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Bulletin No. 252

Series { B, Descriptive Geology, 57
{ O, Underground Waters, 33

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

GEOLOGY AND WATER RESOURCES OF CENTRAL OREGON

BY

ISRAEL C. RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF GEOLOGY AND PALEONTOLOGY,
Washington, D. C., June 28, 1904.

SIR: I have the honor to transmit herewith the manuscript of a Preliminary Report on the Geology and Water Resources of Central Oregon, by Israel C. Russell, and to recommend its publication as a bulletin.

The report contains interesting and valuable information concerning a little-known region. The field work on which it is based was done under the joint auspices of the western section of hydrology and the division of geology and paleontology. Although it contains a large amount of information concerning the water resources of the region, it is primarily a geologic report, and is therefore offered for publication as a bulletin.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

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

PRELIMINARY REPORT ON THE GEOLOGY AND WATER RESOURCES OF CENTRAL OREGON.

By Israel C. Russell.

INTRODUCTION.

ROUTE OF RECONNAISSANCE.

The observations recorded in this paper were made during a rapid reconnaissance from east to west through the central part of Oregon in the summer of 1903, and are in continuation of similar work in the same general region previously done by me, reports concerning which have been published.[a] The arrangement of the matter is geographic, and the audience addressed consists of the people living in the region visited. While my main aim is to indicate where artesian water can be had, I have chosen to present the observations made in this and other directions in a popular form, with the view of interesting those for whom this report is especially intended in the geologic history of the land about their homes.

With Messrs. C. E. Wilson and H. C. Dewey as field assistants, I left Boise, Idaho, on June 28, with the necessary camp equipage, etc., and traveled westward, reaching Burns, Oreg., on July 15. The reconnaissance made by me during the previous summer (described in Bulletin No. 217) terminated on the west near Burns, and the work of the present season practically began there. On leaving Burns the route followed led westward through the western portion of Harney County, across the southeastern and central portions of Crook County by way of Prineville and Sisters, and thence southward through the northwest portion of Klamath County to Fort Klamath. From the last-named place, in order to reach a convenient locality for disband-

[a] Russell, Israel C., Geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431–464; Geology and water resources of the Snake River Plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 1–192; Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903, pp. 1–51; Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, pp. 1–83.

ing my party, the journey was continued westward across the Cascade Mountains to Medford, in Jackson County, a station on the Southern Pacific Railroad, which was reached on September 15.

Owing to the absence of railroads in the central portion of Oregon, considerable time was occupied in traveling to and away from the region concerning which information was desired. During these parts of the journey only observations of the most general character were undertaken, some of which, however, are set forth in the following pages, as they supplement previous reports.

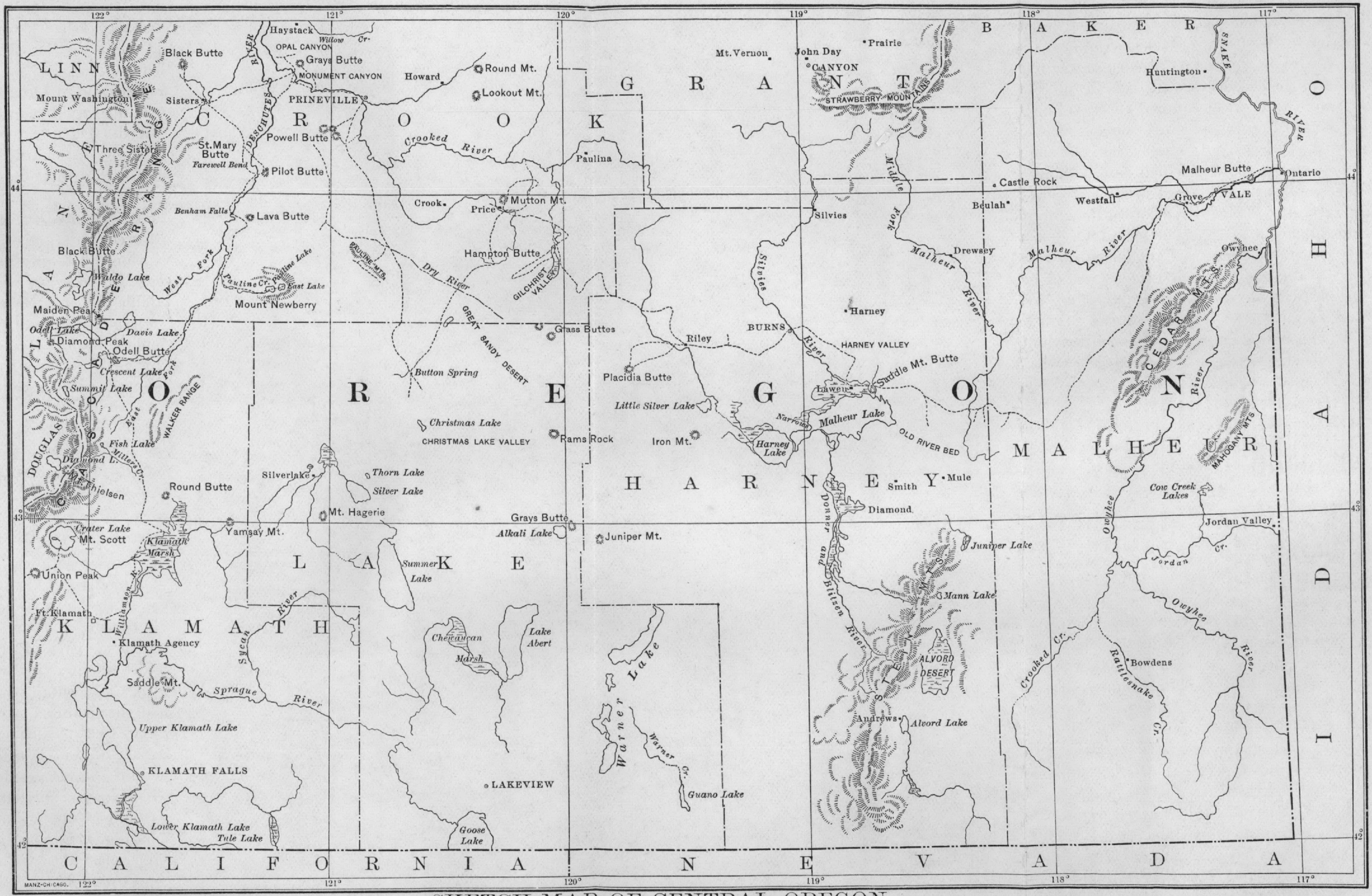
The region to which attention is here invited is indicated on the map forming Pl. I. The portion of Oregon referred to is not only new to geologists (so far as I am aware, no descriptions of its physical features, water resources, or geology are in print), but has not been topographically surveyed. The only map available for use during my reconnaissance was a map of the State of Oregon, drawn to a scale of 12 miles to an inch, published by the General Land Office of the Interior Department. To a large extent this map is devoid of data in reference to even the more conspicuous elements of the relief of the central portion of the State.

The critic who may pass judgment on the value of this report should bear in mind that the observations recorded were made during a rapid reconnaissance through a geologically unknown region, without the assistance of a map showing even the major features of the topography.

GEOGRAPHY.

The part of Oregon under consideration has been briefly indicated above, but its location will perhaps be better understood from a summary account of its relation to the larger features of the drainage of the Pacific slope of the United States.

The region examined includes the extreme northern part of the Great Basin (an area of about 210,000 square miles situated principally in Oregon, Nevada, Utah, and southeastern California, from which no streams flow to the ocean) and a part of the drainage area of Deschutes River and of its principal tributary, Crooked River, which joins it from the east. It lies east of the part of the Cascade Mountains included between Mounts Jefferson and Thielsen, and north of the extensive region in southern Oregon and northern Nevada which was notably deformed by faulting in late geologic time, so as to give origin to several deep valleys, now holding lakes of alkaline water, such as Abert, Summer, Silver, and Christmas lakes. The portion of Oregon and Nevada referred to is unique, owing to the fact that it is a lake region in an arid country, at a distance from lofty mountains.



SKETCH MAP OF CENTRAL OREGON

ROUTE OF TRAVEL INDICATED BY BROKEN LINE

Scale

10 5 0 10 20 30 40 50 miles

1904

TOPOGRAPHY.

GENERAL FEATURES.

The relief of surface in central Oregon presents well-marked contrasts, ranging from the nearly level, featureless surfaces of the desert valleys, where the general elevation is about 4,000 feet, to the rugged, snow-clad summits of the Cascade Mountains, the highest of which, Mount Jefferson, reaches a height of about 10,350 feet. The contrast between the region extending 150 or more miles east of the Cascade Mountains and the great series of peaks and ridges bounding it on the west is so great that the former region, although actually rugged, seems by comparison monotonous and lacking in variations in relief of surface. But for the overshadowing importance of the great mountains on its west border, however, the central portion of the State would in general be recognized as mountainous.

GREAT SANDY DESERT.

The most extensive tract of nearly level land is situated in the geographic center of the State and is designated in part on the maps as the Great Sandy Desert. This region, termed "sandy" on account of the thick sheet of pumiceous sand and dust that covers large portions of it, extends from the south-central part of Crook County southeastward across the northeastern portion of Lake County and far into Harney County. Its length is in the neighborhood of 150 miles and its width from 30 to 50 miles. So nearly uniform is the surface that one might drive throughout its length, and even for a much greater distance than that indicated above, without meeting any greater obstruction than the rigid sagebrush and—to indicate the aridity of the region—without finding a single watering place for men or animals.

The boundaries of this vast, nearly smooth tract are indefinite, as it is bordered by mountains both of volcanic origin and of upheaval, between which lie the extensive valleys that unite to form the central plain. On the plain itself there are prominent elevations, either standing as isolated buttes or as groups of hills and mountains, which are rendered especially conspicuous because of the general smoothness of the surfaces from which they rise, as well as by the steepness and, in some instances, the ruggedness of their sides.

CLASSES OF ELEVATIONS.

The topographic elevations in central Oregon may be classed in two groups—hills or mountains and plateaus due to upheaval, and hills or mountains produced by volcanic eruptions. Of these two classes the second contains by far the greater number of examples. Each of the groups of land forms referred to as standing in relief may again be divided into those that have derived their most conspicuous characteristics through the action of the forces which brought them into existence, and those that have been modified in an important way by erosion. In other words, there are both old and young hills and plateaus due to upheaval and old and young volcanic cones. These contrasts in age refer mainly to the degree of topographic development produced by erosion, but also indicate in a general way the relative dates at which the various elevations in each class came into existence.

The broad irregular plateaus north of Burns, which extend west to near Prineville, form an uplifted region, perhaps with many minor inequalities, but in general a broad upward swell or anticline produced by upheaval. Its surface has been trenched by streams, but in general is not minutely dissected. About 30 miles south of these plateaus are Powell Butte and the Pauline Mountains, and in the intervening space is a prominent ridge termed locally Pine Mountain. Each of these elements is a remnant of a geologically ancient upland cut down by erosion.

To the east of the central region rise Steins Mountains, a prominent north and south range due to the upheaval and tilting of a large block of the earth's crust adjacent to a line of deep earth fractures—that is, it is a monoclinal or "block mountain." Similar tilted blocks form the prominent, generally north-south, ridges in the vicinity of the alkaline lakes to which Lake County owes its name. These elevations are mentioned because to a great extent they define the boundaries of the less rugged central portion of Oregon traversed during the reconnaissance which furnished the data for this paper, although, in most instances, no fresh information is here presented concerning them.

In central Oregon the most common and most conspicuous elevations are due to volcanic eruptions. In traveling west from Burns to Sisters a few old volcanoes are met in the first half of the journey, such as Placidia Butte, the Glass Buttes, and Hampton Butte, and farther west are seen other ancient craters or much-eroded volcanic peaks and numerous young volcanoes. These young volcanoes are situated for the most part in the northern part of Lake County and the southwest part of Crook County. Their cones, so recent in numerous instances that erosion has not yet broken their crater rims, are so numerous that 50 or more can frequently be counted in a single view, while a change of a few miles in the position of the observer brings perhaps as many more within the range of vision. The cones increase in abundance as the Cascade Mountains are approached, a fact significant of the conditions on which the distribution of volcanoes depends.

The Cascade Mountains border the interior basins and valleys of Oregon on the west, crossing the State from north to south in a continuous belt, which, south of the Columbia, is nowhere intersected by a transverse valley and across which there are no low passes, though at three localities wagon roads have been constructed which furnish routes of travel between the interior of Oregon and the region west of the mountains. The mountains, so far as known, are composed entirely of elevations due to volcanic eruptions, and consist of lava flows and the fragmental products of volcanoes. The eastern border of the range in the portion visited, although well defined, is not abrupt. In the portion of the border between the Three Sisters peaks and Mount Thielsen the recent volcanoes of the interior region extend westward and, becoming more and more closely associated, merge with the volcanic cones which form the Cascade Range. In general it seems to be true that the great number of volcanoes forming the Cascades are situated along a belt of fractures running north and south, from which, at least in the portion of the range between the Three Sisters and Mount Thielsen, branching fractures trend away toward the southeast. Along both the main line of volcanic vents and the extensions from it toward the southeast eruptions have occurred during a long period of time, ranging, as the evidence in hand indicates, from early Tertiary to near the present day. In general the older volcanoes erupted andesitic lavas, while the more recent ones discharged basalt, though marked exceptions to this rule are furnished by certain andesitic volcanoes situated about Pauline Lake, which are among the most recent of the entire region. The most conspicuous feature of the eastern border of the Cascade Mountains is that the range has been built by volcanic eruptions, and only subordinate features of the relief are due to the work of streams and glaciers. This eastern border does not give evidence of being due to a fault or series of faults, as is the case of the corresponding eastern margin of the Sierra Nevada. If a displacement of the basement rocks of the range is present, it is, so far as known, completely buried beneath more recent volcanic ejecta. In no part of the border of the range visited during the reconnaissance here described do the rocks on which the volcanoes rest and through which their conduits were extended appear at the surface. This same generalization, I understand from the observations of others, can be extended to the entire Cascade region in Oregon.

SUMMARY OF TOPOGRAPHY.

In brief, the topography of central Oregon is characterized by the boldness of its elevations, which are due in a minor way to the presence of eminences left by widely extended erosion, but principally to constructive volcanic activity. The valleys between the mountains, buttes, hills, etc., are, in general, level floored, owing in part to the deposition of alluvium brought from the uplands by streams, but mainly to the extensive lava flows and the wide distribution of fragmental material blown out of volcanoes in the condition of gravel (lapilli) and dust. Sheets of basalt which have invaded the valleys and given them level floors, occur widely throughout the central part of the State, and in many localities form the present surface. These lava sheets range in thickness from 80 to 100 feet, as an average minimum, up to probably several hundred feet. In certain localities, as along Deschutes River, in the vicinity of the mouth of Crooked River, the recent basalt rests on stratified lapilli, the revealed thickness of which is about 800 feet. The extent and thickness of these modern volcanic products, both liquid and fragmental, have changed the topography of the land, and, by filling the depressions, have tended to subdue the relief. The valleys, like many of the uplands, are constructional topographic forms.

Later than the spreading out of the deposits just referred to came a heavy and widely distributed shower of pumiceous fragments, ranging in size from dust particles to masses of highly vesicular pumice 2 to 3 feet in diameter, which still remains on the plains and mountains and ranges in thickness up to at least 70 feet. This covering of the land lies on it like a great snowfall, over an extent of several thousand square miles, particularly to the east of the Cascades. It also extends over the mountains and down their western slopes for a score or more miles. It not only has produced many changes in the minor features of the relief, but on account of its extreme porosity is one of the leading factors controlling the agricultural value of the country it covers.

DRAINAGE.

THE GREAT BASIN.

The feature of the surface drainage of central Oregon of greatest interest to geographers is that the Great Basin there reaches its northern limit. The most northern point on the rim of the region of interior drainage is in eastern Oregon, at the head of Silvies River, which flows southeastward and empties into Malheur Lake. To the west of the country sloping to Malheur and Harney lakes the Great Basin divide passes westward through an arid region, where the valleys are broad, nearly level floored, and in large part without stream channels. In the portion of its course between Glass Butte and Pauline Mountain the slope of the surface is so gentle that a careful survey would be required in order to determine where the parting between streams flowing south to some one of the neighboring drainless basins and those flowing north to Deschutes River and the Columbia would be in case precipitation should become sufficiently abundant to form a surface run-off. From the Pauline Mountains southwest to the bold cliffs overlooking East Lake on the east and thence southwest to the Walker Mountains the divide is well marked in the relief of the land, although the deep surface layer of pumiceous dust and lapilli in that region prevents to a great extent the occurrence of streams. South of the Walker Range the divide is irregular, marking the water parting between the numerous streams flowing southwest and south to Klamath and Goose lakes and those flowing north to Silver and Summer lakes. The boundary in the region just referred to is again difficult to determine, for the reason that Goose Lake, although fresh, overflows only during high-water stages. At certain seasons it is to be reckoned as occupying one of the many component depressions of the Great Basin, and at other seasons as a part of the Sacramento drainage system.

The portion of the Great Basin in south-central Oregon comprises the country west of Harney and Malheur lakes and north of Warner, Abert, Summer, and Silver lakes, and also about forty townships northeast of the Glass Buttes. It is practically without surface streams, owing to the small precipitation, the porous character of the soil, and the fissured condition of the underlying lava sheets. The characteristics of the country within the northern portion of the Great Basin and of the region adjacent to it on the northwest are essentially the same. That is, the entire region shares in the same general geologic and climatic conditions; the valleys are occupied for the most part by basaltic lava flows; the surface over broad areas is composed of loose, porous material, largely volcanic dust and lapilli; the rainfall is small; and surface streams are generally absent.

A characteristic feature of the Great Sandy Desert and of the adjacent country, and closely related to the present drainage, is the presence of eroded valleys and canyons disproportionately large in reference to the weak streams now occupying them, and what is even more conspicuous, the presence in several instances of stream channels no longer occupied by water. These features are similar to and, in fact, form a part of the characteristics of the Great Basin and of much of the country adjacent to it, particularly on the north, showing that what is now an arid country was formerly well watered. This is also shown by the well-known greater extent of many of the lakes of the Great Basin region during a former period.

In central Oregon one of the most conspicuous records of formerly greater precipitation, at such a late geological period that the country had its present relief, is furnished by an old river channel, which leads northwest from the vicinity of the Glass Buttes and joins the canyon through which Deschutes River flows. The length of this now streamless channel is about 75 miles. Its course is in the main well defined, and in certain localities, as a few miles north of Pauline Mountain, it is a narrow steep-sided canyon at least 300 or 400 feet deep, cut in basalt. During winter seasons portions of this channel are occupied by running streams, and in summer an occasional water pocket occurs in it, but the inhabitants of the region traversed by it assert that it has never been known to receive sufficient water to form a continuous stream. The reason for the abandonment of the channel referred to does not seem to be solely a decrease in humidity, however, as the lower portion of its course is through a region that has recently been deeply covered with loose volcanic dust and lapilli and crossed by open-textured lava flows. These additions to the surface, which, as will be described later, have caused conspicuous changes in the history of Deschutes River, have also exerted a yet more important influence on this weak tributary.

CROOKED RIVER.

In central Oregon, to the north of the Great Basin and of the adjacent region which slopes toward Deschutes River but has no perennial streams, is situated a rugged plateau drained by Crooked River. This stream, of much importance to the country in which it is located, has its source in a number of copious warm springs about 10 miles east of Hampton Butte, and flows north and west through steep-sided canyons all the way to its junction with the Deschutes, a distance of about 115 miles. In its upper portion, just after leaving the alkaline marsh in which it rises, it receives copious contributions from springs, and in its progress rapidly increases in volume, even in late summer, when there is no surface run-off. It is reported to receive contributions from other springs at various localities along its course until it nears Prineville. Below that town it diminishes in volume, and in late summer its bed near Forest, about 12 miles below Prineville, is frequently dry. This marked decrease is now due largely to the use of the water of the stream for irrigation in the expanded portion of its canyon below Prineville, but under strictly natural conditions it is known to have experienced conspicuous seasonal variations. When the volume of the stream diminishes below Prineville, it exhibits the characteristics common to many streams that flow from the uplands of arid regions and suffer absorption and evaporation as they pass through the lower portion of their courses where springs are absent. Owing to the absence of saturation at any but great depths, percolation is away from instead of toward the stream channels, and such flow as persists becomes tepid, more or less alkaline, and unwholesome.

Another and still more remarkable change occurs lower down the channel of Crooked River, about 10 miles northwest of Forest, where springs of great volume appear in its bed and along its sides.

One of these springs, conspicuous on account of its large volume, is known as Opal Spring, for the reason that in the sands it brings to the surface are kernels and grains of opal, derived from the basaltic rock through which its supplying conduit passes. Other springs come in near at hand, and the river quickly becomes a rushing torrent of clear, cool water. The volume is here about 200 cubic feet per second, practically all of which comes from springs. This conspicuous instance of copious springs rising in the lower course of a river in an arid region finds its explanation in the depth and wide extent of the loose volcanic débris through which the river has cut its present canyon, as will be described more fully in discussing the interesting geology of the Deschutes basin (p. 117).

DESCHUTES RIVER.

The conspicuously arid and treeless portion of central Oregon merges on the west into a less arid region drained by Deschutes River. This fine stream of clear, cool water has its main sources on the east slope of the Cascade Mountains, between the Three Sisters peaks and Mount Thielsen, flows northward, and joins the Columbia about 15 miles above The Dalles. The country it drains is forested and holds several lakes, of which Davis, Odell, and Crescent are the largest. These lakes are exceedingly beautiful on account of the clearness of their waters and the primeval wildness of the forest-covered mountains about them. Owing to the retention of the main tributaries of the river in lakes, as well as the shelter afforded the land by its nearly universal forest covering, which breaks the force of the descending rain, its waters are conspicuously clear. Another and still more important factor leading to this same result is the presence over a large part and, as it seems, nearly the whole of the region drained by the head branches of the river, of a thick surface sheet of pumiceous dust and lapilli. This mantle of porous débris acts as a filter, and the many copious springs issuing from it are clear and cool.

The tributaries of the Deschutes above the mouth of Crooked River come mainly from the west and drain the east slope of the Cascade Mountains. The most marked exception, in reference to direction of flow, is Pauline Creek, which has its source in a lake of the same name, situated in the summit portion of an old and deeply eroded volcanic mountain about 35 miles east of the crest of the Cascade Mountains. The Walker Mountains, also situated well to the east of the Cascades, send some tribute to the Deschutes. The streams just referred to, like the tributaries of the main river from the west, flow over a region deeply covered with pumice, and are clear and cold.

Owing to the efficient filtering the water of the Deschutes receives, and also to the influence of the several lakes discharging into it, which serve as settling basins, its waters are conspicuously clear. It is a swift-flowing stream, broken by many rapids and cascades, where its greenish-blue waters are churned into foam, and is a delight to the beholder on account of its beautiful colors, refreshing coolness, and the frequently picturesque and, in some localities, impressive scenery of its canyon walls, as well as a blessing to the arid region, to which it brings its flood of water for irrigation and other purposes. It is also an attraction to the angler, as its waters are abundantly stocked with trout. Salmon ascend its lower portion, but on account of falls do not reach its upper course.

In addition to the features just described, the Deschutes is of especial interest to geographers, as it exhibits certain peculiarities not commonly met with. Although flowing from high mountains on which precipitation varies conspicuously with seasonal changes and where snow melts rapidly as the heat of summer increases, its volume, throughout a large section of its course, is practically constant throughout the year. From the mouth of Crooked River upstream to Benham Falls, near Lava Butte, a distance of about 50 miles, the variations in the height of the river throughout the year is not more than 8, or perhaps 10, inches where the width is not abnormally restricted. Wooden bridges which cross the river in the portion of its course referred to are placed only two or three feet above its surface during the summer stage, and even the amount of space thus afforded beneath their floors is determined by the height of the approaches and not by the fluctuations in the surface level of the water.

The reason for the practically constant volume of the Deschutes between Benham Falls and the mouth of Crooked River is mainly because it is bordered throughout a part of its course in this section by cellular lava, of recent date, into which its waters flow when a tendency to rise is experienced. This and other instructive features of the river will be described later in this report (p. 117).

CLIMATE.

RAINFALL.

By reference to the general weather maps of the United States, issued by the Weather Bureau,[a] it will be seen that this portion of central Oregon, lying in the northern part of the extensive arid region which intervenes between the Rocky Mountains on the east and the Sierra Nevada and the Cascade Mountains on the west, is credited with a mean annual rainfall of between 10 and 20 inches. While these figures express the average of such weather observations as

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[a] Rainfall and snow of the United States, compiled to the end of 1891. Atlas, Bull. C, U. S. Weather Bureau, 1894.

were available at the time the maps referred to were published, they give a higher average than now seems justifiable. Records kept during the past five years, although somewhat irregularly, at Prineville, Farewell Bend, and Silver Lake, in the central and southwestern portions of Crook County, indicate that the average yearly precipitation in the valleys of that region is about 8 inches.

That these records, though meager, do not pertain to exceptionally dry conditions at the points of observation is apparent to one traveling through the section of the State where they were made. Indeed, if there is any exception to be noted, it is in the direction of ascribing even greater aridity to the more sparsely inhabited portions of the county adjacent. Although no weather records are available concerning the Great Sandy Desert, the nature of the vegetation, and especially the absence of juniper trees over vast areas, as well as the lack of streams and springs, indicate that it is more arid than the country about Prineville, Farewell Bend, and Silver Lake, where junipers thrive. This conclusion needs to be qualified, however, by the recognition of the fact that both the Great Sandy Desert and the region adjacent on the west are covered to a depth of many feet, in places fully 50 feet, with a layer of pumiceous gravel and dust, which permits the quick descent of surface waters.

But even after giving due consideration to the influence of the physical condition of the soil on vegetation it is apparent that the controlling element of the climate of central Oregon is aridity. The small amount of annual precipitation falls principally during the winter months and largely in the form of snow. A notable fact in reference to the rainfall is the strong contrast between the arid country at the east base of the Cascade Mountains and the well-watered higher peaks of that range, which are white with snow throughout the year, and which descend on the west into a decidedly humid region. Farewell Bend, for example, with a mean annual precipitation of about 7 inches, situated on the Deschutes River near Pilot Butte, at an elevation of approximately 3,700 feet, is only about 20 miles east of the snow fields on the neighboring portion of the Cascade Mountains, and not over 100 miles from the coast region of Oregon, where the mean annual precipitation is 70 or more inches.

TEMPERATURE.

Owing to the dryness of the air both the daily and yearly range in temperature is great. On the broad desert-like valleys in summer the thermometer, which frequently registers 100° F. or more in the shade at noon, drops so rapidly in the evenings, owing to the active radiation, that the nights are cold and occasionally marked by frost. In winter the temperature frequently drops to zero or lower and the skies are prevailingly cloudy, though only a few inches of snow lies on the ground for any considerable time.

WINDS.

There are at least two features of the weather of west-central Oregon that should repay careful investigation because of their bearing on interesting climatic questions and on the former distribution of glaciers. One is the absence, so far as I have been able to learn, in the vicinity of the Cascade Mountains of what are termed "chinook winds," which are of the same nature as the foehn winds of central Europe. These winds, as is well known, are warm, drying currents of air which blow during the winter months and cause a rapid melting, or rather evaporation, of the snow, if any be present. The localities where these winds occur are lowlands or valleys on the leeward side of high mountains, across which the air currents move. The accepted explanation of the warmth and dryness of chinook winds is that the air in passing across a mountain range parts with some of its moisture, which falls as snow, and on descending into adjacent valleys is warmed by compression and in consequence of its increase in temperature has its capacity for moisture increased. It would seem that the topographic conditions in west-central Oregon adjacent to the east base of the Cascade Mountains are most favorable for the production of such winds, but the inhabitants of the region, many of whom are familiar with the nature of chinook winds elsewhere, report that they do not occur.

RELATION OF CLIMATE TO ANCIENT GLACIERS.

The second suggestion in reference to the climate of the region in central Oregon to the east of the Cascades is what seems to be an abnormally low mean annual temperature for its geographic position and its elevation above sea level. This suggestion is not based on accurate observations and would perhaps not be worthy of mention if it were not that glaciers during recent geologic time (Pleistocene) had a surprisingly great development in the same section of the State. The existence of some relation between the former extent of glaciers and the present distributions of precipitation and of temperature has been shown. In this instance, however, what is now a cool, arid region was formerly occupied by extensive glaciers. The study of the two phenomena together might result in instructive conclusions in reference to the causes of glacial conditions.

FORESTS.

DISTRIBUTION.

In reference to the distribution of trees over central Oregon and the relation of the species of trees present to climatic and soil conditions, the portion of the State visited presents marked contrasts.

The magnificent forest, principally of pines, firs, and cedars, which clothes the part of Oregon situated west of the Cascade Mountains extends eastward across that range, with but little change in its general characteristics until the valleys of the west-central part of the State are reached, in which locality a decided change begins.

The Cascades are forest-covered on both their east and their west slopes up to an elevation of about 8,000 feet, and, as comparatively few peaks rise above that height, nearly the entire range is dark with evergreens, but few bare cliffs or crags being visible. The few great peaks that do rise above the general crest line of the range, like Mount Hood, Mount Jefferson, the Three Sisters peaks, Bachelor Mountain, Diamond Peak, and Mount Thielsen, are covered with perpetual snow, except where the slopes are precipitous. This forest has been invaded by lumbermen to only a slight extent and, barring the destruction due to fires, nearly everywhere recognizable, still retains its natural wildness and pristine beauty.

On the east side of the mountains the forest, while it descends to their base and advances into the adjacent arid valleys, exhibits a change due to a decrease in humidity. Firs, sugar pines, and cedars, which occur on the slopes of the range, do not appear in the valleys. The yellow pine, however, which is the most abundant tree on the eastern side of the range, and which has adapted itself to a wide range of climatic and soil conditions, forms an open forest which extends well into the arid portion of central Oregon, including the southwest part of Crook County and the adjacent portions of Klamath and Lake counties, reaching nearly to Christmas Lake, and covering the Pauline Mountains, which are situated 50 miles east of the crest of the Cascades.

Beyond the frequently sharply defined eastern limit of this widely distributed species is a still more open growth of juniper trees, which in turn die out in the valleys where the soil is light and porous and the precipitation meager. East of these barren valleys of central Crook County, junipers, succeeded on the higher lands by yellow pines, again appear and extend southeastward across Lake County and far into Harney County.

The table-lands and low, broad mountains in the region drained by Crooked River and farther eastward, reaching nearly to Burns and Harney, are clothed with a fine forest of yellow pine. The forests on both the west and the northeast border of the treeless central part of Oregon are not only extensive, but contain magnificent, well-grown trees, which will be of great commercial value when railroads shall have been built, which will bring them within reach of markets. The lumber resources of Oregon to the east of the Cascades are immense, but owing largely to the surprisingly small extension of railroads in that portion of the State but little seems to be generally known concerning its timber resources. It is fortunate that these great forests have escaped the demands of industry so long, as large portions of them have now been included in national forest reserves and can be utilized under the supervision of skilled foresters, so that their continuance is assured.

DEPENDENCE OF FORESTS ON WATER SUPPLY.

The striking contrasts seen in central Oregon in the distribution of trees may be indicated by describing briefly some observations made from a few of the more commanding mountains and isolated buttes that were visited.

One of the most conspicuous landmarks in the eastern part of this field is Placidia Butte, situated in Harney County, about 8 miles from its western boundary, in the midst of the vast tract of arid land that extends westward from Harney Lake. Placidia Butte is an old basaltic volcano, the crater of which, if one ever existed, has been broken and defaced by erosion until only a single sharp summit remains, appearing as a cone when observed at a distance from any point of view. The butte has an elevation of 700 to 800 feet above the neighboring plain and gives from its top an unobstructed view over a great extent of country. On looking southeastward the eye ranges over a basaltic plain which descends gradually until, at a distance of 20 miles, the white salt-incrusted shore of Little Silver Lake is seen, beyond which the bare summits of Iron Mountain and other and more distinct elevations south of Harney Lake can be distinguished. There is not a tree on the vast stony plain. In fact, with the exception of a few dwarfed junipers on adjacent ridges, not a tree can be distinguished within the field of view, although the dark shading on the mountains to the north is due to the presence of the forest of yellow pines that covers the hills and table-lands to the northwest of Burns. The landscape to the west is far extended, but is also barren and lifeless, with here and there depressions containing small ephemeral water pockets, the shores of which are white with saline incrustations. Far away, at a distance of about 145 miles, gleams the white conical summit of Mount Jefferson. To the southwest, shutting out from view the Cascade Mountains in that direction, are Pauline and Walker mountains, situated well within the arid region, but, on account of their height, dark with forests. To the south many ruddy hills are in sight, but they are bare of all vegetation except the ever-present sagebrush and its usual associates on arid plains. Bunch grass is abundant, but, owing to the almost total lack of water in summer within a radius of a score or more miles, the pastures are but little utilized.

The general characteristics of the country, which are conspicuous to an observer standing on Placidia Butte, pertain also to the region in view from the summit of. Glass Buttes, situated 20 miles to the west, and again to that seen from the top of an old companion volcano, known as Hampton Butte, which rises from the adjacent sagebush valleys about 15 miles still farther to the northwest. Each of these prominent and deeply stream-sculptured mountains has a height of approximately 1,500 feet above the adjacent plains, and each bears groves of pines on the shaded northern slopes of its steep ridges, but for the most part only sagebrush, bunch grass, and their usual associates on its other portions. While the forests of the plateaus and mountains to the southwest of Burns are in sight from the summit of Hampton and Glass buttes, and while dark areas, like the shadows of clouds, mark the sites of open growth of gnarled and aged junipers on the desert plain to the west and south, the far-reaching landscape everywhere bears evidence of the dearth of water. The Glass Buttes rise boldly from a barren plain, and to reach them by the most favorable route one must traverse at least 12 miles of nearly flat sagebrush-covered land. This statement, however, does not convey an adequate idea of their isolation, as the watering places throughout the region are wide apart and in most instances are but small openings in the sands in which the diminished extremities of brooks have sunk into the soil. The few watering places, separated by wide intervals, in the surrounding country are well known to the residents of the region, and can readily be found by the stranger by following the well-beaten trails, but one might travel in a straight line almost in any direction from the buttes for distances of 40, 50, or more miles without discovering a flowing stream or a spring. So desolate is the country and so widely scattered are the few places where water can be had that even experienced "cowboys" in attempting to traverse it have in some instances become lost during storms and have nearly perished from thirst.

Few localities in the continental portion of the United States present to view a greater extent of mountains or offer for study a more interesting assemblage of topographic forms than may be beheld from the summit of any one of the many isolated volcanic cones and craters which rise from the sagebrush valleys and broad desert plains of central Oregon. These elevations also afford excellent localities for observing the distribution of trees. The dark forest mantle which clothes the entire Cascade Range with the exception of its higher spires and more lofty craters may be seen descending their eastern slopes and extending far out on the lower and less rugged country adjacent to their well-defined base, ending in an irregular line in the shadeless valleys. The conditions favoring or opposing the growth of trees are there delicately balanced, and each variation in the nature of the soil, in elevation, or in position in reference to the mountains finds expression in the tints of the vegetation. Adjacent to the base of the Cascades and within what may be termed their rain shadow, the hills and valleys alike are dark with forest trees, which lessen the sharpness of the relief of the land. Farther eastward elevation becomes the controlling factor, and only the hills and the isolated mountains have a forest covering, the valleys being broad expanses of russet brown and gray, the characteristic colors of sagebrush lands. Farther from the great mountains only the summits of the higher elevations support trees, which, in such localities, are in many instances confined to the northern or shaded and consequently less arid slopes of peaks and ridges. Well within the arid region even prominent hills are without vegetation of higher growth than the all-embracing sagebrush.

DRY AND COLD TIMBER LINES.

To an observer, where the desolate plains of central Oregon are in view at the same time with the near-by snow-covered mountains, the fact of there being a "dry timber line"—a definite limit to forest growth determined mainly by lack of the requisite moisture—is fully as apparent as is the existence of a "cold timber line," dependent on the low mean annual temperature and the destructive action of winter storms, etc., in the higher mountains. The recognition of these two principal limitations to forest growth furnishes convenient terms by which to designate the chief boundaries of arboreal vegetation in such regions as central Oregon, where the forests terminate abruptly both above and below. On the Cascade Mountains, in the region referred to, the cold timber line has an elevation of about 8,000 feet, while the dry timber line, marked by the cessation of the yellow pine, may be taken as approximately 4,000 feet. The junipers reach lower and extend farther into the broad arid valleys than do the pines, but even when most abundant can scarcely be considered as forming true forests. They also, however, have a lower or desertward limit, determined mainly by decrease in soil moisture, which is in advance of or below what may justly be termed the dry timber line.[a]

[a] The terms cold timber line, dry timber line, and another, the wet timber line—convenient names by which to designate the three most conspicuous natural boundaries of forests—were proposed by me in the Nat. Geog. Mag., vol. xiv, pp. 80, 81, and were used also in Bull. U. S. Geol. Survey No. 199. Objections to the recognition of the names referred to, and especially the substitution of cold timber line for the time-honored term timber line, have been presented by Dr. C. Hart Merriam in the Nat. Geog. Mag., vol. xiv, pp. 114, 115. While it is true, as stated by Merriam, that the word timber line is widely current in the sense just stated, yet other limitations to the distribution of forests are fully as conspicuous in certain regions and demand recognition. The several conditions which determine the boundaries of forests seem to make it desirable to employ the term previously used to designate one of them, in a generic sense, and to recognize "species" of timber, or perhaps better, tree, lines. This matter is also briefly discussed in the Nat. Geog. Mag., vol. xv, Jan., 1904, pp. 47-49.

GENERAL GEOLOGY.

The rocks of eastern and central Oregon belong to two general classes, volcanic and sedimentary, the former being the more abundant and, so far as surface outcrops are concerned, by far the more conspicuous.

VOLCANIC ROCKS.

The rocks of Oregon which were derived from volcanoes are mainly rhyolites,[a] andesites,[b] and basalts.[c] In each of these three classes, as defined by chemical and mineralogical composition, there are two conspicuous subdivisions based on the physical condition of the material at the time of its extrusion from the earth's interior. One of these is composed of fragmental products blown out by volcanoes during explosive eruptions, such as volcanic dust, volcanic gravel or

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[a] Rhyolite; name derived from a Greek word meaning to flow; given to a certain group of rocks which owe their origin to the consolidation on cooling, with more or less complete crystallization, of certain of the material discharged from volcanoes in a fused condition. Rocks of this group usually present subdued shades and tints of red, brown, purple, yellow, gray, etc., and frequently have a banded structure as if composed of many thin, irregular layers, which show variations in color and texture. The edges of the layers, when seen in section, usually appear as irregularly curved bands and lines, or what is termed "flow structure." The most abundant minerals present, and the only ones usually visible to the unaided eye, are quartz and the variety of feldspar having the appearance of clear glass, known as sanadine. Rhyolite contains in general about 74 per cent of alumina and several other oxides of the alkaline earths, etc., in smaller proportions. As indicated by its high per cent of silica, the rocks of this class are difficult to fuse, a fact which has an important bearing on the forms the lava assumes on cooling and also on the shattering of the rock during eruption so as to form fragmental products.

Rhyolitic tuff is composed of angular fragments, grains, and dust-like particles of rhyolitic lavas which were blown out of volcanoes during explosive eruptions and showered on the adjacent land or water, so as to form beds or sheets. The beds of this material are commonly more or less consolidated and not infrequently sufficiently compact to be used as building stone, although in many instances they retain their original incoherent condition and are simply loose gravel, sand, and dust. Their colors have as wide a range as those of the associated rhyolitic lava sheets, although perhaps in general more decided; in sunlight they frequently appear brilliant. Both rhyolite and rhyolitic tuff are common in central and eastern Oregon. The latter is used as a building stone at Burns.

[b] Andesite; named from the Andes Mountains; is typically a compact, usually rough and porous rock, in which crystals of feldspar and small scales of mica, hornblende, etc., may be detected by the unaided eye. The colors are usually some shade of gray, green, or red. In chemical composition the andesites are poorer in silica than the rhyolites, the percentage ranging from 56 to 70, and are also richer in alumina, the next most important constituent, which ranges from 14 to 19 per cent, the remainder of the material present being for the most part as oxides of other alkaline earths. The rock is refractory, and during explosive volcanic eruptions is frequently blown out in fragments.

[c] Basalt; name dating back to the days of the Romans; now used to designate certain common rocks of volcanic origin, usually black or greenish black, though frequently red, owing to a higher state of oxidation of the iron present. The rock seldom exhibits individual minerals to the unaided eye, although grains and kernels of bright green olivine are not uncommon. The essential minerals are augite, plagioclase, feldspar, and olivine in the normal variety, together with several accessory minerals. Although variable in composition, silica usually forms about 55 per cent, and alumina, lime, magnesia, and oxides of iron and manganese from 7 to perhaps 14 or 16 per cent each. On account of the easy fusibility of several of the constituent minerals the rock melts at a comparatively low temperature and becomes highly liquid. Basalt in the condition of broken fragments is less common than in the case of rhyolites and andesites, and the chief products of the volcanoes from which it is extruded take the form of lava flows. The black, compact, and frequently columnar rocks of central Oregon are mostly basaltic.

lapilli, and the other of lava flows. The fragmental material was discharged in a solid condition, and the lava flows in streams of molten rock.

In general the rhyolites and andesites of central Oregon are older than the basalts. Certain andesites and andesitic tuffs, however, like those described later as occurring about Pauline Lake, are among the youngest of the lavas outpoured in the entire region. Again, in the west-central part of the State and including a part at least of the Cascade Mountains, there is, as already mentioned, a surface sheet of pumice, composed of angular fragments that were showered on the land during the explosive eruptions of neighboring volcanoes, and that now mantle the surface like a blanket. This material is in large part a highly scoriaceous or froth-like andesitic lava, and shows that volcanoes discharging such material were in a state of vigorous eruption in west-central Oregon at a recent date.

SEDIMENTARY FORMATIONS.

In addition to the volcanic rocks which cover the greater part of the surface of Oregon there are areas hundreds of square miles in extent which are occupied by soft and in part unconsolidated sedimentary beds of Tertiary age. These beds consist of clays, sands, volcanic dust, etc., are mostly light colored and frequently white, and in general are best exposed in the valleys and in the walls of canyons. The sedimentary beds of Malheur and Harney counties are in part a direct continuation of the extensive Payette formation, so admirably exposed along Snake River in southwest Idaho. Similar sedimentary beds occur in the southeastern part of Crook County, as at Logan Butte, near Price, and are a part of a widely distributed formation which is well developed on John Day River, from which it has been named.

These Tertiary sedimentary formations are in many places covered by sheets of basalt, or by layers of consolidated rhyolitic tuff which have protected them from erosion. Where the resistant, covering beds have been cut through by streams, canyons with rim rocks either of basalt or of rhyolitic tuff are a conspicuous feature in the topography. The sedimentary beds occur mostly in the valleys, for the reason that when exposed without a protecting cover of more resistant material they are readily removed by erosion, and thus give origin to depressions. Yet in certain instances, and especially in reference to the John Day formation, extensive movements in the rocks have occurred and the beds have been elevated so as to form plateaus in which the component layers are now inclined, commonly at angles of 10° to 15°.

GENERAL SURFACE DISTRIBUTION OF ROCKS.

In Malheur and Harney counties rhyolite and rhyolitic tuff are the most common of the surface rocks, though basalt of later age has a wide distribution, while rocks of a similar character but older than the eruptions which supplied the rhyolite and with a thickness of at least 5,000 feet are admirably exposed in the east-facing escarpment of Stein Mountain, as previously reported.

To the west of Harney County, and extending to the east base of the Cascade Mountains, basalt predominates, although much eroded andesitic mountains or buttes and widely extended sheets of tuff of the same general nature are present. The old volcanic piles are represented by the Glass and Hampton buttes, and the sheets of rhyolite, and the still more abundant and more widely spread sheets of rhyolitic tuff, form the surface in the southeast part of Crook County and extend eastward into the northern part of Harney County. Basalt occupies the surface throughout nearly all of the region bordering the Great Sandy Desert and throughout the extensive tract of country in the western portion of Crook County drained by Deschutes River. To a conspicuous extent, as shown in the canyons of the streams, it occurs in comparatively thin sheets resting on lacustral deposits or beds of stratified volcanic tuff. The canyon walls are margined above by black cliffs or rim rocks of basalt forming the eroded margins of sheets which in general are 80 to 125 feet thick. The basalt occurs as widely extended sheets, usually, it is presumed, of Tertiary age, which can not be traced to the craters from which they came, and also as much later flows of a similar character, which in part occupy canyons cut in the older basalt and underlying gravels, sands, and tuffs, and in many instances bear a definite and determinable relation to volcanic craters which still preserve their constructional forms.

FEATURES OF THE REGION, BY COUNTIES.

MALHEUR COUNTY.

GEOLOGY AND TOPOGRAPHY.

PAYETTE FORMATION.

The Payette formation, which consists principally of unconsolidated sands, clays, gravel, etc., together with important beds of light-colored and frequently white volcanic dust, and which is widely exposed in southwest Idaho, extends westward into Malheur County, Oreg., where it forms a large portion of the surface. This formation was crossed during my reconnaissance in 1902, and again in 1903, but its entire extent in Malheur County can not, as yet, be stated. It occupies the Snake River Valley, from near Owyhee northward beyond Ontario, and extends westward to a locality about 30 miles southwest of Vale. Similar beds occur also along the courses of Jordan and Succor creeks, and in several other valleys. As exploration progresses it will probably be found that many of the valleys of Malheur County are floored to a depth of several hundred feet with soft unconsolidated deposits like those of the Payette formation and probably of the same or of approximately the same age. Whether all of these deposits are portions of one continuous formation, or were laid down in separate and contiguous basins, is not as yet determined. It is probable, however, that they were accumulated in much the same manner that beds of like character are now being spread out on the surface of the valleys of the same region by existing streams. In most of the sediments referred to as being analogous to the Payette formation, however, volcanic dust added materially to the depth of the deposits.

At Ontario a well put down by the city reached a depth of 1,056 feet, all in soft material, without reaching the bottom of the formation. The surface portion of this deposit is clearly a part of the Payette formation, and it is presumed that the entire depth of the well is in the same formation. But even the considerable thickness of soft material shown by this boring does not give the original thickness of the Payette formation, since at least several hundred feet of similar material has been removed by erosion from the surface of the region referred to. The material removed has been carried away by Malheur River, along which sloping gradation plains, as they are termed, lead down to Snake River, the master stream of the country. The Snake has also cut down its valley, the material removed having been carried through the magnificent canyon it has excavated in its course across the rugged country where the Seven Devils and the Powder River Mountains are located.

From the broad plain through which Malheur River flows, and about midway between Ontario and Vale, there rises a conspicuous and picturesque landmark known as Malheur Butte. This in general conical elevation with precipitous sides rises, as determined by aneroid measure, about 500 feet above the adjacent portion of Malheur River, and from its summit commands a view of a far-reaching and instructive landscape. Geologically it is composed of dark basic volcanic rock resembling basalt (determined by F. C. Calkins as basalt containing hypersthene), compact and massive at the base of the butte, where it is penetrated for a short distance by a tunnel excavated for the passage of an irrigation ditch, but vesicular at the top, and containing oval cavities due to the expansion of steam in its material while it was yet plastic. These cavities are now in part occupied by infiltrated siliceous minerals. The butte is probably the much-eroded remnant of a volcanic crater. Associated with the basalt are small exposures of sedimentary beds, hard and compact, which have the appearance of having been baked by the heat of the molten rock which came in contact with them. The sedimentary beds still clinging to the sides of the butte indicate that several hundred feet of similar material have been eroded from the region about it, thus leaving it as a prominent topographic feature. The interpretation of these facts seems to be that a volcanic conduit was extruded upward through a thick deposit of sedimentary beds, presumably belonging to the Payette formation, and built a crater above. Erosion has since removed the crater and cut deeply into the stratified sediments which its conduit penetrated, leaving the rock, which hardened in the conduit, standing in bold relief as a so-called " volcanic neck."

From the top of Malheur Butte the light-colored rocks of the Payette formation may be seen outcropping in every direction. On the east side of Snake River, to the north of Ontario, the strata dips southward for a long distance at a low angle, probably less than 2°, showing that the formation has been broadly upraised and tilted. Similar evidence of movements in rocks of the same nature and probably of the same formation can be detected in other directions. As shown by this and other related evidence there have been considerable and widely extended movements of the nature of broad uplifts, and perhaps of equally broad subsidences, between the various upraised regions since the Payette beds were deposited.

The nature of the rocks composing the Payette formation, the conditions under which they were deposited, whether in lakes or in streams, the records of life they contain, the deformation their beds have experienced, the erosion that has taken place in them, whether due to their own upheaval or to the deepening of the canyon of Snake River farther down its course, and the local geology about Ontario, Malheur Butte, Vale, etc., all furnish material for study that would yield much interesting and instructive information.

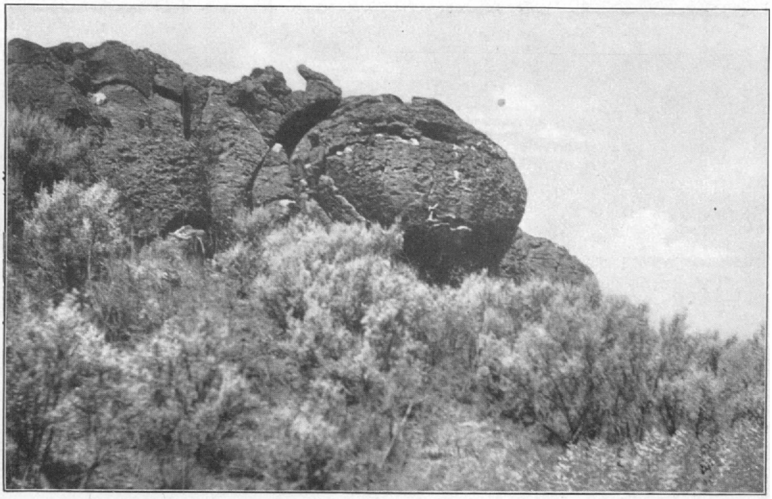
VOLCANIC ROCKS.

A few miles south of Grove the topography changes conspicuously. The broad valley excavated in soft rocks gives place to bold and in part rugged uplands, through which the Malheur and its tributaries have cut deep canyon-like valleys. These uplands, beginning near Grove and extending far to the south, are composed largely of rhyolite and rhyolitic tuffs, in part at least of older date than the Payette formation, and associated with extensive sheets of basaltic lavas. In the walls of the canyons well-defined rim rocks are conspicuous, beneath which are less resistant beds, probably of sedimentary origin, or of the nature of volcanic-dust deposits, presumably belonging to the Payette formation. The resistant layers are of volcanic origin, and their gentle dip to the north is evidence of broad, widely extended movements in them since the material of which they are composed was spread out. More than a general idea, however, of these widely extended terraces could not be obtained during my rapid survey.

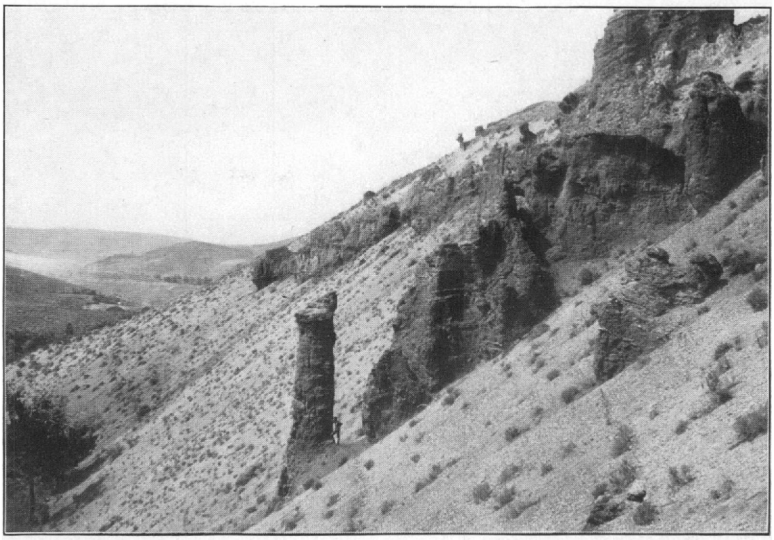
Volcanic dust.—A representative example of the geology of this portion of Malheur County occurs in the vicinity of what is known as Harpers Flat, situated on the Malheur about 30 miles southwest of Vale. At this locality the river has excavated a valley about 2 miles wide in soft, unconsolidated sand and clays which contain a large proportion of white volcanic dust. Some of the layers of nearly pure volcanic dust are from 20 to 100 feet thick. Sections of these beds are exposed at many localities in the precipitous walls of the valley beneath rim rocks of basalt. A roughly measured section on the eastern side of the valley, about 1 mile south of the narrow canyon at the northern end through which Malheur River outflows, contains in vertical section about 650 feet of soft stratified beds, consisting principally of white volcanic dust overlain by a sheet of basalt 25 to 30 feet thick. Similar sections are more or less well exposed all about the valley. At numerous localities, particularly on the precipitous northern border, landslides have occurred, giving to the bluffs the characteristic features of landslide topography.

A conspicuous characteristic of the fine-grained shaly layers which occur at different horizons in the soft deposits about Harpers Flat is that they have been indurated, probably by the infiltration of silica through the agency of hot percolating water, and have the physical characteristics of white or gray flint or chert. The débris from similar beds occurs at many localities in the northern portion of Malheur County. The sedimentary and tuff beds beneath protecting sheets of basalt are also exposed along the creeks which join Malheur River near Harpers Flat, and present a wide range of variations in appearance and composition. In certain localities, as on Willow Creek 4 to 5 miles from its junction with the main stream, the beds exposed on the sides of the valley consist largely of dark volcanic tuff, weathered into conspicuous monumental forms, one of which is shown on Pl. II, *B*. The dips of the beds are gentle, but change in inclination from place to place, indicating that moderate deformation of the nature of broad folding has occurred.

Rhyolite and rhyolitic tuff.—To the south, along a road that leads through an extensive and as yet unsurveyed region, indicated on the General Land Office map of Oregon as lying northwest of Cedar Mountains, the hills become bolder and more abrupt, assuming the characteristics of mountains. From 20 to 40 miles north of Harpers Flat the surface rocks over great areas are essentially horizontal, but deeply eroded. Broad rolling uplands devoid of trees but clothed with sagebrush and bunch grass are the dominant features of the landscapes. The table-lands are covered with basalt, but the presence on them of many flakes and shreds of black volcanic glass or obsidian indicates that sheets of superimposed rhyolitic tuff have been eroded away. Although basalt is the prevailing rock on the surfaces of the broad, plateau-like uplands, as well as in the precipitous walls of the canyons, sheets of rhyolite are also present, and



A. CONCENTRIC JOINTING IN RHYOLITIC LAVA, CROWLEY CREEK, MALHEUR COUNTY.



B. EROSION COLUMNS OF VOLCANIC TUFF, COTTONWOOD CANYON, NEAR HARPERS FLAT, MALHEUR COUNTY.

to the south become at times the prevailing terranes in sight. Characteristically the basalt and rhyolite occur in essentially horizontal sheets, and give evidence of but slight disturbances.

The general features just mentioned pertain to the country traversed until Crowley Creek was reached, about 50 miles southwest of Harpers Flat, whence our route led west and northwest to South Fork of Malheur River, in the vicinity of Riverside. With our advance, however, rhyolite and rhyolitic tuff became more conspicuous than the outcrops of basalt, and at last formed the prevailing rock. Rhyolite is abundant in the region drained by Crowley Creek and thence west to South Fork of Malheur River. Some of the hills are composed of rhyolitic tuff and agglomerate in inclined layers, and are plainly the much eroded remnants of ancient volcanic tuff craters. From one such eminence, situated in the central part of T. 36, R. 26, and rising about 2,000 feet above the adjacent valleys, a widely extended view of the surrounding country was obtained, disclosing the leading characteristics of a region several hundred square miles in area. From the summit of this butte, which commands a view of about 100 miles in every direction, no rocks except rhyolite and rhyolitic tuff could be distinguished, even with the aid of a powerful field glass.

Without attempting to weary the reader with a presentation of notes, which, owing to the country being unsurveyed, can not be accurately located, I may say that the portion of Malheur County traversed bears evidence of having received a covering at different times of widely extended sheets of rhyolite and of rhyolitic tuff. The ruins of some of the volcanoes from which this material was extruded can still be distinguished. The lava, poured out in a molten condition, and the thick sheets of rhyolitic tuff are evidences that these volcanoes were of the explosive type and showered vast quantities of ejecta on the country in the same manner that Mount Pelee and La Soufrière, in the West Indies, recently added a layer of volcanic dust and lapilli to the surface of the islands on which they are located.

It is an instructive fact that volcanoes erupting refractory material, largely of the nature of rhyolite, had a wide distribution in central and eastern Oregon during Tertiary time. The contributions of this nature to the surface rank in extent and thickness with the vast basaltic overflows of the same region. As stated in a previous report, the evidence now in hand shows that several veritable inundations of basaltic lava occurred in eastern Oregon (as is shown, for example, by the exposures of rocks of that nature more than 5,000 feet thick in the east-facing escarpment of Steins Mountains) and were succeeded by great rhyolitic eruptions. Still later than the rhyolite came a renewal of basaltic eruptions which continued from time to time almost to the present day.

DRAINAGE AND WATER RESOURCES.

Throughout the portion of Malheur County traversed, and in fact over nearly all of central Oregon, there is abundant evidence of greater precipitation and more active erosion immediately preceding the present period of aridity and weak streams. The present streams, often the diminutive representatives of former rivers and creeks that excavated wide valleys, are now, in many instances, engaged in filling or aggrading their ancient channels. In many cases the present streams are ephemeral and flow only during the wet season, and many broad, flat-bottomed valleys of erosion are without surface drainage. Outstanding buttes, and mesas surrounded by mural escarpments, and sharp ridges, trenched on their slopes by deep excavations, etc., speak of climatic conditions different from those which now exist and make it evident that the leading feature in the climatic change that has taken place was a decrease in humidity.

The surface of the valley between Ontario and Vale and the continuation of the same broad depression for 6 or 8 miles upstream from Vale presents many interesting features in reference to the manner in which streams shape land surfaces and leave records of their work in terraces, flood plains, sloughs, etc. The flood plain of the Malheur, between Malheur Butte and Vale, is in general about 4 miles wide, and during exceptionally high-water stages is inundated. These expansions of the river occur in spring, when much floating ice is brought down from the upper reaches of the stream and left stranded on the flooded tracts. In some instances considerable quantities of gravel and sand, attached or frozen into the ice, are brought down, to be deposited irregularly in association with the fine silt that the expanded waters sift down on the land they temporarily cover. The stream in summer is greatly reduced in volume, and in recent years, owing to the demands made on it for purposes of irrigation, usually becomes dry in July and August, or has water only in the deeper depressions in its bed and in adjacent sloughs. It may be classed as an alluvial stream in this portion of its course; that is, one engaged in filling in its valley, or aggrading. It flows in many curves through the nearly flat land it has formed, and furnishes excellent illustrations of the meanders that sluggish rivers develop, and also characteristic examples of the cutting off of curves during periods of high water. The portions of the curves thus abandoned form sloughs and illustrate the character and mode of origin of oxbow lakes. The surface layer of the flood plain, as is usual in such formations, is largely composed of fine silt. The depth of this layer is in general about 10 to 12 feet, and beneath it is coarse gravel. The gravel was also laid down by the stream and is the lower member of the flood-plain deposits. Wells dug in the flood plain reach water on entering the gravel, finding there an abundant supply for household purposes, watering of stock, etc. As yet, however, none is pumped for use in irrigating.

In the northern half of Malheur County, the only portion here considered, the flat lands suitable for irrigation are located mainly along the border of Malheur River, below Grove. There are small areas of bottom land farther up the stream, as at Harpers Flat, and also an area of several square miles on the Owyhee near its mouth and adjacent to Snake River, which are of value for agriculture, and in fact are now, to a considerable extent, under irrigation. The valley of the Malheur, from near the site of the former post-office of Grove, about 6 miles south of Vale, north to Snake River, contains a large amount of rich agricultural land (about 100 square miles, by a rough estimate) well located for irrigation; but at present, owing to scarcity of water during the growing season, farmed to but a small extent. In a state of nature this extensive and beautiful valley was a meadow of luxuriant bunch grass and tall, grain-like rye grass; now, owing to overgrazing, it is essentially a desert.

The only surface water available for irrigating the lower portion of Malheur Valley is that flowing through the channel of Malheur River. Along that stream there are favorable sites for storage reservoirs, which could be made to retain all of the winter run-off. One such site, that at Harpers Flat, or Harper's ranch, has already been investigated by the United States Geological Survey.[a]

Owyhee River also furnishes desirable localities where storage reservoirs could be advantageously, and I think, economically, constructed, and its winter run-off conserved for use on the flat lands near its north end, adjacent to Snake River. The possibility of diverting a portion of the waters of Snake River onto these same lands has been suggested, but the enterprise is one of such magnitude that detailed surveys are necessary before even an approximate estimate of the benefits to be expected can be made.

From such facts as are known concerning the extent of the lands along the lower course of Malheur River and near where Owyhee River joins Snake River, which are favorably situated for irrigation, and also concerning the volumes of Malheur and Owyhee rivers, it is evident that when all of the available water, including the winter run-off, shall have been utilized, only a comparatively small portion of the land can be made productive. Another source of supply has been

[a] Second Ann. Rept. Reclamation Service, U. S. Geol. Survey: H. Doc. 44, 2d sess. 58th Cong., 1904, p. 435.

pointed out, namely, the Lewis artesian basin,[a] which includes much of the region under consideration, but the quantity of water that can be obtained from that reservoir and the area of land below the artesian head of the basin are as yet only approximately known. Seemingly, however, under the most favorable results to be expected from the use of artesian water for irrigation, only small areas, principally gardens and orchards, can be supplied.

The portion of Malheur County traversed to the south of Grove, with the exception of certain small areas immediately adjacent to Malheur River, is almost entirely destitute of water, and owing to its considerable elevation, rugged topography, and especially its deep dissection by streams, is, so far as can be judged, beyond the hope of reclamation by irrigation. The nature and structure of the rocks are not such as to suggest the presence of artesian basins. The value of the region evidently lies in its use for grazing, and even for this purpose the scarcity of water prevents stock from reaching extensive natural pastures which are still clothed with luxuriant bunch grass.

Previous journeys have shown that these remarks apply equally well to the greater portion of Malheur County farther south. There are a few notable exceptions to the barrenness of the land, especially along some of the small streams and where springs come to the surface, producing abundant crops of native grasses, but their combined areas are probably less than 1 per cent of the area of the uplands, on which there is no suggestion that irrigation can be practiced. The aridity of Malheur County throughout, and the scarcity of water, whether surface or artesian, are such as to show that the chief economic returns it can be expected to furnish are in the direction of stock raising. The practical lesson furnished by these considerations is that the utmost economy in the use of the limited water supply should be practiced and the most thoroughly scientific methods of agriculture and horticulture employed wherever practicable.

HARNEY COUNTY.

GEOLOGY AND TOPOGRAPHY.

The sheets of rhyolite and of rhyolitic tuff which form so conspicuous a feature in the geology of the west-central part of Malheur County continue west and are well exposed in the hills to the east of Harney Valley. In this region, however, the nearly horizontal position of the beds, noted farther east, becomes less conspicuous, and faults, accompanied by tilting of the rocks adjacent to them, influence the topography to a marked degree, especially in the region drained by the headwaters of Crane Creek. In the uplands on the east border

[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

of Harney Valley extensive areas are occupied by basaltic rocks, and in the canyon walls rim rocks of both rhyolitic tuff and basalt are present. Beneath the resistant layers forming the rim rocks occur beds of soft stratified material composed largely of white volcanic dust.

SOUTH FORK OF MALHEUR VALLEY.

South Fork of Malheur River, near Crane, is situated in a deep canyon-like valley, which furnishes a record of extensive erosion, and is a part of a widely extended series of valleys and canyons, which bear evidence of having been excavated by streams of larger volume than those now flowing through them.

In the valley of the South Fork, near its extreme southern prolongation, and in the valley of one of its small tributaries, there is a fresh basaltic lava flow, the first of recent date met during the reconnaissance. It terminates in a steep slope at its distal end and along its bordering escarpments, and for several miles up the course of the congealed current shows evidence of a sluggish flow, due largely to the blocks of the broken crust which became involved in the material beneath while it was yet plastic. The surface of the lava is black, vesicular, and exceedingly rough, and over large areas has the characteristics of an aa lava surface—that is, it is composed of the broken fragments of the first-formed crust, piled in confused heaps, and in many cases standing on edge or inclined at various angles. Occasional pressure ridges are also present, produced by the upward bending of the thick rigid crust, with its involved fragments of the first-formed and thinner crust; these are due to lateral pressure produced by the flow of the lava beneath, or to the shrinkage of the lower portion of the material as it cooled.

The lava stream occupies the bottom of the canyon-like valley in which is occurs for a distance of at least 10 miles, and is, on an average, about a mile wide. Where Crane Creek joins Camp Creek its breadth is nearly 2 miles. The blackness of the lava and the scarcity of evidence of disintegration or decay, as well as the absence of vegetation other than sagebrush and the plants usually associated with it, give an impression of recency, but the weak stream that flows down the valley has cut a channel from 50 to 75 feet deep near where it leaves the lava. The scarcity of soil and of vegetation is due to the aridity of the climate, and is not in itself an index of youthfulness in the soil beneath, while the considerable amount of work accomplished by the weak and now ephemeral stream is suggestive of centuries of slow erosion. The lava stream can not, therefore, be considered as young in years, although, with the exception of the Jordan and Diamond volcanoes and lava flows,[a] it is the

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

latest considerable addition to the surface rocks that has been made in eastern Oregon.

The valley in which this lava stream lies is a direct continuation of a level-floored gap which extends from Camp Creek westward and opens out into Harney Valley. This gap, or canyon-like valley, was excavated by a stream flowing from the broad basin in which Malheur and Harney lakes are situated, and is consequently an old river channel. Its level floor is a continuation of the present surface of the adjacent portion of Harney Valley, and is due to the lava flow. A direct connection between the fresh lava in the upper portion of South Fork of Malheur River and the similar but less rugged sheet just described was not established by actually traversing the entire length of the lava-floored depression; as seen through a field glass from neighboring hills, however, the two portions seem to be parts of a single flow. Their source is not known, but the nearest recent volcanoes, so far as present explorations have shown, are the Diamond Craters, situated about 15 miles to the southwest, and it is probable that they came from there.

CRANE CREEK.

From Camp Creek the road followed passes up Crane Creek and through a well-defined but peculiar gap or pass leading west to Harney Valley. Crane Creek receives Coyote and Gorman creeks as tributaries from the north. These two creeks and the upper portion of Crane Creek, above the abrupt bend in its course where the road leading to Malheur Lake leaves it, flow south in nearly parallel valleys, due mainly to faulting, and enter a large valley with bold walls, which trends about east and west. This larger valley has several peculiar features which at once attract attention. In a general view it appears as a deep stream-cut valley, about one-half mile wide, leading directly through the hilly country it traverses, and affording a low-grade pass to Harney Valley. The impression is that it was formed by a river which escaped from Harney Valley, but, as already stated, there is a similar valley some 10 miles farther south—the old river bed mentioned above—which is lower, and has an almost perfectly flat floor at the same level as the adjacent portion of Harney Valley. One is puzzled to know how two valleys so similar in their geographical relations came into existence.

In traversing the Crane Creek Pass, as it may suggestively be termed, from east to west, one ascends Crane Creek, which has a well-defined gradient, until about 10 miles below its ultimate source, where a steep ascent of about 100 feet leads to a divide, or rather a crest that would be a divide if surface waters were present, separating the slopes on the east draining to Crane Creek from the slopes on the west draining to Malheur Lake. On the west the floor of the pass is approximately level. Throughout the two portions of the old valley the width is about one-half mile, and the bordering escarpments are bold and steep, and in general 200 or 300 feet high. The valley is clearly the result of stream erosion, and is a part of the record inscribed on the land, showing formerly greater precipitation than now. The divide which crosses the course of the valley from north to south is due to movements in the rocks subsequent to its excavation, and is of the nature of a fault, the west side of which has been upheaved in reference to its eastern side. Other illustrations of faulting and tilting are present in the same region, and are suggestive of the causes which produced changes in the direction of flow of the modern streams in respect to their former and larger representatives.

In ascending Crane Creek from its junction with South Fork of Malheur River and passing west into Harney Valley, one leaves a region where rhyolitic rocks are well displayed and enters an extensive area occupied by basalt, bordering Harney Valley on the east.

For several miles along the middle course of Crane Creek the rocks are basalt, spread out in sheets ranging from 40 to 60 feet in thickness, and associated with sheets of soft sedimentary material, largely volcanic dust. The series of resistant basaltic sheets and weak interbedded sedimentary material dips gently westward. Conspicuous for several miles on the south side of Crane Creek Canyon is a rim rock of rhyolite and rhyolitic tuff of irregular thickness, in general measuring 40 to 50 feet on its vertical escarpments. This sheet of rhyolitic material, like many other similar sheets in eastern Oregon, occurs above a series of basaltic rocks and in turn is overlain by other basaltic overflows. In places the edge of the sheet exhibits good examples of spheroidal jointing, as illustrated on Pl. II, *A*.

Although, as stated above, basaltic rocks become the prevailing terranes as Harney Valley is approached by way of the Crane Creek Pass, rhyolitic rocks impress their characteristic colors on the landscape in the neighboring hills to the north. The Crane Creek Hills, for example, on the north side of the valley are, as previously recorded,[a] composed mainly of rhyolite and rhyolitic tuff.

HARNEY VALLEY.

From commanding elevations on the east border of Harney Valley that great level-floored basin with its surrounding hills and mountains makes an impressive picture. The valley, as is well known, is the largest single expanse of practically level land in Oregon; although irregular in outline, its diameter in any direction is approxi-

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

mately 50 to 60 miles. Extending into the level-floored basin, however, at several localities on its border are cape-like projections from the surrounding highlands, and well within its sea-like expanse are a few isolated buttes. The most conspicuous of the salients on its borders occurs on its west side, where a flat-top table-land of basalt, with steep bordering slopes due to erosion, projects at least 10 miles toward the center. Near the north and east shores of Malheur Lake are three buttes, which are conspicuous on account of their isolation and the flatness of the country in all directions about them. The monotony of the topography of the basin is also broken by a low swell rising to the east of Malheur Slough, about 5 miles west of the entrance to Crane Creek Pass, which is composed of basalt and is surrounded on all sides by fine soft clay-like deposits.

Saddle Mountain.—Of the three buttes referred to, only one, Saddle Mountain Butte, was visited. This butte, situated at the north side of Malheur Lake, is about 300 feet high and from 1 to 1½ miles in diameter. It derives its name from its shape, as seen from either the east or the west, being composed of two ridges, running about east and west, with a depression between them. The rocks are scoriaceous basalt. There is considerable loose scoria on the surface, but no bombs were found and no evidence of a cinder or lapilli cone. Although the eminence is probably the remnant of a volcanic crater, it is so deeply eroded that no positive assurance of such an origin could be obtained. Its borders are steep on all sides except the east and bear evidence of long-continued erosion, and the entire hill may reasonably be considered as a remnant of a basaltic plateau surrounding an old crater. It is now densely clothed with sagebrush, beneath which there is abundance of bunch grass.

From the summit of the butte a fine view is furnished of the great plain from which it rises. To the southeast may be seen two other similar buttes, situated near the east border of Malheur Lake, which from their color seem also to be composed of basalt. To the east the deep, flat-bottomed notch in the rim of Harney Valley, through which the draining stream of the plain formerly flowed, is in plain sight, although about 15 miles distant; the continuation of the valley floor into the bottom of the old channel without a perceptible change in slope is a notable feature. Farther to the southeast, about 50 miles distant, rises the rugged crest of Steins Mountains, on which snow lingers throughout the summer.

Malheur Lake.—To the south of Saddle Mountain Butte, and so broad that its farther shore can not be discerned from the summit of that elevation, lies Malheur Lake, some account of which has been presented in a previous report.[a] The lake is shallow, not over 8 feet

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[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

deep in the deepest part, as I have been informed by persons well acquainted with it. A mile from its shore at almost any point the water is only a few inches deep. Its water is always yellowish with material in suspension, a common feature of alkaline lakes. It is in fact a so-called " playa lake; " that, is a lake which on evaporating to dryness leaves a mud plain or playa. Although Malheur Lake has never been known to disappear, it experiences conspicuous variations in area and may be expected to evaporate to dryness if but slight climatic oscillations favoring less rainfall or more active evaporation should occur. The open water of the lake is bordered by rank growths of dark-green rushes, which also form many island-like areas here and there on its surface, rising in general from a foot or two of water. During periods of high water the lake expands and reaches within a few hundred feet of the south base of Saddle Mountain Butte. East and west of the butte it frequently expands so as to carry its margin about 4 miles beyond its low-water limit. These fluctuations have not been observed long enough to determine what their maximum may be, and it would not be surprising if portions of the plain now inhabited, as, for example, the site of the village of Lawen, should be sometimes inundated. The portion of the lake bed now left dry each summer is in places brightly colored with the reddish and yellowish coral-like plant known as *Salicornia*, and is overgrown with salt grass, which is harvested each year.

Hot spring.—About 4 miles northeast of Saddle Mountain Butte is a spring which, as observed by H. C. Dewey, forms an irregular pool from 75 to 120 feet in diameter and 20 to 30 feet deep. The water is clear, without odor, and near the margin of the pool has a temperature of 122° F. The discharge, which is about 430 cubic inches per second, is now utilized for watering stock. This spring rises at a locality on the surface of the broad valley, at least 4 miles from the nearest upland, and is a true fissure spring, having a deep source, shown by its temperature to be probably not less than 3,500 feet below the surface. Like other hot springs in the same valley, some account of which has been published,[a] it indicates the presence of artesian conditions.

Wells.—At the village of Lawen, situated about 6 miles west of Saddle Mountain Butte and about 3 miles north of the summer margin of Malheur Lake, eight wells have been drilled, and within a radius of 2 miles of the village six other wells have been put down. These wells range in depth from 18 to 40 feet, the differences being due principally to the inequalities of the surface, as they all obtain their water from about the same horizon. They pass through fine yellowish silt, and reveal the nature of the surface layer that covers large portions

[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

and, as nearly as can now be judged, practically the entire area, of Harney Valley. The material is fine throughout, with but slight indications of stratification, and contains no beds of gravel or other coarse deposits. It agrees in physical character with the silts the rivers of the region deposit during high-water stages. Similar material was observed on the banks of Silvies River, and also on the borders of Malheur Slough, as the channel is termed, through which Rattlesnake and other creeks on the north side of Harney Valley discharge to Malheur Lake during periods of high water. It is probable that the widely extended sheet of material forming the surface of Harney Valley is mainly a stream deposit, while the portion near the lake was laid down in still water. This is an instructive illustration of the fact that stream and lake deposits merge into each other and in many instances have no definite line of separation. On the surface of Harney Valley also there are wind-laid deposits of sand and dust, but for the most part they are inconspicuous.

The depth at which water is reached in the wells in and about Lawen shows the position of the water table, which is probably controlled by the surface level of Malheur Lake. The water is raised by means of windmills and is used for domestic purposes, watering stock, and the irrigation of small gardens. The supply seems to be inexhaustible. The temperature of the water in one well, 18 feet deep and 14 feet to water, is 50¼° F., which probably represents about the mean annual temperature of the locality.

In the southern part of Lawen, on land belonging to Mr. G. L. Sitz, a well 5 inches in diameter was drilled in the year 1900 to a depth of 432 feet with the hope of obtaining artesian water. The water table was reached at 10 feet and artesian water at about 200 feet; below that depth, as thought by the driller, no additional water was obtained. The well discharges continuously through a 3-inch pipe. The section passed through, as reported by Mr. Sitz from memory, is as follows:

Section in well at Lawen.

	Feet.
Sand and clay	200
Lava, about	50
Gravel, cemented	4
Hard and soft layers, from 8 inches thick to 4 feet thick	100
"Hard blue granite" (basalt)	78
Total depth	432

This fragment of information concerning the geology of Harney Valley is in harmony with what has previously been learned in reference to that basin, and indicates that artesian water can be had if drill holes are put down. To adequately test the artesian conditions at Lawen, a well at least 1,000 feet deep should be drilled, but the possibilities in reference to water stored under pressure will not even then be exhausted, as water-bearing layers probably exist at still deeper horizons.

The depth of the surface layer, 200 feet, given in the above section, is of interest and indicates that the surface filling of the valley is not great. Beneath the silt, reported as "sand and clay" by Mr. Sitz, there probably occur sheets of basalt, rhyolite, and rhyolitic tuff, perhaps with lacustral or stream-deposited sediments such as clay, sand, and gravel between them. So far as the facts in hand furnish data on which to judge the structure of the rocks, the position in which they occur, and their nature, whether porous or impervious, all favor the hope, as previously reported, that flowing water can be obtained over a large part of the basin.

Soil.—The broad, level expanse of Harney Valley is traversed by roads connecting localities where water can be obtained, and but for the wire fences placed about the extensive tracts held for pasturage the level-floored valley could be crossed by wagon in practically all directions. A representative portion of the valley, situated between Lawen and Burns, shows that the surface has minor inequalities due to the abandoned channels of streams flowing from the surrounding uplands. The surface of the soft material forming the present floor of the basin is alluvium brought by streams from the uplands and deposited in broad, low-grade, alluvial fans. Over these deposits the streams have run in various channels or distributaries, and as they shifted their positions the abandoned channels remained as records of their former courses. Over the stream-shaped surface the winds have deposited some material in the form of sand and dust, but this covering is thin and in most localities inconspicuous. Even the transient visitor is impressed with the fact that the valley contains a vast quantity of good land which only needs water to make it fruitful. The climatic conditions, however, and especially the common occurrence of frost in summer, render it evident that in the future, as in the past, industrial development will consist principally in hay growing as a basis for stock raising and in dairying.

Rhyolitic tuff.—At Burns and especially along the border of Silvies River, to the west of the town, there are conspicuous outcrops of rhyolitic tuff. A widely extended sheet of this material underlies the surface over a great extent of the hilly and even mountainous country to the northwest, but its boundaries have not been traced. The region referred to is forest-covered and furnishes the watershed of Silvies River. An intimate relation between the character of the surface rock and the water supply is here shown, since the thick sheet of tuff referred to (as may be seen in the rim rocks bordering the narrow valley through which Silvies River flows) is porous and absorbs the rain water falling on its surface, allowing it to percolate slowly to the stream. In the valleys cut in the widely extended tuff sheets, hillside springs are common. The tuff is well exposed at Burns, and, as may there be seen, is a brown porous rock of low specific gravity, composed of angular fragments of scoriaceous rhyolite. The beds are easily quarried and the blocks obtained readily squared for building purposes by means of an ax. Although an inferior building stone, because of its porosity, which permits it to absorb water almost as readily as a sponge, and because also of its sombre color, it is nevertheless useful, especially in a region where the rainfall is small. A church at Burns has been built of it, and this and similar material will no doubt be extensively used in the towns of central Oregon in the future.

LITTLE SAGEHEN CREEK.

The stage road leading southwest from Burns follows the border of Harney Valley for about 6 miles and then turns west, crosses a low divide, and ascends Little Sagehen Valley. Through this runs Little Sagehen Creek, the diminutive representative of the former stream of considerable size that excavated the well-defined valley. It is dry in its upper part in summer, but in its lower part several warm springs come to the surface and supply natural irrigation for extensive meadows of native grasses.

The rocks forming the major portion of the hills southwest of Burns are composed of rhyolitic tuff, similar to the brown building stone at Burns, but a prominent butte, overlooking both Harney Valley and the narrow stream-cut valley of Little Sagehen Creek, is composed of reddish scoriaceous basalt, a remnant left by erosion of a formerly extensive sheet of the same material. Little Sagehen Creek has cut a steep-sided trench-like valley through the basalt, leaving a broad plateau on each side, that on the north extending east to within about 6 miles of Malheur Lake, where it terminates in a line of bold escarpments. The sheet of basalt also extends widely to the south of Little Sagehen Creek, forming a nearly level plateau which reaches nearly or quite to Little Silver and Harney lakes. Over the monotonous surfaces of these broad plateaus the bare black basalt with which they are covered is nearly everywhere exposed. Along each side of Little Sagehen Creek for a distance of about 25 miles, the broken edges of the lava sheet form bold palisades about 40 feet high, below which steep talus slopes conceal from view the soft stratified beds underlying the resistant lava that shields them and that, where unbroken, has preserved them from erosion.

From the basaltic butte referred to above good views were obtained of the mountainous country to the northwest of Burns, which confirmed previous observations in reference to the eastward dip of the rocks in that region and showed that they pass beneath the floor of Harney Valley, thus favoring the conclusion that artesian conditions are present beneath its broad arid surface.

The north wall of the canyon of Little Sagehen Creek for a distance of about 10 miles near its head is composed of irregular hills of rhyolitic tuff, the weathering of which has produced numerous isolated crags and monumental forms. On the south the canyon is bordered by a continuation of the palisade of basalt, marking the border of the extensive plateau, which extends far to the south. The basalt is here thin, in places being not over 15 or 20 feet thick. Beneath it are soft white sedimentary beds, consisting largely of volcanic dust, at least 250 or 300 feet thick. The basalt was spread out as a widely extended sheet after the rhyolitic tuff, which was showered on the land in vast quantities, had been consolidated and deeply eroded. After the inundation of basalt erosion continued, and the canyon of Little Sagehen Creek was excavated. From our general knowledge of the relations of the rhyolitic tuffs and basalts of central Oregon to sedimentary rocks containing fossils it may reasonably be inferred that the soft beds in question are of Tertiary age. The cutting of the canyon in the basalt is, it seems, an event of post-Tertiary time.

At the head of Little Sagehen Valley there is a low, irregular, flat-topped divide. The road leading westward ascends from the canyon by means of a steep grade and traverses a portion of the basaltic plateau referred to above. The junction of the basalt with the older rhyolitic tuff, which there forms irregular hills, can readily be traced 1 or 2 miles to the right of the road. The tuff has been deeply dissected by streams, and furnishes examples of old topography in striking contrast with the level surface of the adjacent plateau of basalt, with its few steep-sided gorges and canyons. The tuff of the uplands is well exposed, and in the walls of deeply cut but flaring valleys sections of beds from 50 to 150 feet thick are revealed. The rocks resemble gray granite in color and, like granite, weather into rounded hills with crags and isolated tower-like masses on their sides and in the walls of the bordering ravines.

SILVER CREEK.

Silver Creek has its source in a dissected plateau, which is an extension to the northeast of the hills just referred to. In summer its upper portion becomes dry and its sole supply is from great springs of cool, delicious water that well out at the base of a bold escarpment of yellowish rhyolitic tuff about 8 miles northwest of Riley. Below these springs is an alluvial plain about 10 miles long and averaging approximately 2 miles in width, through which Silver Creek meanders, bordered by rich agricultural lands. The water supply is meager, however, and only a small percentage of the land favorably located for irrigation is under cultivation. About 2 miles south of Riley the valley contracts and becomes a gorge with bluffs and rim rocks on its sides. Bold hills of basaltic rock rising near the creek on its south side have the form and appearance of much-eroded volcanic craters. About a mile south of these hills is the true border of the valley, there defined by a rim rock of basalt which trends southwestward and forms the southeast border of a valley or depression tributary to that through which Silver Creek flows. The line of cliffs is a conspicuous topographic feature and one of much geologic interest. To the south of Riley it is from 200 to 300 feet high, and from its crest the descent to the southeast is abrupt for about a quarter of a mile, when the surface of the broad basaltic plateau extending far to the south and east is reached. The sheet of basalt forming the plateau is evidently slightly upturned along the line of cliffs defining its northwest border, and is broken so as to form palisades. These conditions indicate the presence of a fault, as will be shown more clearly a few pages further on.

PROMINENT PEAKS.

From east to west across central Oregon there is a succession of prominent peaks which serve as landmarks to the traveler and furnish a series of convenient stations for studying the geography and geology of the region lying between Steins Mountains on the east and the Cascade Mountains on the west. These peaks, in their order from east to west, are: Iron Mountain, a sharp conical elevation about 5 miles south of Little Silver Lake; Placidia Butte, 18 miles northwest of Iron Mountain; Glass Buttes, 18 miles farther northwest; Hampton Butte, 12 miles northwest of the Glass Buttes, and the Pauline Mountains, about 30 miles farther west, from which the Cascade Range is in full view, although 50 miles distant. In the interval there are several isolated peaks, such as Pilot Butte, Lava Butte, Black Butte, etc.—steep-sided conical elevations with sharp summits, ranged across the country like signal stations—each of which at some time in its history has been aglow with volcanic fires. They are not all of the same age, and, although having a similar history, present many variations in the details of the events they record. Some of them, like Iron Mountain, the Glass Buttes, and Hampton Butte, are of ancient date, and were built by volcanic explosions which hurled fragments of congealed lava into the air during the earlier part of the Tertiary period of geologic history; others, like

Lava Butte, covered the region about them with streams of molten lava but a few centuries since.

Iron Mountain.—Iron Mountain, some account of which has been given in a previous report,[a] is a much-eroded volcanic cone built of acid lava resembling rhyolite. It commands a far-extended landscape, characteristic of the arid east-central portion of Oregon; from its sharp summit not an individual tree can be distinguished, although the shadow-like appearances on the mountains far to the north are known to indicate the presence of a valuable forest. About the base of the butte are widely extended basaltic lava flows, and near at hand broad, yellow mud plains margined by bands of white efflorescent salts. The waters of Little Silver Lake lap on shadeless shores, and serve to emphasize rather than relieve the desolation that forms the most prominent feature of the landscape in every direction. To the northwest, 18 miles distant, rises the sharp summit of Placidia Butte, the most prominent object in a seemingly boundless plain of somber sagebrush-covered basalt.

Placidia Butte.—The nearest habitation to Placidia Butte is at Riley, about 12 miles eastward, the road for the entire distance being without water, except such as is furnished by melting snow in winter and spring or by the stagnant contents of small water pockets in early summer. During our visit to the butte we crossed the Silver Creek Meadows to the base of the bold palisade or rim rock that borders them on the south. Choosing a notch in the almost continuous crest line of the palisade the top was easily reached. The crest of the palisade, instead of being the margin of a level plateau, as is so frequently the case where rim rocks occur, is really the edge of a tilted block, which stands in relief above the gently sloping plain that extends from its base 20 or more miles to the southeast. Along the crest of the ridge there are numerous elevations having about the same height, between which notches occur resembling the abandoned stream-cut channels termed "wind gaps." That they were really stream cut was not satisfactorily determined, but they at least suggest that the region was dissected by small streams tributary to a southeastward-flowing river before the ridge was uplifted.

The plain extending southeastward from the ridge slopes downward gently from its base, and is remarkable for its evenness and smoothness. No more than faint suggestions of stream-cut channels are visible on its vast monotonous surface. If such once existed, as is probable, they have been filled and obliterated by alluvium and wind-deposited débris. To the southeast Iron Mountain and Little Silver Lake are in plain view and seemingly only 8 or 10 miles away, instead of 18 or 20 miles, as they really are. To the southwest, 7 or 8

[a] Russell, I. C., Notes on geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

miles distant, rises the remarkably regular conical peak known as Placidia Butte, with a height above the adjacent plain of from 700 to 800 feet. On its eastern side, about a mile from its base, is a much lower elevation, composed of reddish, highly scoriaceous basalt, much eroded, which marks the site of a secondary or parasitic eruption. Possibly a stream of lava came to the surface at this locality, but erosion has so altered the topography that definite evidence of such an occurrence is not obtainable.

On ascending Placidia Butte we found it to be a volcanic cone built during explosive eruptions, which blew out angular fragments of scoriaceous basalt, but discovered no bombs to show that plastic lava was erupted. The sides of the cone are steep, and when seen in profile reveal long sweeping curves concave to the sky, typical of many similar cones composed of hard fragments of various sizes. It is doubtful if these curved slopes are a part of the original constructional surface of the cone, however, since much erosion has occurred, and erosion curves in the case of such piles of loose débris simulate constructional curves. On the southwest side of the cone there is a line of rough crags of scoriaceous basalt; on the west there is a similar line; and on the north there are suggestions of a third. These lines of crags radiate from the summit portion of the pile and mark the location of cracks in its sides, which were injected with molten lava so as to form dikes.

All these features are normal, or at least common, in the case of scoria and lapilla craters. An exceptional occurrence, however, is furnished by the massive angular crags of reddish-brown rock which form the summit of the cone and enable erosion to give it a sharp terminus. This summit mass, or capstone, is a volcanic agglomerate, but unlike most similar rocks, is lacking in fine material, such as volcanic dust and lapilli, to serve as a mortar for the larger masses. It is composed of sharply angular fragments of scoriaceous basalt, adhering firmly one to another and ranging in size from 1 or 2 up to 8 or 10 inches in diameter. In places there are angular holes and irregular cavities between the adjacent blocks. The explanation is that this agglomerate is composed of fragments blown out of the deeper portion of the conduit in a solid condition, and accumulated in the crater at the top of the volcanic pile as the volcanic energy decreased. The finer fragments, being carried higher, fell outside the crater or were removed by the wind. The larger fragments were hot and adhered to one another, the accumulation being also to some extent consolidated by the pressure of its own weight. The mass of material thus produced was similar to the "cone of eruption" observed in the case of many active or recently extinct volcanoes, and at first was encircled by a lapilli crater.

Stated in another way, the agglomerate is the higher portion of the plug or neck which hardened in the volcano's conduit as its energy decreased. At no great depth below the portion now exposed compact lava may be expected to be present. Erosion has removed the crater which once surrounded the summit of the plug and a portion of the compact agglomerate which accumulated within it. The central mass is resistant to all forms of mechanical erosion, and, owing to the dryness of the climate, has not been exposed to active chemical erosion. Although the plug is probably about 200 feet in diameter at a short distance beneath the exposed top, its summit has weathered to a rough but moderately sharp apex.

From the summit of Placidia Butte an unobstructed view in all directions is obtained. Perhaps the most characteristic features of the desolate landscape are the vast expanse of the apparently smooth plain of basalt, extending, with its covering of sagebrush, far to the east and southeast, and the hills to the south in the vicinity of Abert Lake, which, judging from their forms and the little that is known concerning them, are much eroded uplifts of rhyolitic lava and tuff of the same lithologic character.

Glass Buttes.—To the west, 18 miles distant, rise the Glass Buttes, consisting of two prominent rounded domes and several lesser hills, which, as known from a previous visit, are remnants of ancient rhyolitic or andesitic volcanoes, now deeply dissected by erosion. They form not only a most prominent object in the vast desert landscape, but add a touch of color to the prevailing gray of the surrounding sagebrush-covered plain by the tawny yellow of the ripened bunch grass and the dark shades of the trees that grow on the northern sides of their prominent ridges. The highest point on these desert mountains, which take their name from the obsidian or volcanic glass scattered over their surfaces, is approximately 2,000 feet above the plain surrounding their widely extended base.

Hampton Butte.—Hampton Butte, which is of similar geologic structure to the Glass Buttes, is situated a little to their right, and about 30 miles away from Placidia Butte, from which it may be seen. From Placidia Butte, in the blue, indefinite distance, may also be noted the snow-covered summits of the Cascade Mountains; these, however, are so dim, as seen through the ever-prevailing desert haze, that only Mount Jefferson can be definitely located.

HILLS AND RIDGES.

Continuing northward past a water pocket lying about a mile north of Placidia Butte, we again crossed the ridge that overlooks Silver Creek Valley and its southwest tributary, and found it to be composed in part of white rhyolitic rock of older date than are the vast sheets of basalt associated with it. Passing through a depression in the rhyolite hills, we gained a platform of basalt which encircles them on the northwest side. This platform, which is about half a mile wide, terminates on the northwest in a precipitous escarpment ranging in height from 200 to 300 feet, in which the edges of several sheets of basalt are well exposed. This escarpment is a direct continuation of the similar precipice climbed in the morning, and judging from its topography is the upraised side of a fault. The trend of the line of cliffs is northeast and southwest, but near its southern end it curves westward. The valley at its base on the west is not floored with alluvium, but has an irregular bottom composed of basalt, which rises in a continuous slope toward the northwest and culminates in the crest of a ridge which presents a steep slope to the west. A detailed study of this interesting region would no doubt yield much valuable data in reference to the influence of movements in the rocks on topographic forms.

To the north of Riley and bordering the meadows and adjacent sagebrush-covered terrace-like uplands on the northeast rise a group of bold rounded hills, which attain a height of between 1,500 and 2,000 feet above the meadows at their base. These hills are composed of compact, apparently basaltic rock, and are thought to be of probably Tertiary age. The hills, although presenting rounded summits when seen from the south, were found on near inspection to consist of a series of nearly east and west ridges, with steep escarpments facing north. This peculiar topography suggests faulting. The hills are thickly strewn with weathered blocks of rock of the same character as those exposed in the cliffs, but scoria, lapilli bombs, etc., are absent. As there are no trails, the thickly strewn blocks covering the surface make traveling difficult. Rich, brown residual soil occurs between the loose stones, and luxuriant bunch grass and an open forest of junipers and pines clothe the surface. These hills extend at least 8 miles northward, and present throughout the same topographic characteristics. Their northern extension is densely forested.

At the head of the Silver Creek Meadows there is a great spring of clear, cool, delicious water, at which a military fort called Camp Curry was formerly located. The spring, with others that occur along its course farther north, is an important source of supply for Silver Creek, which here emerges from a narrow canyon cut in a bed of rhyolitic tuff at least 100 feet thick, the rock being of the same nature as the tuff at Burns, and presumably a continuation of the same great sheet.

At the spring the stage road from Burns to Prineville makes a sharp turn to the west and ascends the precipitous border of a plateau. The rock removed in grading reveals excellent illustrations of the angular fragments of which the tuff is composed. Highly porous, it has been leached by percolating water and changed from the brown color that unweathered portions usually present to bright pink and even white. Resting on the tuff is a sheet of black basalt about 20 feet thick, which, by protecting the weaker rock beneath, has led to the preservation of a nearly flat table-land many square miles in area. The road traverses this plateau for about 4 miles, crossing on the way the desiccated bed of an ephemeral lake, surrounded on all sides by a low rim of basalt. In summer the bed of this lake is a smooth playa, but in winter it is flooded and the traveler has to skirt its northern border.

FORESTED PLATEAU.

To the west of the generally smooth basaltic plateau the road enters an extensive plateau region that has been somewhat deeply dissected by streams. The surface rock is rhyolitic tuff of the same character as that of the sheet so well exposed along Silver Creek to the north of the site of Camp Curry. A remarkable and pleasing change is here experienced by the west-bound traveler, who passes from an area thousands of square miles in extent over which not a tree is to be seen to a region covered with an open but luxuriant forest. For 10 or more miles the road, which is smooth and hard, winds through the forest, now descending steep valley sides, traversing beautiful shadowy vales, and again ascending to the level of the general plateau surface, from which exquisite pictures of the primeval forest are beheld on every hand. The forest is composed mainly of yellow pine, as yet untouched by the woodman, and gives promise of great commercial value in the future when means for transportation shall have been provided. Beneath the tall, straight pines grow thickets of mountain mahogany resembling groves of olive trees, which here, as in many other localities on the uplands of Oregon, add picturesqueness to the rocks and crags among which they make their homes. The forest, so welcome after weeks spent in the glare of the sun on gray deserts, extends far to the north, and probably continuously to the Blue Mountains of eastern Washington. In part it is included in a national forest reserve, and if properly cared for and the mature trees harvested, leaving the younger ones time to grow, will be valuable for ages to come.

On the south this great forest terminates abruptly, and from beneath the shade of the great trees on its margin one can look down on the bare hills of the desert land which it borders. Yet the only conspicuous difference between the forested plateau and the bare hills to the south is the nature of the underlying rocks, the plateau being composed of rhyolitic tuff, while the hills have been carved mainly from sheets of basalt. Beneath the portion of the forest traversed the porous surface rocks drink in all the water that comes to them and permit it to slowly percolate away and feed the springs and the streams in the countless erosion channels. The general elevation of the forested country, about 5,000 feet, is, however, greater than that of the vast treeless region bordering it on the south, thus favoring cooler climatic conditions in summer and retarding evaporation, and the precipitation, especially the snowfall in winter, is probably greater on the broad upland than on the desert valleys with their isolated hills, although of this there is no positive record. More study is required to show which is the determining cause leading to such a conspicuous change in the flora. In fact the several conditions favorable and unfavorable to tree growth seem to be delicately balanced, and the special factor in control is probably not the same throughout either the forested or the unforested region.

At Buck Creek, which flows south from the forested plateau, the road descends to the extensive sage-covered plain in which Crooked River has its source and enters Crook County.

WATER RESOURCES.

The rainfall throughout Harney County is too small to permit agriculture without irrigation. Owing to the considerable general elevation—the lowest altitude being the surface of Malheur Lake, which is about 4,150 feet above the sea—and the clearness and dryness of the air, which permit active radiation, frosts are of common occurrence during every month of the year, and only forage plants can be expected to yield adequate returns to husbandry. The uplands and valleys alike were clothed with bunch grass while in a state of nature, and wherever the soil was naturally moist and not too alkaline the coarse rye grasses formed luxuriant meadows. These several conditions indicate that the chief farming industries must be stock raising and dairy farming. The problem that meets the hydraulic engineer is how to utilize the available water supply so as to best serve these demands.

SURFACE WATER.

Rivers and streams.—The surface-water supply, although well known to the residents of the country, has only just begun to receive critical study. About all has already been done that can be accomplished by individuals and small communities in the way of diverting and utilizing the summer flow of the streams, but the main resource lies in the direction of storing the winter run-off in upland valleys and conducting it through canals to the most favorable portions of the lower valleys. There are but two streams that offer favorable conditions for such enterprises on a large scale, namely, Silvies River and Donner and Blitzen River. Of these the former is by far the more favorable, and detailed surveys are in progress by the United States Geological Survey [a] for the purpose of determining accurately what can be accomplished by means of it. The possibilities of Donner and Blitzen River have not as yet been considered by hydraulic engineers, but they demand careful study, such general knowledge as is available concerning the valley through which it flows certainly favoring the hope that advantageous sites for storage reservoirs occur along its course.

Water pockets.—About a mile north of Placidia Butte is a water pocket 500 or 600 feet in diameter, capable of holding 4 or 5 feet of water. This and several other similar depressions in the same region are of interest not only on account of their value as watering places for stock, but on account of their origin. Seemingly they are depressions due to wind erosion, but this explanation is not entirely satisfactory, since a similar basin on the forested plateau to the north of the Silver Creek Meadows has a rim of basalt all about it. These depressions are natural reservoirs in which water collects during the winter and spring months, but as they are filled to a depth of several feet with soft, fine silt their value as watering places for stock is much impaired. By reexcavating them a supply of water sufficient for a large number of cattle might be easily and cheaply procured.

HARNEY VALLEY.

The great plain forming Harney Valley and its several side extensions offers an abundance of irrigable land suitable for forage crops, far more in fact than under the most sanguine hopes can ever be reclaimed through the use of the water flowing from its bordering uplands. There is an urgent demand for more water than the run-off can supply, and to secure it the only resource is to obtain water by means of wells.

Wells.—Ordinary dug wells with a depth of less than 100 feet and usually less than 25 feet have proved successful in many portions of Harney Valley, particularly in and about Lawen, which is situated near the level of the lowest point in the basin. But while these wells are of value for household purposes and for watering stock, little use can seemingly be made of their water for irrigation. The hope for water for irrigation purposes, in addition to that furnished by surface streams, centers on a subsurface or artesian supply.

As explained in a previous report,[b] Harney Valley is located in an extensive depression, which for several reasons is considered to

[a] Second Ann. Rept. Reclamation Service, U. S. Geol. Survey, H. Doc. 44, 2d sess. 58th Cong., 1904, pp. 435–436.

[b] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

be an artesian basin that may be expected to yield a valuable water supply. The favorable opinion expressed in the report referred to in reference to obtaining artesian water was strengthened by the observations made during the reconnaissance which forms the basis of the present report, and the advisability of putting down a test well with all the care that can be exercised is again urged. A favorable locality for such a test, which should be carried as deep as practicable, is at or in the vicinity of Lawen.

Water storage.—In addition to Silvies River and Donner and Blitzen River, the possibilities for storing water on Rattlesnake Creek above the village of Harney, and also the advisability of constructing small reservoirs on Silver Creek above Riley, need to be investigated; but even at the present time it is evident that, owing to the limited water supply, the best returns to be hoped for from such undertakings are not great.

In the extensive area of hilly and even mountainous country embraced in the southwestern portion of Harney County the rainfall is small—probably less than 10 inches—and the land favorable for irrigation is restricted in area and widely scattered. The conditions do not seem to favor the storage and utilization of the surface water, and there is no suggestion of the existence of an artesian supply. This extensive region is favorable for grazing, however, bunch grass being abundant, and something can certainly be done in the direction of developing springs[a] and of deepening natural water pockets so as to obtain local supplies for maintaining stock during the summer months.

CROOK COUNTY.

CROOKED RIVER.

On emerging from the forest that occupies such an extensive area in the southwest part of Harney County we descended Buck Creek to the extensive valley at the east base of Hampton Butte, in which Crooked River has its source. The canyon of Buck Creek, which was traversed for about 6 miles, furnished a suggestion as to the character of the geology of the series of hills, or deeply dissected plateau, through which it flows. The canyon is from 500 to 600 feet deep, and has a conspicuous rim rock of basalt on each side, beneath which there are at least 700 feet of soft, mostly fine, sedimentary deposits, composed in part of volcanic dust. Along the canyon there is in places a narrow flood plain, which gives room for several small hay ranches. Where the creek emerges from the canyon and enters the broad valley or sagebrush plain to the south its water soon disappears.

[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 54, U. S. Geol. Survey, 1901.

and even its former channel is almost lost in the wind-deposited sands.

GILCHRIST VALLEY.

The valley at the head of Crooked River, in which Buck Creek sinks, is about 20 miles long from north to south and, in general, 10 or 12 miles wide. On the southwest its border is low and indefinite, and in a general view it seems to merge with the Great Sandy Desert, which extends for at least 60 miles in a southeast and northwest direction across the southeast portion of Crook County and far into Lake County. This valley has no specific name, and for the sake of convenience, as well as a fitting acknowledgement of the enterprise and industry of its first settler, Mr. C. A. Gilchrist, whose hospitable home is still there, I propose to term it Gilchrist Valley. The valley contains, by estimate, fully 200 square miles of rich land, the greater part of it well situated for irrigation. Unfortunately, there are no surface streams rising in the bordering uplands that can be looked to for water enough to supply a single square mile. In a state of nature not only the valley, but the surrounding hills and buttes on all sides, were clothed with bunch grass, but now, owing to overgrazing, all the land not inclosed with fences within a distance of about 6 miles from any one of the few summer watering places is practically a desert.

On the south border of Gilchrist Valley rise the Glass Buttes, to which reference has already been made, with bold, rounded summits and long, sweeping slopes, which make them particularly attractive, but they are desert mountains, rising from a featureless and excessively arid valley. The upland area on the north side of the buttes, which slopes to Gilchrist Valley, is extensive, but has no life-giving streams. On the west of the valley, rising boldly from its margin, stands Hampton Butte, a mountain mass similar to the Glass Buttes, and also waterless, so far as streams tributary to the adjacent valleys in summer are concerned. Uplands border the valley on the east, but are more remote and of less height than those on the west.

Warm springs.—Crooked River, which has its source in a group of warm springs at the north end of Gilchrist Valley, flows northward through an irregular, and, in part, "box," canyon, with a conspicuous rim rock of light-colored rhyolitic tuff on each side. Other springs swell its volume in the first few miles of its course. The land about the springs in the north end of the valley has been inclosed with fences, and the water that rises to the surface used for irrigation. Small storage reservoirs have been constructed, with favorable results. The land, although alkaline, by careful irrigation has been made to yield favorable crops of hay.

The warm springs in Gilchrist Valley are not only of interest on account of the use that is now being made of their waters, but because they supplement other evidence pointing to the probability that artesian water can be had over a large portion of the basin in which they are located. The springs range in temperature from 60° to 87° F. and are scattered for about 2 miles along a narrow north-and-south belt. They are all small, but it was not practicable to make accurate measurements of their discharges at the time of my visit, owing to the flooding of a part of the area where they rise by the storage reservoirs that have been constructed. Where the waters of the springs are combined at the outlet of the valley, they make a creek of warm water, the volume of which, by a rough estimate, is between 20 and 25 cubic feet per second. The temperature of the water, as it rises in the copious springs, indicates that it comes from a considerable depth. The rate of increase in temperature with depth is not the same at all points on the earth's surface, but where recent volcanic heat is not present is, in general, 1° F. for each 50 to 60 feet in depth below the stratum of no seasonal variation, which in Oregon may be taken at about 50 feet below the surface. The stratum of no seasonal variation has a temperature equivalent to the mean annual temperature at the surface, which in central Oregon is about 49° F. Assuming that the rate of increase in temperature with depth is 1° for each 60 feet, we find that the depth from which the spring in Gilchrist Valley are supplied is at least 2,200 feet. Perhaps a safer estimate, allowing for loss of heat as the water rises, would be 2,500 feet. At about that depth there is a supply of water at least sufficient to maintain the springs, which appear at the surface continuously throughout the year. As the springs rise through openings, in part at least, in soft material, there must be lateral seepage, and probably much loss in other ways. These springs may be justly termed artesian springs, as they flow by reason of the pressure of water at higher levels, and render it evident that if wells should be drilled to the requisite depth near them and properly cased a more abundant outflow might reasonably be expected.

Artesian wells.—While the presence of warm springs in Gilchrist Valley alone would furnish a strong argument in favor of drilling wells in their vicinity with the hope of obtaining artesian water, other facts also sustain the conclusion that they are situated in an artesian basin.

On all sides of Gilchrist Valley, except the northeast, the rocks dip toward it in such a way as to be readily seen. On the northeast the country rises for a long distance, until the forest-covered plateau drained in part by Silver Creek is reached, and the rocks become so nearly horizontal that the determination of their dip is difficult. On the north the layers of basalt and volcanic tuff are conspicuously flat, but, as revealed by the rim rocks on the sides of Crooked River

COLUMNAR RHYOLITIC TUFF AT NORTH END OF GILÇHRIST VALLEY, NEAR HAMPTON BUTTE, CROOK COUNTY.

Canyon, are gently inclined toward the south for a distance of at least 10 miles. The hasty examination I was able to make favors the conclusion that Gilchrist Valley is situated in a structural basin. The rocks passing under the valley are in many instances porous, as may be seen in the eastern slope of Hampton Butte, along Crooked River, etc.; that is, they are of such a nature that they permit water to percolate through them. The presence of impervious layers, or rocks of such a close texture that, if resting on a pervious bed, they would prevent water from escaping upward from it, is less easy to demonstrate, and, in fact, no good evidence was obtained that such beds are present.

While it is not just to claim from the observations thus far made that Gilchrist Valley is in reality situated in an artesian basin, the facts presented above, and the impression gained while traversing the region and searching for adverse as well as favorable evidence as to a possible artesian water supply, certainly favor the opinion that a true artesian basin of considerable size is present.

The source of supply of the water rising in the springs referred to is most probably in the plateau region to the northeast, and, as the volume of the springs and the extent of the supposed gathering ground indicate, will probably be found ample to supply a number of artesian wells.

The object of my examination was mainly to determine if the conditions present warrant the expense of putting down test wells for the purpose of demonstrating the presence or absence of water under pressure. To this question, so far as Gilchrist Valley is concerned, an affirmative answer is abundantly justified. The test well may be located anywhere in the basin where flat land occurs, but would serve its purpose best if put down on the north and south axis of the valley, anywhere from 1 to 3 miles south of the Gilchrist brothers' ranch, on which the most copious springs come to the surface.

If a test well is put down, a careful record of the nature, thickness, etc., of the rocks passed through should be kept, the well properly cased, and the pressure of the water in every water-bearing layer met accurately measured. Suggestions in these and other directions, together with a list of reports, papers, etc., relating both to the theory of artesian water supply and the art of well drilling, have been presented in a previous report.[a]

PRICE VALLEY.

From the foot of Gilchrist Valley our route led westward to the now abandoned post-office of Price, situated on Camp Creek, at the south base of Mutton Mountain.

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[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

At the outlet of Gilchrist Valley a bed of conspicuously columnar rhyolitic tuff, about 20 feet thick, which dips west at an angle of about 8°, is well exposed. (Pl. III.) The direction of the inclination of this and of other similar blocks in the vicinity is not the same, and in many instances is to be ascribed to landslides rather than movements having a more general cause. The prevalence of sheets of compact tuff and of basalt, resting on soft sedimentary beds or on sheets of fine, incoherent volcanic dust and lapilli, affords favorable conditions for the occurrence of landslides throughout an extensive region drained by Crooked River in the upper portion of its course and by Camp Creek, its principal tributary from the west. Along the canyon walls of these streams numerous illustrations of landslide topography are conspicuous.

The uplands between Gilchrist and Price valleys bear evidence of long-continued weathering, and stand in relief above the adjacent valleys because of the resistance offered to erosion by the widely extended sheet of rhyolitic tuff of which mention has already been made.

Camp Creek has excavated in soft sedimentary beds a valley in general 400 or 500 feet deep and about 2 miles wide. From its head to a narrow outlet, through which the stream escapes through a canyon to join Crooked River, is a distance of about 8 miles. In this basin, which it is convenient to term Price Valley, there are abundant outcrops of fine gravel and light-greenish shales, which in several localities have been weathered into typical badland topographic forms, as illustrated by Pl. IV. Much of the south side of the valley is crowned by a conspicuous rim rock of rhyolitic tuff, while the north side is more irregular and rises precipitously to form Mutton Mountain, the rocks of which are basalt. Basalt also forms a conspicuous remnant left by erosion on the south side of the valley.

John Day formation.—The soft fresh-water sedimentary beds so well exposed in Price Valley, particularly near its head, have become known to geologists on account of the large number of well-preserved fossil bones discovered in them, and have been shown to be a part of the John Day system. Judging from their close lithological similarity to the John Day beds at typical localities adjacent to the river after which they are named, descriptions of which have been published by John C. Merriam,[a] the lower and middle members of that series are represented, but I am in doubt as to the presence of the upper member. However, previous observers refer the beds in question to the middle and upper John Day.

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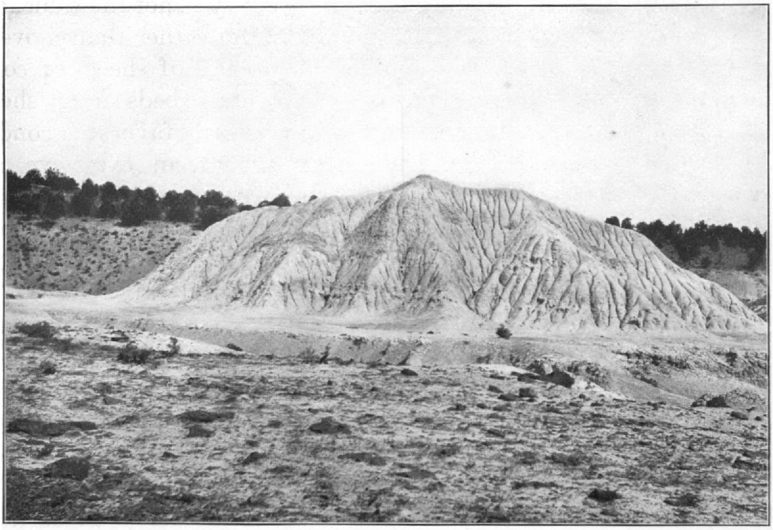
[a] A contribution to the geology of the John Day basin: Bull. Dept. Geology University of California, vol. 2, Berkeley, Cal., 1901, pp. 269–316. In this paper summaries of previous writings pertaining to the John Day formation are presented. A description of the fossil flora of the John Day formation, and a discussion of its geologic age, are presented by F. H. Knowlton in Bull. U. S. Geol. Survey No. 204, 1902.



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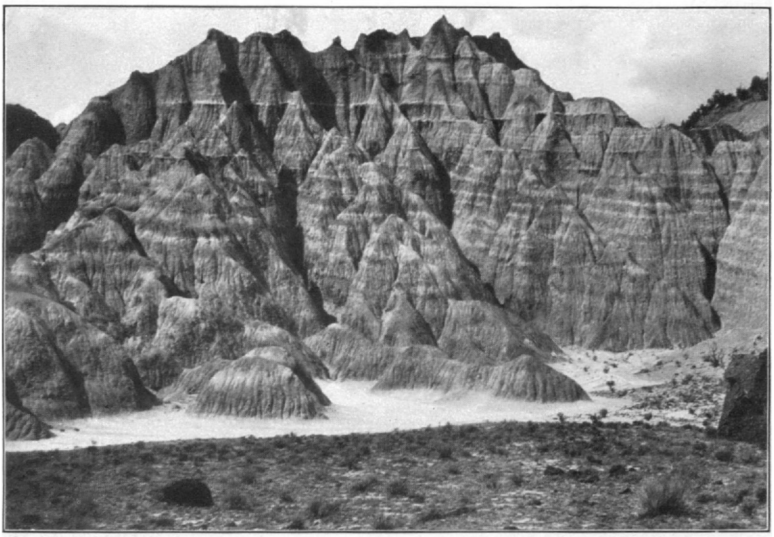

B

ERODED JOHN DAY BEDS, NEAR LOGAN BUTTE, CROOK COUNTY.

The lowest exposures in Price Valley consist of soft, highly colored shales, among which dark-red layers are conspicuous. Associated with these are similar beds, ranging in color from buff to white, and composed, to some extent at least, of volcanic tuffs. These beds, on weathering, produce rounded hills, in the sides of which the variously colored layers make concentric bands. These beds at least may be provisionally referred to the lower John Day.

Resting on the vari-colored beds just described are evenly stratified, bluish green shales having a dip of about 15° to the northeast, which are well exposed and form the most conspicuous outcrops of the valley. Their thickness was not measured, but is evidently considerable, probably amounting to 3,000 or more feet. Near Price the conspicuous bluffs of these bluish green shales have been penetrated by prospecting tunnels, in which the fresh rock has been revealed.

The best exposures of the bluish green shales, here referred to the middle John Day on account of their similarity to the rocks of that formation as described by Merriam, are seen between Indian Creek and West Camp Creek, where fine examples of badland topography occur. At this locality, rising from a most instructive group of deeply sculptured and artistically beautiful hills and ridges, is a prominent landmark known as Logan Butte, which is capped by a remnant of a resistant layer of rhyolitic tuff. The main portion of the butte and of all of its flanking ridges, as well as of the associated but lesser buttes, has been carved from these light-colored shales. In these beds numerous well-preserved bones of extinct mammals have been found, but only a few imperfect specimens were obtained during my visit. A view of Logan Butte as seen from the south and a nearer view of its capping layer of resistant rhyolitic tuff are presented on Pl. V, *A* and *B*. The most interesting feature of the section exposed is the presence beneath the capping layer of tuff of nearly horizontal beds of dark-brown and reddish shales, volcanic dust, and conglomerate, which rest unconformably on the eroded surface of the conspicuously inclined middle John Day beds. These features are shown in more detail in the following section of the upper portion of the butte:

Geologic section of Logan Butte, Crook County, Oreg.

	Feet.
1. Compact, massive, homogeneous, light-brown tuff, with many angular fragments; no stratification lines; strongly jointed vertically; rests evenly and conformably on the bed below	50
2. Dark-red or brown sandstone passing below into yellowish brown stratified sandstone, in part tuff	35
3. Fine white volcanic dust or tuff	2
4. Brown sandstone, soft but weathering, with steep escarpments	8
5. Conglomerate composed of well-worn pebbles 6 to 8 inches in diameter, and varying in thickness	0 to 8
Unconformity.	
6. Blue-green and buff shales, dipping northeast 15° to 18°, evenly laminated, thickness exposed estimated at	800

Whether the stratified sedimentary beds above the unconformity noted in the section should be classed as upper John Day or as belonging to a higher formation remains to be determined.

Information in this connection has been supplied by Prof. John C. Merriam, of the University of California, who in a letter dated January 15, 1904, writes as follows:

The exposures of John Day beds at Price, Crook County, Oreg., were visited by Mr. V. C. Osmont, of the University of California, in 1900, and from his notes I quote the following:

"At Logan Butte itself, between 800 and 900 feet of the blue beds (middle John Day) are exposed. * * * On the northeast side of the butte they may be traced down the valley without a break for 1½ miles, and then are covered with alluvium for a mile, then as the ground rises, buff beds (upper John Day) for one-half mile occur. Wherever exposed the beds referred to have a dip of about 15° to the northeast."

Judging from Mr. Osmont's description, and from the collections which he made at Logan Butte, I suppose both the upper and middle divisions of the system to be present. I do not remember whether I have mentioned any unconformity as existing between the middle and upper John Day. At one locality on the John Day River there seems to be an erosion interval represented between these two divisions.

The formation which you mention as resting unconformably on the middle John Day at Logan Butte is described as follows in Mr. Osmont's notes:

"The John Day is protected from erosion by a horizontal layer of very much more recent formation, resembling closely the hard, light, reddish columnar tuff which so universally covers the Loup Fork (Marshall formation). This tuff rests unconformably and horizontally on the middle or possibly the top of the blue beds (middle John Day), the tuff beds (upper John Day) and the uppermost part of the blue beds having been cut away at this point. This recent formation is made up of columns 30 to 40 feet through and 50 to 75 feet high. Beneath it are three or four distinct layers of red, blue, and yellow clay with white volcanic ash. The total thickness of this formation averages about 75 feet."

At the time of Mr. Osmont's visit to Logan Butte I had not named and described the Rattlesnake formation, which you will find mentioned in my paper.[a] After his return, Mr. Osmont informed me that the formation at Logan Butte was almost exactly similar to the Rattlesnake formation of the John Day Valley.

Volcanic rocks.—The conspicuous capstone of Logan Butte is a remnant of a widely extended sheet, other and far larger portions of which form the surfaces of table-lands a few miles distant to the south and east. This sheet, as noted on the previous page, is well exposed in the rim rocks of Camp Creek and Crooked River canyons, and the soft beds beneath it are probably portions of the widely extended John Day formation.

At several localities on the borders of these canyons the layer of tuff presents two well-marked divisions, but there is no distinct plane of separation between them. The upper portion of the bed, which

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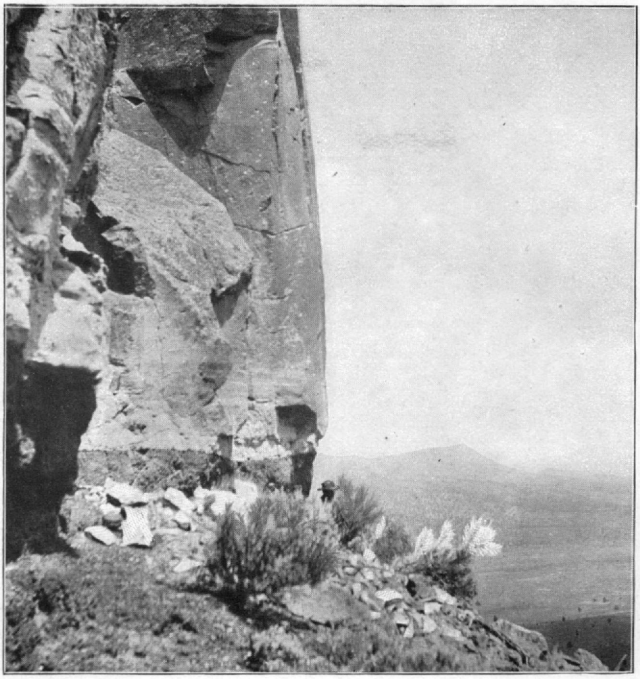
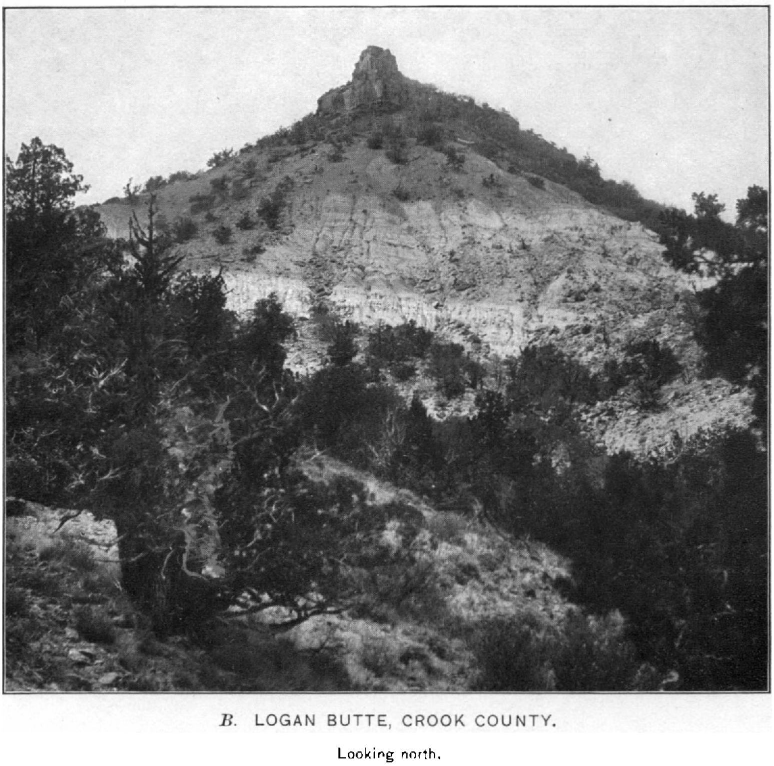
[a] Univ. California, Bull. Geol. Dept., vol. 2, pp. 299-314.



A. JOINTED RHYOLITIC TUFF AT SUMMIT OF LOGAN BUTTE, CROOK COUNTY.



B. LOGAN BUTTE, CROOK COUNTY.

Looking north.

frequently has a thickness of 40 feet, is massive and of a brown color, and at its base passes abruptly into a still more massive layer, which at times has the appearance of shale and is nearly black in color owing to the presence of numerous thin angular fragments of rhyolite with "perlitic" structure. The thickness of the lower division, where best seen, is exposed for 30 feet without revealing its base. The entire bed is frequently strongly jointed, the columns produced being at times as prominent as in the case of well-jointed basalt, the joints passing from one division of the bed to the other without change, thus showing both portions to be products of the same period of deposition. The differences in the two divisions of the layer are no doubt due to changes in the nature of the volcanic fragments which were showered on the land, and form the entire deposit. The absence of stratification in this and other similar sheets of volcanic débris, and also the fact that in some instances the thin, plate-like fragments entering into their composition stand on edge, are evidences that the tuff fell on land and is not a water-laid deposit. The difference just noted between the upper and lower portions of the tuff sheet in question is thought to furnish a means for identifying it at widely separated localities.

Artesian conditions.—In the central portion of Price Valley there are springs with a temperature of 67°. Near them two wells have been drilled, each of which reached water under sufficient pressure to cause free discharge at the surface. The record of one of these wells, furnished in part by Richard Hurley, is as follows:

Completed in 1885; bored with hand auger; diameter, 2 inches; total depth, 229 feet; reached water under pressure at 130 feet, which rose about 20 feet above the surface of the ground; discharge estimated at 12 cubic inches per second; water hard and tasted of sulphur; temperature, 73°; lower 100 feet of well yielded no additional supply of water; material passed through reported to be clay; owing to a disturbance of the discharge pipe on bending it, most of the flow was lost; water used for irrigation and farm purposes. The other well, situated about 380 yards northeast of the one just described, depth not ascertained, also yielded artesian water.

The structure of the sedimentary beds in Price Valley gives no indication of the presence of a synclinal basin—that is, the inclinations of the strata do not correspond with those found in such basins as commonly yield water under pressure. The temperature of the water, 73° F., indicates that it comes from a much greater depth than that of the boring through which it rises, and probably from at least 1,300 feet below the surface. These two facts favor the conclusion that a deep artesian basin, or other conditions favoring the storage of water under pressure, exists beneath the formations outcropping in the valley.

These two successful artesian wells, neither of which has been cased, and one of which gave an artesian head of at least 20 feet above the surface of the ground where it was drilled, are an assurance that other wells put down to a depth of about 150 feet in the portion of the valley where they are located would meet with equally favorable results. At a distance of over a mile from the existing artesian wells drilling will very likely have to be carried deeper than 150 feet, but hope of obtaining a surface flow should not be abandoned so long as soft rocks are met.

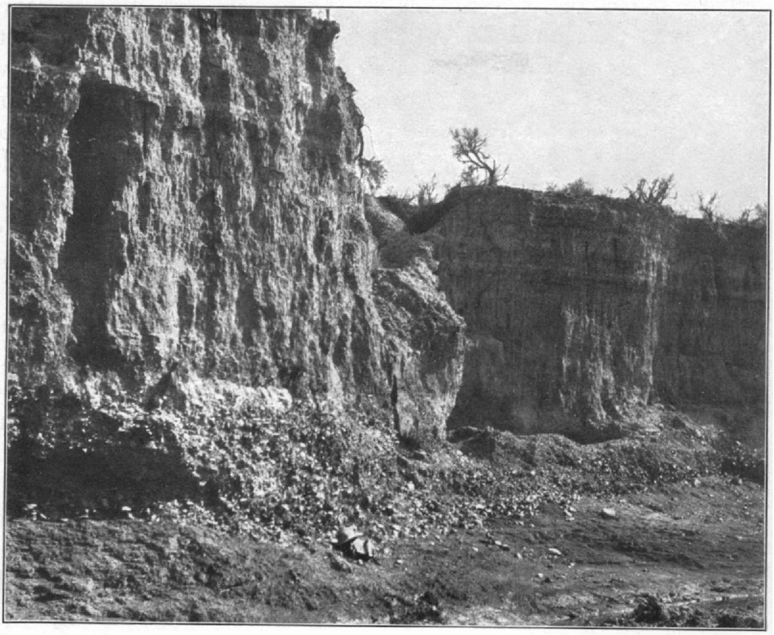
There is a large body of excellent land in Price Valley which can not be irrigated by means of surface streams, but which should be rendered of value by the presence of water under pressure at small depth, provided rigid economy and common sense are exercised in utilizing the supply.

Drilling in Price Valley, as has already been demonstrated, can be done with a hand auger to a depth of at least 200 feet, but each well put down should be properly cased, and if a surface flow is obtained the water should be shut off when not being utilized.

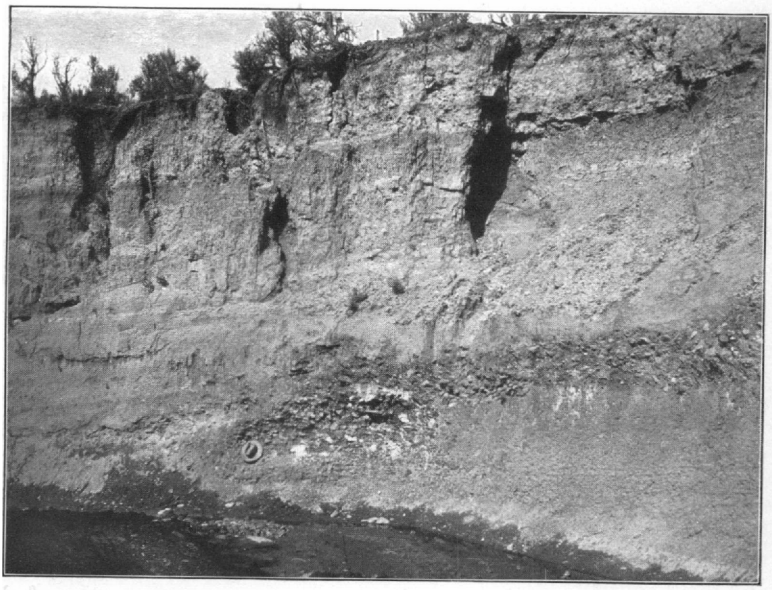
Recent erosion.—The floor of Price Valley, when seen from its north or south border, presents the appearance of a smooth sage-brush-covered plain. In crossing the valley, however, one finds that its surface is intersected by arroyos, or small canyons, through which water flows during the wet season. Joining the main trenches are several branches, each of which has the characteristics of a young stream-cut canyon. The main trench, which follows the longer axis of the valley, ranges from 60 to 100 feet in width, is approximately 25 feet deep, and has vertical walls throughout the greater portion of its course. The walls of the arroyos reveal admirable sections of the unconsolidated silts of recent date which floor the valley and, together with the recent erosion that has taken place, present facts of much interest. The appearance of the main trench about 2 miles east of Logan Butte is shown on Pl. VI, *A*.

The upper 17 to 20 feet of the arroyos' walls are composed of fine, gray, silt-like material which reveals obscure laminæ but no conspicuous stratification. Beneath the silt there is an irregular sheet of gravel from 0 to 6 feet in thickness, which rests on the eroded edges of layers of weathered shale like that exposed in the valley sides, and presumably belongs to the John Day formation.

The interpretation of the condition described is that Price Valley was excavated in the John Day beds, and then filled to a depth of about 20 feet with fine-grained, stream-deposited silt. The silt is a flood-plain deposit, the counterpart of which can be seen in many places along the borders of streams throughout the arid portion of Oregon. These deposits correspond in age and in mode of deposition with the adobe and related deposits of the Great Basin and of other portions of the arid region of the Pacific mountains. After the valley was filled to the depth stated a change occurred in the



A



B

WALLS OF RECENTLY ERODED STREAM CHANNELS IN ALLUVIUM, NEAR PRICE, CROOK COUNTY.

action of the streams. Instead of continuing to deposit silt and raise the floor of the valley, they began to erode, not only cutting through the soft bed of silt and the irregular sheet of stream-deposited gravel on which that material rests, but even in places excavating channels to a depth of 4 to 6 feet in the underlying Tertiary shales.

The change that caused the streams to excavate instead of deposit was certainly very recent, probably dating back only about fifteen or twenty years, although no note of its occurrence seems to have been taken by residents of the region. The renewal of the energy of the streams, however, is a part of a widely extended change, some account of which has already been recorded,[a] and probably coincides with the introduction of domestic animals in such numbers that the surface covering of bunch grass was largely destroyed, and in consequence the run-off from the hills accelerated.

HAMPTON BUTTE.

Rising boldly from the northeast border of the Great Sandy Desert, in the southeastern portion of Crook County, is a much eroded volcanic mountain known as "Hampton Butte." When the geologic story of central Oregon is written, this butte, together with the Glass Buttes of similar history, 15 miles to the southeast, will occupy a leading place, since each of these elevations was built by explosive volcanic eruptions which discharged acid lavas and, as seems probable, furnished much of the material for the formation of the widely extended tuff sheets which form the surface over hundreds of square miles of the adjacent country. In the history of each of these ancient volcanoes there are two prominent chapters, one dealing with their construction or upbuilding and the other with their destruction or erosion.

GEOLOGY.

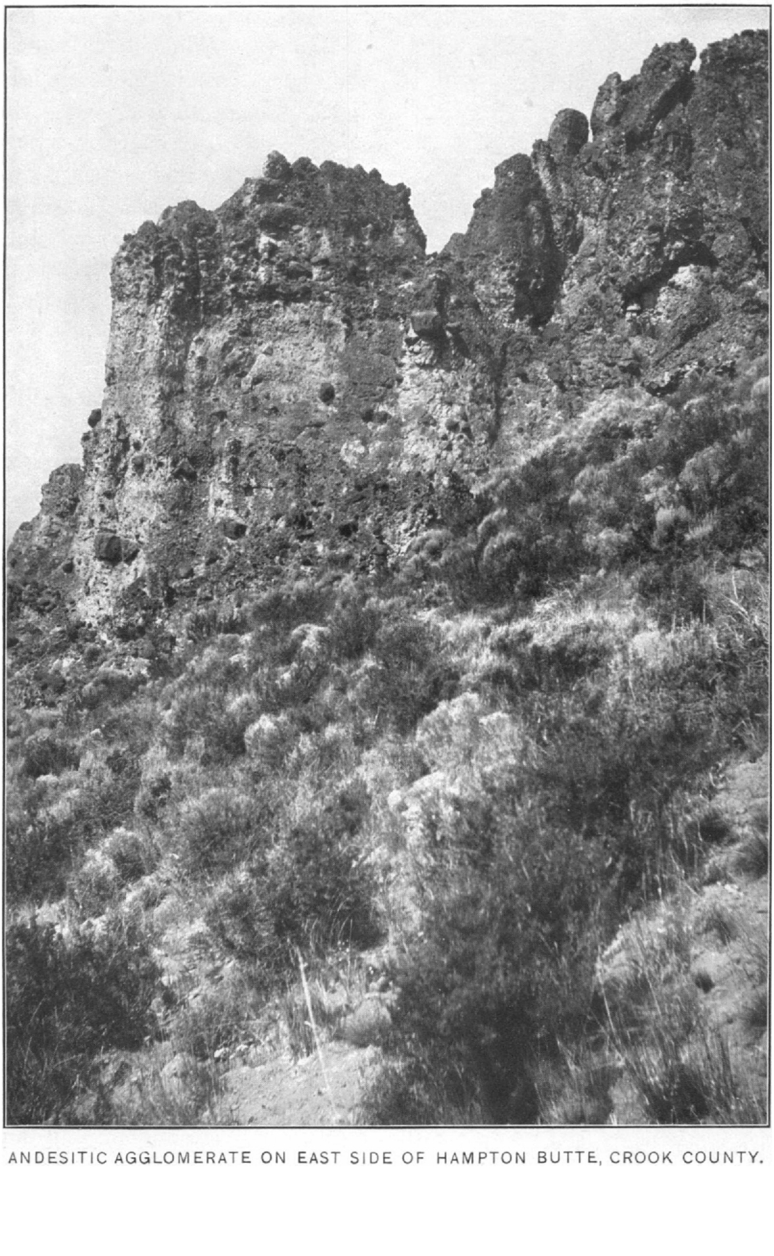
Hampton Butte has an elevation, as determined by aneroid measurements and subject to probably important corrections, of about 2,500 feet above the nearly level surface of the broad desert plain to the south. Its base is irregular in outline, owing principally to the deep dissection of its sides by stream erosion, but in general measures about 6 miles in diameter. The butte has three prominent summits, the one farthest southeast, on the site of the mountain's peak when in its prime, is higher than its companions. It is composed of massive andesitic lava, and is the deeply eroded summit of the column of rock that cooled and hardened in the conduit of the volcano. The peak about 1 mile distant to the west of the central core is also

[a] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 145–146.

of solid lava, but seems to be part of a lava flow; and the prominent ridge about 1 mile north of the summit, like the greater part of the butte, is composed of volcanic agglomerate. On all sides of the butte, forming its widely extended slopes, are beds of stratified agglomerate, which dip away from its central portion in all directions at angles in general of from 3 to 5 degrees. The dip of these beds decreases with distance from the vent from which the material composing them was blown out, and the component fragments show a decrease in size in the same directions. The agglomerate exposed in the border of the butte at a distance of 2 or 3 miles from its summit, consists largely of angular blocks of light-colored lava ranging from 2 to 4 feet in diameter, firmly held in a compact matrix of angular volcanic sand and gravel. It weathers into monumental forms, admirable examples of which occur on the northeast side of the butte overlooking Gilchrist Valley (Pl. VII) and at many other neighboring localities. The thickness of the agglomerate beds on the sides of the butte is not less than 1,200 feet, though a full measure was not obtained.

An exception to the statement that Hampton Butte is composed of andesitic lava and fragmental material of the same nature occurs on its southeast side, and in a neighboring but intimately associated ridge, sometimes termed "Cougar Butte," in which black rock resembling basalt is well exposed. The eruptions which furnished the black rock were evidently later than the period of activity of the andesitic volcano which built the main portion of the mountain, but their full history remains to be studied.

The records now exposed and clearly legible show that Hampton Butte was at one time a conical mountain much higher than at present, and as may be judged from analogy with other similar volcanic piles that are yet in their prime, formerly had a crater with an encircling rim of lapilli at its summit. All vestiges of such a crater have disappeared, however, and the once smooth, sweeping slopes of the conical pile have been deeply trenched by streams which flowed away from its central portion in all directions. Ten or twelve gulches carved by these streams still lead downward to the bordering plains. The butte now presents a rugged surface; nearly everywhere the soil is composed of light-colored volcanic sand, containing many loose blocks, and has been formed principally by the disintegration of the agglomerate beds on which it rests. The rain that falls is at once absorbed and surface rills are uncommon, but cold springs come to the surface in most of the gulches and, as noted below, have an instructive relation to the stratification of the beds from which they issue. The hills and the valleys alike are clothed with luxuriant bunch grass and the north sides of several of the ridges bear beautiful groves of yellow pine, showing a delicate adjustment in the



ANDESITIC AGGLOMERATE ON EAST SIDE OF HAMPTON BUTTE, CROOK COUNTY.

distribution of soil moisture. Less restricted in their distribution than the pine and extending far out on the bordering plains are open growths of juniper trees.

WATER RESOURCES.

Hampton Butte is not not only isolated in reference to its associated mountains, but is also remote from centers of industry and far removed from usual routes of travel. On the north its nearest neighbor of comparable prominence is Mutton Mountain, about 12 miles distant, and on the southeast the Glass Buttes, about 15 miles away, across a nearly level sagebrush plain. In all other directions comparable elevations are remote. There are a number of cabins about the butte, all occupied by energetic and most hospitable ranchers. The watering places have been inclosed by fences, and small areas about the lower slope of the butte are irrigated and produce good hay crops and some wheat. The value of the butte and the region about it, however, lies almost solely in its excellent pastures, its usefulness as a stock range being due largely to the fact that it is an outpost of industry in a generally waterless land. To the south the great desert, which in winter furnishes abundant pasturage, extends without a resident for 40 or more miles, while the butte itself is so thinly settled and the extent of the uninhabited country about it so vast that it is still almost in a state of nature. Its grasses are still luxuriant, and deer and antelope continue to make it their home; mountain sheep were formerly abundant, but have now vanished.

The remoteness of Hampton Butte from all commercial centers, the abundance of grass on its hills and vales, the number of its cool refreshing springs, the beauty of its groves of whispering pines and junipers, and, perhaps more than all, the almost continuous sunshine that bathes its breezy slopes, make it wonderfully attractive to the traveler, from whatever land he may have wandered. As a health resort and place of rest and recreation it has but few rivals.

Springs.—Hampton Butte, as stated above, is located in an arid region and in the midst of broad plains on which there is scarcely any perennial water. The demand for water is very great, not only for irrigation, but for watering stock and for household purposes. To meet this demand the only source of supply now utilized is the scanty outflow from springs.

About the butte, at an elevation of approximately 5,000 feet above the sea, or 1,000 feet below the highest summit, there are several springs, for the most part of small volume. They are located in gulches eroded in the outward-dipping sheets of agglomerate and tuff which surround the central plug of lava, and come to the surface where retentive strata outcrop. The retaining layers, as indicated in at least two instances, are thick beds of coarse but firmly cemented agglomerate. On account of the dip of the beds of agglomerate and the manner in which radiating gulches have been excavated in them, the more resistant beds extend far toward the summit of the butte on the crests of the ridges between the radiating gulches, in the bottom of which their lowest outcrops occur. The springs are all cold, their temperature being from 51° to 53° F., and their source of supply is clearly the rain and snow that falls on the butte above the outcrops of the retentive layers, which cause the water to appear at the surface.

The conditions just described render it evident that something can be done in the way of improving the springs and conserving the water that now percolates away and is lost. The best method of doing this is to excavate tunnels in the rocks, beginning a few feet, or rather as low as practicable, below where a spring now appears and continuing the excavations toward the center of the butte with a gently rising gradient until the retentive bed is passed through and more porous material reached. The tunnel should then be extended in two branches, like the arm of the letter Y, so as to intercept and furnish a free escape for the percolating water. The length of the main tunnel in each instance would have to be governed by local conditions, and chiefly by the thickness and dip of the retentive layer of agglomerate to be penetrated, but in no instance, so far as can now be judged, would an extent of more than 300 or 400 feet be required. Suggestions as to this method of utilizing what may be termed horizontal wells have been presented in a previous report.[a] Several if not all of the springs about Hampton Butte might be improved in the manner just suggested and the available water supply considerably increased. The main or entrance tunnels in each case should be floored with impervious material, as clay or cement, and the water obtained conducted in pipes to the localities where it is to be used. This method of utilizing the water in the case under consideration is especially recommended, since the localities where it can be employed are well separated one from another, and each rancher owning a developed spring would not be in danger of having his water supply drawn upon by his neighbors, and hence would in his own interest be led to the utmost economy in its use.

In place of excavating a tunnel, as suggested above, at each of the localities where a spring appears in a well-defined gulch, a similar end can be reached by drilling a vertical well a few yards or a few rods downstream from the locality where water now comes to the surface. Such drill holes, if carried to a depth of about 250 or 300 feet, should in most instances yield flowing water. It is not possible at present to state just how deep such drill holes should be carried, but the con-

[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 54, U. S. Geol. Survey, 1901, pp. 98–101.

ditions are favorable, and the depth mentioned might reasonably be attempted unless success is secured sooner.

As already explained, the stratified tuffs and agglomerates forming the greater part of Hampton Butte dip away from its central portion and decrease in their degree of inclination with increase in distance. The size of the fragments composing the beds also decreases with the distance from the vent from which they were discharged. These conditions favor the hope that artesian water can be had about the outer border of the butte. On its north side there is a lake basin, or rather water pocket, several hundred acres in area, about which, particularly on the southeast, there are several square miles of nearly level sagebrush land. This locality is sufficiently near Hampton Butte to favor the hope that artesian water can there be had, owing to the outward dip of the beds of tuff, etc., as just explained. There does not seem to be any way to test this possibility except by means of the drill, but the value of a flowing well at the locality referred to would be sufficient to warrant giving weight to the known favorable conditions. After due consideration I venture to suggest that it would be well to put down a drill hole at the locality mentioned to a depth of at least 1,000 feet.

When the several springs about Hampton Butte are developed so as to yield their full quota of water it is to be expected that practically all the irrigable land immediately below them can be converted into hay ranches. The actual areas of such irrigable lands have not been computed, but are well known to the ranchers of the vicinity, and, although small in each instance, are of great value in the aggregate from the use to which the hay can be put in the feeding of stock during unusually severe winter weather. Summer pasture is abundant, but the critical condition that limits the number of head of stock a rancher can safely maintain is the necessity of tiding them over the stormy periods of winter. Hence every effort should be made to increase and conserve the limited water supply.

Water pockets.—The extent of country over which stock can range about Hampton Butte, as is the case throughout the arid region, depends on the presence of watering places. With a wide summer range, the grass near winter supplies of hay can be conserved, and thus greater benefits be derived from it. As summer watering places in the valleys and on the plains about the buttes are far apart, a suggestion offered on page 53 in reference to deepening natural water pockets may here be repeated. At Dry Lake, as it is termed, referred to above, situated about 6 miles north of the butte, a reservoir could be excavated which would contain sufficient water to supply a large number of cattle throughout the summer. The advantage of excavating a reservoir to as great a depth as practicable may be readily judged from the fact that water now stands in the basin each spring to a depth of a few inches over an area of a square mile or more. By restricting this supply to a smaller area the loss from evaporation would be lessened and the duration of the supply increased; besides, an excavated reservoir would serve as a well and lead to the percolation to it of the ground water from adjacent areas.

The plans outlined above for the increase and concentration of the water supply about Hampton Butte call for only small investments, such as the returns to be expected amply justify, and I trust will receive careful consideration from the intelligent and progressive ranchers of the locality.

GREAT SANDY DESERT.

HAMPTON BUTTE TO BUTTON SPRING.

The route followed on leaving Hampton Butte led southwest across the Great Sandy Desert toward Christmas and Silver lakes. The first water met, with the exception of a small ephemeral lake, or "pocket," of alkaline water unfit for human use, occurs at Button Spring, about 35 miles from the west base of Hampton Butte.

For about 4 miles from the springs on the west side of Hampton Butte the country rock is andesite and andesitic tuff similar to the material composing the butte itself, from which it probably came. Judging from the topography, this same rock extends far to the northwest. At a distance of about 6 miles from Hampton Butte, however, in the direction mentioned, is a low conical elevation, which, judging from its color as seen at a distance, is composed of basalt, and about it is an extensive lava flow of the same character. The butte referred to is on the "upper desert;" that is, it lies to the north of the long line of bluffs that form the northern border of the Great Sandy Desert, or the "lower desert," as it is locally termed. This line of bluffs, which sharply defines the north border of the Great Sandy Desert for fully 20 miles northwest from near the south base of Hampton Butte, is composed of sheets of basalt, the eroded edges of which reveal a thickness of between 80 and 100 feet. The beds are gently inclined and dip northward at an angle of about 1°. In places the steep escarpment is concealed by pumiceous sand, which has been drifted over it by the prevailing westerly winds.

On descending this south-facing escarpment of basalt through a notch that seems to have been eroded by a south-flowing stream the nearly level surface of the lower desert is reached; thence southwestward the road follows an almost straight course bearing S. 25° to 30° W. for about 15 miles across a plain of light-colored pumiceous sand, with occasional exposures of basalt. The outcropping layers of basalt dip north at a low angle, probably 1° or 2°, until the axis of the valley is passed, at a distance of 5 or 6 miles from the line of bluffs bordering it on the north. This dip is revealed in the gradient of the road, which, when followed southward, ascends long, gentle slopes, at the top of each of which is a short, steep descent to the base of another gentle rise. The beds of basalt on the south side of the valley for several miles, although seemingly nearly horizontal, have a gentle downward slope to the south. From the facts noted along the section traversed in crossing the Great Sandy Desert, that depression appears to be of the nature of an anticlinal valley; that is, it has been eroded in the summit portion of a gentle upward fold or anticline.

The Great Sandy Desert is without water, except such as gathers in small basins and forms water pockets during the winter. Wells dug, as I have been informed, to a depth of about 70 feet failed to reach water, the material passed through, like that forming the surface, being pumiceous sand. No method of obtaining water on the desert, even for stock ranches, seems to be practicable, except the deepening of the natural water pockets. So far as the geologic structure is known, it gives no suggestion of the presence of artesian conditions.

On the southwest side of the Great Sandy Desert, or in a general way about 25 miles north of Christmas Lake, there are a large number of low and for the most part rounded buttes, each of which marks the site of an old volcano. This region, like the arid plain adjacent to it on the north, is without water, and, as is manifest from the number of volcanic cones present, as well as the apparent absence of the necessary geologic structure, offers no encouragement to the searcher for artesian water.

BUTTON SPRING.

Button Spring is located about 15 miles northwest of Christmas Lake, and with the exception of two or three wells that have been dug near the road between these two localities, is the only available water within a radius of 15 miles, and in most directions of 30 or more miles. To the east of the spring extends a waterless region without trees, except an open growth of junipers, but on the west the country is shaded by a magnificent forest of yellow pine, which continues west over a region rendered rugged by many recent basaltic craters and several mountain-like elevations eroded from more ancient andesitic lavas, to the Cascade Mountains and thence to the shore of the Pacific. The forest terminates abruptly on the east in what may be designated as a dry timber line. The grass on the eastern border extends into the forest, forming beautiful glades, and grows luxuriantly beneath the trees, but the absence of water renders these natural pastures useless. Great as is the demand for water in this inviting region both for stock and, as will no doubt soon be the case, for sawmills, no practicable method of supplying it can at present be suggested, except that small storage reservoirs might be made in some of the valleys.

Button Spring is a weak hillside spring which emerges at the base of a rim rock of basalt on the side of a small valley. The volume of the spring was formerly greater than at present, and, as is reported, served for the irrigation of a few acres of land, but attempts to increase the supply by excavating a vertical well resulted in a loss of the water. The well is said to have been 100 feet deep, but it has now been filled to within a few feet of the surface. The excavation reached a light-colored, highly porous layer, probably of volcanic dust, beneath the surface sheets of basalt, thus permitting of the ready escape of the water. Much water is evidently still being lost in this way, but the value of the spring can no doubt be restored by placing a water-tight floor or shallow cement basin in the bottom of the excavation as it is at present and allowing the water to flow out as formerly. The excavation of a horizontal and not a vertical well would have been the proper method for developing the spring.

LAVA CAVES.

About half a mile east of Button Spring there is a locality where the falling of a portion of the roof of a cavern has formed an opening about 14 feet across, by means of which access can be gained to a subterranean chamber of the ordinary type of lava tunnels, formed by the outflow of molten lava from beneath the thick, rigid crust of a sheet of basalt. The tunnel on which the opening is located trends east and west, but owing to the falling of parts of its roof can be followed for only a few rods. The opening leading down to the cavern suddenly expands about a foot below the outer surface into a vaulted chamber approximately 100 feet in diameter and 45 to 50 feet deep. Snow entering the chamber through the hole in the roof remains until late summer, and, as persons familiar with the region state, sometimes endures, in part changed to ice, from one winter to the next. A little ice was present at the time of my visit, July 29, 1903, and the temperature of the air in an extension of the main chamber and at a depth of 40 to 60 feet below the surface was 49° F. This opening may therefore be termed an ice cave, and, like others in the same general region, may be considered as a natural ice house, in which the presence of ice is due to the preservation of snow and ice formed during winter months.

In the vicinity of the cavern just described there are irregular, steep-sided, canyon-like valleys from 40 to 50 feet deep which owe their origin to the subsidence of the roofs of similar lava tunnels.

BASALTIC CRATERS.

All about Button Spring there are conspicuous buttes, mostly with rounded summits, which by their shapes at once declare their volcanic origin. These hills, of which typical examples are shown on Pl. VIII, are old volcanic cones composed of basaltic lava, for the most part in the form of lapilli and scoriæ, usually of a reddish color, and to a minor extent of well-formed bombs. In a few instances they extruded lava in streams that spread out in sheets on the adjacent plain. In most cases the cones have yielded to the weather to such an extent that the craters which once existed in their summits have disappeared, and their tops have been fashioned into dome-like shapes, in most instances presenting examples of what are termed weather curves. From a hill near Button Spring 28 individual volcanic craters were counted within a radius of about 7 miles, lying mostly to the east of the place of observation. Many other similar volcanoes are also known to exist in the forested region to the west of the same locality and still others to the south. The majority of the old craters are small, ranging in height from 150 to 200 feet, but some of those to the southeast, as noted below, are much higher.

These elevations furnish good illustrations of the weathering of accumulations of porous material, such as scoriæ and lapilli, in their passage from a conical shape with steep sides to rounded hills and gently swelling mounds. An instructive fact in connection with the weathering of cinder and lapilli cones is that they sometimes give origin to crescent-shaped and even nearly straight ridges which are steep on one side and slope gently on the other. In the case of the crescent-shaped ridges the steep slope is on the concave side. Such weathered remnants find an explanation in the form of the original piles, due to the agency which built them and in some instances partly destroyed them. A symmetrical volcanic cone composed of scoriæ and lapilli changes under the destructive action of the atmosphere to a symmetrical mound which expands and flattens as weathering progresses, while a crater, one side of which has been blown away or removed by an outflowing lava stream, weathers to a crescent-shaped hill. If the destructive action of the volcanic agencies has been greater and only a fragment of a comparatively large crater wall is left standing, it sinks as weathering progresses into a ridge, at the same time broadening, owing to the removal of material from the summit and its deposition on the sides and about the base of the pile, finally becoming a ridge in which the original curvature of the longer axis may be entirely lost.

The weathering of the volcanic piles near Button Spring has brought out still another feature which is not uncommon in the topography of ancient craters. In the case of a small cinder cone about 1 mile east of the spring a lava flow originated in a summit crater, descended the northeastern slope of the cone, and reached the plain at its base. The portion of the lava stream which cooled and hardened on the side of the cone forms a sheet 30 to 50 feet thick and 400 or 500 feet wide, inclined at an angle of approximately 20°. After the lava hardened the crater from which it came was deeply eroded and all vestiges of its rim removed, leaving the upper portion of the lava stream in bold relief as the highest part of the unsymmetrical hill of which it forms the steepest side. A photograph of this instructive butte is presented in Pl. VIII, *A*. The margin of the lava sheet facing the site of the crater from which it came is precipitous and its lateral margins are also bold. As weathering continues, it is to be expected that the solid lava will become more and more prominent until at a late stage all vestiges of the cinder and lapilli cone from which it came will have disappeared. It will then be left as an isolated inclined bed, with a gentle slope on one side and a steep talus on the other; that is, it will have the appearance of a local uplift of a portion of a previously horizontal sheet of basalt.

The sequence of topographic changes just outlined may be illustrated by a series of ideal examples, as in the following figure, which shows stages in the change referred to:

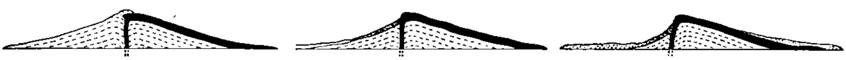
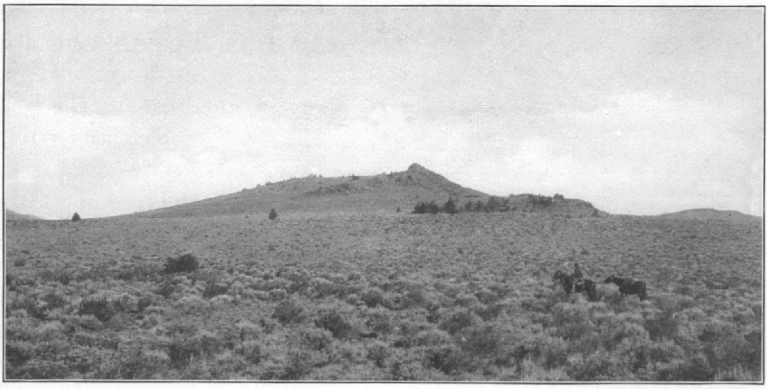


FIG. 1.—Sketch of cinder cone with summit lava flow.

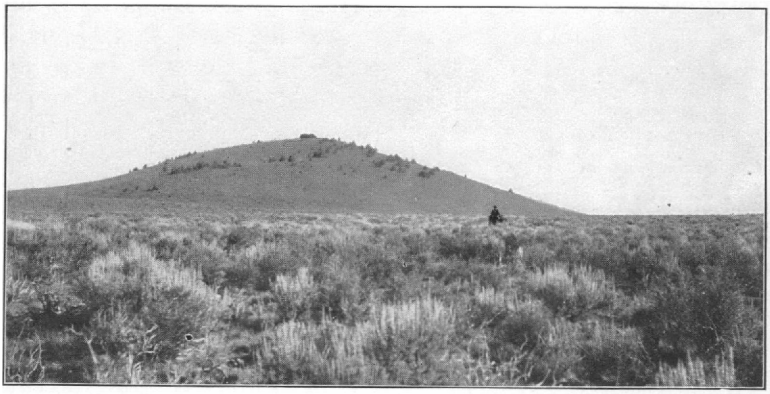
The sketches represent vertical sections through a cinder cone from which a summit discharge of liquid lava occurred at various stages during its erosion. The first sketch to the left represents a section of the young crater, and the succeeding ones the changes passed through up to the time the cinder cone has mostly disappeared, and only the inclined sheet of more resistant lava remains.

Not only are inclined sheets of solid lava left exposed by the erosion of the cinder and lapilli craters from which they were discharged, but, as is suggested by some of the craters near Button Spring, the tuff beds on one portion of a crater may be more resistant than other portions of the same accumulation and be left, as erosion progresses, as isolated inclined beds. As it seems, also, flows of brecciated or angular fragmental material simulating true lava streams in the manner of their extrusion are sometimes discharged from summit craters and descend their outer slopes. Such outpourings also may endure as local exposures of inclined beds when erosion has removed the cones on which they originated.

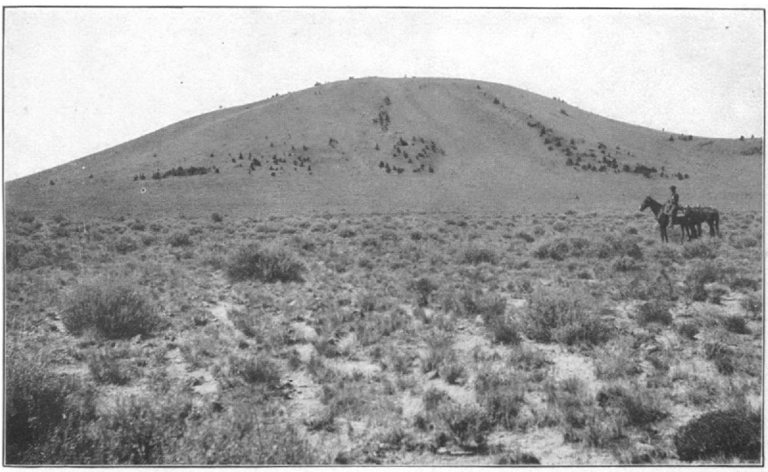
The weathering of a cinder or lapilli cone, from which a stream of lava has been extruded from a summit crater, in the manner de-



A



B



C

BASALTIC CINDER CONES NEAR BUTTON SPRING, LAKE COUNTY.

A, With summit lava flow, *B*, with residual mass of tuff at summit; *C*, weathered cone.

scribed above, furnishes an explanation of the nature of certain curious buttes in Oregon and Idaho, which have been a puzzle to all who have seen them. For example, some 10 miles northeast of Button Spring there is a butte about 250 feet high, which has an inclined table on one side and is locally termed the Soldiers Cap, in reference to its resemblance to the caps worn by Union soldiers during the civil war. Although I have seen this butte only from a distance, it appears to be of the nature of the cone near Button Spring, described above, but in a more advanced stage of erosion. Again, on the north border of Snake River, about 12 miles south of Caldwell, Idaho, there is a conspicuous butte about 125 feet high, which has an inclined table on its eastern side, and is apparently another example of the same nature. A third illustration is furnished by Middle Butte, situated midway between East and Big buttes, on the Snake River Plains, about 28 miles northwest of Blackfoot, Idaho. In this instance a sheet of basalt 100 feet or more thick rises boldly from the plain with a slope of about 10° toward the southeast, and breaks off in a precipitous escarpment on its northwest border. The butte is about 500 feet high, approximately a mile long from northeast to southwest, and about half a mile wide. Surrounding it on all sides is a plain of basalt of more recent date than the rock of which it is composed. This example of what appears to be a local uplift may well be a large example of a lava stream on the side of a cinder cone that has been left isolated by the erosion of its parent crater; in this instance, however, subsequent basaltic flows from neighboring craters have assisted in concealing evidence of the cinder cone from which the inclined sheet of lava was probably erupted. This same hypothesis seemingly furnishes an explanation for the presence of the inclined sheet of basalt referred to in describing Hampton Butte, designated on the General Land Office map of Oregon as Cougar Butte, but locally considered as a part of the large butte to the northwest.

The several examples just referred to were seen by me before I visited the butte near Button Spring, and were passed by without being understood; now they seem to be explainable on the hypothesis here presented.

BLACK MOUNTAIN.

From any commanding point of view near Button Spring the most conspicuous elevation in sight is a prominent black butte with a triple summit, about 8 miles to the southeast. As seen from the direction just mentioned the cathedral-like elevation consists of a central dome about 800 feet high, flanked on each side by smaller domes approximately 200 feet lower. The grouping of the three is strikingly symmetrical, and their slopes descend to the black lava field which surrounds them in long, sweeping curves. The blackness of the group, which has suggested its name, is due to the color of the basaltic lava of which it is composed, but has been enhanced in recent years by the burning of the open forest that clothed its sides and extended over the surrounding lava flow. A younger forest has sprung up, however, and now the lava field and central elevations are overgrown with junipers, mountain mahogany, and a few pines.

On visiting Black Mountain the symmetry of the grouping of its three central domes is found to depend on the point of view from which they are observed. The central elevation is composed of coarse lapilli and scoriæ, among which a few well-shaped volcanic bombs occur, but it is only a remnant of the original crater. The part remaining is the northern portion of the rim of a bowl-shaped depression, about three-fourths of which has been removed, the outline of the missing portion being indicated by low ridges of lapilli. The crater seems to have been breached by an outflow of lava from its southern side, but may have been ruined by an explosion. The west elevation is closely connected with its higher companion, and is a lapilli and scoriæ crater 100 feet deep with a complete rim about 450 feet in diameter. The southeast elevation, which appears as a rounded dome when seen from the north, in close proximity to the central elevation, is in reality about three-fourths of a mile distant and is but the ruin of a crater composed of reddish scoriæ.

All about Black Mountain there is a fresh basaltic lava field, with an irregular margin, in general from 1½ to 2 miles in radius. This lava came to the surface near the base of the central crater, and perhaps represents the results of more than one eruption. Its surface is fresh in appearance and excessively rough. On its margin it terminates in steep, irregular escarpments. The roughness of the surface and the steepness of the bordering slopes show that the rock of which it is composed flowed out either in a highly viscous condition or that its motion was retarded by the fragments of the first-formed crust which became involved in and were carried along by the still viscous material beneath and into which they sank. The surface slope of the lava field is between 2 and 3 degrees near the the craters with which it is associated, but at a distance of less than half a mile flattens out and becomes essentially horizontal. On its northern portion there is a group of small, fresh-looking craters, probably produced by superficial explosions.

From the summit of Black Mountain an instructive view is furnished of a land dotted with craters in various stages of erosion, of which about 25 still retain enough of their characteristic constructional shapes to be recognized as being of volcanic origin. On the east the bare mud plain about Christmas Lake, in places white with salt and other efflorescent products, is in view. The entire landscape eastward of the mountain, and extending for a score of miles on each side of the desolate plain in its midst, is typical of the arid region of which it forms a part. This is the northern extension of the Great Basin and is similar to the vast expanse of arid country embraced in the series of drainless basins in Nevada, Utah, etc., with which it forms a connected series. On the west occur many recent basaltic craters and more ancient hills and ridges that have resulted from the dissection of light-colored andesites and rhyolites; all are covered by the great pine forest to which reference has already been made.

GENERAL GEOLOGY.

In traveling toward Button Spring from Hampton Butte, all the solid rocks exposed, after reaching the line of basaltic cliffs, described on page 68, which defines the northern border of the Great Sandy Desert, are basalt. To the east and south of the spring also nothing but basalt was encountered in the various excursions made from that locality, and the many old craters in sight from Black Mountain and other neighboring eminences, within a radius of about 10 miles, are dark in color and appear to be composed of basaltic rocks. On the west of the spring also several basaltic craters were visited, and others recognized by their color, mode of weathering, etc. All of this goes to show that basaltic eruptions from many craters have there taken place. The number of craters in various stages of erosion and decay within a radius of 10 miles from Button Spring is by estimate not less than 50. Beginning about 2 miles south of the spring and extending far into the forest to the southwest are abundant outcrops of light-colored lavas (andesites and rhyolites) and variegated tuff beds, which contain large masses of black obsidian. These rocks weather into bold cliffs and have been deeply trenched by stream-cut valleys, now without water except in winter or when the snow is melting, and in many instances without rill channels in their deeply filled and nearly flat bottoms.

The region about Button Spring contains the records of at least three groups of events: First, a prevalence of volcanoes, probably in the early Tertiary age, which discharged acid lavas and were characterized by the violence of their explosive eruptions; second, a long period of denudation, during which the previously formed lava flows and tuffs were deeply eroded (this time seems to relate in part at least to the Sierran epoch), and, third, a modern period, during which a large number of volcanic vents were established and basic lavas extruded, both during explosive eruptions and quiet discharges of liquid rock. These recent basaltic volcanoes, although comparatively young and furnishing the last important chapter in the geologic history of the region, are actually centuries old, and in most instances have suffered much defacement from the attacks of the denuding agencies of the air. The later chapters in this interesting geologic history, when fully interpreted, will include an account of a climatic change from humid to the present arid condition.

From Button Spring a road leads north to Prineville, on following which one passes over basalt nearly all of the way. Rocks that are older, however, and that differ in character from the seemingly universal sheets that floor the valleys, form the three prominent groups of hills, namely, Pauline Mountains, Pine Mountain, and Powell Butte, which were visited during the journey. In places, as midway between Button Spring and Pine Mountain, the basalt forming the plains is concealed beneath an extensive series of dunes composed of pumiceous dust and lapalli.

DRY RIVER.

Our first camp after leaving Button Spring was in the bed of an ancient stream known as Dry River, which at one time drained the Great Sandy Desert. The course of the channel is well marked from the west end of the desert to Deschutes River, a distance of over 50 miles. At our camp, about 6 miles east of Pauline Mountains, the old river bed is a well-defined canyon, 30 to 40 feet deep and 150 feet wide, with walls of columnar basalt. About 12 miles farther west the canyon becomes deeper, and for a distance of 4 or 5 miles is a narrow defile with vertical walls of basalt. In the river bed at the time of our visit there was no water, but by digging in the sand that partly fills the channel a sufficient supply for camp purposes for a single day was obtained at a depth of 6 feet.

PAULINE MOUNTAINS.

The name Pauline Mountains is used on the General Land Office map of Oregon to designate a prominent group of hills situated 42 miles directly south of Prineville and approximately in the geographic center of the State. Locally, however, the same name is also applied to other equally conspicuous elevations in the vicinity of Pauline and East lakes. Although these two groups of picturesque hills or mountains are connected by a tract of high land, they are independent, so far as their geologic histories are concerned, and as they will no doubt receive much attention from geologists and others in the future, it is thought advisable to designate them by separate names. For the group of hills termed the Pauline Mountains on the map referred to above that name will be used in this report, and for the exceedingly interesting and conspicuously beautiful mountain in the summit of which Pauline and East lakes are situated a special name will be proposed on a later page (see p. 97).

The Pauline Mountains proper rise boldly from the bordering basaltic plain to a height of about 1,500 feet. The main summit is a sharp ridge trending N. 70° E. (magnetic), which at each end curves abruptly southward, so as to partly inclose an amphitheater nearly 2 miles in diameter. The rock along the crest of the ridge and forming the conspicuous pinnacles rising from it is a hard, purplish material resembling quartzite, but from field observations simply is believed to be mainly a consolidated rhyolithic tuff. The sides of the mountain are thickly covered with quartz sand. The stratification of the rock is well defined and the dip on the crest of the main ridge is downward to the east at an angle of about 16°, the strike being at right angles to the trend of the ridge. In the curved western portion of the ridge, and exposed in the west wall of the great amphitheater, the dip is south at an angle of from 16° to 17°. The mountain is thus shown to be an eroded remnant of what was probably at one time a great volcanic cone older than the surrounding basalt, but no fossils were discovered by means of which its age might be determined. To the northwest of the main ridge and about half a mile distant rises an outstanding butte composed of rock of the same character as the main elevation, left in bold relief by erosion.

The floor of the amphitheater on the south side of the Pauline Mountains is deeply covered, over an area of 3 or 4 square miles, with nearly white pumiceous lapilli, which the wind has drifted into dunes. This barren area is bordered on the south by an open forest of junipers. The mountain itself, more especially its northern slope, bears groves of yellow pine and has a well-defined forest about its western base.

The view from the topmost pinnacle of Pauline Mountains is far-reaching and superb. In the east, beyond the barren yellow plain of the Great Sandy Desert, Hampton and Glass buttes are in plain sight, and the tapering summit of Placidia Butte can be recognized in the blue distance. To the south, in the vicinity of Button Spring, about 50 recent volcanic craters can be counted, and in the western sky rise the snow-clad summits of several of the great peaks that dominate the generally even crest line of the Cascade Mountains.

POWELL BUTTE.

In the extensive region drained by Crooked River to the east of Prineville there are numerous hills, which, in places, are sufficiently bold and lofty to merit the name of mountains. These uplands for a distance of about 30 miles south of Prineville terminate abruptly on the west, where they meet a seemingly level but in reality gently westward-sloping plain of basalt. The junction of the hills with the plain resembles the margin of a rugged land adjacent to the ocean, except that the hill descends to the lava without change of slope such as the ocean's waves produce in the land. This resemblance to ocean-shore topography is due to the fact that extensive inundations of basaltic lava have partly filled a wide valley and encroached on its indented border. The lava flows extended up the gorges and ravines in the border of the old valley, leaving the ridges between them to project as capes into the black plain formed by the congealing of the lava flow.

Offshore, so to speak, in the once molten sea, about 4 miles from the nearest cape on the border of the uplands to the east, rises an island-like butte, completely surrounded by the lava plain. This conspicuous elevation, known as Powell Butte (not Paul Butte, as given on the General Land Office map of Oregon), is about 7 miles long from east to west and approximately 5 miles wide from north to south, but its margin is irregular, owing to the deep sculpturing which preceded the outflow of basalt which surrounded it and entered for short distances the high-grade valleys eroded in its sides. The butte rises, by aneroid measurements, 1,500 feet above the surrounding plain. The material from which it has been sculptured is a hard, resistant rhyolitic tuff, with, perhaps, some quartzite. The rocks are of a brownish and purplish color, weathering on steep cliffs to a rich brown. The bedding is distinct and steeply inclined. Inclinations of from 65° to 70° to the southwest are common, and in places the outcrops are vertical, with a northwest and southeast strike.

The facts just stated show that Powell Butte is a remnant of an ancient upland, which was deeply eroded before the coming to the surface of the extensive basaltic lava flows which now form the floor over an extensive portion of the valley of the Deschutes. In all of these features the butte resembles another rugged island in a congealed sea of lava, situated in the State of Washington and known as Steptoe Butte, some account of which is already on record.[a] This last-named butte is typical of the topographic features and geologic history which it illustrates, and all similar island-like areas surrounded by lava flows may for convenience be termed "steptoes." Powell Butte, therefore, on account of its isolated position and the fact that it rises through the lava of the encircling plain, may be designated a steptoe.

The sides of Powell Butte, particularly the bottoms of the gulches in its sides, are covered with fine rich soil, which owes its origin in large part to the deposition of dust by the wind. In the gulches this material has been washed down by ephemeral streams and spread out in broad alluvial fans with conspicuously inclined surfaces, which descend to the surrounding plain. These alluvial fans in certain

[a] Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, pp. 38–40; Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, pp. 19–pp.

instances are not scored by stream channels, and when cultivated yield good harvests of wheat without the aid of irrigation. At the heads of a few of the gulches small, cool, hillside springs come to the surface and furnish a water supply for household uses and for the watering of stock. The only method of increasing, or rather of conserving, the meager water supply is to excavate horizontal wells where springs appear, in the manner suggested on page 66, but owing to the excessive hardness of the rocks, the practicability of such a method seems doubtful. Water is now obtained at several localities about the butte by means of ordinary dug wells, and nothing need be said concerning the possibilities in that direction, as they are well understood by the few energetic, and for the most part successful, ranchers of the region.

DESCHUTES PLAIN.

Powell Butte forms one of the succession of admirable observing stations previously referred to as extending from east to west across eastern and central Oregon, and when the country is surveyed will furnish a favorable primary triangulation station. From its summit the view westward is particularly instructive. The plain of basalt which surrounds its base can be traced as on a map far to the west, across the seemingly level valley through which Deschutes River flows, to the base of the Cascade Mountains. To the southwest, 15 miles distant, across the level lava plain, rises the conical summit of Pilot Butte, an old volcanic cone, also a steptoe. Still farther south a widely extended group of recent volcanic cones can be recognized. The great plain of basalt also extends far to the northwest, and about 7 miles away meets a bold ragged crag of light-colored rock, which projects into it from the east. Crooked River here touches the high land bordering the basaltic plain, and for a distance of about 2 miles has cut away its base and caused a precipitous escarpment to appear. The area of the plain of basalt in sight, although not accurately known, is by estimate not less than 2,000 square miles. One seems justified in concluding that the basalt covering it is a southward extension of the vast lava flow of Washington and northern Oregon, to which the general name Columbia River lava has been applied. Previous estimates of the area covered by these lavas place it in the neighborhood of 250,000 square miles, but seem too conservative to an observer standing on Powell Butte who has in mind the various records previously made and remembers the notes presented in this report concerning the occurrence of similar rocks, which extend almost continuously from Steins Mountains on the east to the Cascade Mountains on the west. It is to be understood that the name Columbia River lava is a general term by which to designate the great basaltic lava flows of the Northwest, and that, as is well known, the various sheets of once molten rock range in age from the earlier portion of Tertiary all the way up to recent time. A detailed study, as the general reconnaissances already made clearly show, will necessitate the recognition of several independent formations, separated by fresh-water deposits and unconformaties in what is now from necessity designated by a single general term.

The fascinating story of deep erosion, of subsequent lava flows of vast extent, and of renewed outpourings of molten rock, followed by another long period during which streams renewed their work of denudation and canyon cutting, to be read in the landscape spread at the feet of an observer standing on Powell Butte, is not the sole attraction of that commanding station. Beyond the broad valley of the Deschutes rise the wonderfully grand Cascade Mountains, in part at least composed of rocks of the same nature as the Columbia River lava, and in a general summary of the history of the region to be classed with it. How far west of the Cascades the outpourings of basaltic rock of Tertiary and later dates extend remains to be discovered. The lava fields and volcanic mountains of the Northwest are probably the most extensive on the earth and demand attention as furnishing one of the most instructive chapters in the geologic history of our planet. One of the startling facts that come to mind in gazing over the seemingly boundless plains and numbering by the score the volcanic mountains in sight is that not less than 150,000 cubic miles of dense rock have there been transferred from deep within the earth and spread out on its surface. The bearing of such an event on the physics of the earth's crust, the condition of its interior, the nature of the forces which cause magmas to rise in volcanic conduits, etc., are some of the now obscure questions which a complete understanding of the lava fields of the Northwest would assist in answering.

As stated above, the region in the west-central part of Crook County, through which Deschutes River flows, is a great lava-covered plain. On traversing the plain in various directions and following the canyons that have been excavated in it, much of interest concerning its history was discovered, an outline of which will assist in explaining certain more special observations to be recorded later.

The valley of the Deschutes, before it was filled so as to produce the broad, generally level surface which is at present its most conspicuous feature, was from 20 to 30 miles wide in the portion west of the Pauline Mountains and Powell Butte, but perhaps had a less width farther north. This large valley, as may be judged from the character of the portions of its bordering slopes now exposed to view, was produced largely by erosion and was at least 800 feet deeper in its central part than the widely extended sheet of basalt forming the surface of the present plain. The material which partly fills the old valley consists largely of water-laid volcanic dust and lapilli, of which sections 700 feet deep are exposed along the lower portion of the canyon of Crooked River and in the adjacent portion of that of Deschutes River. The total depth of this deposit, however, is as yet unknown, as its bottom is not exposed. After the volcanic dust and lapilli, together with minor quantities of sand and clay, was deposited a sheet of basaltic lava, in general about 80 feet thick, was spread out. Possibly two or more sheets of lava were formed at about the same time which are so similar that their recognition is difficult, and they appear to represent but a single outpouring.

After a lava covering was given to the deep deposit of current-bedded volcanic dust, lapilli, sand, etc., Deschutes River and its tributary, Crooked River, displaced from their former courses, flowed across the plain and excavated canyons, which for many miles near their junction were at least 800 feet deep and in general about a mile wide. The nameless stream which flowed northwest from the Great Sandy Desert (see p. 76) also cut deeply into the lava plain and its underlying deposits of loose material, and joined the Deschutes about 14 miles south of the locality where Crooked River now comes in. Following the period of erosion, during which not only the main streams of the region, but also their tributaries, cut deep canyons, came another considerable discharge of basaltic lava, which entered the canyons in the region where Deschutes and Crooked rivers now mingle their waters and filled them to a depth of at least 500 feet. Later still, Deschutes and Crooked rivers reexcavated their canyons in the hard resistant basalt to a depth of over 500 feet without, so far as known, reaching its bottom. There are thus at least five important episodes in the history of the Deschutes plain that are clearly legible in its present topography.

It would greatly facilitate a description of the several events in the history of the Deschutes plain if names could be applied to the beds of tuff and sand and the two lava flows mentioned above, but as such a course would perhaps lead to confusion when the rocks referred to are correlated with those of adjacent areas, and particularly with the formations of the John Day basin, described by John C. Merriam[a] and others, no attempt to give them names or to assign them a definite position in geologic history will at present be attempted. Apparently, however, the thick deposit of lapilli, etc., beneath the older sheet of basalt is of Tertiary age, and the two periods of canyon cutting belong to the time of general erosion recorded by deep excava-

[a] Merriam, J. C., Contribution to the geology of the John Day basin: Bull. Univ. California, Dept. Geology, vol. 2, 1901, pp. 269-314.

tions in many parts of North America, and named by Joseph LeConte "the Sierran epoch."

PRINEVILLE VALLEY.

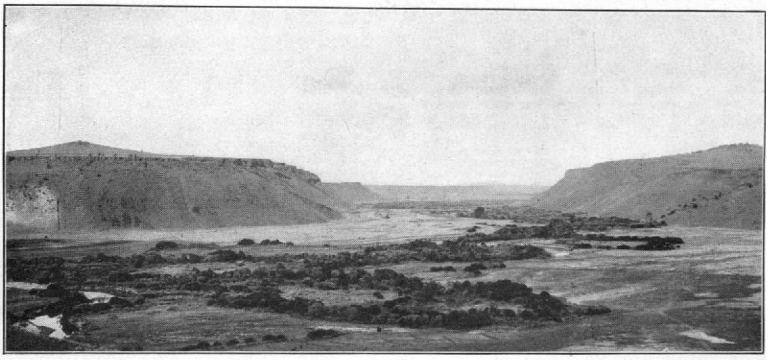
GEOGRAPHY AND GEOLOGY.

Prineville, the county seat of Crook County, a town of about 900 inhabitants, is situated on the border of Crooked River, at the head of an alluvial plain about 6 miles long and from 3 to 4 miles wide. This valley, although small, is of importance on account of the aridity of, and general absence of irrigable land in, the region in which it is located, and is an exceptional feature in the geography of Crooked River, which in all other portions of its course flows through a succession of narrow canyons.

East of Prineville Crooked River flows west through a rugged valley in which outcrops of soft material carrying fossils are reported to occur. About 6 miles before reaching the town it traverses a narrow canyon with vertical walls of basalt about 650 feet high. The basalt is in well-defined layers, with scoriaceous surfaces, of which at least 7 are exposed. The stream has not as yet cut through the pile of basaltic sheets, although a few miles farther up its course the underlying rocks are exposed. This basalt, so far as can be judged from the facts in hand, is to be correlated with the older and more widely extended lava of the Deschutes plain, though present in several sheets instead of a single one. Only one of the sheets, near the top of the section, however, seems to extend west of Prineville.

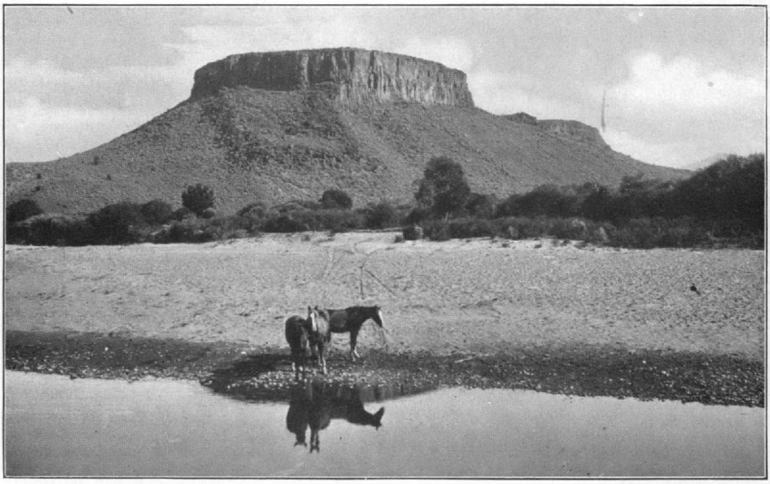
Less than a mile above Prineville the canyon of Crooked River becomes abruptly wider, and for 6 miles west of that town has a width of 4 or 5 miles, this abrupt increase being due to the presence of soft material beneath the basalt. The canyon is here bounded on the northeast by rocks (probably rhyolitic tuffs) which formed the border of the old Deschutes Valley. Crooked River flowed across the basalt, cutting a canyon near its margin, and, on gaining the soft beds beneath the resistant surface layer, widened its canyon, locally, into a valley. On the west and south side of the river where it turns from a northerly to a westerly course, near Prineville, the surface sheet of basalt is but 30 or 35 feet thick. The base of the sheet is scoriaceous, and embedded in it are fragments of the soft shaly beds on which it rests. The fine sediments immediately beneath the basalt grade downward into soft, coarse sandstone 20 to 30 feet thick, below which are coarse, well-worn gravels and other sedimentary beds reaching, in the face of the cliff, nearly to the river. The canyon wall with its rim rock of basalt is about 250 feet high by aneroid measure.

West of Prineville the wall on the south side of the valley of Crooked River presents a continuation of the condition just de-



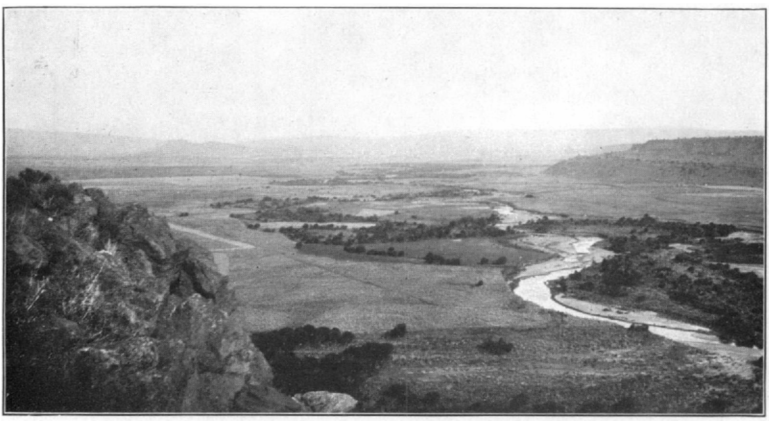
A. CANYON OF CROOKED RIVER, 6 MILES BELOW PRINEVILLE, CROOK COUNTY.

From butte shown in *B*; looking west.



B. REMNANT OF BASALT SHEET, 6 MILES WEST OF PRINEVILLE, CROOK COUNTY.

Looking north.



C. PRINEVILLE VALLEY, CROOK COUNTY.

From butte shown in *B*; looking east.

scribed—a rim rock of basalt rising above a talus-covered escarpment that conceals thick water-laid beds. At several localities landslides have occurred and produced interesting variations in the otherwise monotonous line of cliffs with steeply sloping talus spurs at their base. About 6 miles west of Prineville the valley contracts in width and once more becomes a narrow canyon with nearly vertical walls, in which the edges of 6 sheets of horizontally bedded basalt are well exposed. The presence of several sheets of basalt at this locality and in a similar section exposed in the walls of Crooked River Canyon above Prineville, while between the two localities but one sheet is present, is readily explained by the fact that the surface on which the lava while yet molten was spread out was trenched by canyons or valleys. The earlier lava flows entered the depression, which, as successive eruptions took place, became completely filled, while the later sheets were spread widely over the former depressions and the intervening uplands or plateaus. Crooked River has since excavated a new canyon, which in places cuts across the lava sheets occupying its previous valley. Where the channel was cut through a pile of lava sheets its course is through a narrow canyon, and where only one, or but a few, thin lava sheets were present, resting on a thick formation of volcanic lapilli, etc., a wide excavation like the one in which Prineville is located was produced.

In Prineville Valley some interesting modern changes in the work of the river are recorded by gravel terraces, one of which has a surface elevation of 60 feet above the present stream channel. All along the course of the river for several miles below the town the stream meanders in sweeping curves through the alluvial bottom lands and affords fine illustrations of the behavior of an aggrading stream.

The isolated table with a cap of columnar basalt, shown on Pl. IX, *B*, stands on the north side of Crooked River about 6 miles west of Prineville, near where the valley changes to a canyon. This remnant, spared by erosion, is by aneroid measure about 250 feet high and is instructive not only on account of its striking topographic form, but because at the base of the basalt there is evidence that the lava of which it is composed, while yet molten, entered water or at least flowed over a wet surface. The base of the sheet for a thickness of from 3 to 7 feet is open textured, or "shredded," and rough, and has masses of the underlying shale involved in it for a distance of from a few inches to fully 3 feet above the general plane of contact.[a]

WATER RESOURCES.

Surface waters.—From the summit of the erosion remnant just referred to a fine view is obtainable of the broad, fruitful valley to

[a] For characteristics of lavas that flowed into water, see Russell, I. C., Geology and water resources of the Snake River plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 113–117.

the east, in which the spires of Prineville, when illuminated by an evening sun, gleam brightly in the middle distance. Bordering the yellow-fringed stream on either side are level fields seemingly well located for irrigation, which in the aggregate have an area of perhaps 8 to 10 square miles. This alluvial plain is far too large to be watered by the summer flow of the stream which meanders through it, even when aided by the few small brooks which have their source in springs in the deeper gulches and enter the valley from the hill on its northern border.

As Prineville will no doubt continue to be a thriving town, and as the adjacent valley contains one of the finest areas of agricultural land in central Oregon, every effort should be made to bring it under cultivation. The first step in this direction is obviously to store the winter run-off of Crooked River and of each of its tributaries that enters the valley. The conditions seem to favor such a plan, but only detailed surveys can be relied upon to show what can be accomplished. One of the difficulties to be met with is the great annual fluctuation in the volume of Crooked River. At times when the snow melts on the mountains to the east, the river rises fully 25 feet above its summer stages, and destructive floods occur. Prineville is within reach of such floods and in danger of a great disaster. In the future growth of the town this should be borne in mind, and safer ground chosen on which to build. Another matter which demands attention is the pollution of the river. Refuse of all sorts is now dumped into the stream or left on its immediate banks, and its water, especially during the low summer stages, is seriously contaminated.

Wells.—Prineville is supplied with water by the Prineville Light and Water Company from a group of 23 "driven" wells, which were put down in 1899 in the eastern portion of the town within a radius of about 100 feet. The deepest well goes down 280 feet; the pipes used are 3 inches in diameter; the water, which is slightly alkaline, is raised by a steam pump, discharging about 300 gallons per minute. The water is stored in a reservoir and distributed through pipes in the usual manner. The material passed through in driving the wells is reported to be as follows:

Section of well at Prineville, Crook County, Oreg.

	Feet.
Soil	5
Gravel, coarse	20
White clay	1
Quicksand, fine	2
Gravel	3 to 4
White clay	2
Quicksand (volcanic dust?)	210

Water was reached at a depth of about 32 feet, but the supply continued to increase until a depth of 60 feet was reached. The main supply comes from the so-called quicksand, probably volcanic dust, found beneath the layer of white clay 32 to 34 feet below the surface. The fine sand, or volcanic dust, is excluded from the pipe by means of wire gauze. The water at first rose 3 to 4 feet above the surface level of the adjacent creek. Its temperature is 54° F.

The rise of the water in the well just described is evidence of artesian pressure and favors the hope that flowing wells can be obtained in the same or adjacent areas. As the wells terminate in the water-bearing stratum, they do not furnish a complete test of the artesian conditions. The formation penetrated is widely extended, and in the walls of the canyons of Crooked and Deschutes rivers near their junction is over 800 feet thick, but the lower limit is unknown. While the thickness of the porous beds in these canyons does not prove that the portion of the deposit beneath Prineville is equally thick, yet it is at least a suggestion that the present wells might be continued much deeper with the hope of obtaining an additional water supply.

The geologic conditions shown by the wells at Prineville and by the sections exposed in the canyons of Crooked and Deschutes rivers, together with such evidence as is available concerning the topography of the region, all favor the hope that artesian water can be had in Prineville Valley.

The presence of a definite artesian basin is not suggested by the known conditions, however, but rather by the possibility that an "artesian slope,"[a] or wedge-shaped beds of previous material inclosed in impervious material, may be present. While no prediction worthy of consideration can be made that flowing water will be obtained in the valley if wells are drilled, the conditions are such as to warrant making a thorough test in that connection at any point on the alluvial bottom lands from Prineville to Forest.

For the benefit of the people interested in the development of Prineville Valley I venture to suggest the propriety of their combining in an enterprise having for its aim the making of a thorough test of the possible artesian conditions beneath the valley. A number of the owners of land in the valley might well contribute to the cost of putting down a well, the expense to be shared by all if failure resulted, and the owner of the land on which the well is drilled to meet the entire cost if flowing water should be obtained. One flowing well would be evidence that others in various parts of the valley would probably be successful. The water-bearing formation, how-

[a] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902.

ever, is composed of many variable layers, and so far as can now be judged no one of them may be widely extended.

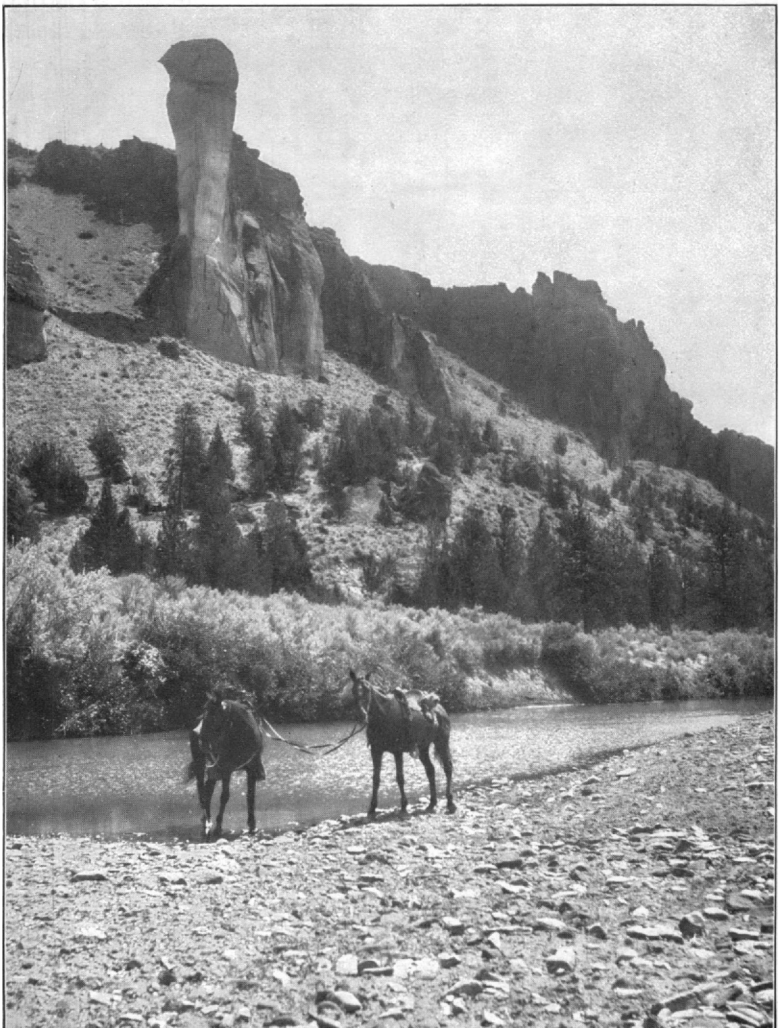
The proposed test well should be put down on the north side of Crooked River, in the vicinity of the medial line of the valley, and continued until hard rock is reached. The well should be drilled under the direction of a competent hydraulic engineer who has had extensive experience in that line of work, and the pressure in each water-bearing layer accurately tested. The nature of the records that it is desirable should be kept while drilling such a well has been indicated in a previous report.[a]

CANYONS OF CROOKED RIVER BELOW PRINEVILLE VALLEY.

About 6 miles west of Prineville, as already stated, the valley excavated by Crooked River contracts in width and becomes a canyon, but for a distance of about 6 miles farther, or to the vicinity of the former post-office known as Forest (where there is now a store and where, as may reasonably be expected, a village will in time be built), there is alluvial land on the borders of the river, now occupied by several valuable ranches. The portion of the canyon above Forest is in reality a continuation of Prineville Valley and shares with it the probability of future agricultural development. Below Forest all the way to the Deschutes, a distance of over 30 miles, Crooked River flows through a narrow canyon with essentially, and often actually, vertical walls, and there is no alluvial land in its bottom. Throughout this portion of the river there is but one place where a team and wagon or even a pack train can be taken across it, namely, at Trail Crossing, about 18 miles below Prineville and 7 miles below Forest. Toward this locality Indian trails formerly converged on each side of the river; later, frontiersmen, with their saddle ponies and pack horses, sought the same breaks in the canyon walls; and within the past few years a road has been graded on the declivities of the opposite-facing precipices and a good bridge thrown across the river. Trail Crossing is thus an instructive locality in reference to the control exerted by geographic conditions on the affairs of men. The canyon, too, is of great geologic interest, and, on account of its wildness and picturesqueness, will no doubt in the future attract to its secluded depths many curious travelers.

The portion of the canyon of Crooked River under consideration may be divided into two portions, which are strikingly different, and for convenience may with propriety be given independent names. From near Forest to Trail Crossing, Crooked River has excavated its canyon along the border of the vast lava fields extending from the brink of its left wall westward, and on the right has eroded the base

[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.



EROSION COLUMN ON NORTH WALL OF MONUMENT CANYON CROOKED RIVER, CROOK COUNTY.

of a rugged mountain composed of light-colored acid tuffs cut by a great basic dike. The tuffs, under the destructive action of wind and rain, have been sculptured into many remarkable monumental forms, one of which is shown on Pl. X. On account of these unique monuments of atmospheric erosion the portion of the canyon to which they add picturesqueness may well be termed "Monument Canyon." Below Trail Crossing the canyon of Crooked River becomes still narrower and assumes the characteristics of what are significantly termed "box canyons." In its bottom, about midway between Trail Crossing and the mouth of the river, a superb flow of clear, cool water, known as Opal Spring, gushes out of the rocks. To the portion of the canyon to which this spring adds an especially attractive feature, giving in summer new life to the exhausted river, the name Opal Canyon may fittingly be applied.

MONUMENT CANYON.

The left, or southern, wall of Monument Canyon, approximately 250 feet high, is surmounted by a rim rock of basalt about 40 feet thick, beneath which are soft, unconsolidated, stratified deposits, consisting mostly of tuff. The contact of the basalt with the formation on which it rests is irregular and even rugged, indicating that the lava, while molten, advanced over a wet surface. Along the plane of contact the tuff beds are changed from their usually gray or yellowish colors to red, on account of the oxidation of the iron they contain. The sheet of basalt exposed in section in the canyon wall extends southward from the brink of the canyon for about a mile, and has an uneven surface in part smoothed over by wind-deposited dust, which forms a rich soil. Its southern margin skirts the base of an irregular escarpment of basalt, about 100 feet high, from the crest of which a plain of basalt extends south and west for many miles. This escarpment is the rim rock of an old canyon cut by Crooked River, which was later invaded by a lava stream, or rather inundation of molten rock, which gave it its present rough surface. Subsequent to this event the river excavated the present and deeper canyon, on the northern slope of which the remarkable erosion columns from which it derives its name are situated.

The north wall of Monument Canyon rises precipitously several hundred feet higher than the nearly level-crested cliff bordering it on the south, and presents striking contrasts to it in nearly every feature. The mountain-like elevation on the north is composed mainly of light-colored, mostly yellowish, tuffs in well-defined beds, which in general dip northeast at angles of 40° to 50°. The beds are of unequal hardness, some being resistant to the destructive action of wind and rain and standing out beyond their neighbors as sharp serrated ridges, along which are numerous pinnacles and spines. Cutting the consolidated and steeply inclined tuff beds is an immense dike of dark basic rock, probably basalt, which has a width of about 1,000 feet and trends northeast and southwest. To the northeast the dike can be traced for a mile or more, and in its present weathered condition forms rounded hills and domes, conspicuous on account of their rich brown colors.

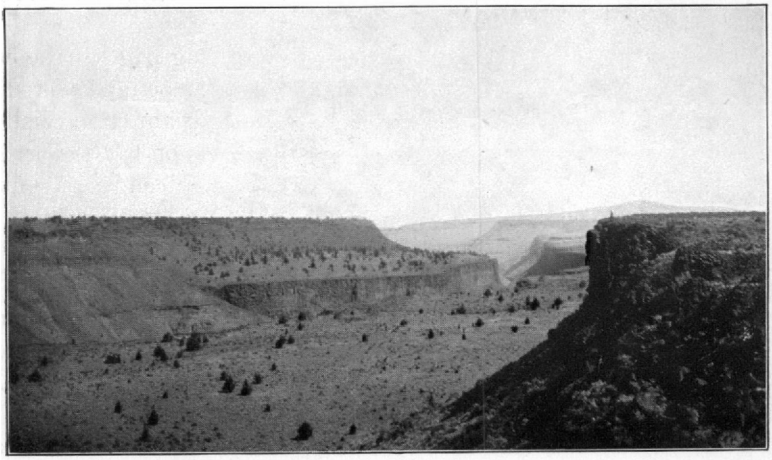
In Monument Canyon a wonderfully interesting page of the earth's history is laid open, but its full meaning can only be interpreted after more careful investigation than my necessarily hurried visit permitted. The lesson it teaches pertains to the region to the north, and particularly to the history of Gray Butte and the country about Culver and Haystack, but must be left for future study.

OPAL CANYON.

Crooked River at Trail Crossing, at the time of my visit early in August, had shrunk to a brook of tepid, muddy, and unwholesome water, across which one could step dry-shod from stone to stone. Its volume, by estimate, was not more than 2 cubic feet per second. The high-water marks along the sides of the canyon, however, were about 25 feet above its nearly dry floor. On descending into the canyon about 12 miles lower down its course I was surprised to find a swift-flowing, clear stream of cool, delicious water, by estimate 100 feet wide and 3 feet deep, with a volume of not less than 300 cubic feet per second. This remarkable renewal or resuscitation of a stream in an arid land is due to the inflow of Opal and other similar springs. The probability that this subterranean water supply comes from far up the course of Deschutes River, where its banks are of open-textured basalt, will be considered later in describing the influence that a recent lava flow from Lava Butte exerts on the volume of the Deschutes (pp. 116–117).

DOUBLE CANYONS.

The most conspicuous fact in the geography of Crooked River Canyon is that in places it consists of two canyons, an outer and an inner one. On crossing the adjacent basaltic plain below Opal Spring and gaining the brink of the outer canyon, one finds that it is margined on each side by a vertical escarpment or rim rock of basalt, in general from 80 to 100 feet thick, beneath which there are soft, incoherent beds, the outcrops of which in the canyon's walls are in most places concealed beneath talus slopes or débris aprons. At a level of 250 feet below the crest of the outer canyon there is a generally flat floor with a surface rough except where wind-deposited dust has accumulated or sand and gravel from its bordering escarpment has been washed out upon it. Cut in this is the inner canyon, which for a distance of from 3 to 4 miles below Opal Spring is 550 feet deep (Pl. XI, *A*, *B*). The outer canyon is here in general form 1 to 1½ miles



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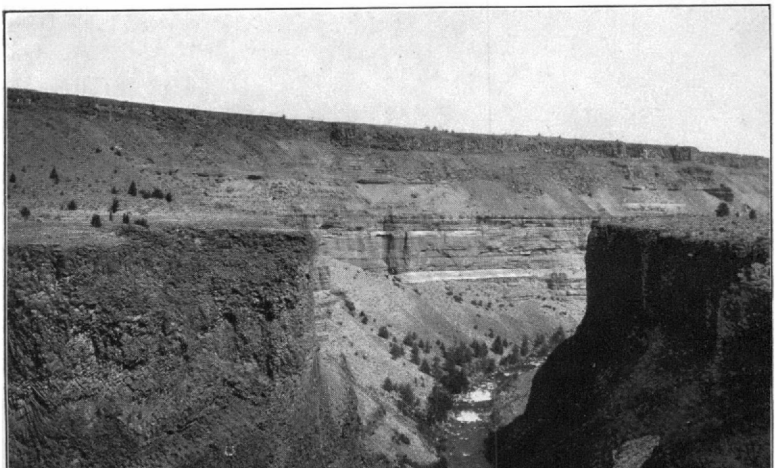


B

VIEWS IN OPAL CANYON, CROOKED RIVER, CROOK COUNTY.

A, Looking north; *B*, showing basalt of inner canyon in contact with stratified beds of outer canyon.

JOINTED BASALT IN WALL OF INNER CANYON, NEAR OPAL SPRING, CROOKED RIVER, CROOK COUNTY.

wide, but has a greater width farther north, where it unites with the similar canyon occupied by Deschutes River. The inner canyon is irregular both in direction and in width. In places it is margined on each side by the floor of the outer canyon and in other places the two canyons have a common wall on one side. The sides of the inner canyon, where it is situated medially in the floor of the outer canyon, are of compact basalt, without well-defined or continuous bedding, but with irregular columns from base to summit (Pl. XII). Where the walls of the two canyons coincide a thickness of 650 feet of irregularly bedded clay, sand, gravel, and volcanic dust and lapilla is exposed, above which is a rim rock from 80 to 100 feet thick of the basalt which forms the surface of the greater part of the Deschutes plain. Where the inner canyon has a wall of basalt on each side it is seldom more than 500 or 600 feet across, but its width increases to 800 or 1,000 feet where the two canyons have one wall in common.

The conditions just described occur again, with nearly the same details, in the canyon of Deschutes River for a distance of about 8 miles upstream from where Crooked River joins it. How far below or north of the junction of the two rivers the inner canyon extends on the Deschutes is unknown to the writer.

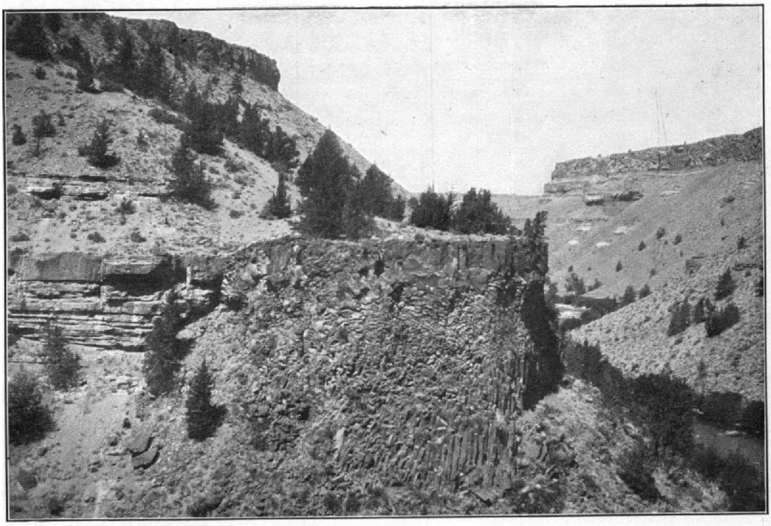
The history recorded in the facts described above is in brief as follows: After the broad ancient valley of the Deschutes had been filled to a depth in excess of 700 feet with loose stream-deposited débris, consisting mostly of black volcanic sand and gravel, and this material covered by the widely extended sheet of basalt now forming the surface of the major portion of the Deschutes plain, the rivers displaced from their former courses flowed across the young lava plain and excavated canyons in it, which, in the case of Deschutes and Crooked rivers, are a mile wide and over 800 feet deep. Next came a flow of molten basaltic rock, which entered the canyons and filled them to a depth of over 550 feet for many miles. Subsequently the same streams, again displaced but still confined to their former but deeply filled canyons, resumed their work of erosion and cut, in solid basalt, the inner canyon described above. In the portion of the canyon examined the task of cutting through this layer is as yet incomplete, and the rivers flow swiftly over solid, compact basalt.

This is one of the most remarkable instances known of a river struggling, as it were, to maintain its right of way against the opposition offered by stupendous showers or downpourings of volcanic dust and lapilli and by vast outflows of lava which hardened into dense, resistant rock. The time occupied in the excavation of the outer canyons was probably not great, as the material in which these were excavated, with the exception of the covering sheet, was loose and incoherent, but the inner canyons, in places, and for distances in several instances of at least 2 or 3 miles, were cut in hard, compact basalt, and their erosion to a depth of 550 feet must have required many thousands of years. It is worthy of note, however, that the conditions along the courses of both Deschutes and Crooked rivers, in the region under consideration, are usually favorable for rapid erosion. The rivers are swift, and the abundance of loose, coarse sand and gravel discharged into them where they wash the borders of the older or outer canyons furnishes as large a supply of abrasive material as the water can transport. In the case of Crooked River these favorable conditions are still more enhanced by the spring freshets that occur, during which the river becomes a raging torrent. These favorable conditions for rapid mechanical erosion are offset, however, by the hardness of the rocks over which the rivers flow, and the task of deepening the channels has progressed but slowly.

Pl. XI, *A*, shows both the outer and inner canyon of Crooked River about 3 miles north of Opal Spring. The view is northward, and the hill on the distant table-land is a low steptoe, about 5 miles northwest of the village of Haystack. To the left in the picture can be seen the junction of the basalt, in which the inner canyon has been excavated, with the stratified volcanic gravel, etc., of the outer canyon. Pl. XI, *B*, shows the wall of the outer canyon as seen from the brink of the inner canyon. Details in the wall of the inner canyon, and especially the irregular jointing of the basalt, are shown on Pl. XII. Contrasted with the vertically jointed basalt of the inner canyon is the horizontal although irregular bedding of the material forming the walls of the outer canyon below their rim rock of basalt, in which white layers of volcanic dust are conspicuous, as may be seen on Pl. XI, *B*. Beds of diatomaceous earth are perhaps also present. Pl. XIII, *A*, shows a remnant of the wall of the inner canyon of the Deschutes abutting against the escarpment of the outer canyon about 8 miles upstream from the mouth of Crooked River. Pl. XIII, *B*, illustrates the topography of the canyon of Deschutes River upstream from where it was invaded by a flow of basalt.

DESCHUTES SAND.

The material forming the walls of the outer canyon of Deschutes and Crooked rivers demands careful study with reference not only to its composition and the evidence it contains respecting the conditions under which it was deposited, but in order to learn how far it meets the conditions favoring the retention of water under pressure. This same formation, it will be remembered, extends eastward and underlies Prineville Valley, where artesian water will probably be discovered. It also underlies the sheet of basalt exposed here and there beneath the rich, wind-deposited soils of a large section of the



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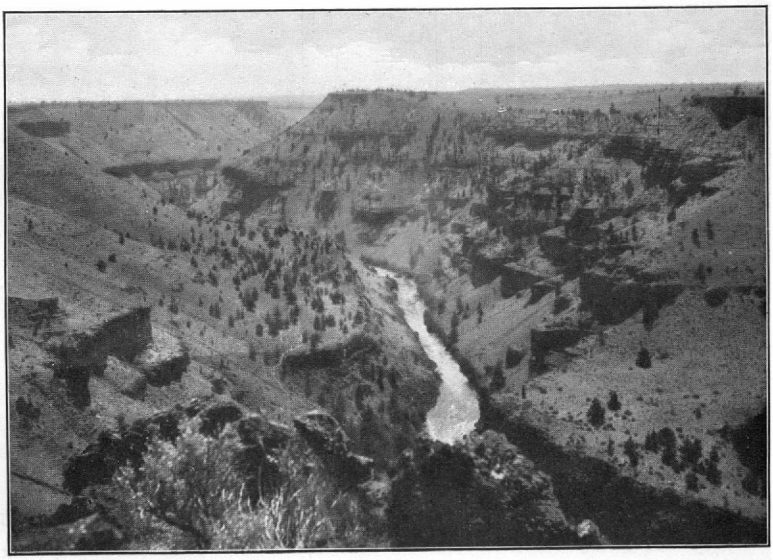


B

VIEWS IN CANYON OF DESCHUTES RIVER, NEAR MOUTH OF CROOKED RIVER.

A, Showing remnant of basalt in canyon excavated in stratified deposits; *B*, looking south.

Haystack country, to the north and east of Opal Canyon. Sufficient attention has not as yet been given to the formation in question to enable a description of it to be put on record, but such notes as are available show that it was waterlaid, probably by widely expanded and fully loaded or overloaded streams, which divided and reunited after the manner of "laced" streams. The nature of streams of this class is indicated by the well-known example of Platte River, Nebraska, which flows over its broad, sandy bed in many locally separate but constantly uniting and again subdividing channels. The material forming the "Deschutes sand," as the formation will perhaps be termed when its history is more fully studied, consists largely of black basic and frequently scoriaceous grains and kernels of volcanic rock, forming a coarse sand, mingled with which are lesser quantities of quartz grains. Although the stratification is distinct and the beds thinly laminated, the individual layers can not usually be traced for more than a few hundred yards. The deposit throughout is frequently cross-bedded; that is, contains evidence of having been deposited by strong currents. Some of the beds are composed of well-worn gravel, the pebbles at times being 6 to 8 inches in diameter. Clay-like beds, which would evidently serve the rôle of retaining layer in an artesian basin, are present, but, so far as seen, are local accumulations rather than widely extended strata. The most conspicuous layers, of which 10 or more can sometimes be counted, are composed of white volcanic dust. A bed of white diatomaceous earth, identical in appearance with the volcanic dust referred to, was found at the lower bridge across the Deschutes, about 20 miles south of the mouth of Crooked River, and other similar beds may be present in the adjacent region. This diatomaceous earth is composed of the beautiful siliceous cases or frustules of certain minute one-celled algæ, and resembles the finer grades of white volcanic dust so closely that a microscope is required to reveal the difference to the eye.

The formation referred to above as the Deschute sands is exposed in the canyon wall of the river after which it is named for at least 25 miles upstream from the mouth of Crooked River, and is probably present for a long distance below that locality. It is also exposed, as has been stated, at many localities in the canyon walls of Crooked River from Prineville west to the Deschutes, and, no doubt, underlies several hundred square miles of the Deschutes plain.

THE HAYSTACK COUNTRY.

SOIL AND SETTLEMENT.

In the north-central portion of Crook County, north and east of Opal Canyon, and east of the Deschutes below the mouth of Crooked River, there is an area embracing at least 8 or 10 townships, most of which is an undulating plain covered with a fine rich soil. In a state of nature this great tract of open country was a prairie of bunch grass roamed over by antelope and deer, and owing to the scarcity of water, which prohibits summer pasturing, much of the land is still well clothed with native grasses. The soil is fine in texture, and evidently owes its origin principally to the deposition of wind-borne dust. In the nature of its soil, the luxuriance of the native grasses, and also in the fact that "dry farming" is successfully carried on, this region resembles the Palouse country of eastern Washington, famous for its highly productive wheat fields. In each of these extensive regions favorable yields of grain can be grown without irrigation, although the mean annual precipitation is too small to permit successful agriculture unless some exceptionally favorable soil condition is present. The determinative condition is the retentive character of the fine, flour-like soil, which permits it to absorb and retain tenaciously all of the water that falls upon it.

The region about Culver, Haystack, Haycreek, etc., or the "Haystack country," as it is familiarly termed on account of the abundant crops of hay obtained in certain favored tracts where water is available for irrigation, is becoming occupied by farms with wonderful rapidity. During the past three or four years the rush of ranchers to this new farming land—new in the sense that the discovery that cereals and even maize can be raised on it is but recent—can be compared to the rush of fortune seekers to a new gold field. The broad, grassy plain, which a few years ago was tenantless, is now dotted with settlers' cabins, the freshly sawed boards of which still gleam yellow in the intense sunlight. This region of dry farming may also be said to be a country of dry housekeeping, since no water is available for domestic use within a distance of several miles of the majority of the recently built houses. In the case of about 300 homes, situated to the west of Culver and south of Haystack, water for domestic use is transported in wagon tanks for distances ranging from 5 to 10 miles. The one most essential thing on which the future prosperity of this otherwise favored region is dependent is the procuring of a water supply adequate at least for household uses and for the maintenance of stock in sufficient numbers to carry on grain and hay ranches.

WATER SUPPLY.

This interesting and economically highly promising region was barely entered during the reconnaissance and no more can be said in reference to its water resources than that it has possibilities that demand careful consideration from hydraulic engineers. As to the question of obtaining artesian water, but little information is available, but that little is suggestive and warrants further study. On the east the Haystack country is bordered by uplands having a mature topography such as hills long exposed to the denuding agencies of the air and of rain and streams commonly present. These uplands were a part of the eastern border of Deschutes Valley before it became deeply filled with volcanic dust, sand, gravel, etc., and flooded with lava. Its rocks are composed, so far as known, and judging from topographic forms seen at a distance, probably to a great extent of compact tuffs, in beds which dip westward and pass beneath the Deschutes plains. The hills when seen in profile from the south present long slopes on the western sides and steep, rocky escarpments facing east. In a general way this structure is favorable to the hope of obtaining artesian water where the rocks referred to underlie the plain to the west, but the nature of the rocks, whether containing alternating porous and impervious beds, etc., is unknown. To the west of the ancient uplands and terminating against them are the lava flows and underlying gravels, etc., of Deschutes Valley. In the open-textured deposits beneath the surface sheet of basalt, as in Prineville Valley, there is a possibility that water under pressure may exist, but an answer to this question can only be had by drilling test wells.

Although nothing definite can at present be said in reference to the probability of obtaining flowing water in the Haystack country, it seems safe to predict that wells drilled through the basalt which occurs beneath the soil of the plain to the west of Culver and Haystack will at least furnish water which can be raised by means of pumps. The localities most favorable for such tests are on the broad plain at as great a distance as practicable from hills. This restriction is made because in at least one locality about 10 miles west of Haystack the older rocks, probably tuffs, which underlie the more recent gravels, basalt, etc., that now give a level floor to Deschutes Valley rise to the surface and form a low steptoe, or isolated hill, in the lava plain. A well put down here would probably pass through about 100 feet of compact basalt, exceedingly hard to penetrate, and enter the thick deposit of gravel, tuff, volcanic dust, etc., which occurs beneath it. As already stated, however, this sedimentary formation had an uneven surface and was in places deeply trenched previous to being covered with the basalt that now rests upon it, so that an even greater thickness of basalt than that mentioned might be encountered. In this connection it may be suggested that if more than 125 feet of basalt should be discovered in drilling a test well the abandonment of the undertaking and another attempt a mile or so away would be justified.

As stated above, my journey took me to the margin of the Haystack country, and although the desirability of making a study of its geology, at least so far as the facts bearing on the possibility of a subterranean water supply are concerned, was fully recognized, the extent of country to be examined was seen to be so great that the hope of traversing it in the time available had to be abandoned. One conclusion reached during my hasty visit which may be welcome to the residents of the region is that the conditions favoring agriculture are there so great that unusual efforts are justified in attempting to supply the demand for water.

I have been informed by Mr. A. M. Drake, president of the Pilot Butte Development Company, that detailed surveys made under his direction have shown that water taken from Deschutes River at Benham Falls can be conducted across the broad lava plain lying between Powell and Pilot buttes and across Opal Canyon to the rich lands lying west of Culver and Haystack. This is a part of an extensive and apparently well-matured plan for the irrigation of a vast extent of now unproductive land in the west-central part of Crook County, concerning which I am not in a position to do more than make mention at this time.

VOLCANIC CONES.

BUTTES.

Character and age.—On the east side of the Cascade Mountains in Oregon, and in general from 15 to 30 miles from their crest, are a number of isolated conical buttes, which from their shapes and what is known of the general geology of the region, as well as the somewhat detailed information concerning a few of them which is in hand, may be safely classed as volcanic peaks. They evidently present a wide range in age and considerable variations in the nature of the rocks of which they are composed.

The buttes referred to are associated with the Cascade Mountains, and in a comprehensive study of the geology of that range should evidently be considered as adjuncts to it. On the other hand, their isolation in many instances and their evident independence of all neighboring elevations make them features of the broad lowlands of the central part of the State.

In the case of mountains left by the erosion of upraised portions of the earth's crust, and also in examples of deeply dissected volcanic mountains, isolated remnants of the formerly more extensive uplands about their borders are frequently left and are conveniently designated foothills. But in the case of the Cascade Mountains in Oregon a magnificent example of built-up mountains is furnished, in which the constructional agency was volcanic energy, and the flanking elevations or foothills, instead of being remnants left by erosion, are of the same character as the main range. These secondary volcanic piles may be roughly classified as ancient or modern. In general, the older series of volcanic cones and associated lava fields are composed of andesite and related lavas, and the younger series for the most part of basaltic rocks. This generalization, however, is not strictly true, and, perhaps, not well founded, since some of the most recent of the volcanoes in question discharged acid lavas of the nature of andesite.

These volcanoes may safely be concluded to range in geologic age from the earlier portion of the Tertiary period to recent centuries. They number several hundred; and extend geographically across the entire width of Oregon and no doubt far into the region to the north and south of the State. Although several of them were visited, only an indefinite and unsatisfactory beginning of their study could be made.

The most prominent examples of the older of these secondary volcanic piles in the portion of Crook County traversed are Pilot and Black buttes. These were visited and something of their histories ascertained.

Pilot Butte.—To travelers on the broad lava plain west of Powell Butte a conspicuous landmark is furnished by an isolated conical elevation, long known as Pilot Butte, which is situated near the recently established town of Farewell Bend, on the east bank of the Deschutes. This butte has a height of about 500 [a] feet above the adjacent plain, and has steep sides and a moderately sharp summit. It is an ancient volcanic cone composed of basalt, containing conspicuous crystals of hypersthene, which occurs mostly in the form of angular fragments of scoriaceous rock, but with an exposure of reddish scoriaceous lava about its summit. No vestige remains of the crater which probably once existed at the top of the cone, and its sides have lost the graceful concave curves that usually characterize such piles when fresh. Basaltic lava of the same character as that forming the lapilli and scoriæ of the cone is present on the northern side of its base, and may be traced for about half a mile to where it disappears beneath more recent basalt. The old lava exposed is probably a portion of a stream which emerged from the base of the butte, but evidence as to the details in its history is wanting.

Pilot Butte is now entirely surrounded by a nearly level sheet of recent basalt and rises as a steptoe above it. A mile west of the butte the Deschutes has cut a canyon to a depth of perhaps 100 feet in the irregular and fresh-appearing basalt which covers the plain. The butte stands at the margin of the vast pine forest, which extends west beyond the crest of the Cascade Mountains and is itself sparsely tree covered. To the east scattered groves of juniper reach far out

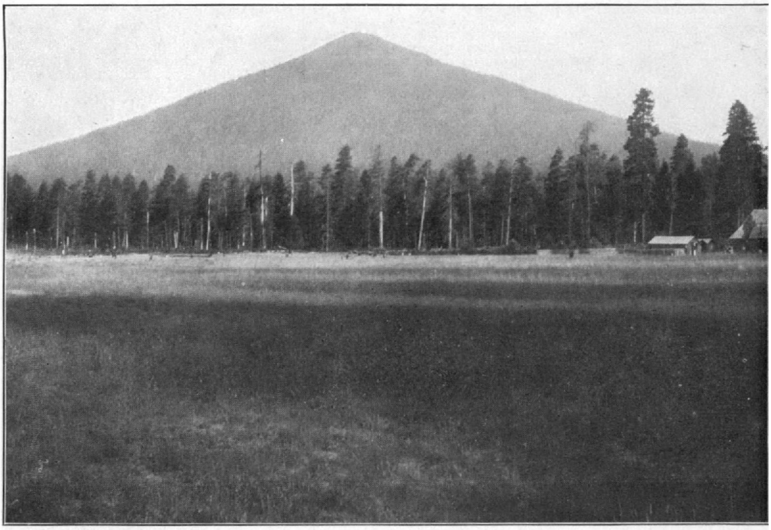
[a] The height of Pilot Butte, as determined by L. D. Wiest, C. E., of the Pilot Butte Development Company, is 4,152 feet above sea level, and the elevation of the Deschutes at Farewell Bend is 3,622 feet, the possible error in each case being ± 40 feet on account of uncertainty of the datum plane.

on the broad lava plain. The view from the summit of the butte is unusually fine, commanding, as it does, the dark Cascade Mountains with their snowy peaks.

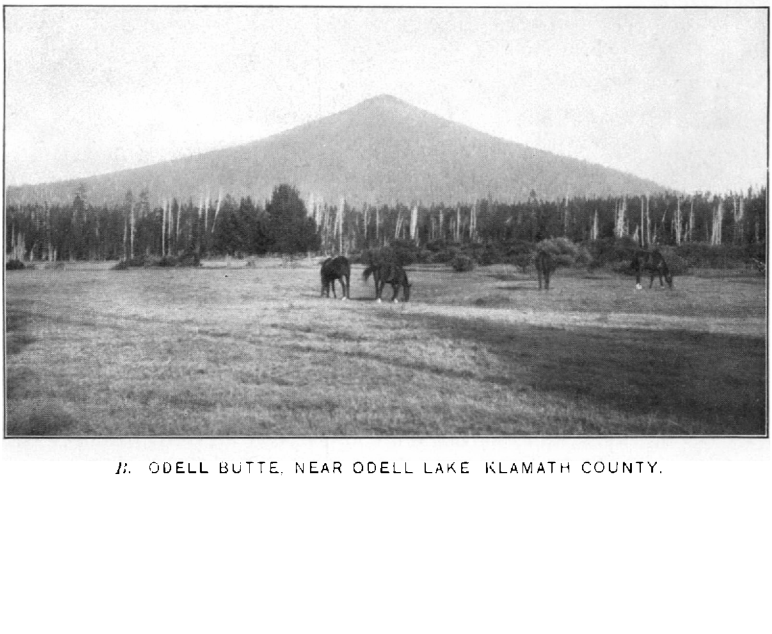
Black Butte.—Rising from the magnificent pine forest which clothes the eastern slope of the Cascades in Crook County and extends far out on the adjacent plain is an isolated peak that is visible for scores of miles throughout the sagebrush country to the east. This peak, known as Black Butte, is situated about 8 miles northwest of the town of Sisters and approximately 15 miles east of the crest line of the Cascade Mountains. The butte is by aneroid measure about 2,500 feet high, is conical, and has a nearly circular base, the symmetry of which, however, has been somewhat marred by erosion. The sides of the butte have lost their original graceful concave curves of construction and are nearly straight when seen in profile, as may be judged from the view shown in Pl. XIV, *A*. The western side has an inclination of 20 to 21 degrees, while the eastern forms an angle with a horizontal plane of about 15 degrees. In each instance the inclination increases somewhat near the summit, the northern slope being the most precipitous and the most modified by erosion. The rock is hypersthene-basalt of about the same character as that composing Pilot Butte, and, so far as surface exposures are concerned, is mostly in the form of angular fragments, imitating a coarse lapilli, but at the top there occur outcrops of massive rock in conspicuous ledges. These summit crags of compact porphyritic rock are evidently the upper portion of a plug or core of lava that cooled slowly and hardened in the conduit of the volcanic pile and was subsequently exposed by erosion. No evidence of a former crater remains. The butte is forest covered, and from its summit a splendid view of the Cascade Mountains and of the arid country to the east as far as the Blue Mountains in northeastern Oregon may be obtained.

From the northeast base of Black Butte a canyon several hundred feet deep leads northeast and is occupied by Metolis Creek, which has its source in a magnificent spring of clear, cold water and forms a rushing brook 40 feet wide with an average depth of 2 feet.

Other buttes.—Besides Pilot and Black buttes there are several similar elevations in the western part of Crook County, which were not visited, but appear to be of the same nature when seen from a distance. Other similar isolated mountains, adjacent to the Cascades and belonging to the same general series of volcanic eruptions that built the mountain range, occur to the south of Crook County; one of these, Odell Peak, is shown on Pl. XIV, *B*. This is also a conical pile of hypersthene-basalt, now considerably eroded, but preserving something of its original constructional form. As in the case of Black Butte, a crater is absent, and at the summit dense lavas have



A. BLACK BUTTE, NEAR SISTERS, CROOK COUNTY.



B. ODELL BUTTE, NEAR ODELL LAKE KLAMATH COUNTY.

been exposed by erosion. The buttes, as may be judged from the amount of erosion they have suffered, are of ancient date and probably belong to the Tertiary division of geologic history.

MOUNT NEWBERRY.

In the south-central part of Crook County, 40 miles in a direct line east of the crest of the Cascade Mountains, there stands a dark-forested mountain of notable height and widely expanded base, in the deeply eroded summit of which Pauline and East lakes are situated. The mountain is surrounded by many lesser elevations, most of which have still recognizable craters, and is connected on its northeast side by intervening highlands with the Pauline Mountains, as designated on the General Land Office map of Oregon. Reference has already been made to the fact that the large mountain in the eroded summit of which Pauline and East lakes are situated is locally considered part of the Pauline Mountains, and the desirability stated of giving it a separate and individual name. For this purpose none seems more appropriate than that of one of the earlier explorers of Oregon, who did much to make the geography, geology, and botany of the State widely known. I refer to Dr. John Strong Newberry, one of the geologists of the "Pacific Railway Survey," and venture to term the mountain in question Mount Newberry in his honor.

The sharp culminating peak of Mount Newberry, according to measurements made by the United States Geological Survey West of the One Hundredth Meridian (the "Wheeler Survey"), has an elevation of 7,387 feet above the sea. The approximate height of the adjacent portion of the valley of the Deschutes is 4,200 feet, making the visual height of the mountain as seen from the west about 3,000 feet. The mountain is prominent from every point of view from which it can be seen, and has a greater height than that of the adjacent portion of the crest line of the Cascade Mountains. The base of the mountain is widely extended, its diameter being in the neighborhood of 20 or 25 miles, but is indefinite on all sides except the west because of the associated but lesser mountains and the numerous volcanic craters of recent date that surround it.

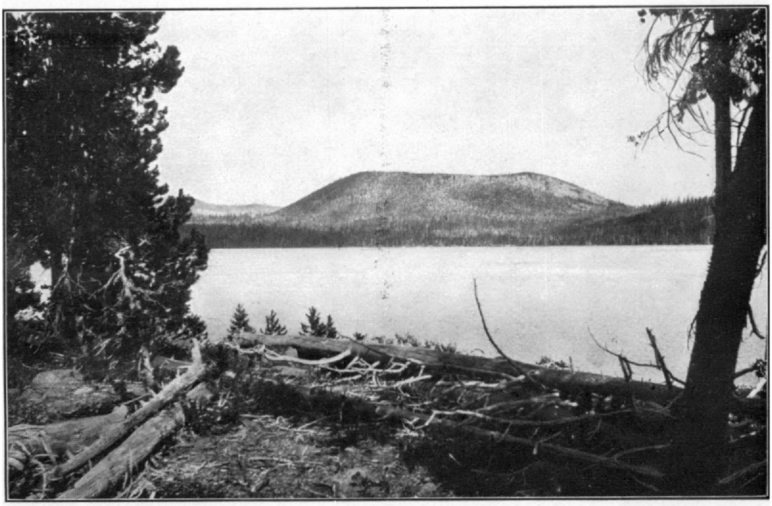
Historical summary.—The salient facts in the history of Mount Newberry may be briefly stated as follows: It is an andesitic volcanic mountain of probably early Tertiary age, the upper part of which has been removed, and a great amphitheater eroded in the summit of the portion remaining. The amphitheater had an opening on its northwest side, and was occupied by a névé during the Glacial epoch, from which a glacier flowed northward for a distance of at least 3 or 4 and probably more miles. During a stage in the shrinking of the glacier it deposited a large terminal moraine across the opening of the amphitheater through which it flowed, thus forming a dam which confined the water as the glacier melted and finally disappeared. A lake thus originated which discharged across the lowest place in its retaining morainal dam, and cut down an outlet, which has since been deepened in the rocks beneath. Subsequent to the melting of the glacier referred to, volcanic energy within the amphitheater was renewed, and five andesitic volcanoes formed along a north and south belt, which crosses the depression slightly to the east of its center. A lava stream discharged from the most northern of the five craters met the cone built by the next in the series and divided the basin into two parts. To the east of the obstruction lies East Lake, which has no surface outlet, and to the west Pauline Lake, which discharges through the outlet mentioned above and supplies Pauline Creek.

More recent than Mount Newberry, and in part at least of later date than the Glacial epoch, are many basaltic craters, mostly of small size, situated on its outer slopes and scattered irregularly over the adjacent country, particularly to the north and the south.

The northern border of the great amphitheater consists of dark lavas and tuffs, which form rounded domes nearly as high as the present summit of the main peak. These rocks are of later date than those exposed in the southern part of the rim of the amphitheater, but are glaciated, thus showing that they are older than the several volcanic craters of the vicinity which still preserve their constructional forms.

Geology.—The rocks composing the older portion of Mount Newberry and situated to the south of an east and west line passing through the center of Pauline Lake are andesite, and, although no critical study of them has yet been made, it may be provisionally stated that they present a wide range in physical characteristics and include obsidian as well as stony and spherulitic representatives. In each variety there is frequently a well-defined flow structure. These lavas occur in distinct beds, which in several instances—as in the cliffs overlooking Pauline Lake on the south—are from 80 to 100 or more feet thick. From these cliffs, in which the broken edges of the strata are exposed in nearly horizontal bands, the dip is outward from the basin occupied by Pauline Lake, at angles of from 10° to about 15°. The cliffs which rise so prominently on the south side of Pauline Lake and from the north wall of the culminating peak extend about the southeast and east side of the basin as shown in Pl. XV, *A*, and, as judged from distant views, are composed of the same kind of rock, at least as far as the southeast border of the basin in which East Lake is situated is concerned.

A



B

VIEWS IN AMPHITHEATER OF MOUNT NEWBERRY FROM WEST SHORE OF PAULINE LAKE.

A, Cliffs on southeast side; *B*, crater No. 2

About the northern portion of the basin the encircling mountains, although precipitous, do not rise in vertical cliffs. The rocks are dark, and in places reveal red and brown colors, in contrast with the gray cliffs inclosing the great depression on the south. Those on the north border of Pauline Lake are dark and massive, having the appearance of basalt, and in part consist of thick beds of agglomerate containing many volcanic bombs. The beds are inclined southward or toward Pauline Lake, and were evidently discharged by a volcano of later date than the one which was eroded to form the cliffs overlooking the lake on the south. It thus appears that the main mass of Mount Newberry is composed of the products of at least two ancient volcanoes.

Amphitheater.—The depression in the summit of Mount Newberry, measured from crest to crest, is by estimate about 5 miles from north to south and 4 miles from east to west. The walls forming its inner slopes are precipitous on all sides except the northwest, and, as stated above, rise in magnificent cliffs about its southern portion. The highest point on the rim of the depression, and the highest pinnacle of the mountain, is shown in Pl. XV, *A*, which is a view from near the outlet of Pauline Lake. The cliffs are, by estimate, 1,500 to 1,800 feet high above the lake and have conspicuous talus slopes about their bases. The rim of the basin is continuous, without a pass or deep notch throughout its entire circumference except where Pauline Creek escapes from it.

As to the origin of the amphitheater, it is to be presumed from the nature of the volcanic mountain, in the summit of which it occurs, that the latter had a crater at its top, when the eruptions which built it ceased. It may reasonably be presumed that this crater was enlarged by erosion and that a stream flowed from it toward the northwest. At a later period the depression was occupied by a névé field which gave origin to glaciers and was enlarged and given the broader features now visible by their erosion. While the amphitheater was being eaten out in the summit of the mountain, its outer slopes, particularly its south side, were becoming scored by radiating canyons. As the amphitheater increased in size, the cliffs bordering it receded, and the canyons on the outer slope lost their upper portions or were "beheaded." The glaciation of these outer canyons and their present characteristics will be noted below in connection with other records left by the former glaciers.

The dimensions and the scenic features of the great amphitheater in the summit of Mount Newberry, in which Pauline and East lakes are situated, are similar to those of the "caldera" in the summit of Mount Mazama, which holds Crater, or Mystic, Lake, already familiar from the writings of J. S. Diller and others.[a] The history of these two great depressions in the summits of mountains of about the same height and approximately of the same age is much the same, and the study of one supplements that of the other.

Lakes.—Pauline Lake, when seen from any of the commanding summits in its vicinity, appears at first to be nearly circular, but a better acquaintance with it shows that its southern portion is indented by a projecting hill of morainal material, to the east and west of which there is something of an embayment. The lake is about 2 miles in diameter from north to south and 1½ miles wide, but these are eye estimates, made in a region where there are no known distances to serve as base lines in assisting one's judgment. The water is clear and of a deep blue, with a narrow purple band, clearly distinguishable in most stages of illumination, about its margin where the depth is small. The shores are everywhere steep, except near the outlet, and in many places precipitous. Where the bordering uplands consist of glacial moraines there is a terrace, the surface of which is about 15 feet above present water level and from a few yards to a few rods wide. On the north shore at the head of a wide-mouthed embayment there is a ridge of gravel the crest of which is about 10 feet above the present fair-weather level of the lake, and there are similar gravel ridges and terraces on the southeast shore. These seem to record the upper limit to which the waves can wash the gravel on shelving shores during the most violent storms. The lake's surface is unbroken by islands, and there is a notable absence of partly submerged rocks or crags about its margin. In several places stones are piled along the shore near the fair-weather level so as to resemble artificial walls. The absence of loose stones and bowlders in the shallow marginal waters and the presence on the border of the encircling land of a ridge composed of blocks of stone much too large for the waves of the lake to move is satisfactorily accounted for by the way in which the ice of small lakes is known to shove stones ashore so as to build ramparts.[b]

No surface streams are tributary to Pauline Lake and there are only a few springs of small volume about its shores. One diminutive spring on the north border of the lake at the water's margin rises through a fissure in black rock resembling basalt, and feels hot to the hand. Its temperature is judged to be between 105° and 110° F. All other springs of the region, so far as known, are cold. With the exception of the insignificant amount of water discharged into the lake from this source, its supply comes from direct precipitation and from percolation through the open-textured or porous material form-

[a] Diller, J. S., and Patton, H. B., Geology and petrography of Crater Lake National Park: Prof. Paper U. S. Geol. Survey, No. 3, 1902.

[b] Russell, Israel C., Lakes of North America, Ginn & Co., 1895, pp. 51–53.

ing its bordering slopes. There is a probability, however, that sub-lacustral springs are present, though no indications of such a source of supply are known.

As to the depth of the lake the only evidence is its uniformly deep-blue color and the generally precipitous character of its immediate banks, both of which indicate that it is deep. A line of soundings extending from near the outlet toward the center of the lake showed that in that portion the bottom is shelving and composed of pumiceous sand, but at a distance of about 600 yards from land a sounding line 125 feet in length failed to reach bottom. As shown by the color of the water when seen from many commanding stations about the lake, its margining belt of shallow water is broadest near the outlet, where the soundings mentioned were made. The character of the stream flowing from the lake is described below.

East Lake, situated in the same great amphitheater that contains Pauline Lake, is about a mile to the east of its companion, from which it is separated by a rugged lava stream composed largely of obsidian, which came into existence as described on page 98.

East Lake, like its companion, is without inflowing streams, but differs from it in not having a visible outlet and in being distinctly alkaline. Like many inclosed lakes, it bears evidence of considerable fluctuations in level, the most conspicuous record of which is a grove of dead spruce trees near its western shore which rise from about 3 feet of water. The trees are about 30 feet high, 10 to 12 inches in diameter, stand erect and still retain their branches. There is no indication that they were carried into the lake by a landslide, but every probability that they grew where they now stand and were killed by a rise of the lake which submerged the surface in which they were rooted. This conclusion needs further study, however, as no other dead trees were seen about the lake, although there were several localities where they should be expected to occur in case a recent rise of the water has taken place. Pauline and East lakes are each inhabited by swarms of insect larvæ, but are without fish. In Pauline Lake, but not observed in East Lake, crayfish are numerous, as they are also in Pauline Creek. It is of interest to note in this connection that the falls in the creek, which present an impassable barrier to the ascent of the fish which are abundant in the lower part of the same stream, are passed by the crayfish by crawling up the nearly vertical rocks adjacent to the border of the stream.

Pauline Creek.—Near where the outlet of Pauline Lake is situated the water is shallow for at least 300 yards from the shore. The adjacent land is low and in part swampy, and the outflowing stream meanders through pumiceous sand for a distance of about 600 yards to where it crosses the solid rock border of the basin. At this, the real outlet of the lake, a narrow channel has been eroded in reddish volcanic agglomerate, and the stream makes a leap of about 10 feet and enters a canyon which becomes rapidly deeper as the stream progresses. The outlet has recently been restricted in width by the building of a log dam with a water gate in its center, which permits a rough measurement of the discharge. The sill of the water gate is a log about 8 inches in diameter, laid at right angles to the current, the drop below the log being about 6 inches. The length of the gate is 11 feet. Through this imperfect weir the water flowed at the time of my visit (August 25, 1903) with a depth of 6 inches, measured by resting the end of a scale on the sill of the opening. Assuming that the conditions mentioned meet the requirements for weir measurements, they indicate a discharge of 781 cubic feet per minute.

For about half a mile below the first fall the creek flows down a canyon, which deepens rapidly and then divides into two channels, separated by a small island, and plunges over a precipice about 80 feet high (Pl. XVI, A), below which the canyon continues westward to the foot of the mountain. In the canyon, below the main fall, there are many rapids and small leaps of 10 to 15 feet. The layer of resistant rock which produces the main fall is composed of a reddish volcanic agglomerate about 40 feet thick, which appears to be nearly horizontal, but really has a slight dip to the east, or upstream. Below the resistant bed softer material of the same nature, also an agglomerate, occurs. The rocks about thef alls and the large angular fragments that obstruct the flow of the water in the canyon into which it plunges are rendered white by a thin nodular incrustation of calcium carbonate, precipitated from the spray of the cataract dashed and blown against them. The sides of the canyon are tree clothed and still retain their primitive wildness and beauty, unmarred by the hand of man. A conspicuous feature of the walls of the canyon where they are moistened by the spray of the cataract and of those of the creek above the precipice over which it plunges is a luxuriant growth of algæ, which mantels the rocks and forms long green streamers in the water.

Water resources.—Pauline Lake is situated in an arid region, high above the flat lands of the Deschutes Valley, and is thus favorably located to serve as a reservoir for water to be used in irrigation. As stated above, a small log dam has been placed at the head of Pauline Creek, but as it appears, for the purpose of securing some claim to the water rather than for actual use. The dam, if intact and its water gate closed, would serve to raise the level of the lake about 5 feet, but this experiment, so far as I have been able to learn, has never been tried; the reason, as I have been informed, being that when the outflow of the lake is checked wells dug in the flood plain of the creek, about 8 miles downstream from the lake, became dry. How high the waters of the lake would rise during the winter interval between

A. FALLS ON PAULINE CREEK NEAR PAULINE LAKE.

B. BENHAM FALLS DESCHUTES RIVER, CROOK COUNTY.

growing seasons is not known and at present can not be computed from the discharge, since the area of the lake is unknown. Taking the single measurement available, however, which was made, as is judged, during the season of least overflow, it has been estimated that the amount of water the lake could furnish if its discharge was stored for a period of nine months would be approximately 300,000,000 cubic feet, or sufficient to flood an area of 10 square miles to a depth of about 1 foot.

By dredging a channel about 600 yards in length and making a cut in soft rock about 100 feet long and 10 feet deep, arranged with a gate, and, in case the water supply is sufficient, provided also with a dam for raising the water above the present level of the lake, an admirable reservoir could be secured at small expense.

All of the conditions pertaining to the storage of water in the manner here suggested are exceedingly favorable, and there is an abundance of land along the lower course of Pauline Creek on which the water could be utilized for irrigation. The critical condition, however, and one which might render such an attempt at irrigation useless, is the extreme porosity of the deep pumiceous layer which forms the surface over all of the flat lands bordering Mount Newberry on the west. Although the belief seems to be general among the few residents of the pumice-covered region of the upper Deschutes that the porosity of the soil will render irrigation fruitless, this conclusion does not appear to have been demonstrated by experiments. It seems probable that irrigation carefully conducted would result in the compacting of the soil and the silting up of its interstices to such an extent that water would be retained at the surface in sufficient quantity to nourish plants. Without venturing to offer an opinion in this connection, however, I feel abundantly justified in recommending that a careful study of the storage capacity of Pauline Lake should be made, coupled with an investigation of the best method of conducting water to the lands to the west and a study of the soil conditions along the lower course of Pauline Creek.

Glacial records.—On the south shore of Pauline Lake, rising precipitously from the water's margin, are hills with an irregular hummocky surface, composed of unassorted rock débris, including many angular blocks from 5 to 10 or more feet in diameter, which are clearly moraines. These hills extend south to the base of the cliffs bordering the basin on that side. About the west side of Pauline Lake and merging with the moraines just mentioned there is again a broad belt of moraine-covered country which, at the north, unites with a region 5 to 10 square miles in area, situated on the mountain bordering the amphitheater in the summit of Mount Newberry on the north. The moraines on the west side of the lake rise steeply to a generally even and broad crest about 250 feet above the present lake surface, and decline westward with a well-defined slope for at least 3 or 4 miles. The full extent of the former glacier was not determined, as the region its traces occupy is so thickly forested or mantled with fallen timber that it could not be explored in the time available.

On the south side of the summit of Mount Newberry there are at least three canyon-like valleys with steep gradients, which lead southward down the outer slope of the mountain. These moderately broad steep-sloping valleys have the characteristic cross profiles of glacial troughs, such as small alpine glaciers produce, and were, without doubt, once occupied by glaciers, although no polished or striated surfaces were seen. On following them to the crest of the cliffs overlooking Pauline Lake, they were found to end abruptly at the summits of precipices several hundred feet high. These troughs will be recognized at once by persons familiar with the published descriptions of Mount Mazama, as being similar to the " beheaded " valleys of that mountain.

The interpretation of the facts just presented, arrived at while studying the region to which they pertain, is briefly as follows:

The great amphitheater in the truncated summit of Mount Newberry was in existence previous to the Glacial epoch, and during that time became filled to overflowing with snow, which formed a névé field from which a glacier from 2 to 3 miles wide flowed northwestward down the previously stream-eroded outlet of the amphitheater. During the retreat of this glacier it formed the massive terminal moraine which now unites the cliffs on the southwest side of the amphitheater with the mountain mass forming the northern border.

From the névé field in the amphitheater of Mount Newberry, the main discharge from which went toward the northwest, small ice streams found their way through notches in the line of cliffs on the south and descended preexisting canyons on the south side of the mountain, enlarging them and giving them broad U-shaped bottoms. That is, the amphitheater became so deeply filled with snow that the névé was built up at least as high as the highest pinnacle on its southern rim.

As will be seen from this explanation, the high grade and now broad-bottomed gorges on the south side of Mount Newberry are probably remnants of water-cut canyons made while the amphitheater in the summit of the mountain was being eroded; the evidence is not considered to indicate, however, that they were glaciated before the mountain was truncated or before a deep amphitheater was excavated in the portion that remained.

In connection with the statement just made in reference to the former glaciation of Mount Newberry it is of interest to note that snow still lingers throughout the summer in the noontide shadows of the cliffs on the south border of the amphitheater. At the time of my visit, August 27–30, snow banks were still present in sheltered places among the lava flows in the eastern portion of the amphitheater, at a height of less than 100 feet above Pauline Lake. It is thus evident that but a moderate climatic change in the direction of increasing the winter snowfall or of decreasing the summer melting would again bring about glacial conditions.

Recent andesite craters and lava flows.—The history of Mount Newberry thus far traced relates to the building of a lofty volcanic mountain, its truncation by erosion, the excavation of a deep amphitheater in its summit, the filling of the amphitheater with snow, the discharge from it of ice streams, and the closing of its outlet by a massive terminal moraine. Another and no less interesting chapter in the long and varied history of the mountain is recorded by material erupted from volcanoes which originated in the amphitheater vacated by the melting of the névé field.

The post-Glacial craters referred to are 5 in number, arranged in a belt running north and south across the bottom of the amphitheater, between Pauline and East lakes. The length of the belt is by estimate about 4 miles, and the position of the 5 vents along it indicate that they are situated on a fissure. Each of the 5 craters is composed of andesitic lapilli, and 4 of them discharged lava streams which on cooling produced, at least superficially, great quantities of obsidian and scoriæ. For the sake of convenience the 5 craters referred to have been assigned numbers, in reference to their positions, beginning at the north end of the series and progressing southward. In reference to their relative age, No. 3 seems to be the oldest, while No. 2 is older than No. 1; Nos. 4 and 5, the most recent of all, are of about the same age.

Crater No. 1 is situated on the southward-facing slope of the north border of the amphitheater to the northeast of Pauline Lake, from the shore of which it rises precipitously. It is not a conspicuous feature and was not visited. The principal fact concerning it to be recorded is that from a breach in the south side of its rim a lava stream was discharged which flowed south with a moderate gradient until it impinged upon the north side of Crater No. 2, where it divided, one branch going eastward toward the site of East Lake and the other branch westward toward the basin of Pauline Lake. The trunk stream and each of its branches is approximately a mile long. It was principally this lava flow which so divided the bottom of the amphitheater in which it originated as to make two basins. The end of the eastward branch forms a portion of the shore of East Lake, while its companion terminates in a steep slope washed by the waters of Pauline Lake. The surface of the lava is excessively rough and irregular, consisting of a succession of heaps of large, angular blocks of obsidian and black scoriæ together with yellowish pumice, rising from 20 to 30 feet above the general level;

between these at many localities are irregular depressions and pit-like openings fully as deep. Both the crater and the lava stream from it are densely overgrown with trees and bushes, which suggest that they are older than the similar craters, Nos. 4 and 5, which, together with their accompanying lava streams, are nearly bare of vegetation. The borders of the lava are precipitous, and in this, as in nearly all other characteristics, correspond with the streams discharged by the two craters at the south end of the series.

Crater No. 2 rises boldly near the east shore of Pauline Lake. When seen from the west shore it presents the appearance well shown in Pl. XV, *B*. The cone is, by aneroid measure, between 700 and 800 feet high, and, as shown in the picture, has a broad truncated summit. Sunk in the summit is a well-defined crater about half a mile in diameter, the south side of which has been breached by an outflowing lava stream. There is also a deep notch on the north side, but it is not so pronounced as the one opposite to it, and is not occupied by a lava stream. The cone is composed of andesitic lapilli, among which pumice is conspicuous, but this may have been showered on the crater during the eruption of the neighboring craters to the south. The outer slopes of the cone are steep and the inner slopes of the pit in its summit precipitous. The entire crater and its small lava stream are overgrown with trees.

Crater No. 3 is adjacent on the southwest to the base of Crater No. 2 and is situated near the southeast border of Pauline Lake, above which it rises to a height of about 200 feet. In comparison with its conspicuous and symmetrical neighbor it is small and its rim is deeply notched by erosion. It is probably the oldest of the group of five craters to which it belongs. Its circular form and both the inner and outer slope of its ring of lapilli are plainly recognizable, and in its bottom there is a smooth plain of yellowish pumiceous lapilli about 500 feet in diameter. This plain is similar to other pumice plains in the same region, and is formed of the same kind of material that floors the depression to the east of Crater No. 5. The walls of the crater are coated with similar material which fell after they were broken, at a date late in the history of the basin. The yellowish pumice referred to is widely scattered about Mount Newberry, and, in part at least, was blown into the air during the eruption of Crater No. 5.

Crater No. 4, situated about half a mile southeast of No. 3, is represented by a portion of its eastern rim, composed of yellowish pumiceous lapilli, which forms a curved ridge, concave to the west. Between the fragment of the crater remaining and the lava which rose within it, and now appears as a rugged, black field or plateau of obsidian, there is a deep moat, in which the water from a cold spring forms a crescent-shaped lakelet about 800 feet long and 30 to 50 feet wide. To the east of the lake is the tree-covered inner slope of the crater, and to the west the precipitous border of the stream of obsidian that rose within it but did not expand to its rim.

The west end of the fragment of the wall of Crater No. 4 disappears beneath a great sheet of black obsidian which came from the south, probably from Crater No. 5. The lavas from Craters Nos. 4 and 5 are of the same character and are united in such a manner that they seem parts of a single outpouring from No. 5. Close examination, however, shows that part of the material came from No. 4, which is several hundred feet lower than its companion and is inconspicuous except when seen from the hills of lapilli bordering it on the east.

Crater No. 5 is situated at the south end of the series, adjacent to the steep southern rim of the amphitheater excavated in the summit of Mount Newberry and about 2 miles from the southeast border of Pauline Lake. The fragments of the sharp-crested ring of lapilli which it formed during its earlier and markedly explosive eruptions are not conspicuous for their height, and, in fact, in a general view from the adjacent portion of the lofty rim of the amphitheater, are easily overlooked amid the rugged topographic forms with which they are surrounded. Sufficient of the crater rim remains, however, to show that it had a diameter of 1,500 to 2,000 feet. Within it the greatest lava discharges of any of the series of volcanoes to which it belongs took place, and in this and several other features it supplements the phenomena displayed by its companions in an instructive manner.

The lava which welled out of Crater No. 5 and buried or carried away its northwestern and northern portion for about one-half its circumference flowed northwest down a rather steep gradient for about 2 miles, but halted before reaching the site of the adjacent shore of Pauline Lake. It is in general about 1 mile wide. The lava field, or rather, the inclined plateau of rugged obsidian and scoriæ, is bordered by rough descending escarpments 50 to 80 feet high (Pl. XVII, *A*). These bordering slopes are now composed of angular blocks of obsidian that form a talus difficult to climb, which, when fresh, must have presented nearly vertical precipices. The surface of the lava is exceedingly rough, consisting of heaps and precipices of obsidian and black scoriæ, between which there are steep-sided depressions and trench-like openings, or fissures, with walls of black glass. The surface is without the general coating of pumiceous lapilli which covers practically the entire region about it, except the similar lava discharged from Crater No. 4. In common with its associated craters and lava flows it is entirely lacking in evidence to show that it was ever covered by ice, and is thus proved to be one of the most recent additions to the rocks of the Newberry amphitheater. There are no trees on the lavas, and scarcely a lichen, but on the lapilli within the craters from which it came, as shown in Pl. XVII, *B*, trees 30 or 40 feet high are growing. The absence of vegetation is evidently due to a lack of soil, and this in turn is due to the slow disintegration of the obsidian and to the open and cavernous character of the rocks, which permits dust and the finer products of disintegration to sink too deeply into them to be available for plant support.

The most novel feature of Crater No. 5, and one which is absent from its companions, is the presence in the central part of the rough lava plain it encloses of a tower-like mass of rugged and angular crags which rise about 250 feet above it. The appearance of these central crags, as seen from the southwest, is shown on Pl. XVII, *B*, The middle distance in the picture is occupied by the rough lapilli surface which forms the greater part of the floor of the crater and encircles the crags rising within it on all sides except the northwest. The crags themselves are composed of dense, granular andesite, and are without obsidian, scoriæ, or pumice, and are interpreted as having been formed by an upward protrusion of solid lava after the manner of the formation of the " obelisk " of Mount Pelee.[a]

The material occupying Crater No. 5 about the base of its central pile of crags presents interesting and novel features, inasmuch as it is composed of angular fragments that occur in irregular heaps, with equally irregular basins intervening. The surface, although generally a plain, is uneven and has hills and hollows resembling those of a glacial moraine, but is composed of angular fragments consisting of pumice, scoriæ, obsidian, and a few imperfectly shaped bombs. The explanation of this seems to be that mild steam explosions took place in it which threw it into piles, leaving depressions where the explosions occurred; after the explosions ceased cracks formed in the more solid rock beneath and permitted a subsidence of the material resting on it along certain more or less definite lines. About the border of the irregular lapilli field flooring the greater part of the crater there is a belt about 150 feet wide composed of angular and upturned blocks of obsidian and black scoriæ, of the same nature and the same general appearance as the surface of the adjacent lava flow. A portion of this broken and very rough bordering belt is shown in the foreground of the view in Pl. XVII, *B*.

A plain of pumiceous lapilli lies east of Crater No. 5, from which the pumice was no doubt blown out. This pumice plain resembles several other small basins in the same region. This sheet of pumice covers the adjacent rim of the amphitheater and is widely distributed over the neighboring plains. As it merges with other similar

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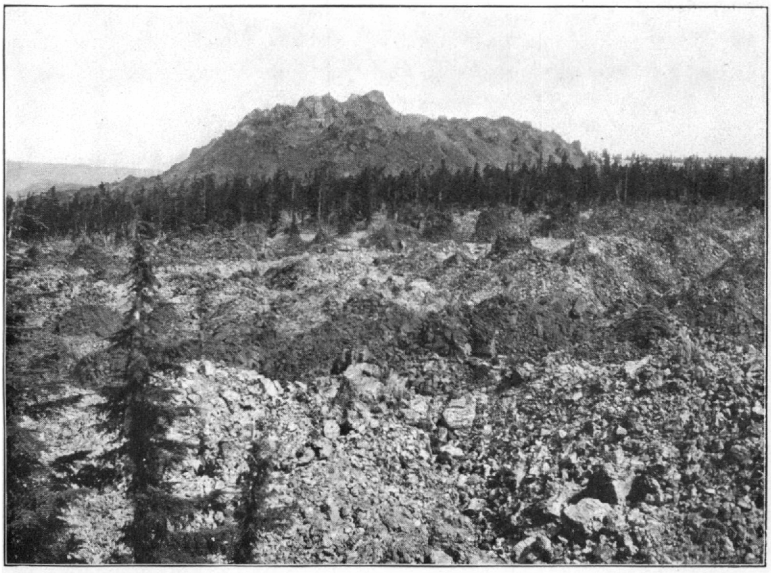
[a] Hovey, E. O., The new cone of Mont Pelé and the gorge of the Rivière Blanche, Martinique: Am. Jour. Sci., vol. 16, 1903, pp. 269–281.

Russell, I. C., The Pelé obelisk: Science, vol. 18, Dec. 18, 1903, pp. 792–795.

Russell, I. C., Criteria pertaining to massive-solid volcanic eruptions: Am. Jour. Sci., vol. 17, 1904, pp. 253–268.

A



B

VIEWS IN CRATER NO 5, MOUNT NEWBERRY.

A, Margin of obsidian lava bed, looking north; *B*, massive extrusion of lava, forming crags; looking northeast.

deposits discharged from craters in the Cascade Mountains, the limits of its distribution can not at present be stated. On Pl. XVII, *A*, the general appearance of the precipitous margin of the lava flows from craters Nos. 4 and 5 is shown. Escarpments of this nature are characteristic of the margins of all the lava flows in the amphitheater and show that the material of which they are composed was thick and viscous at the time it flowed away from the craters from which it was discharged.

The interpretation of the records made by the volcano designated as Crater No. 5 may be stated briefly as follows:

The volcano was the last (or perhaps the next to the last in case Crater No. 4, which is of about the same age, was in action at a later date) of those which originated along a fissure in the bottom of the Newberry amphitheater. Its activity at first was characterized by violent explosions, which blew out pumiceous lapilli and distributed it widely over the adjacent region, particularly on the encircling cliffs to the south and east. An encircling ring of lapilli, in general about a hundred feet high, with a sharp crest, was formed, having a diameter of approximately 1,500 feet. Later came an outwelling of thick, viscous lava which flowed northwest and expanded somewhat before cooling. The sluggish flow of this lava is indicated by the fact that it descended a slope with a well-marked gradient—about 500 feet to a mile—and came to rest with precipitous borders 50 to 80 feet high on all sides. Following the extrusion of the viscous lava came a massive-solid eruption, during which the material congealed at a considerable depth in the supplying conduit was forced up, so as to form the pile of crags in the center of the crater. That the lava composing these crags cooled and hardened at a depth and under pressure is shown by the absence of glass and scoriæ and by the incipient crystallization which resulted in a granular structure of the material. The magma which once rested on this more slowly cooled material was perhaps discharged as viscous lava, but more probably was blown away in the condition of a fragmental-solid discharge. After the central column had been forced upward and out of the summit of the conduit as a solid protrusion mild explosions occurred in the crater about its base and produced lapilli and a few bombs, which were left in heaps, with irregular depressions intervening. After the explosions ceased there was some movement in the solid rock beneath the lapilli, which caused it to become fractured.

The volcano that built Crater No. 5 thus left records of having undergone fragmental-solid, effusive, and massive-solid eruptions.

The reason for assigning the five volcanoes just described to a post-Glacial date is because, although they occur within an amphitheater which was at one time, presumably during the Glacal epoch, occupied by a névé field that gave origin to glaciers, neither their craters, composed of loose fragments, nor the rough surfaces of their lava flows bear any evidence of glaciation; without question they did not exist when their sites were occupied by flowing ice.

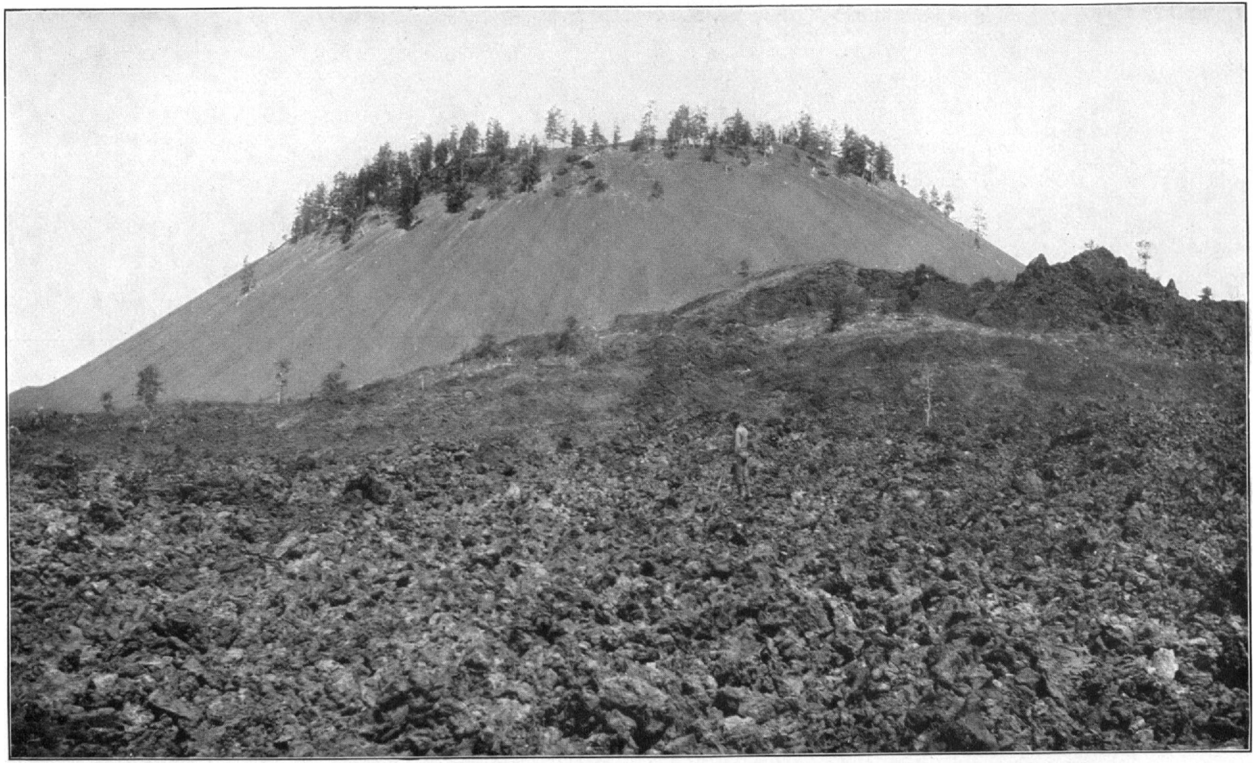
RECENT BASALTIC CRATERS.

A large number of comparatively small, black or reddish, conical elevations, some of them with depressions in their summits, are clustered about the base and on the sides of Mount Newberry, but more especially north and south of the central elevation. These secondary hills have the form and color of basaltic cinder and lapilli cones, and a long, narrow, black area 5 or 6 miles south of Mount Newberry and trending about northeast and southwest, and bare of trees, though the adjacent land is densely forested, reveals the presence of a rough lava flow, probably of basalt. Besides Lava Butte, which belongs to the same series and is described below, only one of the score or more of the recent craters referred to was visited, and that one, situated about 4 miles west of Pauline Lake, was found to be a basaltic crater built of lapilli, with a well-defined rim about 150 feet high on the outside, inclosing a depression approximately 100 feet deep and 600 feet across. This crater is in the region traversed by the glacier which flowed out of the Newberry amphitheater, and as it is unglaciated, is evidently of post-Glacial date. It is overgrown with trees, however, and is probably older than the bare, black lava stream to the south of Mount Newberry, and also older than Lava Butte, described below.

From the similarity of the several secondary craters to the north and south of Mount Newberry to the one just mentioned and to Lava Butte, it is judged that they all consist of basaltic rock and are post-Glacial in age. The score or more volcanic piles here considered are a part of a much greater group, which includes the 50 or more craters and cones in the neighborhood of Button Spring, briefly described on page 71, and also probably part of a still larger number of similar topographic forms situated to the south of Mount Newberry and known in part as the Walker Range. A vast field for the study of volcanoes, and one which will richly repay investigation, is here inviting attention.

LAVA BUTTE.

Location and general features.—Situated about 12 miles slightly west of north of Mount Newberry and about 2 miles east of Deschutes River, at Benham Falls, is Lava Butte, a conspicuous lapilli cone with a deep crater in its summit, from the south base of which a stream of basaltic lava was poured out and flowed toward the northwest at a recent date. The position of the lava flow in reference to the cone from which it came, the manner in which the lava turned



LAVA BUTTE, NEAR BENHAM FALLS, CROOK COUNTY.

Looking northeast from near south margin of lava bed.

Deschutes River aside, etc., are indicated on the following map, based on surveys made by the Pilot Butte Development Company.

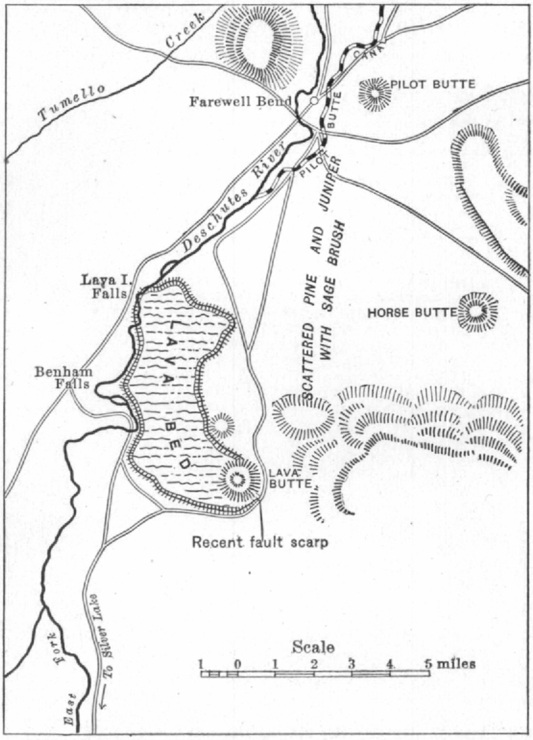


FIG. 2.—Sketch map of Lava Butte and vicinity.

Lava Butte is sparingly overgrown with pines, but the associated lava flow is nearly bare of vegetation, except that here and there a juniper tree has taken root. The scarcity of vegetation on the lava, however, is not an index of extreme youth, since trees are found upon it wherever the conditions have permitted the accumulation of sufficient soil. Dead juniper trees from 16 to 18 inches in diameter, now bleached to a silvery whiteness, which lie on it, in several instances midway down its surface, show that it was extruded at least a hundred and probably more than a hundred and fifty years ago.

The cone of Lava Butte rises about 500 feet above the adjacent forest-covered country, and is composed mainly of a coarse, angular, basaltic lapilli and scoriaceous fragments varying in size up to 3 or 4 inches in diameter. The color of this material is mostly red and black. Mingled with the angular fragments, especially within the crater, are many volcanic bombs and oval scoriaceous masses 3 or 4 feet in diameter, which were blown out as clots of viscous lava. A crater about 150 feet deep, which is situated at the summit of the butte, is without lava which rose in a fused condition, and is now partly filled with débris which has fallen from its walls and given it a conspicuous inverted-cone shape.

The appearance of Lava Butte as seen from the southwest, near the southern margin of its accompanying lava field, is shown on Pl. XVIII. As can be seen in the picture, the lava rises higher than elsewhere at the south base of the cone and stands in rugged crags. This fact is connected with one of the most instructive features that the volcanic cone and its accompanying lava stream presents, and may be considered as a contribution to the characteristics of volcanoes previously recorded.

Lava delta.—The lava escaped through the base of the lapilli cone forming Lava Butte on its south side, but did not breach it, and flowed south for a few hundred yards and then in the main curved and went toward the west and the northwest. At a late stage in the discharge of the lava it formed a " lava gutter " of the same character as the miniature examples about one of the Jordan craters, described in a previous report,[a] but was 500 feet long, about 100 feet wide at the bottom, and fully 80 feet deep. The nearly vertical walls of this black, ragged trench reveal no lava " drip," but are composed of the broken edges of thin scoriaceous lava sheets which are inclined away from the longer axis of the gutter at low angles. The steepness of the walls is due in part to disintegration, and the fall of their original surfaces. The bottom of the gutter is now a chaos of fallen fragments. From the crest of the walls of the gutter the surface slopes steeply down to the rough, but in general nearly level, bordering lava field. That is, the gutter is in the summit of an elevated ridge. At its lower or distal end it divides into three diverging gutters, with rugged crags between, one of which leads west, another south, and the third southeast.

The west distributary, as it may be termed from its analogy to a division of a river in a delta, is the smallest of the three. It is about 30 feet wide at the bottom, with vertical walls 20 to 30 feet high, on which are honeycombed or stalactite-like shapes produced by the dripping of the molten rock which adhered to them when the stream of lava ceased to flow and left its channel empty. The bottom of the gutter, when followed in the direction of the lava flow, descends sharply, and at a distance of about 500 feet merges with the surface of the lava field with which it is confluent. The lava in the bottom of the gutter is highly scoriaceous and presents swells and concentric ridges. The ridges occur in series which forms concentric parabolic or pointed curves, convex on the downstream side, and showing that the last weak discharge of lava cooled and stiffened as it flowed.

[a] Russell, I. C., Bull. U. S. Geol. Survey No. 217, 1903, pp. 52-53.

The divisions of the main gutter that lead south and southeast from the base of the butte are in each case 50 to 60 feet wide at the bottom, and have precipitous walls 30 to 50 feet high, in which the broken edges of thin scoriaceous sheets of basalt are exposed. In a few places, however, the walls of the gutters still preserve the original coating of congealed lava which was left adhering to them when the lava streams subsided and left their channels empty. The length of the two diverging channels referred to, although indefinite, is in the neighborhood of 600 or 700 feet. Their borders are elevated ridges which slope down steeply to the adjacent lava surface, as in the case of the main or trunk channel.

The interpretation of the facts pertaining to the great lava gutter and the three separate parts into which it divides is briefly as follows: The lava from Lava Butte escaped from it through a tunnel at its base on the south side without breaking in or in any way defacing the great pile of loose material from which it came. The explosions which blew out lapilli, clots, and bombs, and built the cone with its deep summit crater, ceased when the discharge of lava occurred, as is shown by the absence of fragmental material on the surface of the lava, although it is present on the adjacent country. The lava ran out in a liquid condition and in large volume, as a stream about 100 feet wide, on the side of which cooling and hardening took place and bordering ridges were formed. As the stream continued to flow it spread over its banks, much as an alluvial river when in flood crosses its natural levees, and the lava which thus expanded cooled and formed thin scoriaceous sheets, which increased the height of the walls bordering the lava stream and produced what may perhaps be termed "lava levees." A great gutter was thus formed which led south for about 1,000 feet, but the molten lava coursing through it broke across its confining walls in two places, in much the same manner that an alluvial river subdivides on a delta, and two distributaries of the lava stream were found, each of which also expanded laterally and formed lava levees of its own. This is the situation in brief. The entire history of the discharge and of the way in which the lava levees bordering the streams of molten rock were built is no doubt much more complex, for the earlier levees formed were buried beneath later ones and assisted in making the prominent elevation into which the lava field rises at its source, as shown on Pl. XVIII.

These gutters therefore present an example of what may be termed a "lava delta," their similarity to the work of an aggrading river being very striking. Similar topographic forms are produced in each case, but by different methods. The manner in which a lava stream overspreads its banks and makes deposits upon them is still more strikingly paralleled by brooks and rills, which in winter sometimes inundate their banks and congeal, forming ice levees.

The volcano which built Lava Butte originated on the east side of the valley of the Deschutes, where the slope was westward. The nature of this slope is revealed in the forested region immediately south of the butte, where a sheet of old basaltic lava forms the surface. The lava discharged by the volcano came from an opening on the south side of the lapilli cone it built, and at first flowed south, but, owing to the inclination of the surface over which it advanced, soon turned and advanced westward into the valley of the Deschutes, which it occupied from side to side, damming the river and extending northward down the valley for a distance of between 5 and 6 miles.

The lava was liquid and no doubt flowed rapidly, but a surface crust formed and became broken by the energetic underflow, and the blocks and cakes produced were carried along and pushed up into heaps, so as to form a typical "aa" surface, as such rough-faced lava streams are termed on the Hawaiian Islands. The roughness of the surface of the lava may be judged to some extent from its appearance as shown in Pl. XVIII. Owing to the large proportion of solid lava involved in the still liquid or viscous portion, the stream, as it advanced and expanded, became sluggish and cooled with a precipitous border in general 30 to 50 feet high. The bold angular escarpment margining the lava field on all sides is composed of angular masses of scoriaceous lava, formed by pushing along the broken fragments of the crust, which hardened before the motion in the deeper portion of the stream ceased, and has suffered but little disintegration or decay since it came to rest. The general plan of the lava's border is excessively irregular and is characterized by the presence of angular projections from its general alignment and equally sharp and angular reentrants.

As indicated on the accompanying sketch map (fig. 2, p. 111), the lava sheet surrounds the butte from which it came on all sides except the east. The same map shows also the fact that Deschutes River meets the lava flow, is deflected from it, and on returning follows its margin for about 2½ miles. The lava completely dammed the former course of the river and caused a lake to form, which found an outlet across a ridge of acid lava, probably rhyolite, on its west border. The outflowing waters cut a deep, narrow canyon, through which the river now rushes, forming a series of cascades, known as Benham Falls (Pl. XVI, *B*). This feature of the river, and the fact that its waters spread into the lava during high-water stages, so as to regulate its flow below the obstruction, will be described a few pages later in connection with other characteristics of the Deschutes (p. 117).

Age of the lava.—The presence of pines on Lava Butte, and the occurrence of both living and dead trees on the lava flow that escaped from it, furnish evidence that the activity of the volcano ceased at least a hundred and probably more than a hundred and fifty years ago. The age of the lava flow relative to other volcanic eruptions in the same region is recorded in part by the presence on the country about it, but not on its surface, of pumiceous lapilli, which cover the slopes of Mount Newberry, and the moraines that form a dam across the outlet of its amphitheater, but are not present on the rhyolitic lava streams within the amphitheater. Lava Butte and its associated sheet of basalt, like the obsidian lavas in the amphitheater of Mount Newberry, is thus shown to have come into existence since the Glacial epoch.

Faulting.—Starting near the south base of Lava Butte and extending at least a mile southward is a fissure in the older basalt of the region, which throughout much of its course is a steep-sided trench about 15 feet wide, varying in depth from a few to 10 or 15 feet. Throughout the length of this break, as far as followed, there has been a movement of the rocks of its walls, which has resulted in raising its eastern from 10 to 30 feet higher than its western side. This fault is of recent date, and perhaps indicates the course of the break which permitted the volcanic conduit that built Lava Butte to gain the surface.

Lava tunnel.—About 2½ miles south of Lava Butte, in a nearly level forest-covered region, where the surface rocks are basaltic lava of earlier date than the lava stream discharged from the butte, there is an open trench about 400 feet long and 50 feet wide, with nearly vertical walls from 30 to 40 feet high. The trench is due to the falling in of the roof of a lava tunnel, and its bottom is composed of angular blocks of basalt variously inclined. At each end of the trench one can descend a steep slope of lava blocks and gain access to portions of the tunnel where the roof is still in place, though the tunnel for several hundred feet on each side of the gap is heavily encumbered with blocks of rock that have fallen from the roof. Farther in, I am informed, where but little dislodgment of blocks of rock from the roof has occurred, the bottom of the tunnel is a level floor of pumiceous sand. It is also stated by parties who have explored the northern extension of the cavern that it can be traversed for a distance of about 2 miles.

This tunnel is like several others in the same region, and is due to the outflow of a lava stream after a roof from 30 to 40 feet thick had been formed by the cooling of the lava above it.

ASSOCIATED CONES.

From the top of Lava Butte a fine view may be had of the surrounding forest-covered region and of the desolate lava field bordering it on the west, as well as of the valley of the Deschutes, the dark eastern slopes of the Cascade Mountains, and the several fine snow peaks that crown their summit. One of the most instructive features of this far-reaching view is furnished by the numerous conical hills to the south. In the direction mentioned, within a radius of about 15 miles, 42 conical hills, ranging from perhaps 250 to 500 feet in height, were counted. These are all recent volcanic cones and craters, but are now forest-covered. In traversing this region still other similar volcanic piles were observed, and their total number must approach, and perhaps exceed, 100. This is but a part, however, of a region some 1,500 to 2,000 square miles in area, extending eastward beyond Christmas Lake, south at least to the Walker Range, and west to the volcanoes of the Cascade Mountains, which is studded nearly everywhere with small volcanic cones, most of which are believed to be composed of basaltic rocks and to be of the type of Lava Butte.

BENHAM FALLS.

The lava stream from Lava Butte, as already described, entered the valley of Deschutes River and formed a dam. The river, thus turned aside, began to erode a new channel across a spur of the old acid lava, which previous to the change formed part of its west bank. The new channel is about half a mile long, and as the task of deepening it to the depth of the old one is as yet incomplete the waters form a series of rapids, to which the name Benham Falls has been given. A picture of this interesting locality is presented on Pl. XVI, *B*, and the relation of the lava to the river is shown on the sketch map on page 111, (fig. 2). The fact that the river has not as yet deepened its present channel to the depth of the adjacent portion of the old channel now occupied by recent basalt is also shown by its sluggish flow above the obstructions, where the still water is from 10 to 15 feet deep. For about one-half mile above the head of Benham Falls and for approximately 3 miles downstream from the foot of the rapids designated by that name the river is margined on the east by a rough, precipitous escarpment of fresh, black, basaltic lava about 40 feet high, which is cavernous and intersected by fissures. The river seems to have filled the interstices in the rock adjacent to the fresh lava over which it flows during ordinary stages, but when a slight rise is experienced the water, after gaining a certain level, escapes into the lava and disappears from sight. At several localities along the border of the recent lava the water of the river, during my visit late in August, was observed flowing into crevices in the rocks along the border of the stream, and it was apparent that a tendency in the river to rise would be efficiently checked in this manner. The greater the volume of the river the more efficient these natural subterranean spillways become. The water on escaping from the river finds its way through or beneath the lava, and, as there are good reasons for believing, again comes to the light, in part at least, in the bottoms of the canyons of Deschutes and Crooked rivers, at a distance of 30 to 40 miles to the north of the localities where it disappears. Opal Spring and other similar springs in the canyon of Crooked River, described on page 88, may reasonably be explained on this hypothesis.

The efficient check on the rise of the waters of the Deschutes so provided exerts a conspicuous influence all the way down its course below Benham Falls to the mouth of Crooked River, a distance of about 50 miles. The annual range in the height of the river throughout this section is only 8 or 10 inches, while above Benham Falls the seasonal variations in the surface level of the river amount to several feet.

LAKES NEAR SOURCES OF DESCHUTES RIVER.

Near the sources of West Fork of Deschutes River and also at the head of the main stem of the river, sometimes designated the Middle Fork, there are beautiful lakes, still surrounded by primeval forests, which furnish instructive examples of water bodies held by dams built by glaciers or formed by lava flows. Some of the lakes referred to also give promise of becoming of importance when the settlement of Deschutes Valley has so far increased that irrigation will have become imperative.

DAVIS LAKE.

On West Fork of Deschutes, near its source, is Davis Lake, which is retained by a dam of lava of recent date. This lake was seen by me from the basaltic hills on its southern border, but was not directly examined. A brief description of it by Lieut. T. W. Symons, who visited it in 1878, which, as I learned from frontiersmen living in its vicinity, indicates its present condition, is as follows: [a]

> Climbing one day around the brow of a hill, we came in sight of another lake, cliff and tree environed and with bottom lands and meadows of great extent, with what appeared to be mud flats near the water. This lake and valley were about 12 by 6 miles in size, and took us completely by surprise, as they were evidently in the course of our West Fork and were not represented on any map. Reaching it we found at its southern end many acres of rich grass and bunches of tall willows. Following around the west shore to the north end we ascertained that there was no visible outlet. We saw the watermarks 20 feet above

[a] U. S. Geol. Surv. W. One Hundredth Mer. (Wheeler Survey), Appendix B, 1879, p. 218.

us on the lava bluffs of the northern and northwestern shores, and camping beside these in the night we heard strange rumblings in the vast pile.

We found the next day that these lava beds formed an impassable barrier extending unbroken for about 4 miles to the north, and at their end were again surprised to find, foaming out from underneath the giant bowlders, the clear, cold river that we had seen lose itself in the lake 15 miles and more to the south.

The value of Davis Lake as a storage reservoir is not clearly shown by the above description, although it at least suggests the desirability of making a survey for the purpose of determining its utility for that purpose. An alternative in this connection is presented, however, by Odell Lake, situated on the same stream, about 6 miles nearer its source.

ODELL LAKE.

This charming sheet of clear, cold water, surrounded by bold, forest-covered mountains, is located on the east side of the Cascade Mountains in proximity to their crest, and receives the water from the snow fields on Diamond Peak, the height of which is 8,807 feet. On the side of that fine, bold mountain and in view from the east side of Odell Lake there is a miniature glacier situated just above the upper limit of tree growth, which may be considered as a much-wasted remnant of an extensive ice stream that formerly flowed eastward from the same elevated region and occupied the valley in which the present lake occurs. The former glacier had several tributaries in its upper portion, and also received contributions from snow fields that covered the less imposing volcanic mountain to the northeast of Odell Lake. The ice that flowed through the previously stream-eroded valley broadened its bottom, rounded and smoothed the ledges and hills of resistant rocks on its borders, and on melting left conspicuous and well-defined lateral moraines on its sides and a series of curved, concentric, terminal moraines about its southern end. The lateral moraines on the sides of the valley slope perceptibly in the direction of ice movement; in general the highest in the series on each side of the lake has an elevation of from 1,000 to 1,500 feet above its surface. The terminal moraines which sweep across the southern end of the basin in a series of open loops are steep-sided ridges composed of bowlders and much volcanic lapilli and pumice. The innermost of the series rises precipitously from the south end of the lake, and forms the dam which retains its waters. The moraine is crossed by the stream flowing from the lake, which has excavated a narrow, steep-sided gorge across it. This gorge furnishes a favorable site for a dam, by means of which the level of the lake could be raised so as to retain all of its winter discharge.

An approximately correct cross profile of the gorge at a locality about 300 yards below where the outflowing stream leaves the lake is here presented:

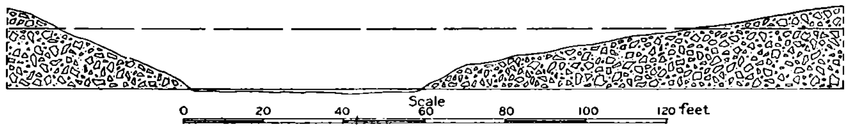


FIG. 3.—Cross profile of gorge at outlet of Odell Lake.

The width of the stream at the locality where the above cross profile was obtained was 57 feet on September 3, 1903, its average depth nine-tenths of a foot, and its maximum velocity, as determined by means of floats, seventy-five one-hundredths foot per second. These measurements show that the volume of the stream was about 31 cubic feet per second. This amount, however, is probably in excess of the actual volume, as the stream is much obstructed by stones and bowlders, and the value given to the measure of the velocity consequently too great. A better approximation to the volume of the discharge from the lake is thought to be 25 cubic feet per second. Owing to the equalizing influence of the lake, the stream flowing from it is not characterized by conspicuous variations in volume, but nevertheless there are seasonal changes to be taken into account in estimating the amount of water available for storage. The lake is said, by persons familiar with it, to rise in winter and spring from 8 to 10 inches above its summer stage, and with such a rise the volume of the outflowing stream can be reasonably assumed to be about three times its volume during its lowest stage, but for what length of time the high-water stage continues is unknown. We can, however, from the data in hand, obtain some idea of the possibilities of the lake as a storage reservoir.

The discharge given above—namely, 25 cubic feet per second—during a period of nine months, the usual interval between the seasonal periods during which water is desired for irrigation, would be 583,000,000 cubic feet. The lake has approximately an area of 6½ square miles, or 181,000,000 square feet, and an increase in its volume by the amount just mentioned would raise its surface about 3 feet. If the winter and spring discharge per second is, during certain periods, three times the lowest summer outflow—and this seems all that the conditions indicate—it is safe in endeavoring to obtain a preliminary idea of the possibilities of the lake for irrigation purposes to assume that the mean discharge during the winter season is not more than three times the mean summer outflow. On this assumption, in case all of the winter water is retained in the lake, its surface would be raised about 9 feet. This is certainly a liberal estimate, and, besides, takes no account of loss by evaporation. In considering the question of how high to build a dam in order to retain all of the winter run-off allowance should be made for probable seasons of more than normal precipitation, and also for the influence of gales blowing down the lake in raising the water at its southern end. Data in these connections are wanting, but, allowing for all probable contingencies, I venture to assume that a dam 15 feet high above the present bed of the outflowing stream, at the locality where the above cross section was obtained, would be all that would be required. A dam of this height, as shown by a broken line on the profile in fig. 3, would have an exposed crest about 160 feet in length.

The material which would have to be excavated to secure a foundation for such a dam is composed of bowlders and angular stones of various sizes up to 3 or more feet in diameter, between which there is compact volcanic sand, pumice, etc. Whether clay is present or not is unknown. The depth of the moraine is such that it is impracticable to reach a solid rock bottom in excavating for a dam, and the depth of the base of the dam below the present stream bed and the length of the lateral extensions required in order to counteract percolation can only be judged when excavations shall have been made. No great difficulty in this connection, however, can reasonably be anticipated.

The lowest sag in the crest of the moraine which retains the lake, as determined by means of a hand level, is between 55 and 56 feet. This, next after the gorge occupied by the outflowing stream, is the lowest notch in the rim of the basin.

The above measurements and estimates, although only approximately correct, will, I think, serve to indicate the nature of the problems to be studied when Odell Lake comes into demand as a storage reservoir.

CRESCENT LAKE.

Situated approximately 4 miles southwest of Odell Lake is Crescent Lake, the source of Main, or Middle, Fork of Deschutes River. This lake is larger and in nearly every way finer than its neighboring water body, and, like it, is surrounded by beautiful scenery and magnificent forests. As nearly as can be judged from the map of the Cascade Range Forest Reserve made by the United States Geological Survey, Crescent Lake is about 4 miles long and 2 miles wide. Its area is not far from 7 square miles. It is retained by a strong, well-defined terminal moraine, which sweeps across the valley in a graceful curve, presenting its concave side to the west, the direction from which came the glacier that built it. The moraine at the immediate border of the lake is one of a series having a breadth of about 2 miles, which unites with the similar series of ridges about the south end of Odell Lake. These moraines are composed of large bowlders, mingled with which is considerable pumiceous lapilli of the same character as the fragments that cover a large portion of the Cascade Mountains in southern Oregon.

The outlet of Crescent Lake is at the north end of the moraine that confines it, where the outflowing waters have cut a gorge of the same character as, but broader than, the one excavated by the stream flowing from Odell Lake. A cross profile of the gorge, made by means of a tapeline and hand level at a locality about 100 yards below where the stream leaves the lake, is here presented:

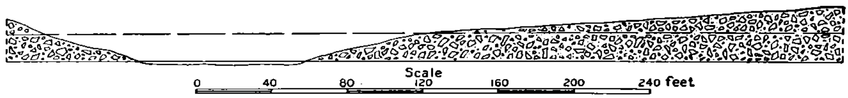


FIG. 4.—Cross profile of gorge at outlet of Crescent Lake.

The width of the stream is 89 feet, and its average depth on September 4, 1903, as shown by 15 measurements, was nine-tenths of a foot. This may safely be taken as its minimum depth during the year. The channel is much encumbered with bowlders and driftwood, so that even an approximately accurate measurement of the velocity of the stream by means of floats is impracticable. Trials in this direction, however, gave a velocity of about 1 foot in three seconds, which, together with the other measures, indicates a volume of about 21 cubic feet per second. But as the stream is plainly of greater volume than the one flowing from Odell Lake, this measure is no doubt too small. Crescent Lake, as reported by frontiersmen familiar with it, rises in March and April about 10 inches above its lowest stage, which occurs in September. These statements are in harmony with the evidence furnished by the beaches about the borders of the lake and by the downward limit of vegetation on its shores.

Not only is Crescent Lake larger than Odell Lake, but the area of mountainous land draining to it is greater, while the rainfall is essentially the same, each lake receiving some of the precipitation falling on Diamond Peak, the highest elevation in the region. Thus in many ways it is more favorably circumstanced than its companion to serve as a storage reservoir. Judgment based on all available data, and giving due weight to the inadequacy and inaccuracy of the information in hand, indicates that a dam 15 feet high would be all that is required to control the winter run-off of the lake. Such a dam, as indicated by a broken line on the profile given above, would need to be about 200 feet in length.

It must be remembered that in presenting these crude estimates my aim is simply to indicate possibilities and to recommend surveys, such suggestions being some of the functions of a reconnaissance.

WELLS.

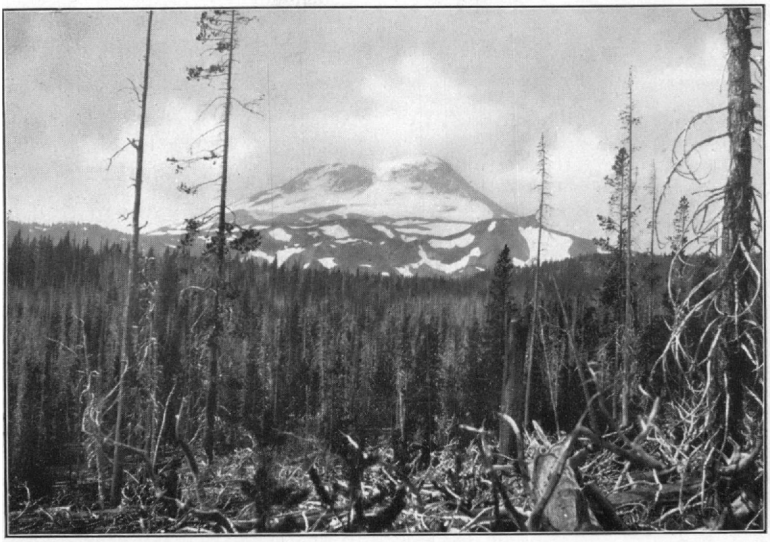
With reference to obtaining water by means of artesian wells in the portion of the basin of the Deschutes under consideration, I failed to find any favorable evidence so far as deep wells are concerned. In the material swept out of gorges in the mountains and deposited as alluvial fans near their mouths, it is possible that small supplies of flowing water in some instances may be obtained. Conditions of this nature occur about Sisters, and in other similar situations along the eastern base of the Cascade Mountains, but no predictions as to the success of wells in such localities are at present warrantable. The structure of these alluvial deposits is unknown, and at best must be irregular. The only method of ascertaining their artesian possibilities is by sinking wells to a depth of a few hundred feet on the lower portions of the alluvial slopes, and thus ascertaining the local conditions by trial.

IRRIGABLE LANDS.

The favorable conditions for storing water, in what may be termed a small way, in the basins of Odell and Crescent lakes leads to the question: Where can the water, if stored, be utilized?

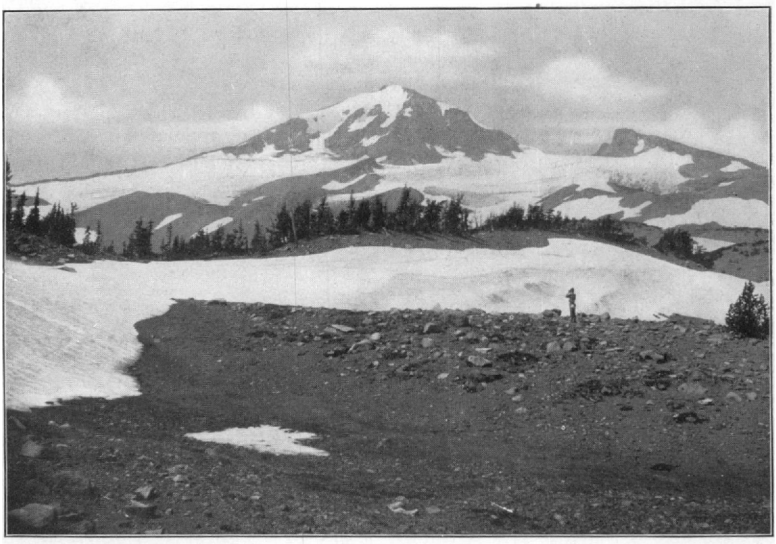
In the basin of the Deschutes above Benham Falls there is a great area of land which, as inspection indicates and private surveys are said to show, can be economically irrigated by means of ditches branching from West and Middle forks of Deschutes River. There seems no question but what, so far as engineering possibilities are concerned, there is more than enough practically level land available for the utilization of all the water that can be supplied for irrigation by the branches of the Deschutes in the region indicated above. The critical condition, however, which will evidently control most irrigation schemes in the entire drainage basin of the Deschutes above Benham Falls, is the nature of the soil.

Over all of the region just referred to, and extending far beyond its boundaries in every direction, the surface layer is composed of pumiceous lapilli, ranging in depth from about 6 feet as a minimum to over 35 feet. The exceptions to this statement occur where marsh conditions prevail and the pumice is covered or mingled with humus material; such areas, however, are comparatively small and are confined to the vicinity of the river, where they are annually or occasionally overflowed. The surface material on the uplands bordering the streams and extending over the adjacent plains and neighboring hills, is light-colored pumice, almost entirely without humus. Water conducted upon such land would almost immediately disappear beneath the surface. This absence of soil is thought by many persons familiar with the region to demonstrate the impracticability of ever



A. SOUTH SISTER PEAK.

Looking southeast.



B. WEST SISTER PEAK.

Looking west. Diller Glacier to left and Hayden Glacier to right of center.

reclaiming the land for farming purposes; others, however, equally well acquainted with the conditions, do not consider the problem so discouraging.

The reason for the absence of soil is not difficult to determine. The region is clothed with trees, but over extensive areas the primitive forest has been burned, and what are termed scrub pines have taken its place. The porous surface material dries each summer and the litter of the forest then becomes highly inflammable, and fires sweep over the land, destroying all the vegetable débris resting on it, and frequently burning the trees as well. This process has gone on year after year, in some portions of the region for an indefinite period, and no vegetable matter has been left for the formation of soil except in the low and usually wet grounds. If the land is to be reclaimed, evidently the first step is to stop the fires that now annually occur. When this is done a soil will begin to form, and by degrees forage plants will take root where now there is only bare pumiceous lapilli.

On small areas of the pumiceous land where irrigation has been practiced soil has gradually been formed and favorable crops obtained. The success of these attempts is such as to favor the conclusion that by skillful agriculture, special care being taken to supply vegetable matter to the ground, good returns can be had by irrigating the open, porous, pumiceous lands. In the nearly level region adjacent to Deschutes River above Benham Falls water can be had in wells that are only 8 or 10 feet deep even in summer, and springs are common along the border of stream channels. Thus the water table is near the surface. The springs are clear on account of the filtering their waters received while percolating through the surface layer of pumice. Their temperatures are low, approximately 50° F., or about the mean annual temperature of the region. The presence of cold water at a small depth below the surface is detrimental to agriculture, as is also the prevalence of frosts during practically every month of the year. Thus in several ways the agricultural possibilities of the region in question are confined within narrow limits.

The most that can seemingly be hoped for in the southern portion of the Deschutes basin is that its forest will be utilized and scientific forestry practiced on all of the region that can not be irrigated, and that where water can be had dairy farming and stock raising will be practicable.

GLACIERS.

During the journey which furnished the basis for this report many commanding summits were reached which furnished admirable views of the east side of the Cascade Mountains. From such distant observations, supplemented by a visit to the Three Sisters peaks, some data which seem worth recording were obtained relative to the small glaciers present about the higher summits.

EXISTING GLACIERS.

From various points of view the higher peaks of the Cascade Mountains were in sight from Mount Adams at the north to beyond Mount Pitt at the south, a distance in a straight line of over 250 miles. In this interval, in their order from the north southward, rise Mount Hood, Mount Jefferson, the Three Sisters peaks, Bachelor Mountain, and Diamond Peak, each of which has one or more small glaciers on its sides. There are other peaks which are white with snow in late summer, but so far as could be seen from the eastward are without glaciers.

Mount Adams and Mount Hood, as is well known, have several glaciers about their higher slopes, but these were too distant from the points of view occupied during the reconnaissance to be recognized.

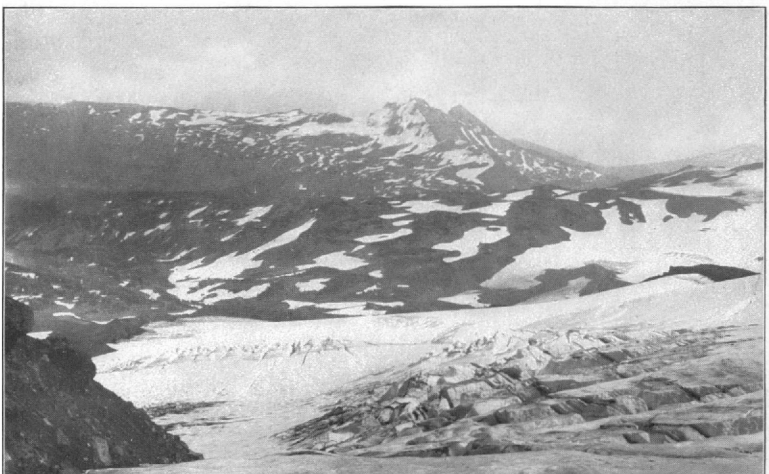
GLACIERS OF MOUNT JEFFERSON.

Mount Jefferson is one of the finest and perhaps the most beautiful of all the individual mountain peaks in Oregon. Standing as an immense white pyramid on the summit of the generally forest-covered Cascade Mountains, it attains a height of about 10,350 feet. The portion of the mountain rising above the upper limit of tree growth is deeply sculptured and illustrates an advanced stage in the erosion of a volcanic cone. To the northeast and to the northwest of its sharp summit are deep amphitheaters, each of which contains a small glacier. The one on the southwest side of the mountain is several hundred feet lower, vertically, than its companion and is separated from it by a prominent cliff facing southward. The névé fields of the northeast glacier extend about the northern side of the peaks and, as may be expected, coalesce with the gathering grounds of another glacier on that side. The glaciers mentioned above are intersected by blue crevasses, reveal a well-marked line between glacier proper and névé, and have marginal moraines about their borders which unite to form terminal moraines at their pointed distal ends. On the 1st of September snow banks still existed below the glaciers and in the upper portion of the adjacent forest. So far as could be determined from a distance the glaciers reveal no evidence of recent recession.

GLACIERS OF THE THREE SISTERS.

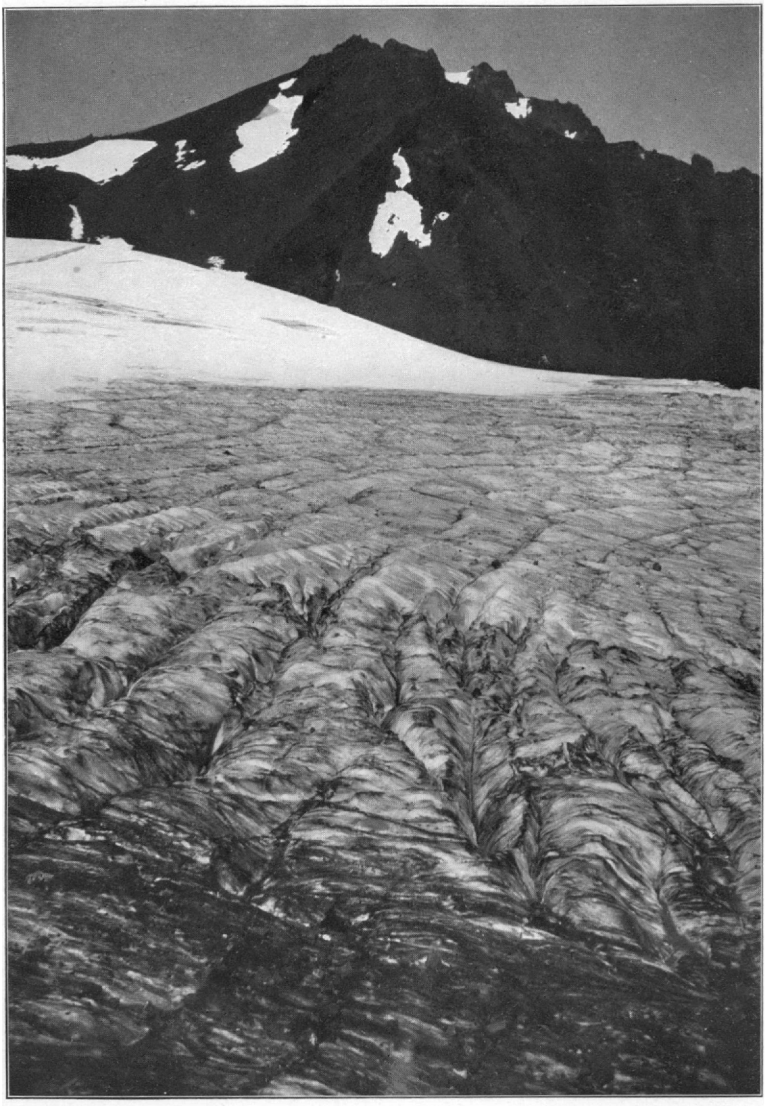
Location and size of the glaciers.—The three sharp pyramidal peaks known as the Three Sisters, which rise from the crest of the Cascade Mountains in west-central Oregon attain in each instance an

A. NÉVE OF DILLER GLACIER AND SOUTH SISTER PEAK.



B. LOWER MARGIN OF DILLER GLACIER; BROKEN TOP IN BACKGROUND.

Looking south.



LOWER MARGIN OF NÉVÉ ON HAYDEN GLACIER; NORTH SISTER PEAK IN BACKGROUND.

Looking north.

elevation of approximately 10,250 feet above the sea. The three peaks occupy the angles of a triangular space which has been excavated so as to form a great amphitheater opening east. This depression, which, measured from North to South Sister, is by estimate about 5 miles across, was formerly occupied by a large glacier which flowed eastward down the slope of the mountains for a distance of at least 10 miles and for an as yet unknown distance beyond. This glacier, on retreating, left massive moraines, which are conspicuous from certain points of view, although to a great extent obscured by the forest that covers them. The old glacier was formed by the union of several tributaries, and as it melted and withdrew within the amphitheater, where its supplying snow fields lay, it became dissected into several smaller glaciers, each of which left well-defined lateral and terminal moraines.

Within the amphitheater and well up on its sides there are at present four small glaciers—one between North and West sisters, one on the southeast slope of West Sister but in its névé portion confluent with the one on the north face of South Sister, and one on the north side of Broken Top, a rugged peak adjacent to South Sister Peak on the southeast. The general appearance of these glaciers is shown on Pls. XIX and XX.

There are also two glaciers, much smaller than those situated in the amphitheater, on the northeast side of North Sister Peak, just above the upper limit of the encircling forest. These glaciers are walled in on the lower margins by sharp-crested moraines, which rise somewhat higher than the ice they inclose, thus indicating a recent lowering of its surface. When viewed from the southeast, South Sister Peak is seen to have a long, narrow glacier of considerable size on its southeast side, which terminates at the forest line, and is not as extensive as the one on the north slope of the same peak.

All of the glaciers mentioned above are on the east side of the crest line of the Cascade Mountains, and the water supplied by their melting flows to Deschutes River; as to the snow and ice conditions on the west side of these peaks I am not informed.

The glacier between North and West Sister peaks (Pl. XIX, *B*), here named Hayden Glacier,[a] is by estimate about 1 mile long, and somewhat less in width in its broadest or névé portion. At the time of my visit, August 16, 1903, the dividing line between the hard, blue, dirt-stained ice of the glacier proper and the clean white snow of the névé was sharply defined, as may be seen on Pl. XXI. As stated above, the névé of this glacier is confluent with the névé of Diller Glacier,[b] adjacent to it on the south. The two glaciers separate at a prominent rocky crag (Pl. XIX, *B*) about 1,000 feet east of the upper

[a] Named for Lieut. E. E. Hayden, U. S. N.

[b] Named for J. S. Diller, geologist, U. S. Geol. Survey, who has carried on extensive geologic surveys in western Oregon.

margin of the névé where it meets the base of West Sister Peak. From this crag a well-defined lateral moraine extends along the margin of each glacier. These moraines are well shown on the illustration just referred to, and other characteristic glacier features are illustrated by this and other accompanying photographs.

Recent shrinkage of glaciers.—The special features of interest concerning Hayden Glacier are the evidences of recent shrinkage, certain "glacier cornices" present on the wall of a crevasse near its source, and a peculiar ridge of stream-deposited gravel on the lower portion of the ice, which simulates the levees deposited by alluvial rivers.

The right lateral moraine of Hayden Glacier is steep sided and has a height of about 40 feet above the ice it margins, but the descent from its crest to its southern base is 20 to 30 feet greater. A feature of the moraine which at once attracted attention at the time of my visit was its double crest. The southern or true crest of the ridge was in general 5 or 6 feet higher than the adjacent but subordinate ridge on the north side, which was separated from it by a space of about 15 to 20 feet, there being a steep-sided trench some 4 or 5 feet deep between (Pl. XXII). Near the distal end of the double ridge, however, the inner or northern crest was higher than its companion. The explanation of the double crest is that the glacier has recently been lowered by melting about 40 feet, but its marginal portion, covered by the stones, etc., of its bordering moraine, was sheltered from the sun on account of the débris covering it and remained inclosed in the north side of the abandoned moraine. The subsequent melting of the buried ice produced a subsidence of the north side of the ridge and caused a depression to form along the crest of the ice inclosing it. As melting progresses the subordinate ridge on the north side of the true crest of the moraine will migrate down the slope of the ridge and finally disappear when the ice within the moraine is completely melted. The presence of ice in the moraine, as just described, is evidence of recent and rapid melting, and is one of the most significant records of such a change that has come under my notice. The statement just made in reference to the recency of the subsidence of the general surface of Hayden Glacier in all of its lower portion, where not thickly covered with débris, is forcibly illustrated by the fact that when viewing the right lateral moraine from the south a few fragments of ice can still be seen projecting above its crest at a locality about one-third of the way from its distal and toward its source. The appearance of the recently abandoned northern slope of the moraine under consideration is shown on Pl. XXIII, *B*.

Below the present terminus of Hayden Glacier there are fresh terminal moraines abandoned so recently that trees have not as yet

A

B

VIEWS OF DOUBLE-CRESTED MORAINE ON SOUTH SIDE OF HAYDEN GLACIER

A, Looking west toward West Sister Peak; *B*, looking east.

taken root upon them, but they are less fresh in appearance than the totally bare double-crested lateral moraine described above.

In connection with the evidences of recent and conspicuous retreat in the case of Hayden Glacier it may be stated that its companion, Diller Glacier, which flows southwestward from the West Sister Peak, is margined by a fresh, sharp-crested moraine from which the ice has recently subsided at least 30 or 40 feet. This feature may be recognized to the left of the center on Pl. XIX, *B*. In the case of each of these glaciers the evidence noted indicates a recent lowering of their surfaces much more conspicuously than it does a decrease in their length.

Glacier cornices.—Near the head of Hayden Glacier there was at the time of my visit a crevasse of the class termed bergschrunds, a part of the lower wall of which had fallen, leaving its opposite wall fully exposed to the sun until noon, when it became shadowed and melting on its face ceased. This cliff of ice, or rather of granular névé snow, was about 26 feet high. In its face were exposed the edges of thick sheets of clear, stratified, granular snow, between which there were dirt bands ranging in thickness from a fraction of an inch to 3 or 4 inches. A view of it is shown on Pl. XXIV.

On the central part of the precipice, where fully exposed to the sun until noon each day, were two conspicuous cornices, which projected in each instance from 6 to 7 inches beyond the surface below them. The under surfaces of the projecting beds where exposed were slightly fluted at right angles to their length, but this feature was not conspicuous. The precipice at its north end passed under an arch of snow, which formed the roof of a cavern. In the portion thus sheltered from the sun there was no jutting above the lower of the two principal dirt banks, which was the only one extending into the cavern. Near the south end of the precipice, but not shown on the picture, the dirt bands were bent abruptly upward and become vertical near where the névé joined the steep face of the mountain. In this portion of the precipice, which was fully exposed to the sky, melting was equal on each side of the dirt bands, and these appeared as black streaks in the bottom of vertical V-shaped grooves 5 to 6 inches deep.

In the instances described above it is evident that the cornices are due to the more rapid melting of the layer of snow below a dirt band than of the layer above it. The evidence sustaining this conclusion is, briefly, that when a horizontal dirt band is traced from where it is exposed to the sun, and has a cornice above it, into a cavern, where the sun's rays do not exert a direct influence, the cornice disappears; and when followed to where it is vertical and fully exposed to the sky, melting is equal on each side.

The more rapid melting of the snow below than above a horizontal dirt band is evidently due to the absorption of the sun's heat by the dark material, as it is dislodged and washed downward so as to slightly stain the surface beneath. The dirt exerts this influence during its passage over the surface of the exposed edges of the layers of clear snow in the face of the precipice.

In addition to the direct evidence just presented, favoring the hypothesis of differential melting to account for the development of cornices, indirect testimony in opposition to the alternative hypothesis of differential motion is furnished by the fact that the distance from the bergschrund to the head of the névé, where it meets the steep upward slope of the mountain, ranges from 50 to 200 feet, and, as is probable, there is practically no motion in the wedge of snow thus left clinging to the rocks.

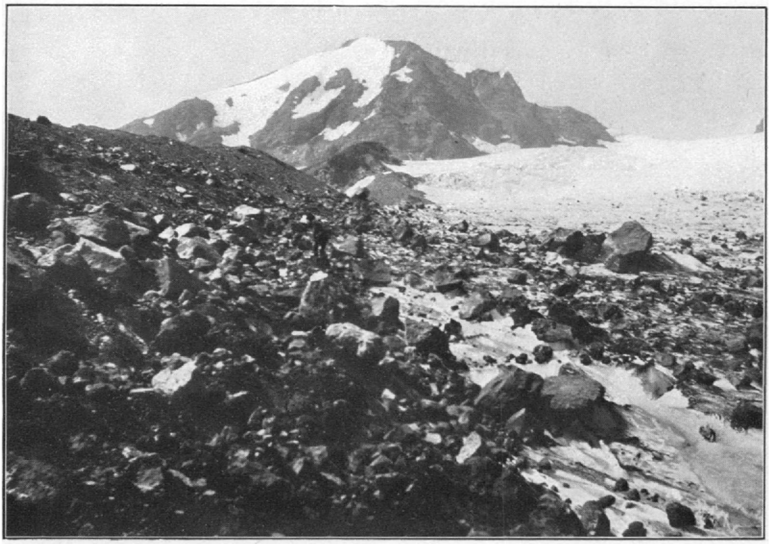
Glacial levees.—At the lower end of Hayden Glacier there was, at the time of my visit, an interesting exhibition of stream-deposited gravel, of the nature of the well-known glacier sand cones, resting on ice and deeply trenched by the stream that deposited it. In this instance gravel was deposited on the ice to a depth of 8 to 12 inches, and for a distance of approximately 150 feet the breadth of the deposit was 15 or 20 feet. The sheet of gravel sheltered the ice beneath and retarded its melting, so that it was left in relief as the adjacent surface of clear ice wasted away, but the stream which deposited the gravel held its position and caused a channel to be melted out along the crest of the ridge, down which it continued to flow as a small torrent during the hours of melting each day. The stream was thus flowing in a trench in the top of a gravel ridge at an elevation of 3 or 4 feet above the general level of the surrounding ice, and resembled an alluvial stream which has formed natural levees along its sides. This analogy in conditions suggests the term glacier levees for raised gravel ridges margining the stream flowing over glaciers, like those shown on the accompanying illustration.

The facts here recorded concerning the recent lowering of the surface in the case of two of the glaciers about the Three Sisters peaks, the explanation of the origin of the glacier cornices described, and the gravel ridges which simulate the natural levees of alluvial rivers, are matters of interest to special students of glaciers, but are by no means all of the instructive features presented by the glaciers under consideration. The Three Sisters peaks, in fact, furnish conspicuous examples of nearly all the characteristic features of alpine glaciers and of the topographic changes such glaciers produce, but to describe them in detail would lead to much repetition of what is already to be found in books descriptive of glaciers in general.[a] The

[a] Russell, I. C., Glaciers of North America, Ginn & Co., Boston, 1897.

A. NORTH SISTER PEAK AND NÉVÉ OF HAYDEN GLACIER.

Looking north.



B. RECENTLY ABANDONED MORAINE ON SOUTH SIDE OF HAYDEN GLACIER; WEST SISTER PEAK IN BACKGROUND.

Looking west.

Three Sisters peaks are also attractive on account of the admirable manner in which they illustrate an advanced stage in the erosion of volcanic cones, as well as for their fine scenery, and furnish a most inviting field for a summer school of geography, geology, and forestry.

FORMER GLACIERS.

As is well known, the mountains in the western portion of the United States were formerly much more extensively occupied by glaciers than at present. Studies in this direction have been made in the Sierra Nevada and in the portion of the Cascade Mountains which crosses the State of Washington, but in Oregon very little has been done in the way of recording the data pertaining to the former glaciers that covered them, and scarcely anything is known, particularly in reference to the glaciers that descended the east slopes of the range. It is on account of the almost total lack of information concerning the glacial records in Oregon to the east of the crest line of the Cascade Mountains that attention is here directed to the few isolated observations in that connection obtained during the recent journey.

RECORDS OF GLACIERS.

The amphitheater on the sides of the culminating pyramid of Mount Jefferson, although seen only from a distance, is evidently due in large part to glacial erosion, and bears evidence of a former much greater extension of glacial ice about that superb mountain than is at present the case.

The presence of strong moraines, both lateral and terminal, on the east side of the Three Sisters peaks has already been mentioned. These moraines show that the great amphitheater opening eastward, on the rim of which the peaks just mentioned, together with Broken Top, are situated, was formerly occupied by an extensive névé, from which a large glacier flowed eastward for at least 10 miles. This glacier probably reached the site of the village known as Sisters, but its maximum extension is as yet unknown.

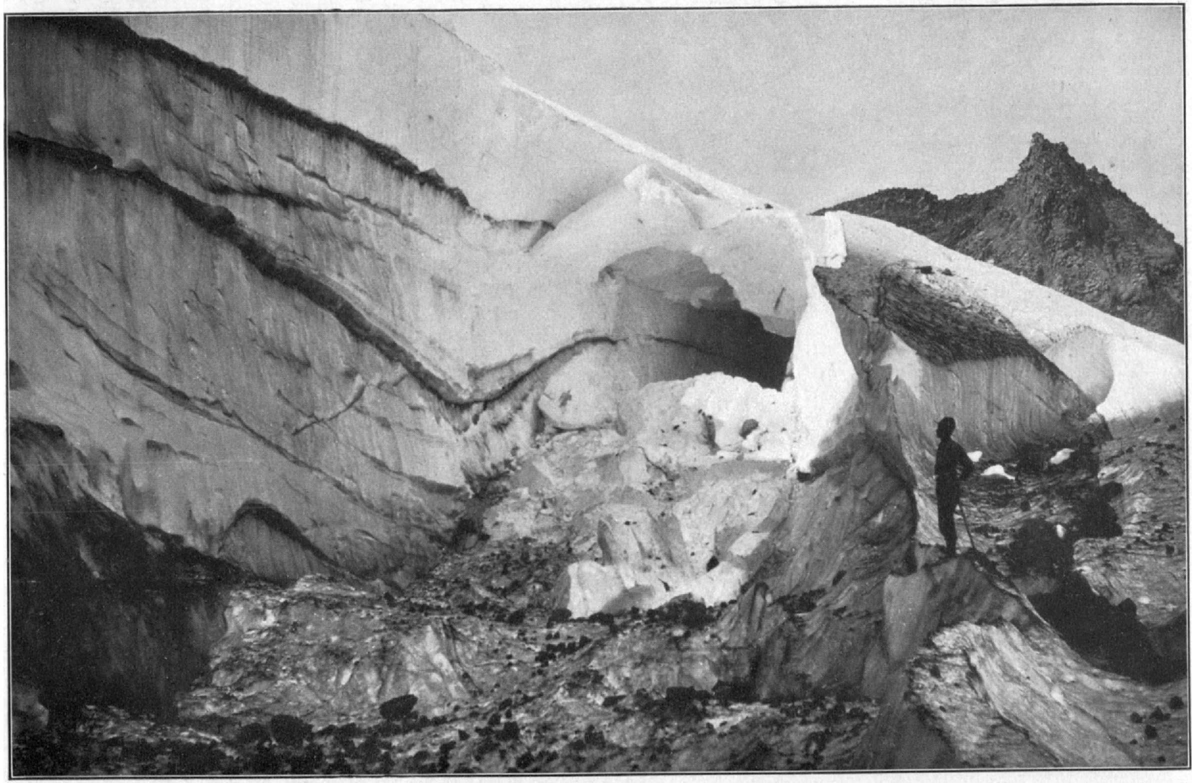
Other glacial records, as already noted, occur on the east side of Diamond Peak, and show that larger alpine glaciers formerly occupied the basins of Odell and Crescent lakes. Still farther south, as has been recorded by J. S. Diller and others, extensive glaciers occupied the region about Mount Mazama. This region was traversed by me during my recent journey, and evidences of more extensive glaciation obtained than have previously been recorded. Between the Klamath marshes and the valley of the Klamath lakes there is a moraine-covered region about 10 miles broad which exhibits the well-known topographic characteristics of glacial deposits. This truly great moraine starts from the elevated region between Mount Scott and Mount Mazama, extends at least 15 miles to the southeast, and forms the bold eastern margin of Klamath Valley in the vicinity of Fort Klamath. The moraine obstructs the drainage of the region about the Klamath marshes and forms a dam through which Williamson River has cut a steep-sided gorge. Only a cursory examination of this extensive region of glaciation was obtained, but from the observations made it is evident that Klamath Valley was formerly occupied by a great glacier having several important tributary ice streams on the mountains from which it flowed. How far to the southeast the glacier extended is unknown, but it evidently occupied a part and possibly the whole of the basin in which the Klamath lakes are situated.

EXTENT OF FORMER GLACIERS.

The observations relative to the glaciation of the Cascade Mountains, just mentioned, although few and fragmentary, taken in connection with evidences of glaciation revealed by the topography of the higher portion of the range as seen from the east, and other related evidence, shows that during a former period, which can be safely correlated with the Glacial epoch, great snow fields covered the summit portion of the Cascade Mountains throughout their entire extent across Oregon, and from this névé region large alpine glaciers flowed eastward down the mountains. Glaciers also occurred on the west side of the range, but no new facts concerning them can be presented at this time. The conditions were of the same general character as existed on the Cascade Mountains in Washington,[a] but the eastward-flowing ice streams were seemingly less extensive. An instructive suggestion in reference to the glaciers on the east side of the Cascade Mountains in Oregon is furnished by the fact that in the southern portion of the State, in the vicinity of Mounts Scott and Mazama, the eastward-flowing glaciers are larger and of greater length than farther north in the vicinity of the Three Sisters peaks and Mount Jefferson. If this conclusion is sustained by future studies, an explanation of it will perhaps be suggested by comparing the present climatic conditions of the two regions.

A conspicuous feature of the topography of the higher peaks of the Cascade Range is the presence of a terrace-like shelf or shoulder about several of them at an elevation of about 8,000 feet and approximately coinciding with the cold tree-line and also with the lower limit of the existing glaciers. A flattening of the mountain side in the manner just referred to, is a noticeable feature of Mount Jefferson.

[a] Russell, I. C., Preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 150–193.



GLACIER CORNICES ON WALL OF CREVASSE AT HEAD OF HAYDEN GLACIER.

Looking north.

and of South Sister Peak (see Pl. XIX, A), as well as several other of the higher summits. The explanation of the origin of the shoulders seems to be that during some former time, when the conditions for the formation of glaciers were more favorable than now, "mountain-side glaciers" were formed about the higher peaks and descended their sides to where the lower margins of the shoulders are located, and by headward extension excavated depressions for themselves. When a peak was entirely surrounded by névé fields, a flattening of the slopes of the mountain resulted and was left as a topographic feature when the glaciers melted; when the névé fields were local individual recesses or cirques were produced, and when a more advanced stage of glacier work was reached "hanging valleys" were excavated. The existing glaciers of the Cascade Mountains in Oregon are, at least in a general way, situated on the shoulders referred to and seem to be broadening them by reason of their headward extension.

In connection with the former great extent of the glaciers of the Cascade Mountains, an instructive fact is furnished by the presence of extensive moraines on Mount Newberry, a brief account of which has already been given. So far as is at present known this small isolated center of glacial dispersion, and a similar area of glacial ice on Steins Mountains, in southeast Oregon, were the only glaciers in the central and eastern portions of the State during the Glacial epoch. Mount Newberry is about 40 and Steins Mountains are approximately 175 miles east of the crest of the Cascade Mountains.

LAPILLI SHEET.

EXTENT AND DEPTH.

On the preceding pages several references have been made to a surface covering of pumiceous lapilli which is widely distributed over west-central Oregon. This sheet of loose, unconsolidated fragments of pumice was first clearly recognized during my recent journey on the Great Sandy Desert to the south of Hampton Butte. It was also observed at many localities about the Pauline Mountains and in the vicinity of Christmas Lake, where it has been drifted by the wind into extensive dunes. It is present in large quantities about Mount Newberry, occurs on the moraine about the Three Sisters peaks, covers deeply the region drained by Deschutes River above Benham Falls, is present in the moraines about Odell and Crescent lakes, is everywhere conspicuous on the flat country about the Klamath marshes, forms a part of the extensive moraines adjacent to Klamath Valley on the east, occurs on the slopes and occupies the gulches about Mounts Scott and Mazama, as has been described by J. S. Diller, and southwest of Crater Lake extends for at least 30 miles west of the crest of the Cascade Mountains. Its known extent is thus about 120 miles from east to west and an equal distance from north to south, or an area of 14,000 square miles. Its actual borders when finally determined will, there is no doubt, be found much to exceed these limits.

The depth of the sheet of pumice varies from place to place, and in only a few localities is its actual thickness known. Its depth is probably greatest in the valleys and least on the steep slopes. Although, like a fall of snow, it originally fell evenly over the surface, though more abundantly and in larger fragments near the volcanoes from which it came than at a distance, it has since been washed down from inclined surfaces and concentrated in depressions. On the Great Sandy Desert excavations 70 feet deep are said to have failed to pass through it. In the generally flat country drained by the Deschutes above Benham Falls excavations show its minimum depth to be from 6 to 8 feet, but in many places and over large areas it is much thicker. In the extensive region north of the Klamath marshes and draining to them, the banks of streams and bluffs above copious springs in several places reveal a thickness of 30 to 40 feet or more of pumice, the bottom of the deposit being still concealed. In describing the sheet of pumice about Crater Lake, Diller [a] mentions a thickness of 10 feet. While conspicuous variation in thickness occurs and no average depth can as yet be stated, the above-mentioned facts show that the volume of the deposit is very great, so great in fact that it is to be measured in tens of cubic miles.

COMPOSITION, SOURCE, AND AGE OF LAPILLI SHEET.

The sheet of pumice just described is composed of rough angular fragments, which on the Great Sandy Desert range in size from dust particles up to grains that are about one-fourth or perhaps one-half of an inch in diameter. It is much coarser about Mount Newberry, where fragments a foot in diameter were seen, but so far as now known the fragments are largest on the flat country adjacent to the Klamath marshes on the west, where angular masses more than 2 feet in diameter are common. The pumice, as shown by determinations made by F. C. Calkins, of the United States Geological Survey, of samples collected on the Great Sandy Desert, on Mount Newberry, and near the Klamath marshes, is andesite. About Crater Lake the surface sheet of pumice is described by J. S. Diller as being principally dacite, with less quantities of andesite. The observations available are too few to permit a final statement, but the facts in hand seem to indicate that the sheet of pumice under consideration is tolerably uniform in character and composed principally of andesite.

As to the location of the volcanoes from which the pumice was

[a] Diller, J. S., and Patton, H. B., Geology and petrography of Crater Lake National Park: Prof. Paper U. S. Geol. Survey No. 3, 1902, pp. 39–41.

blown into the air and widely distributed, for the most part only tentative suggestion can at present be offered. In part it came from the recent volcanoes, five in number, situated in the old erosion amphitheater of Mount Newberry. This conclusion is based on the fact that the crater rims of those volcanoes are largely composed of andesitic pumice, and large fragments of the same nature are abundant all about the region where they occur. This was probably not the only center of dispersion, however, as the fragments of pumice are still larger and more abundant in the region draining to the Klamath marshes, and, as stated by Diller, were supplied at least in part by eruptions in the great depression now occupied by Crater Lake.

In reference to the date of the explosive volcanic eruptions that supplied such vast quantities of pumice, the fact that this material forms a large percentage of the glacial moraines on Mount Newberry, the Three Sisters peaks, and about Odell and Crescent lakes, shows that the eruption occurred previous to or during the Glacial epoch. The moraines about Mount Newberry and near the lakes just mentioned are covered with pumice, showing that at least in part the eruptions which furnished it were of later date than the glaciers which deposited the moraines. This last conclusion is sustained also by the fact that the recent lapilli craters in the old erosion amphitheater of Mount Newberry and the lava flows given out by them are clearly subsequent to the time when that depression was filled with glacial ice. According to Diller the eruptions of pumice about Crater Lake occurred during and after the time the region about it was occupied by glaciers.

IMPORTANCE OF LAPILLI SHEET.

The sheet of pumice that covers so much of central and western Oregon is thus of much scientific interest, and when its history is fully known will furnish a most instructive chapter in the geologic records of the State. It is also of great practical importance, since it forms the surface covering over thousands of square miles, and has a determining influence on the agricultural possibilities of the entire region it occupies.

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