fault. In the banks of Yakima river, where it crosses the plain adjacent to the Columbia, there are small exposures of John Day beds and of sheets of basalt interstratified with them. At the east base of Rattlesnake mountain, also, there are several stream channels which have been cut down into basalt. These sections show that the remnants of John Day beds on the plain are thin. A well dug at the east base of Rattlesnake mountain, near its southern end, showed that the surface soil is there but a few feet deep and rests on basalt about 60 feet thick, beneath which there are soft sands and clays at least 50 or 60 feet thick. The layer of basalt penetrated by this well is the layer found so generally in the eastern part of Yakima county near the base of the John Day system.

Much as artesian water would be prized in the desert tract described above, its presence is not to be expected, for the reason that the John Day beds are thin and in places scarcely conceal the basalt beneath. The great thickness of the Columbia lava renders it inexpedient to search for a deeper source on account of the expense of drilling, even if the general conditions were favorable. Besides, Rattlesnake and other faults along the west side of the plain necessarily cut off an underground water supply from that direction; and as the general inclination of the strata beneath the plain is eastward, a source in any other direction seems equally impossible.

The conclusion just stated receives support, also, from the record of a well, 600 feet deep, drilled at Pasco, where the conditions are essentially the same as on the west side of the Columbia. No definite record of this well has been obtained, but it is reported to have passed through the following beds without reaching flowing water:

| | Feet. |
|---|---|
| Sand | 72 |
| John Day beds | 200 |
| Columbia lava | 330 |

The fractures along the northeast base of Rattlesnake mountain have opened a way through which subterranean waters rise to the surface. One of the springs on this line of faulting situated on the south margin of the valley known as Higgins bottom, is one of the largest springs in the country. Both northward and southward of this fountain there are smaller springs, which also flow throughout the year, and, like fissure springs generally, do not show variation dependent on monthly changes in the local rainfall. In Higgins bottom near the end of Yakima ridge, and forming the source of Higginbottom creek (also called Rattlesnake spring by many ranchmen) there is a spring discharging, by estimate, a little more than a cubic foot per second. This is also a perennial spring, and is reported to flow summer and winter without visible change. The water rises through soft lake beds, from a concealed fissure below, and, together with the occasional surface drainage, has cut a canyon, in the soft strata, a quarter of a mile long and 50 or 60 feet deep. The stream flowing from this spring is 8 or 10 miles long in early summer, but disappears before reaching Yakima river, into which the drainage from that portion of the desert formerly flowed.

*Rattlesnake mountain.*—This sharply defined uplift, although only about 20 miles long, is one of the most typical monoclinal mountains in central Washington. Its sharp, well-defined crest is curved so as to be convex toward the northeast. Its northeast escarpment is an exceeding bold bluff rising nearly 3,000 feet above the plain extending from its base to Columbia river,[1] and is formed by the broken edges of the strata of Columbia lava, which dip gently toward the south and southwest, and give the mountain its long gentle, southern slope. Owing to the fact that many landslides have fallen from its precipitous northeastern face, the outcrops of the beds on that side have been covered with debris and greatly obscured. The character of the exposures to be seen, however, suggests that the heavy layers of the basalt are separated by thin sedimentary layers or by sheets of lapilli, thus giving the conditions favorable for the formation of landslides. The fault producing Rattlesnake mountain has such a great displacement that it may bring up the rocks on which the Columbia lava rests, but whether this is the case or not could not be satisfactorily determined, owing to the vast amount of debris covering and concealing the lower portion of the escarpment.

The southwest side of Rattlesnake mountain has a long, gentle slope, as just stated, conforming with the dip of the strata. Near the crest, as is common in many similar uplifts, the dip is quite steep, averaging perhaps 15 or 20 degrees, but soon decreases to 8 or 10 degrees, and grows gradually less and less until the beds become horizontal in the valley at the base of the mountain.

[1] Elevations on the crest of the ridge, according to the North Transcontinental Survey, are 3,558, 3,515, and 3,420 feet above the sea. The elevation of the Columbia river at Pasco is about 380 feet.

The crest is formed of a hard layer of columnar basalt, but a little way down the southwest slope sedimentary beds occur, in which there is at least one interstratified sheet of basalt, having a thickness of from 50 to 70 feet. This interstratified sheet marks a secondary crest on the southwest side of the main crest, owing to the unequal waste of hard and soft beds, but it is not conspicuous for the reason that the disintegrated rock is not removed as fast as it is formed, and hence the character of the rocks beneath is obscured.

The southwest slope of Rattlesnake mountain is covered with soft John Day beds, which have been cut by many small streams flowing down the mountain side during the occasional heavy rains. These stream channels are peculiar, owing to the fact that they are steep on one side and have a gentle slope in the opposite direction. The streams cut down through the soft beds until they meet a layer of basalt, which has a gentle inclination not coinciding with the direction in which the water flows, and then tend to follow down on the hard layer, but in so doing are forced to remove greater and greater quantities of soft strata as they proceed. The result is that the soft beds stand in a steep bluff on one side of a stream, while the opposite bank is a gentle slope formed by the hard sublayer. In the northern portion of the mountain, the dip of the hard layer is, in general, westward, and the streams have their steep bluffs on the west side.

In viewing the southwest slope of the mountain from a distance, especially near sunset, it will be noticed that many of the stream channels scoring its surface are curved to the left in reference to their direction of flow, i. e., they are concave to the east. The reason for their general curvature is not apparent in the slope of the strata or in the nature of their material. What the true explanation may be, whether due to the earth's rotation or some other cause, remains to be decided after more careful study.

To obtain a general knowledge of the character of the uplifts in the eastern part of Yakima county and of the broad plateau east of the Columbia, one can not do better than to climb Rattlesnake mountain and study the relief of the country spread out at his feet. In such a view one sees a vast plain to the east, with scarcely any relief, the limits of which are but dimly suggested by the Blue mountains of Oregon to the southeast, and the higher peaks of the Cabinet mountains in Idaho to the east. Across the plain winds the Columbia, its course rendered especially distinct by the bluffs of white rocks forming its eastern bank. Between the observer and the river lies the desert plain described in the preceding section. The most interesting feature in the topography of the land in view, however, is the series of monoclinal hills marking the course of Rattlesnake fault toward the southeast. This fault, defined at the north by the bold uplift on which the reader in fancy is standing, first makes a symmetrical curve 20 miles in length, convex toward the northeast; it then extends southeast, at first with a gentle concavity towards the east, then becoming nearly straight; but on looking along the series of crests marking its course, we find that it is slightly convex toward the west. The total length of the graceful double curve is about 50 miles.

The small uplifts marking the southern extension of the fault, like the great cliff to the north, present bold escarpments to the east, which are from 400 to 500 feet high and slope gently westward in conformity with the dip of the beds of which they are composed. The southern extension of the fault is not marked by one continuous scarp, but by a series of long, narrow ridges. Each individual ridge is accompanied by a short lateral escarpment extending northwestward from the main fault, and making an angle with it of about 30° by estimate; these branching escarpments are formed by cross breaks, thus admitting of the elevation of separate portions of the border of the main fault.

South and west of Rattlesnake mountain we look down on a broad desolate valley, the southern limit of which, 6 or 8 miles distant, is determined by another abrupt escarpment, produced by the upraised border of another fault block, the gentle slope of which is southward. The crest line of this uplift as seen from the north appears nearly level, and beyond it we can see portions of the gently sloping plateau formed by the surface of the tilted block, and known as Horseheaven.

The valley intervening between Rattlesnake mountain and Horseheaven expands to the north, and beyond it there are several monoclinal ridges having a history similar to the uplifts just noticed, but too distant to be clearly recognized from the crest of Rattlesnake mountain. Far beyond these indistinct ridges rise the snow-clad summits of the Cascade mountains.

What especially strikes the attention of the observer viewing the magnificent panorama surrounding Rattlesnake mountain is the desolation of the scene. Not a trace of the deep green of forests or of the more vivid tints of cultivated fields arrests the eye. There is not a tree in sight, except on the far-off western mountains. The light at midday is blinding in its intensity, and the absence of shadows renders the far-reaching picture flat and expressionless; the surface of the desert land becomes heated and the waving atmosphere renders all but the nearer objects uncertain. But when the oblique lights of evening cause the mountains to cast long shadows on the plains, and each drainage line and fault cliff is brilliantly illuminated or dark with shadows, the scene acquires a new life. The character of the topographic forms and the main features in the geological structures then stand out with such wonderful distinctness that one may read the history of the land as clearly as if it had been carefully modeled for his study.

*Horseheaven plateau.*—Horseheaven is the name given by ranchmen to the broad, sloping plateau in the southeast part of Yakima county, south of Yakima river, which is bounded on the north by the fault scarp noticed to the south of Rattlesnake mountain. In a state of nature this upland was covered with luxuriant bunch grass and afforded abundant pasturage. The rainfall is there more abundant than in the adjacent valleys, and wheat is now grown on the more favorable portions without irrigation.

The northern border of Horseheaven plateau is formed by a great displacement, having two branches which meet near the town of Kiona, a station on the Northern Pacific railroad. The shorter of the two fault lines runs southeast from Kiona and dies out at a distance of 8 or 10 miles; but the longer arm can be traced by its great scarp for over 50 miles toward the southwest. Near Kiona, where the two faults unite, the escarpment is 1,600 feet high. The southeastern arm decreases gradually in elevation and finally merges into the plain, but the larger northwestern arm maintains a remarkably straight course, rising toward its western terminus and traversing a region of general elevation bordering the Yakima hydrographic basin on the west. The fault scarp is thus shown to be of later date than the region of general elevation which it crosses. Other faults crossing the same range of foothills farther north will be noticed later. The great Horseheaven escarpment, with a gently undulating crest line, slightly notched in places by stream channels, appears like a mountain wall when seen from the valley to the north. The rocks forming it, like the beds on the precipitous face of Rattlesnake mountain, are mainly Columbia lava, but the outcrops are largely concealed by landslides. The slides have formed many small, undrained basins on the face of the steep slope, and also irregular lines simulating terraces. A very large portion of the details in this, as well as many other fault scarps formed of broken strata of Columbia lava, are thus accounted for. Reference to similar features in other uplifts will occur again and again as we proceed.

The reason why landslides have been so numerous on the steep slope of Columbia lava, whether formed as fault scarp or as precipices due to the undercutting of streams, is because the strata are in layers, separated in some instances by thin sheets of lapilli or of clay and sand, which weather out and allow large slices of the denser rock resting on them to break off. In the greater fault the rock beneath the Columbia lava may have been brought to the surface, thus furnishing a soft layer below a hard one, and again favoring the production of landslides.

The crest line of the Horseheaven fault scarp is formed of a layer of basalt sharply upturned, back of which, toward the plateau formed by the surface of the upheaved block the dip decreases and becomes more and more gentle until the rocks 10 miles distant from the fault are practically horizontal.

Far away to the southeast there is another uplift running about parallel with the longer arm of the Horseheaven fault, but far smaller in all of its dimensions. This ridge was not closely examined, but its appearance, as seen from a distance, favors the idea that it was also formed by upheaval along a line of displacement.

A well has been drilled at the joint expense of Yakima county and the state of Washington on Horseheaven plateau, about 5 miles from the great fault bordering it on the north. This well is in section 16, township 8 north, range 26 east, Willamette meridian. It has a depth of 630 feet and passes through the following strata, as I have been kindly informed by Mr. Thomas F. Corbett, the contractor in charge of the work:

| | Feet. |
|---|---|
| Soil | 18 |
| Basalt | 212 |
| Clay, soft, black | 70 |
| Basalt | 170 |
| Sand rock | 160 |

If there has been no mistake in this record it shows that the passage from the John Day beds to the Columbia lava is there quite different from what it is in other portions of the county where natural exposures or the records of other wells show the succession of the strata. The first and second beds of basalt are thicker than elsewhere, as is also the sedimentary layer below the second basalt. I call attention to this simply as a matter of record, as it is not to be expected that a series of strata, in part sedimentary and in part of erupted rocks, will retain the same individual thickness for any considerable distance. Variation and rapid changes are to be expected instead of the extension of the same sequence over wide areas.

If the Horseheaven plateau were a basin instead of being a sloping table land, the section given above would indicate favorable conditions for obtaining artesian water, but as the strata slope away from a great fault and are not again upraised so as to form a basin, the probability of their receiving water and of retaining it under the requisite pressure is but slight.

*Satas creek.*—North of the longer arm of the Horseheaven fault and bordered on the north by another similar uplift known as Satas ridge, there is a tract of moderately elevated country 6 or 8 miles broad, which slopes gently eastward toward Yakima river and is drained by Satas creek. The dip of the strata corresponds approximately with the slope of the plateau. This is a portion of the elevated basaltic region bordering the drainage of Yakima river on the west, and is included between two east and west faults.

The interesting feature of this region is that the main trunk of Satas creek as well as all of its larger branches flow through steep-walled canyons 300 or 400 feet deep. The general section exposed in the sides of the canyons is as follows:

| | Feet. |
|---|---|
| Clay, soft, sandy, light colored | 0–20 |
| Quartz pebbles, coated with iron oxide, and sand | 30–50 |
| Basalt | 40 |
| Clay, soft, sandy, light colored | 100 |
| Basalt in thick layer | 175–200 |

On the borders of the canyons the layers of soft material above the interstratified basalt are wanting, and have also been eroded away from all of the higher portions of the region, but toward the Yakima they increase in thickness and form the desert surface for several miles in breadth adjacent to the river. Midway up the slope the streams have cut wide valleys through the 40-foot layer of basalt and much narrower channels in the lower and heavier layer beneath. In this way a broad terrace has been formed which follows all the windings of the gorges. In the scarp of this terrace the white lake beds are sometimes exposed. The terraced canyons branching in every direction through the sloping plateau produce most interesting and beautiful topographic forms, and everywhere reveal a richness of detail that is bewildering to the eye.

Along the main drainage line the canyon bottoms are filled with groves of cottonwood trees, while the plateau surfaces in the interstream spaces are bare of all vegetation except sage brush and bunch grass. In places where the canyons are shallow the tops of the trees within are flush with the surface of the plateau between the drainage lines, making a mosaic of brown and green as one looks down on the deeply dissected plateau. These narrow, steep-walled canyons are a good example of young stream channels and like nearly all of the topographic features of the region underlain by Columbia lava show that, as geologists reckon time, the rocks have not been long exposed to the action of the atmosphere, or else, owing to climatic conditions, the action of the subaerial agents which sculpture the land has been slow.

*Satas ridge.*—I have adopted this name for the prominent east and west ridge of basalt separating the drainage of Satas creek from that of Topinish creek. The highest peak on the ridge is named Satas peak on the maps published by the North Transcontinental Survey and has an elevation of 3,000 feet above the adjacent valleys.

Satas ridge is very similar to the west arm of Horseheaven fault, and begins at the west in the rugged basaltic region separating the drainage of Yakima river from that of Klickitat creek. The ridge crosses this rugged, deeply dissected region, the general trend of which is north and south, at right angles, forming an east and west ridge, which at once attracts the attention as being different from the surrounding topography, due to the erosion of an upheaved mass that is without any well-defined form. The great fault scarp on leaving the highlands is prolonged into the valley to the east and divides it like a wall. The ridge holds its characteristic form for 25 miles and ends in a low point which passes beneath the level, sage-brush-covered plain, close to the Yakima river and about 5 miles from a short, sharp uplift, known as Snipes mountain, in the center of the valley.

Satas ridge is monoclinal with an average dip at the crest of 8 or 10 degrees. The dip soon decreases to the eastward, however, and the strata merge with the gently tilted rocks in the deeply dissected region drained by Satas creek. The north side of the ridge is steep and bold, and is formed of the broken edges of the inclined basaltic strata. In all of its principal features it agrees with the Horseheaven and Rattlesnake uplifts, already described.

On following the ridge eastward I found that the monoclinal structure was well defined to within about five miles of its eastern terminus, where a low pass occurs, which is crossed by a wagon-road. At this pass and thence eastward to the end of the ridge, the rocks forming the edge of the thrown block, that is the beds beneath Topinish valley, are bent upward and form a secondary ridge along the base of the main escarpment. The uplift is there really a fold which has been partially broken down by weathering. The outer layer of soft beds have been mostly cut away, leaving an interstratified sheet of basalt variously inclined and in places standing in relief. South of the wagon pass, the interbedded basalt arches over the top of the ridge from the east and forms a flat table on the summit, with light colored lake beds beneath it. A sketch section of the ridge at this locality is shown below.

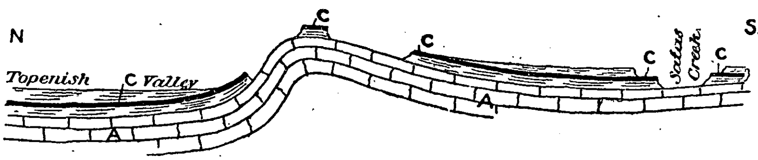
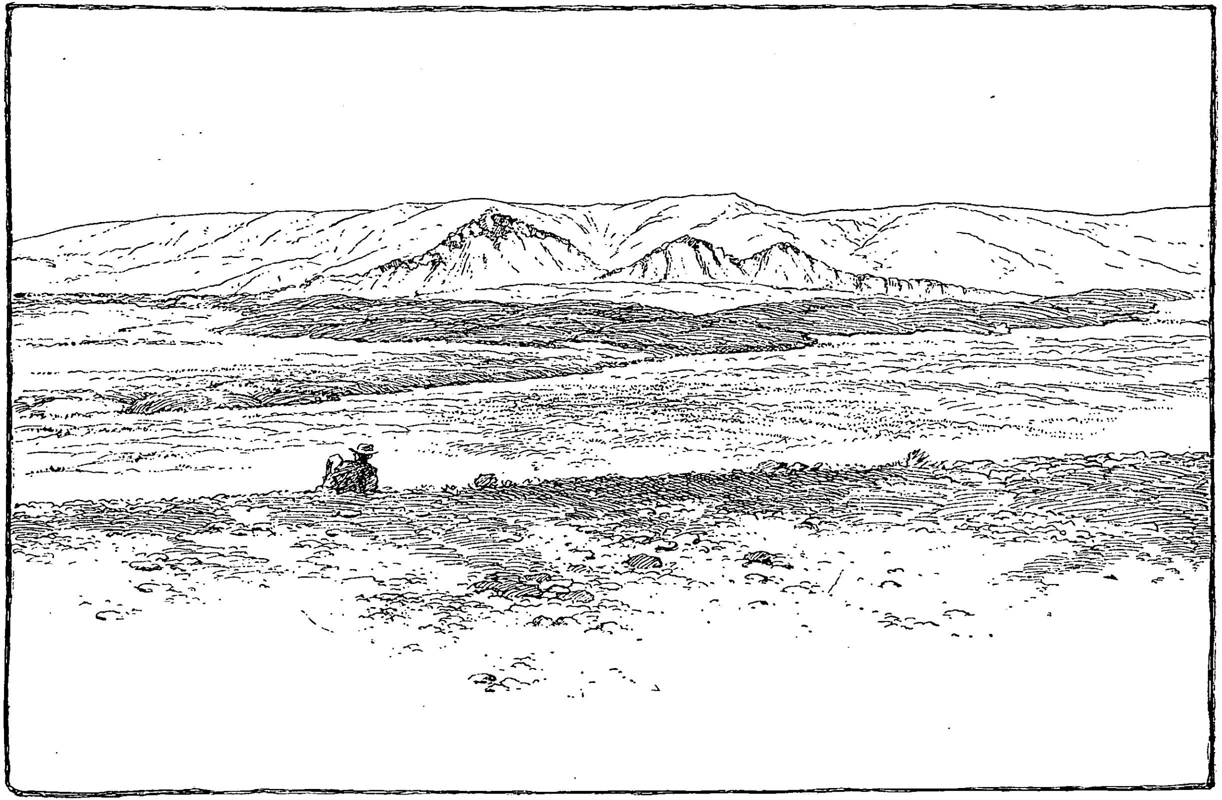



FIG. 7.—Sketch section across Satas ridge. A A, Columbia lava; C C, layer of basalt interstratified with soft John Day beds.

Farther east the covering of lake beds and of interstratified basalt has been more completely removed, but occurs at intervals all the way to the end of the ridge, either on the gentle southern slope or at the base of the steep northern escarpment.

If weathering had not taken place the ridge would be a long, narrow, monoclinal uplift, formed by the upheaval and tilting of the south side of a great fault which decreased in throw toward the east and changed to a monoclinal fold before disappearing beneath the plain. The weathering of this uplifted ridge and the falling of landslides from its steep northern face has produced the secondary topographic features which now give variety to the primitive form.

On the crest of the ridge, near Fort Simcoe, there are large stumps of fossil oaks and pines projecting 3 or 4 feet from the surface of lapilli which showered down about them from some neighboring volcano and buried them in the position in which they grew. They stand at right angles to the gently sloping surface in which their roots are inclosed. The stumps are now exposed at the surface owing to the removal of several hundred feet of John Day beds with interstratified sheets of basalt from above them, and are relics of a great forest, as



GENERAL VIEW OF SIMCOE LANDSLIDE.

fragments of similar fossil trees are found at about the same horizon in the rocks at points scores of miles apart, throughout central Washington. During the intervals between the eruptions of the various thick sheets of Columbia lava, the surface of the previously formed layer was disintegrated sufficiently to form a soil on which forests grew, only to be buried beneath the next succeeding shower of volcanic ashes and lapilli; this layer in turn became buried beneath subsequent lava flows. Heated waters percolating through the rocks dissolved the woody tissues and replaced them, atom by atom, with silica. In this way the grain of the wood, as well as the knots and even the most minute pores and ducts, has been accurately reproduced in stone. When sections of the fossil wood, ground down until they become thin enough to be translucent, are examined under the microscope, the minute structure is as faithfully shown as if a thin shaving had been taken from a living tree. Millions of years have passed since the fossil wood was formed and the species which it represents no longer live.

On the steep northern escarpment of Satas ridge there have been many landslides caused by the breaking away of portions of the face of the fault scarp. Two of these are of large size and of such a recent date that the scars they left are fresh in appearance and unclothed even with lichens. These breaks seem to have been formed within the past few years, but on inquiring of the Indians living in the adjacent valley, I found that they did not know when they were formed and had no traditions concerning them.

The larger of the slides referred to is situated about 5 miles southeast of Fort Simcoe and will be called the "Simcoe landslide;" the smaller is some 15 miles further east, may be plainly seen by travelers over the Northern Pacific railroad after passing Topinish station, in going east, and will be called the "Topinish landslide."

*Simcoe landslide.*—The mass of rock which broke off from the face of the ridge and formed the Simcoe landslide is about half a mile long and ploughed out onto the plain for a distance of nearly a mile. At the foot of the steep broken scarp left on the face of the ridge, there is a deep narrow valley, bounded on one side by the mountain and on the other by the backward slope of the mass which fell. In this basin there is a lake about 2 acres in extent, without surface outlet. The mass which fell is broken and exceedingly irregular, but slopes from the steep ridge near the base of the mountain down to a thin edge at its outer margin. The tract of country covered by the fallen mass is rudely semicircular, but somewhat pointed at the center of the curve. About its outer margin and forming a rude semicircle of irregular hills, looking like the terminal moraine of a small glacier, is the material pushed ahead of the mass which fell. These hills are from 200 to 250 feet high, with very steep outer slopes. The material ploughed up is composed of loose rocks, volcanic lapilli, and lake beds. In this material the trunks and branches of fossil trees occur in considerable number. The singular topographic forms produced by the slide have been but slightly modified by erosion, as the rain falling on the disturbed tract finds its way out through the loose rocks and forms springs about its lower margin. A valley which existed previous to the landslides was obliterated by it, but is still clearly marked below the outer, moraine-like hills.

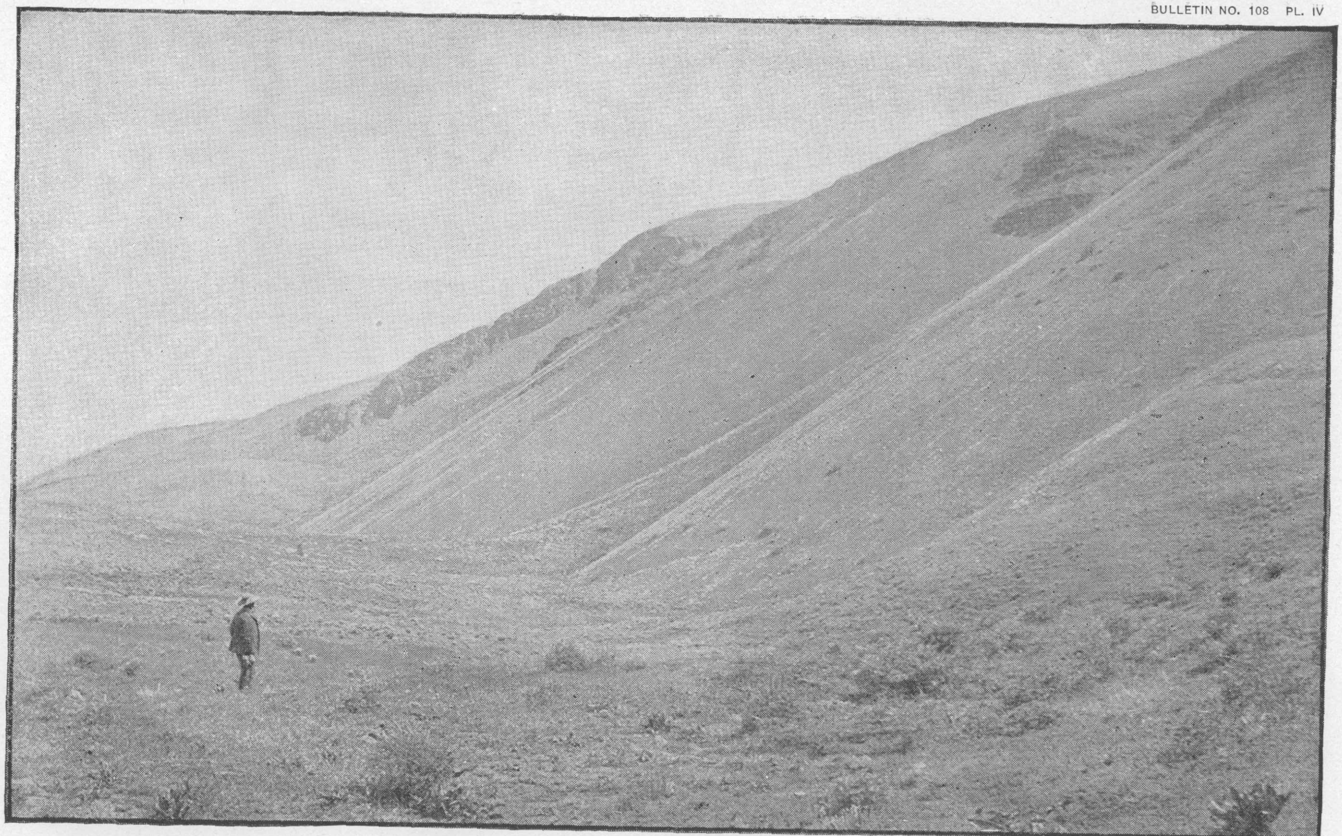
The features described above may be recognized in the illustrations forming Plates III and IV. The first is a general view taken half a mile in front of the pushed-up ridge, over the top of which the surface of the fallen mass may be seen; above this is the steep scarp left on the mountain face. Plate IV is a nearer view of the precipice left by the slide, which is now largely covered by talus slope.

*Topinish landslide.*—This is smaller than the one near Fort Simcoe, and did not force up an outer-moraine-like ridge. The mass which fell is piled in confused heaps and ends in a low slope. A general view of this slide taken from the left bank of Topinish creek, is presented in Plate V. Another view taken from above, looking down on the confused piles of loose stone composing the fallen mass, is shown in Plate VI. The scarp in the foreground in this view is the backward slope of the fallen mass. Topinish creek was turned from its course by the slide and now makes a broad bend in order to get around it.

These fresh slides, the details of which are unmodified and clearly visible, serve to explain many irregular features in the topography of neighboring fault scarps, in which a large part of the secondary topographic features have been produced by ancient slides, the characteristic features of which have in many instances been greatly modified by weathering.

The principal topographic forms resulting from the falling away of a portion of a steep scarp, are the scars left on that mountain and the confused piles of debris lower down. There are also irregular terraces, and inclosed basins which sometimes hold ponds of considerable size, but more frequently the basins are floored with mud and in later stages are overgrown with grass and shrubs. The basins are due to the fact that a sliding mass of rock frequently leaves a space between it and the cliff from which it broke away. Basins are formed also, because the surface of the sliding mass after it comes to rest usually slopes backward, toward the cliff from which it fell; for the reason, as is well known, that the base of a mass of rock or earth that has broken away from a steep slope comes to rest at a lower angle than it occupied before the catastrophe, and also because the falling mass is frequently broken into separate blocks or minor slides, which pile up on one another, thus giving to the surface a backward slope.

*Snipes mountain.*—This narrow isolated ridge is about 6 miles long and rises above the surrounding desert to a height of 400 or 500 feet; it stands on the left bank of the Yakima river, 5 or 6 miles east of the eastern end of Satas ridge. Its general trend is nearly southeast, or at right angles to the direction of the great fault scarp described above.



TALUS SLOPES ON CLIFFS, LEFT BY SIMCOE LANDSLIDE.

In the central portion of the uplift the strata dip away from the main axis at an angle of from 20 to 30 degrees, but the crest has been broken and eroded away so as to form a longitudinal valley, as indicated in the following cross section:


FIG. 8.—Sketch section through Snipes mountain.

The lowest rock exposed in the central valley is scoriaceous basalt, on which rest fine light-colored lake beds, about 100 feet thick, together with beds of volcanic dust having concretions of yellow chert at the base. Above the lake beds there is a sheet of basalt 30 to 40 feet thick forming the outer slope of the ridge in most places, and resting on this are other lake beds. At the contact with the overlying basalt the lake beds show considerable metamorphism. On the surface of the interstratified basaltic sheet there are the remains of a layer of yellow pebbles and fine lake beds. In the southern part of the ridge the beds on the southeast side of the break have not been elevated, and the uplift is there a simple fault scarp in which the strata dip eastward.

Scattered over the hills are blocks of granite and other rocks, only found in place far to the north. These are a portion of the widely spread drift carried over the valley of central Washington by bergs floating in Lake Lewis.

The trunks of fossil trees are reported to have been found on the south slope of the ridge.

The outcrops of scoriaceous basalt in the bottom of the valley in the crest of the uplift are not sufficiently well exposed to allow one to decide whether it was intruded since the beds above it were deposited, or whether it is a portion of the upper layer of the Columbia lava. Its scoriaceous character and an apparent alteration of the sedimentary beds resting on it suggest that it was intruded at the time the ridge was upraised.

Snipes mountain is an interesting example of the way in which small faults sometimes occur in the bottom of valleys, and will be referred to again in discussing the manner in which the porous strata flooring a valley may be charged with water from below. Another instance of this same nature will be noted in Selah valley.

*Yakima valley (in part).*—The Yakima river, after passing through Union gap 6 miles south of North Yakima, flows through a broad sagebrush-covered plain which is exceedingly fertile, where water can be had for irrigation. A large portion of this valley on the right bank of the river is now included in the Yakima Indian reservation. Forty-five miles east of Union gap, between Rattlesnake mountain at the northern escarpment of Horseheaven, the valley again contracts and the river escapes through a narrow canyon sunken about 100 feet deep in basalt.

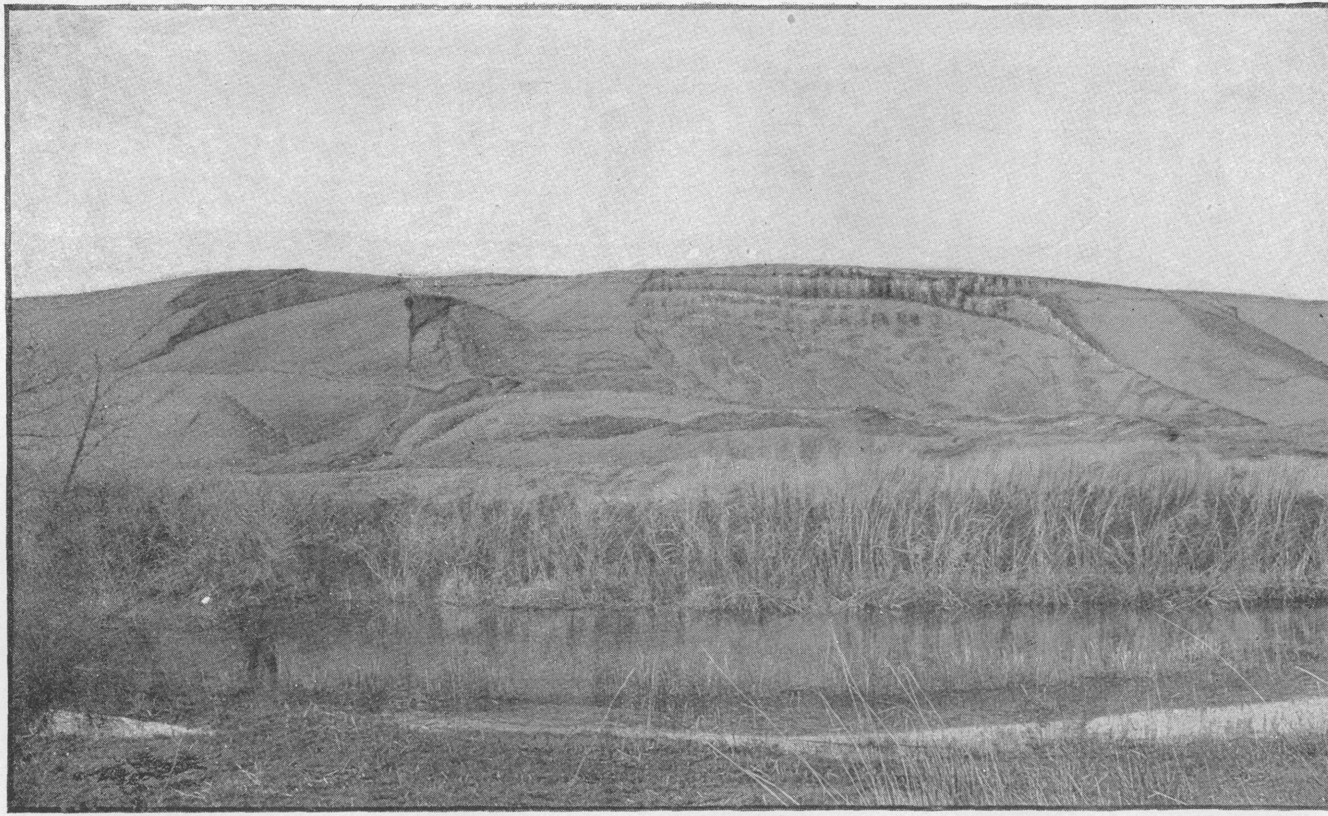
The valley is floored throughout with fine lacustrial sediment resting on basalt, as is shown in numerous sections where the rocks are upturned in the bordering highlands and in Snipes mountain, just described, which stands in the center of the basin. The occurrence of basalt at the surface where the river leaves the valley shows that upstream from that locality there is a basin of basalt which is occupied by John Day beds. These beds are of fine sandy clay and well exposed along the Yakima, where bluffs 50 feet high occur on the convex sides of the curves formed by its meandering. The best example of such an exposure is at site of the new town of Zillah, which unfortunately has been placed on the bank of the stream where it is being rapidly cut away.

The portion of the Yakima valley referred to, although irregular and partially divided by Satas ridge, is surrounded on all sides by uplands formed by an elevation of the strata, thus forming a basin. So far as its structure is concerned it presents conditions favorable for an artesian water supply. The lacustral sediments which partially fill the basin are not of great thickness and do not extend up its western slope where the greatest amount of rain falls. On the abrupt northern slope and on the long gentle ascent extending to the top of Rattlesnake mountain but little precipitation takes place, probably not more than 6 or 8 inches annually. These facts indicate the conditions that are unfavorable for a subterranean water supply.

Another unfavorable circumstance is that at Snipes mountain, which, as already explained, rises in the central part of the basin and is due to the fracturing and upheaval of the beds forming its floor, there are no springs. If the superficial strata contain water-bearing beds the water would be expected to escape through this break, unless, as seems quite possible, an extension of volcanic rocks has there occurred which closed the fissures.

In spite of the unfavorable conditions, however, the drilling of an experimental well would be warranted in order to determine by actual experiment if water under pressure exists in the basin. A test well in a basin which may contain artesian water should be drilled at its lowest point, unless there is reason to suppose that the strata are more open near its borders than at its center. If a test well located with judgment fails to reach water under pressure, all subsequent expense in prospecting may be avoided. If artesian water is obtained the pressure under which it rises will determine the extent of territory in which other wells may be drilled with a promise of success. For example, if a well should be drilled at the lowest point in a valley and flowing water be reached, which would rise in an open tube 50 feet above the surface of the ground, then so much of the adjacent region or layer below the level to which the water rose would be in favorable territory.

The most promising locality in the valley now under consideration for making a test well is within a radius of from 5 to 6 miles to the west of the railroad, between Topinish and Simcoe stations. It is not



TOPINISH LANDSLIDE, FROM BELOW.

possible to predict the depth of the strata which there overlie the basalt, but the most probable estimate places it at 300 or 400 feet. It is to be expected that a strata of basalt from 50 to 75 feet thick, interstratified with the lake beds, will be met with. A test well should be driven through this layer and continued into the next layer of basalt that is met with, at least 50 feet, if flowing water is not previously reached, in order to be assured that there is not more than one interstratified sheet of basalt above the real floor of the basin.

A desire to obtain artesian water at Fort Simcoe has been expressed by persons interested in the Indian agency, but as that locality is without the limits of the lake beds occupying the valley to the east, and is situated on basaltic rocks which, as shown in neighboring exposures, are many hundreds of feet thick, the chances of obtaining flowing water are too small to warrant the expense of a trial.

It is perhaps not out of place for me to suggest that the streams flowing from the forest-covered highlands west of Fort Simcoe present good sites for reservoirs, in which enough water could be stored during the rainy season to irrigate a large portion and perhaps the whole of the rich valley lands between Fort Simcoe and the Yakima river, which can not be watered by ditches supplied by the Yakima river itself.

*Yakima ridge.*—This name is applied to the bold ridge separating Atanum, Moxee, and Rattlesnake valleys on the north from the portion of the Yakima valley described in the last section. It is not a single elevation, either topographically or geologically, but as I do not wish to duplicate geographical names, the designation already used will be retained.

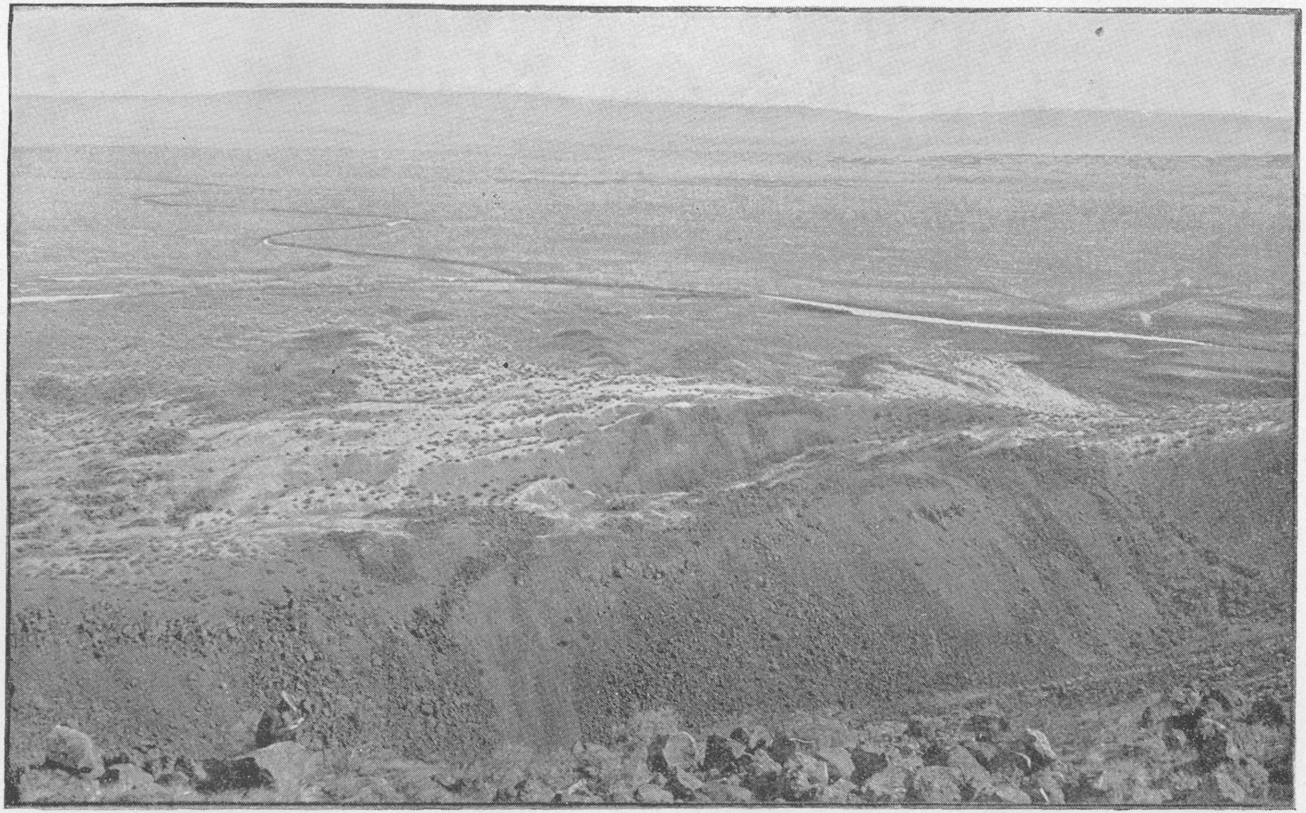
The ridge begins on the west in the irregular and deeply eroded country between the head waters of Topinish and Atanum creeks and runs east, with slight sinuosities, for 50 miles. Its breadth seldom exceeds 1 or 2 miles, even when its gently sloping borders are included, and in general it rises from 1,000 to 1,800 feet above the surface of the adjacent valleys. At the east it approaches and in a manner merges with the northern portion of the Rattlesnake uplift. It is crossed at right angles by Yakima river, which has cut a deep gorge, known as Union gap, through it. In the walls of this gorge the arched strata of basalt of which the ridge is composed are well exposed.

The portion of the ridge through which the Yakima has cut a channel has been formed by an abrupt arching of the Columbia lava and of the John Day beds resting on it. Erosion has since removed the soft superimposed beds from the elevation, but their upturned edges may be dsitinguished in places along either base of the ridge. The key to the structure is furnished in part at Union gap, where the arching of the basalt may be seen, but is more readily recognized about 5 miles farther east, where the basaltic ridge dies out and passes beneath undisturbed John Day beds. A low gap then occurs, which affords an easy passage for the wagon road connecting Moxee valley with Konewock. On the west side of this pass, and extending nearly to

Union gap, there are good exposures of John Day beds which have been turned up on the flank of the ridge into a vertical position. These outcrops reveal a thickness of approximately 1,200 feet, and exhibit the characteristics of the beds which floor the adjacent valleys. The continuation of Yakima ridge eastward from Konewock pass has a different structure from the portion already described. On following the crest of the ridge eastward one will find places where the beds have been notched by lateral streams and a central or longitudinal valley also eroded. In such localities it will be seen that the beds sloping up on each side of the ridge—but much more markedly on the south side—are composed of fine clay and sand, together with layers of volcanic dust, and inclose a single sheet of columnar basalt about 40 feet thick. It is the outcropping edge of the upturned sheet of basalt that has produced the most marked of the secondary topographic forms to be seen along the summit of the elevation. Between the V-shaped notches made in the basalt by small streams flowing off from the ridge, the hard layer extends far up the slope and sometimes reaches the top of the uplift. The strike of the secondary ridge follows the gentle curves of the main elevation, and on looking along the crest it may be distinctly recognized for several miles.

In the bottom of the longitudinal valley, between the main ridge and the secondary crest formed by the interbedded sheet of basalt on the east, there are occasional exposures of scoriaceous basalt which has been injected from below into the fine lake beds, hardening them and otherwise changing their character along the surface of contact. In part, at least, the injection of molten matter from below has been instrumental in lifting the John Day beds and interbedded basalt into the long, narrow ridge which we now find. The explanation of its origin seems to be that there was a break, and probably a fault, in the Columbia lava, which caused an elevation of the soft beds resting on it without breaking them, and also admitted of the extrusion of molten lava, which found its way into the soft strata and raised them still more, but did not break completely through and overflow.

The Yakima ridge as a whole shows considerable diversity of structure. From the mountains on the west, where the ridge is first clearly defined, eastward to Konewock pass it is an arch, with possibly a break along portions of the northern base. At the east end of this section it decreases in height, at the same time broadening and curving southward, and ends in a low point which passes beneath but slightly disturbed strata. East of Konewock pass it is principally a ridge of John Day beds, with an interstratified layer of basalt, which have been upheaved in part by the faulting of the much harder beds beneath and in part by an injection of molten basalt. The weathering of the narrow ridges thus formed has resulted in the almost complete removal of the John Day beds from the portion west of Konewock pass, leaving only low buttresses along the bases of the uplift, and has produced a variety of topographic forms in the eastern continuation of the ridge. Details



TOPINISH LANDSLIDE, FROM ABOVE.

in the structure of the eastern portion of the uplift where it approaches Rattlesnake mountain were not carefully observed, owing to the fact that stormy weather prevailed during the time that that portion of our field was traversed.

*Selah ridge.*—This ridge borders Atanum and Moxee valleys on the north, and, like the one just described forming the south wall of the same basin, may be divided into sections having various structures. Starting at the west in the elevated region between the head waters of Atanum and Cowiche creeks, and extending to the junction of Cowiche creek with Naches river, the ridge is formed by an uplift of Columbia lava in which the structure is indefinite, and ends in a low point curving southward and passing beneath moderately disturbed John Day beds.

On the east of the Naches, in the same general line with the uplift to the west, there is a sharp ridge of upturned Columbia lava presenting a broken scarp to the south and sloping gently northward. On the lava rest light colored strata belonging to the John Day system, with a layer of interstratified basalt about 40 feet thick. This fragment of a ridge lies between the Naches and Yakima rivers, just above their junction, and is about 2 miles long. It is monoclinal and the John Day beds and interbedded basalt, forming its upper portion, dip north, at first gently and then at a high angle, which soon flattens, and the same beds pass under Wenas valley, where they are horizontal. East of Yakima river the same uplift continues with a slightly varying strike for about 40 miles and rises between Moxee and Selah valley to an elevation of 4,150 feet, and nearly 3,000 feet higher than the adjacent valleys. Its east end passes beneath the flat lands bordering the Columbia, without any special changes in character. In the main this ridge is a monoclinal uplift, the gentle slope being south, and passing beneath Moxee and Rattlesnake valleys, while its abrupt, broken face overlooks Selah valley. At the west, near Yakima river, the fault to which the uplifting of the monoclinal block is due, changes to a fold, but local modifications tend to complicate the topographic form resulting from its weathering, so that careful attention is required to determine the primitive form.

In the west end of the ridge, separated from the main portion by the deep transverse canyon cut by Yakima river the east side of the fold is wanting. It may have been cut away by the Naches, which flows along its base, but more probably was carried down by a fault which may have been continuous with a break to be seen on the south side of the ridge and east of the Yakima.

There is also a cross break running north and south which determined the course of the Yakima river. This is shown by the lack of correspondence in the dip of the light colored John Day beds occurring on the sides of the canyon.

East of Yakima river the John Day beds underlying Moxee valley slope up on the flank of Selah ridge, but do not reach the summit.

They are broken by weathering and to some extent by faulting. The edge of the hard interbedded layer of basalt, already mentioned as being interstratified with the John Day beds, forms a secondary ridge close to the main uplift in the vicinity of Yakima river, but recedes more and more, as one follows it eastward, until it finally sweeps entirely across the valley, and a few miles east of Willow spring joins the outcrop of the southern edge of the same sheet on the south. The dip along the outcrop of this bed changes from 30 or 40 degrees at Yakima river to 6 or 8 degrees at the east end of Moxee valley.

East of the gorge cut by the Yakima, the beds underlying Selah valley are carried up over the top of the ridge, for a distance of 4 or 5 miles, and appear in a broken escarpment on its eastern face. It is the outcrop of those light colored beds capped by an interbedded sheet of basalt, which forms such a conspicuous feature in the face of the ridge as seen from North Yakima. A section of the rocks there exposed is as follows:

| | | Feet. |
|---|---|---|
| | Basalt, scoriaceous, and slaty below, columnar above | 40 |
| John Day beds. | Conglomerate of well-worn pebbles | 10-15 |
| | Clay, soft, light colored, sandy | 20 |
| | Sand, light gray, unconsolidated | 6-20 |
| | Clay, fine, light colored, sandy | 60 |
| | Sand, coarse, with water-worn pebbles 8 inches in diameter | 40 |
| Columbia lava. | Lapilli, yellowish brown | 30 |
| | Basalt, columnar, with horizontal bedding | 30 |
| | Basalt, scoriaceous cavities partially filled | 50 |
| | Lapilli and scoriaceous basalt; divisions indefinite | 190 |
| | Basalt, compact, weathering in concentric forms | 400 |
| | Basalt, brown, scoriaceous, to Yakima river | 75 |

The divisions made in this section of the Columbia lava are mostly arbitrary, as the characteristics mentioned pass one into the other without well-marked bedding. The clearly defined stratification of the basalt, displayed in many other places, is not here well shown. There are also reasons for suggesting that the scoriaceous basalt at the base of the section may have been a subsequent intrusion.

The structure of Selah ridge is too complex to be described intelligently without the aid of map and detailed section, but these are not to be had on account of the lack of an accurate survey. The ridge is an exception to other similar uplifts in the same region, for the reason that it changes from a monoclinal ridge at the west, where the dip is towards the north, to a monoclinal ridge at the east having a gentle slope to the south. The general form of the ridge is that of a long, narrow arch, broken at the west end by a fault on the south side, and by another fault on the north side, for the greater part of its length.

*Atanum and Moxee valleys.*—Between Yakima and Selah ridges there is a remarkable valley some 75 or 80 miles long and nowhere more than 5 or 6 miles wide. It is divided into two drainage areas, however, by a slight north and south uplift, which crosses it about 18 miles east of Yakima river. The portion of the orogenetic valley situated between Yakima river and the divide just mentioned is known as Moxee valley. The portion west of the Yakima, in which Yakima City and North Yakima are situated, has no special name, but is drained in large part by Atanum creek. The Yakima river flows from north to south across the basin and has cut deep notches in its bordering ridges. The basin is floored with John Day beds, which, together with the thin sheet of basalt interstratified with them, are bent upward along its borders so as to form a long, narrow basin.

In the western part of the basin the John Day beds may be traced for 8 or 10 miles west of Yakima river; they then give place, with but slight change in the topography, to basalt, which forms a plateau rising gradually to the west, and merging with the hills separating the two main branches of Atanum creek.

The Atanum-Moxee basin owes its existence to the upheaval of its border. It is formed of Columbia basalt on which rest layers of John Day beds, and thin but widely spread lava sheets, which are inter stratified with the lake beds. The effects of erosion during and subsequent to the upheaval of the side of the basin has resulted not only in cutting the deep notches in the bordering ridge, through which the Yakima flows, but has also removed several hundred feet of lake beds from the portion of the valley adjacent to the river. From the top of the bordering ridges a large part and in many places all of the John Day beds, which were originally more than a thousand feet thick, have been carried away.

The valley as we now find it is thus the result of the upheaval of the rocks about its border so as to form a basin, and the erosion of the deformed surface so as to leave the hard layers in bold relief. The basin was not robbed of all of its soft beds, as occurred in some of the neighboring valleys, but as shown by borings that have been made, nearly a thousand feet in vertical thickness still remain. It is in the more porous of these beds, composed principally of sand, that artesian water has been found.

The successful wells are located from 10 to 12 miles east of North Yakima. These, as well as other wells, which do not flow, are described below. The greater part of our information concerning them has been kindly contributed by the Yakima Land Company, which has conducted most of the drilling. In this connection I am especially indebted to Mr. H. B. Scudder, manager of the company, and to Mr. Fred. Read and Mr. Samuel Storrow, for the information here presented.

The first well drilled by the Yakima Land Company was put down in July and August, 1891, and was the pioneer well in Yakima county. The attempt to obtain artesian water on Horseheaven plateau was begun earlier, but is not yet successful.

Well No. 1, of the Yakima Land Company, is in Sec. 3, R. 20, T. 12. The elevation of the surface at the well is, by aneroid readings, 166 feet above the railroad at North Yakima, or 1,166 feet above the sea. Diameter of well, 6 inches. Flow of water, two-thirds of a cubic foot per second. In an open tube the water rose 26 feet above the surface, or to 1,192 feet above sea level, when well No. 3, 300 feet distant, was closed. Temperature of the water, 75° F. The water is clear and sparkling, but has a slight odor of sulphuretted hydrogen. The section passed through is as follows:

| | Feet. |
|---|---|
| Gravel | 12 |
| Sand, cemented | 2 |
| Clay, hard, blue | 28 |
| Clay, green, compact | 19 |
| Gravel | 1 |
| Basalt | 13 |
| Sandstone | 3 |
| Basalt | 16 |
| Sandstone | 4 |
| Clay, blue | 2 |
| Sand, basaltic | 10 |
| Sand, gray, gneissic | 100 |
| Clay | 1 |
| Sand and sandstone | 39 |
| Clay and shale | 6 |
| Sand and sandstone | 58 |
| Depth | 314 |

Well No. 2, drilled by the Yakima Land Company, in Sec. 4, R. 20, T. 12, has a surface level of 1,206 feet above the sea, as determined by Mr. Storrow by means of an engineer's level connecting with well No. 1, the elevation of which is given above. The well has an 8-inch casing. Water rose to within 11½ feet of the surface or to an elevation of 1,194·5 feet above sea level. Temperature and character of water about the same as in well No. 1. The section passed through is as follows:

| | Feet. |
|---|---|
| Gravel | 6 |
| Sand and yellow clay | 45 |
| Gravel | 5 |
| Scoriaceous lava, changing to black basalt | 58 |
| Sandstone, metamorphosed | 5 |
| Green clay, increasing in hardness toward the bottom | 132 |
| Sandstone | 6 |
| Sandstone, micaceous | 18 |
| Sandstone, soft | 8 |
| Sandstone, hard | 42 |
| Sand, loose | 16 |
| Sandstone, soft | 34 |
| Clay | 8 |
| Sand, soft | 60 |
| Pebbles | 8 |
| Sand | 47 |
| Clay, blue | 5 |
| Sandstone and sand | 55 |
| Clay | 14 |
| Basalt | 66 |
| Depth | 618 |

Well No. 3, drilled by the Yakima Land Company, in Sec. 3, R. 20, T. 12; 300 feet from well No. 1. Elevation of surface, 1,154 feet, and 12 feet below well No. 1. Diameter, 6 inches; flow of water, 1 cubic foot per second, well No. 1 being open. When well No. 1 was closed the water in No. 3 rose in an open tube 34·5 feet above the surface, or to 1,188·5 above sea level. Temperature and character of water the same as in well No. 1. The record of the section passed through has been lost.

Well No. 4, drilled by the Yakima Land Company, is in Sec. 4, R. 20, T. 12. Elevation of surface 1,266 feet; water rose to within 80 feet of surface, or to 1,186 above sea level. Temperature and character of water about the same as in well No. 1. Section passed through:

| | Feet. |
|---|---|
| Gravel and boulders | 30 |
| Clay | 30 |
| Basalt | 62 |
| Clay, blue | 12 |
| Basalt | 62 |
| Sand and sandstone | 100 |
| Clay, blue | 17 |
| Clay, yellow | 19 |
| Sandstone, soft, blue, water-bearing | 14 |
| Clay, blue | 18 |
| Sandstone, soft water-bearing | 43 |
| Gravel | 6 |
| Sand and gravel | 27 |
| Clay, blue | 46 |
| Basalt | 54 |
| Clay, greenish blue | 3 |
| Basalt, containing pockets of mud with charcoal | 40 |
| Depth | 583 |

Well No. 5, drilled by the Yakima Land Company, in Sec. 25, R. 19, T. 13, is now in progress (August 1, 1892).

Well No. 1, drilled by the Washington Irrigation Company, is in Sec. 31, R. 20, T. 13; elevation of surface 1,085 feet. Flow of water by estimates, $\frac{1}{3}$ cubic foot per second. Temperature 73°. The well is without casing; the flow is probably retarded and the temperature decreased on this account. The drilling was done with a rotary drill, through which water was forced from the surface. The section kindly furnished by Mr. W. T. Clarke, who had charge of the work, is as follows:

| | Feet. |
|---|---|
| Soil with boulders | 20 |
| Soft sand and clay | 356 |
| Basalt, (?) soft and hard | 70 |
| Soft sand and clay | 440 |
| | 886 |

Two wells have been drilled west of North Yakima in what is known as Wide hollow. The first is on land belonging to P. S. Wood, in Sec.

22, R. —; T. 22 (?). Depth 256 feet, entirely in soft strata; basalt not reached. The well ended in sand from which water rose 6 feet. The second well is on land belonging to Mr. John Miller, in Sec. 28, R. 18, T. 13: elevation 1,125 feet. A hole about 630 feet deep was drilled through soft sand and clay in which water was reached at 80 feet below surface, but does not appear to have been under pressure. Basalt was not met with.

The pressure under which the water rises in each of the wells in Moxee valley indicates that it is derived from the same stratum. The rise of the water is limited by a plain, having an elevation of about 1,190 feet above the sea and 190 feet above the railroad track at the station at North Yakima. If the water is supplied by precipitation on the upturned edges of the porous strata, in the way that artesian wells are commonly fed, we should look for its source in the adjacent ridges, more especially the ridge to the north, where the strata outcrops several hundred feet above the wells; but the rainfall in that section is so small, probably not exceeding 5 or 6 inches per year, and is distributed over such a wide interval that a very large per cent is lost by evaporation. The only possible conclusion seems to be that precipitation on the outcropping edges of the porous beds is entirely inadequate as a source of supply for the wells in the valley below. It may be surmised that the water-bearing strata have been charged for a long time and that the present flow is from a reservoir which is not being replenished, but the constancy with which the pressure has been maintained in wells Nos. 1 and 3, which have been flowing for several months, does not favor this supposition.

The hypothesis that first occurred to me on entering the Moxee basin was that the water-bearing strata extend westward and outcrop in the elevated region closing the valley in the vicinity of Tampico. An examination of the western part of the valley, however, showed that basalt forms its bottom from a line beginning about 8 miles west of North Yakima and extending to the hills closing the depression at the west. The limit of the John Day beds in that direction, approximately shown on Pl. II, is below the 1,200-foot contour, and besides, as is indicated by the depth of lake beds in the wells drilled by Wood and Miller, they end abruptly against an escarpment of basalt. The water flowing from the wells in Moxee valley could not therefore have been derived from the mountains to the west, and besides the notches cut in the edges of the basin of Yakima river are 200 feet below the plain to which the artesian water rises and would afford a means of escape if the underground water came from the west, unless, as seems quite possible, the upturning of the strata rendered them impervious.

The problem is still further complicated by the fact that there is a north and south fault of considerable magnitude where the Yakima river has cut across Selah ridge. How far this fault extends into the valley can not be told, as the soft beds flooring the basin do not reveal its presence. The region is one of great and by no means regular disturbance, and an extension of the break referred to, clear across the valley to Union gap, would not seem at all improbable, but there is no proof of such extension in hand. Moxee valley is far from being a typical artesian basin; it is rather an accidental basin due to several irregular uplifts and faults. Neither is its water supply, as already stated, derived from precipitation on the outcropping edges of the porous strata, as is the case in what may be considered a normal artesian basin. On the north side of the valley there are several small fissure springs, situated a thousand feet above the bottom of the basin. These rise from a deep source through fissures and have no connection with the water-bearing strata in the valley, unless it is that they contribute a small amount of water to the outcropping edges of the porous layers, but the amount they supplied is certainly trifling.

The temperature of the water in the wells is 75° F. This is considerably higher than would be expected for their depth, and indicates that the water comes from a deep source, or perhaps that the basalt beneath the valley has not yet cooled down to the normal subsurface temperature. As the basalt in Yakima ridge from 1 to 3 miles south of the artesian wells has been injected into the John Day beds since they were laid down the presence of basalt beneath the valley yet retaining its original heat is not a violent supposition.

After trying many hypotheses to account for the flow of water in the Moxee wells, and finding them widely at variance with the facts, I have been led to assume that the basin is supplied from below by water rising through fissures or from the leakage upward of a lower artesian basin. Support is found for this hypothesis in the temperature of the water and in the absence of any adequate surface supply; in addition, we have the structure of the basin next south and of Selah valley next north of Moxee valley to assist us in this supposition.

In the Yakima valley to the south, as already described, there is a fault in the bottom of the basin, which has formed a short but sharply uplifted ridge, known as Snipes mountain. This has been produced by the upheaval of one and is part of both sides of a fissure which must be of great depth, but does not reach water-bearing strata or connect with fissures carrying water. The breach occurred after the John Day beds were deposited, and is a part of the irregular fracturing and tilting to which the rocks throughout the whole of Yakima county have been subjected. Again, in Selah valley, the counterpart of Moxee valley in many ways, but in which the John Day beds have been mostly removed, there is a fault running with the larger axis of the trough. In this case also a long ridge was upheaved, as will be described later. Along the line of this break, farther east than the prominent fault scarp, there are large fissure springs. There several facts lend support to the hypothesis that there is a break in the basaltic rocks beneath the porous John Day beds occupying Moxee valley, and that water rising through the break has sufficient pressure to charge the beds above up to a horizon of about 1,190 feet. The irregular depth at which the water-bearing beds were reached is perhaps explained, in part, on this supposition; but may also be due in part to the inclination of the axis of the trough. The irregularity of the basin is also shown by the want of correspondence in the records of the wells, no two of which agree even in the more prominent features of the sections.

The subsurface water met with in Moxee valley, not only in the wells already referred to, but in several small wells in Section 8, T. 12, R. 20, is to be accounted for by the leakage of the artesian basin beneath.

The extent of the Moxee artesian basin can be determined in part by tracing the 1,190-foot contour. The east rim of the valley is precipitous, however, and its structure irregular, owing to volcanic injections from beneath. Just how near the eastern wall, on which the 1,190-foot contour falls, it will be expedient to sink wells will have to be determined by experiment. The irregularities in the character of the basin also render it impracticable to draw the western limit at which flowing water can be obtained. There is no promise that wells to the west of Yakima city would be successful, but there is little positive information concerning that portion of the valley on which to base judgment. The quantity of water to be derived from flowing wells in Moxee valley can not be stated, but will have to be determined by experiment. It can not be considered as inexhaustible, and in fact must be small, judging from a knowledge of the outflow of fissure springs in general throughout central Washington. The strictest economy should be practiced in using the water and all waste prohibited, or else only the lowest well in the basin will be assured of commercial success.

*Selah valley.*—North of Selah ridge there is another remarkable east and west depression bounded by bold ridges, which extend from high lands on the west drained by Cowiche creek eastward to the Columbia, a distance of about 75 miles. Its width is seldom over 4 miles and averages perhaps 3 miles. This long narrow valley, for which no general name is recognized, is divided into several minor portions. About 20 miles east of where the Yakima crosses it there is a low divide, due to the same gentle north and south axis of elevation that determines the eastern end of Moxee valley; between this divide and Yakima river, the depression is known as Selah valley.

The abrupt north and south borders of Selah valley are the upturned edges of tilted blocks. The valley itself occupies the depressed border of one of these long narrow fragments into which the surface beds have been divided by profound fractures. The ridge on the south presents its broken scarp to Selah valley and slopes gently southward, in conformity with the dip of the strata which pass under Moxee valley; the ridge to the north of Selah valley presents its broken scarp to the north, while the strata slope south and pass beneath the valley itself. The rocks forming these ridges are Columbia lava, and in the deep trough between them nearly all traces of John Day beds have been removed. Selah valley is the counterpart of Moxee valley in its structure, but its drainage has been more perfect and the soft beds, corresponding with the thousand feet of clay and sand in Moxee valley, have been carried away. The practical absence of John Day beds in Selah valley answers in the negative the question of the possibility of finding artesian water there. The Columbia lava beneath Selah valley carries thin beds of interstratified clays and sand and also irregular layers of volcanic lapilli, but drilling into this material in hopes that some of the porous layers may carry water is too uncertain and too expensive to warrant a trial. Besides the absence of porous beds in the valley, the fact that it is arid and has no connection with the humid region to the west, afford still further reasons for considering it impossible to obtain artesian water within its borders.

In that part of Selah valley where the Moxee and Ellensburg road crosses it there is a fault in the bottom of the basin running east and west, parallel with the larger axis of the depression. This fault has produced a ridge about 100 feet high, which presents its steeper escarpment to the south. The ridge is of basalt, but on its gentle northern slope lake beds belonging to the John Day system are exposed, and may be traced far up the north border of the valley. The fault in the bottom of the trough is about 5 miles long, and at the east end the scarp of basalt connected with it passes beneath lake beds which form a low anticline. The passage of a fault in the Columbia lava into an arch in the soft beds resting on it, to be seen at the extremities of many of the great faults in Yakima county, is here illustrated on a small scale. At the west end of the break the lake beds have been removed and expose a gentle upraising of the Columbia lava in the form of an anticline, which has broken open along the larger axis, so as to direct the course of Selah creek, which has widened the break and cut out a deep canyon leading west to Yakima river. In the walls of this gorge the edges of the upper layer of the Columbia lava are exposed, together with so much of the John Day beds as lie beneath the widely spread interstratified sheet of basalt, which has already been mentioned many times. Selah valley ends on the west at Yakima river, but the same geographic depression continues westward and is known in part as Wenas valley and in part as Naches valley. The nomenclature that has been fastened on the country is widely at variance with the geologic structure as well as with the topographic relief, a fact which makes the task of describing the country difficult.

*Wenas and Naches valleys.*—Wenas valley is floored by John Day beds from Yakima river for about 12 miles northwest. These beds, together with the underlying basalt, are bent upward along its northern and western margin. Near the mouth of Wenas creek and along the Yakima the interstratified basalt near the base of the John Day beds is exposed. Between Wenas and Naches valleys there is an irregular plateau, the surface of which is in general 800 feet above either valley. The material forming this plateau is fine sandy clay, volcanic lapilli, and coarse conglomerate, arranged in strata that are essentially horizontal, but slope abruptly upward at the east, where they ascend and cover the west slope of the portion of the Selah ridge lying between the Naches and Yakima rivers. At the north the beds are also sharply upturned, as may be seen at the south end of Yakima canyon, through which the Yakima enters Selah-Wenas valley. Along the western outcrop the vertical edges of beds of conglomerate stand as a wall along the east side of the bold mountain mass, 455 feet high, which separates Wenas creek from the Naches river. The wall of conglomerate owes its presence to the weathering of vertical strata, and is situated from 1,800 to 1,900 feet above the continuation of the same beds between Wenas creek and Naches river, where they are horizontal. This is one of many striking examples of the great disturbances that have affected all of the region treated in this paper since the John Day beds were spread out.

The beds exposed in the borders of the plateau between Wenas and Naches valley vary considerably in different localities, but their pervading character is shown by the following section taken on the west side of the uplands in the highest portion. The section shows a general absence of fine clay and fine volcanic dust such as is found in abundance in the outcrops of the same system in White bluffs, on the Columbia, but certain beds of conglomerate and layers of coarse angular lapilli. Volcanic dust in layers several feet thick is exposed near the bottom of the escarpment, adjacent to where the following section was taken. The basalt at the base of the section in either the topmost layer of the Columbia lava or an interstratified sheet near the base of the John Day bed is brought up by a gentle anticline running east and west through the center of the plateau. The thicknesses given below are from eye estimates, checked by aneroid readings:

| | Feet. |
|---|---|
| Blown sand at top of section | 10–20 |
| Sand, with coarse gravel near the top | 125 |
| Sandstone and lapilli, with clay seams | 30 |
| Sandstone, compact, with pebbles 8 inches in diameter, forming a vertical scarp | 20 |
| Pebble, stained black on the surface | 10 |
| Sand, soft, unconsolidated | 90 |
| Sandstone, compact, with lapilli | 3 |
| Pebbles, with some sand | 4 |
| Lapilli, compact | 3 |
| Pebbles of white pumice | 2 |
| Clay, gray, sandy | 14 |
| Sandstone, drab, with pebbles of pumice | 5 |
| Clay, sandy | 40 |
| Sandstone, soft, light yellow | 4 |
| Sandstone, soft, gray | 16 |
| Clay, very fine, weathering white | 20 |

| | Feet. |
|---|---|
| Pebbles, with some sand, dark | 20 |
| Sandstone, soft, with thin, hard layers | 80 |
| Lapilli, with layers of pumice pebbles | 18 |
| Sand, unconsolidated | 60 |
| Sandstone, friable, with pebbles | 14 |
| Conglomerate of pumice pebbles, usually forming a cliff | 1 |
| Clay, fine, gray | 1 |
| Sandstone, yellowish, coarse, friable | 2 |
| Clay, gray, thin bedded | 8 |
| Clay, reddish, thin bedded | 3 |
| Sandstone, gray, cross bedded | 60 |
| Unexposed, soft sandstone (?) | 40 |
| Basalt to level of Naches river | 60 |
| Depth | 765 |

These beds are sometimes considered as affording indications of the presence of coal, and in fact portions of the region which they occupy have been sold for "coal lands." The exposures are abundant, however, and although they contain thin and very local layers of poor lignite the evidence against their containing layers of coal or even of lignite of any commercial value is abundant and positive.

The surface of the plateau is covered with bunch grass, and affords good pasture, and many inquiries have been made concerning the probabilities of obtaining water for irrigation by means of artesian wells. This question is answered by the deep erosion of Wenas creek and Naches river, which have cut the lake beds to the bottom so as to expose the Columbia lava, proving conclusively that wells drilled with the hope of obtaining flowing water would be a failure. Abundant reasons might be given for concluding that artesian water can not be had anywhere in the region drained by Wenas creek or Naches river. The rocks are there mainly basalt, which has been upturned and broken in such a violent manner, and is also so deeply eroded, that, did the character of the rock favor the presence of water-bearing strata, the position in which the beds lie and the manner in which they have been broken would exclude the hope of their forming artesian basins.

Both Wenas creek and Naches river, after entering the basin in which stands the plateau of John Day beds described above, widen their valleys on account of the ease with which the lake beds were eroded, and become sufficiently broad to be of agricultural importance. Their upper courses are in narrow, steep-sided canyon-like valleys, eroded in an elevated region of basalt rock, from which, so far as known, every trace of the John Day beds which once covered it have been carried away, excepting in the upper portion of Wenas valley, where a few remnants of sandstone are reported. The valley of the Naches is especially remarkable for its wild scenery, and the Tiaton, which joins it from the west, just before the valley broadens, flows through some of the most attractive scenery that Yakima county can furnish.

On the right bank of the Naches, between the Tiaton and where Coweche creek joins it, there is a plateau with a rough, hummocky surface, which is exceptional, both topographically and geologically, to anything seen elsewhere during our reconnaissance. The plateau was formed by a recent lava flow which welled out as a flood of molten rock, somewhere in the elevated region drained by Tiaton creek, and, following a previously eroded valley, flowed east to where the Tiaton now joins the Naches and then turned abruptly southward and flowed on for 12 miles, to where the Cowiche now unites with the Naches. The lava stream broadened as it progressed until its lower part is nearly 2 miles wide. It followed previous lines of drainage and displaced both Tiaton creek and the Naches river, causing them to erode new channels along its border. The course of Cowiche creek was also changed and thrown to the south of its former position.

The flood of molten rock which produced this change was from 300 to 500 feet thick, as is revealed in its abrupt border overlooking the Naches. A mile above where the Cowiche joins the Naches the old surface of Columbia basalt, over which the lava flowed, is exposed.

The rock, on cooling, assumed a columnar structure, which is much confused in places, owing to its hardening about various centers, as is well shown along the road between the Cowiche and the Naches, at what is sometimes called "Pictured rocks." Other examples of the columnar structure may be seen all about the margins of the plateau, especially near the summit of its bounding cliffs. The borders of the original sheet have been cut away by the streams skirting it, thus indicating that they are striving to regain their ancient channels, which lie deeply buried beneath the resistant lava.

The rock forming this flow is black and solid, but has crystals of feldspar scattered through it, which appear as white rectangular figures on freshly broken surfaces. Samples of the rock have been studied microscopically by J. S. Diller, who pronounces it an andesite; as it contains crystals of the mineral known as hypersthene, it is termed a hypersthene andesite. Mr. Diller's description of this interesting rock is as follows:

> The lava of the recent flow near Naches bridge is dark colored, varying from dark gray to pitch black. The lighter colored portions are full of steam holes, while the darkest are dense. All portions, so far as may be judged from specimens collected, contain a multitude of small but distinct crystals of feldspar and pyroxene, which render the rock decidedly porphyritic. The long, narrow crystals of feldspar are clearly outlined and striated in a way that is characteristic of the plagioclase group. Crystals of greenish pyroxene are less abundant, especially in the darker portions of the mass.
>
> In the small steam holes of the vesicular portion of the lava there are minute crystals of some zeolite, but they were too small for closer determination.
>
> The ground mass of the rock, which is everywhere dark colored, is composed chiefly of a dark-brown glassy base, which under the microscope is seen to contain swarms of feldspar and pyroxene microlites of a later generation than the large crystals which render the rock porphyritic.

The pyroxene is strongly pleochroic and has the form and extinction characteristic of hypersthene. No other pyroxene than hypersthene was observed, nor could any olivine or quartz be found. The rock is a good example of hypersthene andesite.

This is somewhat surprising when we remember that it is the youngest lava of that region, and, in a geological sense, of recent eruption. At most other points on the slope and border of the Cascade range the youngest lavas are basalts.

The eruption of this stream of molten rock was among the very latest episodes in the varied history of Yakima county. It occurred after the general breaking and upturning which followed the deposition of the John Day beds, and after weathering and erosion had cut away these soft strata from all of the more prominent ridges and, to a great measure, reduced the valleys to the lowest level at which material could be removed from them. The country was channeled by streams in the same manner as at the present day, and one of these drainage lines, probably forming as fair a valley as that through which the Naches now meanders, was overwhelmed and filled by the fiery flood. The surface of the flow presents peculiar topographic forms, especially near its lower end, where there are scores of irregular hummocks and piles of scoriaceous rock 30 or 40 feet high, with irregular, undrained basins between. Farther north, just between the junction of the Tiaton and Naches, the surface is more even and is covered with grass. The soil formed by the decay of the andesite is a fine, dark-brown earth, which with irrigation would furnish rich agricultural land.

The Naches, for a score of miles at least above the mouth of Tiaton creek, flows through a deep canyon, bounded on the east by the precipitous face of a long, uplifted mountain mass having the topographic form of a great fault scarp, in which the inclination of the strata is northeastward. The country about the upper portion of the Naches was only seen from a distance, however, and may have a more complete structure than is here suggested.

Our line of march led up Wenas creek to the divide overlooking Ellensburg; we then turned back and, after revisiting Moxee valley, proceeded to Kittitas valley by the wagon road on the east side of Yakima canyon.

*Yakima canyon.*—The rocks on the head waters of Wenas creek are Columbia lava, broken and upturned in fault scarps, which merge into a general region of uplifts to the west, but become separated and well defined in traversing the desert country to the east. The ridges thus found agree in their principal features with nearly all the east and west ridges in Yakima and Kittitas counties. One of the lines of east and west faulting between Wenas and Kittitas valleys is marked by Umptanum ridge, which presents its bold escarpment to the northward. North of this, again, are the Beavertail hills, which are also a monoclinal uplift.

Yakima river on leaving Kittitas valley flows at right angles to the trend of these lines of uplift, and has cut a picturesque canyon 15 miles long and from 1,000 to 1,800 feet deep directly across them. A view of the northern end of this canyon, looking upstream to Kittitas valley, is presented on Plate VII and will serve to show the narrow, trench-like character of the excavation. The absence of a flood plain along the stream indicates the incompleteness of the task that the river has undertaken.

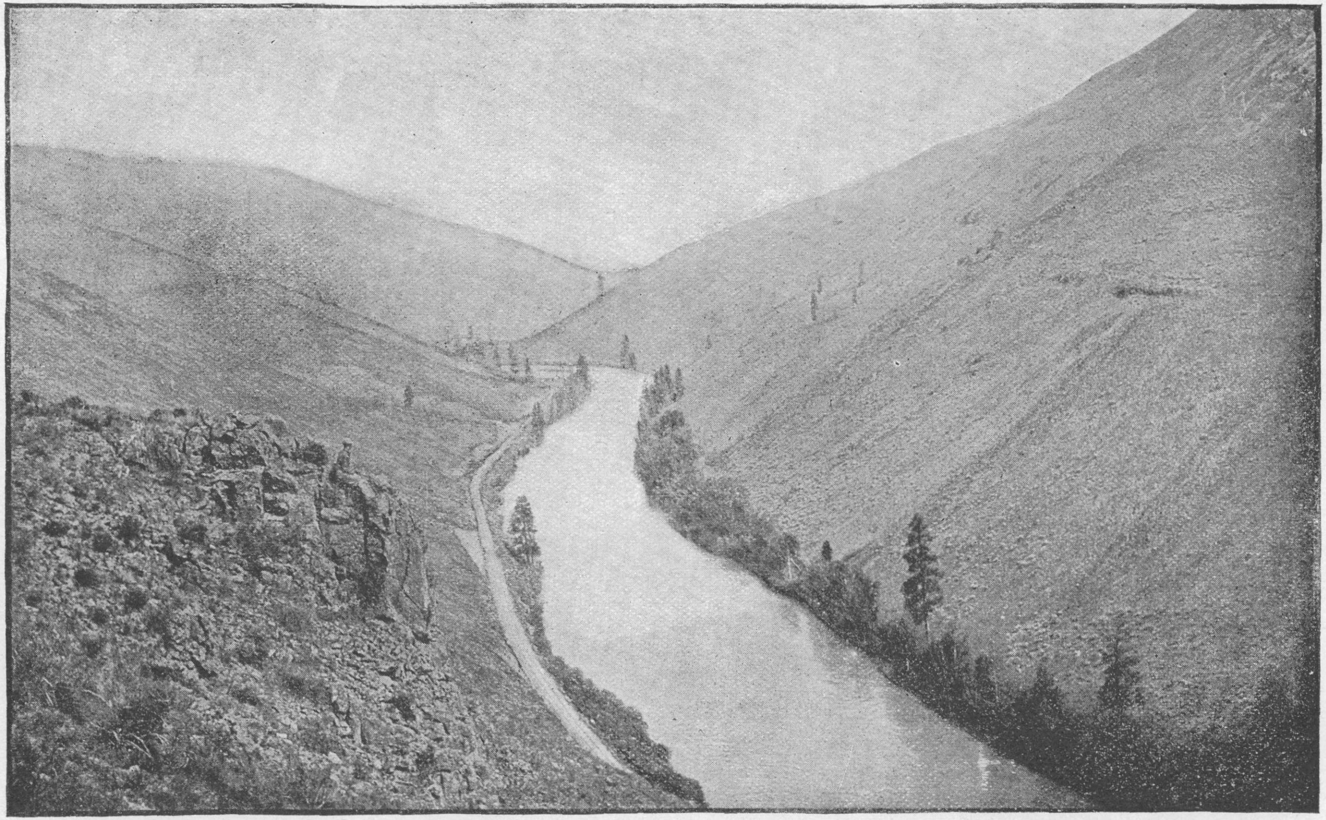
*Umptanum ridge.*—East of Yakima canyon this ridge is continued toward the southeast and becomes more and more clearly defined until it reaches Priests rapids. Its monoclinal structure is well marked, especially near its eastern terminus, where the base of its precipitous northern face is washed by the Columbia. As previously mentioned, the ridge disappears at the east in the plain bounding the Columbia, but rises again a few miles to the east and forms isolated ridges which stand like islands in the desert. These lost mountains have been called the Gable hills.

The country north of Umptanum ridge to Beavertail hills and to Saddle mountain, west of the Columbia, is a rocky region in which the black basalt is scarcely concealed from sight by the sandy soil. This region is drained by Squaw and Burnt creeks, flowing west to the Yakima, and by Alkali and Hunson creeks, flowing east to the Columbia. It has been deeply trenched by these streams, although they are now dry the greater part of the year. The creeks near their mouths flow in canyons several hundred feet deep. The land is much too rough to be irrigated from surface streams, and artesian water is not to be thought of. With the exception of a strip of rich land about a quarter of a mile broad, in the bottom of Squaw creek canyon, near its mouth, the country is valueless for agriculture, but bunch grass grows luxuriantly among the rocks and affords good pasturage. In the spring lovely wild flowers deck the sides of the canyons and the rocky plateau above in such profusion as to change the somber tone of the landscape and render it less forbidding.

The prevailing rocks are basalt, yet, in looking down the deeply dissected region from elevated summits on its borders, one can trace light-colored bands along the winding canyon walls, made by thin sheets of lake beds interstratified with the volcanic rock. In places on the interspaces between the branches of the streams one may see remnants of the heavy deposit of John Day beds which once covered the entire region.

In threading one's way across this dreary valley, fragments of fossil wood and even large parts of tree trunks, now changed to stone, frequently attract the attention and show that in former ages the now desolate region was forest covered.

Our reconnoissance embraced practically the whole of the basin drained by Wenas creek, but did not extend up the Naches river beyond the mouth of Tiaton creek. All of the rugged and highly picturesque western border of Yakima county was left unexplored. For a



YAKIMA CANYON, LOOKING TOWARD KITTITAS VALLEY.

long distance up both the Naches and Tiaton valleys the rocks are mainly basaltic, and stand in bold cliffs, leaving but little room for flood plains. How far to the west the basalt may occur is not known, but the presence of coal-bearing rocks at Cowlitz pass, and also the occurrence of deeply excavated valleys of which the Tiaton basin is an example, suggests that the basalt is limited on the west by a region in which erosion has been sufficient to remove the basalt and lay bare a lower series of rocks. Possibly the Kittitas system, which forms the surface in the western part of Kittitas county, will be found to extend southward through Yakima county.

### KITTITAS COUNTY.

Only a small portion of Kittitas county has been geologically examined, and nothing like an adequate account of the history of its rocks or of the origin of its diversified and attractive scenery can be given.

In the eastern portion of the county the rocks are Columbia basalt with remnants of John Day beds in the valleys. The lava forms conspicuous cliffs along the Columbia to within 5 or 6 miles of Wenatchee, the cliffs then turn abruptly southwest and are prolonged in a bold escarpment facing west, which determines the eastern limits of Schwak creek drainage, and is cut through by the Yakima a mile or two below Teanaway. South of Yakima river the basaltic escarpment continues southwest for many miles, but has not been definitely traced.

West of the western limit of the Columbia lava, between Columbia and Yakima rivers, there is a rolling, forest-covered, hilly country, which has been deeply dissected by stream erosion and shows, by its topographic forms, that it differs in nearly every way from the region of basaltic rocks to the east. In the rugged country referred to, drained by Schwak creek and Teanaway river, the surface rocks are sandstone and shale, with coal seams in certain localities. Coal has also been discovered in thin seams in the neighborhood of Wenache, and provisionally the formations in these two areas will be included in one system which, for convenience, is called the "Kittitas system;" a portion of its eastern boundary is shown on the map forming Plate II.

The rocks of the Kittitas system adjacent to the base of the bold escarpment of Columbia lava, between Columbia and Yakima rivers, is now exposed at the surface, because the basalt which formerly covered it has been eroded away. The strata are penetrated by an extensive system of dikes of hard basaltic rock, which accounts for many of the features in the relief of the land. These are of special interest because they seem to have been the source of the great sheet of basalt which once covered this portion of the Kittitas system. In places beneath the escarpment formed by the western edge of the Columbia lava there are large dikes which lead up to the basalt and merge with it. Their immediate junction with the lava crowning the cliffs was not closely examined, but the dikes in the slope below have every appearance of being connected with it, and lend support to the hypothesis of fissure eruptions to account for the great flood of basalt covering such a large part of the northwestern states. The dikes referred to were formed by the filling of vertical fissures in the sandstone and shale of the Kittitas system, with molten rock injected from below. The intruded material has changed the strata through which it passed, and on cooling formed compact basalt similar to the Columbia lava, but not porous or scoriaceous, as is sometimes the case in the surface flow.

In the gravels of Schwak creek there is considerable placer mining. The gold obtained is coarse and has been traced to large auriferous quartz ledges near the head of the stream. This region was examined by Mr. Diller, who informs me that the Kittitas system extends up the Schwak creek road to within 1¼ miles of the summit, where they are replaced by the older rocks in which the Pechastin mines are located.

*Kittitas Valley.*—Like the valleys farther south in Yakima county, already briefly described, this broad basin owes its existence to the upheaval of the rim of basalt which surrounds it. The John Day beds, between 700 and 800 feet thick, flooring its bottom, have been preserved, owing to their depression below the level at which the drainage of the valley escapes at the head of Yakima canyon. The soft beds still partially filling the basin are easily eroded, but the depth to which they can be cut by streams is controlled by the horizon of the bottom of the notch in the rim of the basin through which the drainage escapes. The river is still at work deepening the outlet of the valley, and various stages in the task of removing the soft beds from within it are recorded by numerous terraces about its borders. This is a plain example, on a small scale, of the wide-reaching law of "base level erosion," first emphasized by Powell, which has an almost universal bearing on the action of streams, and on the origin and development of topographic forms. The base level, to which the surface of the entire continent and of all land surfaces is being reduced, is sea level.

Kittitas valley is approximately 18 miles long from north to south and 10 to 12 miles broad. Its area is in the neighborhood of 150 square miles. Yakima river flows through it from north to south and receives the drainage of several creeks which rise on its mountainous borders. The rocks forming the rim of the basin, as already stated, are Columbia lava, upraised sometimes along fault lines, but more frequently, in a broad, general way, without clearly revealing the structure that has been impressed upon it. The borders of the basin to the east and west are between 5,000 and 6,000 feet in altitude, and the general level of the bottom of the basin is but 1,500 feet. The streams draining the elevated rim have cut canyons many hundred feet deep through the solid basalt, but the same streams on emerging into the valley flow over the surface of the soft lake beds without forming channels. Instead of cutting they are depositing the material derived from the hard rocks on their upper courses; this is because in the valley they have reached a base level and can not cut deeper.

The soft John Day beds flooring the valley do not extend far up its sides, as is the case in many similar basins farther east, but usually end abruptly against the base of the bordering slopes. At a few localities, however, to the southeast of Ellensburg, there are small outcrops of sandstone and conglomerate at an elevation of 200 or 300 feet on the side of the basin, and again at the south end of the valley fine marly clay is exposed on the side of the Beavertail hills.

The layer of basalt interstratified with the lower beds of the John Day system in Moxee and Wenas valleys occurs again beneath Kittitas valley and outcrops in the surrounding hills, but is much thicker than farther south and has only a thin sheet of sandstone beneath it. It is with difficulty that the layer of sediment beneath the first lava sheet can be recognized, yet in a few localities it is plainly exposed. Just within the mouth of Nanum canyon, about 12 miles north of Ellensburg, there is a heavy ridge of basalt following the general course of the border of the plain below and presenting a bold cliff 200 or 300 feet high to the north. In a narrow depression at the base of this cliff there are occasional exposures of an interbedded layer of sandstone. Farther up Nanum creek there are other obscure exposures of sandstone and shale, showing that the layers of basalt forming the picturesque highlands of that region have occasionally thin layers of sedimentary rock between them.

The soft porous beds underlying Kittitas valley do not now extend far enough up the border of the basin to furnish an artesian head for wells in the valley, but their eroded borders are upturned to some extent on nearly all sides and the basin is without outlet except through Yakima canyon. For these reasons the prospect of obtaining artesian water in the valley, although not promising, would seem sufficient to warrant the drilling of an experimental well. This has been done by Mr. Charles A. Sanders at a locality about 2 miles northwest of Ellensburg, in Sec. 30, R. 19, T. 18. A well was there drilled which passed through clay with layers of cemented sand and reached compact basalt at a depth of about 700 feet. Water was reached at a depth of 80 feet and when the well was abandoned stood 40 feet below the surface. Although flowing water was not obtained, the well is of value, as it demonstrates that the water beneath Kittitas valley does not exist under sufficient pressure to force it to the surface, and renders further experiment useless. Sander's well ends at the surface of the Columbia lava. By sinking it some two or three hundred feet deeper the first thin layer of sandstone interbedded with the basalt would be reached, but there is small hope that it would be water-bearing. The heavy layer of molten rock spread out above the sandstone has changed its structure, and even if sufficiently porous its small thickness and the manner in which it outcrops do not favor the hope that it would carry sufficient water to make it of economic importance.

Fortunately Kittitas valley is so situated in reference to the Yakima river and to the creeks that flow down its mountainous borders that nearly every acre of agricultural land in its bottom can be irrigated. The canyons in the sides of the basin afford good sites for storage reservoirs; and the creeks flowing through them carry sufficient water, if properly stored, to irrigate all of the land in the valley without drawing on Yakima river.

In exposures of the John Day beds having a vertical thickness of about 200 feet, along the left bank of Yakima river in Kittitas valley, the beds are seen to be mostly white volcanic lapilli with two strata of sandstone 6 to 8 feet thick, composed largely of well-rounded pebbles, from 5 to 8 inches in diameter.

At the south end of the valley, about a mile north of the entrance to Yakima canyon, there is a small quarry where a light friable sandstone, composed largely of volcanic dust, has been taken out and used in the front of a bank building in Ellensburg. With the soft sandstone there are thin beds of well-worn gravel and thick layers of exceedingly fine white clay. Some of the layers of sandstone and much of the clay are charged abundantly with the impressions of leaves, which have preserved with the greatest accuracy even the most minute venation of the ancient foliage. These leaves were blown into Lake John Day or drifted in by tributary streams and became buried in soft sediments which have since hardened to sandstone and clay. Sometimes the leaf impressions have a delicate greenish tint, a remnant of the ancient chlorophyll, which increases their resemblance to living foliage. A small collection of these fossils has been examined by Mr. F. H. Knowlton, of the U. S. Geological Survey. His report concerning them will be found in the Appendix.

Kittitas valley lies at the east base of the moderately elevated and quite humid region bordering the Cascade mountains on the east. Its bottom is without forests other than those of cottonwood trees which grow along the immediate banks of the river, but the hills and mountains bordering it on the west and north are clothed with an open park-like growth of pine, hemlock, and spruce. The soil is everywhere rich and is exceptionally so beneath the forests on the uplands, where the disintegration and decay of basaltic rocks have produced a fine, dark-colored deposit, which is usually rather thin, but sometimes has a depth of several feet. This soil is retentive of moisture and is everywhere covered with luxuriant bunch grass and flowers. The shaded upland pastures afford sustenance to thousands of sheep, but their expanse is so great that their verdure is unimpaired. My visit to this charming region was in springtime, when the mountain slopes were fresh and green and were kept free from dust by frequent showers. During the hot summer the grass becomes dry and withered and the tender green of spring gives place to the brown and gray of summer and autumn.

The views to be had from the pine-covered heights above Ellensburg, especially to the south of the town, are unusually fine even for a region which abounds in attractive panoramas. From many points of view one may look out through a framework of rugged trunks and drooping branches over the broad valley with its shining river meandering through groves of cottonwood and past fruitful farms; beyond the valley to the north, rise bold foothills covered with dark forests from base to summit, while still farther away beyond the valley's rim and beyond indefinite foothills softened in outline by their distance, rise rugged and angular mountain peaks which reach far above the limit at which trees can grow, and retain their wintry covering far into the summer. These are the Wenache mountains. The highest of their clustering spires is Mount Steward. Although not nearly as high as Mount Tacoma, which may be clearly seen to the southwest, it is far more attractive to the dwellers in Kittitas valley and is a mountain of which any land might be proud. From many points of view Mount Adams as well as Tacoma and Steward are in sight and also many lesser peaks and snowy crest lines, all combining to form a picture on which the eye loves to dwell.

*From Ellensburg to Wenache.*—From Ellensburg our reconnoissance led us across the high basaltic table-land bordering Kittitas valley on the north. We followed a much used freight road and reached the Columbia nearly opposite the mouth of Moses coulee. Our way lay across a plateau of Columbia lava which terminates a few miles to the west in a great escarpment, already noticed, at the foot of which the rocks of the Kittitas system form the surface. The only rocks seen during this portion of our journey were basalt. The general level of the plateau is about 5,000 feet, but near its western border it slopes upward before breaking off, and is there about 6,000 feet in general elevation.

In climbing the border of Kittitas valley the views to the south were varied and extensive, embracing the level floor of the basin about Ellensburg with vivid green alfalfa fields and more delicately tinted ground where young wheat grew; beyond were rolling wooded hills rising in picturesque irregularity to the base of the snow-covered Cascade mountains.

On the surface of the plateau we were shut in by forests of pine and spruce trees, beneath which the snow still lingered. The channels cut in the borders of the upland are fed by branching watercourses which flow away from the elevated region in conformity with the present slope of the rocks, showing that their courses have been determined by the form which the plateau now has, and are not an inheritance from an older condition, or from an overlying bed, now washed away. In other words, the drainage is consequent and the minor topographic forms are due to the weathering of the present surface.

From a camp beneath a grove of pines on the verge of the steep descent leading from the forest and grass-covered plateau above, where winter yet lingered, to the hot, barren desert below, we had a splendid view of the deep canyon of the Columbia and of the table-land to the east, which extended bare and desolate as far as the eye could reach. The pines clothing the plateau we had crossed descend a few hundred feet down its borders, but are there clustered in small groves and follow the lines of drainage as if fearful of approaching too near the parched region below. Beyond the lowest groves the luxuriant mantle of grass extends far down the slopes, but before reaching the valley loses its freshness and becomes brown and withered. In the distance, across the Columbia, there is not a tree in sight, and the vast plain, as it appears from our elevated station, has the brown and gray tone characteristic of the desert. A narrow white line on the desert, extending eastward with apparently a straight course until it was lost to view, we know to be the Great Northern railroad in process of construction, and the clouds of dust rolling away from the fresh embankments make us wish that the engineer and workmen who were laboring there in the heat could enjoy with us the freshness and coolness of the mountains.

In the evening the strong side light thrown on the desert made it glow with a ruddy color, seemingly due to the heat of the surface, and brought out in startling relief every ridge and canyon in the plateau surface and each cleft and column in the great wall of basalt which rises from the river and joins the desert 2,000 feet above. The strange panorama, thus strongly illuminated when the glare of the day gave place to the soft radiance of sunset, is a hundred miles in extent from north to south, and to the east is limitless, and fades away in the purple glow of the desert air.

We could see the abrupt rampart formed by Saddle mountain far to the south, and noted a white horizontal line just below the crest which is formed by the outcropping edge of a sheet of John Day beds, interstratified with the basalt forming the main mass of the ridge. The soft, light-colored stratum has been preserved by the sheet of basalt above it, the broken edge of which now forms the even crest line of the mountain. We were looking at the bold escarpment of a monoclinal ridge formed of the broken edges of strata which dip gently away from us, and form the gentle southern slope of the mountain.

At the base of Saddle mountain we could trace the course of Crab creek for many miles and see that it is really an abandoned stream channel sunken in the basalt. We note, too, that the direction of the ancient stream which excavated the channel was controlled by the fault which gave origin to Saddle mountain. North of Crab creek there is a broad desert surface unscarred by drainage and with but little detail except in the line of precipices formed by the cutting away of the border of the plateau by the Columbia. Tracing the apparently level plain northward from Crab creek to within about 5 miles of Moses coulee, the eye detects a gentle rise in the surface which culminates in a ridge extending eastward but curving south at its more distant extremity. This ridge breaks off abruptly on its northern side and has a line of drainage at the base of its northern slope which leads to the Columbia. This depression is Wake Cumtux coulee. Its relation to the small ridge just south of it is the same as the relation of Crab creek coulee to Saddle mountain. In each instance there has been an east and west break in the stratified basalt forming the plateau; the south side of the break in each instance has been upraised so as to form a long, narrow, monoclinal ridge, and surface drainage directed by the break at the foot of the steep escarpment of each ridge has carved a deep canyon or coulee leading to the Columbia. A later chapter in the history of these coulees is recorded by the fine beds which partially fill them; these belong to the time when the drainage of the Columbia was obstructed and Lake Lewis existed.

Moses coulee is a broad, flat-bottomed canyon which heads in several branches far back in the plateau. It is the result of stream erosion, which was initiated by a break in the rocks of the same character as the fractures that gave direction to Crab creek and Wake Cumtux coulees. The south wall of the canyon is a precipice of basalt about 500 feet high, from which the strata dip very gently southward. The northern wall is not so high as the one on the south, and the strata exposed in its face are practically horizontal. The disturbance of the beds adjacent to the break is so gentle, however, that it would scarcely be detected except in a distant view when the beds are seen in profile. The desert surface north of Moses coulee rises gently for some 10 miles to where another east-and-west uplift forms the sky line, as seen from our camp beneath the pines. In the edge of the plateau a few miles north of Moses coulee there is a break occupied by a deep drainage channel, the south wall of which is again higher and has a different dip than the north wall. The fact that the coulees forming such a unique and characteristic feature of Douglas county are due to the erosion of streams which followed lines of fracture and faulting, is one of the most interesting portions of the geologic story to be read in a general view of the region.

The east wall of the canyon of the Columbia, like the walls of the coulees opening from it, is a series of palisades rising 2,000 feet above the river. In these great cliffs, unbroken for scores of miles, the edges of the layers of basalt underlying the plain to the east are exposed and reveal the fact that the rocks are in distinct layers, many of them being formed of vertical columns, and ranging from perhaps 50 feet to 200 or 300 feet in thickness. Between some of the layers there are thin, irregular sheets of volcanic lapilli or of sedimentary layers, but most of the contacts are marked simply by a line separating rocky layers of different structure, and may be the result of cooling. Near the top of the cliffs, especially above Rock island, there is a band of light-colored lake bed, perhaps 40 feet thick, which is usually weathered back, and forms a terrace. The lower portions of the cliffs are concealed by vast talus slopes which stand with surface slopes of about 40° and reach half way up the escarpment. Viewed directly these conical piles of angular fragments seem perpendicular, and only reveal their true forms when seen in profile.

The Columbia from the neighborhood of Lake Chelan southward to where it passes through the Cascade mountains is a desert stream. Its banks are without trees and lack the bright green tints that usually margin rivers and fresh-water lakes. The gray-brown of the desert touches the water's brink, but does not change its character. Sage brush and greasewood, with other desert vegetation, fringe the banks in places and have a somewhat more luxuriant growth than farther away on the deserts, but this is all the change that the river has produced in the vegetation on its shores. The absence of cottonwood trees is especially noticeable, since the courses of streams in the arid regions are frequently marked by them. A few miles below Lake Chelan the first pine trees are met with in ascending the river, and from there northward they are of common occurrence, although seldom forming dense growth.

In the canyon of the Columbia above Saddle mountain there are many terraces. The highest and broadest of these is at the same level and unites with the flat bottom of the coulees, extending back into the plateau to the east. It is evident that both the main canyon and the coulees branching from it have been filled to a level of approximately 700 feet above the Columbia, and that subsequently the channel of the river was reexcavated, leaving terraces along its sides, while in the lateral canyon there has been too little drainage since the period of filling in to excavate even faint channels along the ancient watercourses.

On descending into the canyon of the Columbia, when we continued our journey to Wenache, we found several stream terraces below the great terrace, and also many irregular terraces, both at higher and lower horizons, which are due to landslides. Terraces resulting from the weathering of the outcropping edges of horizontal sheets of basalt were also distinguished. In places landslides have reached the river and partially obstructed its course with huge masses of basalt.

The Columbia lava, which has such an immense development in the eastern parts of Yakima and Kittitas counties, was found to terminate, on ascending the Columbia, about 12 miles below Wenache. The black precipices bordering the river on the west there turn abruptly southwest, as previously noted, and extend in an irregular line of towering cliffs across an exceedingly rugged and generally elevated region to the Yakima river below Teanaway, and then southwest for an unknown distance. At the west base of this great escarpment, which rises almost vertically from 1,000 to 1,500 feet, the topography changes immediately and the broad plateau features give place to drainage lines inclosing rugged hills. At the immediate base of the great scarp, and for 2 or 3 miles west of it, the topographic forms are especially irregular, and the hills and ridges surround basins so as entirely to inclose them and leave them without outlets.

Near the cliffs the characteristic features produced by landslides are clearly shown. The irregular ridges are formed of masses of basalt which have fallen and slid to their present position and have usually an inclination toward the cliff whence they came. Evidently the great escarpment is retreating, owing to the breaking away of portions of its face. More distant from the cliff the secondary ridges become less pronounced and the surface is strewn with broken masses of basalt; still farther away the basaltic blocks have mostly disappeared, leaving an irregular rolling topography which is dissected by stream channels and acquires a relief due to denudation and to the structure of the rocks beneath. How far west of its present limit the basalt formerly extended is not possible to determine with accuracy, but it must have been at least several miles.

From where the escarpment of Columbia lava turns southwest, near Rock rapids, to the mouth of Wenache river, and thence westward for at least several miles, the country rocks are sandstones and shales, with thin beds of coal, and are supposed to belong to the Kittitas system. These rocks are older than the Columbia lava, and at the base of the escarpment just mentioned pass beneath it. The rocks of the Kittitas system were folded and eroded before the Columbia lava was spread out over them. To the north the lava overlaps their border and rests on the decayed and eroded surface of granitic rocks.

A few miles south of Wenache there are thin layers of basalt capping the hills, which show that the inundation of molten rock in that region began with the spreading out of a sheet of lava from 20 to 50 feet thick, which was succeeded by sedimentary layers of about the same thickness, so far as can be judged, and then came the great flood of molten rock forming the widely spread formation named the Columbia lava.

The Kittitas system occurs on the east side of the Columbia from Rock rapids some 15 miles up stream. Soft sandstones and shales, usually of light color, but sometimes brilliant red and yellow and looking as if they had been baked by the burning of coal seams, form the steep slope leading from the river opposite Wenache to the base of the palisade of basalt crowning the heights above. This strip of country formed of sedimentary rocks is about 3 miles broad, but becomes narrower down stream; the rocks also dip eastward and are carried below the level of the river and disappear beneath the basalt at Rock rapids. Along the east bank of the Columbia above Wenache the sandstones and shales give place to quartzites and schists, which immediately underlie the Columbia lava. Farther up the river no traces of the Kittitas system have been observed. They continue for at least 20 miles up the Wenache river, as has been observed by Diller, and then give place to crystalline rocks.

The coal found near Wenache occurs in thin seams which are much disturbed and dip at all angles. It is of poor quality and so far as known is of little economic value. The presence of even thin seams of coal, however poor, is sufficient to encourage further search, and the field should not be condemned until every layer of rock that it contains is thoroughly known and its value for fuel or other purposes demonstrated.

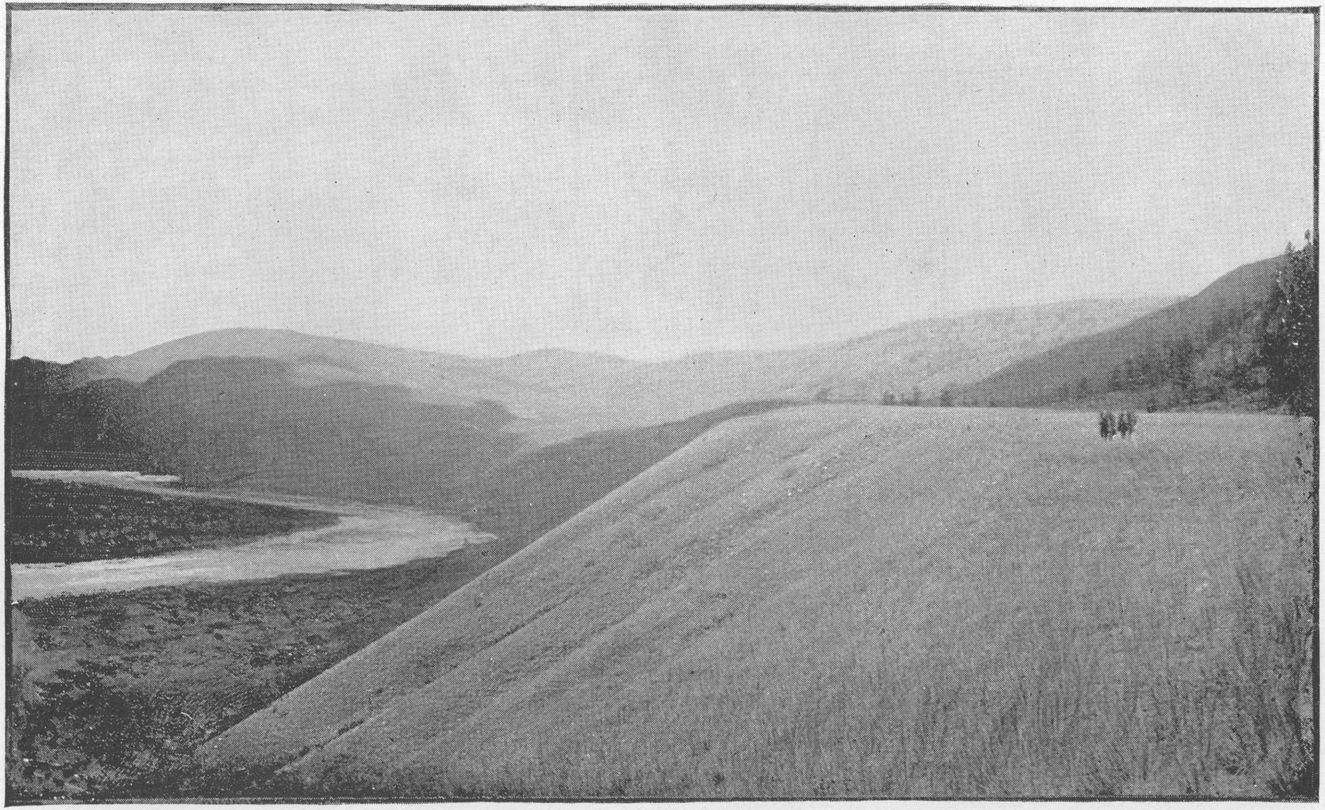
Much as we desired to ascend Wenache river and explore the geologically unknown country to the west, which is full of promise to the geologist, we were constrained to turn to the less inviting arid region to the east, where the artesian well problem demanded attention. Our line of travel followed the Columbia in a general way, to the mouth of the Grand coulee at the northeast corner of Douglas county, where we turned south, as will be described in advance. In journeying along the Columbia and in ascending Lake Chelan, observations were made on the main features in the geology of the southern border of Okanogan county, which it may be well to record, since so little is known of that promising region.

## OKANOGAN COUNTY.

Okanogan county is rugged and mountainous throughout. The mountains are composed mainly of granitic rocks, which have been long exposed to the action of the atmosphere. As we now see them with all their picturesque detail, they are not the direct results of uplifts, as are the mountains in the basaltic county to the south, but have been slowly sculptured from a broad region of general high relief by running water and glacial ice, assisted by the decay and disintegration to which granite is especially prone.

The rocks in the southern portion of the county, just north of Wenache, are quartzites and schists. Farther north, in the neighborhood of Lake Chelan, these give place to coarse granite and closely allied rocks. In the northern part of the county, drained by Okanogan river, there are gold mines which are now attracting much attention. The rocks in which the gold-bearing quartz is found are also granitic, and the reports of prospectors show that the same formation has a wide distribution north of the Columbia. On a geological sketch map, by Willis,[1] a broad belt through the eastern and northern part of the county is represented as being occupied by granite and crystalline schists. It is from this general source that the gold so widely distributed along the streams of central Washington had its origin. Although our knowledge of the geology of Okanogan county is but meager and fragmentary, it seems safe to conclude that the county is occupied almost entirely by crystalline schists, granites, quartzites, etc., rocks

[1] U. S. Geol. Survey, Bull. No. 40.



GRAVEL TERRACE IN CANYON OF THE COLUMBIA, NEAR CHELAN CROSSING.

which are everywhere looked to for precious metals and a great variety of useful minerals.

An exception to the prevailing rocks forming the surface occurs on the east side of the valley of Okanogan river, where a tongue of Columbia lava runs northward and probably extends beyond the Canadian boundary. This northern extension of the lava sheet forming the Great Plain of the Columbia occupies an ancient valley which was excavated previous to the lava inundation and is one of a series of old drainage lines which were either wholly obliterated or greatly changed by the inundation of lava. Many of these drainage channels were again modified by the glaciers which occupied them at a later date. Fire and frost have thus conspired to efface the work of the rivers. Okanogan valley was one of several ancient drainage lines which suffered a double invasion. The glacier which filled it flowed south and, crossing the Columbia, occupied the northern portion of Douglas county. Another great glacier flowed down from the highlands to the north through Methow valley, and the deep depression in which Lake Chelan now lies was also filled with ice from end to end. Other glaciers probably existed in the valleys along the east slope of the Cascades farther south, but their records have not been examined. All of the glaciers in Okanogan county, as shown by the scorings they left on the rocks and the character of the bowlders strewn along their paths, flowed southward and drained snow fields on the Cascades. Many changes in the direction of the streams resulted from this ice occupation, as has already been mentioned. A few of the modifications have been described by Willis in the bulletin already referred to. After the retreat of the glaciers the valleys along the southern border of the county, including the deep canyon of the Columbia, were left partially filled with gravel and sand and clay, into which the streams have reexcavated channels, leaving numerous terraces along their border. Some of the details in this general history will be noticed in the following itinerary of our journey.

*Approach to Lake Chelan.*—Our route from Wenache to Lake Chelan was by way of Waterville, and falls within the limits of Douglas county, next to be described.

On reaching the west border of the plateau on which Waterville is situated, we had a wide extent of the mountainous region embraced in Okanogan county in view. Nearly every feature in the landscape changed at once. The broadly undulating surface of the great plateau forming the Great Bend country ends abruptly on the west in an irregular line of basaltic cliffs overlooking the Columbia, 2,000 feet below. Standing on the verge of the canyon we note that the basalt is only a "rim rock;" below it there are less precipitous slopes formed of schist and granite and clothed scantily with pines. For the first time since seeing the Columbia we find trees along its margins, showing that the climate is much less arid than further south. The west bank of the river is also rugged and precipitous, but unlike its eastern wall, does not rise to a level-topped plateau, but is formed of bold mountain spurs separated by deep valleys. Beyond the first forest-covered hills there are others still higher, but without apparent arrangement, which merge in the distance with lofty snow-clad peaks.

On descending the side of the canyon, by means of a road following a deep high-grade gorge, we notice that there are many terraces on each side of the river. The most remarkable of these, and one of the finest examples of terrace structure that can be found anywhere, is a level-topped shelf formed of gravel and water-worn bowlders, the surface of which is 700 feet above the Columbia. This truly remarkable terrace is best developed about 2 miles below, where we descended into the canyon. It is there several hundred feet broad and runs back into lateral gorges, showing that the sides of the main canyon are deeply scored by lateral drainage before the gravel forming the terrace was deposited. On the west side of the valley there are other fragments of the same deposits, forming a less conspicuous shelf, which has been built against the steep slope, and has the same level as the great terrace on the east side of the river. The valley was excavated lower than the bottom over which the Columbia now flows, and then filled in from side to side with stream-borne stones, gravel, and sand before the present channel was excavated. In the reexcavation fragments of the deposits filling the canyon have been left clinging to its slopes. Streams flowing down lateral gorges have cut channels across the terrace, thus revealing its structure even more plainly than the steep slope leading to the river. A view of the level surface of the terrace and of the steep slope toward the river, formed by the undercutting of the stream and the sliding of material from above, is shown in Plate VIII.

Above the valley opening in the west wall of the canyon and leading to Lake Chelan there are other large remnants of the same great terrace, this time on the west side of the river. In the broad plain formed by the surface of the terrace there stands a lofty pyramid of solid rock completely surrounded by the gravel deposit and rising like an island from its level surface.

The terrace gravels extend into the valley of Lake Chelan and form conspicuous terraces about its lower end. For many miles both up and down the Columbia other fragments of the same level topped deposit occur, always forming striking features in the landscape, owing to the marked contrast of their smooth horizontal lines with the vertical line due to the erosion of rills and creeks.

Beside the great terrace described above there are many others but less conspicuous horizontal lines on the sides of the Columbia canyon. Some of these below the horizon of the main terrace are stream terraces, made by the river in lowering its bed. A more numerous but much less regular class are due to landslides, of which there have been many. Other horizontal lines are due to the unequal weathering of the strata of basalt and of interstratified sedimentary beds.

Still another class of terraces, both numerous and conspicuous, have been formed as moraines on the sides of the glacier that once filled the canyon up to an elevation of 1,200 feet above the river as it flows to-day. The moraine terraces are of older date than the great terrace described above, and about the entrance of Chelan valley have been partially buried by it.

In the canyon of the Columbia for several miles above Lake Chelan its rugged sides are strewn with thousands of perched bowlders, left by the retreat of the ice. These have a definite upper limit, but mingled with them are masses of basalt that have fallen quite recently from the cliffs above.

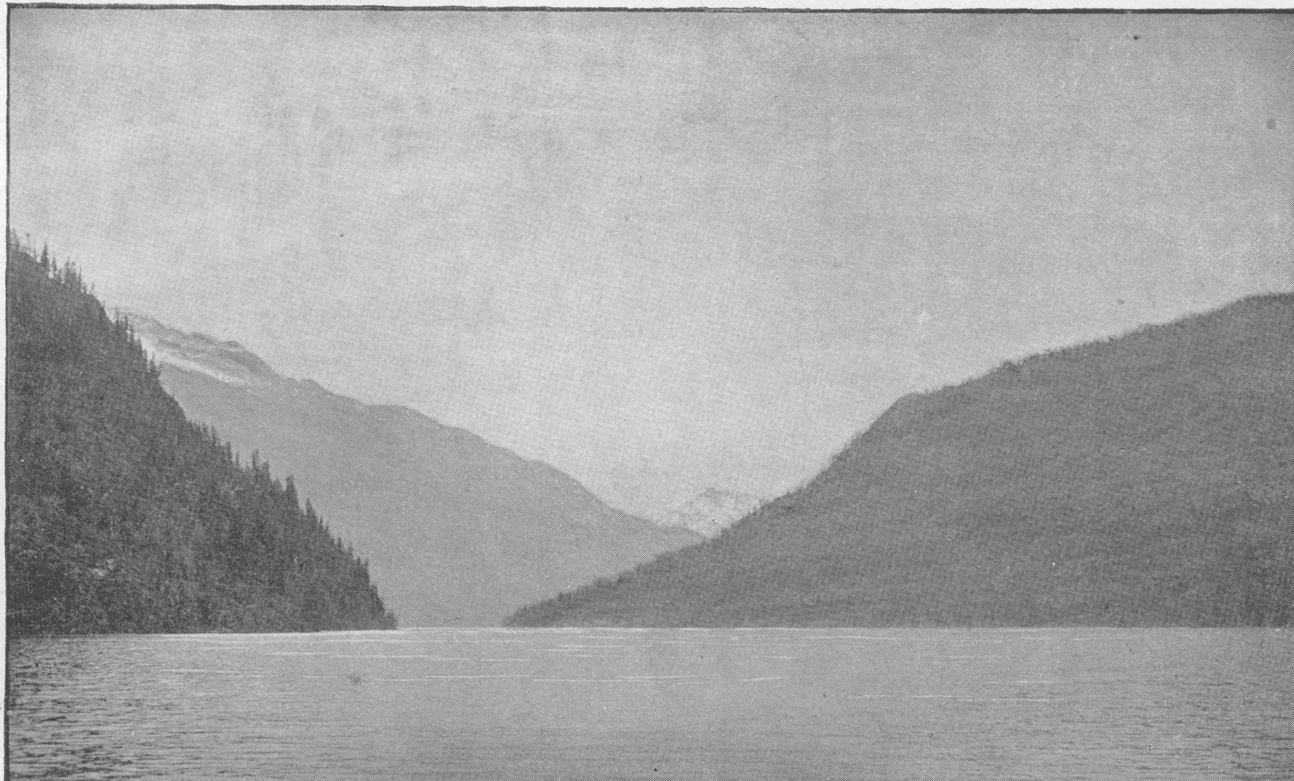
In embayments along the sides of the main canyon and back of the ridges of stone and bowlders left by the ancient glaciers, there are flat areas which have been filled in with fine material, washed from higher levels. These plains have in some instance been cut by small streams flowing across them, thus adding other horizontal lines to the complex topography of the canyon walls.

It is not practicable to describe these terraces in detail, but those who visit Lake Chelan will have an opportunity to read for themselves the remarkable history which they record. In studying them, however, the traveler must bear in mind that the canyon, after being cut through various rocks to a depth greater than it now has, was occupied by a great glacier, and then by an arm of a large lake, and that river, glacial and lacustral records are inscribed on the same slope. In addition there have been many landslides, producing deceptive, terrace-like forms, and terraces due to the unequal weathering of hard and soft beds.

The approach to Lake Chelan is so full of interesting features that the traveler will hesitate to press on in spite of the attractive lake scenery beyond. From Chelan crossing to Lake Chelan is about 2 miles. The surface of the lake is, by aneroid, 325 feet above the river. The stream flowing from the lake is a bright, clear river, which runs at such a rate, even in its more quiet reaches, that its surface is everywhere flecked with foam. The freshness and irregularity of the channel through which it makes its wild descent is one of the first facts to attract attention. It emerges onto the lowest terrace bordering the Columbia from a deep, impassable gorge as one mass of shining foam. The walls rising above the stream show fresh breaks and are very precipitous. It is evident at a glance that the channel has but recently been excavated and has but few of the characteristics of a valley formed by stream erosions. In brief, the history of the outlet of the lake is this: When the great glacier which occupied the valley of Lake Chelan up to an elevation at the south end, of nearly a thousand feet above the present water surface, melted back and slowly retreated up the valley, it left a terminal moraine across the entrance where Chelan city now stands. With the retreat of the glacier came the advance of Lake Lewis, which filled the channel of the Columbia up to the level of the great terrace, which still remains in the canyon. Lake Lewis also occupied the lower part of Chelan valley and left its record as a broad terrace 325 feet above the lake. When the waters of Lake Lewis fell the Columbia canyon and the entrance of Chelan valley were filled to a common level with moraines and stream-borne gravels. The Columbia began to reexcavate its channel, a task still unfinished, and the drainage from Lake Chelan cut a new outlet as the main river progressed with its task. The overflow from Lake Chelan, however, did not take the direct course to the Columbia, which a former outlet had occupied, but instead was turned abruptly to the south by a break caused by a landslide, and reached its goal by a tortuous channel between two immense fallen masses of the mountain side, each of which is fully half a mile long. The outlet of the old channel, which is now deeply buried, may be recognized a hundred yards up the main stream, from where Chelan river now enters the Columbia. Large springs occur at that locality, formed by the water that percolates through the gravel filling the old valley.

On each side of the entrance to Chelan valley there are many terraces. The broadest of these is the old lake terrace 325 feet over the present lake. The highest terraces of all and also some at lower horizons are due to lateral moraines, which accumulated along the border of the old glacier. These may be distinguished from the lake terraces by their lack of uniformity in height, by their being built largely of angular and partially rounded bowlders, and by the fact that they are not level topped terraces sloping lakeward from a sea cliff, but form free ridges of coarse material, with a narrow valley back of them. The moraines above the broad lake terrace are much more distinct than those below that level, because the lower ones have been partially removed and partially covered by clays and gravels deposited in the deeper portions or along the shores of the old lake. A curved moraine, having a height of about 175 feet above the present lake, was thrown completely across the entrance of the valley, where the site of Chelan city has been chosen. The moraine was buried by the sediments of the post-glacial lake, but when the drainage was reestablished it was cut through and a section of its central portion half a mile long removed. The remaining fragments of this moraine, containing many large bowlders, may be seen, one on the south side of the Chelan river, where it leaves the lake, and the other on the north side of the flat on which the town is located.

*Lake Chelan.*—On looking at a map of the state of Washington it will be noticed that Lake Chelan is the only large water body in the state. It is exceptional in its form also, and not only differs from all of the smaller lakes in the state, but does not have a counterpart any-



VIEW NEAR THE HEAD OF LAKE CHELAN, LOOKING WEST.

where in the Cascades or Sierra Nevada. The only lakes which seem to be closely similar to it in the Cordilleran region are Arrow and Kootenay lakes in British Columbia. Lake Chelan is a narrow, river-like sheet of water, which extends from the south border of the mountainous country forming Okanogan county 65 to 70 miles northward, right into the heart of the mountains. The extension of the valley northwest of the head of the lake which has been filled in by stream deposits is reported to be 15 to 20 miles in length, making the whole depression about 100 miles long. The breadth is remarkably uniform throughout and seldom exceeds 2 miles at the level of the lake, except at the south, where the mountains embrace it less closely. It then expands to probably 3 miles in width, and has terraced shores which are comparatively low, especially on the south side. The subdued landscapes about this portion of the lake present a pleasing contrast to the wild, canyon-like scenery farther within the water filled gorge.

The mountains inclosing Lake Chelan on each side, north of the somewhat expanded southern terminus, rise abruptly from its margin to great heights and are unbroken by deep side valleys. For 50 miles the walls inclosing the valley rise to heights of 5,000 to 6,000 feet. All of their lower slopes are dark with pines, but their bare, serrated crests are white with snow long after the flowers of spring have faded on the lower slopes.

The waters of the lake are clear and sparkling and have the deep blue of the ocean. The sounding line has shown a great depth. Although our examination was hasty and we were not prepared for a systematic survey, we found that the depth in the upper portion of the lake exceeded 1,100 feet, the length of the line that was extemporized for the measurement. The surface of the lake is only about 950 feet above the sea; its bottom is therefore below sea level.

The mountains throughout the entire extent of the lake are of granite and closely allied rocks. When one attempts to discover how such a mighty gash, 100 miles long, from 6,000 to 7,000 feet deep, and reaching below sea level, could have been excavated, it is best to pause until all the accessible facts bearing on the question can be assembled and their meaning interpreted.

Our trip up Lake Chelan and return was made in a small steamer named *The Bell*, which was much more comfortable than one would be apt to anticipate in such an unfrequented corner of the world. The start from Chelan city was made at 7 in the morning on a beautiful June day, and at 5 in the evening the little boat was moored among the tall trees overhanging a sheltered inlet at its head. All day long we traversed placid waters, each turn in the gently curving shores revealing more and more wonderful scenes and still increasing splendors. The cliffs rise vertically from the water, usually not leaving space enough on which a fisherman might stand, and tower aloft to such dizzy heights that the pines clinging to each ledge and filling each side ravine, lose their individuality and become mingled in a general covering of green, which fades to the gray of lichen-covered slopes before the shining snow fields on the higher summits are reached. Much of the charm of the fascinating scenery is due to the fact that its wild, natural beauties have been untouched by the destroying hand of man. The threads of silvery foam descending from unseen regions above gleam and flash through the overhanging ferns and flowers just as they did for centuries before man came to admire their freshness and beauty.

The splendors of the mighty mountains on each side of the lake continued on and on as we penetrated deeper and deeper into the unknown region. Nor does the wonder cease when the head of navigation is reached and a dense forest replaces the shimmering plain of blue. The valley continues still farther northward, the bordering walls inclosing it continue to increase in height and more and more of their summits are snow-covered, and far away against the sky glimpses are revealed of still mightier summits, which we were told were a portion of the Cascades.

The walls of granite inclosing Lake Chelan are rounded and worn, showing the work of glaciers which once flowed through the valley; but, except in the general form of the outstanding buttresses and domes, the records of ice action are slight. There is a remarkable absence of débris on the slopes. No traces of moraines can be recognized, except in some of the lateral gorges, and as already stated, at the foot of the lake. In a few sheltered places on the surfaces of swelling domes, however, the grooves and striæ made by glacial action can be recognized, and in themselves are sufficient, if unsupported by other evidence, to show that glaciers had flowed through the valley.

We remained at the head of the lake one night, and the next day returned to our camp near Chelan city. It was with a feeling of relief that we emerged from the portals of the magnificent valley, and saw again the green, terraced slopes where the scattered houses and the gleaming church spire of an Indian village gave a suggestion of civilization to the scene. The milder beauties of the southern end of the lake add a pleasing contrast to the magnificence of the northern portion, and make the scenery of Lake Chelan more attractive than that of any other lake in the Far West. Not even far-famed Tahoe, with its wide expanse of deep, blue waters and wild, wooded shores, can be said to excel Chelan in magnificence. The lakes at the southern base of the Alps are more nearly of the same type, but their natural beauties, bare of the poetry and romance that has been woven about them, are no more attractive than the river-like sheet of colorless water which fills a mighty cleft in the Cascade mountains in northern Washington.

The completion of the Great Northern railroad to Wenache will bring Lake Chelan within easy communication with a main line of travel. Small steamers running on the Columbia will enable the traveler to reach the lake within ten or twelve hours after arriving at Wenache.

If the few words of praise which I have given to Lake Chelan should induce weary mortals in quest of rest and recreation to visit its shores, I shall be fully repaid. The lake abounds in trout, and on the mountains overlooking it I am told there are deer and mountain goats. The hotel accommodations are not of the best, but will no doubt improve. Delightful camping places can be had at many points along the water's edge. Those who wish to fully enjoy the grandeur and romance of a wild life in a wild country can not do better than to provide themselves with a suitable boat and camping outfit, and move from one point of interest to another along the lake shore as their fancy may dictate.

## DOUGLAS COUNTY.

Douglas county is bounded on the north, west, and south by the Columbia river. It comprises the greater part of what is popularly known as the Big Bend country. Its surface is largely a sagebrush desert of little value, where water can not be had for irrigation; yet in the higher portion to the west and north in the vicinity of Waterville, and again along the border of Lincoln county, the rainfall is sufficient to allow of the raising of wheat without irrigation. As a rule the crops are light.

The greater part of Douglas county is so situated that waters can not be had for irrigation at a warrantable expense. The Columbia river, skirting three-fourths of its border, flows in a canyon 2,000 feet below the surface. After leaving its canyon and cutting through Saddle mountain, its banks are much lower and in places favor the use of the stream for irrigation. The project of constructing a large ditch to start at the gateway through Saddle mountain and carry water to the sagebrush desert north of White bluff, is already under consideration. Plans for taking water from Spokane river and conducting it westward to the thirsty land of Lincoln and Douglas counties has also been suggested. These projects, however, involve the expenditure of large sums of money in order to carry them into effect, even if engineers report them practicable.

The dearth of water for irrigation and the partially insurmountable difficulties in the way of securing it from streams, have led the citizens of Douglas county to hope that artesian water could be found within their border. Our reconnoissance, however, did not show that the geological conditions are at all favorable to these expectations.

The rocks of Douglas county are mainly and characteristically basalt. The Columbia lava occupies every square mile of area, with the exception of a strip less than 2 miles in average width along the Columbia upstream from Rock rapids to the mouth of Grand coulee. The average thickness of the basalt is thought to be about 2,000 feet. In this exposed edge overlooking the Columbia, its general thickness is not over 500 or 600 feet.

Beneath the Columbia lava opposite Wenache, there are sandstones and shales as already explained, which belong to the coal-bearing rocks better exposed at Wenache and at Roslyn. How far these extend eastward and northward beneath the basalt we have no means at present of knowing. In the northern half of the county the basalt rests directly on granite and gneiss. The lower rocks were much disturbed and deeply eroded before the basalt was spread out above them, and the basin structure necessary to secure an artesian flow does not exist. Hence the conclusion that it is useless to drill for water for agricultural purposes even though the demand for it is great.

In the southern part of the county there are heavy deposits of John Day beds above the basalt, as may be seen especially at White bluffs along the Columbia. Farther north these beds are thin and in many places have been almost entirely eroded away. Glacial deposits and the slight records left by Lake Lewis will be noticed in advance. The conditions necessary for the existence of subterranean water under pressure do not exist in these superficial deposits; this conclusion is sustained by borings that have been made at Pasco and to a less depth at other stations on the Northern Pacific railroad.

*Wenache to Waterville and Chelan crossing.*—At Wenache the Columbia makes a broad sweep to the west and is cutting away its right bank. On the east side of the river there is a narrow tract of low land covered in part with drifting sand beyond which there are high terraces concealing sandstones and shales, while far above rise basaltic cliffs formed by the edge of the Columbia lava. To gain the top of the plateau, rising as it does 2,000 feet above the river, is not an easy task even for the pedestrian. In order to reach it with our wagon we followed the stage road along the east bank of the river for about 12 miles and then turning sharply to the right traversed a road up a high grade gorge which led to the summit.

About Wenache and along the river to the south, there are great quantities of angular bowlders, some of them of large size, composed principally of quartzite, granite, and schists, which were carried to their present positions by ice. The great increase in the number of bowlders, as well as their large size, to be noted as one approaches Wenache in ascending the river, indicates that a change in the geology may be expected.

Two or three miles above the ferry landing opposite Wenache, we came to bold outcrops of gneiss formed by contorted and for the most part nearly vertical layers, on which rested light colored sandstones and shales in a horizontal position. The sedimentary beds belong to the Kittitas system and are conspicuous on account of their prevailing light colors and also because of many brilliant red layers, which, as already suggested, probably owe their bright tints to the burning of thin coal seams.

Farther up the valley the steep precipitous eastern bluff is composed of gneiss and quartzite up to the base of the precipice of columnar basalt crowning its summit. Many landslides have fallen from the eastern escarpment and greatly modified the minor features in its relief. These slides are sometimes 200 or 300 feet high and a quarter of a mile long. In places they obstruct the river and have even turned it from its course. The larger masses that have fallen are of gneiss, but in the confused heap of débris there are many angular blocks of basalt derived from the precipice far above. The narrow strip of low land adjacent to the river is so heavily encumbered with these fragments that it is with difficulty a roadway has been found among them, but in one or two places there are sheltered nooks large enough for peach orchards and gardens. The west bank of the river is formed of bold bluffs of gneiss about the base of which there is not room enough for a man to pass. The banks of the canyon are so steep even on the east that but faint traces are left of the terraces still so strongly marked along the river both above and below.

On the plateau surface near Waterville, there are rounded hills with broad flat-bottomed valleys which mark the courses of former drainage-lines, but now the amount of moisture supplied by rain and snow is so small that it is absorbed by the soil and does not flow over the surface sufficiently to cut even rill channels in the grass covered surfaces of the filled valleys. Hard rock seldom appears at the surface. Wells sunk in the soil reveal a layer of marly clay, a remnant of the sediments of Lake John Day, which formerly covered the entire plateau. Some of the wells having a depth of about 200 feet, pass through 15 to 20 feet of soil, 20 to 30 feet of fine, evenly stratified clay, 40 to 50 feet of basalt, 25 to 30 feet of sand and clay and then enter a second bed of basalt which has never been penetrated, but is probably 400 or 500 feet thick.

The rainfall in this otherwise ideal farming region is small, but is yet usually sufficient to insure a fair crop of wheat without irrigation. The soil is unusually rich as is the case generally throughout Douglas county, but irrigation is impossible as the only stream in the region is the Columbia, which flows 2,000 feet below the surface of the plateau. Where the soil is not under cultivation there is a luxuriant growth of bunch grass which, together with the light rainfall, has much to do with the origin and formation of the subdued topographic forms.

This beautiful region with its gentle relief and flowing outlines, its green fields and comfortable houses, has a rural beauty that places it in pleasing contrast to the brown and barren desert lands with which it is bordered on the east, and to the rugged mountains west of the Columbia. Its principal interest to the geologist lies in the evidence of a formerly greater rainfall and in the absence of all glacial records. The glaciers from the highlands beyond the Columbia passed to the west and also to the north, leaving this high plateau unscored and without moraines or bowlders. Its elevation placed it above the waters of Lake Lewis, so that icebergs freighted with stones were not floated over it.

Waterville is a thriving agricultural town without either railroad or steamboat connections. Our route lay through the town and westward across undulating prairie lands that extend to the brink of the great gorge through which the Columbia flows. As we approach the western verge of the plateau the full grandeur of the snow-tipped mountains along the western horizon become more and more fully revealed. At the brink of the canyon the ground falls away in vast precipices, and far below we can trace the winding course of the river, so deeply sunken that it appears like a silvery brook. When the mountains are cloud-capped and bands of shining vapor roll eastward over the plateau, sending down refreshing showers and relieving the monotony of the plain by dashes of sunshine and dark gliding shadows, the scene becomes wonderfully beautiful and presents such marked contrasts that the eye does not soon weary of the picture.

The canyon of the Columbia at Chelan crossing, with its interesting terraces, has already been noticed in the account of our approach to Lake Chelan. After returning from our excursion up the lake, we renewed our journey on the plateau and followed the general course of the Columbia to the north of the Grand coulee.

*Chelan crossing to Grand Coulee.*—On traveling northeast from the border of the plateau overlooking Lake Chelan, for about 10 miles, we gradually left behind us the farms that cluster about Waterville and crossed a still more prairie region in which the carpet of bunch grass was unbroken. Just when our ride was becoming monotonous, our attention was attracted by a new feature in the topography of the prairie. In front of us rose an irregular undulating ridge, which started at the brink of the canyon on our left and ran for many miles to the southeast, until lost to view in the distance. On the ridge and rendering it conspicuous from a distance of several miles were hundreds of bowlders, some of them larger than the cabins of the settlers to be seen here and there among them. Actual measurements show that many of the blocks are between 50 and 60 feet in their various diameters. Beyond the first line of bowlders resting on the ridge others could be seen, and on gaining the top of the ridge, we found that the country to the east as far as the eye could reach was strewn with them. Sometimes the bowlders are piled in heaps, but usually they are separated by a few rods of grassy meadow. The greater part of the bowlders and all of the larger ones are black basalt, which in many cases shows a well defined columnar structure. A strange appearance is given to the scene by the various directions in which the joints dividing the volcanic blocks are inclined. With the angular masses of basalt there are also occasional bowlders of granite, gneiss, etc., of smaller size, but frequently measuring 8 or 10 feet in diameter.

The reason for the change in the character of the surface of the plateau was easily detected. The evidence of ice action was not only recorded by the bowlders, but in the surfaces of outcropping layers of basalt which were planed down and scored by lines running southeast, conforming with the trend of the long lines of bowlders and showing the direction in which the ice invasion moved.

The great glacier which carried bowlders in thousands over the northern border of Douglas county came from the north down the broad valley now drained by Okanogan river, and crossed the canyon of the Columbia without being deflected from its general course. The passage of the Columbian canyon is remarkable, as the great glacier on reaching its southern wall formed by basalt resting on granite met an escarpment running directly across its course and 2,500 feet high.

The granite on the face of this bluff is much disintegrated, but in places from top to bottom the scoring of the ice can be recognized. Where the earth has been recently removed the surface of the rock is highly polished and covered by fine striæ.

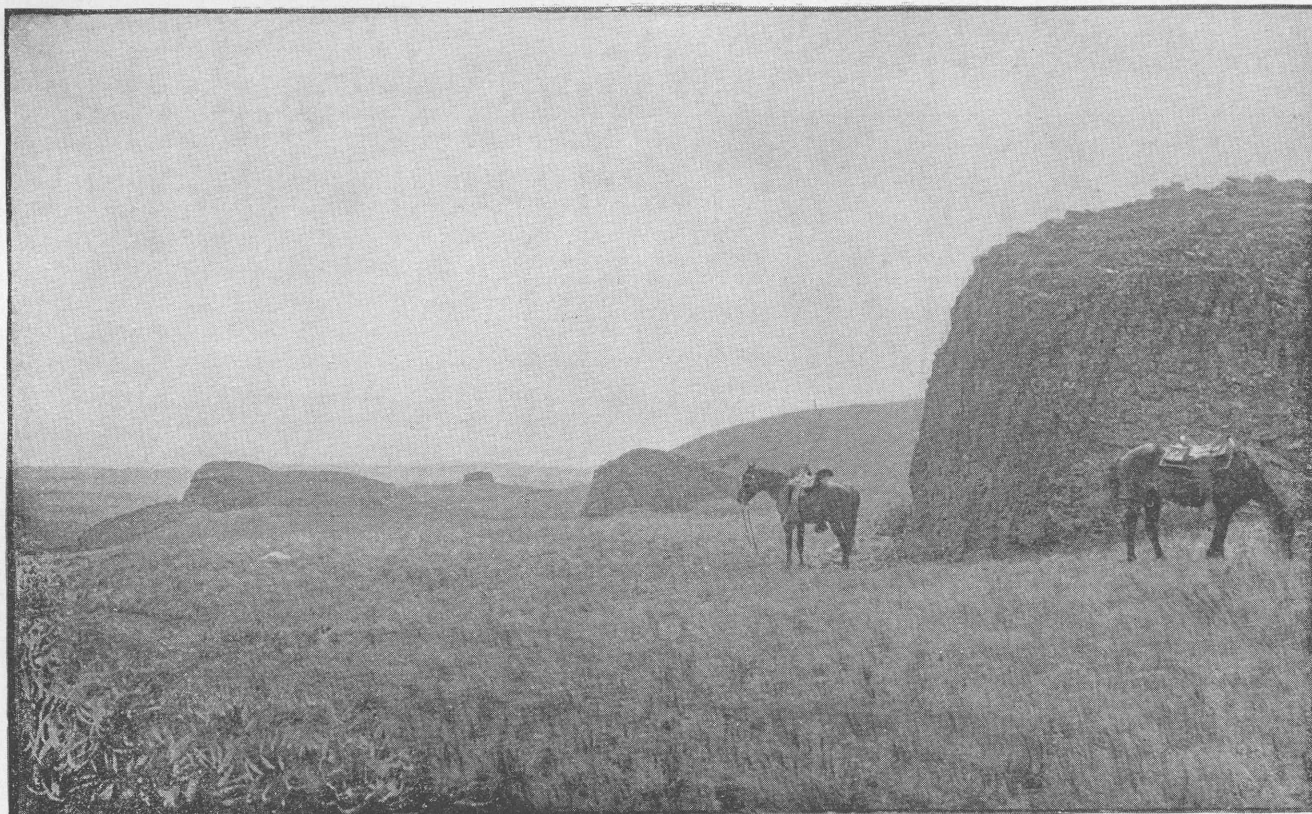
The glacier from Okanogan valley on reaching the Columbia divided; one arm flowed down the river valley to join other glaciers from Methow and Chelan valleys, but the course of this branch has not been traced. The greater part of the glacier continued on southeastward, however, and reached to about the present site of Coulee city, where it ended in Lake Lewis. The eastern border of the glacier after reaching the basaltic plateau of Douglas county was determined by the Grand Coulee, which was cut before the ice invasion. The huge bowlders and piles of debris left by the glacier may be traced to the western verge of the Grand Coulee, all the way from Coulee city northward to where the great gorge in the plateau joins the canyon of the Columbia. Bowlders and all other evidences of an ice invasion are absent to the east of Grand Coulee. The country there assumes the characteristics of the region about Waterville and wheat fields and farmhouses give diversity to the landscape. The subsoil is once more of fine, sandy clay, belonging to the John Day system. Our reconnoissance only touched the southern limit of the formerly glaciated region of northwestern Washington and anything like a discussion of the condition of that region during the glacial period will have to be postponed. After leaving Chelan crossing our next camp was in the valley of West Foster creek. Here again we found an example of the way in which the basaltic plateau inclosed by the Big bend of the Columbia was cut by deep lines of erosion at some former period when the rainfall was more copious than now. Foster creek has three main branches, or, more accurately, the canyon through which it flows when the spring and winter rainfall gather force enough to make a stream, has three deep, wide branches, which receive secondary gorges. The branching of the canyons and their wide bottoms show that the streams which cut them were sustained long enough to form a well developed drainage system with several branches. The branches converge toward the main channel, which leads northward and joins the Columbia by a steep descent of 300 or 400 feet. Foster creek with its various branches is plainly a part of the Columbia drainage, and has been produced by the same general conditions that admitted of the excavation of the greater drainage channel to which it is tributary.

The cutting of Foster creek canyon was assisted by the fact that the basaltic covering of the granite is there thin and of irregular thickness owing to the inequalities in the surface on which it rests. The thickness of the basalt varies from a few feet up to 400 or 500 and in places along the Columbia to the east of Foster creek it is not less than a thousand feet. The surface of the basalt is practically a plain, and its unequal thickness, as well as the decay and disintegration of the granite beneath, shows that the basalt was poured out over an old land surface which had been deeply eroded. This conclusion is also sustained by islands of granite in the neighborhood of the Grand coulee which rise through the basalt. These isolated areas are within a few miles of the border of the basaltic flood. Farther south its thickness is so great that all traces of the relief of the surface over which it flowed have been blotted out and a new topography initiated.

The bowlders so conspicuous on the plateau in which the canyon of Foster creek and its branches have been cut, do not appear in the bottom of the channels except where they have been laid bare by erosion. The floors of the canyons and the lower slopes of their walls are deeply buried beneath fine white silt and clay. These beds are the records of a time when a lake occupied the canyon subsequent to the ice invasion. The highest limit of these deposits is about 125 feet above the bottoms of the gorges, or 450 feet above the Columbia. This is about the level, judging from aneroid measurements, of the surface of the great terrace in the canyon of the Columbia near Lake Chelan and of the highest water lines left by Lake Lewis on the slopes of Badger and Saddle mountains.

After Foster creek canyon was left dry by the recession of the lake which once occupied it the fine sediments left in its bottom were reexcavated, leaving well-formed terraces along some portions of the channel, more especially in the East fork, a view of which is given in Pl. XI.

From our camp on Foster creek Mr. Storrow and I rode northwest along the summit of the cliffs overlooking the Columbia and finally reached a grove of pines crowning the highest point on the brink of the canyon opposite the mouth of Okanogan river. The view from this point is especially instructive, as it embraces not only the bowlder-strewn plains to the south, but also the deep gorge of the Columbia and the mountains beyond, from which the ancient glaciers came. From an advanced station on the verge of the cliffs we could examine the south wall of the canyon and see the



BOWLDERS OF BASALT ON GREAT PLAIN OF THE COLUMBIA.

junction between the sheet of lava forming its summit and the coarse reddish granite beneath. An absence of debris on the steep escarpment was especially noticeable, and has its explanation in common with the origin of the large number of bowlders of basalt on the plain extending south from the top of the escarpment. The great glacier that descended Okanogan valley was of sufficient thickness to ride over the cliff 2,400 feet high which crossed its path and to carry away huge masses of its hard capping layer and leave them scattered over the plain beyond for a distance of 50 miles.

At the junction of Columbia and Okanogan rivers there is a triangular valley or expansion of the canyon of the Columbia, which was deeply filled with light-colored clays and gravel deposited by the waters which succeeded the occupation of the valley by ice. Since the lake was drained these deposits have been beautifully terraced by the rivers as they reexcavated their channels. The sagebrush covered plains at the junction of the two streams is so situated that it can be irrigated without great expense and is one of the most promising tracts of land for agricultural purposes in the region.

To the east of the valley of the Okanogan and occupying a portion of a much wider valley of older data there is a basaltic plateau which extends at least 15 or 20 miles north of Douglas county and is a part of the series of volcanic rocks which covers the Big Bend county, but it is now detached owing to the cutting of a channel across it by the Columbia. The surface of this northern arm of basalt, like the much greater plane to the south, is strewn with immense bowlders, some of which attract the attention from a distance of 10 miles.

How far north the basaltic sheet in Okanogan valley may extend is not positively known, but on a sketch map published by Willis,[1] the country about Mount Bonaparte, 50 miles to the north, is indicated as being of the same geological character as the rocks of Douglas county.

The mountains on each side of Okanogan valley are subdued and rounded in contour, suggesting glacial action, or long disintegration and decay. The report of Willis, and my own observations of the character of the debris and of the nearer portion of the uplifts themselves, indicate that these mountains are composed of granite.

From Foster creek our line of march leads almost due east to the mouth of the Grand Coulee, a distance of about 35 miles. The plateau surface throughout this portion of Douglas county is strewn with bowlders and on the outcropping edge of basaltic sheets the familiar striations left by moving ice were seen in several places. Bowlders are scattered broadcast over the plain, but without much regularity or order; there are, however, no conspicuous moraines and only a slight accumulation of what might be called ground moraine. The hollows in the rocks are filled mostly with angular granitic sands. In places there are inclosed basins of all sizes up to several acres in extent,

[1] U. S. Geol. Survey, Bull. 40.

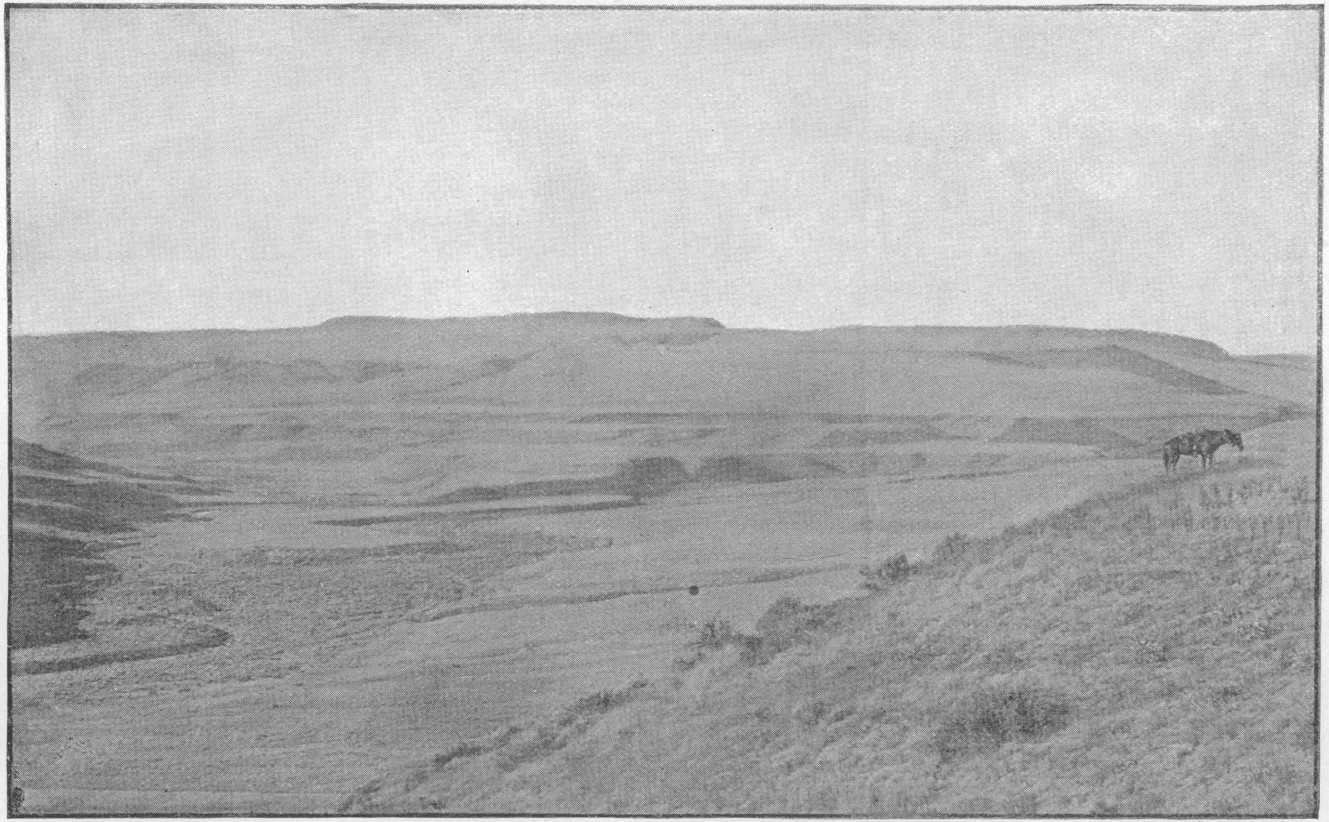
some of which hold water, while others have been filled so as to form swampy meadows. Springs are frequent along the bases of basaltic outcrops, indicating that the surface waters percolate downward until they meet the junction of two sheets of lava, perhaps with a thin layer of lapilli between, and then travel laterally until a canyon or broken scarp is reached, where they rise to the surface. These springs are supplied by the rainfall of the immediate region, and are of the nature of hillside springs so common the world over, and do not indicate an artesian basin, as many sanguine persons have been led to suppose.

Turning south at the locality where the east boundary of Douglas county reaches the Columbia, we traversed Grand Coulee to Coulee city and thence south to Moses lake and the White bluffs on the Columbia.

*Grand Coulee.*—As remarked by Symons[1], the Grand Coulee is one of the most notable features of the Great Plain of the Columbia. It is a canyon with vertical walls 300 or 400 feet high, between which there is a flat-bottom valley occupied in places by lakes, some of which are strongly alkaline. Its length from the Columbia at the north to Coulee city is about 30 miles; its eastern wall then disappears and the level floor of the canyon merges with the plain which extends eastward; the western wall is continuous for 20 miles farther, and over, looks a narrower but still wilder and more desolate valley, which is bounded on the east by another vertical wall that begins just south of Coulee city. The top of the east wall of the canyon south of Coulee city is on a level with the bottom of the gorge to the north. The descent from one gorge to the other is made in one vertical descent over which a river formerly rolled, as will be explained in advance. In the lower canyon there are several lakes; those at the north are fresh and sometimes overflow, while those at the south are inclosed and strongly alkaline. At the south end of the lower canyon the east wall again disappears, and the gorge opens out on a plain, but the line of ancient drainage is again continued farther south by another narrow gorge, occupied in part by Moses lake.

In the part of Grand Coulee, north of Coulee city, the width is about a mile and a half at the south and probably about 4 miles near the northern end. The abrupt expansion at the north is due to the fact that the basalt is there thin, and in places is wanting altogether, the granite rock beneath rising through it like islands. Some of the isolated rocks standing in its northern portion are of granite; others are of granite with a capping of basalt, while still others are composed entirely of basalt. Below Coulee city the canyon is less than a mile broad and its walls are entirely of basalt. Something of the wild scenery of the canyon walls may be gathered from the illustration forming Plate XII, which is reproduced from a photograph taken north

[1] Report on the Upper Columbia river, p. 119.



STREAM TERRACES, FOSTER CREEK, DOUGLAS COUNTY, WASHINGTON.

of Coulee city. The rocky face of the precipice shown in this illustration has been retouched and given a more massive appearance than it has in nature.

The history of the Grand Coulee and of its southern prolongation is the same as is recorded in Crab creek bottom, Wake Cumtux, and Moses coulees, and Foster creek canyons, which have already been noticed.

On looking north from Coulee city it is noticeable that the strata on the east side of Grand Coulee have a slight inclination eastward, while the strata on the west side are horizontal. Again, in the canyon south of Coulee city, the strata in the west wall, which is much higher than the eastern dip west, i. e., away from the canyon, at an angle of 8° or 10°, while the strata in the east wall are practically horizontal. The west wall retains its superior height all the way to Soap lake, which is at the south end of the middle section of the coulee. The presence of a fault in this portion of the coulee is also plainly shown by the relation of the strata on its opposite sides. About Moses lake no evidence of a break was distinguished, and the strata on each side are about horizontal.

The coulees are due primarily to breaks in the basalt forming the plateau, along which the rocks were generally faulted. The breaks gave direction to the drainage when the climate was much more humid than at present, and canyons were eroded. The partial filling of the canyons at a subsequent period, when many of them were occupied by arms of a large Pleistocene lake, accounts for their level floors, in which modern drainage has failed to make any but the most insignificant records. The deposits which obstruct the drainage below Soap lake appear to have been laid down in the Pleistocene lake, but in this connection my observations are meager. Recent changes of level along the old fault lines are suspected in certain instances, but have not been clearly demonstrated.

One of the most interesting episodes in the history of Grand Coulee remains to be noticed. Its bottom at the north, where it opens out into the much larger canyon of the Columbia, is 500 feet above the present river, and the descent from one to the other is a precipice. There was once a cascade here, which was cut back or receded about half a mile, when the water of the Grand Coulee flowed to the Columbia. When the ice from the Okanogan country discharged south it crossed the Columbia and dammed its waters, which then escapes southward by way of Grand Coulee.[1] This deep, broad canyon, as previously stated, limited the extension of the ice to the east, after it deployed upon the Big Bend country; its debris occurs up to the very brink of the canyon on the west, but is absent on the east. At this time the glacier must have poured over the western wall and, breaking off, charged the river with bergs. These were swept along and spread out over the plain to the south, where the gorge opened out at the present site of Coulee city,

[1] A temporary occupation of Grand Coulee by the water of the Columbia was recognized by Symons. Report on the Upper Columbia river, p. 109.

and there dropped in immense quantities and still obstructs the plain. During a part of the time at least, when the Columbia flowed through Grand Coulee, it emptied into Lake Lewis, at the present site of Coulee city, but a careful study of levels is required before the details in the history of the river and of the lake can be satisfactorily made out.

The canyon below Coulee city is about 400 feet lower than the bottom of the great gorge leading north to the Columbia. For a portion of the time that the great river flowed through the coulees it plunged into the lower canyon over a precipice approximately 400 feet high and wore out deep basins in the rocks below. The basins at the foot of the precipice are now filled with water by the rains of winter, and form the first of a series of lakes which do not ordinarily overflow. The lakes in this series farther south are alkaline, the last one, Soap lake, being heavily charged with soda salts.

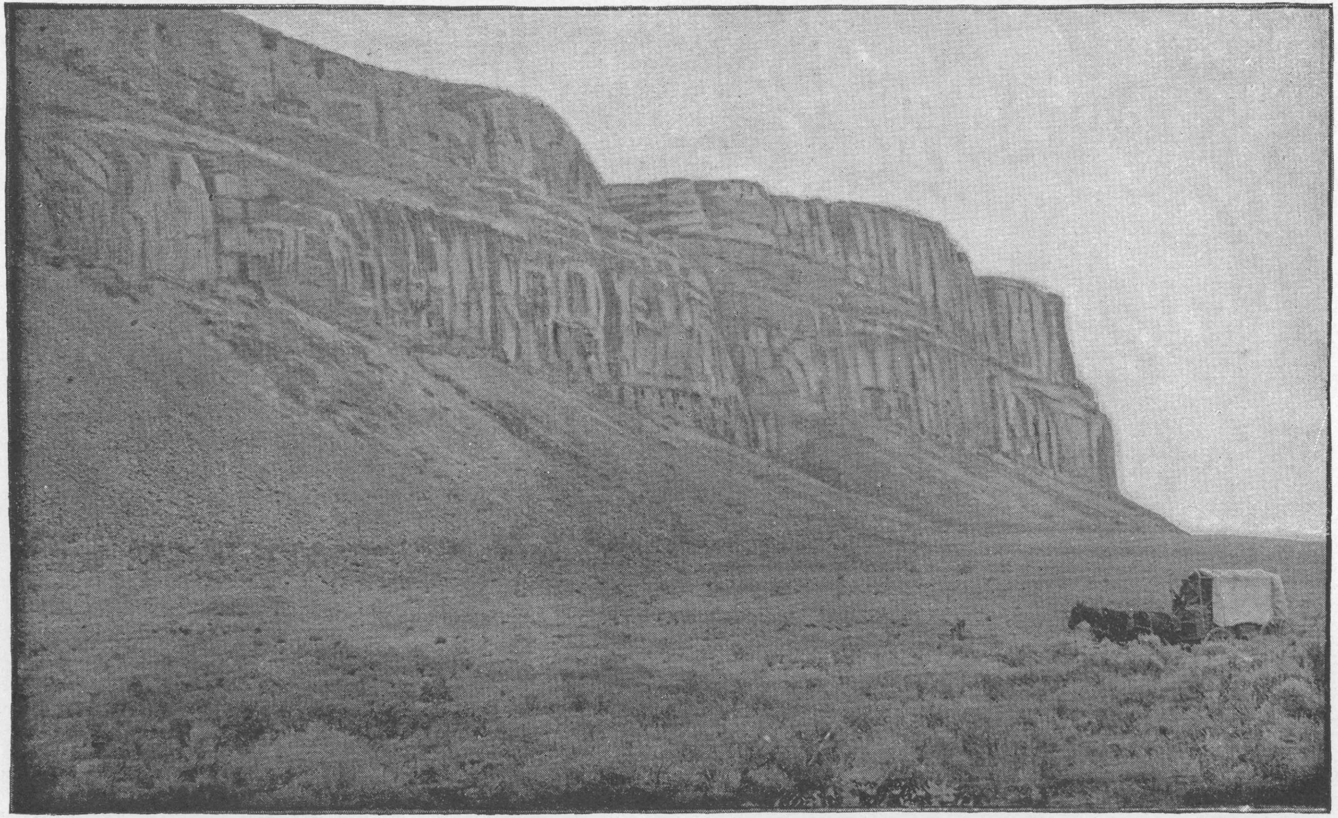
No more impressive scene can be found in the Big Bend country than is presented by the great cliffs of black basalt below Coulee city, over which the Columbia once poured, but where now all is hushed and desert shrubs grow in the ancient channel.

Moses coulee, like the gorge below Coulee city, begins abruptly and has small lakes at its head. The beginning of this deep depression in the basaltic plateau was not visited during the present reconnoissance; all the information we have concerning it is derived from Symons's report and from conversations with ranchmen. The fact that it begins at about the southern limit reached by the ice invasion from the north, suggests that it may at one time have been flooded by water from the melting ice.

The existence of the coulees along lines of fracture and of faulting was recognized by Symons, who extended the hypothesis to the canyon of Snake river and other streams crossing the region occupied by Columbia lava. Whether this extension is sustained by observation or not I have failed to learn, but I venture to suggest that the facts reported by others do not seem to favor it.

*Lakes.*—Several of the small lakes in the coulees described above are of fresh water, and in some instances occasionally overflow; others are alkaline, and in at least one instance strongly charged with saline matter. The water of a small lake in the bottom of the coulee, about 4 miles north of Coulee city, is too alkaline to be drank, but is not sufficiently dense to be of economic importance. The lake is shallow and belongs to the class of desert lakes termed "playa lakes," for the reason that they sometimes evaporate to dryness and leave broad mud flats or playas.

The lakes in the canyon just south of Coulee city overflow at times into other lakes farther south. This is in reality the beginning of a series of evaporating pans which ends in Soap lake. A sample of the water of this lake was collected by Mr. Storrow and myself and has been analyzed at the chemical laboratory of the U. S. Geological Survey.



WEST WALL OF GRAND COULEE.

*Analysis of the water of Soap lake, Washington, by George Steiger.*

| Constituents. | Parts in a thousand. | Per cent in total solids. | Hypothetical composition. Constituents. | Parts in a thousand. | Per cent in total solids. |
|---|---|---|---|---|---|
| Silica, $SiO_2$ | 0·113 | 0·40 | Sodium chloride, NaCl | 5·810 | 20·61 |
| Sulphuric acid, $SO_4$ | 4·362 | 15·47 | Sodium sulphate, $SO_4$ | 6·453 | 22·88 |
| Carbonic acid, $CO_3$ | 9·625 | 34·13 | Sodium carbonate, $NaCO_3$ | 11·340 | 40·22 |
| Chloriné, Cl | 3·526 | 12·50 | Sodium bicarbonate, $NaHCO_3$ | 4·412 | 15·65 |
| Calcium, Ca | Trace. | Trace. | Magnesium bicarbonate, Mg $H_2(CO_3)_2$. | 0·066 | 0·23 |
| Magnesium, Mg | 0·011 | 0·04 | Calcium bicarbonate, $CaH_2(CO_3)_2$. | Trace. | Trace. |
| Sodium, Na | 10·504 | 37·25 | Silica, $SiO_2$ | 0·113 | 0·40 |
| Hydrogen in bicarbonates, H. | 0·053 | 0·19 | | | |
| | 28·194 | 99·98 | | 28·194 | 99·99 |

NOTE.—Mr. Steiger also noted that the reaction of the water was strongly alkaline; and that it contained a sediment amounting to about four parts in a million, which was composed of calcium, a small amount of sulphur, and organic matter. The water also contained a large amount of organic matter in solution.

A comparison of the above analysis with analyses of other lakes in the arid region, some of the most important of which are given in the following table, shows that although the proportions of sodium carbonate and bicarbonate in the water are not as high as in other instances, amounting only to 15.7 per cent, yet in the weight of total solids they are greater than in any other similar instance at present known, amounting, as shown in the last column in the above table, to nearly 56 per cent.

*Analyses of the waters of alkaline lakes in the arid region.* [1]

[Expressed in parts in a 1,000.]

| Constituents. | Albert lake, Oregon.[2] | Great Salt lake,[3] Utah. | Humboldt lake, Nevada. | Soda lake, Nevada. | Mono lake,[2] California. | Owens lake, California.[3] |
|---|---|---|---|---|---|---|
| Sodium, Na | 14·245 | 49·690 | ·27842 | 40·919 | 18·837 | 26·836 |
| Potassium, K | ·521 | 2·407 | ·06083 | 2·357 | ·920 | 1·548 |
| Calcium, Ca | | ·255 | ·01257 | | ·109 | ·013 |
| Magnesium, Mg | | 3·780 | ·01648 | ·245 | ·054 | ·004 |
| Lithium, Li | | Trace. | Trace. | | | |
| Chlorine, Cl | 13·055 | 83·946 | ·29545 | 40·851 | 11·582 | 18·214 |
| Bromine, Br | | Trace. | | | | |
| Carbonic acid, $CO_3$ | 9·199 | | ·20126 | 16·858 | 13·100 | 18·265 |
| Sulphuric acid, $SO_4$ | ·685 | 9·858 | ·03040 | 11·857 | 6·384 | 7·067 |
| Phosphoric acid, $HPO_4$ | | | ·00069 | | | |
| Nitric acid, $NO_3$ | | | | | | |
| Boracic acid, $B_4O_7$ | | Trace. | Trace. | ·286 | ·153 | ·346 |
| Silica, $SiO_2$ | ·224 | | ·03250 | ·278 | ·067 | ·207 |
| Alumina, $Al_2O_3$ | | | | | } ·003 | ·023 |
| Iron, sesquioxide, $Fe_2O_3$ | | | | | | ·013 |
| Organic matter | | | | | | |
| Hydrogen, in bicarbonates | ·056 | | | | ·049 | ·059 |
| | 37·985 | 149·936 | ·92860 | 113·647 | 51·168 | 72·595 |

[1] Compiled principally from Table C. in U. S. Geol. Surv., Monograph No. XI.
[2] Analyses by T. M. Chatard, Am. Jour. Sci., ser. 3, vol. 37, 1888, pp. 146–150.
[3] In 1869.

*Analyses of the waters of alkaline lakes in the arid region*—Continued.

| Constituents. | Pyramid lake, Nevada. | Sevier lake, Utah. | Soap lake, Washington. | Walker lake, Nevada. | Winnemucca lake, Nevada. |
|---|---|---|---|---|---|
| Sodium, Na | 1.1796 | 28.840 | 10.504 | .85535 | 1.2970 |
| Potassium, K | .0733 | ............ | ............ | Trace. | .0686 |
| Calcium, Ca | .0089 | .118 | Trace. | .02215 | .0196 |
| Magnesium, Mg | .0797 | 2.600 | .011 | .03830 | .0173 |
| Lithium, Li | ............ | ............ | ............ | ............ | ............ |
| Chlorine, Cl | 1.4300 | 45.500 | 3.526 | .58375 | 1.6934 |
| Bromine, Br | ............ | ............ | ............ | ............ | ............ |
| Carbonic acid, $CO_3$ | .4990 | ............ | 9.625 | .47445 | .3458 |
| Sulphuric acid, $SO_4$ | .1822 | 9.345 | 4.362 | .52000 | .1333 |
| Phosphoric acid, $HPO_4$ | ............ | ............ | ............ | ............ | ............ |
| Nitric acid, $NO_3$ | ............ | ............ | ............ | ............ | ............ |
| Boracic acid, $B_4O_7$ | ............ | ............ | ............ | ............ | ............ |
| Silica, $SiO_2$ | .0334 | ............ | .113 | .00750 | .0275 |
| Alumina, $Al_2O_3$ | ............ | ............ | ............ | ............ | ............ |
| Organic matter | ............ | ............ | Much. | ............ | ............ |
| Hydrogen, in bicarbonates | ............ | ............ | .053 | ............ | ............ |
| | 3.4861 | 86.403 | 28.194 | 2.50150 | 3.6025 |

The analysis shows that the water of Soap lake is a valuable brine that may be utilized in the manufacture of sodium carbonate and sodium sulphate. The first step to be taken in attempting to separate these salts is to experiment on large quantities of the brine for the purpose of ascertaining the best way of manipulating it. This can be done successfully only by an experienced chemist. Natural soda has been obtained on a large scale and for a number of years from the waters of the Ragtown ponds (Soda lakes), Nevada, and Owens lake, California. The methods there employed have been minutely described by T. M. Chatard,[1] and should be studied by any one intending to utilize the water of Soap lake.

NOTE.—The small percentage of calcium carbonate in solution in Soap lake is of interest for the reason that tufa is now being deposited from its waters through the agency of plant life. Near the south shore of the lake, where the water is about 2 feet deep, there are many branching and exceedingly irregular coral-like forms rising from the bottom to a maximum height of 14 or 16 inches. They are formed of cellular calcium carbonate, and are covered, even to the tips of the many spire-like branches, by a thin layer of living bright green and brown algous growth. The interior of these masses is composed of thin white laminæ of calcium carbonate, among which there has been a secondary deposition of the same material, thus cementing the blades together or covering the walls of the cells with small excrescences. No organic structure could be detected in the tufa when examined under the microscope.

It has been pointed out by Weed in an exceedingly instructive paper on the hot spring deposit of the Yellowstone park (Ninth Ann. Rep. U. S. Geol. Survey, 1887–'88) that both calcareous and siliceous deposits are there being made from heated water by fresh water algæ. This process is thought to be due to the vital action of the plants, which abstract carbonic acid from the waters and thus lead to the

[1] Natural soda, its occurrence and utilization. In Bulletin No. 60, U. S. Geological Survey; Washington, 1887–1888.

precipitation of the calcium carbonate which was previously in solution as the bicarbonate.

The coral-like masses, with a green and brown epidermis of living algæ, rising thickly over portions of the bottom of Soap lake, are good evidence that calcium carbonate is there being abstracted from the water through the agency of plants, in a manner similar at least to the processes by which siliceous and calcareous scinters are being deposited from the waters of hot springs.

The origin of the oolitic sand now forming in Great Salt lake have recently been referred to the action of algæ by Rothpletz. (Am. Geol. vol. 10, p. 279.)

The agency of algæ in separating calcium carbonate from dilute solutions is a matter of great geological significance, especially to those interested in the ancient lakes of the Great Basin. In Lake Lahontan, particularly, immense deposits of calcium carbonate, or tufa, of various kinds were deposited. The manner in which these accumulations were formed is not fully understood, and there now seems to be doubt if the usually accepted explanation of the more common, and it was thought, least puzzling of the deposits is really the true one. In former reports [Quaternary History of Mono Valley, U. S. Geol. Survey., Ann. Rep., pp. 188-222, and Monograph No. XI, U. S. Geological Survey], I suggested that the tufa was deposited in some instances about sub-lacustral springs which rose in dense waters, and in consequence of chemical reactions parted with their calcium carbonate on coming in contact with the waters in which they rose. This process seemed to be in action in Mono lake, where large sub-lacustral domes of tufa still have spring water pouring out of their summits. In referring to my notes I find that these domes are coated with green and brown algous growths, very similar, as I remember them, to the living surfaces of the tufa now being formed in Soap lake. At the time I visited Mono lake I was not acquainted with the fact that algæ play an important part in precipitating calcium carbonates, and concluded that the tufa domes were simply a support for the vegetable growths covering these surfaces, in the same way that rocks in the sea afford anchorage for marine algæ.

It now seems possible, however, that the mingling of the fresh water from the springs with the denser solution in the lake, instead of resulting directly in the chemical precipitation of tufa, supplies the conditions necessary for the growth of algæ which are able to separate calcium carbonate from dilute solution of that salt. The springs bring food to the plants in the same way that currents in the ocean favor the growth of corals and other marine invertebrates.

The deposition of calcium carbonate in Soap lake, unlike the similar occurrence in hot springs, takes place at normal temperatures. How dependent the plants are on the chemical composition of the water remains to be determined; it may be that algæ of various kinds flourish in water of different chemical character, and hence the variation in the structure of the tufa deposited. The study of the calcareous and siliceous deposits of the hot springs of the Yellowstone park has thrown a new light on the question of tufa deposits generally, and suggests many inquiries that it will be interesting to make in the lakes of the arid region. Even the formation of "thinolite," another of the calcareous deposits found in the basin of Lake Lahontan and in Mono valley, which chemists have labored in vain to explain, may perhaps be profitably reviewed in connection with the part that algæ play in the origin of related accumulations.

The rugged cliffs overlooking Soap lake on the west, in which the strata dip westward, mark a line of faulting. On the east side of the break the wall is lower and the general inclination, although slight, is eastward. The lake occupies a fault basin, and in this and in other respects has many counterparts in the arid region extending south from central Washington, among which Abert and Summer lakes, Oregon; the lakes in Surprise valley, California, and Walker and Pyramid lakes, Nevada, are the most nearly analogous and the best known.

Moses lake, a few miles south of Soap lake and situated in the most southern of the series of canyons which connect with Grand Coulee, is supplied mainly by springs and is itself sufficiently fresh to be drinkable. The walls of the canyon in which the lake lies are of stratified Columbia lava and seldom rise more than a hundred feet above the lake. No indications of faulting were there observed. At the south end of the lake the canyon is filled with sand dunes which retain the water, but allow sufficient to percolate through to form large springs. The water from these springs finds its way to Crab creek bottom and after sinking and rising again several times finally disappears from the surface. The water of the creek, except near where it finally disappears, is fresh and wholesome.

*Saddle mountain.*—On leaving Crab creek bottom we crossed Saddle mountain, and reached the Columbia at the northern end of the long series of river cliffs known as White bluffs. Saddle mountain, as previously mentioned, belongs to the series of monoclinal uplifts due to faulting, which extend eastward from the foothills of the Cascades. This long, narrow, sharp-crested ridge is perhaps the most remarkable of these uplifts, as it extends farther east than any of its companions and clearly reveals its structure where the Columbia has cut through it.

The terminus of Saddle mountain at the west has not been traced, but it is thought to be a monoclinal ridge starting in Kittitas valley about 10 miles east of Ellensburg. If this identification of the west end of the ridge is correct its length to where it dies out and passes beneath the undisturbed surface of the desert, east of the Columbia, is about 50 miles. Its height at Sentinel bluffs, where the Columbia cuts through it, is about 1,600 feet above the river. It is there a well-defined monoclinal ridge, dipping sharply southward and presenting a bold scarp to the north. The dip of the strata of basalt of which it is composed corresponds with the gently sloping southern side. The line of fracture is on the north side of the ridge, and the steep northern face is a fault scarp. Toward the eastern end the fault scarp decreases in height and finally dies out, and the John Day beds pass over and conceal the Columbia lava. The dip of the strata on each side of the ridge toward its eastern end becomes about the same, showing that the fault passes into a fold.

The presence of John Day beds interstratified with the upper sheets of Columbia lava has been mentioned. These show conclusively that the ridge was upraised subsequently to the deposition of the John Day beds. In all of the features mentioned in connection with Saddle mountain we find strict parallels in other similar uplifts in Yakima and Kittitas counties, thus strengthening our interpretation of the general history of central Washington.

That the climate of Douglas county must have been arid since Saddle mountain was upraised may be inferred from the absence of drainage lines on its southern slope, where easily eroded lake beds form the surface. Another interesting conclusion to which the history of the mountain points is that Columbia river had its course established before the mountain was upraised, and has maintained its right of way by cutting a gateway 1,600 feet deep directly across the uplift. The relation of the Columbia to Saddle mountain is the same as that of Yakima river to several similar uplifts. The evidence that the main drainage lines of central Washington were established before the present relief was initiated, is cumulative and abundant. The rivers began to flow when Lake John Day was drained, and had their courses determined by the slope of the surface of the bottom of the old lake. Since then mountain ranges have been formed by faulting, but the larger streams, i. e., the Columbia and Yakima, were able to cut down their channels as rapidly as the ridges were upraised athwart their channels. It may be that the draining of Lake John Day was due to the beginning of the orographic disturbances which afterward deformed its basin. Volcanoes were active during the existence of the lake as is shown by the abundance of volcanic dust and lapilli in its sediments. From field observations as well as from a microscopical examination of the sediments it seems safe to assert that more than half of the John Day system is composed of volcanic dust. This material is highly siliceous and differs widely from the basic lava beneath.

The country sloping south from Saddle mountain to the Columbia is a desolate, sagebrush-covered region, occupied in part by drifting sand, and has been but lightly sculptured by rain or streams. There is one deep canyon-like valley in the lake beds, however, which starts near the east end of Saddle mountain and leads to the Columbia. This is clearly an ancient drainage channel, but its individual history has not been traced.

*White bluffs on the Columbia.*—The conspicuous white bluffs along the left bank of the Columbia, beginning 12 miles above Pasco and extending 30 miles up the river, are formed by the edges of soft strata of fine, thin-bedded sand and clay with layers of pure white volcanic dust, which were deposited as horizontal sheets in Lake John Day and have not since been disturbed. This is the most typical section of John Day beds to be seen in Washington. The cliffs have a maximum height of about 600 feet, but are in general about 500 feet high. The river is still cutting away their bases at several points, and its general tendency is still to work eastward, leaving a low, sand-covered plain on its right shore. As suggested while describing Rattlesnake mountain, this remarkable eastward shifting of the Columbia may perhaps be due to a movement of the rocks to the east of Rattlesnake fault.

The character of the loose unconsolidated material forming these bluffs is shown by the following section observed near this southern end:

| | Feet. |
|---|---|
| Light yellowish sand, loose and incoherent | 20 |
| Hard cemented layer, light yellow, "alkali" | 6–10 |
| Thin-bedded, yellowish, sandy clay, with thin yellow lines, weathering into monumental forms, passing into | 100 |
| Fine clay with volcanic dust | 10 |
| White volcanic dust[1] | 20 |
| Loose, fine yellow sand, changing to | 15 |
| Greenish clay, passing into | 20 |
| Yellowish sand, with concretions | 15 |
| Yellowish sand, compact at base, cross bedded | 50 |
| Fine, light, sandy clay | 50 |
| Pebbles, sometimes wanting | 1 |
| Light-colored, sandy clay, with large flat concretions | 35 |
| Yellow sand, passing into clay, sometimes concealed by terraces of water-worn stones, to river | 150 |

The dividing lines between the various beds above are not sharp, the strata are conformable throughout and pass one into another by insensible gradations. The strata were formed by continuous sedimentation far from shore, and are remarkable on account of the immense amounts of volcanic dust scattered through them.

On the face of the bluffs the fossil bones of large animals have been found, but these have not been studied and their significance is not known. Similar fossils from the exposures of the same system on John Day river have been studied by Leidy, Marsh, Cope, and Bettany, and found to present a strange array of mammals, all of which are now extinct. The White bluffs afford favorable ground for collecting fossil bones and would, I think, well repay careful search.

In all of our examinations of the Johnday system we never found a fossil shell which could be referred to them. This absence of molluscan remains is remarkable and probably points to some peculiar condition of the old lake. An examination of a few samples of the sediments of the lake also failed to show the presence of diatoms or other minute organisms. It is possible that the waters were warmed by the immense beds of lava beneath them and perhaps charged with gases from the same source. The immense quantities of volcanic dust that fell in the lake may also have rendered it unfavorable for animal life. These are

[1] The volcanic dust in this section and occurring also at many other localities is pumice which has been blown to powder by the expansion of steam which it contained at the time of its eruption. It is highly siliceous, practically insoluble, and could probably be used for many of the purposes for which diatomaceous earth (tripoli) is now employed. It will probably be found of service in polishing wood, stone, bone, and ivory, and metallic articles, and could be utilized in the manufacture of certain kinds of soap. Experiments should be made for the purpose of ascertaining whether it can be employed as an absorbent for nitroglycerine in the manufacture of high explosives.

only suggestions, however, as the absence of life gives nothing but negative evidence on which to base hypotheses. The shores of the lake were bordered by a varied and beautiful flora, among which many strange animals found congenial homes; their bones were sometimes swept into the lake, and, sinking to the bottom, became entombed in its sediments. Why the lake itself should have been so barren in life while its banks were luxuriantly clothed and abundantly inhabited, is one of the perplexing features of its history.[1]

Our field work ended at Pasco, adjacent to the region in Yakima county, which was traversed during the early portion of the season. Our work was closed because no more funds were available for continuing it, but covered sufficient territory to show that the state of Washington has a most interesting geological history.

*Absence of artesian basins.*—Much of the central and southern portion of Douglas county is arid and desert-like and crops are impossible without irrigation; the higher and more productive region about Waterville, where light crops of wheat are now grown, would also be greatly benefited, could water be supplied. The soil throughout the country is deep and rich, and, where not too alkaline, would yield abundantly if the one element lacking could be furnished. These conditions have led the people of Douglas county to hope that their lack of water might be supplied from artesian sources. My examination of the county does not favor this hope, however, and I have failed to find that the county contains any artesian basins.

The springs throughout the county are supplied by the local rainfall. No fissure springs deriving their supply from deep sources were ob-

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[1]A few species of fresh-water and land mollusks have been described from the John Day system in Oregon, by C. A. White (U. S. Geological Survey, Bulletin No. 18, Washington, 1885), and shown to be closely related if not identical with species still living. This is such a remarkable announcement that additional information is seemingly required before it can be considered as fully established.

In searching for fossils in the John Day system it should be remembered that the same basin has also been occupied by a Pleistocene lake, and that the sediments of the Tertiary and of the more recent lake might easily be confounded. The bones of fossil mammals in the Tertiary lake might, in some instances, have been washed out of the sediments in which they were originally entombed and redeposited, together with recent shells in the clays and sands of a younger water body. As an illustration of this, I may mention that at the southern end of the White bluffs, about 15 miles above Pasco, I found a number of specimens of large fossil bones derived, without question, from the John Day beds, in a recent river terrace which was banked against a cliff formed of the edges of horizontal strata of the John Day system. The strata in the terrace were horizontal, and to all appearance in most places extended beneath and formed the lower portion of the cliff against which they had been deposited. The deception in this case was so complete that at first there seemed no question but that the sand and gravel containing the bones were of the same age as the strata in the cliffs above, and it was only after several hours of search that I succeeded in convincing myself of their recent deposition.

Future discoveries of fossil shells in these rocks are to be hoped for and would be particularly interesting if they sustained the conclusion already advanced.

served during our reconnoissance, although they may occur along the various lines of fracture. Even if copious fissure springs should be found, it would not follow that they derive their supply from artesian basins, in accordance with a prevailing supposition. On the contrary, fissure springs are fortuitous in their occurrences and depend on the existence of breaks in the rocks which give direction to underground waters, but are so irregular that it is impossible to trace them. Fissure springs arising from an artesian basin would be unfavorable to the hope of obtaining flowing water from borings rather than favorable signs, for the reason that they would indicate a fracturing of the impervious layer above a water-bearing layer, and thus tend to destroy or counteract the very conditions on which the storage of water in porous strata is made possible.

## CONCLUSIONS IN REFERENCE TO ARTESIAN WATER SUPPLY IN THE REGION EXPLORED.

The reconnoissance described in the preceding pages has shown that the geological structure of the region traversed is in general unfavorable to the hope of obtaining artesian waters. The principles governing the flow of artesian wells and the characters of the rocks in the region visited, as well as the attitudes in which the strata occur, have been described in order that the reader might see for himself the reasons on which this adverse conclusion is based, and be enabled to review the question for his own satisfaction in the locality in which he is especially interested.

As has been shown, the arid country in central Washington is underlain by a thick sheet of basalt composed of many layers, above which there was formed a heavy deposit of clay, sand, and volcanic dust. These two widely spread formations were originally horizontal, but are now broken by many lines of fracture, some of which are scores of miles in length; the blocks between the breaks are tilted in various directions and their edges in many instances upturned into mountain ranges. It is evident from the general structure that any great artesian basin would have been broken and destroyed by the mountain building that has taken place. A broad artesian basin beneath the basalt and extending from the Cascade to the Rocky mountains is for these reasons not to be expected.

When the basalt and the deposit of lake sediment resting on it has been bent upwards so as to form basins, the conditions favoring the existence of underground water under pressure may exist. The possibly water-bearing strata in these local basins lie above the basalt, but may have thin sheets of basalt interstratified with them. The bending up of the strata so as to form local basins is of rare occurrence in the portion of the state which has been examined, and when it has taken place other conditions may still render it impossible that the basins should hold water under pressure. When the basins are perfect in general form they are sometimes broken by fractures, or channels have been cut across their rims by drainage which is inconsequent to the structure. When such a drainage channel occurs the stratified beds within the basin of basalt have sometimes been completly removed. Small basins in the more arid portion of the state, which have escaped these various accidents, would not receive water enough from the limited rainfall to be of commercial value.

With these various limiting conditions in mind, I feel that the reader who has the patience to read the preceding account of the geology of central Washington will agree with me that, with one or two exceptions, the conditions are there unfavorable to the hope that artesian water can be obtained. The exceptions are Moxee valley, where the existence of a small artesian water supply has already been demonstrated, and possibly the eastern part of the Yakima Indian reservation, where, as suggested in a previous page, the conditions are such as to justify further inquiry. In the remainder of the region examined I do not consider that further expense in drilling wells is warranted.

# APPENDIX.

## REPORT ON FOSSIL PLANTS FROM NEAR ELLENSBURG, WASHINGTON.

By F. H. KNOWLTON.

The leaves from near Ellensburg, Wash., are preserved in a moderately soft white chalky matrix, that is in general very similar to the well known material from the auriferous gravels of California, and the John Day valley in Oregon. The matrix is a little harder than that from other localities mentioned, but is very well fitted to preserve plant remains.

Notwithstanding the seeming abundance of the material, I find that more than half of it belongs to a single species, and the whole number of species that I have been able to determine is only ten. They are, however, well preserved, and are numerous enough to make the determinations reasonably certain. I give first a list of the species, followed by some biological annotations, and finally a brief discussion of the light they seem to throw on the question of age.

*List of species.*

Salix varians Göpp.
Populus glandulifera Heer.
Populus Russelli, sp. nov.
Alnus sp.?
Ulmus californica Lx.
Ulmus pseudo-fulva Lx.
Platanus dissecta Lx.
Platanus aceroides? (Göpp.) Heer.
Paliurus Colombi Heer.
Magnolia lanceolata Lx.

ANNOTATIONS.

*Salix varians* Göpp.—This species is represented by a great number of specimens, embracing, as stated above, more than half of the entire collection. This is undoubtedly the same as the specimen figured as this species by Prof. Lesquereux,[1] from Table mountain and Corral hollow, California, the only differences being that many of the leaves are larger and somewhat more rounded at the base. I doubt very much whether this is the real *S. varians* of Heer from the Swiss Miocene, although some of the smaller leaves closely approach some of those figured by Heer.[2] They seem rather to be intermediate between this species and some of the smaller leaves of *S. macrophylla* Heer (op. cit., p. 29, Pl. LXVII). As I said, I would not incline to regard it as identical with the European plant, but as it is the same as the leaves so named by Lesquereux from two localities in California, it is sufficient for the present purpose. It will probably be best to give it a new name when the subject is finally worked up.

[1] Cret. and Tert. Floras, p. 247, Pl. LV, Fig. 2.
[2] Fl. Tert. Helv., II, p. 26, Pl. LXV.

*Populus glandulifera* Heer.—There is only one specimen that I refer to this species, and it is not therefore entitled to great weight. This species was found by Lesquereux in the Van Horn's ranch material, in the John Day valley.

*Populus Russelli*, sp. nov.—There are several very finely preserved leaves of what seems to be a new species of *Populus*. The leaves are broadly deltoid, with an exceedingly long, slender acute apex. They are wedge-shaped at base and have the margins provided with regular, shallow teeth. The petiole is long and flattened as in several living species. This species has close relations in the European Miocene, but is perhaps most closely related to the living *P. balsamifera* var. *candicans*, the well-known balm of Gilead.

*Alnus* sp. ?—There are one or two leaves evidently belonging to this genus, but they are not well enough preserved to admit of positive determination. They may possibly belong to *A. Kefersteinii* Ung., a species detected by Lesquereux in specimens from Van Horn's ranch.

*Ulmus californica* Lx.—Based on a number of well preserved and satisfactorily determined specimens.

*Ulmus pseudo-fulva* Lx.—The specimens representing this species are not so numerous as those of *U. californica*, but they are fairly well preserved and the identification made certain.

*Platanus dissecta* Lx.—The collection contains a considerable number of well-preserved leaves of this species. They agree closely with those figured by Lesquereux from the auriferous gravels of California, and their identification may be regarded as positive.

*Platanus aceroides* (Göpp.) Heer.—One or two leaves are referred to this species with hesitation. They are very similar to leaves so named by Lesquereux from Van Horn's ranch, but the real status of this species, as well as the closely related if not identical *P. Guillelmæ* Göpp., has yet to be worked out.

*Paliurus Colombi* Heer.—There is a single leaf referred to this species, and only one was found by Lesquereux in the Van Horn's ranch material.

*Magnolia lanceolata* Lx.—This species is represented by a single leaf, but as it is a fairly good one, the identification may be regarded as certain. One specimen is also reported by Lesquereux from Van Horn's ranch.

Of the ten species enumerated, seven, among which are the species most abundant in specimens and the most positive in identification, have been found in the auriferous gravels of California. Seven of the species have also been reported from the John Day valley, Oregon, of which number three are common to the auriferous gravels. The new species (*Populus Russelli*) has great affinities with Upper Miocene species of Europe.

From this examination it appears that there can be no doubt but that the plants from Ellensburg are similar in age to the auriferous gravels and the John Day valley. The John Day valley deposit has always been called Miocene. The auriferous gravels, on the other hand, were regarded by Lesquereux and others as Pliocene, but a recent examination of that flora based on extensive collections from Independence hill, Placer county, California, seem to indicate that they also are probably upper Miocene in age.

The plants from the auriferous gravels are mainly endemic and have no known distribution in general outside of these beds. The only way of determining their value in settling the question of age, is by a careful comparison with similar floras in other parts of the world. This work has not yet been exhaustively done, but so far as general resemblance goes, as well as by what has recently been worked out regarding their stratigraphy, it is altogether probable that they are Upper Miocene in age.

# INDEX.

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