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A RECONNOISSANCE IN SOUTHEASTERN WASHINGTON.—RUSSELL

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

A RECONNOISSANCE IN SOUTHEASTERN WASHINGTON

BY

ISRAEL COOK RUSSELL

WASHINGTON

GOVERNMENT PRINTING OFFICE

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, February 17, 1897.

SIR: I have the honor to transmit herewith a paper entitled "A Reconnoissance in Southeastern Washington," by I. C. Russell, professor of geology at the University of Michigan, and to recommend that it be published in the series of pamphlets upon water supply and irrigation. During his long connection with this Survey Professor Russell obtained such familiarity with the western part of the United States that it seemed desirable to secure his services in the continuation of the examination of the water resources. He has already published in Bulletin No. 108 a description of the geologic structure in and adjacent to the drainage basin of Yakima River, Washington, and the great plains of the Columbia to the east of this area, giving especial attention to the occurrence of artesian waters. The field work of the last season was to a certain extent a continuation of this examination still farther to the east and south, covering areas in southeastern Washington, northeastern Oregon, and adjacent portions of Idaho. The region, though not arid, depends for its development upon more complete methods of utilizing the water supply, and this in turn rests upon a thorough knowledge of the underground structure. The latter, therefore, has been examined and described at some length, as preliminary to a discussion of the employment of the water resources.

Very respectfully,
F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

A RECONNOISSANCE IN SOUTHEASTERN WASHINGTON.

By Israel C. Russell

INTRODUCTION.

Acting under the instructions of Mr. F. H. Newell, hydrographer of the United States Geological Survey, I made an examination of the geology of the southeastern portion of the State of Washington in the summer of 1896 for the purpose of ascertaining how far the nature and position of the rocks of that region favor the hope of obtaining artesian water. The time devoted to field work extended from August 11 to September 21. The region traversed embraces about 5,000 square miles. It will be seen at once, from the time available and the extent of territory examined, that nothing more than a general, or, perhaps more accurately, a preliminary, reconnoissance was aimed at. The conditions, however, are unusually favorable for rapid geological exploration, the region being practically free from forests and the rocks nearly horizontal. For these reasons more confidence, I think, can be placed in the results obtained than at first thought might seem warrantable.

The region examined.—The country chosen for the commencement of my studies is that portion of southeastern Washington which lies south of Snake River. By referring to the accompanying map, it will be seen that a well-defined region, bordered on the south by Oregon, on the east by Idaho, on the north by Snake River, and on the west by the Columbia, may be briefiy designated as lying south of Snake River. It is frequently spoken of as the "Walla Walla country," for the reason that Walla Walla is the principal town, or perhaps because the whole of it was formerly included in Wallawalla County.[1] At present this region is divided into four counties, namely, in their order from west to east, Wallawalla, Columbia, Garfield, and Asotin.

[1] Wallawalla County was established in 1854, and originally embraced a much wider territory than is mentioned above, as it extended from the Cascade Mountains eastward to beyond the present eastern boundary of Washington.

The region bounded as described above embraces about 4,000 square miles. In order to learn its geological history, however, it was found desirable to make an excursion southward into Oregon as far as Wallowa, about 30 miles in a straight line south of the Washington-Oregon boundary, and another northward, traveling by rail, through the eastern border of the "Palouse country," as far as Spokane. The hasty reconnoissance northward included a visit to Pullman, Palouse, Garfield, and Spokane. Short excursions were made from each of these towns, and the more general features in the geology of their environs were ascertained. The excursions mentioned were of much assistance in understanding the geology of the region south of Snake River, which is the portion of Washington definitely considered in this report.

Mode of travel.—Southeastern Washington is largely a rich agricultural region. The cultivated lands are inclosed by wire fences, and roads have been laid out through the greater portion of it in a rectangular system governed by section lines. Farmhouses are numerous, except in the more arid western portion and in the Blue Mountains. The geological traveler has to take account of these conditions in planning his journey.

To facilitate my work and to be able to reach all parts of the region to be examined, I chose to "camp out." At Walla Walla I hired two men, Messrs. F. W. De Forest and A. C. Rud, to act as cook and teamster, respectively. We had a two-horse farm wagon, a saddle horse, tents, cooking utensils, etc. To one familiar with the vicissitudes of exploration in unsettled regions, camp life in southeastern Washington offers but few attractions. Nearly every night we camped near a farmhouse, and obtained hay for our horses from the farmer's barns, and in many instances wood for our camp fire from his wood pile. Our camps were of necessity at localities that could be reached with a wagon, but by making side trips with a saddle horse or on foot I was enabled to visit practically all localities that seemed to offer opportunities for gaining information concerning the geology of the country.

The accompanying map (Pl. I), on which the routes followed are shown in a general way, will serve to indicate to some extent how much of this report is based on actual observation and what degree of confidence can be placed in it.

CLIMATE.

The climate of south-central Washington, in the region about Pasco, for example, is decidedly arid. The annual rainfall, judging from weather records in neighboring towns, as Kennewick, Sunnyside, etc., must be less than 5 inches. To the east and west of this arid region a gradual increase in humidity is shown by changes in the character of the vegetation. The nature of the climate on the eastern portion

SKETCH MAP OF SOUTHEASTERN WASHINGTON.

of the plateau which occupies nearly all of southeastern Washington is shown to some extent by the following weather records:[1]

Mean precipitation and temperatures for 1895.

Locality.	Precipitation.	Temperature.
	Inches.	°*F.*
Pomeroy	7.37	
Pullman	15.00	
Rosalia	13.69	45.6
Spokane	13.46	48.1
Walla Walla	14.89	53.1

The mean annual precipitation at Spokane for a period of fourteen years was 17.94 inches, the summer average being 6.77 and the winter average 11.17 inches. At Walla Walla, for a period of eight years, the mean annual precipitation was 16.80 inches, of which 5.96 inches fell in the summer season and 10.84 inches in winter.

The average annual rainfall throughout the eastern portion of Washington, over a belt of country about 50 miles broad and extending southward from Spokane River to the Blue Mountains, may probably be taken at 15 to 17 inches. Some years it is considerably less than this, as is shown by the records given above for 1895, and again may exceed this amount, which is assumed as a general average. Westward from this belt a gradual decrease is shown by the character of the natural vegetation, and by a decrease and final cessation of agriculture.

An interesting feature in the precipitation is the manner in which it is distributed throughout the year, and the nature of the rain and snowfall. Precipitation is greatest in December and January, and is then principally in the form of snow; July, August, and September are particularly rainless months. The rain usually falls gently. At no time, I have been informed, is it torrential, except at wide intervals, when what are termed "cloudbursts" occur. The fact that precipitation is normally in the form of gentle showers or snow is of vast importance to agriculture. The meteoric waters are absorbed and retained by the fine, deep soils, and do not gather in rills, except when the ground is frozen.

In winter, when the land is snow-covered, warm southwest winds, termed "chinook" winds, sometimes blow, and the snow evaporates and disappears rapidly without melting. This is unfavorable to agriculture, as much moisture is thus lost which would be absorbed by the soil if the snow were melted slowly. Again, in spring and summer,

[1] Compiled from the First Annual Report of the Bureau of Statistics, Agriculture, and Immigration [of the State of Washington], by J. H. Price, Olympia, 1896, pp. 22-24.

"hot winds" sometimes wither the grain, and then immense damage is done.

No measures of the rain and snow falling on the Blue Mountains have been made, but the precipitation in that section is known to be much more abundant than on the lower plateau to the north. I have been informed by persons familiar with the Blue Mountains that the snowfall in their higher portions frequently has a depth of 12 to 15 feet. In deep gulches and under the shelter of the forest it remains unmelted until late in the spring. It is this abundant snowfall that insures the permanency of the many creeks which flow from the mountains. Evidently, in a region where there is such a delicate balance between climatic conditions that admit of profitable agriculture and those that are accompanied by a failure of crops, care should be taken to preserve the forests on the mountains, for the reason, if for no other, that they prevent the blowing away of snow, and by sheltering it from the sun delay its melting.

The range in temperature and precipitation of southeastern Washington is shown by the following averages, by counties: [1]

Temperature and precipitation, by counties.

County.	Locality.	General elevation of cultivated portions.	Length of record, in years.	Number of stations.	Temperature.			Precipitation (rain and melted snow; inches and hundredths).		
					Mean annual.	Highest on record.	Lowest on record.	Average annual.	Summer average.	Winter average.
Columbia	Snake River Valley.	1,685	6	1	49.1	109	−15	27.77	9.12	18.65
Franklin	do		2	1		112	−1	9.70		
Garfield	do	1,600	4	1	52.1	100	−2	13.93	5.80	8.13
Lincoln	"Big Bend"	1,600	10	1	47.4	105	−31	13.06		
Spokane	East	1,900	14	1	47.5	102	−30	17.94	6.77	11.17
Wallawalla	Snake River Valley.	930	10	1	53.1	108	−17	16.80	5.96	10.84
Whitman	"Palouse"		5	3	46.0	98	−19	18.21	6.73	11.48
Douglas	"Big Bend"	2,400	5	2	47.4	104	−30	12.70		

VEGETATION.

In the western portion of the area represented on the accompanying map (Pl. I) the vegetation has the desert-like character found so commonly between the Rocky Mountains and Sierra Nevada-Cascade uplifts. Sage brush (Artemisia) growing in scattered clumps gives a monotonous, grayish-green tone to the desolate, treeless landscape. Of brighter green is the common greasewood, which is also familiar to

[1] First Annual Report of the Bureau of Statistics, Agriculture, and Immigration [of the State of Washington], by J. H. Price, Olympia, Washington, 1896, p. 22.

every traveler in the more arid portions of the West. Beneath these desert shrubs bunch grasses grow abundantly, unless eaten off by stock, and in early spring the ground is beautified by many lovely blossoms.

As one travels eastward and gradually rises to the summit of the basaltic plateau which forms the greater part of eastern Washington, the desert shrubs disappear and the hillsides and valleys alike are clothed with bunch grasses and are destitute of trees and shrubs. In recent years cattle and horses ranging over these seemingly boundless pastures have eaten off the nutritious herbage and made the land practically a desert.

Before the plateau of southeastern Washington was cultivated, the bunch grasses extended all the way to the mountains of Idaho. The surface of the plateau was then one vast, rolling prairie. The Palouse River, which drains a portion of the plateau, derives its name, it is understood, from the French word "pelouse," meaning greensward, lawn, etc., and is descriptive of the region as it existed for many years after the coming of the white man.

The forests still retain the regions they originally occupied, although inroads have been made with the ax. The Blue Mountains are covered with a varied and beautiful open forest of pines, spruces, and tamaracks, which are valuable for lumber. With these more important trees grow cedars, mountain ash, the haw, and a multitude of wild roses and berry bushes. Similar vegetation clothes the mountains of Idaho and extends down the water courses that enter the plateau region between Spokane and Snake rivers. A few of the buttes in the "Palouse country," which rise like islands through the basalt of the plateau, are also scantily clothed with pines and spruces.

Along some of the streams there are scattered growths of cottonwood, alders, elders, willows, and roses growing in dense thickets. The cottonwood, however, seldom reaches the large size and picturesque development that is seen along the Yellowstone and on the border of many other streams in the Rocky Mountains. The canyon of Snake River, like the valley of the Columbia in its middle course, is treeless. Above Lewiston, however, cottonwood and occasionally a pine appears, and in the canyon of Grande Ronde groves of pine along the river's banks and on islands in midstream, as well as in lateral gorges, give an additional charm to that wild and picturesque region.

Over nearly all of the agricultural portions of southeastern Washington wood of any kind is wanting, and all supplies for buildings, fences, fires, etc., are brought with much labor from the mountains. Wood and water are each highly prized in most of the agricultural regions. Water is frequently carried in tank wagons for a distance of 10 or 15 miles and stored in cisterns for domestic use and the watering of stock. The conditions that have given large portions of Washington wonderfully rich and easily cultivated soils have been less favorable to man in other directions.

TOPOGRAPHY AND DRAINAGE.

Prevailing topographic features.—The portion of Washington lying to the south of Spokane River, together with what is termed the "Big Bend country"—a region in the central part of the State, bounded on the north and west by Columbia River—is, when minor features are disregarded, a great plateau. This plateau has been moderately disturbed by movements in the earth's crust which have caused elevations at certain localities and depressions at others; the uniformity of the surface has also been broken by stream erosion, and great canyons have been formed. The plateau is lowest in its southwestern portion, where the elevation above the sea, as at Pasco, is but 386 feet, and rises, particularly on its eastern border, to a general level of between 2,000 and 2,500 feet. The general slope in the region between Spokane River and the Blue Mountains is westward. In the absence of accurate topographical surveys, it is impossible to state just what is the slope of the general plateau surface, but from such information as is in hand a broad belt adjacent to the Washington-Idaho boundary appears to be but gently inclined. The chief portion of the descent from the eastern border to the depressed central region near the Columbia is due largely to erosion.

An exception to this general and very gentle westerly inclination of the plateau's surface occurs in the extreme south-central portion of Washington, beginning a mile or two south of Wallula, on the Columbia, and extending far into Oregon. In that region a large block of the originally level plateau has been tilted so as to incline gently southeastward. The Columbia below Wallula has cut a steep-walled canyon some 600 or 800 feet deep through this upraised region. Again, in what may be designated as the southeast corner of Washington, and extending far southward into Oregon, there has been another upheaval which has formed the Blue Mountains. These so-called mountains are essentially a low, flat dome, elevated about 2,000 feet above the general plateau surface. The uplift is so broad in comparison with its height that it is in reality a plateau, although now deeply dissected by stream erosion.

The reader will be greatly assisted as he reads the following pages if he will bear in mind that southeastern Washington, northward from the gentle uplift just mentioned, all the way to Spokane River, is a nearly uniform plateau, the general surface of which is inclined very gently westward. Over much of this vast region, embracing fully 25,000 square miles, and particularly in its eastern half, the country is so nearly level that no one on looking over it could distinguish any departure of the general surface from a plain. This

BASALTIC PLATEAU NEAR PULLMAN, WASHINGTON.

Showing characteristic topography of the wheat lands.

plateau is, as will be explained later, the surface of a series of horizontal basaltic lava sheets, and will for convenience be spoken of as the "basaltic plateau." On the east this plateau is bordered by the mountains of Idaho. The junction of the plateau with the mountains coincides in a general way, from Snake River northward, with the Washington-Idaho boundary.

The basaltic plateau is crossed from east to west by Snake River, which flows through a deep, steep-walled canyon. There are several streams that rise in the mountains of Idaho and in the Blue Mountains of Washington and Oregon which traverse the plateau in deep, narrow, trench-like valleys, which in fact are true canyons. There are also a few small streams which have their sources on the nearly level plateau and flow through deep valleys, which again are frequently canyon-like. Although the plateau has been deeply cut by the streams flowing across it, yet broad, flat-topped interstream spaces still remain to show what would have been the character of the entire region if it had not been deeply dissected.

Standing on the plateau between the branches of the various streams that have sunk their channels deeply into the rocks, the valleys, canyons, and ravines are concealed from view, and a limitless plain extends away to the horizon in all directions, or to the bordering mountains. In some regions, particularly in the "Palouse country," the surface of the plateau is roughened by short, rounded hills 50 to 80 feet high; but in a general view none of the hills are prominent, and they do not detract from the impression that the surface is essentially level. If one tries to travel in a straight line in any direction across the plateau, one soon learns that it has characteristics which are in marked contrast to its level surface. One may travel through the deeply sunken valleys and canyons for scores of miles, and in the case of Snake River Canyon for over 150 miles continuously, and be shut in at all times by walls of rock that seem like mountain ranges on either hand.

On the plateau's surface solid rock is not in view unless it is in the walls of some neighboring canyon. The soil is fine and deep, and not a pebble is to be seen. In the canyons the somber walls on either side are formed of the edges of thick sheets of basalt, and frequently columnar precipices rise tier above tier, each step being from 50 to 100 feet or more in height. The walls of the smaller canyons are in numerous instances from 500 to 1,000 feet high. The lateral canyons that join Snake River have a depth of 2,000 feet, that being the general depth to which that master stream has dissected the plateau from Lewiston nearly to its junction with the Columbia.

The views beheld on the uplands and in the valleys are thus as strongly contrasted as if they belonged to entirely different regions. As the railroads usually follow the valleys, a traveler is impressed with the prevalence of black basaltic rocks. In crossing the uplands, the total absence of rock exposures over broad areas frequently leads one to wonder if solid rock actually exists at a moderate depth below the fine soil of the surface.

Where the general plateau rises to make the lower slopes of the Blue Mountains, and throughout that more elevated portion of the plateau, deep erosion has taken place, as well as deep rock disintegration and decay. The foothills of the Blue Mountains are rounded, and have beautifully curving outlines and contours. The first impression one gets on seeing these mountains from the north and west, as from the vicinity of Walla Walla, for example, is that they are composed of soft, easily eroded rocks. The similarity of the hills in slopes and general features to the forms assumed by elevations composed of unconsolidated clay or easily eroded shales, as they waste away beneath the beating of rain and are cut by rivulets and brooks, is so striking that one is astonished when one learns that the Blue Mountains are in reality composed of layer on layer of horizontally bedded basalt, a rock that is among the most resistant to mechanical wear of those commonly found on the earth's surface. As the reader will learn later, the basalt, although hard and resistant to forces tending to abrade it, yet yields with comparative rapidity to agencies which lead to disintegration and decay. The basalt in the region here considered weathers readily, and the loose products of disintegration are not carried away so rapidly as they are formed. A fine, soft, residual soil covers the land and imparts to nearly all its minor features the characteristic flowing outlines and gentle curves so common in regions where soft rocks alone occur. It is only in the canyons, even in the elevated and most completely dissected portion of the plateau forming the Blue Mountains, that the angular forms due to solid rock exposure attract attention.

The prevailing colors in the landscape to be seen on the plateau's surface, when not due to vegetation, are light yellowish-gray in the western part and dark brown—the color of rich humus soil—in the eastern portion. The bright reds and yellows so common in many regions of deep rock decay, especially where the climate is humid, nowhere meet the eye. Not a trace of the deep red so characteristic of the soils of Virginia, and of the southern Appalachian region generally, can be found in all of the deeply decayed surface of the basaltic plateau.

In a far-reaching view during the summer season over the surface of the plateau surrounding the Blue Mountains, except on the east, and also northward through Whitman and Spokane counties to Spokane River, the universal colors are brown and yellow—the brown of plowed land and the golden of wheat fields. The wheat lands as a rule are sown but every other year, so that practically half of the land lies fallow each summer. After the harvest, when the stubble fields are plowed and the soil is moistened with rain, the fields become dark brown and appear almost black. In the canyons, where one is overshadowed and shut in by walls of basalt, the tone of the landscape is always somber, and frequently oppressive. The black walls of rock find but little contrast in the scant vegetation. The polished and shining stems of the bunch grass, however, which grows on every jutting ledge and smooth talus slope, frequently clothe the dark precipices with a silken garment of pearly gray.

Throughout the entire region from the Blue Mountains northward to Spokane River, and westward from the mountains of Idaho for 100 miles or more, the general features of the land are the same. The topography is young. The streams have not advanced far in their task of cutting away the rocks forming the plateau and of reducing the land to sea level. This appointed task, although well begun, has been delayed, and over the central and western portions of the plateau has been entirely checked by a decrease in rainfall. It is a relief to leave this region of broad plateau surface and narrow trench-like valleys—not only of young but infantile drainage—and visit the extreme southeastern corner of Washington, where a similar work has been carried on more energetically. The Snake River has there cut through the eastern flank of the Blue Mountain uplift and excavated a canyon about 4,000 feet deep and not less than 15 miles broad from brink to brink. An important tributary river, the Grande Ronde, rising in many branches in the Blue Mountains, has excavated an intricate series of branching canyons, the main trunk of which is as deeply sunken in the rocks as the magnificent gorge of the master river. In this region the topographic features were originally the same as in the less completely dissected portions of the lava-covered country, but for certain reasons the work of the streams is further advanced. The spaces between the streams are no longer flat-topped remnants of the plateau's surface, but the entire region bristles with sharp-crested ridges and is diversified in a wonderful manner with spires and pinnacles.

If a person climbs to the summit of one of the higher ridges and gains an elevation of about 3,000 feet above the canyons on either side, he will see that many other ridges rise to approximately the same heights and that what appears to be a group of sharp, angular mountains, separated by a labyrinth of canyons with silvery threads of water in their bottoms, is in reality a deeply dissected plateau. The topography is still young, although approaching maturity. The streams have not yet widened their valleys materially, but rapid decay has crumbled the walls between. The region treated in this report thus furnishes splendid examples of the various stages in the process by which a plateau is eaten away by streams. If space permitted, it would be instructive to take the reader to the mountains of ancient crystalline rock surrounding the basaltic plateau on the east and north and point out the characteristics of a region that has long been exposed to the rain, sunshine, and frost, and from which the streams have been carrying their burdens of disintegrated rock for geological ages. We could thus learn what is meant by the term old topography. The forms of the original uplifts are lost, and only the remnants of once lofty mountains remain.

The bases of the old mountains were partially submerged by the overflow of molten lava that formed the plateau of southeastern Washington. The lava entered the valleys and gave them level floors of rock. Mountain spurs project into the plateau, like headlands along the ocean shore. Some of the old mountains, separated by erosion from their neighbors, were completely surrounded by the inundations of lava and now rise as islands above its surface. Steptoe Butte is an example of these ancient peaks which project through the lava of the plateau. These interesting features in the topography of the border land between Washington and Idaho will be better understood, however, after the character and origin of the basaltic rock of that region are discussed.

General characteristics of the drainage.—All of the lines of drainage in the portion of Washington here treated lead to Columbia River. The principal stream is Snake River, which flows across southeastern Washington from east to west in a deep canyon, which is the strongest natural boundary in the region. South of Snake River, all of the perennial streams rise in the Blue Mountains and flow in all directions, their courses being determined by the original slopes of the uplift. In the language of the geographer, these are "consequent" streams. All of them, as was stated in describing the general topographic features of the region, traverse deep gorges in the flanks of the Blue Mountain uplift, and in numerous instances, on gaining the less undisturbed plateau surrounding it, flow through deep canyons. The streams from the Blue Mountains, which are tributary to Snake River, join that stream in canyons that at their mouths are as deeply cut as the canyon of the main river.

Throughout the basaltic plateau north of Snake River the principal streams rise in the mountains of Idaho, and, with the exception of Spokane River, have their sources near the Washington-Idaho boundary. In crossing the basaltic plateau, the valleys and canyons of these streams sink deeper and deeper. The minor streams from the mountain are tributary to two rivers—the Palouse, which empties into Snake River, and the Spokane, which joins the Columbia before it makes its wide detour to the westward.

Besides the streams mentioned—which, however, include nearly all the perennial surface water in the portion of the basaltic plateau under consideration—there are minor streams, mere brooks, in fact, which rise in valleys excavated in the plateau when the rainfall was more abundant than at present, and are fed mainly by springs and the general seepage from soil and rocks. The channels of many of the small streams are dry in summer, or their water may flow for a short distance, but fail to reach the main rivers. Some of these trunkless branches are indicated in the accompanying map (Pl. I), but as they are sensitive to minor climatic changes they vary materially in length from month to month, and almost from day to day, and can not be accurately plotted.

Snake River.—As already stated, the principal river of the southeastern portion of Washington is Snake River. With the exception of the Columbia, this is the only navigable river in Washington east of the Cascade Mountains. It has its source far to the eastward, in the vicinity of the Yellowstone National Park, and flows through southern Idaho. In what may be termed its middle course, for about 35 miles, it forms the boundary between Washington and Idaho, and then bends abruptly westward, where Lewiston is situated, and for 130 miles flows in a deep trench in the basaltic plateau to the Columbia.

At the southeast corner of Washington the canyon of Snake River is fully 4,000 feet deep, but below Asotin the height of its walls decreases, and thence to near its mouth it has a nearly uniform depth of 2,000 feet. The walls of the canyon are precipitous throughout, and in numerous instances are nearly vertical for a large portion of their height. This great gash in the rocks, of which the 160 miles below Mount Wilson is but a portion, has been worn by the river in dense, resistant rocks. The canyon walls throughout the region treated in this report are, with slight exceptions, formed entirely of the edges of horizontally bedded basalt. The weathering of the edges of the basaltic sheets has caused them to recede unequally and form steps or terraces in the faces of the precipices. Where the walls are steepest they present a series of narrow steps covered with soil and clothed with grasses, separating vertical rises of bare and frequently columnar rock, varying in height in most instances from 50 to 125 feet.

The canyon walls, to an observer from below, frequently appear to be nearly vertical, but the impression of their steepness gained from such a view is usually much exaggerated. Owing to talus slopes on the shelves and the fact that the escarpments of solid rock are frequently broken by side gulches, I think it is safe to say that nowhere is there a space half a mile in length up which one might not climb. Cattle and horses graze on the canyon walls in many places. Experience has made these animals nearly as sure-footed as goats, but bleached bones at the base of the precipice show that occasionally accidents happen to them.

The walls of the canyon are scored by steep lateral gulches, with buttress-like ridges standing between. Many tributary streams enter the canyon at the level of the river, and have curved and branching lateral canyons and gorges which extend away from the river 10 miles or more before gaining the surface of the plateau. The work performed by flowing water in excavating the numerous canyons and valleys is impressive, and most striking examples of stream erosion meet one on every hand.

Snake River is a swift stream, the descent in the portion below Lewiston, as determined by the United States Engineer Corps, being 2.48 feet per mile, and is still engaged in corrading the bottom of its channel. Rapids due to solid rock occur at numerous localities.[1] Many of these obstructions have been removed for the purpose of facilitating navigation, but at low-water stages danger still exists. Steamboats have ascended the river from its mouth to Wild Goose Rapids, a distance of about 170 miles; but owing to numerous rocks and shoals below Riparia, where a branch of the Union Pacific Railroad now crosses the river, navigation is practically confined to the portion of the river which lies between Riparia and Lewiston. Other navigable reaches of the river occur above Wild Goose Rapids, but they are beyond the region under consideration.

Measurements of the volume of Snake River are not necessary to impress the beholder with the fact that it is an important stream. Its broad, swift current assures one that the waters of a vast region are there journeying to the sea. At the lowest stages the river is in general about 1,000 feet broad. Measurements made by officers of the United States Engineer Corps at Texas Rapids show that 26,000 cubic feet of water flow past during each second. When the snow is melting on the mountains of Idaho and Wyoming the river rises from 20 to 30 feet above its summer stage, and becomes a wild, rushing flood of muddy water. Its volume at such times must be in excess of 100,000 cubic feet per second.

As has been stated, the river is still deepening its channel. But little lateral erosion has taken place, and no general flood plain borders its shores. Where the river forms sharp bends, more particularly in the portion below Lewiston, there are frequently deposits of sand which rise a few feet above ordinary high-water stages. These "bars," as they are termed, are in some instances 200 or 300 acres in area. When planted with fruit trees and properly irrigated these light, sandy lands yield splendid crops of peaches, apricots, plums, grapes, etc. The warm climate of the canyon is especially favorable for fruit raising. Above Lewiston, where the canyon is deeper, and where certain changes occur in the character of the rocks inclosing it, the gorge is wider than where it crosses the basaltic plateau in its westward course, and the terrace-like lands in its bottom are of greater extent, although nowhere more than a few hundred feet broad.

An interesting episode in the history of Snake River Canyon is recorded by fragments of a high gravel terrace that occur in it. At

[1] In connection with the fact that Snake River is still deepening its channel, it is of interest to note that Columbia River is engaged in a similar task. At the head of the steep-walled canyon through which the Columbia flows, below Wallula, ledges of basalt cross the stream, but steamers can generally traverse the deeper channels. This obstruction is due to movements, apparently still in progress, in a large block of the basaltic plateau which has been uplifted across the course of the stream, and for a time caused it to spread out and form a large lake.

almost any locality on the bank of the canyon an observer will have in view, usually on the concave side of a curve in the river course, a terrace of coarse gravel and sand, the surface of which is about 360 feet above the stream. The descent from the flat surface of the terrace to the river is usually a smooth slope with an inclination of from 18 to 22 degrees. The canyon was at one time filled from side to side with deposits of the character shown in the terrace and to a depth recorded by the level of the deposits remaining. The river has since reexcavated its canyon, leaving fragments of the former filling at localities from which the current was deflected. The gravel and sand referred to show that the river, after excavating its canyon to its present depth, was checked in its rate of flow or so greatly overloaded that it could not carry away all the débris brought to it, and deposited its excess of load so as to raise its bed 360 feet. Subsequently, renewed energy, or a decrease in the supply of débris delivered to the river by its tributaries, allowed the stream to carry away the greater part of the material deposited.

The gravel deposit referred to extends into each tributary canyon. In such situations the lateral streams have cut modern channels through it, leaving terraces as in the main canyon. These gravel deposits are composed in part of worn and rounded fragments of basalt, but consist principally of quartzite, granite, and igneous rocks of older date than the basalt. The nature of this material shows that it was brought by Snake River from far up its course. The gravel was carried from the main canyon in some instances for several miles up the tributary canyons, as may be seen especially along Tokanon River at Starbuck, and checked the flow of the lateral streams. Small lakes were formed in some instances in the side canyons, owing to the abundant deposition of material at their mouths.

Terraces similar to the great terrace in Snake River Canyon occur along the upper Columbia on the border of Spokane River, and to a less marked degree in the canyons and valleys of the streams flowing from the Blue Mountains, showing that the widely extended influence which caused the streams to deposit a part of their loads affected a very large portion and probably the whole of the hydrographic basin of Columbia River at a comparatively recent date. The nature of the change which caused so many streams to partially fill their channels and then reexcavate them will be discussed later.

Walla Walla River.—This is one of the few streams having river-like proportions which rise within the region covered by the Columbia lava. Its various branches head in the northern and northwestern portions of the Blue Mountains and follow westerly courses. Their united waters, which enter the Columbia at Wallula, form a stream that in late summer has an average width of 50 to 60 feet, and discharges by estimate from 100 to 150 cubic feet per second. During high-water stages their volume is increased many fold.

In common with all other streams in southeastern Washington, the Walla Walla is clear except after rains, and furnishes wholesome water for domestic use. Where the many branches of the river leave the mountains they are especially clear, for the reason that they are supplied by infiltration, and all matter in suspension has been removed. The Walla Walla and its branches furnish instructive examples of what geographers term "consequent" streams—that is, streams which are directed in their course by the original surface slope of the land. As has been stated, the Blue Mountains are an upraised portion of the basaltic plateau. The uplift has the form, at the north at least, of a low, flat-topped dome, in which the rocks are horizontal except about the gently inclined margins. The general plateau surface to the northward, as already stated, slopes gently westward. The streams from the mountains radiate in all directions, but those which reach the lower plateau change their courses in obedience to the general slope of the surface in which they have sunken their channels. This is seen especially in Touchet River, the principal tributary of the Walla Walla from the north. This stream is formed by the union of several branches which start on the north side of the Blue Mountains and flow northward down the gentle slope of that uplift until the lower plateau is reached and then bend westward. The trunk stream of the Touchet has its direction determined by the westward slope of the plateau it traverses for 20 miles. This slope is not continued to the Columbia, however, but an upheaval of another portion of the tableland lying principally to the west of that river, and briefly described in the next paragraph, changes the direction of the Touchet and causes it to flow southward for about 12 miles before joining the Walla Walla.

Immediately south of Wallula is another block of the Columbia lava, which, as previously stated, has been gently tilted. The tilting is so moderate and affects such a large area that the edges of the lava sheets appear horizontal. The upraised area is bounded on the north by a line of cliffs near the Columbia. When followed eastward, these cliffs lose the precipitous character and change to hill slopes which die away, some at a distance of 20 or 25 miles. This line of abrupt change in slope probably indicates the presence of a break and the upheaval of the rocks on its southern border—that is, the uplift has been by faulting. In looking westward from the Blue Mountains, it is evident that the uplift just described has given a southeasterly slope to the surface of the country, which extends far southward into Oregon.

The Walla Walla River on leaving the Blue Mountains flows westward in a deep canyon, the direction of which was determined by the slope of the uplift. At the foot of the mountain it emerges as a surface stream, and is turned northward by the slope produced by the upheaval south of Wallula. Not only does the branch of the Walla

Walla, for which the name of the trunk stream is retained, behave in the manner described, but several other branches, of which Cottonwood, Russell, and Mill creeks are the most important, also become surface streams on leaving the mountains. These various branches, where they come together in the vicinity of Whitman, about 6 miles west of Walla Walla, are depositing the loads they carry during floods and building up their channels and flood plains. On account of the filling that is in progress, some of the branches, notably Mill Creek, divide, after the manner of a stream on its delta, and contribute their waters to the Walla Walla through two or more mouths. As one continues on down the Walla Walla to its junction with the Columbia, its channel grows gradually deeper and deeper, and below the mouth of the Touchet and near Wallula is certainly 50 or 60 feet below the general surface.

This abnormal behavior of the Walla Walla and its branches has led to legislative enactments which determine what proportion of the waters should be allowed to flow through certain of the bifurcating channels.

The manner in which the streams near Whitman are raising their channels so as to allow their waters to divide is a matter of much geographical interest, as it indicates that movements in the basaltic plateau are still in progress. The depressed region between the Blue Mountains and the smaller uplift to the west is probably slowly sinking. The rate of this subsidence is such that the streams are barely able to keep pace with it by grading up their beds. During high-water stages, I have been informed, expansions of the streams occur which resemble lakes. The expanded waters of the creeks are then united and much of the individuality of the various channels is lost.

The several branches of the Walla Walla furnish excellent sources of supply for town water and for irrigating purposes. In another section of this report the manner in which Mill Creek is utilized at the city of Walla Walla will be described. For purposes of irrigation, in order to make full use of the natural conditions, it will be necessary to store the winter run-off in the canyons of the Blue Mountains and hold it for summer use. If this can be done economically, a very large portion of the rich lands along the Walla Walla and its tributaries can be made many times more productive than they are at present.

Tokanon River.—This so-called river and its principal branch, the Pataha, rise on the north side of the Blue Mountains and enter Snake River through a deep canyon. The Tokanon and Pataha flow northward in their upper courses, their direction having been determined in their infancy by the slope of the surface, but before uniting they curve westward, in obedience to the gentle westward inclination of the plateau into which they have carved their channels. After the Pataha joins the Tokanon the latter flows west for 6 miles and then turns at a right angle on entering a gorge which leads it to Snake River. A careful survey would probably show that the Tokanon in its youth continued to flow westward and became tributary to the Touchet, but that it was diverted at the present site of Starbuck by a small high-grade stream that flowed to the Snake.

The Tokanon at its mouth is but a brook in summer, across which one may step on the larger stones strewn along its channel without wetting one's feet. The Pataha was dry in its lower course when I visited its valley in August, and had shrunk back as far as Pomeroy. The canyons and valleys through which these two streams flow are deep and out of all proportion to the streams that occupy them. In its lower course the Tokanon is nearly 2,000 feet below the general level of the adjacent plateau. Many other examples of this nature indicate that the streams of the basaltic plateau were formerly larger and more numerous than at present.

Deadman Creek.—The creek with this doleful name, which, however, is suggestive of its own nearly terminated existence, is an exception to most of the streams of the basaltic plateau, for the reason that it does not rise in an elevated region, but is supplied in a feeble manner by the rains falling on a portion of the plateau that is almost completely cut off by deep canyons from all other portions. The deep, canyon-like valley through which it flows has a steep grade and many branches, some of which are now dry. Its catchment basin when the drainage was most vigorous was about 100 square miles in area, and the development of the streams had progressed until its numerous branches furnished a convenient avenue of escape for the waters that fell on every part. The stream in its days of vigor cut down its channel nearly to the present level of Snake River—that is, to a depth of about 2,000 feet—in the solid basalt. At present, as already stated, many of the once tributary valleys are dry and desolate, and the trunk stream is shrunken during the summer season to a mere rill. The soil throughout the valley is deep and rich, but there is no water for irrigation. The hillsides and the remnants of the plateau surface are also fertile, and fortunately absorb sufficient moisture from the light rains and winter snow to admit of their cultivation for wheat.

Alpowa and Asotin creeks.—The drainage from the northeastern slope of the Blue Mountains in Washington is conducted to Snake River through two channels, known as Alpowa and Asotin creeks. Each of these creeks rises in many branches on the slopes of the mountains, and all at first are surface streams, but on account of the cutting down of Snake River Canyon, into which they discharge, they have sunk deeply into the plateau and near their mouths have lowered their channels as rapidly as the master river. The Alpowa is little more than a brook in summer, but its waters serve to irrigate some 300 acres of orchard lands near where it joins the Snake. The Asotin is large and brings a never-failing supply of pure water to the little town of Asotin. A costly irrigating canal is now being built for the purpose of conducting its water to a broad area of bottom land in Snake River Valley opposite Lewiston. Some account of this bold undertaking will be given on another page.

Grande Ronde River.—On the east side of the Blue Mountains the drainage is through a deep, wild canyon, which furnishes the finest scenery that can be found in southeastern Washington. The river that excavated this canyon is the Grande Ronde—or, as it is usually called by the inhabitants of that region, the "Grand Round"—a bright, swift, winding stream that is walled in on either side by precipices and mountain-like slopes 3,000 feet high. The canyon is not a narrow gash, for the upper portion of its inclosing walls have receded, and side streams, most of them temporary rills, have cut a multitude of steep, lateral gorges, between which outstanding buttresses extend far into the main gorge. In many places ridges that descend the opposite sides of the canyon overlap in its bottom and the stream makes sharp curves in order to pass around their extremities. The main tributaries of the Grande Ronde, like Joseph Creek, which is indicated on the accompanying map, have also sunk deeply into the basaltic tableland, as has each branch of these secondary streams. A great region that, but for the excavating power of the streams draining it, would be a flat-topped plateau, has been transformed into an intricate, branching system of sharp-crested ridges, with profound gorges and canyons between. The general height of the land has thus been reduced about 1,000 feet, but the sharp, angular mountains that have been sculptured out of the upraised block are so steep and their crests so narrow that their loss in actual elevation is scarcely appreciated.

The canyon of Grande Ronde throughout the lower 20 or 30 miles of its course is in general 2,700 feet deep. The distance between the "rim rocks" bordering its walls is from 8 to 10 miles. The great buttresses that start from the main walls, however, extend far out into the canyon and make its width seem much less than it really is. Throughout the entire region drained by the Grande Ronde the rock, as in the lower plateau to the north of the Blue Mountains, is basalt in horizontal sheets. Everywhere throughout the rugged walls that remain the horizontal courses of black basalt may be distinctly followed. A magnificent example is thus furnished of the dissection of an elevated plateau consisting of horizontal layers of hard rock by the slow process of weathering and stream erosion.

A peculiar feature in the topography of the canyon of the Grande Ronde, and one which adds greatly to the interest of its wild scenery, is the manner in which the spurs from the bordering mountain walls project into the gorge and overlap or dovetail. These lateral ridges decrease in height from the borders of the canyon toward its bottom until a height of about 1,000 feet above the river is reached; they are then prolonged at about the same level nearly across the bottom of the canyon. The crests of the lateral spurs where they project far into the canyon are sharp and serrated and end in precipices. Between these interlocking spurs the river makes long bends and flows about these steep extremities in abrupt curves. The sharp, serrate ridges projecting from the north wall of the canyon frequently extend almost completely across the canyon and enter reentrant angles in the south wall. Between the cliffs forming the ends of these spurs and the precipitous and frequently apparently vertical south wall the river flows in a narrow, rocky channel.

It is impossible to describe briefly the peculiar topography of Grande Ronde Canyon so as to convey an idea of its ruggedness and of the many peculiarities due to the interlocking of lateral ridges just mentioned; but if we imagine the canyon as having been excavated to a depth about 1,000 feet less than at present and widened so as to be about 3 miles broad at the bottom, we shall have the general character of the upper gorge in mind. If over the nearly level floor of this wide-bottomed gorge we see the river winding from side to side, and at the ends of the southward curves cutting at the base of the cliffs bordering the valley on that side, and then fancy the region elevated a thousand feet, so as to give the stream renewed energy and allow it to cut a tortuous gorge in the bottom of the older valley, the ridges between the abrupt bends weathering to sharp crests and pinnacles, we shall be able to appreciate not only the characteristic features I have attempted to describe, but their mode of origin.

Two roads cross the canyon of Grande Ronde from north to south, but the excessive ruggedness of the canyon's bottom has thus far prevented the construction of even a safe bridle trail from east to west along the river.

Next to Snake River, Grande Ronde is the largest stream in southeastern Washington; but owing to the almost complete absence of bottom lands throughout that portion of its course which lies in Washington and for many miles south of the boundary, its waters can not be utilized for irrigation. Far south in Oregon the topography is different. Broad bottom lands there exist and the conditions are favorable for agriculture. Luxuriant bunch grass abounds, however, throughout the Blue Mountains and on the steep canyon sides. Stock raising is there the natural industry, but excellent fruit can be grown in all of the deeper valleys and gorges. In the gardens about the few houses and cabins that have been built by stockmen in the canyons of Grande Ronde and Joseph Creek vegetables of many kinds grow luxuriantly when properly irrigated, and tobacco plants as large and fine as any in Virginia or the Carolinas are now raised for domestic use.

Palouse River.—North of Snake River are a number of streams that head in the mountains of Idaho and flow westward in channels which increase progressively in depth, and finally become steep-sided canyons. The generally westward direction taken by these streams in their infancy and retained as they excavated their valleys and canyons in nearly horizontal sheets of basalt was determined by the gentle westward inclination of the plateau—that is, they are consequent streams.[1] These streams unite to form Palouse River, a tributary of Snake River. This river was not examined during the reconnoissance which furnished the basis of this report, but is understood to be comparable with the Walla Walla in size. Symons states, in the report just referred to, that "the falls of the Palouse form another of the interesting objects of this section. In the lower portion of its course the Palouse flows through a deep fissure in the basaltic rocks, portions of which take fantastic forms, as towering pinnacles. At the falls the river descends perpendicularly for about 120 feet into a narrow basin, from which it flows off through its deep canyon for about 9 miles to the Snake River." The fall in the Palouse, whatever may be its history, is a marked exception to the even grade established by, I think, all associated streams, excepting Spokane River, and should claim attention, not only from geographers, but from those interested practically in water power and irrigation. The abrupt change from a westerly to a southerly direction that the Palouse makes in its lower course is perhaps due to a diversion of the river by the cutting back of a small high-grade stream flowing to Snake River. I fancy the falls have some connection with such a capture of the low-grade and comparatively sluggish river by a smaller but more energetic rival.

Owing to the presence of sheets of clay and sand interleaved with the basalt in much of the region drained by the Palouse, springs are numerous along its branches, and supplement in an important manner the drainage from the mountains.

The broad plateau surface adjacent to the "Palouse country" on the south and west has not been visited by me, but, as shown on the maps of the United States land survey, it drains westward. The feeble streams are frequently interrupted and small lakes are formed. The origin of these lakes has not been explained, but the suggestion is made that the streams occupy old drainage channels that have been partially filled with sand and soil derived from the adjacent portions of the plateau. These lakelets are apparently similar in many ways to Moses Lake, in the Big Bend country, which is held by a dam formed of drifted sand.[2]

Spokane River.—Like the Snake, this river heads in the mountains, well to the east of the basaltic plateau of southeastern Washington, and flows across it, much of the way in a deep canyon that has been excavated in horizontal sheets of basalt. As in the case of

[1] It has been suggested by T. W. Symons, in a Report on the Upper Columbia River, Washington, 1882, p. 116, that the streams here referred to have had their courses determined by glaciers which moved in the general direction that they follow. My observations failed to sustain this suggestion, as no evidence of the former presence of glacial ice was found anywhere in southeastern Washington.

[2] Bull. U. S. Geol. Survey No. 108, 1893, p. 96.

Snake River, also, the canyon of Spokane River was deeply filled with gravel at a recent episode in its history, and has since reexcavated its channel in part, making an inner steep-sided gorge in the gravels that fill the older and wider valley up to a certain level. When the stream renewed its work of excavation it did not flow in a straight course over its gravelly bed, but in curves. As the channel was deepened, projecting spurs of solid rock in the buried valley were discovered and had to be cut through before the modern gorge could be extended upstream. Some of the ledges of basalt that the stream met with as it progressed with its task of reexcavating have been cut through, but work is still in progress at one of them, as is shown at Spokane City. A curve in the course of the stream, when it began to clear out the gravels it had previously deposited, carried it across a buried ledge. This accident, as it may be termed, led to the growth of the thriving and beautiful city of Spokane.

A gauging station was established on this river at Spokane, Washington, in October, 1896, the gauge being at the bridge of the Oregon Railway and Navigation Company. The drainage area at this point is 4,005 square miles. A measurement made on August 27, 1896, by Mr. Cyrus C. Babb, when the water stood at a height of 2 feet, gave a discharge of 2,937 second-feet (cubic feet per second), while a later measurement, on October 17, 1896, at a gauge height of 1.46 feet, gave a discharge of 1,722 second-feet.

Precipitation formerly more abundant than now.—Throughout southeastern Washington there is abundant evidence that the rainfall was formerly greater than at present, and that the streams were larger and more numerous than we now find them. This is shown particularly in those portions of the plateau which are not crossed by streams flowing from the mountains to the eastward, as, for example, in the region with slopes leading to Deadman Creek, and over still larger portions of the plateau situated to the west and north of Palouse River. The valleys and canyons in the districts mentioned, while without question due to stream erosion, are disproportionally deep and wide in reference to the streams now occupying them. In many instances deep, trench-like valleys, such as streams are known to make, and which lead to similar valleys now occupied by water courses, are flat bottomed from side to side and entirely without drainage channels. Evidently in such instances there has been no surface drainage for a long term of years All the rain that falls is at once absorbed by the thirsty soil.

Similar evidence of a former period of greater humidity than the country now enjoys can be had throughout the basaltic region of southeastern and central Washington, as has been stated in a previous report.[1]

The time of the abundant precipitation, when the most marked of

[1] Bull. U. S. Geol. Survey No. 108.

what may be termed the secondary topographic features of the basaltic plateau came into existence, may for several reasons be considered as the Glacial epoch, when the higher mountains of Washington and Idaho were occupied by extensive snow fields and glaciers.

GEOLOGICAL FORMATIONS.

The geological problems presented in southeastern Washington are simple and easily understood. The rocks in this region fall conveniently in eight divisions. These are, briefly:

1. Crystalline and metamorphic rocks of unknown geological age, consisting principally of schists, gneisses, granites, and quartzites.

2. Dikes of igneous rock, which break through and are intimately associated with the metamorphic terranes just mentioned.

3. Coal-bearing sandstones and shales of Tertiary age, which form the surface at the eastern base of the Cascade Mountains and extend indefinitely eastward, may occur in southeastern Washington beneath the lava which forms the next group of rocks here enumerated.

4. Vast basaltic overflows, which cover all of the plateau region of central and southeastern Washington and extend widely into neighboring States. These rocks were poured out in a molten condition during what is known as the Tertiary period of geological history. This formation has been named the Columbia lava.

5. Interbedded with the sheets of basaltic rock composing the Columbia lava are beds of clay, sand, volcanic dust, and lapilli, which were deposited in part by streams and in part in lakes during intervals between the lava flows.

6. Above the Columbia lava in certain localities there are thick deposits of gravel, clay, and volcanic dust, constituting what is termed the John Day system. The rocks of this system were deposited in a Tertiary lake named Lake John Day.

7. In the canyons of Snake and Spokane rivers and along several of the more important secondary streams there are deposits of gravel and sand which were laid down by these streams after they had excavated their channels to their present depth.

8. As important as any of the rock groups just enumerated, but not usually classed as an independent geological formation, are the soils. Reference is here made especially to the deep, rich soils that mantle practically the entire surface of the Columbia lava. These soils are almost entirely a product of the disintegration and decay of the underlying basalt and represent what are termed residual soils. Mingled with the residue left by the decay and partial solution of the basalt is a minor quantity of volcanic dust which was blown out by some distant volcano and scattered widely over the land by the wind.

Each of the rock groups briefly enumerated extends far beyond the region treated in this report, and in part has been described in a previous publication.[1]

[1] Bull. U. S. Geol. Survey No. 108.

METAMORPHIC ROCKS.

In the report on a geological reconnoissance in central Washington, just referred to, there is a brief description of the crystalline rocks occurring in the mountainous region north of the Big Bend of the Columbia. From what little is known of the geology of northern Washington and western Idaho, it seems evident that this same great system of granites, schists, quartzites, etc., not only forms the mountains bordering the basaltic plateau, but to a considerable extent the floor beneath it. These ancient crystalline rocks were elevated into mountains and deeply eroded before the Columbia lava was poured out. The deep trench carved in the basaltic plateau by Snake River has revealed the underlying rocks at three localities.

Gneiss[1] *at Granite Point.*—The first exposure of metamorphic rock met with on ascending Snake River is about 24 miles below Lewiston and is known as Granite Point. The rock in the bottom of the canyon at this locality is granitic in character and is what is known commercially as "granite." More strictly speaking, however, it is a gneiss—that is, a rock having the same mineralogical composition as granite, but in which the minerals are arranged in bands and folia. The rock is dark in color, owing to the abundance of black mica scattered through it in irregular bands.

At Granite Point this rock is exposed on each side of the river for a distance of about 1,500 feet and rises to a height of 160 feet above the water. The canyon walls, rising fully 2,000 feet above the gneiss, are composed of the edges of horizontal sheets of basalt, and show the minimum depth to which the summit of the ancient hill, perhaps a prominent feature in old topography, was buried by the basaltic overflows.

The gneiss has been opened by quarrying to a depth of a few feet, but it is of dark color, of rather coarse texture, and has a foliated structure, which will probably preclude its use as a building stone except for rough masonry, such as the abutments of bridges, foundations, etc. The rock is fresh in appearance, and no products of disintegration mantle its surface. Evidently the portion exposed is the summit of an elevation from which, previous to the inundation of basalt, loosened fragments were carried away as rapidly as they originated. Both up and down stream from Granite Point for scores of miles the walls of the canyon are composed from bottom to top of horizontally bedded basalt. Downstream, however, especially on the left bank of the river, a westerly dip in the lower sheets of basalt, amounting to perhaps 2 degrees, can be detected. This is one of the few instances throughout the basaltic plateau to the north of the Blue

[1] The designation of this rock as a gneiss is from field notes and is provisional. There are reasons for believing it to be a quartz-diorite, and therefore igneous and not metamorphic in origin. This same remark applies also to the rock occurring at Granite Point, a few miles south of Pullman, mentioned on page 37.

Mountains in which any departure of the lava sheets from a horizontal position has been observed.

Schists at Buffalo Rock.—About 15 miles up the Snake River from the town of Asotin there is a locality known as Buffalo Rock,[1] which is of special geological interest. This locality can be reached conveniently from Asotin by following a road recently opened along the west side of the river and at the bases of the great precipices of basalt that form the canyon walls. Above Asotin the canyon of Snake River is deeper than below that locality and furnishes many striking exposures of columnar basalt, which rise tier on tier to a height of over 3,000 feet. In the neighborhood of Buffalo Rock, however, an important change occurs. The metamorphic rocks which formed the surface of the country before the vast inundation of molten lava took place again appear above the level of Snake River and rise at least 2,000 feet into the horizontally bedded basalt. The river has cut its gorge across a buried mountain so as to expose the rocks composing it for about a mile on each side of the stream. The horizontal layers of basalt abut against the steep sides of the old mountain and show no evidence of disturbance at the contact. It is evident that the lower rocks have not been forced upward into the basalt, but that the latter was poured out in successive sheets and flowed about a mountain of schist and finally overtopped its summit and buried it from sight. Additional overflows of the same character were spread over the site of the buried mountain and reached a thickness of fully 1,000 to 1,500 feet above its summit before Snake River began to excavate its canyon.

The sides of the buried mountain, where they first appear above the river, are steep and without talus slopes or other products of disintegration. Although 3,000 feet of horizontally bedded basalt are exposed in the canyon walls adjacent to the outcrops of schist, it is evident that the valleys of the old land lie below the level to which Snake River has corraded its channel.

Where the schists rise from the river and form the lower portion of the canyon walls, marked changes occur in the topography of the profound gorge. The horizontal lines and bands formed by the edges of lava sheets give place to apparently structureless walls, which are extremely precipitous. The schist is more resistant to atmospheric agencies than the basalt, and the gorge cut in it is narrow. Vertically above the schist the canyon widens, so as to make reentrant angles in its general course. This increase in the width of the gorge above the schist is especially conspicuous when viewed from its borders.

The rocks which cause these important changes in the character of the canyon are mostly greenish, spotted schists, and are evidently

[1] The name, I have been informed, refers to certain rock inscriptions made by Indians, some of which are thought to represent buffalo. A large rock on the west side of the river is covered with figures made by pounding the surface with a dull instrument, probably a pebble. Similar designs are said to occur also on the rocks of the opposite shore.

of sedimentary origin, as well-rounded pebbles and angular masses of rock may still be recognized in them. Samples may be collected showing a transition from conglomerate, in which the pebbles are still prominent, through schistose rock containing flattened and elongated pebbles, to greenish schist with spots and blotches due to altered pebbles, and from these, again, to fiñe, even-grained, silky schists of uniform color. Near the southern end of the exposure there are rocks of plutonic origin[1] which appear to be dikes breaking through the schist, but as a similar rock occurs as pebbles in the schist, it is evident that at least some of the intrusives were formed before the material since metamorphosed was deposited.

The schists are traversed by small veins of quartz, which are probably gold bearing, as gold is obtained by placer mining in the gravels and talus slope bordering the river. What success has attended these mining operations I was unable to learn during my brief visit. No true fissure veins were seen in the schists, and from such examinations as I was able to make it seems doubtful if quartz mining will ever be profitable.

Schists at Wild Goose Creek.—Upstream from Buffalo Rock one may follow the river by a bridle trail to beyond the mouth of Grande Ronde River, a distance of about 8 miles. Throughout this portion of the canyon the walls are precipitous, frequently rising in sheer cliffs, and are composed from base to summit of horizontally bedded basalt. The canyon walls increase in height as we ascend the river, and at the mouth of the Grande Ronde are about 4,000 feet high. The actual margins of the canyon, however, recede from the river, and it is only when one gains a commanding point on the rim of the vast gorge, like the summit of Mount Wilson, for example, that its full grandeur is revealed.

Just above the mouth of the Grande Ronde metamorphic rocks again rise above the level of the river and form a large part of the canyon walls for at least a score of miles. The full extent of this fine exposure is not known, but it is prolonged far to the south of the southern boundary of Washington. The metamorphic rocks appear suddenly above the level of the river at a locality about a mile south of the mouth of the Grande Ronde, and rise from the water in what appear to be vertical precipices to a height of approximately 2,500 feet.

The leading phenomena presented at Granite Point and Buffalo Rock are here repeated, but on a grander scale. The horizontal basalt abuts against cliffs of schist, and shows no change at the contact. The sides of the buried mountain range, as seen in section in the canyon walls, are precipitous. On the east side of the river, where the schist first appears as one journeys upstream, the buried

[1] Thin sections of this rock have been examined by Mr. J. S. Diller, who states that it is a porphyry, composed chiefly of granular quartz with much biotite, forming a groundmass in which are embedded phenocrysts of quartz and feldspar, chiefly plagioclase.

mountain side slopes about 45°, and is free of débris. The base of the mountain is evidently far below the level of Snake River. Each successive layer of basalt extended farther and farther over the metamorphic rocks, until at a height of about 2,500 feet the summit of the range is covered. The horizontally bedded lava above the highest peak of the buried mountain is not less than 1,500 feet thick. A clear section of fully 4,000 feet of horizontally bedded lava sheets is there exposed, but the base of the pile is not seen.

The metamorphic rocks that appear beneath the basalt between the mouth of Grande Ronde River and Wild Goose Creek were only hastily examined, and attention can only be given at this time to their more general features.

The rocks are plainly of sedimentary origin, as their stratification is prominent. They have a thickness of several thousand feet. The strata in the northern part of the section are inclined northward at an angle of 40° to 45°, and in places are nearly vertical. A great dome of ancient rocks has been cut through. The upper layers of the dome are thin-bedded siliceous limestone containing indefinite fossils;[1] beneath this are thick layers of thinly laminate, granular limestone, containing some silt and organic matter, which appear in conspicuous white ledges. This rests on schists that show a diversity of colors, varying from green to red, and are frequently fine and silky in appearance. Marked contrasts are apparent in the schists, some layers being schistose conglomerates or breccias, while others resemble the finest roofing slate. The schist has great thickness, and is believed to rest on granite. The lower contact of the schist was not seen, but granite occurs abundantly in the pebbles along Snake River, and is reported by miners to come to the surface a short distance above Wild Goose Creek. The topography in that region bears out this statement.

No more than a hasty outline of the character of the rocks here referred to is possible at this time, as my opportunities for observation were, for several reasons, very limited. It seems evident, however, that a broad uplift, with a granite core, passing upward into schist and then again into but moderately altered limestones, was buried beneath the basalt and again exposed and deeply dissected by erosion. The geologic age of the schists and limestone is unknown, but a careful search in the limestone would very likely reveal fossils by which it might be determined.

Standing on the summit of Mount Wilson, which is a remnant of the basaltic plateau left isolated by the cutting of the canyon of Snake

[1] Samples of this limestone have been studied by Mr. J. S. Diller, who reports that thin sections examined under the microscope "do not show fossil forms nearly so distinctly as the weathered surfaces. The specimen was shown to Mr. G. H. Girty, and he agrees with me not only that the fossils are crinoids, but that one of them has a pentagonal stem. Crinoids with stems of this sort are not definitely known to be older than the Permian, and it is probable that this one is considerably later. The specimens examined look very much like the Triassic limestone of California, in which fossils are abundant."

River and the much narrower but nearly as deep gorges of Joseph Creek and Grande Ronde River, one may command a far-reaching view of the deeply dissected region about, and may read the leading facts in its geological history as plainly as from a printed page.

Eastward from Mount Wilson one beholds the deepest and wildest portion of Snake River Canyon. Fully 50 miles of the great gorge are in full view. To one familiar with the narrow, trench-like character of the same canyon for 100 miles or more below Lewiston, it is at once apparent that marked variations in nearly all its features accompany the change produced by the unearthing of the buried mountain range already briefly described. The canyon is deeper, also, than farther downstream, for the reason that Snake River has here cut across the flank of the Blue Mountain uplift. Where the metamorphic rocks form a large portion of the canyon walls the excavation is probably four or five times as wide as where it is cut wholly in basalt. The distance from the remnant of the old plateau surface forming Mount Wilson across the canyon to the fringe of pines growing on the crest of the opposite wall is, by estimate, fully 15 miles. In this interval there is what seems at first a bewildering maze of mountain-like ridges, palisades, towers, and battlements. Many of the forms are strikingly architectural in appearance. Vast buttresses of schistose rock, rising precipitously from the depths of the canyon, form the basements of huge castle-like masses of basalt, in which the horizontal bedding resembles courses of cyclopean masonry. The student of topographic forms sees at a glance that not only the more prominent features of the rugged landscape, but the details in the sculpturing of the seeming castles and palaces conform to well-known laws of erosion, weathering, and rock structure. In the upper portion of the canyon walls the horizontal bands formed by the edge of lava sheets may be traced on either hand as far as the eye can reach. Many of the lava sheets are columnar. The long colonnades, lessening in perspective, may be followed into each alcove and lateral gorge, and far out on the buttressing ridges. At the ends of many of the spurs there are groups of towers and pinnacles formed of the ruins of isolated masses of columnar rock.

Below the basalt are sharp crests and ridges rising between lateral gorges that lead down from the battlements above to the silvery thread formed by the river in the depths below. In the lower portions of the canyon walls, where schists and granite are exposed, the prevailing lines are vertical, and are due to the erosion of lateral streams and rills. Where the lateral ridges approach the river they end in precipices, which frequently descend nearly vertically for a thousand feet to the water's edge. At such localities there is no room for one to pass between the river and the towering cliffs. It is the abruptness with which the lateral spurs plunge down to the river that gives the vast gorge much of its canyon-like character.

In breadth and depth and in the multitude of details this canyon is comparable with the greatest of all canyons in North America, namely, the Grand Canyon of the Colorado. One of the greatest charms in the wonderful scenery of the Colorado, however, is wanting in Snake River Canyon, namely, the varied and brilliant coloring. The canyon of Snake River is dark and somber. The black and brown of weathered basalt and the dull gray of schist and granite find scarcely any relief from brighter colors. The pleasing tints imparted to the scenery of many regions by the iron oxides in residual soils are absent. The vegetation is too scanty to mask the angular forms or enliven the somber tones of the rocks, although the massive cliffs are in places veneered with yellow lichens, and in the lateral gorges, where springs well out, there are faint lines of verdure. In autumn these thickets of willow, haw, and roses assume brilliant hues. The talus slopes between the horizontal cliffs of basalt, as well as the surfaces of the ridges and domes of schist and granite, are clothed with bunch grass, which gives to them a silvery sheen that is ever changing when the wind blows.

On looking across Snake River Canyon from the summit of Mount Wilson, the junction of the horizontally bedded basalt with the schists and granite beneath can be distinctly traced for a score of miles. The crest line of the buried mountain is rugged and serrate. The gorges between the higher crests and spires are filled with horizontal sheets of basalt, showing that the fiery flood flowed about the ancient peaks, leaving them for a time as islands in a sea of molten rock, and then overtopped their summits and completely buried them from sight. This impressive spectacle of what was once a sharp-crested mountain range, rising at least 2,500 feet and probably more than 3,000 feet above the adjacent valleys, and subsequently buried beneath horizontal sheets of molten rocks, and ages later revealed by the slow down-cutting of a river canyon, is one of the most instructive lessons that the student of geology and geography will find anywhere in the world.

Glancing westward from Mount Wilson into the magnificent canyon of Grande Ronde, which has been excavated in the Blue Mountain uplift, one sees at least a thousand feet of horizontally bedded basalt which lies above the level of the summit on which one stands. The Columbia lava is, therefore, not less than 5,000 feet thick. Of its maximum thickness we have as yet no measure.

But to return to the metamorphic rock. No granite was found by me in the canyon of Snake River; but, as already stated, it is reported to occur a little above the mouth of Wild Goose Creek—that is, to the south of the point where the Washington-Oregon boundary meets the river. In the canyon walls, as we have seen, the basalt is clearly distinguishable from the rocks beneath it. The schists also have topographic forms of their own, in which the bedding, now highly inclined, and the joint planes play an important part. As the eye ranges along the cliffs bordering Snake River upstream from the mouth of Grande Ronde, a marked change is apparent in the sculpturing of the older rock-series a few miles south of Mount Wilson. The sharp crests and steeply inclined bedding planes of the schist there give place to rounded domes and hillocks. The immediate banks of the river are precipitous, but at a height of perhaps a thousand feet above the water the slopes are more gentle, and a rude terrace with rounded curves and flowing outlines, some 3 or 4 miles broad, leads to the cliffs of basalt which define the upper margin of the canyon. The forms seen on the terrace-like slopes are such as are familiar in many localities where granite is the surface rock and where weathering is far advanced. Further exploration in this interesting region will probably show that the series of limestone, schist, etc., already briefly described, rests on granite, and that for many miles along the boundary between Oregon and Idaho this rock will be found in the immediate banks of Snake River. I have spoken of the rocks beneath the basalt as belonging mainly to the metamorphic series, but whether this granite is a sedimentary rock changed by heat and pressure or is of igneous origin I leave others to discover.

The schists exposed in Snake River Canyon, like the similar rocks a few miles farther downstream, are traversed in every direction by small segregated quartz veins, which have been reported to be gold bearing. Several mining claims have been located along the canyon wall on each side of the river, but whether any of these will repay mining is not known. From a knowledge of similar rocks elsewhere the value of these mines seems doubtful. In the alluvial deposits along Snake River at the mouths of lateral gorges in the schists, placer mining has been carried on from time to time for several years. Hydraulic mining on a small scale has been attempted, but with what success I am unable to state.

Granite, schist, quartzite, etc., north of Snake River.—The eastern boundary of Washington to the north of Snake River cuts across the foothills of the mountains of Idaho, leaving some of the ridges and outstanding buttes to the west of the line. The geology of western Idaho is as yet unwritten, but, as shown by the sand and gravel in the streams which enter Washington, the rocks to the eastward include granite, gneiss, quartzite, diorite, etc. Mountains consisting largely of these rocks form the eastern limit of the overflows of Columbia lava in the region here considered. The great basaltic plateau meets the mountains in a sinuous line which in a general way coincides with the interstate boundary. The mountains along this boundary resemble a rugged coast line, but the sea is replaced by the plateau of lava. Rounded and weather-beaten capes and promontories on the shore of the lava sea project into the wheat lands of the plateau and a few islands of quartzite break the monotony of its surface.

To term the rolling prairie lands of the "Palouse country" a sea and the hills to the eastward its rugged shore is not entirely a rhetorical figure. The basalt forming the vast plateau was once molten and flowed over the land in successive inundations of liquid rock. The plateau was then a sea of fire. As sheet after sheet of molten rock was spread out, the floods rose higher and higher on the rock-bound coast. Valleys and embayments in the mountains were flooded and now have level floors of basalt. The eastern limit of the region covered by these fiery inundations is sharply defined not only by the topography but by the junction of the wheat fields which flourish on the soil formed by the decay of the lava with the uncultivated uplands.

The lavas are less deep in the neighborhood of the mountains than farther westward, and at one locality at least have been cut through by stream erosion so as to expose the granitic rocks beneath. At what is known as Granite Point, on the Northern Pacific Railroad, about 8 miles southeast of Pullman, in township 13, range 6, a few hundred square feet of gneiss (?) may be seen in the bottom of a shallow valley. This rock has been quarried in a small way and found serviceable for rough masonry. It is somewhat weathered, but the usual products of long-continued disintegration and decay are absent. The shape of the rock surface exposed and the absence of débris on it suggest that it is the summit of a hill from which all loose material had been removed before the floods of lava buried it from sight. The rock at this locality is of the same character as that already mentioned as occurring at Granite Point, in Snake River Canyon, about 10 miles distant. The difference in elevation between these two exposures of the old land surface beneath the basalt is approximately 2,000 feet. This is one of many observations which indicate the roughness of much of the country which was changed to a level plateau by the basaltic overflows.

The most striking evidence, however, of the ruggedness of the topography of the buried land and of the ocean-like character of the inundation of molten rock that flowed over it is furnished by the old mountain peaks, that now rise as islands above the yellow wheat lands. These islands are within a few miles of the border of the basaltic overflows. All of the old landmarks where the basalt is deepest are completely buried. Islands of granite surrounded by basalt, near the northern border of the plateau, in the neighborhood of the Grand Coulée, in the Big Bend country, were described in a previous report[1] but far more impressive examples of the same general character are furnished by Kamiack and Steptoe buttes in the Palouse country.

Kamiack Butte.—In Whitman County, 9 miles north of the town of Pullman, there stands a picturesque hill of quartzite and of quartzose conglomerate rising 500 or 600 feet above the surface of the surrounding basaltic plateau. This is the summit of a bold hill that was completely surrounded by the inundations of molten rock.

[1] Bull. U. S. Geol. Survey No. 108, 1893, p. 90.

The soil on Kamiack Butte is sandy and was derived from the disintegration of the underlying rock. It differs in a marked way from the soil of the adjacent wheat lands. There is no evidence to show that the basalt ever covered the butte, although it rose between 100 and 200 feet higher than the present plateau surface. The lowering of the surface of the plateau is due to the disintegration and decay of the basalt and the removal by stream and wind erosion of some of the fine soil thus produced. It is an instructive fact, as will be noted in advance in considering the origin of the low hills of the originally level plateau surface, that the soil of the plateau has not been blown over the rocks forming the butte.

To the southwest of Kamiack Butte and about 2 miles distant is another but lower elevation of the same character. To the eastward, also, there is a range of hills, apparently composed of quartzite, which extends into Idaho, and is of the nature of a cape projecting into the sea of formerly molten rock. The extremity of this ancient headland is separated from Kamiack Butte by 2 or 3 miles of basalt.

Steptoe Butte.—This remarkable feature in the relief of eastern Washington is situated in Whitman County, 8 miles west of the town of Garfield, and 10 or 12 miles from the hills which bound the basaltic plateau on the east. It rises between 1,000 and 1,100 feet above the plateau which surrounds it on all sides. From every direction, over a wide extent of country, the butte is a prominent landmark, and from whatever point of view it is seen it appears as a steep-sided and sharp-pointed pyramid. When viewed from the eastward, its southern slope makes an angle of 18° and its northern sides an angle of 19° or 20° with a vertical line. Each side is gently concave and gives to the eminence the appearance of a volcanic cone. The slopes on all sides except the west, which is easiest of ascent, are about as steep as is shown by the measurements just given.

Steptoe Butte, like its lesser companion described above, is composed mainly of quartzite, but at the summit the rock has the character of a quartz-schist. Its sides are not encumbered with loose débris, and but little soil has formed from the disintegration of the hard, resistant rock. It is plainly the summit of a bold mountain peak, the base of which was deeply buried by the overflows of lava that surrounded it and left it as an island.

The instructive panorama spread before an observer on Steptoe Butte leads naturally to a digression from the study of the geology of the butte itself. From this commanding summit we can with advantage, I think, review some of the leading features in the geography of the region under consideration.

To accommodate tourists, a commodious hotel has been built on the apex of the great pyramid. From about the hotel we may in an hour obtain a far more graphic idea of the characteristics of the surrounding region than days of travel across the plateau and over the neighboring mountains would furnish. In all directions from the base of the butte extend the vast wheat lands of the basaltic plateau, which are seemingly as level as the sea. The short hills and level-floored depressions on the surface of the plateau enhance rather than detract from this resemblance. It is a stormy sea, but none of the wave-like hills rise above a certain general level. The distant horizon is undulating, like the sky line on the ocean after a storm. The view to the north, west, and southwest is limitless. Not a single landmark rises above the general level of the roughened plain. Far away to the south a long, low arch, forming a silhouette in blue against the sky, reveals the outline of the Blue Mountains. The base line of the arch is 30 or 40 miles long, and the height of its crest not over 1,200 or 1,500 feet above the general level of the intervening plateau. We know that in the vast plain that extends to the Blue Mountains there is a deep canyon through which Snake River flows, but it is only under exceptionally favorable conditions of the atmosphere that its course, easily mistaken for the shadow of a passing cloud, can be traced through the yellow wheat fields. To the eastward one sees the dark forest-covered hills and mountains of Idaho, and can trace the sinuous line formed by the junction of the intervening plateau with the highlands that determine its border. Each level-floored inlet and embayment is yellow with grain and each headland dark with pines. These and other features of the border of the once molten sea of lava can be as easily recognized as the inlets and headlands of the coast of Maine when viewed from the summit of Mount Desert Island.

Before the rich soil of southeastern Washington was furrowed by the plow it was covered with bunch grass, but destitute of trees and shrubs. At present practically every acre of the plateau surface is under cultivation. The observer on the summit of Steptoe Butte looks down on a limitless patchwork of brown and yellow. The brown is the soil of fallow land, the yellow the golden of the wheat fields. It is the custom to take but one crop from the land in two years, so that each summer practically half of the land lies fallow. The yellow grain fields and the brown, plowed lands are interspersed with each other as far away over the plateau as the eye can reach. Although there are thousands of farmhouses in the field of view, they are nestled in valleys and hollows, and only a few near the immediate base of the butte are in sight.

Next to the boundless expanse of the level plateau, the most interesting feature of the landscape is furnished by the wave-like hills and streamless depressions that give diversity to the grain fields. When I visited Steptoe Butte late in September the wheat had been harvested, and the paths of the reapers surrounded the hills like the contour lines on a map and served to accent the peculiarities of their forms. The origin of the hills, however, and the nature of the deep, rich soil of which they are composed can be better understood from a nearer inspection and will be discussed later. Let us now return to our study of the ancient crystalline rocks.

The uplands, consisting largely of quartzite and granitic rocks which occur north of Snake River along the general course of the Washington-Idaho boundary, swing westward near Spokane and form the mountainous region of northeastern and northern Washington. This region is known in an indefinite way as the "Okanogan country." As described in Bulletin No. 108, the Columbia River in making its wide detour termed the "Big Bend" follows the base of the mountains that determine the northern border of the basaltic plateau. The same great series of crystalline rocks is continued westward and forms the mountain about Lake Chelan and the northern part of the Cascade range. Much of this region of crystalline rocks is rich in minerals, and excellent building stone abounds. This most promising field for geological study awaits exploration.

KITTITAS SYSTEM.

In west-central Washington, notably in Kittitas County and crossing the Columbia at Wenatchee, there is an important system of sandstones and shales carrying valuable beds of coal, which rests on the series of ancient crystalline rocks described above, and is covered in part by the lavas next to claim attention. The coal mines at Roslyn are in this system.

In Bulletin No. 108 I have proposed the name of Kittitas system for these coal-bearing rocks, for the reason that they form the surface over a large part of Kittitas County. The rocks of this system have not been studied and their boundaries are unknown, but in the central part of Kittitas County they pass beneath the series of lava sheets forming the basaltic plateau of central and southeastern Washington, and may possibly extend beneath the region described in this report. No outcrops of the rocks of the Kittitas system are known, however, east of the Columbia, except in the neighborhood of Wenatchee, but it is not improbable that they extend somewhat widely beneath the lava rock of the central basin.

COLUMBIA LAVA.

As already stated, the great basin between the mountains of Idaho and the Cascade range, including what is known as the "Big Bend country," or the Great Plains of the Columbia, and all of the southeastern portion of Washington, is covered with what is termed, in a general way, lava rock. Since a convenient geographical name for this lava is desirable, I have suggested the term "Columbia lava," for the reason that much of the country covered by it is drained by the Columbia River and its branches.[1]

Origin.—The Columbia lava was poured out from openings in the

[1] Bull. U. S. Geological Survey No. 108, 1893, p. 21.

earth's crust in a molten condition, in much the same manner that volcanoes at the present day are discharging similar material. It probably came from fissures in the earth's crust, however, instead of from individual vents, as in the case of Mount Rainier, for example, and spread away from the fissure in highly liquid sheets, which flowed rapidly.

As is shown wherever canyons have been cut in the Columbia lava, it is not one vast flow, but is composed of many beds, frequently from 50 to more than 150 feet in thickness, which are separated by scoriaceous layers and other partings. The surfaces of flows which cooled before the next sheet above was poured out are frequently rough and of a cellular or scoriaceous character and are occasionally covered with lapilli, as well as with widely extended layers of clay and sand and old soils.

The statement that the lava was poured out through fissures is based in part upon an hypothesis which is held for the reason that the features characteristic of volcanoes are absent and no plausible account of the origin of the lava, except by "fissure eruptions," has been suggested. The fissures through which the lava is supposed to have reached the surface would be filled with similar material and would give origin on cooling to what are known as dikes. At one locality in Kittitas County, where the rocks beneath the lava have been exposed by erosion, large dikes of this nature have been seen.[1] This observation is in direct support of the fissure-eruption hypothesis. The large number of separate sheets of lava, however, demand under the hypothesis mentioned that the earlier overflow should have been broken by fissures, in order to admit of the escape from below of the molten material which rose and overflowed the surface so as to form the later sheets. Dikes should therefore be expected to occur in the lower sheets of lava leading up to the superior layers. Although the Columbia lava has been deeply dissected by stream erosion, only three or four dikes cutting across the layers have been seen. These are situated in the walls of Grande Ronde canyon and are all small, the largest being only about 30 feet thick. Whether these dikes lead to lava sheets higher in the canyon wall and indicate the fissures from which material forming the superior sheets was derived is not certain, for the reason that disintegration has obscured the upward extension of the dikes and made it impossible to trace them for more than a few hundred feet above the present level of Grande Ronde River.

Throughout the hundreds of miles of cliffs formed by the walls of stream channels through the Columbia lava that have come under my notice, with the exception of the locality just mentioned, dikes are absent. There is thus seemingly a weakness in the evidence which should be looked for in support of the fissure-eruption hypothesis,

[1] Bull. U. S. Geol. Survey No. 108, 1893, pp. 67-68.

but this may be removed when the region covered by the Columbia lava, especially in the vicinity of the Cascade Mountains, is more extensively examined.

Extent.—The Columbia lava is by far the most extensive of the geological formations in the far Northwest. It is also the most important from an economic point of view, since by the disintegration and decay of its surface layers it has furnished the wonderfully rich soil on which a large portion of the grain of Washington and adjacent States is raised.

The boundary of this great series of volcanic overflows in eastern Washington, from Snake River northward to Spokane River, and thence westward along the Columbia, has already been briefly described. The Columbia lava occurs also in the Cascade Mountains of Washington and Oregon, and extends southward into California. To the east of the Cascade Mountains it occupies much of Oregon and large portions of southern Idaho. Although its boundaries have not been mapped, it is known to occupy an area of not less than 200,000, and possibly as much as 250,000, square miles.

Thickness.—The Columbia lava, as already stated, was poured out in a molten condition and spread over the country like a series of fiery inundations. The surfaces of the various sheets were originally practically horizontal, but the surface of the inundate country was uneven and, in part at least, mountainous. The depth of the hardened lava at various localities would therefore depend on the character of the topography of the region it covers. The original thickness has been decreased by erosion, but, except in the canyon, this is not great. The loss from the surface of those portions which have not been upraised or tilted is, under the most liberal estimate, not over a few hundred feet.

The maximum thickness of the lava, or, considering it as a congealed sea of molten rock, the deepest sounding, is not known. About the margin of the basaltic flows along the Columbia River, in the "Big Bend country," canyons 300 or 400 feet in depth reveal the granite beneath. Along Snake River Canyon for over 100 miles from its mouth 2,000 feet of lava is in sight. Where Snake River and the Grande Ronde cut into the Blue Mountain uplift, between 4,000 and 5,000 feet of horizontally bedded lava is exposed. This is the deepest section yet discovered, but even there the base of the series is not seen. It seems safe to conclude that the maximum thickness is in excess of 5,000 feet. In the Cascade Mountains, according to Prof. Joseph Le Conte, 3,700 feet of lava is to be seen. From my own observations in that region, however, I should not be surprised if much greater thicknesses are discovered. The average thickness for the Columbia lava in the State of Washington was thought by Lieutenant Symons[1] to be not far from 2,000 feet. In a former report I was dis-

[1] Bull. U. S. Geol. Survey No. 108, 1893, p. 21.

posed to agree with this estimate, but observations since made along Snake River certainly indicate that the average thickness over large areas must be much in excess of the amount stated. Estimates of the average thickness can at present have but little value, however, as even single measurements of the total thickness are lacking, except near the borders of the lava-covered region.

Character of the rock.—The general appearance of the rock forming the widely extended formation under discussion is familiar to everyone in southeastern Washington. It is the common black rock of the country. It underlies all of the wheat lands, and is splendidly exposed in the canyons of the Grande Ronde, Snake, Palouse, and Spokane rivers, and along nearly all of their branches west of the Washington-Idaho boundary. To the geologist this rock is known as basalt.[1] It is dark, usually black, in color, but various tints of gray, green, brown, and red are not uncommon. Most of the variations from the normal black or nearly black color are due to weathering. The upper surfaces of some of the sheets, however, are red, owing to the oxidation of the iron in the rock while it was yet highly heated.

One of the latest lava flows in the great series here considered occurs in Yakima County, between Cowiche and Natches creeks, and differs from all other portions of the Columbia lava now known. The lava sheet referred to consists of what is termed hypersthene-andesite, and contains prominent crystals of the mineral hypersthene.[2] When the Columbia lava is critically studied, it is probable that other rocks nearly related to basalt, but differing from it in chemical and mineralogical composition, will be discovered.

Except when the molten magma cooled with excessive rapidity, as on coming in contact with water, or flowed over wet sands and clays, the material composing it became crystallized. The slower the cooling, the larger the crystals that were formed. The central portions of the various sheets are for this reason usually coarser in texture than their surfaces. In a few instances the bottom of a layer is almost glassy for an inch or two in thickness, owing to sudden cooling. Fragmental material, sometimes found in sheets between the layers, and probably formed by the disintegration of the highly heated rock on coming in contact with water, is also excessively fine grained and vitreous in luster.

The crystals of which the basalt is composed can seldom be seen by the unaided eye, but when thin sections of the rock are studied with

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[1] A characteristic sample of this rock from Mill Creek, near Walla Walla, has been examined by Mr. J. S. Diller, who reports as follows concerning it: "The rock is a characteristic basalt, composed of plagioclase feldspar, augite, olivine, and magnetite, with considerable globulitic base. The feldspars are well developed, with crystallographic boundaries. The augite is less well developed and is generally granular, as is also the olivine. The magnetite is mostly in octahedral crystals, which for the most part are arranged in groups made up of lines perpendicular to one another. The rock is perfectly fresh and unaltered."

[2] Bull. U. S. Geol. Survey No. 108, 1893, pp. 64-65.

the assistance of a microscope their nature is clearly shown. The minerals which make up the bulk of the rock are feldspar, augite, olivine, and magnetite, and crystals of other minerals are scattered thickly through uncrystallized portions of the magma, which forms a glassy groundmass. The minerals mentioned are silicates of alumina, magnesia, soda, potash, lime, iron, etc., and when the rock decomposes on weathering these substances are more or less perfectly liberated.

Chemical analyses of basalt show that in general it contains from 46 to 57 per cent of silica and from 11 to 22 per cent of alumina, together with lime, magnesia, potash, etc., in proportions varying from a small fraction of 1 per cent to over 10 per cent. It is the presence of lime, potash, and phosphoric acid in the basalt that gives the soils formed from its decay much of their richness for agricultural purposes.

Columnar structure.—The columnar structure of many of the lava sheets gives interesting details to the massive architecture of the canyon walls at many localities. This structure, as is well known, is due to the shrinking of the rocks on cooling. The columns have their longer axes at right angles to the cooling surfaces, and consequently, in horizontal sheets, are vertical. When a canyon is cut through a series of beds having this columnar structure, the section of each layer presents the appearance of a long colonnade of closely set vertical shafts.

The columns are most commonly hexagonal in cross section, although other forms, with sides ranging from three to eight, may be found They are frequently 3 or 4 feet in diameter, but sometimes larger, and from a few feet to 30 feet or more in height. The larger columns are not usually sharply defined, as their sides are apt to be irregular. The most perfect examples have usually a diameter of from 15 to 25 inches. One of the best displays of columnar structure that I have seen occurs on the left bank of Snake River, about 3 miles above the mouth of Alpowa Creek. A long colonnade is there exposed, forming a vertical wall 30 to 40 feet high, in which the shafts are remarkably even and of uniform size. The columns are mostly six-sided and about 14 inches in diameter. Beneath this columnar layer is a bed of pure-white volcanic dust. The removal of this soft layer by the river has led to the undermining of the heavy sheet of basalt resting on it and the breaking away of the jointed rock, so as to form the wall in which the columnar structure is so well displayed.

The breaking of the basalt into columns is due, as stated above, to shrinkage on cooling. Breaks in the rock, termed joints, are thus formed. These are best developed when cooling is slow, and for this reason the central portions of lava sheets are frequently regularly jointed—that is, divided into well-defined columns—while the top and bottom portions of the sheets are confusedly jointed, and separate into blocks of all shapes and many sizes. The irregularly jointed rock does not fall apart so readily as that in which the joints are parallel and well developed. It is for this reason that the rows of columns exposed in the canyon walls so frequently rise from a projecting base and support an overhanging cornice above.

In some localities, particularly where the basaltic columns are of large size, their surfaces present a network of grooves looking like the cracks formed in the surface of mud on drying. The origin of these peculiar markings was not apparent until weathered surfaces were examined. It was then found that the columns frequently have a well-defined internal structure. They are formed of small columns similar in form to the main shafts, but usually only an inch or two in diameter. These secondary columns radiate from a confusedly jointed central core and terminate in more or less regularly shaped prisms at the surface of the main column. It is the junction of the bounding planes of the secondary columns with the surface of the main shafts that gives rise to the peculiar figures mentioned above. These figures, frequently six-sided, but usually irregular, are best seen when the surfaces of the main columns are somewhat weathered. The cracks or planes of jointing that define the sides of the large columns are, as already stated, at right angles to the cooling surfaces. The secondary columns are at right angles to the master joints, which determined the cooling surfaces of the material forming the columns bounded by them.

The best locality for studying this secondary columnar structure that I have noticed is on the left bank of Snake River, about 6 miles above Asotin, where an excavation for a road has recently been made at the base of a great precipice.

The sides of the columns into which the Columbia lava has so frequently been broken seldom present plane surfaces, but are irregular in many ways. The convexities on the side of one column fit accurately into depressions in the sides of the adjacent columns and serve to lock the columns together, and thus admit of their standing in vertical precipices. The columns in the face of a cliff are frequently so loose that one can move them with the hand, but the interlocking of their irregular sides with their neighbors holds them in place.

The series of vertical joints which divide the horizontal sheets of basalt into columns are frequently crossed by other joints or breaks, which are horizontal. There are at least two classes of these horizontal joints, one of which affects individual columns, while the other runs through a large series of columns.

The cross joints which affect individual columns break them into sections from a few inches to perhaps 3 or 4 feet in length. The summit of each section is commonly concave, or depressed, so as to form a saucer-shaped hollow, into which fit the rounded ends of the sections next above. It is seldom, however, that this ball-and-socket arrangement, so well displayed at the Giant's Causeway, Ireland, on the Isle of Staffa, Scotland, and in other classical exposures of basaltic rock, is characteristically exhibited in the Columbia lava.

The other variety of horizontal jointing, of which mention was made above, extends for long distances, and frequently affects a series of vertical columns several miles in length. These breaks make important division planes in the canyon walls. While in general horizontal, they sometimes make sharp downward bends, but when this occurs the columns still maintain a direction at right angles to the breaks—that is, the joints are parallel with the cooling surfaces that controlled the arrangement of the columns. When the horizontal division planes make a sharp downward curve, the columns radiate from a center situated above. When two or more generally horizontal division planes have been developed, they are strictly parallel with each other and have similar downward curves where groups of radiated columns occur. The vertical distance between two well-defined planes is in some instances not over 3 or 4 feet; at other times the interval is 20 or 30 feet.

The widely extended horizontal joints just described may be distinguished from bedding planes by the fact that the generally vertical columns cross them without change in direction, and also by the fact that they are narrow and sharply defined; and again, for the reason that the rocks above and below are not scoriaceous and have none of the features that characterize the surface and basal portions of lava flows.

So far as I am aware, these widely extended horizontal joints have never been explained, but their parallelism with the surfaces of the lava sheets suggest that they are due to the shrinking of the rock as cooling progressed from the surface downward.

While the systems of vertical columns and frequent presence of horizontal joint planes make the regular jointing conspicuous, the fact is not to be overlooked that the rock, where this systematic arrangement is not pronounced, is also broken in a similar way, but without regularity. This becomes especially evident when apparently solid cliffs crumble on weathering, and an irregular series of joints is developed.

Scoriaceous surfaces and amygdaloids.—The surfaces of the various flows of Columbia lava are usually cellular or scoriaceous, while at a depth usually of a few feet the rock is compact and practically without cavities. As is well known from the study of modern lava streams, the oval holes and blebs, sometimes drawn out by the flow of the still plastic rock so as to be greatly elongated, are due to the expansion of steam and gases within the highly heated and still pasty material. On account of the action of the oxygen of the air on these rocks while still heated, or afterwards as they cooled and weathered, the iron contained in them was usually oxidized and the rocks acquired a red color. The scoriaceous layers are therefore frequently red.

The upper surfaces of the various sheets are characterized especially by a cellular or scoriaceous condition; the under surfaces also have the same characteristics, although usually not so well marked. As a lava stream advances, its surface becomes cooled and forms a scoriaceous crust, which may be sustained for a time on the still moving and highly liquid lava beneath. A hardened crust also forms on the extremity of the moving sheet, and is rolled under as the sheet advances. Scoriaceous rock is thus transferred from the surface to the base of a lava stream. Where sheet has succeeded sheet, each formed by an outpouring of molten rock, it is frequently difficult to say just where the junction plane separating them is located, for the reason that the rough, scoriaceous surface of the lower sheet is involved and embedded in similar material, which was poured out over it.

The basal portions of lava sheets, especially when they rest upon soft deposits like clay, are sometimes smooth, and have a dense outer rind with a glassy structure, due to rapid cooling. An instance of this nature observed at Spokane is described on page 53.

The cavities in scoriaceous lava frequently become filled with mineral matter, and on breaking open the rock that has undergone this change kernel-like grains are found instead of cavities. The mineral matter in such instances, most frequently some form of quartz, has been deposited from solution by percolating water since the rock hardened. Rocks containing cavities which have been filled in this way are termed *amygdaloids*, from the resemblance of the kernels to almonds. The kernels or amygdules may be of any shape, however, and not infrequently in the Columbia lava are very irregular. In some of the layers of the lava, as was observed especially in the canyon of the Grande Ronde, the cavities are not completely filled, but each one has a thin lining of quartz. As the rocks weather the small hollow kernels are liberated and occur scattered through the soil.

Larger cavities in the lava at times become filled with a form of silica known as chalcedony, which has a yellow color and looks like bright yellow resin. When this mineral presents bands or layers of different color, it is known as onyx. The presence of this mineral in the Columbia lava has led to crude mining at a few localities with the hope of discovering beds of onyx, but thus far little if any material of commercial value has been found.

Another form of silica, known as opal, also occurs as amygdules in the Columbia lava, and very beautiful stones having bright colors have been obtained. These stones are of the variety known as harlequin opals, and are frequently of great brilliancy and in every way of excellent quality. Opal mining has been carried on in a small way at Moscow and a few other localities in Idaho, and the conditions seem favorable for continuing this industry. Common opal, of a milky-white color and without the gorgeous play of colors that makes the harlequin opal one of the most beautiful of gems, occurs at very many horizons, and so long as we do not know the precise conditions that cause the variations in the character of the silica deposited in cavities in the lava, one may hope to find the variety having brilliant colors at almost any locality.

Extent and thickness of individual sheets.—In the walls of many of the canyons that have been excavated in the balsatic plateau, and especially in Snake River Canyon and along Spokane and Columbia rivers, individual layers of lava may be traced for miles, and even for scores of miles, without notable variation in thickness or in general characteristics. I have not made continuous journeys of more than 25 or 30 miles through the canyons, but have entered them at various places. Localities on their brinks frequently command a view of 10 or 15 miles of the opposite wall, and from exceptionally favorable localities for observation, like the summit of Mount Wilson, the edges of the lava sheets may be seen clearly exposed for not less than 40 miles. In no instance have I seen a lava sheet thin out or in fact present any marked variations. It is evident that the lava was highly fluid at the time of its extrusion, and that it spread widely over the country in horizontal sheets of remarkably uniform thickness. Few exact measures of the thickness of individual sheets have been made, but by eye estimates it is safe to say that many sheets are from 40 to 60 feet thick, and not infrequently layers of more than double these amounts occur. The average thickness, I should judge, would be 60 or 80 feet.

Number of overflows.—In almost any view of the walls of Snake River Canyon, which furnishes the best section known of the Columbia, 50 or 60 well-defined bands may be seen, which at first sight appear to be the edges of individual lava sheets. A closer examination will show, however, that some of even the most conspicuous horizontal partings do not mark the junction of separate lava sheets, but are due to the horizontal jointing already described. Some of the bands, too, are due to the columnar structure of the central portion of the various sheets adjacent to other portions of the same flows which are confusedly jointed. For these reasons, and also because the terraces or steps in the canyon walls are covered with loose rocks and soil, banked high against the cliffs above, it is difficult to determine how many individual lava sheets have been cut through in order to form the canyon. Reliable evidence of the vertical extent of the individual sheets of lava is sometimes furnished by interbedded layers of sedimentary origin, like sand and clay, and also by sheets of fragmental material, termed lapilli and volcanic dust. It is infrequent, however, in eastern Washington that evidence of this nature can be had. Usually, the only safe method of distinguishing the individual flow is by noting the occurrence of scoriaceous bands.

On counting the numbers of scoriaceous bands exposed in the walls of Snake River Canyon, I found that at least eight lava sheets had been cut through to form the canyon where it is 3,000 feet deep. I am by no means confident, however, that this is the total number of sheets in sight. Although the canyon walls appear to offer abundant facilities for learning the number of individual flows exposed in them, yet difficulties arise when one attempts to measure an actual section, for the reason that large portions of the cliffs are concealed by talus slopes. I must confess that I did not make such a detailed study of the canyon walls as I had hoped to do, for the reason, in part, that I delayed the task until the most favorable locality should be found. The best localities for such a detailed study are in Snake River Canyon, above Asotin, but when in that section my time was too limited to do all the work I desired to accomplish.

Geological age.—Beneath the Columbia lava in Kittitas County there are coal-bearing rocks, termed the Kittitas system, which, as shown by their abundant plant remains, are probably of Eocene age, the oldest of the principal divisions of the Tertiary. Resting on the lavas in the same general region, and in part interbedded with them, is another series of beds which have been referred to the Miocene, or the middle portion of the Tertiary. This evidence seems conclusive that the Columbia lava was poured out somewhere near the middle of the Tertiary period.

Road material.—The basalt will probably never be in demand for architectural purposes, for the reason that it is too hard to be smoothed or polished economically, and also because of its dark color. It is of value, however, for rough masonry, as, for example, the foundations of buildings, abutments of bridges, etc. When crushed, it furnishes a most excellent material for macadamizing roads and streets or ballasting railroad tracks.

The fine soil of central and eastern Washington makes poor roads, as it wears easily, rises in dust when dry, and is soft and slippery when wet. At present the country roads and even the streets in the towns have but little attention given to them. But as the State grows in wealth and culture better roads will be demanded. The basalt will then furnish a limitless supply of material for their improvement.[1]

Artesian wells.—The artesian wells at Pullman, Palouse, and other places in Whitman County and adjacent portions of Idaho have been drilled in the Columbia lava. If other similar wells are to be had in southeastern Washington, they will have to penetrate the same series

[1] In Walla Walla and some other towns the practice prevails of covering the dusty streets to a depth of 5 or 6 inches with wheat straw. This temporary expedient is an improvement, but should not be allowed to delay the making of solid and practically dustless roadbeds with broken stone, on the macadam plan.

The country roads throughout southeastern Washington are frequently impassable for loaded wagons during wet weather, and, besides, follow section lines, without reference to hills or valleys. Economy, if no higher principle, demands that the rectangular road system should be abandoned in many regions and an effort made to give the roads gentle grades and smooth, hard surfaces.

The improvement of country roads, especially by the macadam process, is discussed by Prof. N. S. Shaler in the Sixteenth Annual Report of the United States Geological Survey.

of lava flows. In dealing with the artesian problem it is necessary to consider various conditions besides the character of the lava, and this discussion will therefore be postponed to a later portion of this report.

CLAY AND GRAVEL INTERSTRATIFIED WITH THE COLUMBIA LAVA.

Yakima Valley.—In the region occupied by the Columbia lava in central Washington, to the west of Columbia River, and described in a previous report,[1] there are several widely spread sheets of clay, gravel, sand, etc., of sedimentary origin, interleaved with the lava sheets. The brief account given in the report referred to, of the relation of the lava to these interbedded deposits, is as follows:

> 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 which appears again in the eastern portion of Saddle Mountain. Above this layer there are other lacustral deposits, belonging to the John Day system. Besides the widely spread interstratified sheets of basalt there are others more local and less well known; one of these was penetrated while drilling the artesian wells in Moxee Valley.

Southeastern Washington.—The examination made of the geology of southeastern Washington failed to show that deposits of aqueous origin, interstratified with the Columbia lava, are there as numerous as in the region mentioned above, to the west of the Columbia. This is an important matter, as it has a direct bearing on the question of artesian water supply. The localities where sedimentary beds occur interleaved with the basalt to the east of the Columbia are mostly near the eastern boundary of the basaltic plateau, in Spokane, Whitman, and Asotin counties.

A possible reason for the fact that a greater number of sedimentary beds interstratified with the basalt have been recognized in the region west of the Columbia than in the country having a similar geological history to the east of that river may be that in the western area the lavas and interbedded deposits have been disturbed from their original horizontal position and the vast blocks bounded by faults have been upraised so as to expose the edges of the strata composing them and to allow the weathering out of the soft beds, in part, in such a manner as to reveal their presence in the topography. In southeastern Washington the rocks are, for the most part, still horizontal, and the only sections exposed to view are in canyon walls. Unless the escarpments are unusually steep, the soft beds are apt to be concealed by talus slopes and soil, and their presence masked. A more detailed study of

[1] Bull. U. S. Geol. Survey No. 108, 1893, p. 22.

the geology of this region will perhaps reveal a greater number of sedimentary beds in the basaltic area than is at present known.

Walla Walla Valley.—At a locality on the south side of Walla Walla Valley, about midway between Walla Walla and Wallula, the upper portion of a bed of fine clay beneath basalt is open to view for a short distance. The thickness of this bed that is exposed to view is only about 4 feet, but its total thickness is unknown.

Asotin country.—Near Asotin, on each side of Asotin Creek and less clearly exposed in the neighboring portion of Snake River Canyon, there are two horizons, one about 360 and the other approximately 700 feet above the town of Asotin, at which light-colored, evenly stratified clays appear between thick layers of basalt. The lower bed of clay is in the neighborhood of 40 feet thick; the upper one is certainly much thicker, but has not been measured. These sheets of clay are probably of wide extent, but owing to the manner in which comparatively thin, soft layers in a great series of hard beds became concealed at their outcrops in canyon walls by débris and soil, their presence was not clearly recognized in the bluffs and precipices bordering Snake River.

Palouse country.—At Pullman the upper portion of a bed of heavy clay is exposed near the bottom of the steep-sided valley in which the business portion of the town is located. This bed, as shown in railroad cuts northwest from the town, and in part by well borings, is about 30 feet thick. Its upper portion, to the depth of from 4 to 6 feet, has been baked and hardened by the heat of the lava that flowed over it, and is frequently dark, almost black, in color. At the immediate junction the clay is so much altered that it is difficult in small exposures to distinguish it from the overlying basalt, especially when the latter is somewhat weathered and disintegrated. Numerous vertical joints in the altered clay also increase its resemblance to igneous rock. This hardened surface portion of the stratum of clay, when traced downward, changes to unaltered clay, which in some places is yellow, light colored, and sandy. The thickness of basalt above this stratum is not less than 150 or 200 feet.

About 60 feet below the clay layer just described there is a second bed of sedimentary origin, composed of light-colored, unconsolidated quartz-sand and gravel, containing an abundance of mica. The rock intervening between these two sedimentary layers is compact, black basalt. The stratum of sand and gravel referred to has been revealed in drilling artesian wells, and has been penetrated to the depth of a few feet, but its thickness is unknown. It is abundantly water bearing.

The upper sedimentary bed at Pullman is plainly the sediment of a lake that existed on the basaltic plateau during an interval between the outpourings of lava. The layer of gravel and sand, 60 feet below, is of the nature of a stream deposit, or possibly the shore formation of a lake, and was derived mainly from the disintegration of the granitic hills bordering the basaltic plateau on the east. The distance from Pullman to the nearest granitic hills to the eastward that rise above the present surface of the plateau is only about 8 miles.

In drilling a well at Palouse, 12 miles northeast of Pullman, a water-bearing stratum of sand and gravel similar to that beneath Pullman was reached at a depth of about 100 feet below the surface. Palouse is, by aneroid measurements, 100 feet higher than Pullman, hence the water-bearing beds at these two localities are not the same. The gravels and sands at a depth of 100 feet at Palouse may represent the clay layers exposed in the streets of Pullman.

At Garfield a drilled well was put down to a depth of about 300 feet, but so far as I can learn no sedimentary deposits were reached. Three miles northeast of Garfield, however, on the farm of James Walters, a drilled well, 113 feet deep, passed through basalt for 65 feet from the surface and entered clay 14 to 15 feet deep, beneath which water-bearing sand was reached, from which water rose and overflowed at the surface.

In a north-and-south belt of country in general, some 8 or 10 miles wide, beginning about 4 miles south of Pullman and extending to beyond Rosalia, there are reported to be 40 or 50 wells that penetrate water-bearing strata interbedded with the sheets of basalt. The records of these wells are not all available, and in general the level of the ground at the surface where they are located is not accurately known. For these reasons it is impracticable at this time to construct a section of the rocks of the region.

A mile south of Palouse, and again about a mile west of Garfield, deposits of sandy clay and of pure white kaolin have been opened. At the first-mentioned locality the clays are used for making fire brick and pottery. These deposits are evenly stratified and evidently of lacustral origin, but the depth of soil about them renders it uncertain whether or not they are interbedded with basalt. There is little doubt, however, that they represent lake deposits that were covered with basaltic overflows, and that they were revealed at a later period by the erosion of stream channels. These deposits are similar to certain clays in Spokane, described later, that are covered with thick sheets of basalt; a fact which lends support to the hypothesis just stated.

The conditions described in a general way as existing from Pullman northward to Rosalia are probably continued northward to Spokane, but this tract of country was not examined. At Spokane I spent two days in making a hasty study of the exceedingly interesting geological features there well displayed.

Spokane.—Excavations made in the southern part of the city of Spokane have revealed important beds of coarse gravel and sandy clay with a thick sheet of Columbia lava above. Similar beds of basalt occur beneath the sedimentary layer, as is shown by other excavations, as well as along the adjacent portions of Spokane River. The most instructive of the excavations referred to is near the south end of Barnard street, now graded, where an electric-car line leaves the street and curves abruptly eastward. This cut is in general about 20 feet deep and approximately 150 feet long. For about 130 feet from Barnard street thin-bedded sandy clays with much mica and containing fossil leaves are exposed. A thickness of 10 or 12 feet of this deposit is in sight, but its bottom is nowhere revealed.

Resting in an irregular manner on the micaceous clays are coarse, uncemented gravels and water-worn bowlders. Above the gravel lies the covering of basalt, which, as shown in neighboring cliffs, is not less than 50 or 75 feet thick. An interesting feature of the basal portion of the covering sheet of basalt is the irregularity of its lower surface. The bottom of the basaltic sheet has rounded, smooth-surfaced protuberances or corrugations, between which the gravel and bowlders, together with detached fragments of the micaceous clay, frequently 12 to 16 inches in diameter, extend upward for 8 or 10 feet. Fragments of the micaceous clay in contact with the basalt show evidences, in their compactness and reddish color, of the effect of the heat of the lava which came in contact with them.

A rough sketch of the exposure described above, as seen in the north wall of the cut, is here reproduced from my note-book:

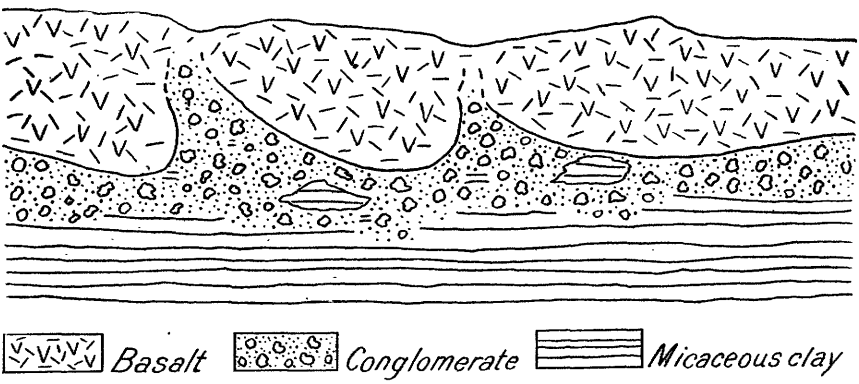


FIG. 1.—Section of lava flow and lake beds at Spokane.

The surface of the basalt is not only smooth, but when broken was found to be exceedingly dense and hard. The rock to a depth of about 2 inches has a vitreous luster and is almost a glass. Evidently this surface layer was cooled quickly.

The explanation of the peculiar relation of the basalt to the gravel and clays beneath it seems to be that the lava in a molten condition flowed over the deposits on which it rests in a direction from left to right, as shown in the above section. The loose deposits were disturbed and forced along in front of the flowing lava until the resistance became sufficient to check its progress, and at the same time the lava became cool and rigid. Still liquid lava broke out from the face of the arrested flow and advanced beyond the previously cooled border, overflowed the accumulation of stones and fragments of the micaceous clay, and again forced up a ridge of the loose material. This process was repeated several times in the portion of the flow exposed, and accounts for the marked inequalities in the under surface of the basaltic sheet and the manner in which confused masses of gravel and detached fragments of clay extend upward into the basalt.

The explanation just suggested is in harmony with the manner in which lava flows are known to advance. In describing the flow of lava streams on the Island of Hawaii, Dutton says:[1]

> After running some miles it [the molten lava] reaches more level ground, where it spreads out in great lakes or fields. It also cools on the surface, which gradually freezes over. But it is still hot within, and beneath its hardened covering the liquid rivers are still running, and at the edges and along the front of the great sheet the liquid lava constantly breaks forth, pushing out fiery rivulets in advance and laterally.

The lava that covers the lake beds and gravel deposit in Spokane appears to have advanced into a shallow lake, the bottom of which was disturbed and forced up in ridges. The contact of the lava with the water caused it to congeal rapidly and to form a glassy outer layer.

Near Spokane there are deposits of kaolin, similar to that already mentioned as occurring near Palouse, but remarkably fine and pure. I have not visited the pits from which this material is obtained, but from its character it appears to belong to the series of deposits under consideration.

Deposits of volcanic dust and lapilli.—On a previous page mention has been made of a layer of pure-white volcanic dust beneath a thick sheet of columnar basalt in Snake River Canyon, above the mouth of Alpowa Creek. This deposit owes its origin to a violent volcanic eruption, the location of which is unknown, that blew great quantities of exceedingly fine dust high in the air. The dust was carried by the wind to great distances and spread as a sheet over the land. This eruption occurred during one of the later intervals in the outpouring of the Columbia lava and the deposit was buried by the next succeeding lava overflow. The stratigraphic relation of this bed of volcanic dust to the overflow of Columbia lava is similar to that of the interbedded lacustral clays and stream-deposited sand.

In excavating for an irrigating canal on the side of Snake River Canyon at Pigeon Rock, below Asotin, a bed of coarse, yellowish, fragmental volcanic material over 10 feet in thickness was exposed. This deposit has compact lava sheets above and below, and owes its origin to the deposition of fragments of volcanic rock, frequently 2

[1] C. E. Dutton, The Hawaiian Islands and People; a lecture delivered at the United States National Museum, 1884, p. 13.

inches in diameter, which were blown out by a volcano, or perhaps formed by molten lava coming in contact with water. The fragments composing this lapilli sheet are of the same character as the dense, vitreous layers already described as forming the under surface of a lava sheet at Spokane. These lapilli deposits, unlike the sheet of white volcanic dust mentioned above, belong to the eruptions that poured out the Columbia lava, and are not, therefore, of distant origin.

Résumé.—Interleaved with the sheets of basalt forming the series named the Columbia lava, there are, as just shown, sheets of lacustral clay and of stream-borne gravel and sand, and layers of volcanic dust and of volcanic fragments termed lapilli. The lake beds appear to occur mostly near the border of the lava-covered country, for the reason that, in eastern Washington at least, the lava sheets flowed toward the mountains, and on congealing dammed their draining streams. The surface of the cooled and hardened lava flows must have had a slight slope in the direction of flow. The supposed absence of lake beds over the more central portions of the lava may be due to a lack of information, but seems to be a necessary result of the manner in which the lava sheets encroached on the mountains and blocked their draining streams. Shallow lakes were probably formed on the surfaces of the cooled lava sheets far from the mountains, but being at a distance from highlands that could furnish débris, they would not be deeply filled, and records of their existence would not be conspicuous.

The layers of volcanic dust, from the nature of their origin, should be widely spread, but up to the present time they have been observed at but few localities. Sheets of lapilli have been noted in the Big Bend country and near Asotin, but whether they are extensive or not remains to be determined. These various deposits found between the layers of Columbia lava at different horizons not only record interesting episodes in the history of the basaltic inundations, but, as will be shown later, have a direct and important bearing on the question of artesian water supply.

JOHN DAY SYSTEM.

In my report of a reconnoissance in central Washington, already cited, certain lacustral deposits are described which rest on the surface of the latest extensive lava flow of the Columbia system. This series of lake sediments consists principally of stratified clays, with thick strata of white volcanic dust, and in certain localities contains beds of coarse conglomerate. It is termed the John Day system, for the reason that it is thought to be an extension of a similar formation which occurs in John Day Valley, Oregon. The connection between these two areas has not been actually traced, however, and the correlation just suggested must be considered as provisional.

Beds of light-colored clay and of white volcanic dust, which have been referred to the John Day system, occur at the White Bluffs of the Columbia, 30 miles above Pasco, and are also well exposed in Naches Valley and near Ellensburg, in Yakima County. At these localities the impressions of the leaves of a large variety of plants and the bones of extinct animals have been obtained. The plant remains indicate that the shores of the ancient lake into which they were blown or washed by tributary streams were clothed in a varied and beautiful flora, resembling, in a general way at least, the vegetation of the South Atlantic and Gulf States at the present day. In the ancient forest and about the shores of the old lake, now known as Lake John Day, a veritable menagerie of strange and in part gigantic beasts found a congenial home.

From the White Bluffs of the Columbia southward to the region described in this report there are no barriers, but the surface of the country rises gradually from the broad valley of the Columbia to the basaltic plateau of northeastern Washington. From studies made along the Columbia in 1892, I was led to the conclusion that Lake John Day extended far eastward and covered nearly all of southeastern Washington, even to the base of the Blue Mountains. This view is now known to have been in part erroneous. The sediments of Lake John Day are but poorly exposed to the east of Pasco and Wallula, and their extent in that direction, although not clearly shown, is certainly far short of the Blue Mountains and of the Idaho boundary. They cover the Eureka flats, however, as is shown by a well 198 feet deep at Eureka Junction, which is all in strata similar to those exposed in the White Bluffs of the Columbia, but does not reach the bottom of the formation. Fossil leaves were found in the rock removed in digging the well similar to those obtained from other portions of the John Day system. With the exception of the rocks found at Eureka Junction, no exposures of the Lake John Day system have been recognized in the region treated in this report. The sediment of the old lake does not occur above the Columbia lava in the vicinity of Walla Walla, Dayton, and Starbuck, and its eastern shore must have been to the west of these localities.

The lacustral deposits described in the preceding section as being interbedded with the Columbia lava are of about the same age as the John Day system and were accumulated under similar conditions. They should perhaps be included in the same system, but further study is necessary before a conclusion in this connection can be reached.

RIVER TERRACES.

In describing the canyons of Snake, Spokane, and other rivers in a preceding section mention was made of gravel terraces which occur in them. Little remains to be said in reference to these terraces, except to indicate their place in the geological history of the region where they occur. That they are younger than the Columbia lava and the lake beds, either interleaved with them or resting on their surface, is shown by the fact that they occur in canyons that have been excavated in these formations. The canyon of Snake River, for example, was cut to its present depth before the gravels forming the great banks which occur at certain localities within it were deposited. The canyon was filled in with gravel from side to side to the depth of 360 feet and then reexcavated. Since the river cut through this gravel deposit, removing by far the greater portion of it, but little if any progress has been made in deepening its bed in the solid rock below. Evidently the gravel deposit belongs to a comparatively modern episode in the history of the great gorge. Several considerations lead to the conclusion that the canyon was excavated to its present depth in late Tertiary times, and was filled in with gravel during the Glacial period. If this inference is correct, the amount of excavation done since the Glacial period is trifling in comparison with the work performed by the river previous to that period.

SOILS.

ORIGIN OF SOILS.

Soils in general consist of more or less thoroughly disintegrated and decomposed rock. The surface layer usually contains organic matter termed humus, derived from the partial decay or chemical alteration of organic matter, principally of vegetable origin.

In many regions the breaking down of the rock supplies more material for soil making than is removed by streams or blown away by the wind. Again, denudation may keep pace with disintegration and decay and all of the loosened soil material be removed, so as to leave bare rock surfaces. Much of the soil material removed from one area is redeposited in another area, and hence it is convenient to recognize two kinds of soils, classified in reference to whether they have been removed from their place of origin or not. These two general classes are *residual soils* and *transported soils*. Under each of these divisions many minor subdivisions, dependent on chemical or mechanical composition, have been recognized.

The residual soils are such as originate from the disintegration and decay of the rocks on which they rest. They are the residue left after a long process of weathering and leaching by percolating water, which has removed most of the more easily soluble constituents. Some movements in the soil cap probably always attend this change, but the residue remains practically on the area where it was formed. In recognition of this fact the term "sedentary soil" is sometimes used instead of the one here employed.

The transported soils consist of the products of rock disintegration and decay and of rock abrasion, which have been removed from the area where they were produced, usually through the agencies of streams, glaciers, or the winds, and redeposited. A familiar example of soils of this class is furnished by the silts, sands, and clays forming the flood plains of streams.

In the region represented on the accompanying map not only are both transported and residual soils abundantly represented, but several varieties of each, dependent on mechanical and chemical differences, may be easily recognized.

SOILS OF THE VALLEYS AND CANYONS.

The soils in the valley bottoms in southeastern Washington, more especially in the smaller valleys and along the borders of the smaller streams, although belonging strictly to the transported soils, are frequently of the same character as the soils of the adjacent uplands, or plateau surface, and have been removed but short distances from their place of origin.

The bottom lands adjacent to Walla Walla River and the sand bars in Snake River Canyon, in the valley of Spokane River and elsewhere, are typical examples of transported soil. The mineral and rock fragments composing these soils are, in general, more varied in character than the grains in the residual soils, and have been brought to the localities where we now find them by stream transportation.

About Wallula and Pasco the country is covered over large areas with sand and dust. The surface coverings of this desert-like region represent another variety of transported soils, in which wind is the transporting agency.

The transported soils in the region under discussion may be easily recognized, particularly on account of their topographic relations and the heterogeneity of the rock fragments contained in them, and need not be considered further at this time.

SOIL OF THE WHEAT LANDS.

The deep, rich soil covering the broad basaltic plateau of southeastern Washington and extending widely into Oregon and southwestern Idaho is a residual soil formed by the disintegration and decay of the lava rocks on which it rests. This is the justly celebrated soil of the wheat lands.

To the residual material left by the breaking down and partial solution of the lava have been added minor quantities of terrestrial and volcanic matter; and cosmic dust, or the particles derived from meteors which come to the earth from space, should also be mentioned in this connection.

The plateau is covered nearly everywhere with a rich soil that is unusually fine and porous and free from stones and obstructions of every kind. To the plow it offers scarcely more resistance than so much meal. The surfaces of plowed fields are of a dark-brown, almost black color, due to organic matter or humus. This humus is in part an inheritance from the centuries during which the rolling

WHEAT LANDS NEAR MOSCOW, IDAHO.

uplands were covered with bunch grass, and in part has been derived from the decay of the stubble of wheat fields. At a depth usually of 5 to 8 feet below the surface the dark color fades away and the subsoil, equally fine and homogeneous, and having the same mineral composition, but of a light and usually a yellowish color, is revealed. The subsoil varies in depth with the relief of the surface and with the topography of the underlying hard-rock surface, but is nearly always deep. Systematic measurements are wanting, but judging from the thickness of superficial material revealed in wells, railroad cuts, and other excavations, the subsoil has an average depth of between 50 and 80 feet. Many natural and artificial sections that were examined revealed a depth of 40 to 50 feet, usually without exposing the underlying rock.

In all sections of the subsoil it appears as a fine, homogeneous, unstratified formation, having a uniform light-yellow color.[1] There are frequently indications of vertical joints, or narrow dividing planes, but whether these have developed in the soil, or are possibly an inheritance from the basalt from which it was derived, is an open question. Traversing the subsoil from top to bottom are innumerable minute and almost capillary tubes. These are, in a general way, vertical, but they are curved and otherwise irregular. A single tube can seldom be traced for more than 3 or 4 inches, and their extremities are seldom discoverable, but scarcely a cubic inch of the subsoil is without a number of them. In the humus layer, however, they are absent.

Geologists will, I think, at once recognize, from the above description, the close similarity of this deep subsoil to loess deposits. This resemblance includes the color, the dust-like fineness of the material, the absence of stratification, and the presence of minute and nearly

[1] A characteristic sample of the soil of the wheat lands has been submitted to a mechanical analysis made by Milton Whitney, chief of the division of soils in the United States Department of Agriculture, with the following results:

Mechanical analysis of soil from near Pullman, Washington.

Diameter (in millimeters).	Conventional name.	Per ct.
2 to 1	Fine gravel	0.00
1 to .5	Coarse sand	0.04
.5 to .25	Medium sand	0.16
.25 to .1	Fine sand	1.31
.1 to .05	Very fine sand	53.72
.05 to .01	Silt	26.29
.01 to .005	Fine silt	2.97
.005 to .0001	Clay	8.58
Total mineral matter		93.07
Loss at 110° C		2.45
Loss on ignition		5.20
Total		100.72

vertical tubes. These features also characterize the adobe deposits of arid regions.[1]

The close similarity between the soils of the basaltic plateau and the loess of China, which is supposed by many to consist of wind-deposited dust, has led some careful observers to conclude that the soil of eastern Washington is really a deposit of dust that has been drifted from a distance by the prevailing winds. The minute tubes referred to are considered under this explanation to be due to the rootlets or stems of grasses about which the dust was deposited, the plants continuing to grow as the dust accumulated. There are several objections to this hypothesis, however, as will be shown below.

In numerous sections the surface of the basalt beneath the subsoil has been examined and always found to be deeply decayed. A gradual change can be traced from hard, black basalt, which reveals no signs of weathering, upward through yellow and partially disintegrated portions of the same layer, to rock fragments that are soft and much decayed, and from this, again, to fine soil containing recognizable rock fragments, and finally to the exceedingly fine porous subsoil. Scores of localities where this gradual change is exhibited have been examined, and the number might easily be increased to hundreds.

Chemical analyses of a large number of soils from various localities in Washington and Idaho, including samples from the basaltic plateau, have been made by the chemists of the agricultural experiment stations at Pullman and Moscow.[2] These analyses show that the chemical composition of the soil on the basaltic plateau is such as might be expected to result from the weathering of the solid rocks beneath.

The disintegration of rocks is usually accomplished in part by changes of temperature and by the expansion of water held in crevices and absorbed by pores and capillary passages, on freezing, and in part by the solvent action of percolating waters and, as recently determined by G. P. Merrill, the expansion of minerals in changing to a hydrated condition. Changes of temperature which cause the minerals composing a rock to expand and contract unequally and the freezing of absorbed water are important agencies tending to fracture rocks which are exposed to the air or but thinly covered with soil. A depth of a few feet of soil, however, checks this action, so that the deep decay so frequently to be observed can be safely ascribed to the chemical action of percolating water. The process is hastened by the presence in the water of organic acids, derived principally from the humus of the surface soil. The disintegration and decay of rocks that are sheltered from changes of temperature is brought about to a

[1] I. C. Russell, Subaerial deposits of the arid region of the United States: Geol. Mag. (London), Vol. VI, 1889, pp. 289-295, 342-350.

[2] Washington State Agricultural College and School of Science, Experiment Station, Pullman, Washington, Bulletin 13, 1894, by Elton Fulmer and C. C Fletcher. University of Idaho Agricultural Experiment Station, Bulletin 9, 1894, by C. W. McCurdy.

VIEW OF PULLMAN FROM THE AGRICULTURAL COLLEGE, LOOKING NORTHWEST.

considerable extent by the removal of some of their constituents in solution. This process allows the grains and crystals which remain unaltered or are but moderately changed to fall apart. We should expect, therefore, that residual soils would contain less of soluble constituents than the parent rock, and consequently a higher percentage of the more insoluble constituents.

Samples of the basalt and of the subsoil and soil resting on it were collected by the writer and submitted to George P. Merrill, curator of the department of geology in the United States National Museum, for special study. Chemical analyses of three of the samples are presented below. The analysis of basalt is of a fresh and unaltered sample, being in fact a part of the specimen of which the mineralogical constituents are given on page 44; the subsoil is from a depth of 30 feet in a railroad cut near Dayton; the surface soil was taken from a depth of about 2 feet in a wheat field near the same locality.

Analyses of basalt, soil, and subsoil from near Dayton.

[Analyst, George P. Merrill.]

Constituents.	Basalt.	Surface soil.	Subsoil.
Silica, SiO_2	47.35	63.58	65.89
Alumina, Al_2O_3 / Iron oxide, Fe_2O_3	34.38	22.36	22.19
Lime, CaO	8.27	2.76	2.36
Magnesia, MgO	4.43	1.82	1.85
Potash, K_2O	1.33	2.27	2.36
Soda, Na_2O	2.55	2.02	2.08
Loss on ignition (principally organic matter)	0.95	4.37	2.60
	99.26	99.18	99.33

Merrill states:

All of the material analyzed was first dried at 100° C. The analyses are not as detailed as I would like to make them, but are all that the limited time permits. Perhaps the most striking fact in the analyses is the similarity in composition between the surface soil and that from a depth of 30 feet; almost the only essential difference being, apparently, the larger percentage of volatile matter of the surface soil. Not having as yet separated the iron and alumina, I am unable to account for the apparent loss of these constituents shown. From previous analyses I am led to suspect that the iron oxides have been very largely removed. I am unable as yet to account for the apparent increase in potash in the decomposed materials. It is possible, though hardly probable, that this is due to errors in analysis.

In reference to the apparent increase in potash in the decomposed material, I wish to state that there is no reason for supposing that alkaline or other fertilizers have ever been applied. Possibly the stubble of the wheat fields may have been burned, but this would only return to the surface soil a part of the mineral constituents derived from it in the growth of the grain.

The close similarity between the composition of the subsoils, given above, and of the rock beneath it, is striking. All of the constituents of the rock except the silica and alumina are classed among the more soluble of the substances present in the earth's crust. The readiness with which they may be removed from rock by the process of solution is influenced, of course, by the manner in which they are combined, but the study of the products of rock decay has shown that lime, potash, magnesia, soda, etc., are much more readily removed than silica and alumina. The analyses given above indicate no departure from this rule except in the case of the potash. The soil analyses show that there has been a loss in all of the constituents of the original rock except silica, alumina (?), and potash. The increase in the percentage of potash, as remarked above, is surprising, and as yet unaccounted for. Organic matter and water have been added. The former may reasonably be supposed to have been derived from humus, while the latter indicates that some of the minerals have taken up water and changed to what is termed a hydrated condition. If we omit these added constituents and recalculate the analysis, it will appear that the percentage of silica in the soil is 67 per cent, a decided increase over the similar constituent in the rock, and that each of the other constituents is proportionately increased.

Several analyses of soils from the basaltic plateau, given in the bulletins of the agricultural experiment stations mentioned above, show that the one just quoted is typical and represents about the average composition of the soils of the wheat lands. The analysis of basalt also is of a normal sample of that rock.

The results of a chemical study of the soils and of the basalt are, then, in harmony with what is revealed on comparing the mineralogical composition of the basalt with that of the soils, and sustain the conclusion that the soil has been derived from the rock which it overlies, and also that the disintegration is due, in part at least, to the solution of the more soluble constituents of the parent rock. The loss in bulk, due to the removal of portions of the more soluble constituents, is counteracted to a considerable extent, however, by the hydration of some of the minerals and by the addition of organic matter. This is an interesting fact, as it indicates that there has been at most but a moderate lowering of the surface of the plateau by the removal of matter in solution. Indeed, as the soil is far more open and porous than the parent rock, there has been a tendency toward an actual increase in the elevation of the surface of the plateau. How much this rise of the surface level has been counteracted by stream and wind erosion remains to be determined. The fact that water percolating through soil leads to the removal in solution of some of its constituents is well known, and has been fully recognized in the case of the soils of Washington by Professors Fulmer and Fletcher, of the Washington State Agricultural College, as is shown in the following quotation:[1]

Results of a large number of analyses have shown almost conclusively that soils in a reigon of abundant rainfall contain less lime than soils in arid regions; providing, of course, that neither are underlaid by or in the vicinity of limestone formations. [It will be shown below that this exception need not necessarily be made.] This fact is well verified in the case of our soils east and west of the Cascade Mountains, the average lime constituent of the former being three times that of the latter. This is specially significant in view of the fact that nearly all the soils of eastern Washington are derived from black basaltic rock.

With the samples analyzed so far, it seems almost as if the lime percentages are inversely proportioned to the amount of annual rainfall.

For example, we find the following relations:

Lime percentages.	Annual rainfall.
1.2127 0.9790 1.7580	About 8 inches.
1.0814 1.1800 0.7810 0.9300	20 to 22 inches.
0.6550 0.7690	24 inches.
0.3625 0.4315 0.1303	48 inches.
0.1090 0.0829	76 inches.

It will be interesting to note whether future analyses will reveal this same relation between the rainfall and the lime content of our soils.

The origin of soils from the disintegration and chemical change of rocks is well known, and there is nothing novel, so far as general principles are concerned, in the interesting statements just quoted in reference to the relation of the chemical composition of soils to climatic conditions.[2]

One of the most remarkable instances of the decrease in the soluble constituents of a rock when it passes into soil, given in the papers just referred to, occurs in the limestone region of the western part of Virginia, which, as is known to me from personal observation, is representative of a vast area in the South Atlantic States. The limestone referred to in general yields on decomposing about 1 per cent of insol-

[1] Washington State Agricultural College and School of Science, Experiment Station, Bulletin 13, pp. 39–40.

[2] The processes of rock disintegration and decay, the formation of soils, their variation under diverse climatic conditions, etc., have been discussed by the present writer in Bulletin No. 52 of the United States Geological Survey. A highly instructive analysis of the same phenomena, by George P. Merrill, of the United States National Museum, may be found in volume 4 of the Journal of Geology, published at the University of Chicago. References to many other papers on the same subject are given in these essays. See, also, A Treatise on Rocks, Rock-weathering, and Soils, by George P. Merrill, The Macmillan Company, 1897.

uble residue which is available for making soil. Analyses illustrating this are here inserted:[1]

Analysis of Trenton limestone and of the residue left by its decay.

[Analyst, R. B. Riggs.]

Constituents.	Unaltered limestone.	Residual clay.
Silica, SiO_2	0.44	43.07
Alumina, Al_2O_3	0.42	25.07
Iron oxide, Fe_2O_3		15.16
Lime, CaO	54.77	0.63
Magnesia, MgO	Trace	0.03
Potash, K_2O	Not determined	2.50
Soda, Na_2O	Not determined	1.20
Carbonic acid, CO_2	42.72	0.00
Water, H_2O	1.08	12.98
Total	99.43	100.64

The residual soil left by the nearly complete solution of limestone at the locality from which the sample analyzed was taken is a tenacious reddish clay, and is so poor in lime that calcined limestone is found to be a desirable fertilizer.

The change from basalt to residual soil on the surface of the great plateau of southeastern Washington is accompanied by less change in chemical composition than in the case cited of the formation of soil from the weathering of limestone, for the reason that so large a proportion of the basalt is composed of silica.

It seems, therefore, both from a comparison of the mineralogical character of the fragments composing the soil with the nature of the minerals composing the basalt, and from a study of the chemical composition of the unaltered rock and of the soil, that the subsoil is the result of the disintegration and decay of the country rock. The surface soil is of the same character as the subsoil, except that organic and atmospheric matter and volcanic and probably cosmic dust have been added.

An unexplained fact under this hypothesis is the presence in the subsoil of the minute and nearly vertical tubes previously described.

TOPOGRAPHY OF THE WHEAT LANDS.

The widely different ideas of the topography of southeastern Washington that one might obtain from traveling through the canyons and from a journey over the plateau surface have already been referred to. It is to the peculiar topography of much of the surface of the

[1] Bull. U. S. Geol. Survey No. 52, 1889, p. 24.

plateau where practically unaffected by the deep dissection accomplished by the larger streams that attention is here directed.

The surface of the plateau in some regions is nearly as level and featureless as the prairies of Illinois, while in other portions it is diversified by hills and valleys, and in its native state, when covered with bunch grass, was a rolling prairie. South of Snake River, especially on the portions of the plateau which remain between the various branches of Touchet, Alpowa, and Asotin creeks, the flat plateau-prairie lands are well displayed. North of Snake River, in the Palouse country, the rolling or hilly prairie predominates over extensive regions.

There is a certain relation between the smoothness or roughness of the surface of the plateau and the arrangement of the streams, but I doubt if this is the sole reason for the contrast between the smooth surfaces of the fragments of the plateau between the deep canyons south of Snake River and that of the hill plains to the north. Where the streams flow across the plateau they have excavated deep canyons, with comparatively few lateral branches. The rain falling on the deep soil of the plateau is absorbed and percolated away. It is thus robbed of its power to erode. Under these conditions surface channels, like those so common in many regions having a clayey soil, are not formed. At a distance from master streams, where the subdrainage was less perfect, the soil seems to have become saturated, and rills and rivulets appeared on the surface and flowed to brooks, and these to larger streams. The soil in such regions has been carved into hills and ridges, with hollows and shallow valleys between. The hills and valleys of the rolling prairie region, as will be shown below, were still further modified by the wind.

When one gains a comprehensive view of the surface of the plateau—as, for example, from the borders of the Blue Mountain uplift or from the sharp summit of Steptoe Butte—it is seen that the controlling features in the topography of the surrounding country are due to stream erosion. A map of the plateau would show that where the broad, level, plain-like features predominate, the land is incompletely drained. There are no rill and brook channels ready to carry off the rain water, should it fall in sufficient abundance to form surface streams. In the hilly portion of the plateau, however, as in the Palouse country, there are countless small valleys and depressions that join large channels and everywhere favor the running off of surface water. The portions of the plateau's surface that have not been etched by stream erosion are, in the language of geographers, young land areas, while the roughened surface of the rolling prairies furnishes examples of youthful topography, or, in this instance, of arrested development in an early stage of growth.

These conclusions may not seem well founded to those who are aware that the portions of the plateau between the deeply cut canyons are without surface streams. Even where the plateau surface is hilly and the numerous minor valleys and depressions favor complete drainage, there are not only no streams at any time during the year, but no stream channels in the valley bottoms. There was formerly a time, however, when precipitation was more abundant than now, and the land in what is now the rolling prairie was sculptured by a multitude of rills and brooks.

The hilly prairie is characteristically developed in eastern Washington, north of Snake River, and probably extends to Spokane River. The most typical portion, so far as I can judge from personal observation, is in the region drained by Palouse River. The towns of Pullman and Garfield are surrounded by the characteristic hills here referred to, and from Kamiack and Steptoe buttes one can look down on tens of thousands of acres of hilly and undulating wheat lands, which in a state of nature formed a vast, hilly prairie.

In this region hills with smooth, even slopes and rounded tops and crests, rising in general from 20 to 80 feet above the adjacent depressions, occur in thousands. Many of the hills rise to one general level, but none reach above it. The fact that the roughened surface of the plateau is a broad plain is always apparent in a general view.

One feature of the hills which especially attracts attention is that they are usually steep on the northeast side and slope gently toward the southwest. The steeper sides frequently have a slope of 20° with a horizontal plane, and in many instances are slightly concave when seen in profile, while the more gently sloping sides descend at angles measuring 5° to 8°, and are frequently gently convex. These features may be recognized in the photographs of characteristic portions of the hilly plateau forming the accompanying plates.

In many instances the extremities of ridges which present a steep slope to the northeast terminate at each end in tapering prolongations extending northeastward, which curve slightly toward each other and partially inclose a hollow. Many of these amphitheater-like inclosures may be seen in the northeast sides of the hills about Pullman and Garfield.

From what has been stated, the fact will be recognized, I think, that many of the hills of the plateau are similar in form to the hills of drifted sand termed "dunes."

The dune-like shape of many of the hills about Pullman was first pointed out to me by President E. A. Bryan and Prof. C. V. Piper, of the Washington State Agricultural College and School of Science. These gentlemen also stated that the prevailing winds of that section of the country are from the southwest. The hypothesis was thus suggested that the soil of the plateau, of which even the highest hills are composed, has been blown by the prevailing winds and piled up in part in dune-like forms. The similarity in physical properties between the fine soil of the wheat lands and the equally fine, dust-like deposits in China, termed loess, and believed by some geologists to be wind-borne deposits, as previously suggested, seemed also to give weight to the hypothesis that the hills under consideration are of eolian origin. The idea has been suggested that the soil of the wheat lands has been brought by the winds from a desert region to the southwest, but there is no extensive desert area in that direction, and besides, as we have already seen, the mineralogical and chemical composition of the soil and its transition into disintegrated rock and finally into solid basalt shows that it originated in the place where we now find it.

The prevailing and characteristic dune-like shapes of the hills is sufficient evidence, however, that their contours have been modified to some extent by wind action. As already stated, the main topographic features, even where the dune-like hills are best displayed, are such as are produced by erosion. The partially filled depressions between the hills have continuous slopes, which would furnish natural and unbroken channels of escape should the rainfall become sufficiently abundant to initiate surface drainage.

The best explanation I can offer of the origin of the hilly topography of the less deeply dissected portions of the basaltic plateau is that the principal changes in the relief of the surface of the originally flat and featureless plateau are due to stream erosion at a time when the precipitation was more copious than now, and that with a decrease in precipitation the forms of the hills, left in relief by the excavation of the valley, were modified by the prevailing winds. The fine soil was blown from the southwest sides of the hills, which trend northwest and southeast, and accumulated on their leeward slopes. But this action has not been carried far enough to obliterate or to greatly modify the topographic forms due to previous stream erosion. In no instance during a careful search extending over several days was I able to find a single valley or depression which was not connected with the present lines of drainage by valleys and dells that would admit of complete surface drainage in the case of a heavy rainfall. This evidently would not have been the case if the wind had been the controlling agency in modeling the relief of the plateau's surface.

The steep northeast slopes of the hills, as already mentioned, frequently have concave profiles. These curved slopes suggest the profiles of volcanic cones formed of fragments blown out of a volcano and falling about its sides. They are the reverse of the convex "weather curves" produced by the removal of the surface of an uplift in the process of weathering. The concave sides of the hills have such profiles as would be formed by material blown over their crests and accumulated on their lee sides; while their summits and southwest slopes present such profiles as normally result from weathering.

Excavations in the hills have in some instances shown a greater depth of fine, dust-like soil on the lee side of their crests than on the windward side. In some cases a clayey subsoil is met with at a depth of a few feet on the southwest side, while on the opposite side a deep loess-like soil prevails. This has been noticed in the college farm at Pullman, as I have been informed by President Bryan, where clay interbedded with the Columbia lava has influenced the character of the soil. In railroad cuts deposits of fine, dust-like soil having a depth of 30 or 40 feet have been observed in several instances on the northeast side of hills; while in similar cuts on the southwest slopes of corresponding hills they would be less thick. Rock exposures are perhaps more numerous on the northern sides of canyons than on their southern sides, owing to the accumulation of soil in the lee of their southern walls, but I am not aware that there is a marked tendency in this direction.

I have thought, also, that a difference is observable between soil that has been moved and redeposited by wind and soil that remains in place, but the differences between the two are so slight and their junction so indefinite that no sharp line of division can usually be recognized.

It is possible that the vertical tubes described on a previous page occur only in the soil that has been moved by the wind. The tubes referred to are certainly abundant in the soil on the northwest slopes of hills, but whether they are absent in soil that has not been disturbed remains to be proven.

The valleys in the surface of the hilly plateau have characteristics, also, which are novel to one familiar only with a well-watered country. The great majority, and in fact nearly all, of the valleys of the plateau, except such as are traversed by streams flowing from the bordering mountains, are flat bottomed and without stream channels. These valleys are usually deeply filled with fine soil of the same character as that forming the adjacent hills. In cross section the valleys are level-floored, but in longitudinal section their even surfaces would show a gentle inclination toward the deeper valleys to which they lead, and in which there are streams flowing from the neighboring mountains.

As stated in connection with the description of other climatic features of eastern Washington, the precipitation is small, averaging about 16 inches annually. The deep, fine, porous soil absorbs the rain as it falls and the water formed from melting snow. It is to this fact that the possibility of raising wheat and other cereals on the broad plateau is due. All of the annual precipitation except what is returned to the atmosphere by direct evaporation, as when snow vanishes before a warm wind without melting, is not only absorbed by the soil, but is retained, to a great extent, near the surface. In excavations in excess of 15 or 20 feet on the plateau surface, I have been informed, dry soil is usually reached.

It is a striking fact, especially on the hilly portion of the plateau, that even the steepest slopes, in many instances having an inclination of from 20° to 30°, are without rill marks. This is not because there is a mat of roots binding the soil together and thus preserving it from washing, for the surfaces of the plowed hillsides are smooth and unscarred by gullies. It is the custom generally throughout the wheat-growing region of eastern Washington, as already stated, to harvest but one crop in two years from a given area. The farmers have learned that by this method they can obtain about as much grain as if the land were sown and harvested each year. Inquiries as to the reasons that make this possible have not elicited satisfactory answers. The suggestion has occurred to me, however, that possibly the evaporation from a plowed field is so much less than from a field covered with growing grain that by plowing the land and leaving it unsown every other year a greater store of moisture is secured for the alternate years, when a crop is raised. This suggestion is in harmony with the well-known fact that the conditions which are favorable or unfavorable to agriculture on the basaltic plateau, with reference especially to moisture, are delicately balanced. When a slight increase over the average annual precipitation is experienced, an abundant harvest is secured; but if the precipitation—particularly the amount of snow—is small, the effect is seen in a diminished harvest. This statement must be qualified, however, since the amount of precipitation is not the only important climatic factor on which the success or failure of the harvests depends. In winter the snow, although perhaps abundant, is sometimes evaporated by warm, dry winds, without melting, and therefore fails to add to the store of moisture in the soil. Hot winds occur sometimes also in spring and early summer, and wither the young grain.

The semihumid character of the climate of eastern Washington, shown by the conditions limiting the cultivation of cereals, leads naturally to the consideration of the possibilities of irrigation and of artesian water supply.

IRRIGATION.[1]

Region south of Snake River.—To a person traveling through southeastern Washington, a truly astonishing feature of the country is the great quantity of water flowing from the Blue Mountains. I have already directed attention to the fact that on what has been termed the wheat-land plateau all of the water that reaches the soil is absorbed. The same is true among the Blue Mountains, which are in reality a more elevated plateau of the same general character that has been deeply dissected by stream erosion. This uplift furnishes a splendid example of mature drainage—that is, a drainage system which has cut down its principal channels approximately to the level

[1] For data on water supply and irrigation from Umatilla River, see Bull. No. 131, Report of Progress of the Division of Hydrography, United States Geological Survey, for 1893 and 1894, pp. 69–73.

of the master stream into which they discharge. The principal streams have developed innumerable lateral branches, so that the entire region is well drained. With the deepening of the stream channels there has been erosion of the interstream spaces, and instead of flat-topped tables, only sharp, serrate ridges remain. These stream channels are no older than the less well-developed channels on the lower plateau, but the advantage gained from the greater elevation of the land has given the flowing waters greater velocity and enabled them to progress with their appointed task more rapidly.

Rock disintegration and decay has kept pace with, and in recent times exceeded, denudation, and every depression and every shelf on the canyon walls is filled and covered with soil. This soil is of the same character as that of the wheat lands, except for the frequent occurrence of angular rock fragments in it. All portions of the intricate system of ridges composing the so-called mountains, except the actual cliffs and precipices, are thus soil covered.

Among the mountains, as on the hill slopes of the wheat lands, there is an absence of rill marks. Earth slopes having a descent of fully 45° are usually without rill marks or scars of any kind due to erosion. The few miniature water courses that do occur on such slopes are the result of the infrequent storms known as "cloudbursts." The water absorbed by the porous soil passes down into the jointed and frequently scoriaceous basalt below, and by slow percolation feeds perennial streams.

As already described in the section of this report devoted to drainage, and as shown on the accompanying map, there are many creeks, some of them having the volume of rivers, radiating in all directions from the Blue Mountains. Each of these streams flows throughout the year and carries a never-failing flood of clear, cold water down to the parched valleys below. Each of these streams, with the exception of the Grande Ronde, can be utilized to its full capacity for irrigation.

The Grande Ronde in all of its lower course, as already shown, flows through such a rugged canyon that scarcely any land can be economically irrigated by it. Here and there along the main river, however, and on its branches, are small areas, some of which may be watered from the river itself or by lateral streams. The productiveness of these areas makes them especially valuable for orchards and gardens. It is in these sheltered recesses that fruit, vegetables, tobacco, etc., may be raised, while the canyon sides and much of the plateau surface, some 3,000 feet above, is available for stock ranges. Toward the headwaters of the river broad areas of the plateau surface still remain and are clothed with forests. This land, when cleared, will produce wheat, but it is to be hoped that much of it will be retained in nearly its natural condition as a forest preserve.

The other streams referred to, which radiate from the Blue Mountains of Washington and adjacent portions of Oregon, flow through canyons, but in most instances are bordered by narrow flood plains, elevated but a few feet above their channels, or by ancient terraces, as in the case especially of the Walla Walla and several of its branches. Of the streams under consideration, the ones least favorably circumstanced for irrigation purposes are Asotin and Alpowa creeks. But even these can be utilized, as is shown by the canal described below, which leads the water from Asotin Creek about the face of the bluffs forming Snake River Canyon and delivers it to irrigable lands opposite Lewiston. The Alpowa flows for a large part of its course in a narrow gorge, but near its mouth and along the adjacent portion of Snake River there are lands so situated that they can be irrigated.

In the absence of a topographic survey of the Blue Mountains and adjacent regions, it is not practicable to designate in a report of the character of the one here presented what lands can be economically irrigated or where storage reservoirs can be constructed to the best advantage. From the point of view of the engineer, however, it seems practicable not only to utilize for irrigation purposes all of the water flowing from the Blue Mountains in summer, but to store a large portion of the winter run-off and hold it for use during the growing season.

As is only too well known, the main obstacles to the full utilization of the water now running to waste in many arid regions—and southeastern Washington is no exception to the rule—is the rivalry of individual owners of land and of water rights. No general plan of using the summer flow from the Blue Mountains or of storing a part of the winter run-off can be carried out, however practicable it may seem to the engineer, until a large number of the owners of land in the region to be affected give their consent and cooperate in carrying out far-reaching plans for the public good.

In writing of the possibilities for irrigation in the region to the north of the Blue Mountains—and what has been said will apply also to large areas in the adjacent portion of Oregon—attention has been directed mainly to the canyon bottoms and to the ancient stream terraces. The engineer sees possibilities, also, in the direction of irrigating some portion of the wheat-land plateau between the deeply sunken stream channels.

To the northward of the Blue Mountains, more especially in Garfield and Asotin counties, the plateau surface rises gently toward the mountains, and in some instances could be watered by diverting the streams near their sources and before their channels became much depressed below the general level of the plateau. Little attention has been directed to the possibility of diverting the waters of the several branches of the Asotin, Alpowa, and Tokanon in their upper courses, and conducting them into the broad areas between the deep canyons of the main streams lower down, but this seems feasible to one making a hasty examination of the region, especially if storage reservoirs can be established. The possibilities here referred to are illustrated at Anatone, about 14 miles southwestward from Asotin, where the water of George Creek, one of the tributaries of Asotin Creek, has been diverted with but trifling expense and carried to a nearly level area of rich wheat land conveniently situated for irrigation. This small experiment certainly suggests other possibilities in the same region. There is reason to believe that a careful survey would show available reservoir sites near the sources of several of the mountain streams, so situated that broad areas of the plateau could be watered from them.

At present little use is made of the water flowing from the Blue Mountains in comparison with what is possible from an engineering point of view. Small ditches have been made in a number of instances, particularly in the neighborhood of Walla Walla, for the purpose of irrigating gardens and orchards. In the lower portion of Walla Walla River about half a dozen water wheels arranged with buckets are in use. These raise the water from the river to a height of 15 feet and allow it to flow in ditches to orchard and garden lands. Each wheel is said to be capable of irrigating from 8 to 10 acres of land. In addition to these uses of the streams for irrigation by individuals a few attempts have been made by companies to construct irrigating canals.

What is known as the "Willis ditch," constructed by the Willis Land and Improvement Company, is taken out of the Walla Walla at the mouth of Mill Creek. The head of the ditch is in the southeast quarter of section 31, township 7, range 35, and extends westward 4½ miles, but is surveyed for 10 miles farther. This canal is 20 feet wide at the top and now carries 16 to 18 inches of water, but when in full operation is planned to carry a stream 2 feet deep. I have been informed that it now irrigates about 4,000 acres of land.

The "Hawley ditch" leaves the right bank of the Walla Walla at Raymo, and is 8 miles long, although only 4 miles are now in operation. It is said to carry 60 cubic feet of water per second, and to irrigate about 1,000 acres. When completed it is estimated that it will irrigate between 1,500 and 1,600 acres.

On the opposite side of Walla Walla River the Walla Walla Irrigation Company has constructed a ditch, beginning farther upstream, and now completed for about 4 miles, but it is not in operation. If the present plans are carried out, this ditch, when finished, will be in the neighborhood of 20 miles long and capable of irrigating some 4,000 or 5,000 acres of land.

In the canyon of Touchet River, about 4 miles above its mouth, a ditch has been constructed on the left bank of the stream. One and one-half miles below its head it is divided, one half being carried across the river to the left bank. Its capacity is about 60 cubic feet per second, and at present it is said to irrigate 2,000 acres.

Such information as is here given concerning the more comprehensive plans that have been made for using the water of Walla Walla River and its branches was furnished by various gentlemen interested in the improvements mentioned. More detailed information could not be obtained, for the reason, in part, that some of the companies engaged in this work are involved in litigation growing out of the complex problem of riparian rights.

Snake River Canyon.—Snake River, although a magnificent stream, is not available for the irrigation of the surface of the plateau through which it flows, for the reason, as we have already seen, that it is deeply sunken in the rocks of the plateau. There are several areas in the bottom of the canyon, however, from a few acres to 300 or 400 acres in extent, which can be irrigated from the main river or by the waters of some of the tributary brooks and creeks. The soil at the localities referred to is river sand, exceedingly light and porous. It contains much mica and considerable lime, due in part to the presence of shells of fresh-water mollusks, and when irrigated is well adapted to fruit culture. Some of the finest fruit raised in Washington is grown on these sand bars, deep in the shelter of canyon walls.

The boldest scheme in the way of irrigation yet put into operation in southeastern Washington is one that was practically completed in 1896 by the Lewiston Water and Power Company, on the west side of Snake River, below Asotin. The canal referred to diverts the water of Asotin Creek, and carries it along the precipitous south side of Asotin Creek Canyon, and about the face of a bluff at the junction of this canyon with the broader canyon of Snake River, and northward along the steep side of the river canyon at an elevation of approximately 600 feet above the river. The canal is designed to furnish water for irrigating about 3,500 acres in Asotin County, Washington, and also 4,000 acres in Idaho, near Lewiston. The following facts concerning this important enterprise have been kindly furnished by Messrs. C. C. Van Arsdol and E. H. Libby, of the Lewiston Water and Power Company:

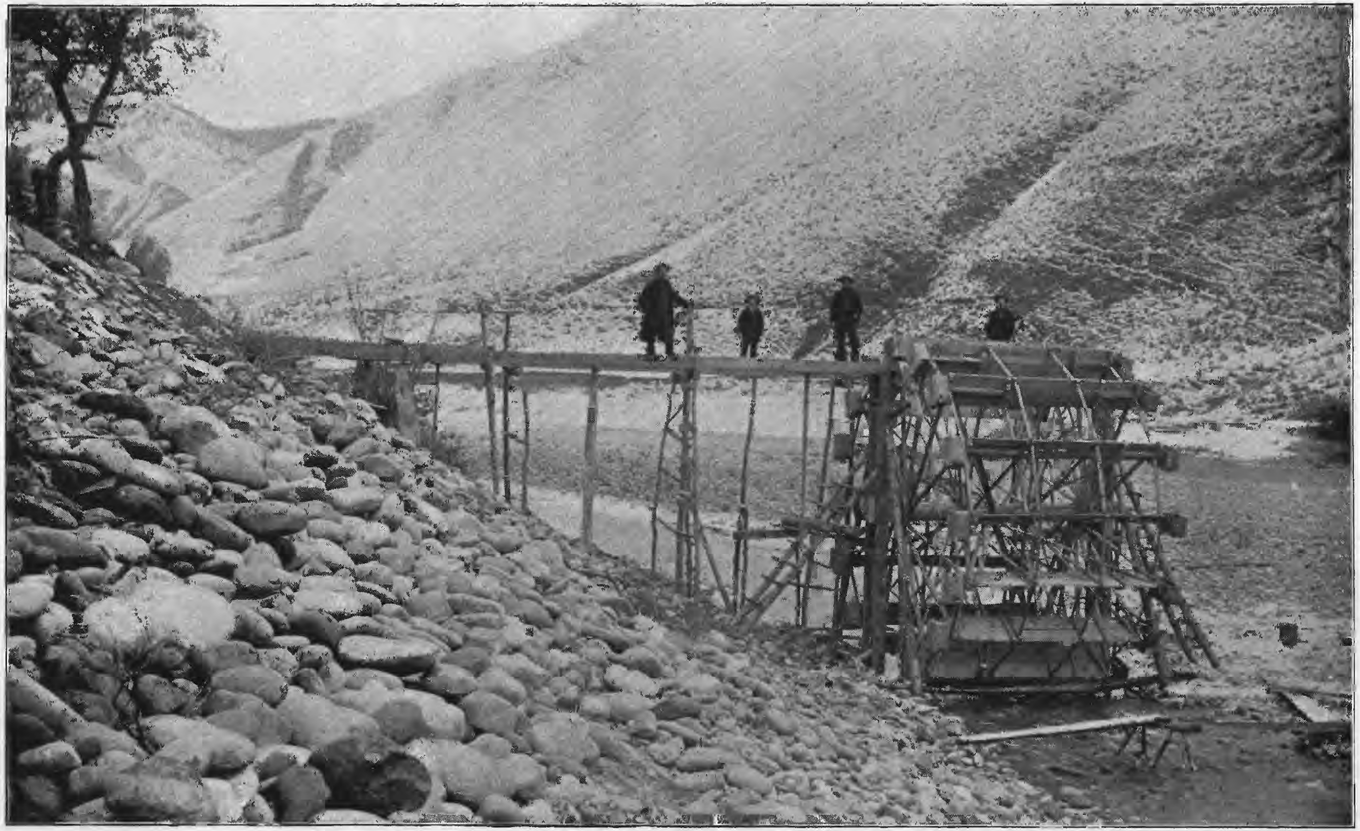
The water is taken from Asotin Creek about 6 miles above its junction with Snake River, at an approximate elevation of 665 feet above Snake River, and is conducted 6¼ miles along the north slope of Asotin Creek by a flume 6 feet wide and 3½ feet in depth, with a grade of 10.56 feet per mile; thence to a point north of Swallows Nest Rock, a distance of 8 miles by canal, 6 feet wide on bottom, 16 feet wide on top, and 5 feet deep, with a grade of 2.12 feet per mile. Estimated capacity, 127 cubic feet per second. From a point near Swallows Nest Rock the distributing laterals diverge.

In the canyon of Snake River, above Asotin, there are narrow, detached strips of moderately flat land, having a width in some instances of 200 or 300 yards, composed of river silt and sand. These are nearly all on the west bank of the stream, and are bounded on one side by the swift-flowing waters and on the other by mountain-like walls of basalt from 2,000 to 3,000 feet high. A few of these narrow areas are now irrigated from small streams that come down the gulches in the canyon wall and are supplied by springs. In this portion of the canyon of Snake River the water of the river itself is not used for irrigation.

Below Lewiston there are also several localities where silt and fine micaceous sand brought down by the river has accumulated in sheltered portions of the bottom of the canyon. The largest of these areas now under cultivation is at the mouth of Wawawai Creek, which supplies water for its irrigation. At this locality about 300 acres are occupied by fine orchards of peaches, pears, prunes, etc. These orchards are wonderfully productive, and furnish fruit of large size and excellent quality. Between Wawawai and the mouth of Snake River there are about half a dozen localities at which from 8 to 14 acres of fruit land are under cultivation. The total amount of land in this section now being irrigated is in the neighborhood of 100 acres. At most of these localities water for irrigation is raised from the river by pumps operated by undershot water wheels, current wheels, located on rafts, as shown in Pl. V. These wheels are, I believe, all of one pattern. They are 18 or 19 feet long by 9 to 11 feet in diameter, and vary in effectiveness with variations in strength of current. One, owned by Mr. H. Gilbert, situated in section 26, township 11, range 33, at the time of my visit, August 19, was operating two suction pumps, each of which made 20 strokes per minute, and lifting about one-half gallon of water to a height of 27 feet at each stroke. At more favorable stages of the river the amount of water raised is doubled. The water is carried away in a small flume and irrigates about 1,000 fruit trees.

The difficulties that have to be contended with in this comparatively inexpensive method of irrigation arise principally from variations in the height of the river. The portion of Snake River here considered rises during floods from 20 to 32 feet above the mean low-water stage. The scows carrying the water wheels and pumps have to be moved from time to time to suit the varying height of the water. In winter the scows must be removed from the river to prevent destruction by floating ice. Dangers from driftwood have also to be guarded against, especially during high water.

The river sometimes rises during floods to within 3 or 4 feet of the cultivated lands, and there is danger at such periods that the river will remove the deposits previously made and thus destroy industries which it has required years to establish. This danger can probably be counteracted in many instances by planting willows and alders along the river banks. The inhabitants in Snake River Canyon should certainly take every possible precaution against unusually high floods in the river, as there is but a small margin between the usual spring rise and the surfaces of the sand bars where orchards and houses are located.



WATER WHEEL LIFTING WATER FROM SALMON RIVER FOR IRRIGATION.

The Palouse country.—The surface of the wheat-land plateau north of Snake River, drained principally by Palouse River, is, as we have seen, a rolling, hilly region. Irrigation is there impracticable, except in the larger valley bottoms. Scarcely any irrigation is now practiced, and my examination of the region was too hasty to admit of an opinion in reference to what may there be possible. It seems probable, however, that here, as in many other portions of the arid and semihumid regions of the United States, the storage of water must eventually be resorted to.

A topographic map.—To those interested in the development of the many and varied industries of Washington, I venture to earnestly recommend the early completion of an accurate topographic map of the State. Such a map, in the sheets covering the more thickly settled areas, and where irrigation is desirable and practicable, should be on a scale of 1 mile to the inch, with contour lines showing relief of surface, drawn with 20-foot vertical intervals.

A knowledge of the drainage and topography or surface relief of a State is an important basis not only for irrigation but for planning country roads, railroads, canals, flumes, town water supply, etc., and in learning the best way to bring mines, timber, and agricultural lands in communication with markets. It is safe to say that the cost of nearly all public improvements and of many private enterprises would be greatly reduced if an accurate map of the State were available on which to base plans and estimates. The educational value of such a map, especially to school children in giving them a knowledge of home geography, is by no means the least of the useful purposes it would serve.

ARTESIAN WATER SUPPLY.

The small rainfall of southeastern Washington, and the fact that it is impossible to irrigate by far the larger part of the grain lands, or, in many instances, to obtain wholesome water for towns and even for farmhouses, from streams or ordinary surface wells, have led to the hope that a subterranean water supply might be discovered. In a number of instances marked success has attended the drilling of artesian wells, particularly in the eastern portion of Whitman County, and stimulated a desire to have similar experiments made elsewhere.

GENERAL CONDITIONS.

Before the expense incident to the drilling of deep wells is incurred it is desirable to give attention to at least two considerations: First, the conditions which render the obtaining of artesian water possible, and second, the geology of the region where it is proposed to drill a well. After a study of these questions in reference to a given locality one may predict with considerable confidence what measure of success is possible.

What are termed "the requisite and qualifying conditions of artesian wells" have already been fully explained in the publications of the United States Geological Survey,[1] and it does not seem necessary to restate them at length in this report.

Briefly stated, an artesian well is one in which water rises under the influence of the pressure of water at higher levels. The suggestion that water sometimes rises in a well or boring on account of gas pressure need not be discussed at this time.

In an artesian well the water sometimes rises to the surface and overflows, or it may be under sufficient pressure to form a fountain-like jet above the surface; in other cases the water rises some distance in the well, but fails to reach the surface. In all these instances the well is classed as artesian. The question of surface flow is determined not only by the pressure acting on the water but by the elevation of the surface at the mouth of the well. For example, a well drilled in a valley might reach a water-charged layer of rock in which the water is under sufficient pressure to cause it to rise fountain-like above the surface; while a well drilled on a neighboring hill and reaching the same water-bearing layer would be only partially filled. If in such instances the casing or pipe of the lower well be continued upward, its top remaining open, the water will rise within it to the same level at which it stands in the well drilled on the neighboring hill; that is, the water is under the same pressure in each instance. I make this explanation in reply to numerous questions asked me during my field studies, as to whether an artesian well is necessarily a flowing well or not. In brief, an artesian well is one in which water rises under pressure; if the water overflows the surface, it is convenient to designate it as a flowing well.

In order that water may rise in a tube drilled in the earth it is necessary for it to be under pressure; in other words, the water must be confined so that it can not flow away and thus relieve the pressure. The most common conditions under which this happens are these: Certain layers of rock of loose texture, as sand and sandstone, become water-charged, and the water is confined in them by other layers above and below which are impervious to water, such as clay. If a water-charged layer of sand between two layers of clay is inclined, the water will percolate through it. If the central portion of such a water-charged sheet is depressed, the water in the surrounding portions will tend to flow toward the depressed central area. The water in the central portion will then be under the pressure of the water in the more elevated portions of the porous layer. Evidently, under such conditions, if a hole is made from the surface through the upper layer of clay, it will allow the water to rise to the surface, or until it stands as high as the lowest outlet in the rim of the basin. These

[1] The requisite and qualifying conditions of artesian wells, by T. C. Chamberlain: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125-173. Residents of Washington may find it profitable to consult also: "General principles pertaining to artesian water," in A Geological Reconnoissance in Central Washington, by I. C. Russell: Bull. U. S. Geol. Survey No. 108, 1893, pp. 32-36.

conditions are illustrated in the following ideal section across an artesian basin:

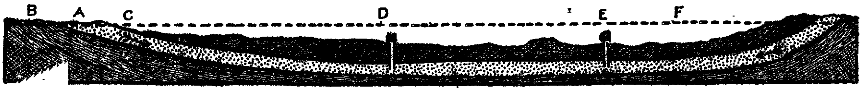


FIG. 2.—Ideal section illustrating the chief conditions of artesian wells. A, a porous stratum; B and C, impervious beds below and above A, acting as confining strata; F, the height of the water level, "artesian head," in the porous bed A, or, in other words, the height of the reservoir or fountain head;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

In nature we find examples of what, for convenience, may be termed incomplete artesian basins; as, for instance, when an inclined pervious bed, a layer of sand, we will say, thins out on its lower edge and allows the sheets of impervious rock above and below it to come together. An ideal example of this character is shown in the following cross section:

FIG. 3.—Ideal section illustrating the thinning out of a porous water-bearing bed, A, inclosed between impervious beds, B and C, thus furnishing the necessary conditions for an artesian fountain, D. (After T. C. Chamberlin.)

If the layer of sand is penetrated by a well drilled at D, the water will rise in an open tube to a height regulated by the pressure of the water in the sand above the locality where the well reaches it.

The source of the water that rises in artesian wells is mainly the precipitation on the edges of the pervious beds where they come to the surface. In some instances the porous beds are charged in this way at their outcrops, hundreds of miles from where the water is liberated by drilling wells.

The height to which water rises in an artesian well, or, in the case of a flowing well, the height to which it would rise in a tube open at the top, if properly attached to the well, is termed the "artesian head." This is illustrated in the waterworks of towns, where the water rises in the distributing pipes to the same level as the surface of the water in the reservoir from which it is drawn.

From this brief outline of the leading conditions which favor the possibility of obtaining artesian water it will be seen that the task of the geologist in this connection consists in ascertaining whether alternating sheets of pervious and impervious rocks exist in the regions he studies, and, if the requisite succession of beds is found, whether the beds are so inclined as to bring a portion of the water in the pervious layers under the pressure of other portions. In addition, the amount of rainfall and the quantity of water brought by streams to the outcrop of the porous beds; whether the impervious beds are broken; the changes which layers of rock undergo from one locality to another; the depth to which the pervious layers have been eroded by streams; and several other limiting and qualifying conditions have to be considered and investigated.

LOCAL CONDITIONS.

In southeastern Washington and adjacent portions of Oregon and Idaho the rocks, as already described, belong in two series: First, the crystalline or metamorphic and igneous rocks, consisting principally of granite, schist, quartzite, and diorite, forming the mountains of western Idaho; and second, the lava sheets and interleaved sands and clays forming the wheat-land plateau and the Blue Mountains.

So far as the question of obtaining artesian water is concerned, we may dismiss the regions where the metamorphic rocks and diorite form the surface. The original bedding in these rocks has been almost entirely obliterated by the changes they have experienced, and there is no succession of porous and compact layers. The rocks have been folded and broken by joints, so that practically none of the requisite conditions for retaining water under pressure are present. The fissures and cavities in these rocks are probably, in many instances, water-filled, so that wells drilled at the proper localities might allow the water in them to rise and possibly to overflow the surface. But these cavities are irregular, and, as far as can be judged, seldom present the conditions just mentioned. It is impossible for anyone to predict where such water-filled cavities exist, and the drilling of a hole in the rocks with the hope of finding one is to take one chance in a million.

The areas where granite, schists, quartzites, and diorites are exposed or occur a short distance below the immediate surface are therefore to be avoided in all attempts to obtain artesian water.

In the region occupied by the Columbia lava the rocks, although for the most part of igneous origin, are in well-defined layers. Between the sheets of basalt, as the reader is already aware, there are layers of sand, volcanic dust and lapilli, and clay. This series of beds, although apparently horizontal over broad areas, is in reality in many localities slightly inclined. Conditions favorable to the hope of obtaining artesian water are thus suggested.

The basalt is not porous, except very imperfectly at the junctions of many of the layers, where it is scoriaceous, and it can not be considered as a pervious rock. It is traversed by innumerable joints and seams, and evidently could not retain water under pressure. In itself, therefore, the basalt presents no condition that would encourage the hope of finding artesian water.

When sheets of sand and clay intervene between the layers of basalt, and the series is slightly tilted, more hopeful conditions evidently result. These conditions are fulfilled in a belt of country, some 10 or 15 miles broad, along the eastern border of Washington, north of Snake River, and extending at least as far as the northern boundary of Whitman County, and possibly all the way to Spokane River.

The westerly inclination of the rocks in this section is extremely gentle, and, although not yet measured, may probably be taken at about 5 feet to a mile. The artesian head is consequently low, and it is only in the deeper valleys—which, however, have not been cut through certain strata of clay—that flowing wells can be obtained.

EXISTING WELLS.

The information here presented concerning the wells that have been drilled in southeastern Washington has been obtained from various persons who were especially interested in the results hoped for, but was furnished principally by Mr. A. L. Ebersol, of Garfield, Washington. Mr. Ebersol began his work as a well driller in the oil fields of Pennsylvania, and has had several years' experience in putting down wells under contract in Washington.

Wells at Pullman.—Pullman is situated partially in a narrow, steep-sided canyon, cut in the basaltic plateau by one of the several branches of Palouse River. The bottom of the now partially filled canyon is about 200 feet below the general level of the plateau. The college buildings situated near the summit of the hills overlooking the business portion of the town are 220 feet above the station of the Union Pacific Railroad, which, as shown by railroad surveys, is 2,340 feet above the sea.

Fifteen wells have been drilled at Pullman, some of them in the bottom of the canyon and others on its borders. Those in the bottom of the canyon, 11 in number, are flowing wells, but those on the sides of the canyon above an elevation of about 2,365 feet do not overflow; that is, the pressure on the water in the pervious stratum penetrated by these wells is sufficient to raise it to a level of about 25 feet above the canyon's bottom.

The hills bordering the canyon at Pullman are of basalt, which appears to be a single flow, and so far as can be ascertained by observation and the use of a pocket level is horizontal. Beneath this heavy sheet of basalt is a stratum of clay, 25 to 30 feet thick, the upper surface of which has been hardened and rendered dark in color by the heat of the basalt spread over it. Below the clay is a layer of basalt 60 feet thick; then comes a layer of granitic sand, which has been penetrated to a depth of about 12 feet without reaching the bottom. This sand is unconsolidated and abundantly water charged.

It is reported that some of the wells furnished artesian water as soon as the clay layer was penetrated and that the volume increased until the sand was reached. This seems to indicate that the water rose through fissures and seams in the basalt, but not with sufficient freedom to furnish the desired supply. The impervious layer is evidently the clay stratum, and the pervious layer is the loose, unconsolidated sand. Sand is thrown out of the flowing wells, and samples collected show that it is mainly quartz sand, with occasional fragments of granite and basalt and much mica. This material is mainly such as would be furnished by the disintegration of the quartzite and granite forming the hills bordering the basaltic plateau on the east. With the quartz sand are mingled grains of basalt, which sometimes give it a dark color.

The first well drilled, that now supplying the Palace Hotel, as stated by M. C. True, the owner of the hotel, was finished in May, 1894. It has a total depth of 77 feet, and reached flowing water at 65 feet. It is 6 inches in diameter, and furnishes about 30,000 gallons per day. The well, beginning at the surface, passes through 12 feet of soil and cobblestone and 53 feet of solid basalt, and after passing through the basalt it reaches about 12 feet in the sand beneath. The elevation at the surface is that of the general level of the canyon bottom, or 2,340 feet. The water rises in pipes about 20 feet above the mouth of the well.

On the opposite side of the street from the Palace Hotel a well was drilled for J. R. Ruply in 1889 to a depth of 73 feet. This well is said to have been drilled in solid basalt, with the exception of the first 8 or 10 feet, which consisted of soil and loose rocks. The report fails to mention the stratum of clay which outcrops in the sides of the canyon near at hand, and which probably exists beneath the surface alluvium throughout the lower part of the town.[1] The Ruply well is 6 inches in diameter. It reached a stratum of micaceous sand, and water rose well above the surface, as is shown in the photograph here reproduced.

The well which supplies the town of Pullman was drilled in 1890, and is 6 inches in diameter and 84 feet deep. The surface level is practically the same as that of the Palace Hotel well. The section passed through is reported to be as follows: Surface soil, 3 feet; clay, 10 feet; basalt, 60 feet; gravel and sand with lignite, 11 feet. The bottom of the layer of sand was not reached. Water rose in an open pipe 20 feet above the surface, or to a level about 2,360 feet above the sea. No decrease in the pressure has since been observed. The water is raised by steam pumps to a reservoir on an adjacent hill and from there distributed for domestic and town purposes.

The three wells just described are typical examples of the eleven flowing wells now in operation in the lower portion of Pullman. The wells on the sides of the canyon, which were begun above the artesian head of the water in the porous stratum, are illustrated by the one which supplies the college buildings. The surface level at this well, as shown by measurements with an aneroid barometer, is 30 feet above the general level of the street in the lower portion of the town, or 2,370 feet above the sea. The well has a total depth of 144 feet, and is reported by Mr. Ebersol, the contractor, to have been all in basalt, except about 30 feet of clay. The clay layer is reported to

[1] In the report obtained of several other wells in Pullman all reference to this clay stratum was omitted. A possible reason for this omission is that the price of drilling is usually varied with the character of the material passed through.

ARTESIAN WELL AT PULLMAN.

have been reached at 65 feet below the surface. The section exposed in the valley of the canyon, however, indicates that the clay should have been first encountered at about 25 or 30 feet below the surface. Water rises to within 6 feet of the surface and is pumped to a reservoir which supplies the college buildings, situated about 200 feet higher than the surface at the well.

It does not seem advisable to record at this time all of the reports obtained concerning the wells at Pullman, as careful records of the character of the rocks passed through were not kept, and in some instances the reports obtained are unsatisfactory for other reasons.

The wells are all 6 inches in diameter. The contract price for drilling in surface earth and clay was in general $1 per foot, and in basalt $4 per foot. The water in all cases is beautifully clear, without occluded gases, and, with the exception of the Palace Hotel well, is soft. The water of the exceptional well has not been analyzed, but its taste suggests the presence of iron. None of the wells are cased, but much loss from leakage through fissures in the basalt is prevented by the clay stratum near the surface. The wells in the lower part of the town begin in the clay or in superficial deposits resting on it. It is to be expected that westward from Pullman, where the branches of Palouse River become deeper, the clay layer has been cut through, and that the conditions favorable for obtaining artesian water will be impaired, for the reason that basalt allows water under pressure to escape through fissures. In such instances it is evident that all wells should be cased down to the water-bearing sands.

Several of the wells at Pullman are allowed to flow, thus wasting a large volume of water and decreasing the pressure. If the blessings accompanying the discovery of an excellent water supply are to be maintained, all wells should be closed when not in use.

Wells at Moscow, Idaho.—At Moscow, Idaho, about 9 miles east of Pullman and near the junction of the Columbia basalt with the granite hills bordering it on the east, several wells have been drilled.

I have been informed by Mr. Ebersol and others that fourteen wells have been drilled since 1890, and that ten of these were flowing in 1891, but since then the pressure has so decreased that the water now stands 8 or 9 feet below the surface. The depth of these wells is in general about 100 feet, the first 50 to 60 feet being through loose material—the alluvial filling of the valley—and the remainder in basalt. Whether a layer of sand was reached or not seems uncertain. The information available concerning these wells is meager and unsatisfactory, but it seems that the alluvium of the valley—much of it fine, clay-like soil—plays the rôle of an impervious layer and retains water under pressure in the seams and joints of the basalt, thus furnishing an approach to favorable artesian conditions.[1]

Wells at Palouse.—Four wells have been drilled within a radius of

[1] It is probable that if these wells were properly cased a surface flow would result.

about 20 feet in the business portion of Palouse, with the hope of obtaining a water supply for the town. The last was completed in 1894. The town is situated principally in a valley with precipitous borders 280 feet high. The wells are in the bottom of the valley, and are said to be about 200 feet deep and to penetrate material as follows:

	Feet.
Earth and stones	14
Coarse gravel	3
Solid basalt	100
Coarse sand	9
"Black slate rock"	30
Sand, water-bearing	25 to 30

Of these four wells, the first drilled is now closed, and the remaining three discharge collectively about 10 gallons per minute. The wells are 8 inches in diameter at the top, but are said to decrease to 6 inches, and again to 2 inches toward the bottom.

The wells are a failure so far as supplying the town is concerned, but it is evident that if casings could be introduced their efficiency would be increased.

Well at Garfield.—A well has been drilled at Garfield with the hope of obtaining artesian water for the town, but did not meet with success. The well is reported to have been drilled to a depth of about 300 feet with a 6-inch bit, and afterwards enlarged by excavating to 8 feet to a depth of 100 feet. From this well water is now pumped for the supply of the town. The excavated portion of the well passed through earth and bowlders; apparently the upper part of this material is a stream deposit and the lower portion disintegrated basalt. Below the open well the drill passed through "honeycomb" rock; by this is probably meant much-jointed and possibly scoriaceous basalt.

James Walter's well.—Three miles northeast of Garfield, at the residence of Mr. James Walter, a drilled well 113 feet deep was completed in 1892. This is a flowing well, and discharges a stream of water $1\frac{1}{4}$ inches in diameter. The section passed through is reported by Mr. Walter as follows:

	Feet.
Dirt	16
Basalt	65
Blue clay	5 to 6
Gray clay	5 to 6
Hard cement	2
Blue and yellow clay, with quicksand, water-bearing	10 to 12

The surface of the ground at the locality where this well was drilled is reported to be higher than Garfield, but no measure of its elevation is available.

Other wells.—Incomplete reports have been obtained of not fewer than a score of wells, in addition to those mentioned above, in a belt of country about 15 miles wide, extending northward from near Snake

River, along the eastern border of Washington. The time available for making a personal examination of this region was so limited that little more than the facts here reported could be obtained.

The success which has followed a large number of the attempts already made to obtain artesian water in this region, and the facts learned concerning the nature and relations of the rocks, certainly indicate that artesian water can be had at a moderate depth over a wide extent of rich agricultural land.

The western border of the region in which artesian water can be had is indefinite. The region to the west of a north-and-south line passing through Garfield, including the greater part of Whitman County and all of Adams and Franklin counties, is geologically unknown, except so far as the conditions there prevailing can be judged from what has been seen in adjacent areas. Whether test wells have been put down in this region or not I have failed to learn.

There is no definite evidence in hand to show that the sands and clays penetrated at Pullman, Garfield, etc., extend far westward, but it is reasonable to suppose that such is the case. It is probable also that layers of clay and sand exist lower in the series than those penetrated at Pullman, which may furnish similar conditions in the region to the west.

Besides the presence or absence of pervious and impervious layers, the dip of the beds and the depth to which they have been dissected by streams have also to be considered. While there seems a probability that artesian wells may be had over a wide extent of country to the west of the region at present explored, lack of definite information concerning that region makes it impossible for one to form an opinion in this connection.

ARTESIAN CONDITIONS SOUTH OF SNAKE RIVER.

The question of obtaining artesian wells in that portion of Washington which lies south of Snake River resolves itself into two considerations with reference to source of supply: First, can water be had under conditions similar to those existing at Pullman from strata leading westward from the mountains of Idaho? Second, are there water-bearing strata dipping away from the Blue Mountains?

With reference to the first of these questions, it is to be remembered that Snake River Canyon cuts off all possible sources of supply to a minimum depth of about 2,000 feet below the general surface of the basaltic plateau. We have only indefinite evidence as to the nature of the rocks below the level of Snake River. As the basaltic layers exposed in the canyon of that river are nearly horizontal, it is evident that the artesian head for any porous layers which may exist below the horizon of the river would be low. The manner in which the series of horizontally bedded basaltic sheets abuts against the metamorphic rocks on the east renders it extremely improbable that any deeply seated porous stratum could be water-charged in such a manner as to make it a source of artesian water.

The considerations just indicated are of such weight that there seems no need of hesitation in declaring it useless to hope for success in drilling wells in the region south of Snake River with the view of obtaining water from sources similar to those which supply the wells in the neighborhood of Pullman.

Turning to the second possible source of artesian water suggested, namely, the Blue Mountains, we find that the rocks dip away from that uplift, and also that they are abundantly water-charged. Two of the primary conditions requisite for obtaining subterranean water under pressure are thus fulfilled. Inquiries in at least two other directions must be made, however, before a conclusion can be reached. These are: First, are there layers of clay and sand interbedded with the basalt? and second, have the rocks been so deeply dissected by streams as to allow pervious beds, if they exist, to be drained?

Beds of clay and of fragments of volcanic rock (lapilli and volcanic dust) interbedded with basalt occur in the neighborhood of Asotin, and possibly extend southwestward and westward, but no exposures of these layers were seen by me in the Blue Mountains. My examination, however, was not sufficiently detailed to prove that they are there absent.

The material forming the clay beds referred to was derived from the mountains of Idaho before the cutting of Snake River Canyon, and probably thin out westward. No layers of sand like the one yielding water at Pullman are known to occur beneath the clays, and the strata of lapilli and volcanic dust are not sufficiently porous to be classed as water-bearing strata. It is thus exceedingly doubtful if the succession of beds in the flanks of the Blue Mountains affords the arrangement of pervious and impervious layers necessary for an artesian water supply.

With reference to the depth to which the rocks forming the Blue Mountains and the plateau extending northward from them have been dissected by streams, it will be remembered that deep erosion has occurred. In the mountains there is a veritable labyrinth of canyons from 2,000 to 3,000 feet deep. This deep erosion, however, is favorable to the process of charging with water any pervious layer that may exist in the flanks of the range, since the edges of the layers are exposed to the rain and to water flowing down the sides of the canyons or percolating through the soil that mantles the cut edges of the strata.

The canyons leading northward from the Blue Mountains soon increase in depth, and the plateau in the northern portions of Garfield and Columbia counties is deeply dissected. Evidently any porous strata that are cut by these canyons could not contain water under pressure. The only possible hope for obtaining artesian water in the counties just mentioned is, therefore, below the level of the canyon bottoms. The expense of drilling wells from 500 to 2,000 feet deep through basalt, as would of necessity be the case on the fragments of the plateau remaining between the streams, even if success at these depths were assured, would preclude the use of water thus obtained for irrigation.

In the canyons there is a chance that artesian water might be reached, but the conditions are so uncertain that the experiment of sinking wells below a depth of 100 or 200 feet should not be made, except as a last resort. The more practical and entirely feasible method of utilizing the surface streams within the canyons makes it unwise to incur expense in the search for subterranean water. The possibility of obtaining water from the alluvium of the canyons will be referred to later.

In the valley of the Walla Walla, in a general way westward of a line connecting the cities of Walla Walla and Milton, Oregon, there is an absence of canyons. In this region, also, there is at least one clay stratum interbedded with the basalt, but no evidence of the presence of layers of sand has been obtained. This is the only region in Washington south of Snake River where the hasty examination I have been able to make suggests the possibility of obtaining artesian water at reasonable expense and where there are lands available for farming. Even in this region the certain method of utilizing the abundant surface water is much to be preferred to the uncertainty of attempting to obtain flowing wells. The geological conditions in the valley of the Walla Walla are not such as to warrant the prediction that success would follow the drilling of a well, but simply that there is a possibility of success. The best locality for drilling a test well in this region is in the vicinity of Whitman. A trial made at Walla Walla would probably be equally decisive. At Whitman a depth of 150 to 200 feet of surface material would probably have to be passed through before rock in place would be reached, but in this upper portion of the section flowing water is likely to be met. At Walla Walla the superficial material—the bowlder and gravel of Mill Creek—is apparently not deep and might also yield flowing water.

In order to test the possibility of obtaining water at Walla Walla I should favor the project, already proposed, of drilling a well at the State penitentiary. To make the test conclusive, the proposed well should be drilled to a depth of 500 feet, if flowing water is not obtained nearer the surface.

WELLS IN ALLUVIUM.

There are flowing wells of another class that require mention, but which are scarcely to be classed with true artesian wells.

The deposits made in stream channels and over flood plains are usually composed of irregular layers of bowlder, gravel, sand, clay, etc., through which the stream waters percolate. The water in the pervious layers is sometimes under moderate pressure and will rise to the surface when wells are dug. The pervious beds are usually irregular and of small extent, and their water supply, being furnished by the stream which deposited them, varies with changes in the volume of the stream. No one can tell, without making practical test, whether the percolating waters in an alluvium-filled valley will rise to the surface or not. The best way to search for such waters, where the alluvium does not contain large bowlders, is by driving pipes into the ground. Where bowlders 1 foot to 2 or 3 feet in diameter are met with, driven wells are impracticable. It is also difficult and expensive to drill through deposits of bowlders, so that the only practicable method seems to be to make the excavation by hand. In some instances, when a strong flow of water is reached, if the bottom of the well is covered with cement, through which a pipe is inserted leading to the surface, a surface flow may be obtained.

As is well known, the bottom of many of the canyons leading from the Blue Mountains are deeply filled with alluvium, in which water may be obtained. An excellent method of conducting the percolating water of alluvial deposits to the surface and making them available for use lower down the valley in which they occur, without pumping, is in operation at Walla Walla.

WATERWORKS AT WALLA WALLA.

Walla Walla is now supplied with water from infiltration ditches prepared in the coarse gravel that forms the flood plain of Mill Creek, about a mile above the central part of the town. The water from the infiltration ditches is conducted into reservoirs, from which it is distributed by gravity. The fall of Mill Creek in the vicinity of Walla Walla is 63 feet per mile. This rapid descent makes it possible to locate reservoirs near the town. The infiltration ditches are dug as open ditches to a depth of from 12 to 15 feet. At the bottom an inverted trough made of planks is placed and covered with clean gravel to the depth of several inches. The gravel also fills the space between the sides of the inverted trough and the undisturbed material forming the walls of the ditch. The material removed in digging the ditch is then replaced. The use of tiles in place of the inverted wooden trough would have advantages, but would be more expensive.

The infiltration ditches are located at angles of 30° to 40° with the direction of slope, and trend upstream. The water percolating through the gravel enters the inverted troughs from below and also flows through the loose gravel covering them, and is conducted to reservoirs. The length of the infiltration ditches varies. As an example of their efficiency I insert the following information, furnished by the superintendent of the waterworks, concerning what is termed "Reservoir No. 2." This reservoir is a tank excavated in the gravel, but not lined, and sheltered by a timber and shingle roof. It is rectangular, measures 51 by 90 feet on the sides, and is 10 feet deep. Two infiltration ditches lead to this tank, one 500 and the other 800 feet long. These discharge during the summer season about 320,000 and 420,000 gallons, respectively, per day.

There are two other reservoirs of similar dimensions, supplied in like manner. The water reaching the reservoir is thoroughly filtered, and at present, as shown by sanitary analyses, is wholesome and of an agreeable temperature.

This method of obtaining a water supply is recommended for its economy, and on a smaller scale might be advisable in many instances for farm purposes, in place of wells now commonly in use. The advantages over surface wells are that the water supply may be drawn from a distance from sources of contamination, and when properly arranged the trouble and expense of pumping are avoided.

The only objection that can be suggested to this method of supplying towns or residences with water is that it comes from superficial deposits and is in danger of contamination from houses, stables, etc., situated upstream from where the infiltration ditches are located. In countries of small rainfall, where the streams are greatly lowered during the summer, the dangers from these sources are multiplied. For 9 or 10 miles above Walla Walla the narrow canyon-like valley of Mill Creek is occupied somewhat thickly by farmhouses and stables. Contamination of the city water supply from these sources is a constant menace.

CONCLUSIONS.

The results of the hasty examination of the geology of southeastern Washington here reported on, so far as the question of artesian water is concerned, may be briefly summed up as follows: In the Palouse country there are reasons for believing that the area in which artesian water has been found will be broadened westward. South of Snake River there is no evidence that success would accompany the drilling of wells on the uplands. In the canyon bottoms there is a possibility of finding artesian water, but further than this the study of the geology does not offer suggestions, except of an adverse character. The chances of failure far outbalance the chances of success. To the northwest and west of the Blue Mountains—more definitely, in the valley of the Walla Walla westward from a line joining the towns Walla Walla and Milton, and possibly extending some distance into Oregon—the conditions are more favorable than elsewhere in Washington south of Snake River and warrant the drilling of a test well should the demand for water be great. Even in this most favorable area, however, I should recommend the full utilization of the streams and the storage of the winter run-off before attempting to obtain artesian water for irrigation purposes.

AN OUTLINE SKETCH OF THE GEOLOGICAL HISTORY OF SOUTHEASTERN WASHINGTON.

Of the ancient geological history of Washington but little is known. The northern portion of the Cascade Mountains, as shown recently by Bailey Willis, is largely composed of metamorphic rocks. Similar rocks occur about Lake Chelan and north of the Big Bend of the Columbia and of the lower portion of Spokane River. From Spokane the hills formed of these metamorphic rocks extend southward along the Washington-Idaho boundary, and from them the mountains of western Idaho have been sculptured.

The rocks just referred to as being of metamorphic character—that is, greatly changed by heat and heated solutions from their original condition—were in many instances of sedimentary origin, but are now granite, schist, quartzite, etc. The granites, however, may be in part of igneous origin—that is, were once in a molten condition—but of this no direct evidence has been observed. The place in the earth's history where these rocks belong is unknown, but their crystalline condition suggests that they are very old, and possibly belong to the series termed Archean. The resemblance of metamorphic rocks in one region to similar rocks at a distance is an uncertain basis for classification, however, for the reason that strata belonging to widely different periods, when changed by heat and heated water, produce granites, schists, etc., having the same characteristics. Some of the granites of the Pacific Coast are known to be of comparatively recent geological date.

The structure of the rocks of the metamorphic regions of Washington—that is, the positions which the rocks occupy, whether folded, contorted, broken, etc.—is not well known; although it is easily seen that those which still retain evidence of bedding, and were without question originally in horizontal sheets, have been upturned and bent into great folds. Throughout the metamorphic region the country is mountainous, and much of the geological history of the region is recorded in their forms. The valleys have been carved out of the upraised mountain masses, and each dome and crest has been slowly fashioned by rain, frost, wind, and rills into its present transient shape. The depth to which the valleys have been excavated and the forms of the bordering hills show that the mountains are old and have formed a land surface for geological ages.

In comparatively recent geological times the mountains of northern Washington and eastern Idaho, although probably higher and more rugged than now, had their present general outlines, but the central and southern portions of the Cascades, as well as the Coast Range, were as yet unborn. The country south of the southward-facing semicircle of mountains, embracing the present great plain of the Columbia and southeastern Washington, was low and partially submerged at times beneath the sea. This vast low-lying area, together with the surrounding mountains, was clothed with varied and beautiful forests, resembling those of the South Atlantic States at the present day. In this valley region, which extended far south, there were lakes and swamps in which vegetable matter accumulated and was later changed to coal. Some of this coal is now mined at Roslyn. The luxuriant vegetation, a part of which has been preserved as coal, furnished food and shelter for a variety of animals, no near relatives of which are living at the present day.

This age, when almost subtropical conditions prevailed, was in the early Tertiary. As time passed, the lakes became filled with sediment, and much of the region sank beneath the sea. Clays and sands were spread out which have since hardened into rock. Upheaval brought these once level sheets of rock above the sea and raised them into a mountain range—the southern Cascade. In central Washington these early Tertiary rocks were eroded, and outbreaks of volcanic energy caused lava sheets to be spread over them. Fissures opened in the earth's crust, and molten rock was poured forth in such wondrous abundance that thousands of square miles of valley lands were inundated by the fiery floods. The lavas were similar to those poured out within the past few years by the volcanoes of the Hawaiian Islands and other regions. The molten rock was highly liquid, flowed rapidly, and spread out in sheets of broad extent. On cooling, it formed the dense, black basalt now so familiar throughout central and southeastern Washington. This is the Columbia lava, so frequently mentioned on the preceding pages.

Vast outwellings of molten rock occurred at intervals throughout a period embracing many hundreds and probably many thousands of years. The time between successive flows was sufficiently long, in numerous instances, to allow the surface of the cooled and hardened lava to crumble and decay under the action of the atmosphere and form soils on which forests of oak and pine took root and flourished. In some instances abundant showers of volcanic dust, similar in character to the fine dust-like material blown out by many volcanoes in historic times, covered the land and buried the still erect trees. Later lava sheets were spread over the entombed forests, and in some localities charred the trees and changed them to charcoal. When the trees were so protected by their covering of volcanic dust that they were not directly influenced by the heat of the lava that flowed over them, heated waters brought silica to them in solution, and they were changed to stone. The stumps of these silicified or fossilized trees, still standing as they grew, may be seen in the sides of the canyons that streams have cut in the thick pile of lava sheets. The replacement of the wood in these buried forests by silica, usually in the form known as opal, was so complete that not only the grain of the wood but each duct and cell is preserved, and when examined in thin sections under the microscope it appears as perfect as the wood of a living tree.

Lava flow succeeded lava flow until the vast valley region embraced in part by the mountains of northern Washington and eastern Idaho, thousands of square miles in extent, was covered with basalt to an average depth of probably 3,000 or 4,000 feet. The molten rock spread widely over the lowlands and about the bases of the bordering mountains and extended up the tributary valley. As sheet after sheet was added the hills in the lowlands became buried; outstanding spurs of the mountains became capes in the sea of molten rock; isolated mountain peaks were surrounded by the fiery flood and submerged, or left as islands rising above its surface.

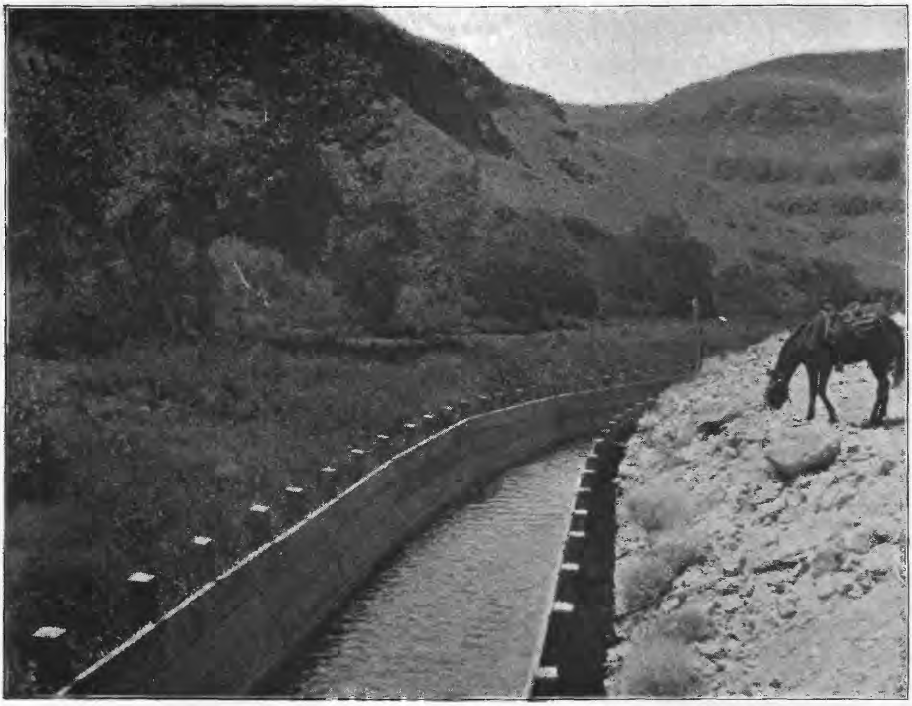
This vast inundation of lava is one of the most remarkable and, I may say, one of the most dramatic incidents in the geological history of North America. It is safe to assume that all the lava poured out by volcanoes within historic times, if run together, would make but a small fraction of the mass under which the region drained by the Columbia is buried.

During the lava flows streams from the bordering mountains met the encroaching sheets of molten rock, and many grand spectacles of conflict between water and fire might have been witnessed, but of the presence of man on this continent at the time of these vast eruptions we have no records. Some of the sheets of volcanic fragments interbedded with the lava sheets appear to have been formed by the shattering and rapid cooling of the highly heated rocks on coming in contact with water.

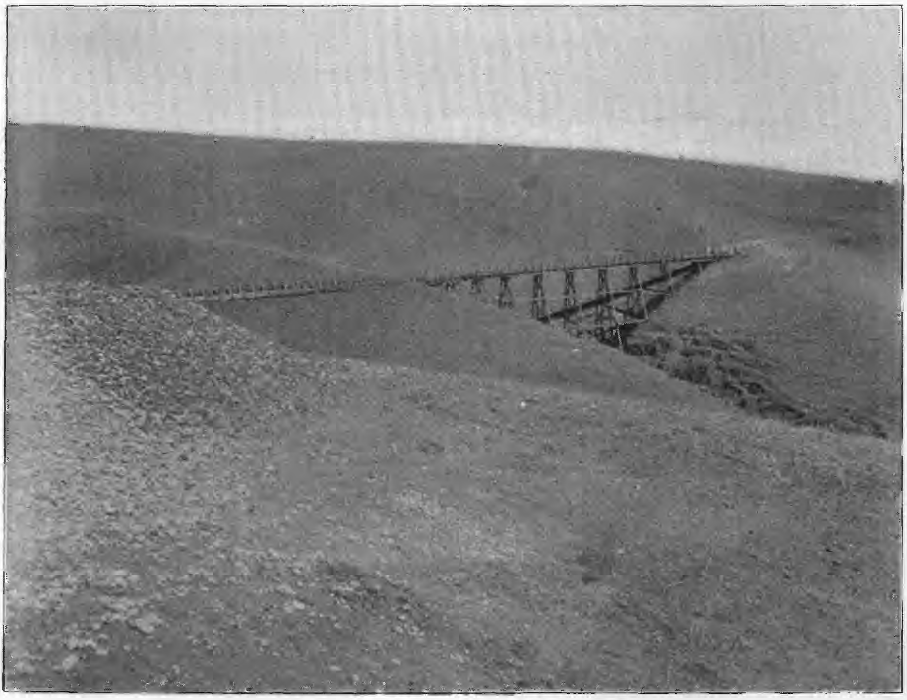
Layers of fine, pure-white volcanic dust between the sheets of basalt show that distant volcanoes were in a state of violent eruption at the time these deposits were made, and the wind carried the dust far and wide over the land. That the dust did not come from the same eruptions that supplied the basalt is shown by marked differences in chemical and mineralogical composition. The dust is an acid rock—that is, rich in silica—while the basalt is basic.

During the intervals between the lava flows lakes were formed on the surface of the cooled basalt and sheets of sediment were laid down. These lakes came into existence, especially about the borders of the lava-covered country, for the reason, in central and eastern Washington at least, that the advance of the lava was toward the mountains, and on cooling formed land surfaces which sloped gently toward the uplands and intercepted their streams. In some instances the lava flowed far up the valleys and gave them a nearly level floor of solid basalt. Sand and gravel, swept out of the mountains by swift-flowing streams, was spread over the lava during intervals between the fiery floods. Alternating sheets of basalt, sand, and clay were thus formed, especially about the borders of the lava-covered region, and furnished the requisite conditions for storing water under pressure. Artesian wells ages later were thus made possible.

Toward the close of the long period during which the lava sheets were spread over the lowlands the lakes formed on their surface



LEWISTON IRRIGATION CANAL.



FLUME IN LEWISTON IRRIGATION CANAL.

became of broad extent, but were invaded from time to time by additional layers of volcanic rock, which were buried by still younger lacustral deposits. At length the volcanic energy ceased and deep and widely extended lacustral sediments were accumulated. The broad lakes in which these sediments were laid down in even layers were probably held in basins formed by the upheaval of the Cascade Mountains. The light-colored and evenly bedded deposits referred to may now be seen at the White Bluff of the Columbia, in Wenas and Natches valleys in Washington, and in John Day Valley in Oregon. Leaves of many kinds of trees and the bones of mammals occur in these deposits and record the fact that after the vast outpourings of lava came to an end the land was again forest covered and inhabited by many large animals, all of which are now extinct. Thick layers of volcanic dust interleaved with the lacustral clays and sands bear evidence of violent eruption in distant volcanoes.

With the drainage of the lakes that covered large portions of the lava country with sands and clays, the streams from the mountains flowed to the sea, and were enabled to carve canyons in the hard lavas. At an early stage in this epoch stream-borne gravels were carried out onto the basaltic plateau, and the most resistant of the stones thus deposited—the hard quartzite—may still be found in many places on the general plateau surface between deep canyons.

Snake River slowly carved out its channel until, at the present time, in the eastern flank of the Blue Mountain uplift it is an immense gorge some 15 miles broad at the top and about 4,000 feet deep. The work of stream cutting is slow. If we could study Snake River for a century where it flows over hard basalt, it would be difficult to determine the depth—probably not over a fraction of an inch—that it had lowered its bed. The river performs this task mainly by abrasion. Stones and sand swept along by the current wear the rocks over which they pass. Basalt is dense and hard, and, although decomposing with comparative rapidity when exposed to the air, yields very slowly to mechanical wear. The task of cutting to its present depth the magnificent canyon which now excites the wonder and admiration of all who behold it must have required an almost infinite time, as it appears to us. This task has been performed, however, since the lava sheets were spread out over southeastern Washington, and for the most part since the lake beds containing the records of extinct floras and faunas resting on the lava were laid down.

There are reasons for believing that the canyon of Snake River was excavated to its present depth before the time in the earth's history known as the Glacial epoch. Space will not permit of a review of all the facts that lead to this conclusion, but a great gravel terrace in the canyon of Snake River and similar terraces in the canyons of Columbia and Spokane rivers show that after they were worn to their present depth they were filled to a height of 300 or 400 feet—360 feet in the case of the Snake River below Lewiston. This filling is attributed to the overloading of the streams with débris furnished by glaciers and by swollen mountain streams. The cause of this change was climatic. During the Glacial epoch Washington and Idaho, in common with the northern half of the continent, had a colder and more humid climate than now. The streams flowing from the mountains were thus enlarged, and more earth and stones were swept into the channels of the main streams than they could transport.

The great climatic change which caused about one-half of the North American Continent to be covered with glacial ice left no records in southeastern Washington except those briefly referred to. Glaciers existed on the mountains of Idaho and Washington, but did not invade that portion of the basaltic plateau now included within the boundaries of Washington except locally at the northwest border of the Big Bend country. This advance of ice from the Okanogan country across the canyon of the Columbia dammed that mighty river and caused it to flow across the great plain of the Columbia, through the remarkable gorge known as the Grand Coulée.

Since the Glacial epoch the streams have shrunk in volume, owing to the combined effects of a decrease in precipitation and an increase in the rate of evaporation, and in their weakened condition they have scarcely done more than recut their channels through the gravel and sand previously deposited in them.

The vast amount of work performed by Snake River previous to the Glacial epoch, the halt in the task due to overloading, and the slow rate at which the weakened stream has been able to renew its task in recent centuries, all indicate that the time required for excavating the canyon has been long. We have no accurate measure of this time, but it is safe to say that it embraced millions of years.

The sheets of Columbia lava were essentially horizontal when they were spread out, and, so far as known, they were not disturbed until after the volcanic eruptions, to which they are due, came to an end. Movements in the earth's crust occurred at a later date, however, and the thick series of basaltic layers were broken into blocks measuring many miles on their sides, and these were variously tilted. This breaking and tilting occurred principally to the westward. Some of the tilted blocks extend far up on the eastern border of the Cascade Mountains, showing that the central and southern portions of that magnificent range have been upraised since the period when the Columbia lava was poured out.

In southeastern Washington the basalt has suffered but little from the forces producing elevations and depressions, and over extensive areas the hardened lava is still horizontal. The portion of the lava forming the Blue Mountains has been elevated into a broad, low, flat-topped dome, on the flanks of which, so far as has been learned, the beds of basalt dip away gently in all directions. The movements that have produced these more general changes in the relief of the basalt-covered country are probably still in progress, as is indicated by the manner in which Walla Walla River is grading up its valley at the western base of the Blue Mountains.

The surface of the basaltic plateau, which is by far the larger part of southeastern Washington, as already stated, remained nearly horizontal, and during the vast lapse of time that witnessed the excavation of Snake River Canyon slowly yielded to the destructive influences of the air and of percolating waters and crumbled to a porous soil. The depth of the products of disintegration and decay is in many places 60 to 80 feet. In fact, over hundreds of square miles the average depth of the fine, yellowish, dust-like material forming the surface layer of rich agricultural districts is as great as the amount just stated.

The surface of the nearly level plateau has been roughened by stream erosion, but its plateau character not destroyed. Numerous level-floored valleys without stream channels bear evidence that the rainfall was formerly more abundant than now. The stream-cut canyons and valleys have been partially filled with fine soil, washed from the adjacent hills or blown from the uplands by the wind. The minor topographic features of the plateau, although due in the main to stream erosion, have been modified to an appreciable and sometimes to a marked extent by the action of the wind.

It is from the soil formed by the slow disintegration and decay of basaltic rocks that the millions of bushels of wheat raised each year in eastern Washington are obtained. The sending of wheat from the State of Washington to the famishing people of India, which has recently been done, is rendered possible because ages ago volcanic rocks capable of furnishing a wonderfully rich soil inundated the Tertiary lowlands where now "rolls the Oregon." The splendid water power at Spokane and the marvelous growth of that charming city can be traced to a climatic change which caused the valley in which it is situated to become deeply filled with stream deposited gravel. When the bright, swift-flowing waters were enabled to clear out their channel, they did not rediscover their former course at all points, but cut across rocky spurs projecting from the sides of the old valley. One such occurrence gave Spokane its beautiful cascade. Many other illustrations of the influence of events in the geological and geographical history of Washington which bear directly on the industrial and intellectual development of the present generation might be cited.

In closing this report of a hasty reconnoissance, I wish to state that the studies thus far made of the geology of Washington show that it is not only one of the most interesting States in the Union to the geologist and geographer, but that it is also rich in mineral and other resources.

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