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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

AND

WATER RESOURCES

OF THE

SNAKE RIVER PLAINS OF IDAHO

BY

ISRAEL C. RUSSELL

WASHINGTON

GOVERNMENT PRINTING OFFICE

1902

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., May 14, 1902.

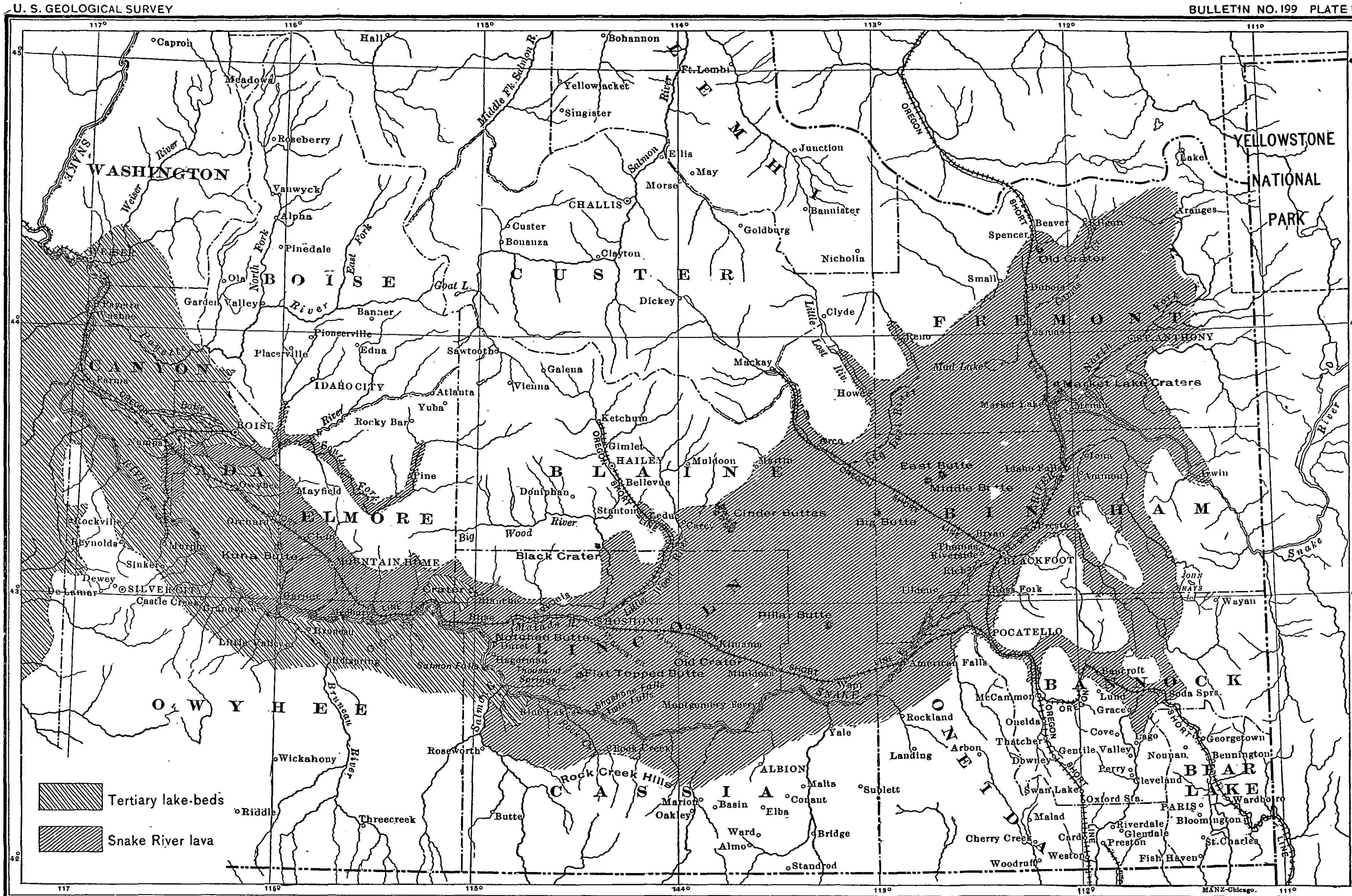
Sir: I have the honor to transmit herewith the manuscript of a report on the geology and water resources of the Snake River Plains of Idaho, by Israel C. Russell, with recommendation that it be published as a bulletin of the Survey.

The field work on which the report is based was done under the supervision of the Division of Hydrography, and the paper was originally intended as a water-supply paper. Mr. Newell has decided, however, that the geological portions of the paper so far outweigh in importance and extent those relating strictly to hydrography that he recommends its publication as a bulletin rather than a water-supply paper.

Very respectfully,

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

Hon. Charles D. Walcott,
Director United States Geological Survey.



SKETCH MAP OF SOUTHERN IDAHO

Showing approximate extent of Snake River lava

BY I. C. RUSSELL

Scale

10 0 10 20 30 40 50 miles

GEOLOGY AND WATER RESOURCES OF THE SNAKE RIVER PLAINS OF IDAHO.

By Israel C. Russell.

PART I.—PHYSIOGRAPHY AND GEOLOGY.

INTRODUCTION.

NATURE AND OBJECT OF THE RECONNAISSANCE.

The field work which furnished the basis for this report was carried on from July 5 to September 12, 1901, under the general direction of Mr. F. H. Newell, hydrographer of the United States Geological Survey. The region examined is in southern Idaho, and is included for the most part in the area that is commonly termed the Snake River lava plains. On account of the general absence of water this region is also frequently designated the Snake River Desert. As the vast tract of approximately level country referred to is not entirely occupied by lava and as by far the greater portion of it is clothed with vegetation, and includes large tracts of open forest, it is evident that neither of the names just mentioned is appropriate, and to avoid conveying false impressions it will be termed in this report the Snake River Plains. The region does not constitute a single level plain, but exhibits considerable variation in altitude, slope, and character of surface, etc., in its various, although indefinitely bounded, parts. In a general way it may be considered as a series of plains which merge one with another and have many characteristics in common.

The main objects of the reconnaissance were to ascertain how far the geological conditions, particularly beneath the broad lava-floored plains bordering Snake River, favor the hope of obtaining flowing water by drilling wells, and where test wells should be put down in order to determine the correctness of inferences based on geological and other conditions. As is well known, in order to ascertain the artesian conditions in any region, it is necessary to have an intimate knowledge of the physical condition of the rocks below the surface, especially as regards the presence of alternate pervious and impervious beds and the position they occupy—that is, whether they are horizontal, inclined, folded, broken, or in any way displaced. To obtain data of this nature in reference to the Snake River Plains, it is necessary to study the geology of a region having an area of 25,000 square miles, but owing to the limited time available only a small part of this task was undertaken.

Work was begun in the region about Boise, Idaho, which had previously been studied in detail by Dr. Waldemar Lindgren,[a] and carried eastward across Elmore, Lincoln, and Blaine counties and into Bingham County as far as Blackfoot. The route traversed was as follows: Snake River from near the mouth of Bruneau River to Shoshone Falls, with excursions southward into Owyhee and Cassia counties; from Shoshone Falls northward through Shoshone, and up Big Wood River, for about 20 miles; northeastward along the west border of the Snake River Plains from Carey to Arco, thence eastward across the broad plain surrounding Big Butte and its two lesser companions to Blackfoot. At Blackfoot the party was disbanded. Included in this report also are certain observations made a year before, during a journey from Market Lake westward to Big Lost and Little Lost rivers, Birch Creek, etc., and back by the way of Mud Lake.

The general routes followed during the two journeys outlined above are indicated on Pl. I. The distance traveled was about 550 miles without reckoning numerous side excursions. The area more or less thoroughly examined includes about 1,200 square miles. As may be judged from these facts, the aim in view was a geological reconnaissance, and not a detailed survey. It is hoped, however, that the main object of the examination was accomplished, and that the numerous observations made will be of value, if for no other reason, because they pertain to a region the geology of which was previously almost entirely unknown.

TOPOGRAPHY.

The Snake River Plains consist of a generally flat area bordered by rugged mountains, and extend in a curved course concave to the north entirely across the southern portion of Idaho. The length of this belt measured along its medial line is about 350 miles and the width is generally from 50 to 75 miles. Its area, as estimated by Lindgren, is 34,000 square miles. Snake River traverses this rudely crescent-shaped plain throughout its length in a great curve concave to the north, which has a radius of some 175 miles. In a far-reaching view the flat country through which the Snake River finds its way presents the broader features of a vast level-floored stream-eroded valley. A nearer acquaintance, however, shows that it is a built-up plain, formed principally of lava sheets, and does not owe its major surface features to erosion.

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[a] Geologic Atlas U. S., folio 45, Boise, Idaho, 1898.

The best way, perhaps, to convey to the reader an idea of the leading topographic features of the country discussed in this report, and at the same time prepare the way for a more detailed study, is to sketch in outline the leading events in its geological history.

Southern Idaho is a region composed of geologically old rocks which formed an ancient land surface having a rugged relief. In the depressions of this surface during later geological time extensive lake and stream deposits and vast lava flows were spread out. The older rocks, sharply separated from the younger by a long time-interval, during which extensive movements in the earth's crust and deep erosion took place, are mainly granite, rhyolite, quartzite, and limestone. The youngest of these is probably the limestone, which is thought to be of Carboniferous age. These rocks were variously folded, faulted, and upheaved into prominent mountains, and deeply dissected by a large river with many tributaries which was long lived. The valley of the main stream, the ancient representative of Snake River, became broad and had many important tributary valleys opening from it and extending far into the bordering mountains. The sharp-crested mountain spurs between the lateral valleys are in some instances prolonged far into the main depression.

After the topography had passed maturity—that is, after the streams had excavated deep valleys, leaving sharp-crested and frequently serrate divides between them—the main stream was obstructed, possibly by lava flows, but as seems more probable, by an upward movement of the rocks athwart its course in the region now included in western Idaho and eastern Oregon, and a lake was formed which occupied a large portion of the country now included in the Snake River Plains. This water body, named by Lindgren Lake Payette, received the sediment brought in by tributary streams and the dust blown out by volcanoes, and became deeply filled. These sediments, with a known depth of over 1,000 feet, are now well exposed, particularly in southwestern Idaho. In places they contain impressions of leaves of trees which grew on the borders of the old lake, the shells of fresh-water mollusks, the bones of land mammals, and other remains. The fossils record a Tertiary (Miocene) age.

Before Lake Payette came to an end the vast lava flows which now form such a conspicuous feature of the Snake River Basin began to be outpoured. In fact, the lava and the sediments of Lake Payette and of a later lake in the same basin, were contemporaneous, the lava and lake sediments being interbedded. Some of the lava flows entered the lake, and the occurrence of thick beds of volcanic fragments (lapilli), and of scoriaceous, glassy lava, with a torn and slag-like structure at the base of thick sheets of usually compact basalt, record the energy of the steam explosions that followed. Highly liquid lava continued to be poured out at various intervals from a large number of volcanic vents, and spread out in the previously formed basin, making, in truth, lakes of molten rock. Besides these two processes of upbuilding, that is, sedimentation in lakes and the outpouring of lava which spread widely, there was a third, namely, the washing of débris from the uplands and its deposition in alluvial cover and widely extended sheets of sand, gravel, and silt in the valleys. In addition, there are wide-spread æolian deposits. The volcanic eruption continued after the lakes were either filled or drained, so that by far the larger portion of the Snake River Plains is directly underlain by sheets of basalt. The last of the extensive volcanic discharges happened in very recent times, and the process of stream deposition still continues.

The leading characteristics of the Snake River Plains at the time of their formation still remain, but the sheets of lacustral and stream-deposited sediments, and the equally well-stratified layers of hardened lava, although for the most part still horizontal, have in places, more particularly in southwestern Idaho, been gently flexed and in certain instances, near the bases of the bordering mountains, broken and faulted. The principal changes in the surface features of the plains since their floors of lava were formed are due to erosion. These changes in general, however, have not been sufficiently pronounced to greatly alter the character of the broad, flat bottoms of the valleys, and to-day, especially when viewed in the strong side light of early morning, or in the greatly lengthened purple shadows of evening, the plains seem to be absolutely level, and from many points of view of ocean-like extent.

The statement that the broad, lava-covered area on each side of Snake River throughout its course across southern Idaho is a plain is strictly true, so far as its prevailing and most impressive features are concerned, but it is a dissected plain. In places its surface is mildly uneven, and in other places excessively rough, owing to the character of the naked lava of which it is in part composed. It is marked also, as the practiced eye readily discerns, by many volcanic cones, and by broad, low elevations, formed of lava which was poured out from widely separated vents and spread in various directions. In the central portion of the northeastern extension of the plains, midway between Snake and Big Lost rivers, there are three prominent buttes, two of which, Big and East buttes, are ancient rhyolitic volcanoes which rise as islands through the surrounding basalt.

The channels cut by streams in the Snake River lava and the elevations that rise above its surface are in reality all minor features of the topography and do not detract from the impression, which is strengthened by familiarity, that the country bordering Snake River is essentially one vast plain from near the eastern border of Idaho to beyond the Oregon boundary.

The northern and southern borders of the Snake River Plains, or more correctly, so far as the southeastern portion of Idaho is concerned, the east and west borders, are defined by rugged mountain ranges, several of which extend into the lava-covered country for a score or more miles in much the same manner that headlands and capes on a ragged coast project into the ocean. In several instances the lava poured out in the great central plain entered tributary stream-cut valleys and flowed up them from 20 to 30 miles, or until the rising gradient checked the advance of the tide of molten rock. The upstream ends of these lateral tongues from the main lava sheets are now usually covered with alluvium brought down by streams from higher portions of their courses. Alluvial fans and talus slopes are conspicuous features about the bases of the mountains, and chronologically both preceded and followed the widely extended lava sheets. This is an instructive fact, as the buried alluvial fans favor the passage of water from the mountains to the strata beneath the lava sheets flooring the plains.

The mountains to be seen from the Snake River Plains are bold and rugged, and as a whole present exceedingly sharp and serrate sky lines. The main range in south-central Idaho, known as the Sawtooth Mountains, expresses both in its name and its salient features the prevailing characteristic of the mountain crests throughout a large portion of the State. These pinnacled mountain tops are to a great extent composed of quartzite, but granite spires and prominent limestone ridges are in numerous instances nearly as sharply defined. The granite, even in valleys and on the immediate borders of the central lava plains, as, for example, between Boise and Mountain Home, presents a vast number of monumental and spire-like forms, which rise from widely expanded talus slopes.

The leading topographic features of southern Idaho may be summarized as deeply sculptured mountains surrounding a vast, nearly level, plain. The mountains rise boldly to a height varying from a few hundred to over 6,000 feet above the plain, and to elevations ranging very commonly from 7,000 to 10,000 or more feet above the sea. In its western part the plain has a general elevation of from 2,900 to 3,200 feet, and in its broadest and most characteristic portion about Big Butte or between Blackfoot and the "Lost River country" of in general from 4,500 to 6,000 feet above the sea.

CLIMATE.

The climate of the Snake River Plains has for its leading characteristics aridity, prevailing high temperatures in summer, and severe cold in winter. One of the most marked features in the atmospheric conditions at nearly all seasons is the great range in temperature between day and night.

The mean annual precipitation is about 13 inches, but many local variations occur. Nearly all the water that reaches the thirsty lands comes in winter and spring. During the growing season the soil is invariably parched, and successful agriculture without irrigation is seemingly impossible.

The summers are decidedly hot. Not infrequently for many consecutive days and even for weeks at a time the temperature during the hours of sunshine is over 100° F. and frequently reaches 105° F., and reports by local observers of 110° to 115° in the shade are not rare. Owing to the dryness of the atmosphere, however, the heat is seldom oppressive, and sunstroke is said to be unknown. Under the prevailingly clear skies in summer radiation is rapid and the nights are nearly always cool. Exceptionally warm nights occur when the sky is clouded, and radiation from the heated soil and rocks is checked.

In winter the atmosphere is even clearer than in summer, as the rain and snow remove the dust which is ever present when the soil is dry. The air is cold and the temperature has a greater daily range in winter than in summer, frequently falling far below zero, Fahrenheit. During the winter of 1898–99 the minimum temperature at Blackfoot was −30° F. and at Minidoka −28° F., while the year following, at Lost River, situated on the western border of the plains, in the entrance to a tributary valley, a temperature of −41° was recorded. During the year 1898 the last "killing frost" in spring at Blackfoot was on June 5, and the first frost during the succeeding fall was on September 29; at Minidoka the corresponding conditions occurred on May 14 and September 4. The snowfall, while aggregating during certain winters from 30 to 45 inches or more, varies greatly from year to year and from place to place, but seldom remains long on the ground. The sudden snowstorms are usually succeeded quickly by thaws during the hours of sunshine, and sleighing is seldom practicable. Warm winds, termed "Chinook winds," frequently occur in winter, during the prevalence of which snow, if present, disappears as if by magic, leaving the plains and the lower slopes of the bordering mountains bare. Large numbers of horses, cattle, and sheep are pastured on the plains throughout the winter, and require to be fed only during the more severe storms. In winter the skies, although frequently clouded, are usually clear, especially at night, and the stars are of phenomenal brilliancy.

The prevailing winds, often heavily dust-laden, are from the west, and at many times, especially in the fall, blow with such strength and constancy as to become trying to a person's nerves. In summer and fall strong afternoon winds frequently occur, which die away at sunset; these are almost invariably from the west. These strong breezes are nearly as regular in their periods as the sea breezes on lands bordering warm seas, but instead of bringing a refreshing coolness they are frequently hot, and to one facing them seem the breath of a furnace. On the broad plains miniature whirlwinds are of frequent occurrence, particularly on hot afternoons, and the dust carried upward by them forms tall columns with hollow centers, in which, when they are near the observer, a spiral motion can be discovered. These dust columns are sometimes 2,000 or 3,000 feet high, and are a characteristic feature of the parched desert-like plain when heated by the intense summer sun.

Owing to the great extent of the plains, their variations in altitude, the influence of the adjacent mountains, and other factors, there are many local variations in the climatic conditions. The most marked differences are in temperature and in the length of time the land is snow-covered. These variations are most marked in the broad, nearly flat areas forming the general surface and in the limited tracts of level land in the canyons and canyon-like valleys. In the canyon of Snake River and its tributaries below Shoshone Falls the atmospheric conditions are markedly different from those on the surfaces of the adjacent plains. In the canyons the temperature in summer, owing to the shelter from the winds afforded by the bordering precipices and the reflected and radiated heat from the black rocks, is usually much higher than on the open plains. Cool breezes frequently blow along the river, however, tempering the intense heat. Again, in winter, owing largely to the ameliorating influence of the river, as well as the protection afforded by the bordering cliffs from the freezing blasts that sweep over the plains, the mean daily and monthly temperatures in the canyon are considerably higher than on the neighboring undissected plain. Snow seldom lies on the ground in the canyon bottoms for more than a few days at a time.

The canyons furnish many favorable places for orchards, vineyards, and gardens, not only on account of the intense heat and strong light during the growing season, when they are essentially hothouses, but because water from springs with a temperature of about 60° F. can frequently be had for irrigation.

In brief, the Snake River plains present a typical illustration of an insular or continental climate, such as is characteristic of regions of mild relief, remote from the tempering influences of the ocean, and deprived of their requisite share of moisture by the presence of lofty mountains in the path of the prevailing winds.

One result of the climatic conditions, and especially of the dryness of the air, is the healthfulness of the land. So far as I am able to judge, it is a region exceedingly favorable to persons suffering from disease of the lungs.

To lovers of nature and all who rejoice in scenes of natural wildness unmodified, or what is too frequently essentially the same thing, unmarred by the hand of man, the plains of southern Idaho present exceptional attractions. One must become familiar with their characteristics, however, and learn to judge them by their own standard before their beauties are fully revealed. To the traveler from humid lands, where every hillside is clothed with verdure and every brook flows through a shadowy vale, they will at first seem repellent deserts, on which a long sojourn would be intolerable. This, I think, will be the first impression, especially if beheld at noontide in summer or beneath a gray wintry sky. But to one who rides for weeks or months across their seemingly boundless surfaces, sleeping at night beneath the stars, they are found to have charms unthought of by the casual passer-by. In the glare of the unclouded summer sun the plains are featureless, or perhaps their expression is distorted and rendered grotesque or vague and meaningless by the deceptive mirage. At such time the flat land vanishes in distant haze, and the bordering mountains, if visible at all, are but uncertain flickering shadows on a glowing sky. In the clear side lights of early morning, however, all uncertainty and indefiniteness vanish. The flat land has details everywhere on its surface. The mountains stand boldly forth as sculptured forms of amethyst and sapphire, every line on their deeply engraved slopes, although leagues distant, clearly visible. When the sun is high in the cloudless heavens the plains are gray, russet brown, and faded yellow, but with the rising of the sun and again near sunset they become not only brilliant and superb in color, but pass through innumerable variations in tone and tint. When the approaching dawn is first perceived, the sun seemingly a great fire beneath the distant edge of the plain, a curtain is quickly drawn aside, revealing a limitless picture suggestive of the view a mariner sometimes has on approaching a bold coast while the actual shore line is still below the horizon. The distant mountains, rising range above range and culminating in some far-off sun-kissed peak, are of the most delicate blue, while all below is dark and shadowy. As the sun mounts higher the colors deepen, becoming violet and purple, of a strength and purity never seen where rain is frequent. Purple in all its rich and varied shades is the prevailing color imparted to arid lands when the sun is low in the heavens. As the dawn passes and the light becomes stronger the rich hues fade, the mountains recede and perhaps vanish in the all-pervading haze, details become obscure even in the immediate foreground, and the eye is pained by the penetrating light. The shadows, if canyon walls are near, are sharply outlined and appear black in contrast with the intense light reflected from the sun-bathed surfaces.

As evening approaches there is a gradual change from glare to shadow. The broad plains become a sea of purple on which float the still shimmering mountains. The shadows creep higher and higher, until each serrate crest becomes a line of light, margining rugged slopes on which every line etched through centuries by rills and creeks reveals its history. The mountains seemingly grow in stature and unfold ridges and buttresses separating profound depths. One marvels at the diversity and strength of the sculpturing on what but a few moments before appeared flat, meaningless surfaces.

As the sun sinks lower there are, perhaps, a few clouds near at hand which are seemingly burned or rendered molten by the intense heat, but more frequently only a nebulous glory appears in the vaporless air. The violet and purple shadows creep higher and higher on the mountain slopes, and at last each crest and pinnacle, still sharply outlined, becomes but a shadow. During the cloudless summer the glories of sunset are on the earth, not in the sky. As the sun disappears a well-defined twilight arch arises in the east, the shadow of the earth on the dust particles in the air. The upper margin of the arch is at first well-defined, but fades as it rises and is lost when the stars begin to gleam in the dark heavens. The cool, star-lit summer nights are wonderfully magnificent. The heavens, without a cloud, are filled from horizon to zenith with stars which burn with a steady planetary light, such as is seen in our eastern humid lands only during clear winter weather.

Although the summers in southern Idaho, in common with the rest of the great arid region of which it is a part, are characteristically cloudless, sometimes completely so for many days and even a week or two, yet as fall approaches vapor banks appear and the glory in the heavens and the magnificence of the earth increase a thousand fold, surpassing the ability of even a poet to describe. One feature of the weather in early fall is the gathering of thunder storms about the mountains and their advance with fierce lightning and deep-toned thunder over the plains, where they melt away and disappear ineffectually in the drier air. At times these struggles of opposing forces are repeated daily, and a more advanced position is gained each afternoon by the invading storm, until a few pattering rain drops fall, or perchance a brief drenching downpour occurs on the thirsty sagebrush lands. More often, however, the vast banks of brilliantly illuminated cumulus clouds are festooned below with descending rain sheets which fail to reach the earth. Accompanying these inefficient thunder squalls there sometimes comes a heavily dust-laden wind which advances across the land like a wall of blackness, obscuring the landscape, and as it passes the observer producing a twilight even when the sun is high in the heavens. At such times the eyes are blinded and the throat is choked by the all-penetrating dust particles. These dust storms, unaccompanied by rain, explain the origin of the fine yellow soil which covers much of the plains, mantles the sides of isolated volcanic hills, and extends far up the neighboring mountain slopes.

The reader will perhaps think that I have devoted too much space in attempting to record some of the leading features of the climate and weather of this region, but it is to be remembered that there is an intimate connection between the surface features of a region and the climatic conditions to which it is exposed. Not only is the nature and origin of the soil of the Snake River Plains to be looked for in part at least in the work of the winds, but the canyon walls, the widely spreading alluvial fans, and the details in the bordering mountains would not be what we now find if humid instead of arid conditions had long prevailed. Still more quickly responsive to climatic conditions is the vegetation which soils are permitted to produce.

VEGETATION.

The ever-present and characteristic plant of the Snake River Plains is the sagebrush (*Artemisia tridentata*), which grows abundantly and we might say luxuriantly in the dry soil, from the bottom of the Snake River Canyon up to an elevation of some 2,000 or 3,000 or more feet on the mountains bordering the plains. It covers the broad arid valleys almost completely and is seldom lacking over any extensive area, except where fires have recently occurred or cultivated fields supplanted it. On the plains in summer fire sometimes sweeps through the sagebrush in much the same manner that it does over the prairies, and "burns" are produced. The "sage," in the localities most favorable to its growth, attains a height of about 10 feet, but usually is not over 3 feet high, the clump of bushes being commonly 6 to 8 feet apart. One can ride or walk over the sagebrush plains with but little difficulty. The light grayish-green leaves of this ubiquitous plant give color, or perhaps more properly lack of color, to the plains and enhance their monotony. Although the Snake River Plains are frequently termed a desert, the name is true only in the sense that they are practically without water. There is comparatively little of the surface that is entirely destitute of plant life. In fact the flora is found to be abundant and varied, if one examines it closely. There are many lovely plants that blossom in early spring, filling the air with fragrance, and in summer and fall the yellow of sunflowers and of the still more plentiful "rabbit brush" (*Bigelovia graveolens*), a relative of the goldenrod, frequently give broad dashes of brilliant color. Beneath the sagebrush in a state of nature nutritious bunch grass grows abundantly and still furnishes pasturage where sheep have not ravished the land. Where the plains are broadest, that is to the north of the Oregon Short Line Railroad and especially in the vicinity of the three steptoes, Big, Middle, and East buttes, much of the land is without sagebrush and in the condition of a rolling prairie which supplies excellent winter pasturage.

One of the surprises met with during the reconnaissance which furnished the basis of this report was the finding of a true forest over several hundred square miles of the surface which is designated on many maps as the "Snake River Desert." On the three prominent buttes situated in the central part of the plain between Blackfoot and Big Lost River there is a thrifty growth of junipers. This forest extends far out on the plain lying east of the buttes, and covers in all about 175 square miles. The trees, although small, seldom, in fact, attaining a height of over 15 or 20 feet, are thrifty and are valuable for fence posts, firewood, etc. On Big Butte there is, in addition to a few junipers, a vigorous growth in the most favorable places of pine and young firs. An older forest, destroyed by fire, is still standing, the trees, principally pines and firs, being from 30 to 40 feet high. The most thoroughly tree-covered portion of the plains, however, is situated near their western border, and extends from a point a few miles south of Arco southwestward about 50 miles, in an irregular belt from 10 to 15 miles broad. This tract, about 800 square miles in area, is an open forest, consisting principally of pine and fir. This forested area embraces the Cinder Buttes, and there touches the mountains bordering the Snake River Plains on the west. In all other portions of the west border of the tree-covered region it is separated from the mountains by black, barren lava flows of recent date. Where the trees grow there is a fine, rich soil covering old lava sheets, and among the trees luxuriant bunch grass clothes the ground. This tree- and grass-covered region, instead of being a desert, is park-like in appearance, and, in reality, is a beautiful and attractive country.

Like many other extensive portions of the Snake River Plains, this region would become highly fruitful if water could be had for irrigation, and it is by no means certain that wheat and other grain will not grow without artificial watering. It is remote from streams and springs, however, and owing to this fact it has been saved from the destructive inroads of domestic sheep and its primitive wildness has been preserved.

To the west of East and Middle buttes there is a tract of about 200 square miles which is without trees or bushes, even the sagebrush being absent, but it is clothed with luxuriant bunch grass, and furnishes as typical an example of a rolling prairie as one can find in the far West.

During the winter months, when snow lies on the Snake River Plains, tens of thousands of sheep are driven there for pasturage, and thrive on the withered grass and nutritious shrubs. Snow supplies the place of water, or else, on melting, fills small depressions and forms water pockets. The area of these natural pastures is so great, however, that but little damage has as yet been done, except in the neighborhood of the streams which flow down from the mountains.

FAUNA.

On the plains, more especially in the broader portions in the vicinity of the three prominent buttes that break their monotony, big game is still to be found. Antelope roam over them throughout the year, while deer and elk find there a safe winter range. The mountain sheep is also present in winter, and the mountain goat is reported to have been met with. The great horn cores of the mountain sheep are occasionally to be seen bleaching among the clumps of sage bushes. Occasionally, also, the horns and bones of the bison are found, showing that southern Idaho was within the former range of that species. Besides the animals just mentioned, the plains are visited by bears, wolves, lynxes, foxes, skunks, etc., and the coyote is only too abundant. Ducks, geese, and other birds visit the occasional ponds and streams, particularly along Snake River and on the west side of the plain in the Lost River country. Grouse of several species are common, and smaller birds are by no means rare. The life of the isolated timbered region referred to, and in fact of the Snake River Plains generally, has not been critically studied, and no doubt has many novelties with which to reward the naturalist.

SOIL.[a]

Although the soil of the Snake River Plains has well-marked variations, it may be said that in general, and in fact almost everywhere, it is fertile and needs but the requisite moisture to enable it to produce a strong growth of either native or cultivated plants. So generally is the condition of the soil favorable to agriculture that it is easier to designate the exceptions than to describe the favored localities. About the border of the plains the material washed down by streams from the mountains is in numerous localities a coarse gravel, but although requiring much water when irrigated such land is not infertile. Over large areas the soil covering is thin and rock fragments are so numerous that under the most favorable conditions for irrigation the land could not be economically cultivated. Portions of the plains, too, are covered with recent lava on which practically no soil has accumulated. Examples of such black, rugged surfaces may be seen along the Oregon Short Line Railroad between American Falls and Minidoka, and again to the north of Shoshone, but the largest tract of recent lava occurs on the west side of the plains opposite Blackfoot, near the Cinder Buttes. Comparatively small areas of a similar character occur near Market Lake and between Big and Middle buttes. In the western portion of the Snake River Plains, south of Snake River, extensive areas of white lake beds are present, but are usually covered with yellowish, quartzite cobbles. Drifting sand occurs, particularly to the

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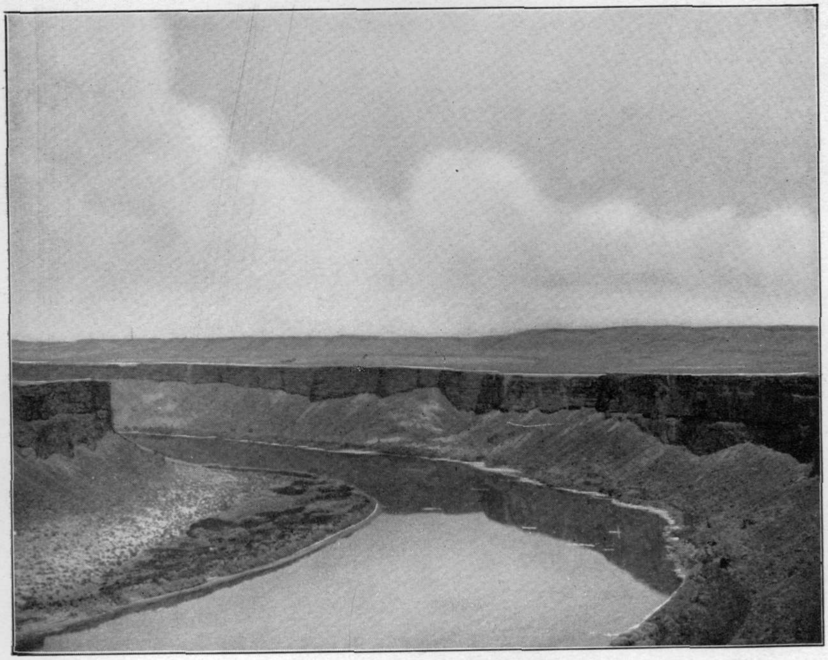
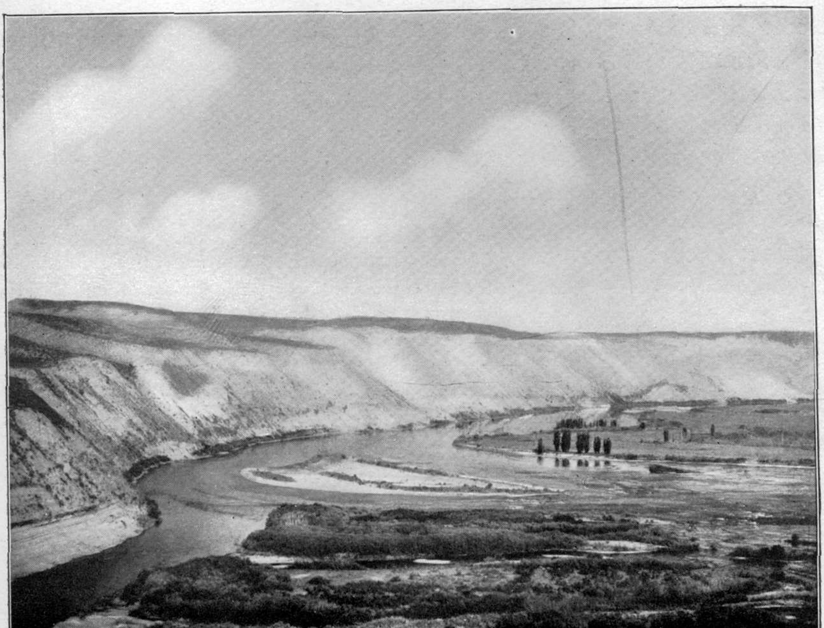
[a] See also pp. 135-141.



A. SNAKE RIVER CANYON BELOW MOUTH OF RATTLESNAKE CREEK, LOOKING WEST.



B. SNAKE RIVER CANYON NEAR HAGERMAN, IDAHO, LOOKING NORTHWEST.

northeast of Market Lake, and small tracts of dunes are present elsewhere. In general, however, the soil of the plains is a fine, yellowish-white, silt-like material, largely a dust deposit, which mantles the surface not only on level tracts but covers hills and broad depressions alike. This material is similar to the celebrated loess of China, except that it usually occurs as a comparatively thin layer, and resembles also the deposit bearing the same name in the Mississippi Valley. Like each of these formations, it is of exceptional fertility if properly irrigated.

STREAMS.[a]

The Snake River Plains lie entirely within the hydrographic basin of Snake River, or the Lewis Fork of the Columbia, as it is sometimes termed. It is much to be desired that this great stream might be named Lewis River, in honor of one of the two bold explorers who secured the far northwest for the United States. The Snake or Lewis River has its headwaters in Wyoming, near the Yellowstone National Park, and drains all of southern and central Idaho. It flows across the southern part of the State in a great curve, concave to the north, to the Idaho-Oregon boundary, where it turns abruptly northward, as is indicated on the map (Pl. I). Its mean discharge, as determined by the hydrographic division of the United States Geological Survey in 1897, at Montgomery Ferry, midway between American Falls and Shoshone Falls, is 10,064 cubic feet per second; the maximum being in May and June, when it reaches about 26,000 cubic feet per second, and the minimum in August, September, or October, during which months its volume is approximately 4,400 cubic feet per second.[b]

In southeastern Idaho many streams join the Snake on the east. Of these the South Fork and Blackfoot River are the most important. Several perennial tributaries come to the main river from the south, such as the Portneuf, Salmon, and Bruneau rivers, besides a number of creeks which flow only during the winter or in May and June, when the snow on the mountains is melting. All of the tributaries from the south are small in volume, particularly in summer. The Bruneau would be an important exception to this rule, as it is supplied mainly by springs, if its waters were not so largely used for irrigation.

One of the most significant peculiarities of Snake River is the fact that between Henrys Fork, on the extreme northeast, and the mouth of Boise River, at the Idaho-Oregon boundary, a distance measured along the general course of the river of about 350 miles, it does not receive a single perennial tributary from the mountains to the north of the

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[a] See also p. 159.

[b] Such accurate data as are available concerning the hydrography of Snake River and its tributaries in the portion of its course bordered by the plains of southern Idaho, may be found in the reports of the hydrographic division of the U. S. Geological Survey, particularly in the Twentieth Annual Report of that survey, pages 61, 469–491; and in the reports of the State engineer of Idaho, especially the biennial report for the years 1899–1900, published at Boise.

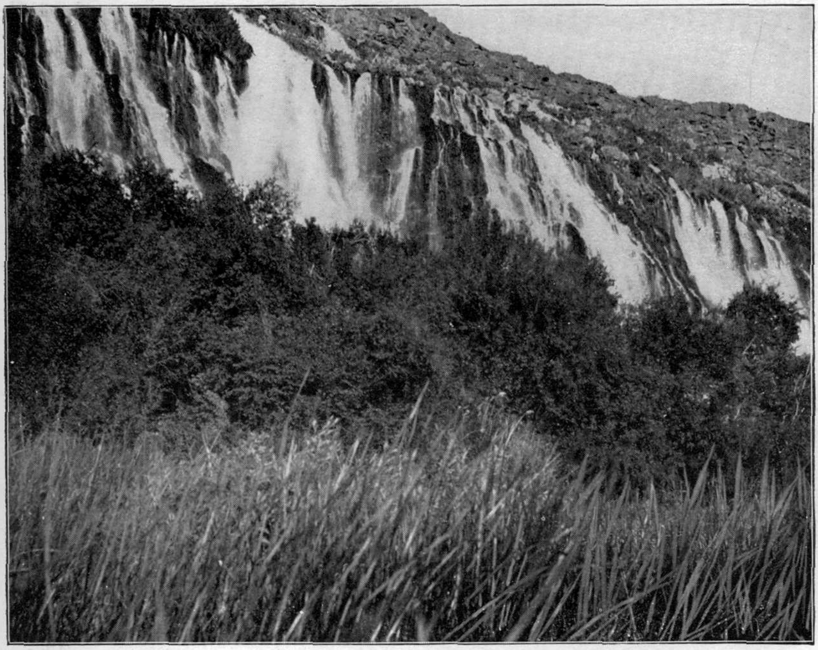
bordering plains. A possible exception to this statement is furnished by Malade River, which would perhaps reach the Snake in summer if its waters were not used for irrigation. The fact that Snake River does not receive a perennial tributary from the north throughout the portion of its course just indicated is the more remarkable when it is remembered that this part of its basin is largely occupied by lofty mountains, on which the mean annual precipitation is probably greater than on the less extensive and lower mountains, in which the streams coming from the south, such as the Portneuf, Salmon, and Bruneau, have their sources. The principal reason for the absence of surface tributaries to the Snake on the north is that broad lava plains intervene between it and the mountains, and all of the water which flows down to the plains or falls on their surfaces is either evaporated or lost in the cellular and fissured lava.

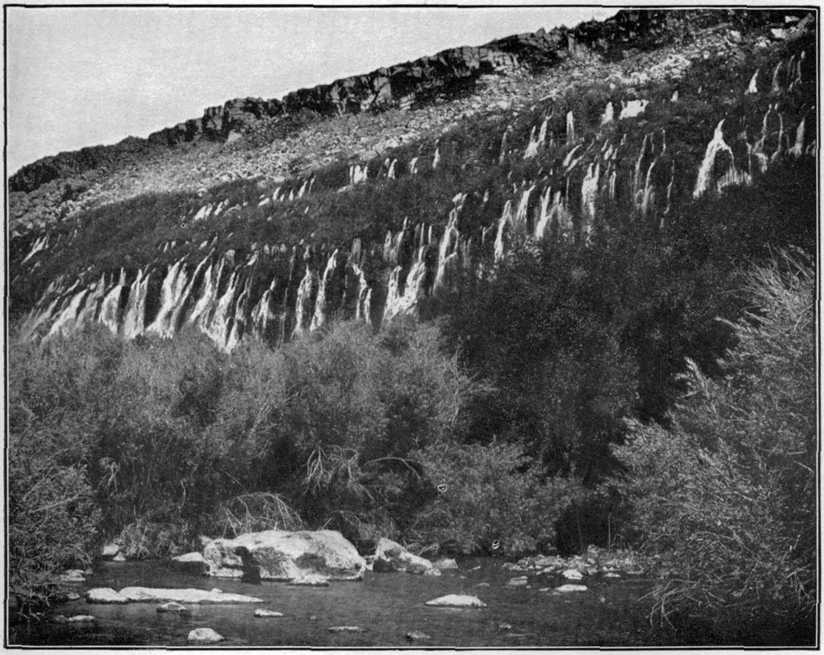
Some of the streams flowing southward from the mountains of central Idaho, as Camas Creek and Little Lost and Big Lost rivers, form temporary lakes on the lava plains, from which the water is removed by evaporation, or descends into fissures in the underlying rocks and joins the underflow. To a large extent, however, the disappearance of streams from the mountains on reaching the plains is due, as just suggested, to the descent of the water into fissures and cellular lava, or into beds of gravel and sand that underlie the lava sheets. The streams, to be sure, tend to fill the openings in their beds with silt, but the extent of the lava-covered country they have to cross in order to reach the master stream to which they would be expected to flow is so great that the task of filling the cavities in the rocks is as yet incomplete. The water which disappears below the surface, particularly on the northern border of the Snake River Plains, to a large extent emerges again in the canyon of Snake River as springs.

SPRINGS.[a]

One of the remarkable features of Snake River Canyon is the abundance of large springs which pour out from its northern wall, especially in the portion of its course between Shoshone Falls and Bliss. The aggregate volume of these springs is many thousand cubic feet per second. They flow steadily without observed fluctuations in volume throughout the year. During August and September, when the Snake is low, their combined volume is estimated to be equal to if not greater than that of the river itself where it passes over Shoshone Falls. Perhaps the finest known exhibition of cataracts formed by springs of large volume issuing from rocks far up the faces of nearly vertical precipices is furnished at what is known as The Thousand Springs, situated on the northern side of Snake River

[a] See also pp. 162-171.





B.

THE THOUSAND SPRINGS, SNAKE RIVER CANYON, IDAHO.

Canyon, near the town of Hagerman, between Salmon Falls and the point where Salmon River enters from the south. Views of a portion of the springs, which leap from the canyon wall at this locality and descend as white sheets of foam and spray over the verdure-covered precipices below, are shown on Pl. III. The more general of the two views (Pl. III, *B*) was taken before attempts had been made to utilize the springs, and indicates the natural conditions; Pl. III, *A*, is from a photograph taken in August, 1901, and shows a portion of the springs where their waters had been concentrated by a flume. In recent years tunnels and flumes have been constructed, which concentrate the waters and make their volume appear even greater than is suggested by the first of the views here presented. Most of the water descends over the face of a vertical wall of clay and lapilli from the cut edge of a layer of cellular scoriaceous basalt, which has an elevation of about 185 feet above the base of the precipice. The water does not make the descent in a single leap, but makes cascades of remarkable beauty and novelty and is churned into foam by its contact with the rocks. The volume of water has never been accurately measured, but within a space about half a mile in length at The Thousand Springs proper is estimated by Mr. A. Ferguson, a hydraulic engineer familiar with the locality, at 20,000 miner's inches (or approximately 500 cubic feet) per second.

West of The Thousand Springs the water-bearing layers which furnish water at this place are inclined and pass below the level of the river, but another similar but higher layer appears which continues to Bliss, a distance of about 18 miles. Throughout the length of its outcrop in the canyon wall copious springs are abundant. At many other localities between The Thousand Springs and Shoshone Falls there are water-bearing layers in the canyon wall and large springs pour out. The greatest of these fountains are situated at the heads of lateral alcoves or small side canyons opening into Snake River Canyon, such as Little and Box canyons, on the north side of the river just above the mouth of Salmon River, and Blue Lakes alcove, about 6 miles below Shoshone Falls. As will be explained later, the remarkable side alcoves, or short "blind" canyons opening into the main canyon, owe their existence to the great springs feeding the streams which flow from them. Another similar "spring alcove," but at first view not so clearly the result of springs undermining the cliffs, is furnished by the lower portion of the canyon of Malade River.

The water of the springs between Shoshone Falls and Bliss has an essentially uniform temperature of about 60° F. throughout the year. The water is clear, but of a bluish color, due to fine particles in suspension. Several of these spring-fed streams are inhabited by trout. It is indeed a surprise to find beautiful trout streams in the central part of a flat, arid plain.

The temperature of the water pouring out of the walls of Snake River Canyon shows that it is not derived from deep fissure springs, and, in fact, has not made a deep descent into the earth. The water no doubt comes from the mountains lying north of the Snake River Plains, and is supplied mainly by the subterranean flow of "lost rivers."

Besides the springs in the canyons already referred to, there are a few fissure springs on the Snake River Plains, usually near the bordering mountains, which have a high temperature, but their combined volumes make but slight addition to the surface run-off. Possibly hot springs rise beneath the lava sheets flooring the plains and influence the temperature of the canyon springs, but there is no direct evidence that such is the case, although the temperature of the canyon springs shows some variation which can not be due to the depth of the sheets of rock from which they appear to issue.

The springs along Snake River and at a few localities near the mountains bordering the Snake River Plains have been utilized for irrigation.

WATER POWER.

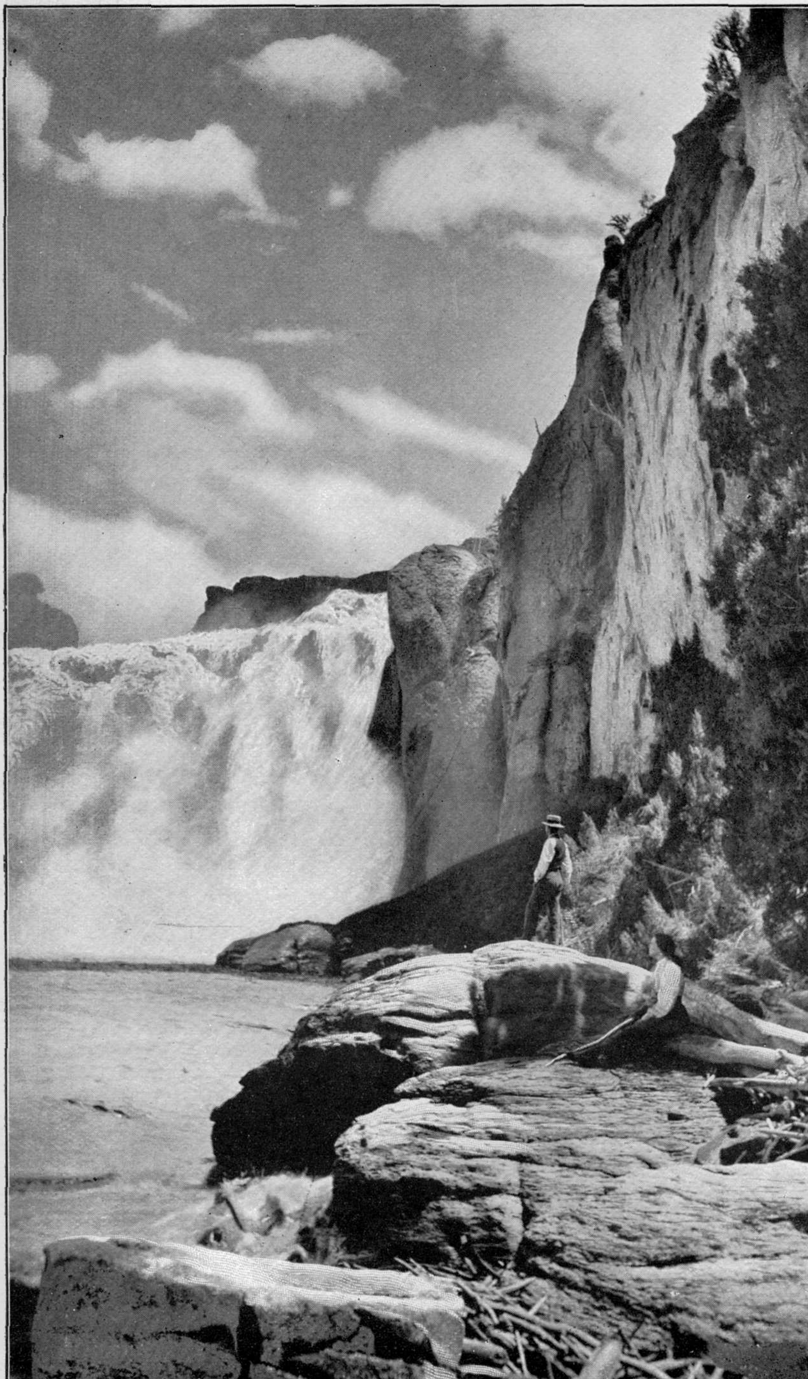
The amount of water power available along Snake River in its passage across southern Idaho is practically unlimited, but as yet is not utilized. The most important falls and their height are as follows: Idaho Falls, 30 feet; American Falls, 50 feet;[a] Twin Falls, 180 feet[a] (Pl. XXII); Shoshone Falls, 210 feet[a] (Pl. IV); Salmon Falls, about 25 feet. Besides these there are many localities where "vertical leaps are made in many cases from 20 to 50 feet, all suggesting, in addition to the natural grandeur and sublimity of the surroundings, the wonderful possibilities through their utilization in the industrial development of the State."[b]

Besides Snake River itself, the great volume of water at The Thousand Springs and at the mouth of Malade River could be easily and cheaply utilized as sources of power. The future greatness of the State certainly depends largely on the proper development and use of this branch of her great resources.

IRRIGATION AND AGRICULTURE.

With the small mean annual precipitation on the Snake River Plains, practically all of it falling during the winter season, agriculture without irrigation is seemingly impossible. As previously suggested, however, over the higher portion of the plains lying southwest of Big Butte the rainfall may be sufficiently above the average, or the soil may retain enough moisture, or possibly the slow melting of the winter

[a] From biennial report of the State engineer of Idaho, 1899–1900, pp. 8, 9.
[b] Op. cit., p. 9.



SHOSHONE FALLS, SNAKE RIVER, IDAHO.

snow may furnish the proper conditions to permit the growing of wheat and other cereals without irrigation. This experiment is at least worth trying.

As agriculture is at present entirely dependent on irrigation, cultivated land occurs only where water from streams and springs can be obtained. Not only is the presence of sufficient water a controlling factor, but the topography and the nature of the soil must also be taken into account. The portions of the Snake River Plains first brought under irrigation are those where the conditions are most favorable for small enterprises. These are the flood plains of the small streams from the mountains, and points where springs can be utilized. Later, came more extensive systems, involving the construction of extensive canals and necessitating the employment of a large amount of capital and labor. The small ditches were constructed by individuals, or by small groups of ranchers, and the canals by communities or incorporated companies. One result of the conditions met with is the isolation of many individual ranches and of small groups of ranches situated along a single stream. The construction of canals led to an increase in the size of the communities, and in some instances to the growth of considerable towns.

The widely separated individual ranches or small groups of ranches are situated mostly where the streams from the mountains emerge onto the plains, and frequently extend as far up the mountain valleys as flood plains occur. In a similar way the springs in Snake River Canyon have in several instances been utilized, and single ranches or small groups of ranches forming a fringe along the river's banks, mostly on its northern side, occur from near Shoshone Falls westward.

The most important communities have grown up along irrigation canals. Typical illustrations of the results of a favorable combination of conditions in this connection occur near the junction of the North and South forks of Snake River, in the northeastern portion of the Snake River Plains, where the streams are upbuilding their channels and spreading out broad alluvial fans. The South Fork, before its waters were so largely diverted into canals, divided into several branches, the positions of which were liable to change during each high-water stage, and furnished unusual facilities for irrigation. In the region referred to, or in a general way, between St. Anthony and Idaho Falls, including lands on each side of Snake River in the vicinity of Market Lake and extending far up the South Fork, there are a large number of ranches on which grain and hay are successfully cultivated, as well as orchards and gardens. There are several flourishing villages in this section also, and evidence of prosperity and thrift are abundant. By no means all of the good land that can be irrigated is under cultivation, however, and still greater results can be confidently predicted.

Although Snake River makes a sharp descent over lava at Idaho Falls, the stream a short distance below has again a low gradient and is upbuilding its channel. The gravel flood plain of the river and portions of former flood plains, now forming gravel terraces, are available for agriculture. Although to a considerable extent the soil is loose textured and requires much water to insure good crops, it is easily irrigated, and an abundance of water is available. Farms border the river on each side all the way to American Falls, where the canyon begins which extends to the Idaho-Oregon boundary. Projects have been matured looking toward the irrigation by means of canals, at higher levels than those now in use, of great areas of fine land extending from some distance above St. Anthony to the Salmon River.[a] Lower down, where the river is upgrading its channel and forming a flood plain, and the large canals are needed for irrigating the surface of the broad plains bordering Snake River Canyon, the most favorable localities for diverting the waters are at places where the canyon walls are not high and rapids or falls occur. In the canyon of Snake River in the vicinity of Hagerman the river makes a sharp turn to the south and west and then to the north, thus forming a conspicuous bend concave to the northeast. Here there is a precipice formed of soft clay and unconsolidated sand, about 600 feet high on its southern and western border, as is shown on Pl. II. The land on the northeastern side of the river at this exceptional bend, about 10 square miles in area, slopes gently toward it, but is bordered to the northward by a lava rim rock, from beneath which issue large springs which are utilized for irrigation. In addition to the natural springs tunnels or horizontal wells have been excavated in the basal portion of a lava sheet where it forms a rim rock and abundant water has been obtained. A large part of the land in the Hagerman Bend is now under cultivation, and much more of it can be utilized. This isolated area, sloping to the sun and sheltered on all sides by canyon walls, is one of the most promising for agriculture in southern Idaho. Below Hagerman copious springs are of frequent occurrence on the right side of the river as far as Bliss, a distance of about 8 miles, and a narrow strip of land in the canyon's bottom is under irrigation. All of the land now under cultivation from Shoshone Falls to Bliss, embracing by estimate about 8,000 acres, is watered from springs. This is the most conspicuous example of the use of spring water for irrigation to be found in Idaho.

A flourishing farming community exists on the borders of Bruneau River, near its mouth, where the stream has broadened its valley in soft beds. The Bruneau, near its mouth, cuts one of the lower sheets of basalt, which extends farther south than the surface sheets forming

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[a] Maps showing the lands which can be irrigated at a reasonable expense along the Snake in the portion of its course which crosses Idaho have been published by the State engineer of Idaho. See Biennial Report of the State Engineer, 1899-1900, Boise (1901).

the plains on the north side of Snake River, and for a few miles flows through a narrow, steep-sided canyon. The fact that Bruneau Valley is comparatively wide above the narrow canyon in basalt through which it enters Snake River is due to the check in downcutting afforded by the basalt, which permitted the stream above the obstruction to meander and broaden its valley. In this broader portion farm lands form a belt averaging about a mile wide and about 9 miles long. Water for irrigation is, for the most part, derived from the river by means of canals, but warm springs, and to a small extent artesian wells, are also utilized.

The variations in geological conditions and in topographical development which favor the utilization of streams for irrigation are again illustrated along the lower portion of Boise River. This river, on leaving its narrow and rather high-grade canyon in the mountains and entering the comparatively wide valley it has excavated in the soft rocks of the plain, where its gradient is low, is unable to bear along the cobbles, gravel, sand, and other material brought from above and has spread out a wide flood plain bordered by terraces, through which it flows with many curves and frequently divides and reunites so as to inclose islands. These conditions have favored the construction of irrigating ditches and high-level canals, and a large area has been brought under cultivation. From the hills near Boise, a thousand feet in height, one may look down on that beautiful city embowered in trees, and toward the west, as far as the eye can reach, behold green fields and orchards surrounding comfortable farm houses. Owing to the abundance of water available for irrigation, as well as the favorable soil conditions, this region has become the most extensive of the highly fruitful areas of Idaho.

The most valuable crop cultivated on the Snake River Plains, where water is now available for irrigation, is hay, principally alfalfa. Cereals, including maize, are also grown, but in minor quantities. Orchards and vineyards thrive and yield abundant returns, especially along Snake River below Shoshone Falls, and in Bruneau Valley, where shelter is afforded by the neighboring canyon walls. Owing to the isolation of the orchards in many instances, the injuries caused by insects are much less severe than in more generally cultivated regions. The greatest obstacle that fruit raisers have to contend with is the late frosts in spring or early summer.

STOCK RAISING.

The greatest of the industries as yet established on the Snake River Plains is stock raising. To this a large part of the cultivation of the soil, the raising of grass, is incidental. In the counties of Idaho which include within their borders portions of the Snake River Plains there are over 1,000,000 sheep, nearly 200,000 cattle, and about 34,000 horses.[a] But little of this stock is fed in barns during the winter and by far the greater part is fed hay only during severe storms. The winter pastures are on the broad sagebrush-covered plains.

MINING.

The Snake River Plains themselves are destitute of metal and ores of economic importance, but the bordering mountains contain rich mines. Along Snake River fine placer gold occurs in considerable quantity, but is difficult to procure. Placer mining has been carried on, in a small way, continuously for many years, however, and the annual production of gold is a considerable addition to the wealth of the State. A large portion of the mining that has been done is a loss to the State, however, as rich agricultural lands which could be made to yield harvests for an indefinite time are ruined by the operation. The single crop of gold obtained is far less in value than the many crops of hay, grain, fruit, etc., which could be secured if the land were tilled.

TOWNS.

The wants of the people engaged in stock raising, ranching, and agriculture on the Snake River Plains or amid the bordering mountains has led to the springing up of several small towns. These towns were first established at localities where water could be easily obtained for irrigation, and later received a new impetus when railroads were built, which increased their importance as shipping centers. In addition to the needs of agriculture and stock raising, the mining interests have also exerted an influence on the growth of certain towns and villages of the plains.

The population, in 1900, of principal towns situated in the portion of Idaho to which attention is here invited is as follows:[b] Boise, 5,557; Pocatello, 4,046; Idaho Falls, 1,262; Mountain Home, 529; St. Anthony, 411.

Boise is the capital of the State, and the center of a large stock-raising, agricultural, and mining region. Pocatello, the second city of the State in number of population, owes its growth principally to the fact that it is an important railroad center. Besides the cities and towns named there are many boroughs or villages, numbering from a very few to perhaps a score of houses. The largest of these unincorporated villages is Blackfoot, which has about 1,500 inhabitants. On maps of Idaho many names of post-offices appear which a person not familiar with the State might assume to be settlements of some importance, but which in a large number of instances are simply post-offices housed in some isolated farm-house or cross-roads store.

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[a] First Ann. Rept. State Bureau of Immigration, Labor, and Statistics. Boise, 1900.
[b] Twelfth Census of the United States, Bull. No. 8.

The total population of Idaho in 1900 was 161,772, or 1.9 to the square mile. In the region embraced in the Snake River Plains the people are, to a great extent, segregated in communities where water can be had for irrigation, leaving vast tracts entirely uninhabited. The counties which include portions of the plains within their border, however, contain more than half of the population of the State and represent about one-half its area. The leading topographic feature of southern Idaho is the great plains, and of its central and northern parts, rugged mountains. The influence on the density of population of barren, uninhabitable plains, encroached upon by agriculture and stock growing, and of mountains where mining industries have been established, is thus seen to be about the same.

RAILROADS.

As is indicated on the map forming Pl. I, the Snake River Plains are traversed throughout their entire length by the Oregon Short Line Railroad. One division of this road, starting from Pocatello, leads westward, and traverses the plains all the way to the Idaho-Oregon boundary, with one branch leading northward to the mining regions about Hailey and another terminating at Boise. A branch about 50 miles long leads southward, crossing Snake River to Murphy. Another division of the road, starting also from Pocatello, leads northward and traverses the northeastern border of the plains to the Idaho-Montana boundary. An important branch of this northern division, built in 1901, begins at Blackfoot and crosses the widest part of the plains, passing between Big and Middle buttes and reaching the region drained by Big Lost River. The aggregate length of the railroads now in operation across the Snake River Plains is about 500 miles. Travelers over these two divisions and various branches of the "O. S. L.," as it is familiarly termed, will be enabled to see nearly all the variations that the plains present and to obtain an idea of their vast extent. To travelers who make such a journey, the most pronounced need of the country—namely, water—will become painfully apparent.

HIGHWAYS.

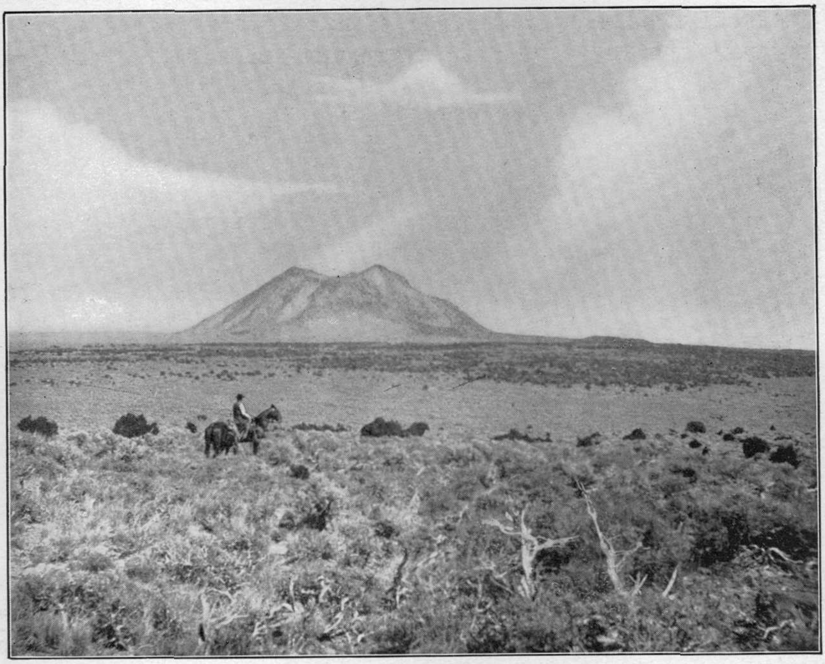
Owing to the flatness of the Snake River Plains and the fact that the lava rocks when present are generally covered with at least a few feet of fine soil, traveling is easy in all directions, except where canyons break the surface. Roads lead across the plains in various directions, and all parts of them can be reached by wagons. The exceptions in this connection are the fresh lava flows, sometimes hundreds of square miles in area, and the portions of the canyons bounded by precipitous walls. In several instances, however, good roads, or "grades," as they are termed, have been constructed which lead into the canyons where the walls seem to be almost vertical precipices. The main difficulty in crossing the plains is the scarcity of water. As in most flat regions where stock raising is a leading industry riding is largely practiced.

BIG, MIDDLE, AND EAST BUTTES.

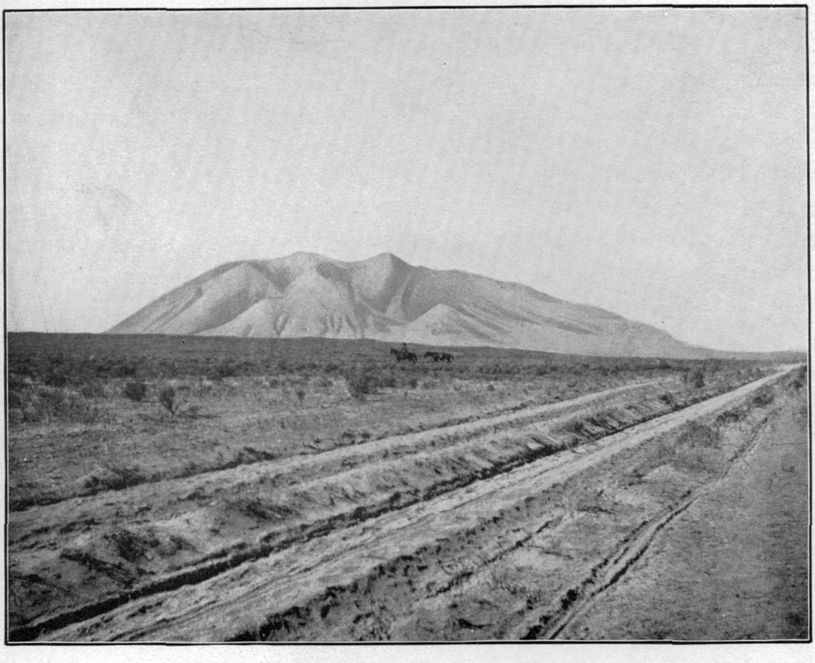
An account of the Snake River Plains, however brief, would not be complete unless it directed special attention to three conspicuous mountain-like elevations that break their monotony. These elevations, known in their order from southwest to northeast as Big, Middle, and East buttes, are situated in the central part of the vast lava-covered region of southeastern Idaho, about 25 miles northwest of Blackfoot. Their location is indicated on the map forming Pl. I. Owing to the apparently perfect flatness of the surrounding plain they are prominent objects in the landscape when seen from distances of 100 or more miles, and are no doubt familiar to many persons who have passed over either of the two divisions of the Oregon Short Line Railroad which diverge at Pocatello, one going northward and the other westward. Owing to the isolation of the buttes and the absence of water in summer anywhere in their vicinity, with the exception of a small spring at the northeast base of Big Butte, they are seldom visited. For these and other reasons it seems appropriate to close this introductory chapter with an account of these three most interesting and instructive elevations.

Two of the buttes, namely, Big and East buttes, are rhyolitic volcanic cones of ancient date, which are completely surrounded by Snake River lava and furnish admirable examples of steptoes, as such islands in a once molten sea of lava have been termed. Middle Butte differs from its companions, being an upraised block of stratified basalt.

The elevation of Big Butte above the surrounding plain, as determined by aneroid measurements, is 2,350 feet, and by estimate the height of Middle Butte is 400 and that of East Butte about 700 feet. Big Butte, as may be judged from Pl. V, rises as a deeply sculptured mountain precipitously from the nearly flat plain surrounding its base, and terminates in two ridges about a mile apart, with a deeper depression between, which is apparently a remnant of a crater. At its base the mountain is 5 or 6 miles in diameter, and is somewhat elongated in a northwest-southeast direction. To reach its summit, no matter how carefully the trip may be planned, true mountain climbing is necessary, and the steepness of the slopes will be forcibly impressed on the climber's mind before he reaches the top. From whatever direction the mountain is ascended the abruptness with which it rises from the plain, without gradual approaches or foothills, becomes impressive. In the gulches and deeply cut ravines there are alluvial fans which extend out onto the surrounding plain for 2 or 3 miles,



A. EAST BUTTE, IDAHO, AN OLD RHYOLITIC VOLCANO SURROUNDED BY BASALT.



B. BIG BUTTE, IDAHO, AN OLD RHYOLITIC VOLCANO SURROUNDED BY BASALT.

expanding and becoming indefinite at their lower extremities and clearly indicating the amount of erosion that has occurred since the encircling basalt was poured out. Equally apparent is the fact that the mountain was deeply seamed by erosion before the basalt flowed about it. The land surface on which the old volcano was built and the streams of acid lava which it may have sent out are buried from sight by the basalt, and no inequalities of the present surface suggest hills or hollows beneath the deep covering of black lava. These contrasts in topography coincide with even more sharply defined differences in the rocks. The mountain is composed mainly of nearly white rhyolitic lava, which presents many variations from compact, banded, and spherulitic layers to light pumice and black glass or obsidian. The encircling basalt is black, with but a single neighboring area at the north base of the white butte, where a remnant of a small basaltic cinder cone reveals a dash of dark red. The ancient steptoe is built of highly acid lava and the surrounding plain is composed of basic lava.

An exception to the statement that there are no exposures of the land surface on which the ancient rhyolitic mountain was built may perhaps occur about 5 miles to the east of its base, where a group of hills, clothed in part with juniper trees, rise to a height of about 300 feet above the recent basalt that intervenes between the two. An examination of this group of hills was cut short by the coming of darkness, but the occurrence of obsidian and pumice in what seemed to be a remnant of a lapilli cone suggested that a small volcano, similar to the greater one which formed Big Butte, may there be represented.

Big Butte, like the surrounding plain, is grass covered, and the numerous deer trails, on which the imprint of the foot of a wolf or a wildcat may occasionally be noticed, show that it is a favorite feeding ground for big game. Elk resort there in winter and bears are common visitors. An arrow point, of obsidian, picked up on the summit of the mountain, suggested that this was formerly an Indian hunting ground. Just before my visit it had rained, and on the plain about 3 miles to the south of the butte there was a small water pocket from which trails radiate in various directions, showing that year after year the same depression had been occupied by water and for a long time had been resorted to by wild animals. Besides grasses and flowers, the mountain is covered in certain favored places on its northern slopes with a young and thrifty growth of pines, firs, and juniper, and much of the summit portion is occupied by a dead forest of coniferous trees, many of them 30 to 40 feet high, which were killed by fire about eight or ten years ago. Over the greater portion of the burnt area, which includes nearly the entire mountain, no young trees have sprouted. There is so little moisture that the forest will never be renewed. It is only in the ravines on the northern slope, where snow accumulates most deeply and remains longest, that conditions are favorable to the growth of young trees. The vegetation, if studied critically, would evidently furnish a delicate index to the climatic conditions.

On reaching the summit of Big Butte on a clear day there is a far-reaching view in all directions, and much of the history of the Snake River Plains may be easily read in the splendid panorama.

In attempting to understand the features of a landscape when beheld from an elevated station, it is necessary to have in mind the scale on which the relief map, for such it appears, which is spread before one, is constructed. In arid regions, in spite of the haze usually present, distances are deceptive. Objects leagues distant seem only miles away.

The mountains to the east are fully 50 miles distant, and the nearest peaks to the west are from 30 to 40 miles away; to the southwest and northeast the flat plain extends indefinitely, and no bordering shore is in sight. In spite of their remoteness, the Lost River Mountains to the west are clearly and even sharply defined. The upward sweep of alluvial fans can be easily traced to where they narrow at the mouths of strongly cut gorges. Above their summits are the outlines of bare crags, where angular rocks form bold convex curves, which replace the concave curves due to stream deposition on the lower slopes. Still higher is a dark band of forest which encircles the mountain like a shadowy wreath. Far above the timber line are bare serrate peaks, all of them light gray and suggesting the presence of limestone or quartzite, except the highest pinnacles of all, which gleam silver white. A recent storm, which brought light showers to the plains, covered the higher mountains with snow. Roads on the plain appear as fine lines radiating from the spring at the northern base of the mountain. Each curve in the yellow line leading west can be clearly followed to Arco, 24 miles distant, where clumps of bushes and a few houses tell of the presence of water. Other clumps of bushes and here and there a field of alfalfa, a rectangular patch of green on the vast gray expanse, reveal the curves of Big Lost River as it flows through the plain, bends northward, and in winter maintains its existence for about 50 miles to where it spreads out in a small lake. To the northeast, and seemingly close at hand, although 15 and 20 miles distant, Middle and East buttes rise abruptly. The nearer butte is black, its sloping surface is inclined to the southeast, in conformity with the dip of the hard rock layers of which it is composed. The western border is abrupt at the summit, but below it has much more gently inclined lines, due to talus slopes. East Butte is white, rises sharply on all sides, is without conspicuous talus slopes, and terminates above in two sharp, angular peaks, between which there is a smooth, saddle-shaped depression, suggestive of a broken crater. A view of this remarkable steptoe, taken from near Middle Butte, is presented in Pl. V.

Still farther to the northeast, and, as one is surprised to learn on referring to a map, 46 miles away, the outlines of Market Lake craters are clearly visible. Their characteristic conical forms, with flat summits, leave no doubt that they are extinct volcanoes. From personal examination I know they are tuff cones with craters in their tops. When the eye has become adjusted to the novel conditions it perceives that the vast plain is not absolutely flat and featureless, and as evening approaches and a strong side light causes even small elevations to cast shadows, many cone-shaped prominences rise from the previously flat surface. That these are extinct volcanoes is clearly shown by an example, only 3 or 4 miles distant to the southeast, from which a black stream of lava with a bare, rough surface, evidently of recent date, extends northward, and expands into a belt a mile or more wide before terminating. This recent addition to the rocks of the plain resembles a great withered and blackened leaf, with its petiole still attached, laid on the flat surface. Another black lava stream, starting from an elevation a few miles to the eastward, also flowed northward and expanded into a leaf-like form several square miles in area. These two recent lava streams indicate that the plain of which they form a part has not been produced by a single vast outpouring of molten rock, but is in reality highly compound and consists of many widely expanded and overlapping lava sheets. A small elevation, the summit of a low cone with an immensely expanded base, occurs about 8 miles to the south. It is similar to those from which lava was recently poured out, but is much older. The lava has evidently flowed away from a small opening in all directions so as to form a cone, with a diameter at the base of certainly 8, and probably as much as 10 miles. When this old volcano is seen in profile from the surface of the surrounding plain it presents the appearance of another similar cone, shown on Pl. XVIII, about 15 miles to the west of Big Butte. The cone just referred to, together with two companions, is also in sight from the summit of Big Butte, and still others of similar shape, all broad, low cones, usually with flat summits, may likewise be distinguished. Most of the small volcanoes are situated south of an east-west line drawn through Big Butte, but to the northeast there is one prominent brown crag only a short distance north of the wagon road leading to Blackfoot. Still farther north, and beyond the straight line formed by the railroad now in process of construction, are two other low mounds, which from near inspection I found to be remnants of basaltic craters. Far to the south, and nearly lost in the dim distance, are still other elevations, which have the same topographic forms as those nearer to hand, and which I believe are also old craters, although as yet unvisited and undescribed. To the west, close to the far more prominent mountains, yellow with withered grass, are the Cinder Buttes, among which a score or more volcanic cones are known to exist. Not including the Cinder Butte, or East Butte, about twenty craters can be counted on the broad plain, and still others occur which can not be readily recognized from a distance. Evidently a very large portion of the lava occurring as a surface covering on the Snake River Plains came from small and inconspicuous craters, many of which have escaped burial by later eruptions and still exist as elevations.

After climbing Big Butte I rode across the plain, in part occupied by recent lava, but mostly a grass and sagebrush covered region, to Middle and East buttes, but owing to lack of time did not climb either of them. Middle Butte, as already stated, is composed of stratified basalt, and does not present evidence of being a cinder or lava cone, and does not mark a site from which either scoria or liquid lava was extruded. About in a line between Middle and East buttes, however, and overgrown with juniper trees, is a low elevation of scoriaceous lava, which appears to be a remnant of a basaltic crater.

East Butte has preserved its original shape much more completely than Big Butte, probably for the reason that it presents much less surface on which water might collect into streams, and also because of its less height. It rises precipitously from the surrounding basalt on all sides (Pl. V, *A*) and is free from conspicuous talus slopes and alluvial fans. The rock is a white rhyolite, and what is clearly a remnant of a crater still exists at the summit.

Middle and East buttes are covered with an open forest of small juniper trees, which extends far over the plain to the east. To the west of them there is a broad, rolling prairie. No water is to be had except in winter, when an occasional depression may perhaps be filled by the melting snow. Except for the absence of water, the region is as fair and inviting as the most favored portions of the prairie States.

The chief lesson learned by a visit to the "Three Buttes" is that two of them are ancient rhyolitic volcanoes, entirely surrounded by the Snake River lava; and that on the encompassing plain there are many extinct volcanoes which poured out basaltic lava.

GENERAL GEOLOGY.

Previous investigations.—Southern Idaho is to a great extent an untrodden field to geologists. The most detailed survey that has been made within its extensive area embraces a region of about 864 square miles in the vicinity of Boise, which has been described and mapped by Waldemar Lindgren in what is known as the Boise folio, published by the U. S. Geological Survey.[a] This folio furnishes an admirable beginning for the study of the geology of the region surrounding the

[a] This folio measures 18½ by 21½ inches, contains 7 pages of descriptive text, 4 full-page maps, sections, etc., and is sold by the Survey for 25 cents per copy.

area of which it treats, and should be carefully studied not only by professional geologists, but more particularly by the people of Idaho.

A considerable portion of the Snake River Plains lying south of the area embraced in the Boise folio has also been explored by Lindgren in connection with detailed studies of neighboring mining districts, and the results have been presented by him in a paper published by the United States Geological Survey.[a] In this paper there is a summary of the observations made by other geologists who have visited southern Idaho.

From the reports just mentioned, as well as my own explorations, it is evident that the geological discussion of the Snake River Plains may be consistently divided into two portions, the first dealing with the older rocks which were upraised into mountains and deeply eroded before the partial filling of the Snake River Basin, and the second with the lacustral and stream deposits, lava sheets, etc., now forming the plains themselves. The former, in geological language, embraces mostly if not entirely, Paleozoic rocks; and the second, Tertiary and Recent rocks. Between the formation of these two great rock divisions there was a long interval, during which deep erosion and the development of a rugged topography took place.

PRE-TERTIARY FORMATIONS.

The rocks of which the mountains surrounding the Snake River Plains are most largely composed are granite, rhyolite, quartzite, and limestone.

GRANITE.

The terrane named the "Boise granite" by Lindgren, from which the rugged mountains which lie to the north and east of Boise have been sculptured, extends eastward from this area and occupies an extensive and exceedingly rugged region lying north of Mountain Home. The eastern border of this area forms a moderately irregular line with an approximately north-south direction, situated between the canyons of Ditto and Syrup creeks. On this dividing ridge the granite passes beneath extensive surface flows of rhyolitic lava which form the mountains drained principally by Syrup and Long Tom creeks, as well as Mount Bennett, and other high land still farther east. The junction of the granite and rhyolite is sharply defined and is easily traced, owing, principally, to the light color of the granite and the dark browns, purples, and reds of the later-formed terranes. The granite is massive, without bedding planes, while the rhyolite is in distinct layers, which are sharply tilted. Near the "Overland road," which skirts the base of the mountains lying northwest of Mountain Home,

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 617-719. This report is accompanied by a geological map of a portion of the western part of the Snake River Plains.

and at a distance of 3 to 4 miles west of Canyon Creek, small exposures of granite occur on the border of the lava forming the plain. Rising steeply from these isolated outcrops, which are significant in reference to the relative age of the two classes of rock forming the mountains, are bold precipices of dark rhyolite. Significant, too, in respect to the geological structure of the region and the relation the plains bear to the mountains, is the fact that the precipitous escarpment bordering the plain on the northeast, between Mount Bennett and Boise, is composed to the eastward of rhyolite and to the westward of granite, but the alignment is unbroken at the junction of the two formations. The major features of this great escarpment, about 50 miles in length, are due to faulting or to the uplifting of the mountains along a line of fracture.

The Boise granite, as has been stated by Lindgren, is intrusive and of ancient date (perhaps pre-Algonkian)—that is, the great granitic area referred to, embracing several hundred square miles, is composed of rocks which were forced upward in a molten condition from deep within the earth's crust, but, so far as known, failed to reach the surface so as to produce volcanic eruptions. The rising magma uplifted the rocks beneath which it was intruded, probably into the form of a dome, which has since been removed by erosive agencies, and, cooling slowly under great pressure, produced a massive, coarsely crystalline rock. Not only has the thick cover beneath which the granitic magma was intruded been worn away, but streams have cut deeply into the intrusive rock itself, and probably many hundreds of feet of its upper portion have been removed. This process of denudation is still going on, as is shown by the soft, broken, and deeply decayed conditions of the portion of the granite now exposed, and by the nearly universal mantle of fragments that covers its surface and extends far down the channels of the draining streams. Owing principally to the decay of its constituent crystals, mica and feldspar, the granite is usually altered to a depth of 100 feet or more below the surface, and exposures of fresh rock, compact enough to be used in finished masonry, are not to be seen. Decay, disintegration and erosion have given to the granitic area an exceedingly rugged surface, the major features of which are deep, generally smooth-sided valleys and bold, rounded hills. One characteristic is the frequent presence of great numbers of crags and castle-like forms of bare rock which project through the nearly universal covering of surface débris.

The stream channels in the granite, and far down their courses after reaching the Snake River Plains, are deeply filled with rock waste. The disintegration of the rocks is evidently progressing rapidly and furnishing more fragments, mostly of the nature of coarse, angular sand and gravel, than the streams are able to carry away. In many depressions, and even in valleys of considerable size, the accumulation of rock fragments has become so deep that rain water is not retained at the surface, and no stream channels are in sight. The concave surfaces of these partially filled depressions meet the convex curve of the bordering uplands, and where the mantle of rock waste is not broken by residual crags the landscape has broadly undulating outlines.

Traversing the Boise granite in the region to the north of Boise, and described by Lindgren, there are numerous dikes of both acid and basic rock which form long narrow outcrops, differing from the inclosing granite. As is well known, they are due to the filling of fissures with molten material injected from below and to the hardening and crystallizing of the intruded magma on cooling. To the east of the portion of the granitic area included in the Boise folio dikes are less common, although several conspicuous examples occur in the mountains drained by Slater, Ditto, and Indian creeks. These dikes are composed of purplish rhyolite, trend nearly due north and south, and have a width of from 30 to 80 feet or more. The dikes are vertical, and owing to the greater resistance they offer to erosion, stand in bold relief above the surface of the inclosing granite. The most characteristic examples thus far examined occur in the mountains adjacent to the border of the Snake River Plains, between Black and Slater creeks; others, but less numerous and less bold and conspicuous, were seen in the mountains between Indian and Ditto creeks. The rock forming these dikes is of the same general character as the rhyolite occurring in well-defined sheets in the mountains to the northeast of Mountain Home and in Mount Bennett, etc., and suggests that much of the granite now exposed was formerly covered with rhyolitic flows, which have been eroded away. The rhyolite is younger than the granite, and an epoch of erosion intervened between the formation of the two terranes.

An outcrop of granite about 5 or 6 square miles in area occurs on the west side of the Snake River Plains, about 75 miles west of Blackfoot, and near the Cinder Buttes. This small isolated area is surrounded by quartzite on all sides except the eastern, where it is bordered by a recent flow of lava which came from the Cinder Buttes. The contact of the granite with the surrounding quartzite is sharply defined, and at one locality on its southern margin a mining shaft has been sunken to a depth of 80 feet, following the plane of contact, which is inclined southward at an angle of about 80°. The bedding planes in the quartzite also dip southward, but at an angle of only 15° to 18°. There is no evidence of an alteration of the quartzite at its junction with the granite, and the contact is evidently a result of faulting. The diverse dips observable in neighboring quartzite ridges show that much movement has occurred along fault planes in the hills about the granite, and it seems evident that the granite itself has been elevated by this process high enough to be exposed by erosion. The granite is light-colored, coarse-grained, and resembles the Boise granite, but there is no evidence of a connection between the two. It it possible, however, that they are of the same age, and perhaps portions of a single intrusion.

As stated by Lindgren in the Boise folio, granite is present in the Owyhee Mountains, in southwestern Idaho to the south of Snake River, but little is known of that region. No other granitic areas are reported to occur in the part of Idaho here considered, but it is to be remembered that large portions of that region have never been visited by geologists, and even the general nature of many of the mountain ranges is unknown. Certain bold peaks to the south of Snake River, to the east of Albion, rise well above timber line, and when seen from a distance present the appearance of weathered granite, but were not visited by me.

RHYOLITE.

The extensive area of rhyolite whose western border, as stated above, is on the divide between Ditto and Syrup creeks, extends southeastward to the vicinity of King Hill Creek, a distance of about 30 miles. The width of the area is 6 or 8 miles, but its full extent to the northward is unknown. It forms Mount Bennett, which rises 5,000 feet above the adjacent portion of the Snake River Plains, as well as the rugged country drained by Syrup and Long Tom creeks, lying north of Mountain Home. On the south it is bordered by the Snake River lava, and on the north, at the head of Long Tom Creek, by a quartzite ridge which slopes steeply on its northern side to the South Fork of Boise River, where granitic outcrops occur.

The rocks in this extensive area are stratified and present two well-defined varieties, one a compact, light-purplish rock with a granular structure and conspicuous crystals of feldspar, and the other a black, vitreous rock which also contains large feldspar crystals. In each variety there is frequently present a pronounced flow structure, which is especially well shown on weathered surfaces. This structure was produced by the flow of the still plastic magma after crystals had formed in it. In many instances parallel laminæ were produced in this manner, which are a small fraction of an inch thick, but may be traced laterally for several feet. An alternation of beds of granular rocks with a dull fracture and of black, vitreous layers gives the formation a distinctly bedded structure. Some of the light purplish beds, particularly near the base of the formation, on the divide between Dry and Syrup creeks, are of the nature of a tuff—that is, they consist of consolidated dust-like fragments, but contain distinct crystals of feldspar. This formation, which may be termed provisionally the Mount Bennett rhyolite, is tilted in various ways, but usually dips toward the northeast. From commanding summits it is easily seen that the tilting is due to movements of large blocks, bounded by faults. The larger features in the relief are produced by fault scarps, but great erosion has also occurred. The faults have a general southeast-northwest trend, but while nearly parallel in several instances they frequently branch and diverge at low angles from the main belt of displacement which determines the bold southwest border of the mountains, overlooking the Snake River Plains. The precipitous southwest escarpment of Mount Bennett is a fault scarp, from which a step-like recession of cliffs has occurred and on which there are prominent talus slopes. The leading features of the structure, as well as of the relief of the Mount Bennett rhyolite area, as is also the case on a yet larger scale in the Lost River country, are due to normal faults. The mountains are of the Great Basin type, but instead of trending northeast and southwest, as is the case in much of Utah and Nevada, they have a direction about at right angles to that course.

Rocks similar to those forming Mount Bennett and the dark brown and purple mountains north of Mountain Home occur also in Snake River Canyon at Shoshone Falls. Beginning on the west, in the bottom of Snake River Canyon near the mouth of the lateral alcove leading to the Blue Lakes, this rock is exposed almost continuously on each side of the river up to Shoshone Falls and for a short way above, a total distance of about 7 miles. The surface of the formation is irregular. In places horizontally bedded basalt rests directly on the terrane referred to, but usually there intervenes a sheet of coarse unconsolidated breccia, made up of angular fragments, frequently 6 to 8 feet in diameter, of the lower formation, loosely united by an earthy connecting material. The thickness of this irregular sheet of angular fragments varies, but in some instances is fully 70 feet. The breccia is not stratified and does not present other evidence of the action of water, but is overlain in places by well-stratified layers of sandy material from a few inches to 20 or 30 feet thick, which usually has the color and texture of a red brick, especially at its upper surface. The color is due to the heat of the overlying basalt. This sheet of moderately metamorphosed sedimentary material, possibly in part composed of volcanic dust and lapilli, is well exposed in the sides of the canyon below the falls, and can be easily traced for a distance of at least a mile. Other similar layers, from a few inches to 5 or 6 feet thick in the central part, but thinning toward each end of the exposed portion, and having a length of a few hundred feet, are to be seen at several localities, interbedded with the basalt forming the walls of the main canyon and of the Blue Lakes alcove.

The rock exposed in Snake River Canyon and forming the precipice over which the river plunges at Shoshone Falls, as well as the fragmental material resting on it, exhibits both the massive, granular, purplish variety and the glossy, black variety, each porphyritic, observed in the Mount Bennett rhyolite. Both varieties also show well-defined flow structure. My observation shows that the Mount Bennett rhyolite and the rock forming the lower portions of the cliffs at Shoshone Falls are essentially identical, but no critical examination of the rocks of either terrane has been made. In the reports of the Fortieth Parallel Survey[a] the rock beneath the basalt at Shoshone Falls is termed trachyte, and no mention is made of the conspicuous layer of coarse breccia between the older massive igneous rock at the base and the basalt which forms the upper portion of the cliffs.

In the hills drained in part by Rock Creek, and situated between 12 and 20 miles south of Shoshone Falls, rocks of the same general character as those forming the mountains to the northeast of Mountain Home, and similar also to the lower terrane at Shoshone Falls, again appear at the surface and form an extensive range of hills or low mountains. These hills, judging from their form, color, etc., when seen from a distance, are formed of the same kind of rock, probably throughout an area of between 150 or 200 square miles, but were not examined by me except for a distance of about 8 miles along Rock Creek to the south of Rock Creek post-office. In the Rock Creek Hills, as on the mountains to the northeast of Mountain Home, the rhyolite is in well-defined layers, and exhibits diverse dips ranging from 10° to 20° in adjacent ridges.

On Rock Creek two flowing wells have been obtained, and will be described more fully in the second part of this report, and springs are numerous. These wells and springs indicate that the rocks are composed of alternating layers of pervious and impervious material, and that when penetrated by the drill or broken by faults, water may rise to the surface. There are reasons, however, for the suggestion that the sheet of rhyolite forming the surface portion of the Rock Creek Hills is comparatively thin and rests on Tertiary sedimentary beds. Should this surmise be sustained by future studies, the hope of obtaining flowing water over a wide extent of country to the south of Shoshone Falls will be greatly enhanced. Springs are also numerous in the mountains composed of rhyolite to the northeast of Mountain Home, and the success attending the drilling of wells in the similar formation on Rock Creek suggests that favorable artesian conditions exist there also. Success in drilling artesian wells in a region of volcanic rocks like that drained by Rock Creek is unusual and inspires a hope that much of the country underlain by stratified rhyolite will be found to be water bearing.

Two of the three prominent buttes described on a previous page, situated in the central part of the Snake River Plains about 25 miles

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[a] Vol. I, pp. 592–593.

northwest of Blackfoot, namely Big and East buttes, are composed of rhyolite, and are the weathered remnants of ancient volcanic cones. The rock of which each of these buttes is composed, as shown by field examinations simply, is mainly a very light-colored rhyolite, which is frequently highly vesicular, and at times becomes a true pumice. On Big Butte fragments of pumice and also of black obsidian occur, and the rock is in places spherulitic.

QUARTZITE.

As is well known, the rocks designated by this name have resulted from the consolidation of sandstone, owing mainly to the deposition of silica from solution in water, between the grains. When this process has been associated with a high temperature, or by movements which produce a shearing of the material under great pressure, a foliated rock, usually containing mica, is produced, which is termed quartz-schist.

Quartzite which in part had the characteristic of quartz-mica-schist has already been referred to as occurring in the hills at the head of Long Tom Creek, overlooking the South Fork of Boise River. The only portion of this formation examined is situated in the northeastern portion of the Mountain Home quadrangle. It extends westward from its eastern border for a distance of 6 miles, forming a range of conspicuous peaks with rounded summits. These peaks with curved saddles between are thickly sheathed with fragments of their own rock. Their northeastern slopes descend precipitously to the South Fork of Boise River, but near the river granite outcrops. It is probable, judging from the topography, that the quartzite occurs to the north of the river and has a wide development in the rugged mountains in that region.

The bold mountains bordering the Snake River Plains on the northwest, between Big Wood and Little Lost rivers, are composed largely of quartzite. Indeed, so far as can be judged from the observations made by me in that region these mountains, with the exception of the small area of granite near the Cinder Buttes and certain limestone outcrops on Lava Creek near Martin, seem to be composed entirely of light-colored quartzite, which extends far to the northwest toward the Sawtooth Range.

The bold mountains between Big Lost and Little Lost rivers, and also the similar range to the northeast of Little Lost River, are in either case sharply defined monoclinal ridges, rising some 5,000 or 6,000 feet above the adjacent valleys, and composed of stratified rocks which dip northeastward. Quartzite and limestones occur in three ranges, but even the prevalent character of the rocks composing them is unknown.

LIMESTONE.

The first limestone noticed in my journey from Boise eastward was at Martin post-office, where there are ledges of this rock, of a bluish color, changing locally to nearly pure white and containing crinoid stems. The strike is southwest and the dip 15° northwestward. About 3 miles to the west of the locality just referred to and on the west side of the valley of Lava Creek a conspicuous ridge of bluish limestone, bearing about northeast and southwest, was in view, but was not visited. In the valley of Little Lost River, near Howe, other outcrops of bluish limestone occur.

The age of the limestone and of the associated and apparently far more abundant quartzite is not known, but judging from their location and their relation to terranes occurring farther north, in the vicinity of Hailey, Challis, etc., examined by G. H. Eldridge,[a] and from their resemblance to other formations of known age in southeastern Idaho and the adjacent portion of Utah, it is probably Paleozoic. It seems likely that future studies will show that they range in age from the Silurian to the Carboniferous.

ROCKS OF SOUTHEASTERN IDAHO.

The geology of the extreme southeastern portion of Idaho, lying east and southeast of Snake River, was studied by the geologists of the "Hayden survey" in 1871 and subsequent years, and is represented on a "geological map of portions of Wyoming, Idaho, and Utah" which accompanies the twelfth annual report of that survey.[b] The portion of Idaho referred to has not been examined by me, but judging from the map mentioned above and the information contained in the itinerary reports by F. M. Endlich, F. H. Bradley, A. C. Peale, and Orestes St. John, published in the sixth and eleventh annual reports of the survey just referred to, it has a close resemblance in the nature of its rocks, structure, topography, etc., to the region to the west of the Snake River Plains, known as the Lost River country. The rocks forming the prominent mountains to the east of Snake River are largely limestone and quartzite of Silurian and Carboniferous age, while the valleys, beginning on the east, near Soda Springs, and extending northwestward to the Snake River Plains, are mostly floored with basalt. In addition to basalt, the valleys contain deep accumulations of débris swept down from the neighboring uplands and deposited as alluvial fans.

LEADING FEATURES OF THE GEOLOGICAL STRUCTURE.

The general trend of the mountains in southeastern Idaho, as is indicated on the maps published by the Hayden survey referred to

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 226–230.

[b] U. S. Geological and Geographical Survey of the Territories; a report of progress of the explorations in Wyoming and Idaho for the year 1878, Washington, 1883.

above, is northwest and southeast. On the west side of the Snake River Plains, in the Lost River country, the ranges, judging from distant views, are prevailingly monoclinal; that is, they are formed by the upturned edges of large blocks of the earth's crust, in which the bedding planes dip in one direction. Under the generally accepted explanation of the origin of ridges of the nature of those just cited, they are considered as having been produced by breaks along which differential movements on the two sides have occurred. The rocks on one side of a break have been elevated or those on the opposite side depressed, producing what is termed a fault. The steeper sides of the ranges are fault scarps more or less eroded and perhaps largely concealed beneath rock waste in the form of talus slopes and alluvial fans. The monoclinal ridges forming the Lost River Mountains are seemingly of the Great Basin type, but, unlike the representatives of that type in Utah, Nevada, southeastern California, etc., trend northwest and southeast instead of at right angles to that course, as is common throughout much of the Great Basin.[a]

The geological structure of the various ranges and ridges composed principally of quartzite situated southwest of the Lost River Mountains is little known, except that the presence of faults is indicated by the diverse inclination of the strata in neighboring ridges and that much movement along breaks trending in general northwest and southeast has taken place. Farther west, from near Shoshone to beyond Boise, as previously stated, extensive faulting has occurred, as may be readily seen in the portion of that region which is composed of stratified rhyolite. Near Boise, where the nearly level Snake River Plains meet the mountains on their northern border, the bold mountain front, composed principally of granite, has been ascribed by Lindgren[b] to faulting. My studies in the same region and in the area east of it to King Hill Creek and near Shoshone, serve to confirm this view. The leading facts tending to support this conclusion are: First, the alignment of the steep precipices which descend from the mountains to meet the plain, and the fact that both the granite and the rhyolite of which the mountains are principally composed terminate abruptly at the escarpment referred to; second, from this line of escarpments branching faults extend into the mountains formed of rhyolite; these branching faults form in fact the main escarpment for a distance sometimes of several miles before departing from it sufficiently to become individualized; third, the presence of recent faults at and near the base of the mountain in the vicinity of Mountain Home, and in the basalt covering the adjacent depression; fourth, the presence of hot springs along the base of the straight mountain face where it meets the plain and where evidence of recent movement

[a] A comprehensive account of the leading structural features of the Great Basin may be found in G. K. Gilbert's Lake Bonneville: Mon. U. S. Geol. Survey, Vol. I, 1890, pp. 340-392.

[b] Geol. Atlas U. S., Boise folio, 1898.

occurs. All of these several lines of evidence when studied in the field lead to the same conclusions, and, I think, prove that the striking change in topography at junction of the Snake River Basin with the mountain to the northeast, in the vicinity of Shoshone, Mountain Home, Boise, etc., is due primarily to faulting. This fault, however, is not a single, definite fracture, but a series of irregular and branching fractures, the rocks on the northern side of which have been upraised or those on the southern side depressed. In the mountains composed of rhyolite, north of Mountain Home, the several faults are readily seen from many commanding summits. The trend of these breaks, which define the borders of prominent monoclinal ridges, is in general from N. 20° to N. 40° W. The strata composing the blocks between the faults are in most instances inclined downward to the northeast at angles of from 15° to 20°. Certain of these fault scarps, when traced southward, merge into and form a part of the general line of bluffs bordering the Snake River Plains. The conspicuous mass of stratified rhyolite forming Mount Bennett, is, so far as can be judged from its leading topographic features, a representative example of a tilted fault block of the nature just referred to, but the secondary elements in the structure of the mountains are unknown. This block presents its bolder escarpment to the southwest, and the beds of which it is composed dip toward the northeast. The extremely bold southwest face of the mountain is a part of the general line of escarpments which descends to and defines the northern border of the Snake River Plains in Elmore and Ada counties.

Practically nothing is known of the structure in the mountainous region bordering the Snake River Plains on the south, except that in the Rock Creek Hills a monoclinal structure similar to that of the Mount Bennett region is present.

The occurrence of folds in the rocks of southern Idaho is not denied, but as structural features influencing the present topography, they are believed to be subordinate to the faults.

Although the details in the structure of the rocks, even along the best known portion of the border of the Snake River Plains, with the exception of the area included in the Boise folio, remain to be studied, and even the major features in the relief are, to a great extent, unmapped, it seems safe to conclude, at least provisionally, that the great depression through which Snake River flows is due in part and mainly to displacements along lines of fracture and an upward bending in the region occupied by the Owyhee Mountains.

EARLY GEOLOGICAL HISTORY OF THE SNAKE RIVER BASIN.

While the great depression in southern Idaho occupied by the Snake River Plains is primarily due to the upheaval of the bordering mountains, it is probable that a large amount of erosion has taken place and that the depression was thus broadened and deepened previous to its becoming partially filled with the lacustral and stream sediments and lava flows which now occur in it and give it an essentially level floor. In traveling through that region nothing in reference to the present relief of the surface is more prominent than the fact that the leading features in the topography, excepting the broad plains, were in existence previous to the deposition of the sediments and the outpouring of the lava which had upgraded the great central depression.

The mountains of central and southeastern Idaho, so far as known, are composed mainly of Paleozoic or older rocks. The exceptions are certain Mesozoic formations described by the geologists of the Hayden survey, which occur in the extreme southeastern portion of the State, and tilted Tertiary beds mapped by Lindgren, in the mountains near Boise. The Tertiary beds referred to, however, and perhaps the Mesozoic (Juratrias) beds to the east of Blackfoot are of fresh-water origin. The general interpretation to be put on these facts seems to be that southern Idaho has been a land surface, in part occupied by lakes, since the close of the Paleozoic. Although up and down movements have occurred since the Mesozoic and are, no doubt, still in progress, the mountains were formed mainly previous to the beginning of that era, and were deeply eroded previous to the beginning of the Tertiary. The great valley now occupied by the Snake River Plains, with its many lateral branches, was in existence previous to the Tertiary, and owes its dominant features to the upheaval of its bordering mountains, and the accompanying depression of the larger valley areas, together with long-continued erosion. During Mesozoic time a river no doubt flowed through the Snake River Valley, which received tributaries from the secondary valleys leading to it, and the land was deeply dissected and was of mature and even old topography previous to the Tertiary. The direction of flow of the stream which preceded the present Snake River is unknown, but was most probably westward. This river continued its work of removing the débris produced by the disintegration and decay of the bordering mountains for a very long period. No attempt will be made at this time to determine the details of the earlier portion of the geographic history of southern Idaho, but the general conclusion that we have there a land surface which has been in existence since near the beginning of the Mesozoic era is one of much interest, on which must be based many conclusions of both purely scientific and economic importance.

As has been stated several times, the valleys of southern Idaho have become deeply filled in many instances with alluvium deposited by streams, the sediments of lakes, and the lava and other products of volcanoes. These deposits demand special consideration, as they are intimately associated with the problem of obtaining artesian water, the development of springs, the desirability of excavating horizontal wells, etc.

TERTIARY AND RECENT LACUSTRAL FORMATIONS.

PAYETTE FORMATION.

During the earlier part of the Neocene (Miocene) period, as determined by Lindgren—that is, during Middle Tertiary time—a large fresh-water lake occupied the Snake River Basin, and the sediments deposited in it are now a prominent feature of the country, especially to the west of Salmon and Malade rivers (Pl. I). These lacustral deposits have been named the Payette formation, for the reason that they are well exposed along the lower courses of Payette River.[a] The formation is extensive. As stated by Lindgren, it lies mainly to the south and west of the Boise Mountains, and occupies the whole of the lower part of the ridge between Boise and Payette rivers, and occurs throughout an extensive area in Oregon to the northwest of the mouth of the Owyhee River.

The rocks of the Payette formation are mainly sands, clays, and volcanic lapilli, with occasional beds of coarse gravel, especially near the bases of the bordering mountains. The strata have in many instances been consolidated, so as to form sandstone and soft shale, but to a great extent they are still soft, loose sands and slightly compacted sandy clays. At several localities in the Boise quadrangle, and again on Schaffner and Indiana creeks, I found the ordinary sedimentary beds to be interstratified with layers of white volcanic dust several feet in thickness. The thickness of the Payette formation, as stated by Lindgren, is over 1,000 feet in the vicinity of Boise, but owing to lack of exposures and to the scarcity of deep borings, its maximum depth remains to be determined. Its extent, as well as its thickness, suggests that it is widely spread beneath the Snake River Plains, but although it was traced by me eastward from Boise to the region crossed by King Hill and Clover creeks, it there disappeared beneath lava flows and alluvial deposits and its presence beneath the central and eastern portions of the plain remains to be ascertained. In the mountains to the north of Boise, Lindgren found several detached areas of the Payette formation in which the strata were variously inclined, sometimes as much as 50°, showing that there have been extensive

[a] On the map forming Pl. I no attempt has been made to separate the Payette and the Idaho formations. West of Mountain Home and north of Snake River lake beds and lava sheets are interstratified in such a manner that it is impossible to represent them separately on a map of the scale used. The great preponderance at the surface of lake beds over lava sheets, in the region referred to, has led to my giving the entire region the color indicating the sedimentary formation. South of Snake River the area colored to represent lake beds is mostly without lava sheets.

The extension of the Snake River lava, shown on the map referred to, eastward from Blackfoot, is sketched from geological maps accompanying the Twelfth Annual Report of the United States Geological and Geographical Survey of the Territories, by F. V. Hayden, Washington, 1883. All of the geological data represented to the west of Garnet are from geological maps published by Waldemar Lindgren in the Eighteenth Annual Report, United States Geological Survey, Pt. III, Washington, 1898, Pl. LXXXVII, and in the Twentieth Annual Report, Pt. III, of the same survey, Washington, 1900, Pl. VIII.

earth movements and deep denudation since the time the sands, etc., were laid down in horizontal sheets in the old lake. No such detached areas have been discovered in the mountains to the east of the Boise quadrangle.

From what is known of the Payette formation, it seems that it has its greatest extent in southwestern Idaho and neighboring portions of Oregon, and while probably present beneath the main portion of the Snake River Plains—that is, to the east of Malade and Salmon rivers—is there deeply buried, but little disturbed from its original horizontal position and not laid bare by erosion.

The upper limit of the beds deposited in Lake Payette is stated by Lindgren to be about 4,000 feet above the sea, but as quite extensive movements have occurred since they were laid down, the precise horizon of the surface of the old lake is difficult to determine. During the later portion of the Tertiary the waters of Lake Payette seem to have subsided, and possibly a new lake was formed in the same basin, principally in southwestern Idaho, in which sedimentation occurred, without, so far as is now known, a well-marked, if any, period of erosion intervening. The beds laid down in this younger lake and by streams discharging their sediments into the same basin, are less consolidated than those of the typical Payette formation, and are mostly loose sands and soft calcareous clays, with minor quantities of volcanic lapilli and dust and well-rounded gravel.

IDAHO FORMATION.

The presence of lacustral deposits in Snake River Canyon of younger date than the Payette is thus referred to by Lindgren in the Boise folio:

> During the eruptions of the Pliocene basalt the extensive Payette Lake had dwindled to smaller dimensions. Its shore line for some time probably remained stationary at an elevation of 2,700 or 2,800 feet, but in this quadrangle [the area described in the Boise folio] there are few marks left of its existence, as most of these later lake beds have been obliterated by Pleistocene river wash. Along Snake River, from above Glenns Ferry down to near Nampa, late Neocene (Pliocene) lake deposits are found as white clays and sands interbedded with thin basalt flows, and well exposed in the river bluffs.

I make the above quotation not for the purpose of controverting the conclusion stated, but to record the fact that the observations presented below pertain to what Lindgren has decided are the deposits of a Pliocene lake, to which the name Lake Idaho was given by E. D. Cope. My observations of the abundant exposures of the Idaho formations on the borders of Snake River Canyon began on the west at the southeastern corner of Ada County and were continued eastward to Shoshone Falls. A few typical sections in this region will serve to show the nature of the deposits and their relation to the associated lava sheets.

In the region examined below the mouth of Bruneau River the lava sheets forming the rim rock of Snake River Canyon on the north side do not extend south of the river. The south wall of the canyon is comparatively low and composed of soft, white, horizontally stratified sediments, which extend southward to the base of the mountains which define the border of the Snake River Basin in Owyhee County. A portion of the border of Lake Idaho is marked by the junction of its sediments with the rocks which formed its shore. The broad tract of exposed lake beds in Owyhee County is deeply sculptured and presents typical examples of "bad-land topography."

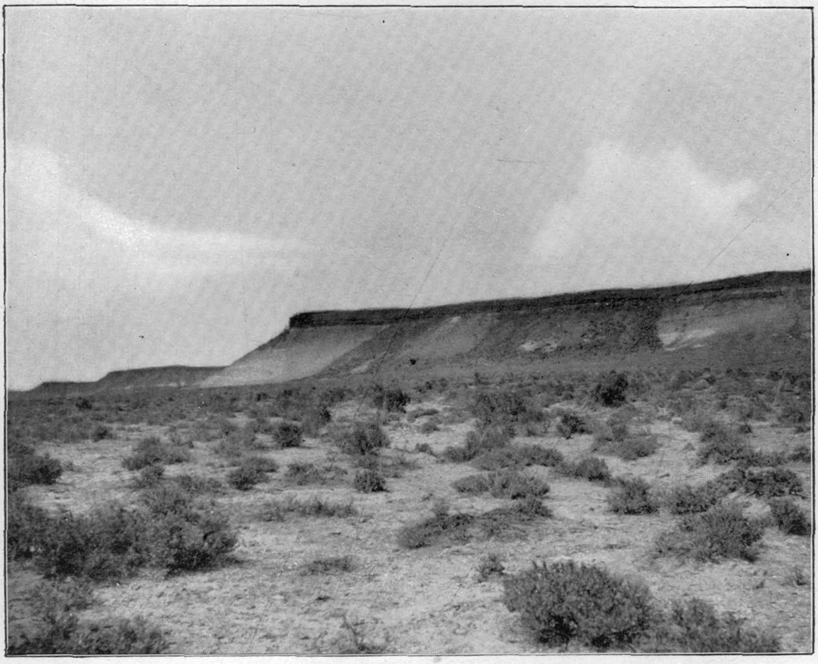
The precipitous northern wall of Snake River Canyon near the boundary between Ada and Elmore counties is about 450 feet high, and is composed of three principal varieties of rock, namely, in descending order, basalt, lapilli, and lacustral clay and sand. In general, the upper portion of the canyon wall is the edge of a lava sheet which underlies in part the thin covering of soil on the adjacent plain, and in part another similar lava sheet. In at least one locality the lapilli, which usually occurs below the basalt, rises higher than its surface, and forms the actual summit of the escarpment. The usual thickness of the basalt is from 20 to 40 feet. The thickness of the yellowish, earthy lapilli beneath the basalt is variable, in places being 180 feet, and at a distance of perhaps a mile from where the maximum exposure occurs, thinning out to but a few feet and even vanishing, the lake beds below thickening and occupying its place. From the locality referred to all the way to Shoshone Falls, the presence of three stages in the filling of the basin is frequently clearly exposed. All of the members of the series vary in thickness, and above the mouth of Bruneau River several sheets of basalt are sometimes present and the lapilli are wanting. The records of a few of the numerous sections examined will serve to illustrate these features in detail.

At a locality in Ada County, about 7 miles below the mouth of Canyon Creek, shown on Pl. VII, the wall of Snake River Canyon reveals the following section:

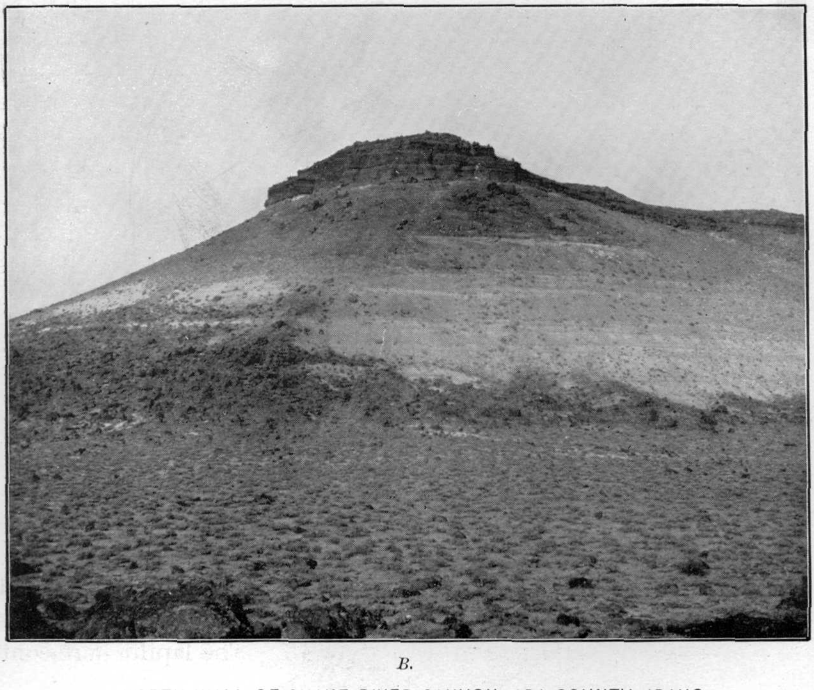
Section of wall of Snake River Canyon 7 miles below mouth of Canyon Creek.

	Feet.
1. Black, compact, but somewhat scoriaceous basalt	20
2. Yellowish, slightly compacted lapilli, with angular fragments of scoriaceous basalt sometimes 2 inches in diameter, and reddish pebbles of granitic rock	100
3. Thinly laminated lacustral clay	180
4. Not exposed to the river, about	150
Total	450

A mile farther west the rim rock of basalt is absent, and the bed of lapilli, there about 180 feet thick, rises above the level of the basalt in the adjacent portions of the canyon wall. The lapilli here contain



A.



B.

NORTH WALL OF SNAKE RIVER CANYON, ADA COUNTY, IDAHO.

blocks of basalt 10 to 14 inches in diameter. In places the bed of lapilli is compact and stands in vertical walls from 20 to 30 feet high, more or less sculptured by wind erosion. In this stratum, also, there are at times local beds, usually less than a foot thick, of thinly laminated soft sandstone. About 2 miles east of the locality first mentioned, and at the end of a prominent bluff (Pl. VI, *B*), still more conspicuous variations were observed in the strata forming the canyon wall, as is shown by the following section:

Section of wall of Snake River Canyon 5 miles below mouth of Canyon Creek.

	Feet.
1. Coarse basaltic breccia, fragments 3 feet in diameter	40
2. Compact, columnar basalt	6
3. Coarse volcanic breccia	20
4. Evenly laminated volcanic sand	9
5. Yellowish stratified lapilli	70
6. Fine, white, laminated calcareous clay	2
7. Yellowish stratified lapilli	7
8. Fine, white, horizontally laminated clays, interbedded with fine, loose, cross-bedded, light-colored sand, becoming pebbly and cross-stratified at the top	120
9. Unexposed to the river, about	100
Total	374

The highest rim rock of basalt, usually present in the portion of the canyon here referred to, is absent from above the summit of the promontory at which the section just given was observed, but is present near at hand. A capping of some 20 to 30 feet of basalt above the highest bed of breccia observed may at one time have existed, but has crumbled and fallen away.

From the mouth of Bruneau River upstream for about 6 or 8 miles the Snake flows between precipitous walls capped on each side by a conspicuous rim rock, as is illustrated on Pl. VI, *A*. This view was taken from the summit of the northern wall of the canyon, just below the mouth of the Bruneau, looking downstream to the southwest, and into the broader portion of the canyon, which is excavated in soft sediment. Beneath the thick sheets of basalt, of which four are easily recognized in the lower part of the canyon of Canyon Creek, there are thick beds of gravel, sand, and clay, but lapilli are seemingly absent. At a locality on the left bank of the river near where it enters the wider portion of its canyon the following section is revealed:

Section of Snake River Canyon near mouth of Bruneau River.

	Feet.
1. Compact columnar basalt	40
2. Stratified unconsolidated white sand	30
3. Waterworn pebbles	15
4. Fine unconsolidated white sand	12
5. Finely laminated, horizontally bedded sandy clay	250
Total	347

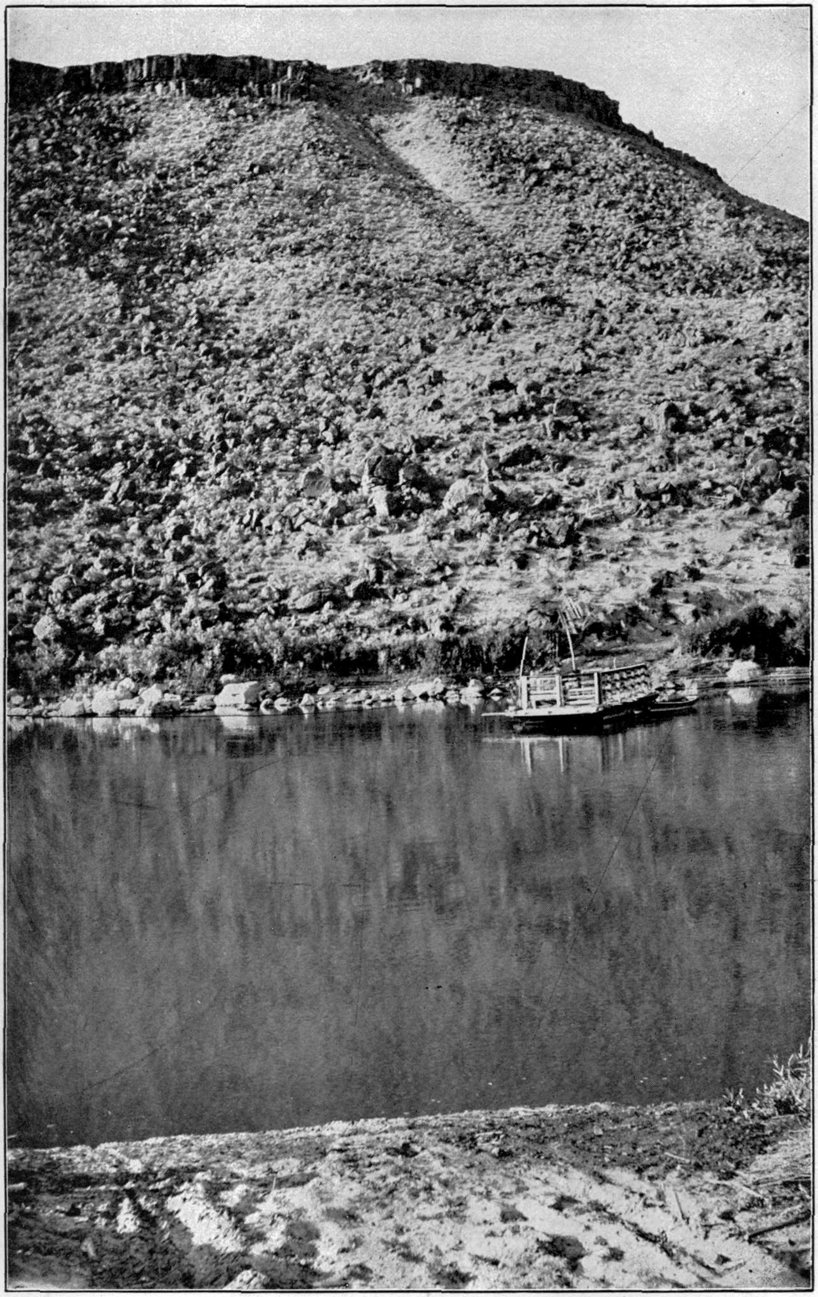
In the vicinity of Leveridges Ferry, just above the mouth of Rattlesnake Creek, the canyon of Snake River is 6 or 8 miles broad, with a steep wall capped with basalt on the northern side and a less precipitous slope formed entirely of soft sediments on the southern side. As is commonly the case throughout the course of Snake River below Glenns Ferry, the plain bordering the canyon on the north rises gently northward, and is covered with fine, yellowish-white soil. In the precipitous and in part vertical escarpment forming the northern side of the canyon the following section was obtained, but the details change in a conspicuous manner, owing principally to variations in the number of sheets of basalt present, when the cut edges of the strata are followed even short distances, either up or down stream:

Section of Snake River Canyon near mouth of Bruneau River.

	Feet
1. Columnar basalt, compact, contains numerous flattened steam holes an inch in length, but is not glassy, and does not rest on a bed of lapilli or breccia	25
2. Horizontally and even-bedded sandy clay, in part clean, loose sand, largely concealed beneath talus from basalt cliff above	210
Terrace about 1,000 feet wide, covered with well-rounded quartzite cobbles and sand; surface irregular. This layer of cobbles is from 5 to 15 feet thick, but is not a part of the section, having been deposited during the excavation of the canyon.	
3. Fine, grayish-white, evenly laminated clay	35
4. Parting of white sand, unconsolidated; can be traced along the face of the bluffs for a mile or more	½
5. Fine, grayish-white clay, like No. 4	20
6. Fine, evenly laminated pinkish clay	30
7. Clean, well-rounded pebbles	1
8. White sandy clay or silt	4–5
Terrace, 200 to 300 feet wide, covered with cobbles.	
9. Basalt, highly scoriaceous, glassy (lower rim rock)	40
10. Fine, unconsolidated sandy clay, base concealed	35
11. Old flood plain, surface level, composed of fine silt	35
12. Modern flood plain, overflowed during high water	15
Total, about	400

The conspicuous variations which occur in the number and thickness of the lava sheets exposed near the mouth of Rattlesnake Creek will be noted later, as well as the significance of the striking differences between the basalt which forms the two rim rocks present where this section was observed. The numerous minor variations exhibited by the sedimentary beds in this same region might be shown by many sections, but space will permit of but one more.

On the south side of Snake River Canyon, at a locality termed Shell Mountain, about 10 miles below Glenns Ferry and nearly opposite the mouth of Bennett Creek, the bold bluffs immediately bordering the river are composed almost entirely of fine, unconsolidated, nearly



SOUTH WALL OF SNAKE RIVER CANYON, HALLS FERRY, IDAHO.

white sand and evenly laminated nearly white clays, together with a thin sheet of basalt, which soon disappears when traced southward. The section observed at this locality is as follows:

Section of Snake River Canyon 10 miles below Glenns Ferry.

	Feet.
1. Light-gray, laminated, fine-grained clay or silt, changing to white below. By estimate	150–170
(This stratum forms the surface for many miles south of Snake River, and rises into low hills; at the border of the canyon it is deeply notched and well exposed.)	
2. Scoriaceous basalt	4–10
(Near at hand two sheets of basalt are present at this horizon; the upper are 6 and the lower are 10 feet thick, with 10 inches to 2 feet of sandy sedimentary material between; this layer is of a brick-red color and is traversed by vertical but tortuous steam holes.)	
3. Associated with No. 2 is a bed of coarse, well-worn gravel	4–6
(This bed possibly indicates the summit of the Payette formation, as the beds below contain an abundance of Miocene fossils; those above, so far as known, are barren of fossils.)	
4. Loose, well-worn pebbles, of a variety of rocks, including basalt, cross bedded, ferruginous, in part loosely cemented	3–10
5. Unconsolidated, fine, nearly white sand, with occasional shaly layers, cemented at times into irregular concretionary bands, charged with fresh-water shells throughout.[a] Thickness above the river	300
Total, about	650

The basalt exposed at Shell Mountain is the attenuated margin of a widely extended sheet which underlies the plain to the north of Snake River, but which has been removed by the erosion of Bennett and other creeks, as well as by the main stream to which they are tributary. This is the only layer in the section that reveals the inclination of the beds composing it; it dips very gently southward.

The facts briefly presented in the last few pages and others that might be recorded, did space permit, show that Snake River in its course for at least 50 miles below the mouth of Salmon River, in general skirts the southern margins of lava sheets which underlie the plain to the north, but occasionally cuts across portions of the lower sheets which extend farthest southward. Where the river crosses a portion of a lava sheet and has cut a channel in it its canyon becomes narrow with steep walls. In such localities, if the basalt is thick, the canyon walls are nearly vertical; and if thin, a conspicuous rim rock appears above steeply sloping bluffs in part concealed by talus and landslides. When two or more sheets of basalt are present, rim rocks occur below the highest one, which forms the rim or "break" of the canyon. When only soft sedimentary beds are present, and this is only on the south side of the river, except in the vicinity of Glenns Ferry, the

[a] A list of the shells collected at this locality is given on p. 56.

canyon widens into a valley, frequently 6 or 8 miles broad, with a precipitous escarpment on the northern side and a less steep and less regular line of bluffs forming its southern border.

FOSSILS.

At Shell Mountain and near Glenns Ferry a large number of fresh-water shells were collected, which, as determined by W. H. Dall, belong to the following species: *Lithasia antiqua* Gabb; *Melania taylori* Gabb; *Corbicula idahoensis* Meek; *Bythinella*, species indeterminate; *Fluminicola*, species indeterminate but like *Amnicola* (*Fluminicola*) *longinqua* Gould, and fragments of *Anodonta*. The *Anodonta* shells occur whole in the deposits, but, on account of their extreme fragility, the specimens collected were much broken.

From lake beds higher in the series than those from which the shells named above were obtained, well exposed in Little Valley, 9 miles west of Bruneau, internal casts of a large indeterminate species of *Cannifex* were obtained.

While the precise position of these fossils in the geological time scale has not been determined, they are certainly of Tertiary age, and, as stated by Dall, probably belong to the Miocene.

In the lake beds so well exposed in the northern portion of Owyhee County the frequent occurrence of fossil bones, some of them of large size, has been reported by ranchmen and others, but only a few individual bones and fragments of bones were collected. These were obtained from the surface portion of the lake beds exposed at the head of Little Valley, and although not sufficiently complete to permit specific determination, are stated by F. A. Lucas to consist of "a portion of the left scapula of a large camel, one of the toe bones of a small camel, and a toe bone of Morotherium."[a] Besides these mammalian remains, the vertebra, teeth, etc., of a fish related to the carp, *Anchybopsis fasciolatus* Cope, and the vertebra of a salmonoid fish, of the genus *Rhabdofario* Cope, were found in considerable numbers. In reference to the age of these fossils Lucas says: "They are all typical Pliocene species, such as are found in the Pliocene of Washington, Oregon, and Idaho."

Although the number of vertebrate remains obtained was small and of little scientific interest, there are indications, especially in the admirable state of preservation of the bones, that the beds from which they came will yield most important results in this connection when carefully searched.

At a locality near the head of Little Valley and in soft white lake beds belonging to the same formation as the neighboring layers from

[a] An early representative of the *Edentates*, including *Megatherium*, etc., which inhabited both North and South America in post-Tertiary times, and are remotely related to the living sloths and armadillos.

which the fossil bones just referred to were obtained, fossil wood occurs in abundance. The wood is in fragments, and was evidently waterworn, as if rolled up and down a beach before being buried, and replaced by silica. Mingled with the fossil wood are occasionally found silicified pine or spruce cones in an admirable state of preservation.

The meager data furnished by the fossils referred to above seems to indicate that the lower portion of the lacustral deposits cut through in forming Snake River Canyon belong to the Miocene and the upper part to the Pliocene, but at present it is impracticable to draw a line of division between the two. A summary of the evidence furnished by previous collections from the lacustral deposits of southwestern Idaho has been given by Lindgren[a] and need not be reviewed at this time.

SUMMARY OF LACUSTRAL CONDITIONS.

The general succession of events recorded by the sedimentary beds considered above seems to be as follows: A large lake or possibly two or more successive lakes in the same depression, the boundaries of which are known only in part, existed in the Snake River Basin in Tertiary times. In this lake several hundred feet of fine, evenly laminated clay or silt and volcanic dust and lapilli were laid down. The fact that loose sand in places 300 feet or more thick rests on the clays previously deposited suggests that the lake became shallow, and the presence of beds, usually thin, of well-worn pebbles consisting of a variety of rock fragments indicates the occurrence of strong currents in a shallow water body, or else that the lake was drained and its exposed bed crossed by streams. These sediments, which in the most typical instances are clearly lacustral, contain beds of coarse, well-rounded gravel, such as is laid down by streams, and it is impracticable at present to determine just what part is the result of still-water and what part of flowing-water deposition. The occurrence of 150 feet or more of fine, evenly laminated sediments above the medial sand and gravel, as at Shell Mountain, shows that the lake after its low-water stage again became broad and deep. So far as known, the lava flows which have produced such marked features in the walls of the Snake River and its tributary canyons were poured out during the middle and later stages in the history of the old lake. Some of these lava streams entered water and flowed over an irregular bottom, as will be described later, while others show no evidence of such an occurrence. These facts seem to indicate that in some instances the lava entered a lake, filling the inequalities in its bottom, or flowed over an exposed and eroded lake bottom and into streams which occupied

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, Part III, 1889, p. 628, and Twentieth Ann. Rept., Part III, 1900, pp. 98-99.

the depressions. There is evidence tending to show that lacustral conditions continued after the highest sheet of lava in the region below the mouth of Bruneau River was poured out, but these higher beds, being unprotected by a hard cover, have been to a great extent eroded away. The volcanic eruptions were accompanied by the blowing out of large quantities of volcanic dust and lapilli; other fragmental deposits were produced when the lava flows, which, as is presumed, followed the explosive eruptions, entered water bodies.

ECONOMIC PROBLEMS.

As to the economic importance of the sedimentary beds just considered, I may say briefly that possibly some of the clays may be found suitable for brickmaking, should commercial conditions make this desirable. It has been suggested that the abundant outcrops of fine clay near Hagerman can be utilized in the manufacture of aluminum, the waterfalls near at hand furnishing the necessary power for electric smelting. The feasibility of such a plan, however, remains to be ascertained.

The principal interest, from an economic point of view, at present attached to the sedimentary beds referred to is in reference to the possibility of obtaining artesian water. As has been stated, these beds are in part close-textured clays and in part loose sands and gravel. The beds of lapilli are in general compact and do not allow the free percolation of water through them. One of the requisite conditions for the storage of subterranean water under pressure is thus present; that is, an alternation of pervious and impervious strata. Another requisite is that the succession of water-bearing and non-water-bearing beds should be inclined, or, best of all, so bent as to form a basin. In the portion of the Snake River Plains to the west of Salmon Falls the strata are not horizontal, but inclined gently downward from the bases of the bordering mountains toward the center of the plains; that is, the central part of the basin has been depressed, or its border raised, in reference to a nearly east-west axis, so as to give the strata a trough-like form. The longer axis of this trough below Salmon Falls has a gentle downward inclination or pitch to the northwest. This trough has the structural features of what is known as an artesian basin, but in the region thus far explored is only a portion of a completely inclosed basin, the location of its western margin being as yet unknown. Whether or not the major axis of the trough rises again to the west can not be told at present, but from such general knowledge as is in hand concerning the western portion of the Snake River Plains and the occurrence of pre-Tertiary rocks in the canyon of Snake River below Weiser, it is presumed that a completely inclosed basin exists. Other facts in this connection, the best method of testing the artesian conditions of this basin, etc., will be considered in the second part of this report.

POSSIBLE EASTWARD EXTENSION OF THE TERTIARY SEDIMENTARY BEDS.

The wide extent of the exposed portions of the lacustral deposits in the western part of the Snake River Plains, and the absence of exposures of such rocks in their eastern portion, is seemingly to a great extent in the nature of an accident. In the region below the mouth of Salmon River, lava sheets are less thick and probably less numerous than east of that locality. Below Shoshone Falls the Snake has cut deeply into the beds beneath the plains, and each tributary stream, at least near its mouth, is also in a canyon; but upstream from the locality mentioned the plains are much less dissected, and over vast areas they are uneroded. The presence of extensive sedimentary beds beneath the lava flooring the broad eastern division of the plains can not now be determined from direct evidence. What is known of the pre-Tertiary topography of the Snake River Basin, however, and the extent and thickness of the sedimentary deposits in its western portion, etc., favor the hypothesis that beneath the surface lava sheets in its eastern part extensive beds of clay, sand, etc., do occur. This is an important question in reference to the possibility of obtaining water in the broad, unbroken portion of the plains, but one that can be definitely answered only by drilling.

SNAKE RIVER LAVA.

The name Snake River lava is here proposed as a general term by which to designate the basaltic rocks that underlie by far the larger part of the Snake River Plains, and to a great extent form their actual surfaces. It includes, also, the lava streams and associated cinder cones, etc., which have descended lateral valleys or adjacent mountain slopes, and united with the sheets of similar material extruded from numerous craters on the plains. When this extensive formation is studied in detail, it will, I judge, be found practicable to separate it into several distinct portions, and to correlate some of these with sedimentary beds containing fossils, and thus determine their precise geological age.

EXTENT AND THICKNESS.

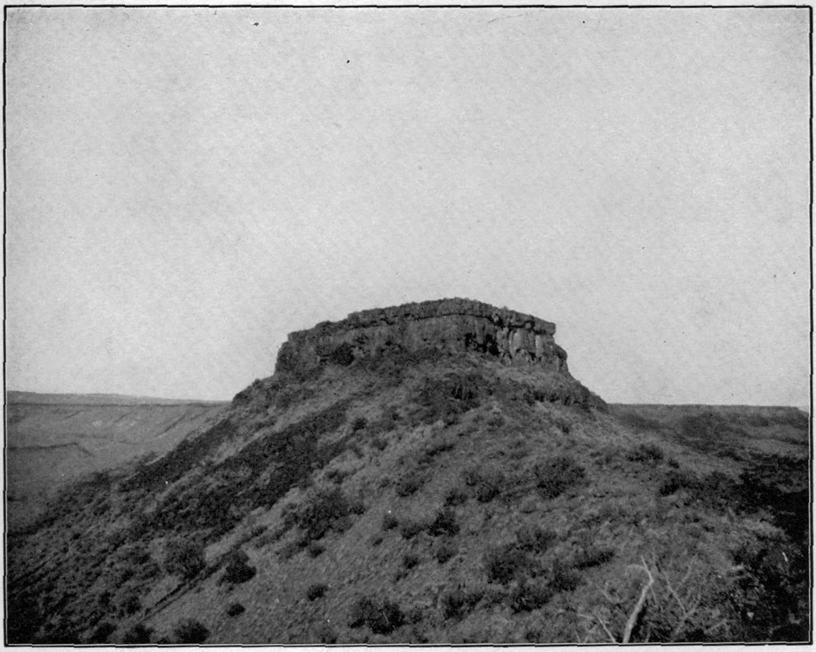
The extent of the Snake River lava is represented approximately on the map (Pl. I), on which the boundaries of the lava-covered country where known are indicated by a broken line, and where merely inferred the shading is not definitely margined. The area shaded by single lines on the map represents the region where lava sheets, and, to a minor extent, beds of scoriæ and lapilli, occur at the surface, or are present beneath a thin covering of soil. In certain localities in the western portion of the Snake River Plains lava sheets are more or less completely covered by sedimentary deposits, and hence are not indicated on the map, which represents only the formations on the surface. The change is gradual from where the lava is the most prominent surface feature in southeastern Idaho to where, at the west, sedimentary deposits greatly predominate, but it was found impracticable to represent this on the accompanying map.

The estimated area covered by the Snake River lava is in the neighborhood of 20,000 square miles. So far as is now definitely known, there is but one lava field in North America of greater extent, namely, the Columbia River lava, the estimated area of which is about 200,000 square miles. In Snake River Canyon, below Shoshone Falls, nearly 700 feet of lava in horizontal sheets are exposed, but whether this is the maximum thickness or not can not be told. As a rule, the various sheets of lava are relatively thin, averaging perhaps 50 to 80 feet, and widely extended. That many independent outflows of lava have occurred is easily seen, but in the walls of Snake River Canyon, where the best sections are exposed, it is difficult to determine their number, unless lacustral deposits, beds of lapilli, etc., occur between them. Near the mouth of Rattlesnake Creek four separate sheets are present, and others not represented at that locality occur but a few miles away. In no single vertical section along Snake River could more than four sheets be definitely recognized; but this number will no doubt be increased when an opportunity is afforded for detailed examination.

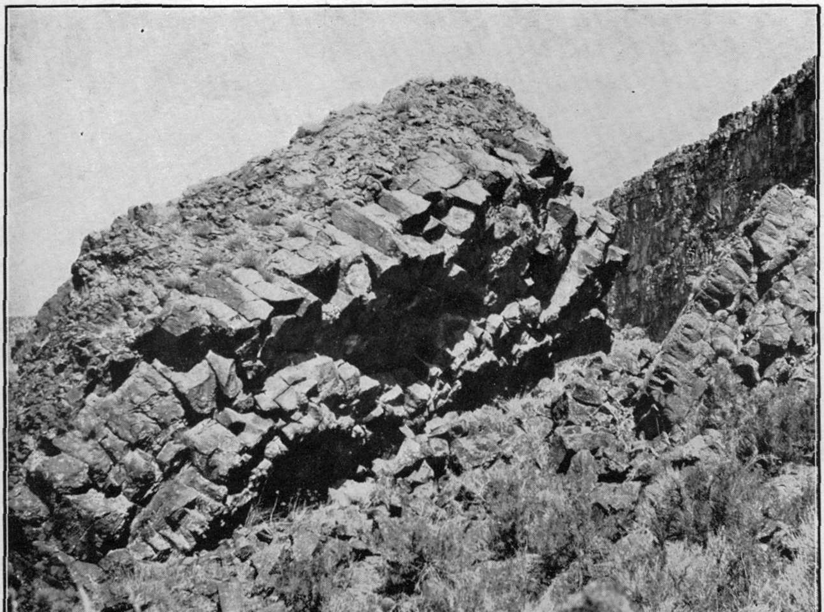
While the various sheets of lava are in general essentially horizontal and in the position in which they were spread out, there are interesting exceptions to this rule. Over an area beginning near The Thousand Springs and extending westward the lava sheets have been gently folded, and near Salmon Falls there is a suggestion that the lowest sheet of lava exposed was gently folded before the thick bed of clay and the lava sheets above it were spread out. These deformations, however, are so gentle and extend over such large areas that much more extended and accurate data than could be obtained during a reconnaissance are needed for their study.

RELATION TO THE COLUMBIA RIVER LAVA.

The lava occurring on the Snake River Plains is so similar in nearly all its features to the still more extensive formation known as the Columbia River lava, through which Snake River has cut a magnificent canyon in western Idaho, near Lewiston, and from there to its junction



A. REMNANT OF SNAKE RIVER LAVA, KING HILL CREEK.



B. BLOCK OF COLUMNAR LAVA, SNAKE RIVER CANYON.

with the Columbia, that the relation of the two becomes of interest.[a] The country separating these two areas of basaltic rock has not as yet been geologically explored, and while it is possible that a direct connection between them may be discovered, it seems more probable that they are distinct and have somewhat different histories. From the evidence now in hand, it appears that the Snake River lava is in general much younger than the related formation to the westward, although its basal members seem to be of about the same age. The principal part of the Columbia River lava, as shown by fossil leaves contained in the associated sedimentary beds, is of Miocene age.[b] The older portion of the Snake River lava, as indicated by its relation to the Payette formation, etc., as stated on a previous page, is also of Miocene age. Much reliance should not be placed in this correlation, however, until it is sustained by additional evidence. Although the first-formed sheets of the Snake River lava are perhaps of about the same age as the main mass of the Columbia River lava, by far the greater part of it is much younger. The latest outpourings of molten rock over the Snake River Plains, as will be described later, occurred probably within recent historical times, and are perhaps not over 100 to 150 years old. While the Columbia River lava is deeply decayed and over large areas changed to a soft clay-like soil having a depth of 60 feet or more, the lava sheets on the Snake River Plains are still fresh, and even in the case of the exposed portions of the older sheets show but slight changes. These older sheets may have been covered for a long time by sedimentary deposits which have since been washed away, and thus preserved from decay, but this explanation can not be made to apply to the greater part of the lava. The evidence furnished by a comparison of the state of preservation of the Snake River and the Columbia River lavas shows conclusively that the Snake River lava is in general much the younger of the two.

HYPOTHESIS OF FISSURE ERUPTIONS.

There is but little literature relating to the Snake River lava, but what has been published in reference to its origin (except by Lindgren)

[a] Descriptions of the Columbia River lava may be found in the following publications:

George Gibbs, Report on the geology of the central portion of Washington Territory: Pacific Railroad Reports, Vol. I, 1854, pp. 473–486.

F. von Richthofen, The natural system of volcanic rocks: Mem. Cal. Acad. Sci., Vol. I, Part II, 1868.

Joseph Le Conte, Am. Jour. Sci., 3d series, Vol. VII, 1874, p. 168.

T. W. Symons, Report on an examination of the Upper Columbia River, Senate Ex. Doc. No. 186, Forty-seventh Congress, first session, 1882.

I. C. Russell: A geological reconnaissance in central Washington, Bull. U. S. Geol. Survey, No. 108, 1893; A reconnaissance in southeastern Washington, Water-Supply and Irrigation Papers U. S. Geol. Survey, No. 4, 1897; Volcanoes of North America: The Macmillan Co., New York, 1897; Geology and water resources of Nez Perce County, Idaho, Water-Supply and Irrigation Papers, U. S. Geol. Survey, Nos. 53 and 54, 1901

[b] F. H. Knowlton, Bull. U. S. Geol. Survey, No. 108, 1893, pp. 103–104.

favors the view that the lava came to the surface through fissures and was poured out after the manner termed by Richthofen fissure or massive eruptions, in distinction from the extrusion of molten rock, lapilli, etc., from well-defined vents, as in the case of Vesuvius and other well-known volcanoes.

The view that the lava forming so large a part of the Snake River Plains was supplied by fissure eruptions, interwoven with a graphic description of the leading scenic features of the region, is expressed in the following quotation from Sir Archibald Geikie's charming book, entitled Geological Sketches at Home and Abroad:[a]

Never shall I forget an afternoon in the autumn of last year [1879] upon the great Snake River lava desert of Idaho. * * * We rode for hours by the side of that apparently boundless plain. Here and there a trachytic spur projected from the hills, succeeded now and then by a valley up which the black flood of lava would stretch away into the high ground. It was as if the great plain had been filled with molten rock which had kept its level and wound in and out along the bays and promontories of the mountain slopes as a sheet of water would have done, * * * I looked round in vain for any central cone from which this great sea of basalt could have flowed. It assuredly had not come from the adjacent mountains, which consisted of older and very different lavas, round the worn flanks of which the basalt had eddied. A few solitary cinder cones rose at wide intervals from the basalt plain, as piles of scoriæ sometimes do from the vapor vents on the surface of a Vesuvian lava stream, and were as unequivocally of secondary origin. Riding hour after hour among these arid wastes, I became convinced that all volcanic phenomena are not to be explained by the ordinary conception of volcanoes, but that there is another and grander type of volcanic action where, instead of issuing from a local vent, whether or not along a line of fissure, and piling up a cone of lava and ashes around it, the molten rock has risen in many fissures, accompanied by the discharge of little or no fragmentary material, and has welled forth so as to flood the lower ground with successive horizontal sheets of basalt. Recent renewed examination of the basalt plateaux and associated dykes in the west of Scotland has assured me that the view of their origin and connection which first suggested itself to my mind on the lava plains of Idaho furnishes the true key to their history.

The reference in the above quotation of "a few solitary cinder cones at wide intervals" is accompanied by a picture showing three conical mounds rising from a broad plain. This sketch is evidently intended to represent the three prominent elevations in the central part of the great plain to the northwest of Blackfoot, known as Big, Middle, and East buttes. As previously stated, these buttes were visited by me and found to be older than the Snake River lava, and entirely surrounded and separated one from another by it. Big and East buttes are the crumbling remnants of rhyolitic cones which rise as steptoes through the encircling basalt. Middle Butte is of stratified basaltic rock, and although its history was not definitely determined, it is certainly not a cinder cone and does not mark a center from which the surrounding basalt came. The elimination of these three buttes from the list of cinder cones seems to make Geikie's conclusion as to the

[a] New York, 1882, pp. 237-238, 242-245.

absence of centers of eruption still more secure, as they are the most conspicuous elevations to be seen throughout the entire extent of the lava plains. Although the idea that the lava reached the surface as immense fissure eruptions has perhaps gained general acceptance, my observations failed to sustain it, but, on the contrary, led me to conclude that many local eruptions from distinct vents are accountable for the origin of the extensive sheets of once molten rock. While future studies may perhaps show that actual fissure eruptions have occurred, I know of no facts to sustain such a hypothesis.

SOURCE OF THE LAVA.

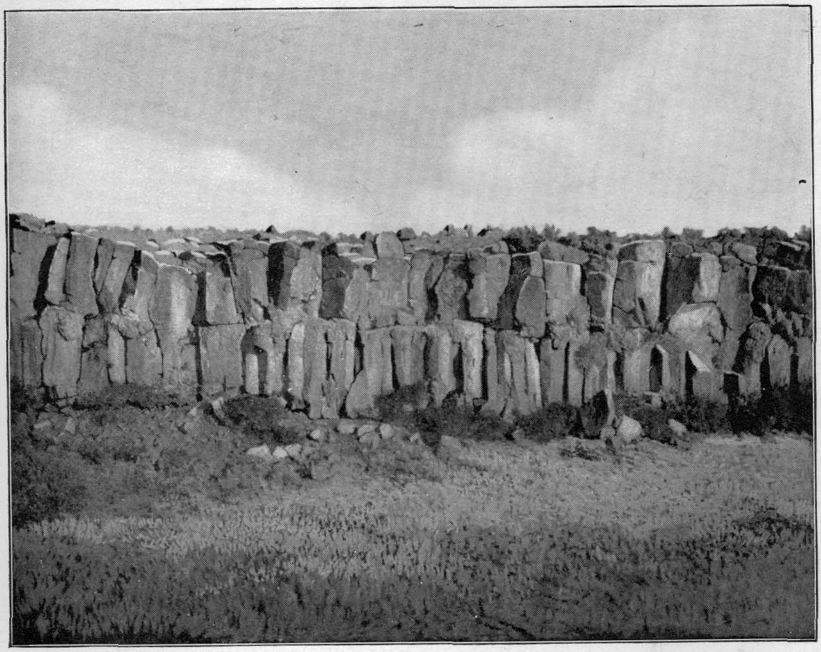
It is true there is an absence of conspicuous cinder cones on the Snake River Plains, and, as stated by Geikie, there is certainly no "central cone from which this great sea of basalt could have flowed." Yet a more intimate acquaintance with the region shows that there are several localities at which lava was outpoured from local vents of the ordinary volcanic type, about which scoria and cinder cones were formed. Besides these more conspicuous monuments of local eruptions, there are many broad, low elevations built of lava of a type not seen by me elsewhere, and, so far as I can judge, not clearly recognized by other observers, which may, for convenience, be designated as lava craters.[a] Instead of an absence of local eruptions from definite vents, my examination showed that there are scores of such localities still recognizable, and suggestions of many other more or less completely buried beneath more recent effusions of molten rock. The well-defined cinder cones referred to, with more or less perfect craters in their summits, are represented by two buttes, each between 500 and 600 feet high, situated on the lava plain about 6 miles northeast of Market Lake (Pl. XVI). About 20 similar elevations occur in what are known as the Cinder Buttes, on the west side of the Snake River Plains, approximately midway between Little Wood River and Big Lost River (Pl. X), and again by Kuna Butte, 15 miles northwest of Mountain Home (Pl. XVII). These well-defined cinder cones, described more in detail below, grade into another variety of elevations, which are still more common, but may pass unnoticed until one becomes familiar with their characteristic forms. The elevation of this second variety is due to the emergence of vast quantities of highly liquid lava from a comparatively small and in most instances a decidedly circumscribed opening, and to its outflow in all directions, except when it met older uplands, so as to form a low elevation with exceedingly gentle slopes and widely expanded base. These elevations are

[a] The nearest approach in form and structure of any volcanic pile yet described to those referred to above are, so far as I can judge, the great volcanic mountains of the Hawaiian Islands. There is too great a discrepancy in size, as well as other features, however, between these two classes of examples to admit of their being referred to the same type

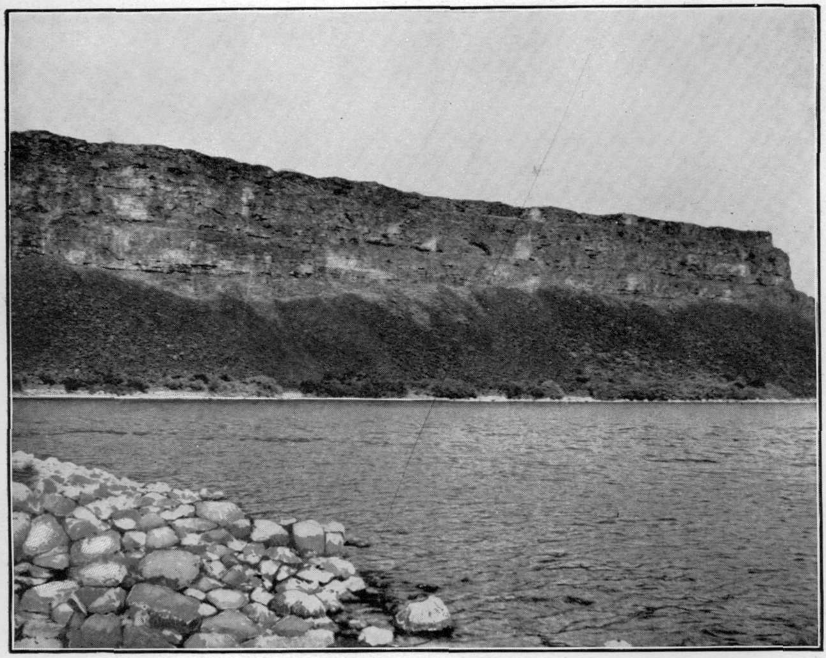
frequently 8 to 10 miles or more in diameter at the base, and perhaps only 200 or 300 feet high. In fact, their bases merge so gradually with the surrounding plain that no eye can recognize where the ascending surface actually begins. The sides of the elevations, although gentle throughout, increase in slope as the center is approached, and rise more perceptibly to meet the usually flat-topped summit portion. The profile of one of these broad, gently sloping elevations is shown on Pl. XVIII. The most noticeable portion of the surface descent from the central flat area seldom has an inclination over 10°, while the long slopes farther away are so gentle that the angle they make with a horizontal line can scarcely be measured with an ordinary clinometer. These broad, low elevations are composed of black lava all the way from their indefinite margin to the flat area forming the summit, which is usually composed of highly scoriaceous, with at times minor quantities of fragmental material (lapilli, etc.). The fragmental material of the nature here considered is absent from the older elevations, or easily passes unnoticed, owing to the effects of weathering and the growth of grass, sagebrush, etc.

The history of these elevations, as recorded in their form and in the nature of the material composing them, is briefly as follows: They represent volcanic vents, from which highly liquid lava in vast quantities flowed away in all directions, and on their outer borders came to rest and hardened in a horizontal position. When the vents opened on a plain, the requisite slope for the outward flow of the lava was obtained by the thickening of the lava sheet itself, and it is this increase in thickness that produced the low elevation still remaining. These outwellings did not occur along the general course of a fissure, but from local vents. These were not accompanied by explosions, or the explosions were of a mild character, and but little fragmental material was produced. Judging from the sequence of events recorded in the Cinder Buttes, described below, the volcanoes of the type here considered probably built cinder cones during the earlier stages of their eruptions, which were carried away and perhaps buried by the subsequent effusion of lava. As stated above, the summits of the low lava volcanoes are characteristically flat when seen in profile. When visited, the flat portion of the fresher cones is found to be composed of highly scoriaceous lava, and may contain a depression. About 15 miles north of Pocatello, a flat-topped butte of the nature just described has a small lake in the bowl at the summit during the rainy season. It is probable that many of the similar elevations once had craters, but in most instances their rims have been broken and the depression within has been filled. It fact, a succession of examples illustrating this process might easily be obtained.

The number of lava craters of the nature just described has not been determined, as they are widely distributed over the lava plains.



A. WALL OF CANYON CREEK CANYON NEAR MOUNTAIN HOME, IDAHO.



B. NORTH WALL OF SNAKE RIVER CANYON NEAR MOUTH OF LITTLE CANYON, IDAHO.

Several examples may be seen from the trains of the Oregon Short Line while passing between American Falls and Mountain Home. One of the elevations on the plain between Shoshone and Shoshone Falls, known as Flat Top Butte, displays evidence of a former crater perhaps more conspicuously than usual. From the summit of one of the craters under consideration, situated about 20 miles north of Shoshone, between Little Wood and Big Wood rivers, I counted eight similar elevations, but others known to be present on the vast plain lying to the east were obscured by the desert haze. Several others were in view from the summit of Big Butte, on the plain to the west and south. The elevations referred to are so broad at the base, and so low, that when looking down upon them, as, for example, from the neighboring mountains, their presence might easily pass unnoticed, except when illuminated by a strong side light, although they are easily recognized from lower points of view, when seen in profile against the even sky line.

Not all of the volcanoes that supplied the lava forming the Snake River Plains, however, are situated on their surface. Several craters which sent long streams of lava down tributary valleys have been mentioned by previous observers, and some of these were seen by myself. Several craters composed largely of scoriaceous basalt are known to exist in the valleys to the southeast of the Snake River Plains, as, for example, in Basalt Valley, Blackfoot Valley, etc., in the vicinity of Soda Springs. They have been described by the geologists of the Hayden survey. Extensive lava streams came from these craters and followed the valleys, principally in a northwesterly direction, to where they open out into the broad Snake River Plains. Certain of the geologists referred to suggest that these lava flows, which gave several extensive valleys level floors, reached the greater valley bordering the Snake and assisted in the formation of its present surface, but that this really occurred is left undecided. In this connection F. H. Bradley[a] states that the basalt bordering Snake River may have come in part from the crater near Soda Springs, but remarks: "It hardly seems possible that after flowing 70 or 80 miles the lava sheets could still have retained sufficient fluidity to be spread out in a solid layer over the plain."

The craters and lava flows just referred to have not been critically studied by me, but what is known concerning them, when viewed in the light of other and similar occurrences, certainly suggests that the lava streams originating at the craters in the vicinity of Soda Springs and descending the valleys occupied by the Portneuf and Blackfoot rivers, Willow Creek, etc., may have retained sufficient fluidity on reaching the Snake River Plains to enable them to spread widely. These

[a] Sixth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., Washington, 1873, p. 204.

lava streams unite with the still more extensive sheets of similar rock along the border of Snake River without any marked topographic or other contrast to indicate that they are not portions of a single series. As will be shown below, lava sheets originating from volcanoes in the broad central basin in certain instances entered the mouths of lateral valleys and extended up them, as the waters of a lake would do, for a score or more miles. The direction from which the lava in the lateral valleys flowed can in many instances be readily determined and the extent of the individual lava sheets ascertained and mapped, but this does not seem to have been attempted by the survey referred to above.

The most definite and, as it seems to me, the most accurate statement in reference to the sources of the Snake River lava to be found in geological literature occurs in the text of the Boise folio, by Lindgren.[a] He says: "The basalts were erupted from a great number of inconspicuous craters, both in the plains and in the adjoining mountains. Their fluidity was remarkable, continuous flows of 50 miles or more being noted. One flow, for instance, followed the South Fork of Boise River for that distance down to its mouth." The lava just referred to was seen by me, and there is no doubt that after flowing fully 50 miles as a stream from 1 to 3 miles wide, and in general about 300 feet deep, it retained sufficient fluidity after emerging from the valley through which it descended and entering the Snake River Plains to spread widely. This lava stream since it cooled and hardened has been dissected throughout its length by the river it displaced, leaving flat-topped terraces at numerous localities.

The sources from which the Snake River lava came are, as stated by Lindgren, in part in the mountains bordering the plains and in part on the plains themselves. It will be instructive, I think, if the volcanoes furnishing these two sources of supply be considered separately.

VOLCANOES AMONG THE MOUNTAINS.

The fact has already been mentioned that a portion of the lava now covering the Snake River Plains came as a narrow stream which descended the valley of the South Fork of Boise River for fully 50 miles and that other and larger streams probably originated in the craters near Soda Springs. These examples need not be considered further, as I have no information to present concerning them in addition to what has already been referred to.

BLACK BUTTE.

The fact that volcanoes situated in the mountains bordering the Snake River Plains poured out lava in much the same manner as

[a] See also papers by the same author in Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 635–636, and Twentieth Ann. Rept., Pt. II, pp. 99–100.

mountain springs supply creeks and rivers, and that the molten rock flowed down valleys leading to the central depression, where it spread out in lake-like sheets, in a similar way to the downward flow and expansion of streams of water under analogous conditions is well illustrated by a volcano of recent date, and the lava poured out from it, situated on Big Wood River, about 20 miles to the north of Shoshone.

This volcano has no name, but in my notes I have designated it as Black Butte, on account of the color of the bare lava of which it is composed. It is situated about 20 miles from the general border of the Snake River Plains, and rises in the center of a valley at a locality where, previous to its formation, the valley bottom was about 500 feet above the level of the neighboring portion of the plains. The volcanic mound is only about 300 feet high, with a base measuring, perhaps, 2 miles in diameter. It is composed of highly scoriaceous lava, which flowed away in all directions in thin sheets. The copious outflow of molten rock was apparently continuous from the beginning of the eruption to its close, and the appearance of thin sheets is due to the manner in which cooling and the consequent stiffening of the material occurred. While the butte is composed of vesicular lava, there is no evidence from the presence of lapilli, cinders, etc., of an explosive eruption. There is no crater at the summit, such as explosive volcanoes build, although a deep, wide gulf at the top of the butte at first suggests such a depression. This gulf, however, is of subsequent origin, due to fractures and the subsidence of a large mass of material, and connects with similar irregular breaks on the sides of the butte, due in part to the falling in of the roofs of lava tunnels.

The fact that this fresh and uneroded volcanic mound, without soil and almost entirely bare of vegetation, is not a cinder cone, but is composed of lava that hardened about the vent from which it was extruded, places it in the same category as the low, flat-topped lava buttes referred to on a previous page as being characteristic of certain of the older volcanoes on the Snake River Plains.

Black Butte is, as stated, situated in a valley, and the lava poured out by the volcano which formed it had greater freedom to flow down the valley than in other directions. Although the conduit leading down into the earth was certainly small, a vast volume of highly liquid rock was poured out and flowed down the valley of Big Wood River for a distance of 35 to 40 miles, and spread out in a sheet from 2 to fully 6 miles broad. The area covered by this single eruption is about 150 square miles. The lava is black, with an exceedingly rough surface, and can be distinguished at a glance from the older sheets of similar material over which it flowed. About 3 miles below its source it passed between two lava volcanoes of the same general type as the one from which it came, but of much older date, and now covered with soil of æolian origin from base to summit and clothed with vegetation. Although black and rugged and not yet dusted over with sufficient soil to support vegetation, except in the cracks and smaller depressions, the age of the lava stream is certainly considerable as measured in years. Big Wood River, after being displaced by the lava stream, continued to flow after the lava cooled, and throughout its length has cut a steep-sided canyon which is, in general, from 20 to 40 feet deep.[a] The walls of this canyon are composed for the most part of hard, columnar basalt, and its excavation must certainly have required several centuries. This is interesting, when taken in connection with the absence of soil on the lava, as illustrating the slowness with which the soil of the Snake River Plains was accumulated. Extensive lava flows, the boundaries of which can not now be definitely traced, were poured out by the two older volcanoes just referred to, and the manner in which they are crossed and in part buried by the recent flow serves to show the manner of formation of the Snake River lava plains, into which the region here referred to merges by insensible gradations and of which it is, in fact, a part.

MARTIN LAVA STREAM.

The descent of lava streams from the mountains bordering the Snake River Plains and the expansion of the lava so as to form a part of the plains themselves are again illustrated by a flow of molten rock, which welled out from two openings in mountains of quartzite in the region drained by Lava Creek, about 5 miles southwest of Martin post-office, in Blaine County. Martin is about 60 miles west of Blackfoot, on the west border of the Snake River Plains in their widest part.

In the bold mountains, at the locality referred to, an exceptional feature in the relief is furnished by a steep conical elevation from 600 to 700 feet high, composed principally of basaltic scoriæ, the weathered sides and summit of which are conspicuous on account of their reddish color. At the base of this butte, on the northern and eastern sides and at an approximate elevation of 500 feet above the level of the adjacent portion of the Snake River Plains, two streams of lava were poured out, which cascaded down the steep slopes below and united to form a trunk lava stream about 400 yards wide, which flowed north-

[a] An interesting feature connected with the erosion accomplished by Big Wood River is the presence in the walls of its canyon at a locality about 2 miles northeast of Black Butte of characteristic potholes. These potholes, of which a score or more were examined, are from a few inches to 10 feet or more deep, and in the larger examples about 20 inches in diameter. They have been excavated in compact basalt by the grinding of sand and pebbles, caused to rotate by a swift current, and have smooth, nearly vertical walls. The only peculiar feature presented by them is the presence in certain instances of central conical elevations at the bottom from a few inches to fully a foot high, which have spiral grooves on their sides. On looking down into a pothole exhibiting this feature, the seemingly spirally twisted elevation at the bottom has the appearance of the end of a large screw. So far as I am aware, the only other observed remnants of cores cut by revolving stones during the formation of potholes have been noted by G. K. Gilbert, Explorations and Surveys West of the one hundredth Meridian, Vol. III, Washington, 1875. p. 73.

ward with well-defined banks. On reaching the lower portion of the valley of Lava Creek, this lava stream expanded to a width of about 1 mile, and continuing on to the Snake River Plains spread out still more widely, forming a thin sheet with an exceedingly rough surface. The length of this stream is not accurately known, but is probably about 10 miles.

Where the lava came to the surface there are no elevations, but instead two circular depressions now overgrown with aspens which make them conspicuous. These depressions are small, probably not over 300 feet in diameter, but discharged a large amount of molten rock. The absence of elevations about the summits of the conduits is due to the fact that explosive eruptions did not occur, and owing to the steepness of the slopes on which the vents were situated the the lava flowed away immediately on emerging and did not cool and thicken about them. The lava, in descending the steep slopes below, where it came to the surface, formed veritable cascades, and on cooling was left with an excessively rough surface. The crust first formed was broken and the fragments were cemented together by still plastic lava, so as to make a coarse breccia. Many masses, composed of united fragments of all dimensions up to 20 feet or more in diameter, were floated far down the stream and out on to the border of the Snake River Plains. The contrast between the rough surface of this high grade, and consequently swift lava stream, and the smooth surfaces formed on sluggish lava streams on hardening, will be referred to later.

Although the lava stream just described is comparatively small and made but a moderate contribution to the filling of the Snake River Basin, it illustrates one of the methods by which the broad plains of that great depression were formed.

The Martin lava stream is black and has but little soil or vegetation on its surface, and is plainly much younger than the lava sheets it crossed and partially buried after emerging on the plain. It has lost much of its freshness, however, and is certainly much older than the lava which came from Black Butte, and is much older, also, than the several lava streams described below, which came from the neighboring Cinder Buttes.

LITTLE CANYON LAVA STREAM.

Little Canyon Creek rises in the rugged mountains about 20 miles northeast of Mountain Home, flows southward for about 20 miles, through a deep, narrow canyon cut in lava and associated sedimentary beds forming the Snake River Plains, and joins Snake River at Glenns Ferry.

After a stream older than the present Little Canyon Creek had excavated a valley in the mountains, it was displaced by a flow of basalt which came to the surface about 5 miles or more to the north of the border of the Snake River Plains and approximately 1,000 feet higher than their present surface. The lava descended a slope which rises from the plain with an estimated gradient of about 200 feet to the mile, and on leaving the mountains spread far and wide on the adjacent plains. The sheet of lava thus formed reached the site of Snake River and appears as a rim rock in the bluffs at Glenns Ferry. In the mountains the lava stream cooled with a rough surface, but on the plain became quite smooth. Its surface is no longer fresh in appearance, and where not covered with soil it is much broken and a sheet of loose, weathered stones and bowlders, with dark soil in the crevices, has been formed. That this lava is of comparatively ancient date is shown also by the amount of work that has been accomplished by the creek that flowed over it. Little Canyon Creek, although now dry during the summer season, and thus evidently a weak stream, has excavated a remarkably rugged canyon in the basalt and underlying rhyolite to a depth of 200 feet where it leaves the mountains. The lava sheet cut through is compact, and at the locality just referred to is about 50 feet thick and nearly a mile broad.

KING HILL LAVA STREAM.

In the region drained by King Hill Creek (the next creek east of Little Canyon Creek), as was observed from a distance, there is a large lava flow, which descended the mountains at about the same time the Little Canyon flow occurred, and spread widely on the plain to the south. The appearance of a remnant of this lava sheet, left as an outstanding butte by the erosion of King Hill Creek, is shown on Pl. VIII, *A*.

BLANCHE CRATER.

In the canyon of Clover Creek, about 1 mile south of Blanche post-office, there is a black cone which rises about 60 feet above the adjacent flood plains of Clover Creek and has a perfect crater in its summit. The conical pile is composed principally of thin cakes of highly vesicular black lava, some of which are strewn about on the surrounding stream-formed sediments and were evidently blown out by the volcano in a highly plastic or actually liquid condition. Within the relatively large conical depression in the summit of the volcanic pile there is a shallow lake of intensely alkaline water, which is supplied by small, warm springs. The concentration of the water by evaporation has led to the precipitation of alkaline salts mingled with organic matter. Forming the shores of the lake and underlying it there is a bed of alkaline salts having an average depth, as reported by Mr. B. C. Brey, who owns a neighboring ranch, of about 15 feet, and an area of 3 acres. This deposit has been utilized in a small way in the manufacture of soap. From the base of the crater a small lava stream extends southward about 1 mile. This stream crossed the valley diagonally and formed a dam that checked the flow of Clover Creek and caused it to spread out a broad gravel deposit, which is now rich meadow land. About a mile north of this interesting crater there are copious springs with a temperature of 117° F.

This crater is one of the latest and possibly the youngest of those visited by me in southern Idaho, and is situated in the bottom of a canyon about 500 feet deep, excavated in Snake River lava and associated beds of lacustral sediment and lapilli belonging to the Payette formation.

SUMMARY.

The lava streams which are known to have originated in the mountains lying north of the Snake River Plains, and which descended to them, are, in their order from west to east, the one which descended the canyon of the South Fork of Boise River and the Little Canyon, the King Hill, Black Butte, and Martin lava streams. These observations abundantly confirm the conclusion reached by Lindgren, already cited, and expressed in part as follows:[a]

> The largest flows, however, originated in the foothills north of Glenns Ferry, or in fact all along a line extending from Smiths Prairie on the South Fork of the Boise to a point northeast of Shoshone. Along this distance of 80 miles the granitic foothills are completely flooded by heavy masses of black basalt flows, which extend far out into the valley and are here beautifully exposed interbedded with lake beds along the canyon of Snake River.

As previously stated, it is probable that the several craters in the neighborhood of Soda Springs furnished similar contributions, which reached the Snake River Plains from the southeastward. Lava is also reported to occur in the Owyhee Mountains, and it is to be expected that other additions to the Snake River Plains from that source will be discovered.

VOLCANOES ON THE SNAKE RIVER PLAINS.

A critical study of the numerous extinct volcanoes of southern Idaho would no doubt show that they may be divided, for convenience, into two classes, namely, those which built up cinder and lapilli cones of the ordinary type, and those which gave origin to but little fragmental material, but formed low, usually flat-topped mounds with immensely expanded bases. This classification, while indicating the present condition of the volcanoes in question, is not strictly logical, as the lava mounds were preceded in many and perhaps all instances by cinder and lapilli cones, which were either destroyed or buried by the great effusion of liquid lava which marked the later stages in the eruptions of the volcanoes which built them. In fact, a gradation can be found

[a] Twentieth Ann. Rept. U. S. Geol. Survey, Pt. III, 1900, pp. 99-100.

between normal cones built of cinders, lapilli, etc., with well-defined craters, and other examples of a similar nature partially destroyed by lava flows which came later, and including, as the other extreme of the series, low, broad mounds, without craters, apparently formed entirely of lava flows. For this reason, and also because a sufficient number of the volcanoes have not as yet been studied, the classification suggested above will not be attempted. The study of the volcanoes of the Snake River Plains is best begun by a visit to the most recent and freshest of the series. None meet these requirements better than a group of volcanic cones termed the Cinder Buttes.

CINDER BUTTES.

LOCATION.

Close to the west border of the Snake River Plains, in their widest part, midway between Cary and Martin, and nearly 70 miles due west of Blackfoot, there is a group of cinder cones surrounded by vast lava flows. These now extinct volcanoes are of recent date, are remarkably fresh in appearance, and furnish most instructive illustrations of the nature of the eruptions which deluged such a large part of southern Idaho with lava. The most conspicuous of the cinder and lapilli cones in the group of elevations here referred to is indicated on the General Land Office map of Idaho as "Old crater." To the residents of the region this conspicuous cone is known as Cinder Butte, and I have thought best to term the entire group of volcanoes, of which it is a part, Cinder Buttes.

The most conspicuous of the Cinder Buttes (see Pl. X) rises with steep slopes to a height of 600 feet above the surrounding plains and is distant about 5 miles from the base of the bold mountains, composed of granite and quartzite, to the west, which sharply define the west border of the northeastern extension of the Snake River Plains. The volcanic mounds and cones comprising this group form a well-defined belt 3 or 4 miles wide, which begins abruptly at the base of the adjacent mountains and extend out on the vast plains in a southeasterly direction for from 10 to 15 miles. The buttes are most closely placed, and in fact much crowded at the western end of the belt, and become wider apart and even isolated in its eastern part. Detached from the main group, and about 5 miles southward from the highest of the buttes, are two small elevations, probably lapilli cones.

TUFF CONES AND CRATERS.

The elevations comprising the Cinder Buttes are composed, to a large extent, of angular fragments, such as dust and lapilli, blown out during violent eruptions. Lapilli, being a technical term, is used to

CINDER BUTTES, IDAHO, LOOKING SOUTHEAST.

designate what may be said to be sand and gravel produced by volcanic explosions. This finer and usually exceedingly rough material, when more or less consolidated, passes under the general name "tuff."[a] Mingled with the tuff, and also due to explosions, are fragments and rough masses of scoriæ, volcanic bombs, and thin, irregular, cake-like forms of lava.

The number of elevations composed of fragmental material of the nature just referred to can not be definitely stated, as the older ones have to a great extent been broken and more or less completely destroyed by the explosions to which the younger ones owe their existence. Several of the more perfect cones and craters stand on the ruins of older volcanoes, and many rounded hills of lapilli, smoothed by the wind, are evidently portions of craters which have lost their characteristic shape. Possibly there are 20 craters either complete or in what may be termed a fair state of preservation, but portions of perhaps as many more may be seen, either isolated or partly buried beneath later-formed piles of fragments. In one place, about a mile northwest of the highest of the buttes, more than half of a crater approximately 150 feet high has been removed, probably by explosions, and three conical depressions, with circular rims of lapilli, have been formed on the site of the ruined part. In certain instances, also, large portions of once perfect craters have been floated away by the lava which flowed from them. About the more conspicuous cones and craters still remaining, and especially to the north of the most prominent butte, there are extensive fields and rounded hills of lapilli which were evidently formed by showers of fragments carried to a distance from the volcanoes which produced them and deposited in broad undulating heaps. These smooth fields and low, rounded hills are in striking contrast with the frequently rough and angular surfaces of adjacent lava streams, and, like the tuff cones, present many pleasing variations in color, ranging from deep red through brown and purple to lusterless black. The older members of the Cinder Buttes are covered with grass and support an open forest of pine and fir, but the younger ones and the younger lava streams which flowed from them are entirely bare. The trees in most instances are rooted in loose deposits of lapilli which have not decayed sufficiently to form what may be termed soil, but this deficiency has been supplied by dust brought by the wind, or by the volcanic dust showered on the coarser deposits during late eruptions.

The highest of the Cinder Buttes rises as a prominent conical mass of reddish and black lapilli to a height of 600 feet above the surrounding plain and is far more prominent than any of its neighbors. About its base the rims of some five or six older volcanoes may still be seen.

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[a] The term *tuff*, as here defined, is to be distinguished from *tufa*, the deposit formed by certain springs.

Like several of the associated cones, it has no crater at the summit, but terminates in a rounded weather curve, the symmetry of which is somewhat broken by crags of dark-red tuff.

The remnants of crater walls in several instances frequently exhibit well-defined stratification, the layers in the outer portion of the once conical pile dipping away from its center in all directions at low angles. An increase in dip occurs from the first-formed or lowest layers to the higher ones, owing to the greater thickness of material deposited immediately about the orifice than at a distance from it. In the best section of a ruptured tuff and cinder cone observed the lower beds are nearly horizontal, while those about 80 feet above dip outward at an angle of 20°. The inward-dipping beds forming the funnel within the rim of a crater dip much more steeply than the outer layers, but are usually not well preserved. In the section of a crater just referred to the position of the former opening is shown by a confused mass of tuff and cinders which, in part, seems to have reached its present position by falling from above.

CHARACTERISTICS OF THE EJECTED FRAGMENTS.

The fragments of volcanic rock which occur in such abundance at the Cinder Buttes, and of which the walls of the craters themselves are built, may be classified as dust, lapilli, scoriæ, clots, bombs, and lava cakes. To classify it in still more general terms, this material may be divided into two classes: First, lava which cooled and hardened in the crater from which it was ejected and was broken into fragments by steam or gaseous explosions, the fragments being sufficiently rigid not to undergo a change of shape during their aerial flight except, perhaps, by fracture on coming in contact with other fragments in the air or on striking the ground; and, second, lava which was projected into the air in a plastic and even liquid condition and assumed various shapes either during its passage through the air or on falling. There is no sharp division between these two classes, however, and a series of specimens grading from angular fragments to rounded bombs and thin, flat lava cakes formed by the spreading and cooling of splashes of highly liquid lava on striking the earth, might easily be collected.

Dust and lapilli.—The material which presumably hardened on the surface of liquid lava within a crater and was broken and blown out by steam or other explosions and fell about the opening from which it came or was widely distributed by the wind, consists mainly of angular fragments of highly scoriaceous lava which vary in size from dust particles to irregular masses several inches, and in some instances 1 or 2 feet in diameter. The most common product of this process is highly vesicular lapilli, composed of rough, angular fragments ranging from a quarter of an inch up to an inch or more in diameter. This material was blown out in abundance and assorted more or less through the action of the wind, so that large surfaces are covered with fragments of a nearly uniform size. The fragments are usually black or various shades of red, and in certain instances have a brilliant iridescence due, I presume, to changes which have occurred since they were exposed to the air, and which resulted in the formation of thin films on their surfaces.

About the Cinder Buttes, so far as observed, there is a notable absence of compact, rounded kernels and stratified beds of granular lapilli, such as form a large portion of the Market Lake crater and occur in stratified sheets, associated with lacustral sediments, in the western part of the Snake River Plains, as for example, near Glenns Ferry.

Clots.—The lava ejected in a highly viscous or nearly solid condition took on various shapes, depending on its degree of plasticity, and perhaps also the length of its aerial flight. This lava seems to have been principally in the form of ragged clots, which were blown out by mild explosions with low initial velocities, and which fell about the orifices from which they came, and built up scoria cones with but small admixtures of lapilli and dust. At times these clots adhered one to another or to the surface on which they fell, but more frequently they were sufficiently rigid on striking to maintain their shapes, and fell so gently that the rough projections were not broken. Evidently these masses, although solid, were not cold and brittle when they came to rest. They are always rough and irregular, and sometimes have a length of a foot with a transverse diameter of only 2 or 3 inches, but more frequently they are excessively irregular but not markedly elongate, and of all sizes up to 40 inches or more in circumference.

Scoria.—Numerous masses of scoria occur also, especially in the walls of certain small parasitic cones. These masses present the appearance of having been blown out of the craters in a highly plastic or semifluid condition, and of having become highly scoriaceous and rudely spherical during their short journeys through the air. These rough, ball-like masses, usually 8 to 16 inches in diameter, were sufficiently soft to adhere slightly one to another on coming to rest. Their exteriors are rough, usually brown or reddish, but not conspicuously scoriaceous, while within they are coarsely vesicular and at times nearly hollow, as is shown in the photograph, Pl. XI, *A*. In one of these spherical masses, in the crust of which a hole had been broken, I found a bird's nest securely sheltered.

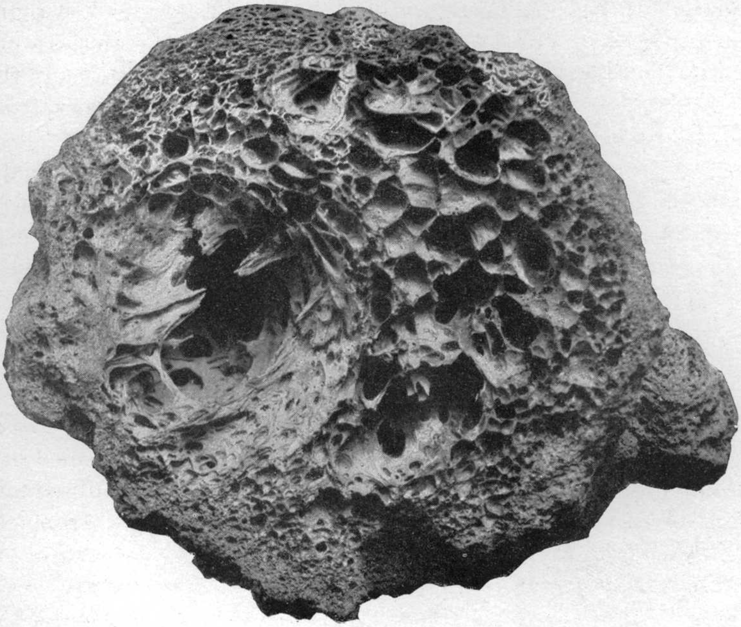
Bombs.—Portions of the highly viscous and fluid lava in the throats of the volcanoes were in many instances thrown high in the air, and on account of rotation during their flight assumed more or less regular spherical forms. Of these volcanic bombs, several varieties were recognized, the differences they present being due to variations in the degree of plasticity of the lava as it left the pool of molten rock from which it was blown and the length of its flight.

The most characteristic of the bombs are oval and in size and shape frequently resemble a modern football with a projection at each end of its longer axis. These characteristic projections, or "ears," show a well-defined spiral twist, as is illustrated on Pl. XII. The surfaces of these bombs are black and glossy when fresh, and without vesicles visible to the eye, but sometimes exhibit more or less spiral lines in relief, which are in a general way parallel with their longer axis and unite with or are prolonged into the twisted ridges on the projections at their extremities. At times also their surfaces are crossed by shallow cracks, as is shown in Pl. XII, which appear to have formed in a thin outer crust, and to have been widened by a slight subsequent swelling of the still viscous mass within. In size they vary from less than 1 inch to several feet in length, not including the projections at the ends, which are usually broken, but in some instances are 3 or 4 inches long. Some examples are nearly spherical, and the "footballs" are sometimes slightly flattened parallel to the longer axis. The one shown at the bottom of Pl. XII is 13 inches long, including the remnants of the projections at the ends, and 7.9 by 4.7 inches, respectively, in its two diameters at right angles to the axis about which it was rotated.[a] The largest specimen of this shape seen measured 9 feet in length and 12 feet in circumference. The nearly spherical bomb represented on Pl. XII measures 5.5 by 4.5 by 4.3 inches. In some instances the bombs, whether nearly spherical or markedly ovoid, appear to have been formed by the rolling together of irregular cakes of plastic lava, the edges of which form ridges and curved lines on the surface of the infolded mass, as may be seen in the photograph to which attention has been directed.

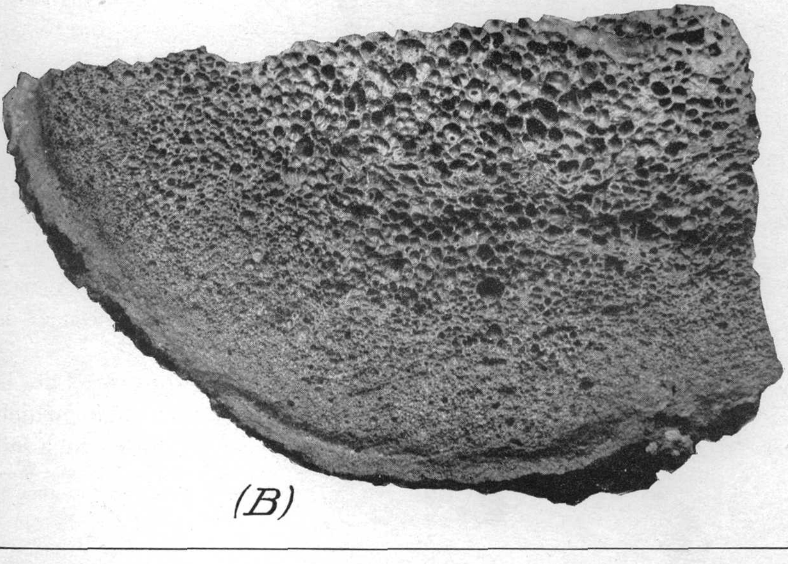
Of the bombs having the external characteristics just described there are at least two well-marked varieties, as is discovered on breaking them. In certain instances there is a distinct outer crust or rind, composed of compact black basalt, measuring in general from a tenth to a fifth of an inch in thickness, and inclosing a highly vesicular interior; in other examples there is no outer rind, and the mass is compact, or nearly so, throughout.

In the case of the bombs having a rind and cellular interior there is sometimes a thin outer layer, perhaps a third of an inch thick, which is scoriaceous and merges with the still thinner compact crust inclosed

[a] This specimen is not from the Cinder Buttes, but from a much older crater, only a portion of which remains, near the north base of Big Butte.



(A)



(B)

SECTIONS OF VOLCANIC BOMB, CINDER BUTTES, IDAHO.

by it, but more frequently this outer cellular layer is absent. Within the thin crust the hollow vesicles or steam cavities are small and increase in size toward the center, where they frequently measure half an inch in diameter. A photograph of the broken surface of such a bomb, showing about one-fourth of its circular cross section, is reproduced on Pl. XI, *B*. The appearance of some of the vesicular bombs when seen in section is almost precisely the same as the interior of a similar body from Ascension Island, a drawing of which has been published by Charles Darwin.[a] It has been suggested by Darwin that the gradation in the size of the vesicles in the bombs found on Ascension Island, from large at the center to small near the inner surface of the inclosing rind, is due to the rapid rotation of the material while in the air, the "centrifugal force" thus generated tending to relieve pressure at the center and to permit the steam-filled vesicles inclosed in that part of the body to expand more than those near the surface. The bombs from the Cinder Buttes having the internal structure described and figured by Darwin were found near the craters from which they came, in several instances lying on their inner slopes, and do not seem to have made long aerial flights. Besides they are nearly spherical and without the spindle-like form with projecting ears, such as characterize associated bombs which cooled while rotating. For these reasons it does not seem that Darwin's explanation is applicable to the examples observed, and as an alternative I venture to suggest the following hypothesis:

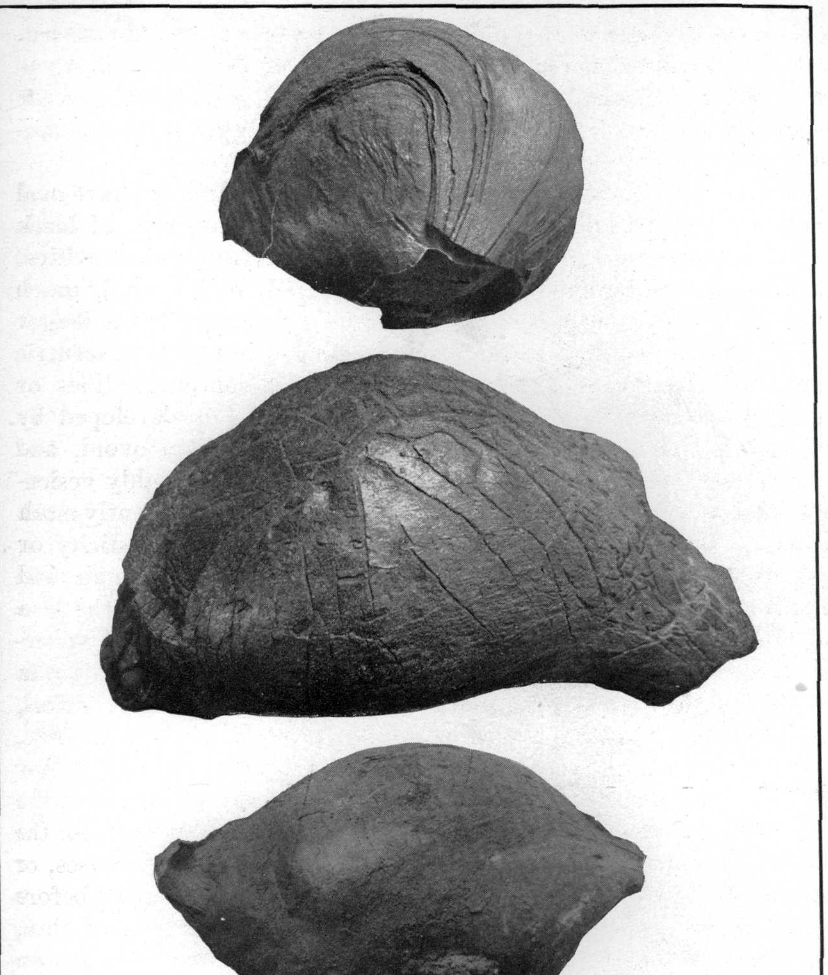
As has been observed, metals on cooling from fusion give out gases which were previously dissolved or occluded in the molten mass, and it may reasonably be supposed that lava, especially if basic and rich in iron, would behave in a similar way. If, then, a mass of highly heated, viscous lava should be thrown out from a volcanic crater and its surface cooled quickly so as to form a crust, the vapors and gases given off by the mass within as it cooled would be retained and tend to form vesicles. As cooling progressed the vapors and gases would be forced toward the center and there form the largest vesicles, room being furnished in part by the shrinkage of the magma. This supposed process, by which the vesicles are produced and increased in size from the rind toward the center of a bomb, is analogous to the formation of a crust on a loaf of bread with a highly vesicular interior. In this connection attention may be again directed to the second figure on Pl. XII, which shows the appearance of the surface of a bomb which became cracked, and the cracks widened owing to expansion from within. This is analogous to the widening of a cut on the surface of a loaf of bread as it bakes. In brief, both

[a] Geological observations on the volcanic islands visited during the voyage of H. M. S. *Beagle*. London, 1844, p. 36.

the absence of evidence of rapid rotation on the surfaces of the vesicular bombs in question and the correspondence of their internal structure with what should be expected to occur if lava on cooling from fusion extrudes previously dissolved vapors or gases favor the hypothesis here suggested.

The compact bombs usually, and, as it seems, invariably, have oval forms and twisted and projecting ends, and are composed of black stony lava throughout, but are never entirely free from steam cavities. The openings are irregular in size and shape and are frequently much distorted, but when seen in sections made at right angles to the longer axis of the projectile are many times arranged in rudely concentric bands. In these same sections, also, there are concentric lines or cracks produced by a rolling up of the material, or developed by weathering. The variations in form from globular to ovoid, and more or less irregular, and in internal structure from highly vesicular to compact and stony, with but few irregular and frequently much elongated vesicles, appear to be due to variations in plasticity or liquidity of the material at the time it was projected into the air, and variations also in the length of its flights. The more plastic the lava and the longer its flight, the greater its tendency to assume a spherical form. So far as I am aware, the bombs exhibiting a gradation in the size of the vesicles occupying the interior are nearly spherical, while the oval or spindle-shaped examples with projecting ends are, as a rule at least, compact in the interior and contain relatively few and frequently unsymmetrical cavities. The absence of scoriæ in the compact bombs is seemingly accounted for on the assumption that the lava was without a high percentage of contained steam or gases, or that the liquidity of the material was such that they escaped before consolidation was far advanced. There are large quantities of thin, nearly flat cakes of compact or but slightly vesicular lava strewn about the Cinder Buttes, which will be described below, and which were, I suppose, formed by the cooling of liquid lava blown out of the volcanoes, after coming to rest. The compact bombs, with more or less spiral bands or vesicles in their interior and spiral and curved ridges on their surfaces, seem to have originated from masses of viscous lava, similar to those which formed the flat cake, but which cooled in the air and, after losing their previously contained steam, were rolled together on account of their rotation so as to assume more or less football-like shapes.

In this connection, however, it should be noted that no forms intermediate between the flat cakes produced apparently by the ejecting highly liquid lava and the well-defined globular or ovoid bombs were noted. There is, so far as I am aware, an absence of bombs which were sufficiently plastic to become conspicuously flattened on striking,



VOLCANIC BOMBS, CINDER BUTTES, IDAHO.

although still retaining something of their spherical form, such as occur abundantly about the Ice Spring crater in Utah.[a]

Lava cakes.—The thin, flat cakes of compact lava, mentioned above, occur in abundance on the side of some of the cones and crater walls forming the Cinder Buttes. They may be seen especially on the southwest slope of the highest cone, where they occur in thousands. These lava cakes, as I term them for lack of a better name, are usually composed of compact or but slightly vesicular black lava, but at times they are scoriaceous; although usually flat, they frequently have thin inclined ridges or offshoots on their upper surfaces; in thickness they vary irregularly from perhaps a fourth to half or, in the larger pieces, two-thirds of an inch. Their margins are usually broken, but sometimes thin out to a sharp edge. They are of all sizes, up to 14 inches or more across. On their under surfaces there are sometimes adhering fragments of lapilli, and occasionally similar fragments are inclosed between projecting ridges, or in the center of a mass composed of two or more adhering cakes. These thin lava cakes occur in abundance not only on the lapilli cones among the Cinder Buttes but on the adjacent lapilli fields and hills, where no distinct crater can now be seen. Similar cakes were observed, also in abundance, around a small and very recent volcanic cone about 10 miles north of Bliss, named on a previous page the Blanche crater. Their abundance in the instances mentioned indicates that they form no inconsiderable part of the fragmental or quasi-fragmental material thrown out by volcanoes of a certain type, namely, those which are supplied with highly liquid lava. In some instances the splashes of lava, after striking the earth, were still sufficiently fluid to flow and united one with another so as to form irregular sheets. Compact layers, usually of a reddish color, seen in vertical sections of some of the cones of lapilli and scoriæ were found to have originated in this manner.

Only the more conspicuous variations exhibited by the fragmental material, including bombs, so abundant about the Cinder Buttes have been noted, but it would not be difficult to select a series showing a complete gradation from angular scoriaceous fragments produced by the breaking and ejection of a frothy, brittle crust, formed on the surface of the lava within a crater, to the irregular lava cakes resulting from the hardening of material blown out in a liquid condition. Such a series would illustrate the fact that the wide variations presented by the material blown from volcanoes depend principally on its degree of rigidity or fluidity on leaving the parent crater. The range is from brittle scoria to highly fluid lava. The variations in shape assumed by lava ejected in a plastic or fluid condition depend on the length of its aerial flight and on the manner in which it rotates.

[a] These flattened bombs are referred to by G. K. Gilbert, in his monograph on Lake Bonneville, Mon. U. S. Geol. Survey, Vol. I, 1890, p. 321.

It may be noted that no foreign or included rocks, such as fragments of granite, quartzite, etc., or pebbles derived from older terranes, except a single fragment of obsidian, were observed about the Cinder Buttes. The buttes are built entirely of basaltic lava.

PARASITIC CONES.

The eruptions to which the Cinder Buttes are due were characterized in their earlier stages by explosive violence, during which comparatively small cones of lapilli, scoria, bombs, etc., were formed, and later by an outpouring of immense volumes of liquid lava. When the lava ceased to flow, the portions remaining in the conduits through which it rose cooled and hardened, and the lives of the volcanoes ceased without a renewal of the steam explosions which accompanied their birth. In one instance, however, there was a partial exception to this rule.

About 2 miles northwest of the highest of the Cinder Buttes, and on the surface of a bare, corrugated lava stream near where it came to the surface, there is a row of seven steep-sided and remarkably regular cones, composed principally of rough ball-like masses of highly vesicular or scoriaceous lava (Pl. XI, *A*). These balls or imperfectly formed bombs are usually from 8 to 14 inches in diameter, and when they fell were sufficiently plastic to adhere one to another, so as to form what at first were nearly vertical walls. The sides of these cones near their summits now have slopes of from 50 to 56 degrees, but decrease below to 34 degrees or less, owing to the accumulations of small quantities of fragmental material about them. Their steep, upper slopes are angular and rough, but the lower slopes, when seen in profile, present curves such as are characteristic of lapilli cones.

Not only were the spherical masses plastic when they fell, but in one observed instance a splash of lava tossed out and falling on the exterior of a cone ran down several feet before cooling. In addition to the pasty and liquid material ejected, there is a minor quantity of angular fragments, but these were not thrown far, and the surface of the lava stream on which the cones stand is entirely bare at a distance of but a few score feet from their bases. The cones are symmetrical and the distribution of the lapilli about them shows no evidence of a strong wind blowing at the time they were formed.

The craters, with one exception, range in height from about 40 to 60 feet. The exception is furnished by the most westerly in the series, which is much lower than its companions and does not rise more than 15 feet above the surface of the adjacent portion of the lava stream on which it stands. The trend of the line of cones is about southeast, or in the same general direction as that of the belt of volcanoes with which they are associated. The cones are located at quite regular intervals of approximately 70 feet, although in some instances the bases of two adjacent cones touch each other. Each of these cones is of the nature of a chimney built about a small vent from which steam was issuing with considerable force and throwing out clots of plastic and even liquid lava. In most instances the chimney-like openings through which steam escaped have been closed by the falling in of the summit portions of their walls, but at the west end of the series there are two craters still complete and having vertical shafts in their interior. The openings referred to are nearly circular in horizontal sections and about 30 feet in diameter at the top and 50 to 60 feet deep; midway down they contract, and expand again below, giving to them in vertical section an hour-glass form. In the smaller cone at the west end of the series the opening in its most constricted part is rudely elliptical, the principal axes measuring about 8 and 12 feet. Its companion is somewhat larger and less regular. The walls above the constrictions midway down are nearly vertical and overhang their lower portions. On the sides there are adhering clots and splashes of lava which ran down before cooling and now occur in part as pendent, stalactite-like forms. When seen from above the walls appear smooth, but on descending part way and looking up the irregularities due to the pendent clots become conspicuous.

At the bottom of the smaller of the two openings there are two chambers or enlargements, looking like the mouths of tunnels, one to the northwest, one to the northeast. These openings are about 15 feet wide and 10 to 12 feet high. The other open shaft has but one expansion at the bottom similar in size to those just mentioned and leading toward the northeast. The enlargements in these two instances are at about the same depth below the summits of the vertical shafts with which they communicate, but owing to the greater height of the pile of lava balls, etc., about one opening they are not at the same depth below the surface of the lava stream on which the cones stand. The chamber at the bottom of the smaller cone is about 20 or 30 feet below that at the bottom of its companion. At the bottom of the shaft in the smaller cone at the time of my visit (September 4, 1901) there was a conical mass of white ice, about 10 feet thick in its central part and about 15 feet in diameter at the base; adjacent to its northern side was a pool of clear water. The ice was exposed to the sky, but could not be reached by the direct rays of the sun even in midsummer. Ice and water are also present at the bottom of the large shaft. These are about the simplest examples of "ice wells" that can be imagined. Clearly the ice is a remnant of the previous winter's snow, compacted by the freezing of percolating water.[a]

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[a] An instructive account of "ice caves," "ice wells," etc., may be found in a book by Edwin Swift Balch, entitled "Glacières, or Freezing Caverns." Philadelphia, 1900.

The linear arrangement of the scoria cones just described, on the otherwise bare surface of a broad lava stream, and the nature of the material of which they are composed indicate that they were built along a fissure formed in the hardened surface of a lava stream while its lower portion was still plastic or liquid. They are thus of the nature of parasitic cones formed about steam blowholes, from which clots of viscous and splashes of still liquid lava, together with some lapilli, were blown out. The shafts of the chimney-like piles formed about the openings in the surface of the frozen lava stream were never occupied by liquid lava, as their walls are far too weak to sustain such a pressure and no streams of lava were given off by them.

LAVA STREAMS.

Reference has already been made to the wide extent of the lava streams which flowed away from the Cinder Buttes, but it is difficult to convey in words an adequate impression of their magnitude, such as is derived from traveling over their surfaces or along their margins, or from a view from the neighboring mountains.

There are six principal lava flows of recent date which have their origin in these buttes, and several more of considerable antiquity, the sources of which are now more or less indefinite. Comparatively little "old lava," as it may be termed, is exposed about the bases of the young volcanoes, except far out on the plain, and some of it may have come from other and distant centers of eruption.

The place of origin of each of the six recent lava streams referred to is plainly distinguishable, but the best defined of all is the crater from which a lava stream that flowed northwestward welled out. This is the first fresh lava met with on leaving the road which skirts the west border of the Snake River Plains and taking a dim trail leading eastward among the Cinder Buttes. This northwest flow came from a crater composed of reddish tuff, the portion of which remaining has a height of about 200 feet. The lava rose within the tuff crater, breached the western side of its encircling wall, and the fragments floated away on its surface. The top of the congealed lava column in the conduit of the volcano is a semicircular plain of ropy and scoriaceous basalt 500 feet across, which is continuous with the nearly level surface of the great sheet of lava that flowed from it and expanded on the plain to the northward. The place of emergence of the lava is surrounded on all sides, except where the breach formed by its discharge occurs, by ragged cliffs of reddish tuff. The lava not only broke the cone in which it rose, but it tore away the base of the outer slope for a distance of fully a mile before expanding on the plain to the northward. On each side of the hardened lava stream for about half a mile below its source there are precipices, similar to those partially inclosing the congealed pool whence it came. The right or eastern bank of the stream is of reddish tuff and is a part of the parent cone; the left bank is composed of large angular blocks of black lava, and is due to the subsidence of the central part of the stream, which left its border stranded.

One of the most striking, if not the most novel of the many interesting features connected with the occurrence just mentioned, is the fact that large masses of tuff torn from the crater's walls were floated down the lava stream for at least 3 or 4 miles, and carried in large numbers far out on the adjacent plain. The floated masses are rough crags, frequently measuring from 20 to 60 feet in diameter and rising 15 to 20 feet above the bare, black, corrugated surface in which they are partially embedded. About the base of each of these masses which was closely examined there is a depression in the surface of the lava, forming a moat-like trough 4 to 6 feet deep. It is plainly evident that the masses of loosely compacted lapilli and scoriæ were of less specific gravity than the molten lava on which they fell, and therefore floated on its surface. How deep below the surface of the surrounding lava the bases of the crags are sunken is not definitely known, but in one instance fissures formed since the lava hardened reveal a downward extension of the tuff to a depth of 10 or 12 feet. That these floated masses came from the tuff cone from which the lava stream emerged is plainly evident, not only on account of the material composing the masses themselves, which is the same as that of the cone, but for the reason that certain of the crags are near their place of origin, having been carried but a few hundred yards, while others form a continuous train reaching far away and expanding to the northward. Not only were masses of relatively light tuff floated away, but blocks of compact basalt which fell from the precipitous western bank after the central part of the lava stream subsided were carried several hundred feet on the flow during its later stage, when the molten rock had become exceedingly viscous.

Another feature in this connection is of interest. The lava which flowed away from the Cinder Buttes was at first highly liquid, as will be shown more fully later, and spread widely on the adjacent plain, but as the supply lessened the lava thickened, becoming exceedingly viscous before it finally ceased to flow. The rate of flow toward the end of an eruption was characterized by a slowness as well marked as was the rapidity of the current during its earlier stages. The floating fragments on the lava, described above, fell upon it late in its liquid state, when it had become viscous and was partially submerged, pressing down the stiff plastic material about them in the same way that a block of stone would indent the surface of a mass of highly viscous pitch or asphaltum. Whether the material that was carried away earlier was floated or sank is not known, as the broadly expanded distal extremity of the lava stream has not been examined.

Although it frequently appears that lava streams in various regions have eroded their banks, the instance just cited is the only one that has come under my notice where the evidence of such an occurrence was conclusive. Evidently a stream of lava in this respect partakes of the character of both a river and a glacier. When the lava is liquid it erodes like a stream of water, with the added advantage of greater specific gravity; and when viscous, it floats away rock masses that fall on its surface in a manner analogous to the way morainal material is carried by a glacier. No evidence was obtained to show that lava from the Cinder Buttes melted or changed in any conspicuous way the rocks with which it came in contact. Such action may have occurred during the earlier stages of the eruption, but does not seem probable.

The rupturing of cinder cones by outflowing lava is a common feature of the Cinder Buttes, and is well illustrated by an isolated volcano which built a complete crater, situated about a mile northeast of their highest peak. From this volcano the lava flowed westward in a strong stream, which made a wide breach in the wall of the crater from which it came, leaving the remainder intact. The lava descended a steep slope before reaching the plain, and is now covered with soil and vegetation. In this instance, as in so many others near at hand, it is evident that the eruption was at first violent and characterized by steam explosions which threw out lapilli and scoriæ, but did not give origin to a lava stream; later, when a perfect cone with a deep crater in its summit had been formed, lava rose from the conduit within, breached the crater's walls, and flowed quietly away without a renewal of the explosive eruptions. This isolated cone with a single lava flow extending from it and expanding on the plain recalls forcibly some of the illustrations contained in Scrope's[a] classical book on the extinct volcanoes of central France.

At the locality where the northwest lava stream came to the surface there is an amphitheater, with rough walls, embracing a generally flat but undulating and corrugated area about 200 yards across, floored with scoriaceous and ropy lava, which looks not unlike a great spring suddenly congealed. The evidence of flow and of viscosity in the now hard material is everywhere conspicuous. The surface is entirely bare of vegetation and without lapilli or other deposits. It is apparent at a glance that this is the hardened surface of the conduit from which the lava stream leading from it was poured forth. One is impressed with the smallness of the source in comparison with the vast volume of material that came from it. The lava stream at first went westward, then, curving, took a northern course about the base of the portion of its crater still remaining, and at a distance of a mile is about 500 yards wide; it continued to expand and reached a distance, by estimate, of 6 or 8 miles, and has a width in its expanded distal extremity of some 4 or 5 miles. These are rough estimates and are

[a] The Geology of the Extinct Volcanoes of Central France, by G. P. Scrope. London, 1858.

probably below rather than above what an actual survey would show. The area covered by the lava stream is not less than 20 square miles, and may be twice that amount.

The absence of angular fragmental material and of volcanic bombs, clots of lava, etc., on the surface of the congealed lava pool, other than fragments near the borders which have fallen from its inclosing walls, is evidence that the later stages of the eruption were not attended by explosions. The lava seems to have been poured out quietly and in immense volume, in much the same manner that a spring of water sometimes comes to the surface and flows down a gently inclined channel. This is more than a casual simile, for the lava during the earlier stages of the eruption was certainly highly liquid, and was in reality a spring of molten rock which was caused to flow, as we have reason for believing, by pressure on a reservoir deep below the surface, which thus formed a stream that flowed far and spread wide on a nearly level surface. The outwelling of the molten rock was so quiet that not only were no volcanic bombs projected into the air, but no pasty clots or drops of liquid lava were spattered onto the bordering walls.

The surface of the lava at the immediate summit of the material filling the conduit is vesicular, and in part highly scoriaceous, but there is nothing approaching pumice or congealed frost to be seen. In fact, but little material of that nature was observed about the Cinder Buttes. The steam which rose with the lava seems to have escaped quietly before the magma became sufficiently cooled and stiffened to retain it until its pent-up energy resulted in explosions. That steam or gases were present in considerable quantity, however, is evident from the fact that nearly all the lava in sight is more or less vesicular and in many instances highly scoriaceous.

The northwest lava stream, and the same is in general true of all the recent lava flows about the Cinder Buttes, came to rest and finally hardened with such a low surface slope that from a little distance no eye can distinguish it from a perfect plain. For the first mile or so below the fountain-like source from which it came there is, it is true, a perceptible northward slope, but it is so gentle that a casual observer would scarcely note its presence.

But a few rods south of the congealed lava pool just described and separated from it by a fragment of a tuff cone, a portion of which was undermined by the lava flowing past its base and broken away after the manner of a landslide, another and larger lava stream came to the surface and flowed southward. This southwest lava flow had its source in two lava pools, but the molten rock discharged by them soon united so as to form one stream, which, at a distance of perhaps a mile, was joined by another and still larger river of lava having its source about a mile to the west of the base of the highest of the Cinder Buttes, and the united flow continued southward for a distance of between 25 and

30 miles.[a] The descent of the surface of the lava in this distance is about 1,000 feet, more than one-half of which is, I judge, within the first 10 miles. In the portion nearest the Cinder Buttes the descent of the surface toward the south can be detected by the eye, but beyond a distance of about 10 miles, the rough lava sheet seems to be level. The fact that the lava flowed so far on such a gentle gradient shows that it was highly fluid and spread almost with the freedom of water. The sheet produced must, in consequence, be thin, unless depressions were present in the surface of the plain over which it spread itself. All these features are such as pertain to yet other lava streams about the Cinder Buttes, as well as to the older lava sheets beneath the Snake River Plains, exposed in part in section in the walls of Snake River Canyon.

In addition to the lava streams briefly described above, there is another immediately at the west base of the highest of the Cinder Buttes, which went southward, and is somewhat older than the neighboring stream on the west. Two other streams, differing in age, went northward from near the same portion of the belt of craters. One of these is comparable in extent and volume with the lava sheet which flowed southward. There are thus at least six recent lava flows about the Cinder Buttes which spread widely on the adjacent plain and in fact nearly surround the most prominent portion of that belt of volcanoes. Other lava flows from craters farther eastward were seen, but all of them are apparently older than those just noted, although in certain instances they are sufficiently fresh to be easily traced to the craters from which they emerged.

The area occupied by the recent lava forming the six flows described above is by estimate between 250 and 300 square miles. There is no ready means of accurately measuring the thickness of these sheets, but they are certainly comparatively thin, as is apparent from the fact that they spread widely on a nearly level plain and cooled with essentially flat surfaces. Judging from the thickness of the various sheets at their margins and the gradients of their surfaces, their average thickness seems to be between 50 and 100 feet, or approximately 75 feet. On this basis the volume of lava they contain is between 7 and 8 billion cubic feet.

In reference to certain general hypotheses concerning the origin of volcanoes, the static equilibrium of the earth, etc., it is of interest to note that the lava poured out by the volcanoes which formed the Cinder Buttes was forced up to a horizon about 6,000 feet above the sea,

[a] While my observations show that the northwest and southwest flows, starting from within a distance of a few rods of each other, were contemporaneous and united with each other, the place of junction of the southwest flow with the next lava stream to the east has not been examined, and from what source the vast lava sheet to the south of Cinder Buttes was mainly derived is not known. Seemingly the southwest flow, and the next one to the east, are of the same age, and unite to form one sheet on the plain to the south.

and at a locality far distant not only from the ocean but from all surface-water borders, and in a region where erosion and deposition practically counterbalance each other.

CHEMICAL COMPOSITION.

A characteristic sample of the lava from near the source of the stream that flowed northwest from the Cinder Buttes—that is, the one nearest the mountains on the northern side of the range of craters—has been analyzed with the following results:

Analysis of recent lava from the Cinder Buttes, Idaho.

[Analyst, W. F. Hillebrand.]

	Per cent.
Silica, SiO_2	51.14
Titanium dioxide, TiO_2	2.41
Zirconium dioxide, ZrO_2	0.12
Alumina, Al_2O_3	13.95
Chromic oxide, Cr_2O_3	None.
Vanadium trioxide, V_2O_3	Trace.
Ferric oxide, Fe_2O_3	2.15
Ferrous oxide, FeO	12.97
Manganous oxide, MnO	0.44
Nickelous oxide, NiO	Trace.
Calcium oxide, CaO	6.56
Strontium oxide, SrO	Faint trace.
Barium oxide, BaO	0.25
Magnesium oxide, MgO	2.21
Potassium oxide, K_2O	2.33
Sodium oxide, Na_2O	3.59
Lithium oxide, Li_2O	None.
Water below 105° C, H_2O	0.12
Water above 105° C, H_2O	0.22
Phosphoric oxide, P_2O_5	1.59
Carbon dioxide, CO_2	None.
Chlorine, Cl	Trace.
Fluorine, Fl	0.10
Iron disulphide, FeS_2 (S=0.08)	0.15
	100.30
Less oxygen computed in place of fluorine	.04
Total	100.26

Specific gravity=2.907 at 24° C.

This analysis shows the composition of a large lava flow as nearly as a single well-selected sample can be expected to indicate the average of a seemingly homogeneous terrane, and probably indicates also about the average composition of all the recent lava discharged from the Cinder Buttes. It was made with much detail, with the view not only of meeting present needs but of furnishing accurate data for use in future discussions of volcanic phenomena.

The rock analyzed, as is shown by its composition and also by its physical and mineralogical characteristics, is a typical basalt, with perhaps a slightly higher percentage of silica than is normal to such rocks. The ratio of acids and bases present, as I am assured by Prof. E. D. Campbell, of the University of Michigan, an expert metallurgist, is such as to favor easy fusibility. From analogy with the composition and behavior of the slag produced in iron smelting furnaces, the fusing points of which are known, the rock would probably melt at about 2,250° F., and yield a highly liquid product, which on cooling would pass slowly from a liquid to a solid state through an intermediate highly viscous condition. This opinion was expressed by Professor Campbell without a knowledge of the physical characteristics of the lava, and serves to increase my confidence in the deductions made from field observations in reference to the highly liquid condition of the lava when extruded and its slow passage through an intensely viscous condition before final consolidation. The gradual change from a plastic to a rigid state was no doubt prolonged, owing to the slow rate of cooling incident to a large mass of fused material, but this is not of necessity the sole cause. In this connection it may be suggested that the ready fusibility of a lava is not entirely dependent on the presence of a high percentage of basic material, as is commonly stated, a basic lava usually being considered easily fusible and an acid lava (one rich in silica) refractory; neither does the behavior of a rock in this respect depend necessarily on the fusibility of the individual mineral present, as claimed by J. D. Dana, but rather on the ratio of the constituent acids and bases. With lavas, as with furnace slags, an excess of either acid or basic material might produce difficult fusibility, while an intermediate condition in which the acids and bases were adjusted to one another in certain definite ratios would produce an easily fusible compound. In the case of furnace slags, as I am informed by Professor Campbell, the time required for the passage from a liquid to a solid condition, or the time required for the material to "set," is regulated not only by the rate at which heat is lost, but by chemical composition. Slags rich in silica pass from a liquid to a solid state, or set much more quickly than basic slags, the conditions favoring the escape of heat being the same. Applying this principle to molten lavas we would expect highly acid lavas to congeal more quickly than basic lavas, even though their temperatures at the time of extrusion and other conditions were the same. As is well known, this agrees with what is found in nature, since streams of acid lavas have frequently come to rest and terminated with precipitous frontal slopes on steep gradients, which has not been observed in the case of basic lava. To be sure, this is not a crucial test, since the acid lavas in general require a greater degree of heat to cause fusion than the more basic varieties, and on reaching the surface may not have been liquid, but only viscous, and indeed in some observed instances nearly solid. The quicker setting of siliceous than of basic slags suggests also a reason why the surfaces of acid lavas are so frequently broken and consist of masses of angular fragments, without the smooth, oval, and flowing forms that basic lava frequently presents.

SURFACE FEATURES.

All of the recent lava streams about the Cinder Buttes, as previously stated, are similar in their general characteristics, but when examined in detail they present interesting variations in surface features, not only in individual streams, but in different portions of the same stream.

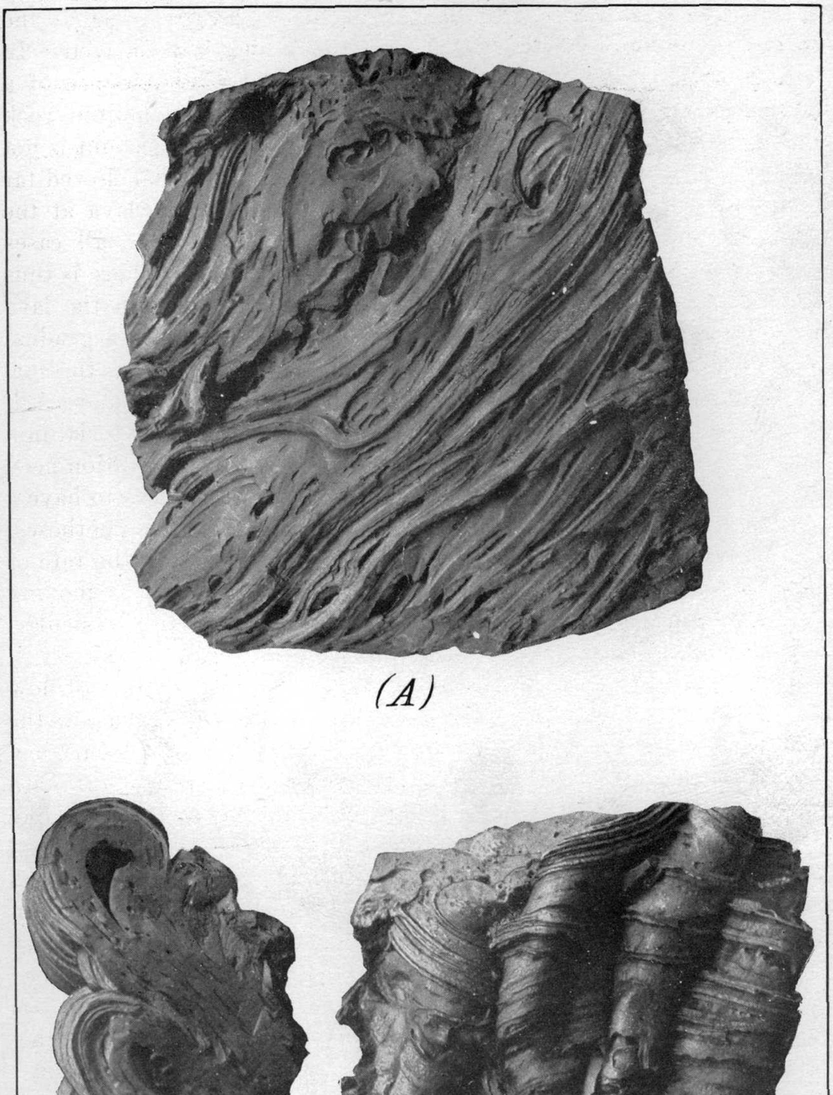
In general, the lava at a distance of from 5 to 10 or more miles from its place of emergence is less vesicular than at the summits of the conduits from which it came. The reason for this is, evidently, that the steam occluded in the molten rock had greater facility to escape when the lava flowed far than when its journey was short. More than this, the lava first extruded from a vent and now found at the distal extremity of the stream it formed flowed much more rapidly than that which came later, either because of a higher temperature and consequently greater liquidity, or by reason of larger volume. To these two alternatives a third may be postulated, namely, a variation in the composition of the lava, which caused it to become viscous near the close of the discharge without a diminution of temperature. While analyses of the lava that flowed far have not been made, the physical appearance of the distal and proximal extremities of the streams do not suggest a difference in composition, and this third alternative can seemingly be disregarded. Between the remaining hypotheses there is an easy choice, namely, that the rate of flow of the lava diminished without a decrease in the initial temperature. This is evident, since if the rate of flow had remained essentially the same from the beginning to the close of a discharge, and the lava had become viscous toward the end of an eruption, it would have acquired a corresponding increase in depth near its source, and if as viscous as the lava now remaining at the summits of the conduits was before hardening, it would have been piled high above the opening from which it was extruded. On the contrary, we find but a slight increase in surface gradient on ascending any one of the lava streams near its source. All the evidence indicates that the volume of the lava toward the close of an eruption gradually diminished until the outflow ceased. The last lava to reach the surface cooled and hardened without lateral motion.

These considerations have a bearing on the theories of the causes of volcanic eruptions. Of these there are two that have claimed special attention. One is, in brief, that steam is the main motive power which causes lava to rise, and the other that the lava is forced to the surface by pressure on the reservoirs from which it is derived. In the lava streams among the Cinder Buttes, there is no evidence of a diminution in the amount of steam occluded in the molten rock toward the end of an eruption, but rather the reverse, if account is not taken of the greater freedom of its escape from lava that flowed far as compared with that which cooled without motion, the lava at the immediate source of a stream being, as already stated, in all cases highly vesicular, and in part even highly scoriaceous. There is thus no reason for assuming a decrease in steam tension within the lava itself. On the other hand, the hypothesis that there was a gradual diminution in the pressure on the lava still remaining below the surface meets all the requirements of the facts observed. There still remains another alternative, namely, that the supply of material in a condition to be extruded gradually diminished. This condition need not be considered at this time, however, as it does not seem to have a bearing on one's choice between the steam and pressure hypotheses. The facts now to be observed indicate that the decrease in the rate of flow was due to decrease in volume, and that the more slowly moving material retained its steam and gases so as to become highly vesicular, while that which flowed far congealed to a more compact rock.

On the rate of flow, or, more definitely, on the ratio of rate of flow to rate of surface cooling, depend certain marked contrasts in the resultant surface features. When motion was slow and continued after the lava had become viscous, the stiffened crust was left with either a generally smooth, flat surface, or acquired oval, stream-like ridges, bulging mounds and dome-like swells, while the crust formed where motion was more rapid or had continued after the surface had passed to a rigid condition became broken and the blocks were variously displaced and heaped up so as to produce excessive roughness. These two leading varieties of surface features correspond with what Dana[a] has termed pahoehoe and aa in the case of the lavas of the Hawaiian Islands. His description of what may be termed the generic characteristics of these two strongly contrasted lava surfaces is as follows:

> Lava streams are of two kinds. (1) There is the ordinary smooth-surfaced lava of volcanoes. It is the pahoehoe of Hawaii, the term signifying "having a satin-like aspect." The surface of the lava shows, by the fine and coarse flow lines over it, that it cooled as it flowed. Through one means and another the surface is usually uneven, being often wrinkled, twisted, ropy, billowy, hummocky, knobbed, and often much fractured. * * * The streams have sometimes a firm, glassy exterior half an inch or less in thickness. When lava overflows from a boiling lava lake it carries along a surface scum 1 to 3 or 4 inches thick, which is a glassy scoria, usually easily separable from the more solid and chief part of the lava stream.
>
> The crusting over of a stream while it is still flowing, owing to contact with the air above, results in the leaving of empty tunnel-like caverns, which are sometimes hung with stalactites.

[a] J. D. Dana, Characteristics of Volcanoes. New York, 1890, p. 9.



BLISTERED LAVA SURFACE AND CORRUGATIONS ON LAVA STREAM, CINDER BUTTES, IDAHO.

(2) The other most prominent kind of lava stream is the aa. The aa streams have no upper flow-like surface; they are beds of broken-up lava, the breaking of which occurred during the flow. They consist of detached masses of irregular shapes, confusedly piled together to a height sometimes of 25 to 40 feet above the general surface. The size of the masses is from an inch in diameter to 10 feet and more. The lava is compact, usually less vesiculated than the pahoehoe, not scoriaceous; but exteriorly it is roughly cavernous, horridly jagged, with projections often a foot or more long that are bristled all over with points and angles. In some cases ragged spaces extend along planes through the large masses, like those of the exterior; but in these, as in other parts, it is evident that the agency was tearing and upploughing and cavity making in its action, and not vesiculating.

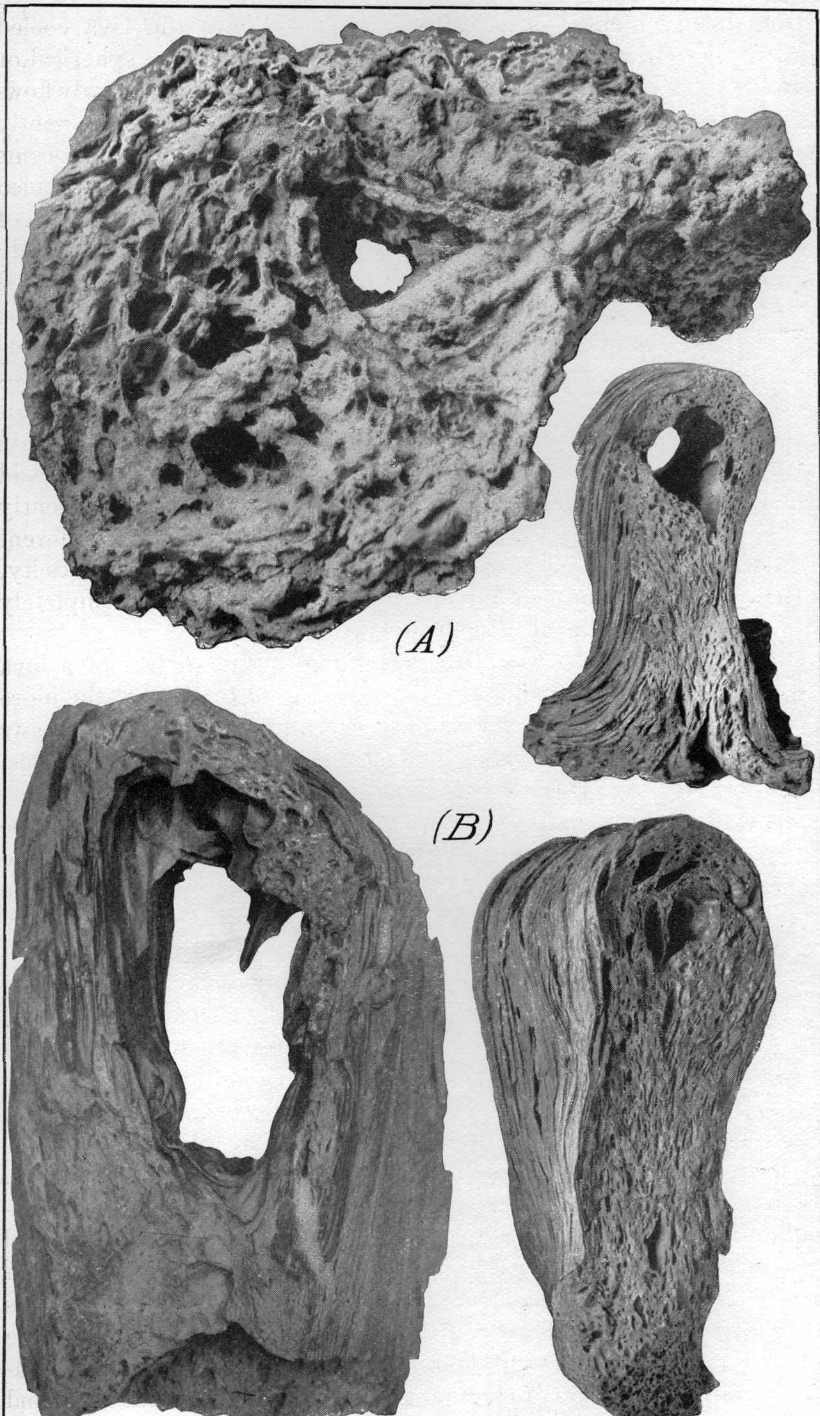
Pahoehoe.—The lava surface having the characteristics included under the term pahoehoe occurs especially near the sources of the lava streams, and in some instances continue for several miles down their courses, and in certain cases are not entirely absent even at their distal extremities. The leading features are broad, generally smooth swells and stream-like ridges with convex surfaces, which cross each other as if braided together, but begin and end indefinitely. Some one has compared the appearance of such confluent outflows of lava to a mass of giant slugs, crawling over each other. The simile is certainly suggestive. Slow motion of many, generally parallel, but occasionally diagonal and recrossing streams, from 2 or 3 to 10 or 15 feet in width, united into a single generally flat sheet, with perfect preservation of form in their central parts, convey some idea of the general appearance of much of the pahoehoe about the Cinder Buttes.

The origin of the peculiar and highly characteristic pahoehoe surface is due to the flow of viscous lava, which in consistency resembled asphaltum or pitch. The onward motion was not a continuous flow, as in the case of thoroughly liquid substance, but the surface and front of the advancing stream stiffened and bulged upward, and the more thoroughly molten material within broke through the tenacious but still plastic surface portion and advanced as a well-defined stream for perhaps a few yards or rods, and in turn stiffened at the surface and expanded on account of pressure from within and halted with a curved front bulging outward. These slow-moving, viscous streams crossed one another, but became more or less thoroughly intermingled. This manner of progression, accompanied by many variations in detail, can be plainly seen on the congealed surfaces now remaining, especially near the sources of the lava stream.

While the curved and swelling forms so characteristic of pahoehoe surfaces are apparently smooth when seen from a distance of a few rods or a few yards, they are rough to the tread, and on close examination are found to be braided over with low ridges and string-like forms inclosing or bordering shallow depressions, as is well shown on Pl. XIII, *A*. The origin of this coarse lace work on the surface of lava which cooled slowly, becoming highly vesicular before its sluggish motion finally ceased, is easily explained. Where the lava cooled without motion, the vesicles once occupied by streams are spherical or nearly so. Where the lava cooled and stiffened while still slowly flowing, the vesicles are elongated. In such instances one may frequently find cavities which were drawn out until the wall at the top became exceedingly thin and was finally ruptured, the material that formed it spreading and leaving an elliptical blister-like depression. Much of the lava with extended cavities has the appearance of molasses candy that has been pulled until it became fibrous. When motion continued after many of the vesicles at the surface of the lava had become ruptured, the material forming the elevated boundaries of the numerous blisters was extended into long, sinuous ridges, and the surfaces assumed the appearance shown in the photograph referred to. This process took place not only at the surface, but at intervals within the mass, as the lower part continued to flow after the surface had stiffened and ceased to move; or what seems to have been frequently the case, successive layers, each a few inches thick, acquired different rates of motion, increasing with depth, owing to increase in plasticity, so that the surface portion of a sheet became more or less completely fibrous throughout a thickness of several feet.

Corrugations and arches.—The wrinkling of the surface of a lava stream after it became stiff and viscous, owing to the flow of the more plastic material beneath in the manner well known in the case of many recent lava streams, is abundantly illustrated about the Cinder Buttes, where several novel variations of the process were observed.

The simplest corrugations occur on nearly flat or bulging pahoehoe surfaces, and appear as a series of concentric ridges an inch or two high, with a flat space perhaps 3 inches wide between them. The corrugations number possibly 10 and possibly 50 individuals. They are drawn out into the form of half an ellipse, or appear as a concentric series of parabolic ridges, which are highest and best defined at the front, where the curvature is sharpest, and which fade at the rear, where the figure is open. These series of ridges are sometimes 10 or 20 feet in length, are sometimes gently curved, but more frequently are long drawn out and reveal the course of a narrow, sluggish stream. Where the motion was greater the spaces between the ridges became narrower and curved downward, forming small troughs or synclines. Frequently the ridges adjoin one another, and are even tightly compressed and inclined in the direction of flow of the plastic material beneath, as is illustrated by the photograph reproduced in Pl. XIII, *B* and *C*. That a flowing motion occurred in nearly solid lava which was yet capable of yielding to a strong force slowly applied is shown by the fact that in some instances the surfaces of the various layers distinguishable in the folds are smooth and polished, having, in fact, the color and appearance of highly burnished blue steel. This polish implies that



A. LAVA EXPANDED BY STEAM ON ENTERING WATER.
B. PRESSURE FOLDS, SURFACE OF RECENT LAVA FLOW, CINDER BUTTES, IDAHO.

the lava was nearly solid at the time the motion producing the folds took place.

Not only simple but compound ridges were frequently formed in the manner just stated. In the case of the compound ridges it is apparent that a congealing of the surface, accompanied by the formation of a series of small wrinkles, was followed by the stiffening of a thicker layer as cooling progressed. This thicker sheet in turn became wrinkled, the larger folds carrying on their surface the smaller wrinkles, similar to the occurrence of small waves on the surface of a larger one. In these instances, also, the larger folds are frequently inclined forward. Still other complexities occur, as when after a series of simple or compound wrinkles had been formed the direction of the underflow changed and a new series of wrinkles and folds was produced which cross the earlier series diagonally.

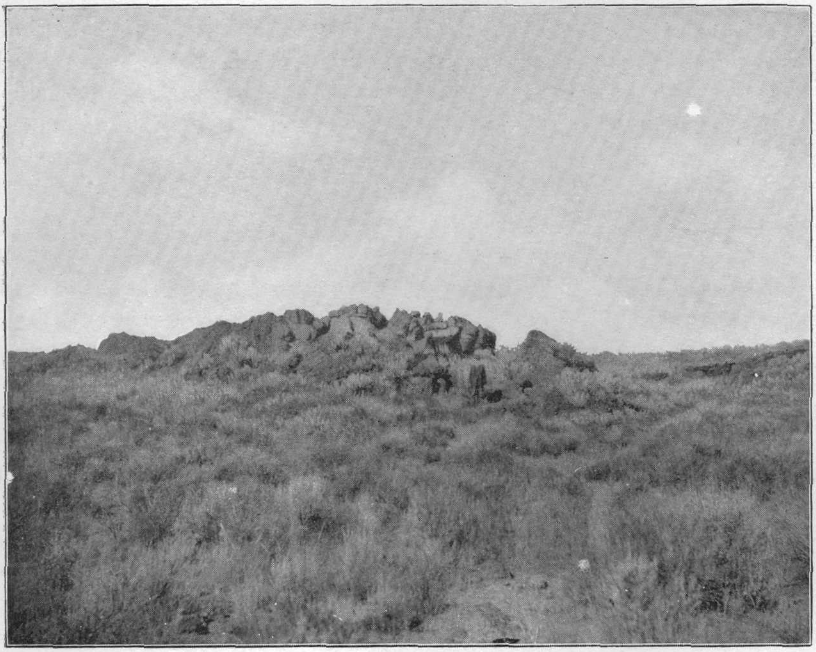
The corrugated like the adjacent unwrinkled portions of the pahoehoe surfaces are blistered, as explained above, by the breaking of the thin surfaces of steam cavities, and cord-like ridges produced by the elongation of the material between the shallow depressions. In such instances the ridges between the blisters were still more elongated and frequently pass from side to side over the curved crest of a fold, producing elevations that suggest the appearance of the thread on a screw. The ridges are parallel, however, and not spiral.

Selecting other examples to illustrate the series, we find that many folds rise sharply from the general surface to a height of 10 to 20 or more inches. In these instances the sides of an individual fold are compressed, while the top may be expanded, so as to reveal in cross section much the appearance of the end of a railroad rail, as is shown in Pl. XIV. At times each member of a series of ridges of this nature is inclined forward in the direction of flow. The expansion of the summit portion of a fold of the nature just referred to is the first in a series of changes that produced surprising results. The next variation is where the stiffened crown of a fold has separated from the more plastic material in its inner portion and been torn away from it, leaving a hollow space, as is shown on Pl. XIV. The expanded summits of such ridges are long, hollow tubes. A still greater movement resulted in the formation of larger folds, in which the hollows are 6 to 10 inches or more in height and 3 to perhaps 5 inches across, as is shown on Pl. XIV, *B*. The inner surfaces of these hollow folds present the appearance produced when a high viscous substance is pulled asunder, as, for example, when a loaf of bread not completely baked is broken apart. In these instances the inner walls of the cavities are exceedingly rough, presenting numerous sharp ridges and projecting points, and are frequently crossed by rods and filaments of brittle lava, which are small in the center where most elongated and expand where they merge with the walls. This appearance is imperfectly shown in the illustration just referred to. All the forms mentioned above, from simple corrugations or ropy forms, as they are frequently termed, up to hollow folds 20 or more inches high, occur in abundance, especially near the sources of the lava streams. It needs no argument to convince the visitor to the Cinder Buttes that various forms were produced by the subsurface flow of the lava, which caused its highly viscous surface to become corrugated and folded. The most interesting fact is the tearing away of the nearly rigid crust from the more viscous portion below and its upward bending into hollow folds. In all these instances the direction of the force acting on the stiffened but still yielding crust was horizontal and slowly applied. Variations in the results dependent on the degree of rigidity of the crust, its thickness, the rate of motion, etc., are numerous.

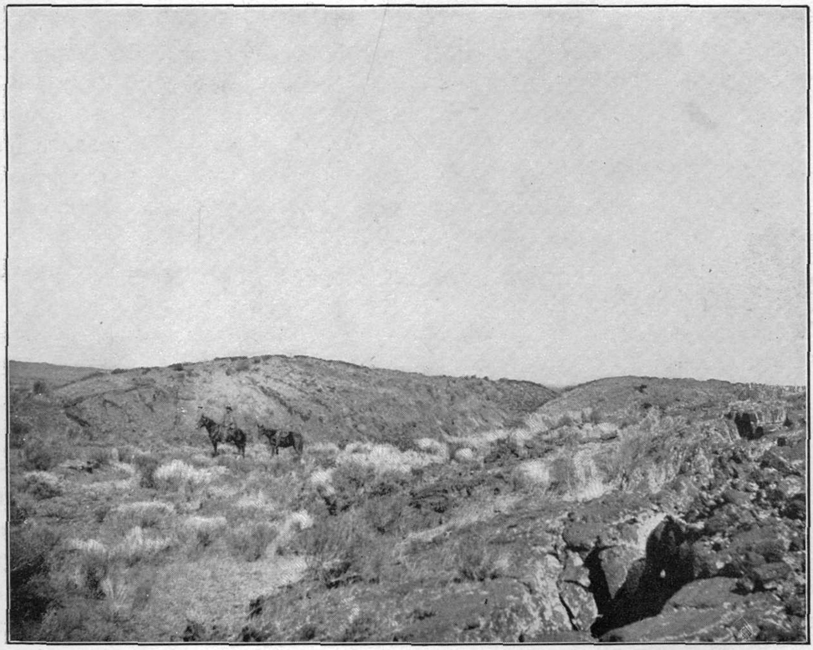
In all of the examples thus far referred to the crust was only 1 or 2, or perhaps 3 inches thick and still plastic and yielding to a slowly acting force. Instances are also numerous where the crust was 2 or 3 feet thick, but still not brittle, and was pressed up into folds that are 6 to 10 feet high and perhaps 15 or 20 feet across at the base. Ridges of this nature form a characteristic feature of the topography of the lava surfaces, and frequently have caverns beneath them through which a person can walk with freedom. The sides and roofs of the caverns are exceedingly rough and frequently bear evidence that the lava was still sufficiently mobile to flow after they were formed. The roofs in many instances are fretted with stalactite-like pendents of congealed lava. The sharpness of the projections is sometimes blunted by the subsequent flow of the lava and its gathering into more or less distinct drops. In one instance I found the floor of such a cavern to be corrugated for a distance of 20 feet or more, showing that there had been a flow of the lava along it. This occurrence suggests that corrugation in the case of old lava flows is not a positive indication that such markings belong to the actual surface.

The ridges and domes just referred to sometimes have cracks along their summits parallel with their larger axes, which it will be remembered are transverse to the direction of the force that produced them. In some instances the sides of such a ridge slope sharply, like the roof of a house, and there is a break on each margin where the descending slope meets the adjacent flat or nearly flat surface. In these cases it is evident that the crust had become too rigid to yield to the tangential pressure applied to it without breaking, and fracture and displacement resulted. The lower surfaces of these inclined blocks present the characteristic "pulled dough" forms referred to in the case of the hollow folds, showing that owing to lateral pressure the rigid crust had been forced or pulled away from the more viscous material beneath.

Openings in lava similar to those just described are mentioned by



A. PRESSURE RIDGE IN SNAKE RIVER LAVA NEAR MARKET LAKE CRATERS, IDAHO.



B. PRESSURE RIDGES IN SNAKE RIVER LAVA NEAR BIG BUTTE, IDAHO.

J. D. Dana as occurring in the lava flows of the Hawaiian Islands, and the explanation is suggested that they are due to the force of steam or gases generated beneath a still plastic crust. This explanation is not favored in the instances observed about the Cinder Buttes, although it might seemingly apply to the larger hollow ridges or elongated domes if they did not form part of a series. The transition from simple corrugations to those having cavities in them, and from these to arches with caves beneath, is complete, and includes also the ridges with sloping roofs which have cracks along the top. The generation of steam or gases beneath a crust can not be accepted as explaining the origin of either the earlier or later members of the series and is unnecessary for explaining the origin of the intermediate forms. That steam may cause arches to rise in the manner referred to by Dana may be true, but it does not seem to have been the cause of the arching seen in the lava streams about the Cinder Buttes.

The ridges with caves beneath, as stated, are frequently from 15 to 20 feet across and rise from 5 to 10 feet above the bordering surfaces; their arched roofs are between 1 and 2 feet thick. Still larger swells on the surface of the pahoehoe lava were observed, but as they were unbroken, it was not evident that openings occur beneath them, and it is possible they are hardened streams of lava instead of pressure ridges.

It is but a step from the larger ridges on the fresh lava streams, just described, to similar but frequently much larger ridges, which form a characteristic feature of many portions of the older sheets of Snake River lava. The forms referred to are dome-like ridges, commonly from 10 to 30 feet high, 20 to 70 feet wide, and from 50 to possibly 500 feet long, which are usually cracked open at the top throughout their length, the cracks being open fissures, usually 3 to 4 feet wide, but sometimes as much as 10 feet (Pl. XV). The fissures referred to narrow downward, and the basalt forming their walls is frequently columnar, the columns being at right angles to the outer surfaces of the ridges. Where these "cracked ridges," as I have termed them in my notes, are in groups, as is frequently the case, their longer axes are nearly parallel, but this is not an invariable rule. In some instances the sides of the ridges, instead of forming an arch in cross section, as is commonly the case, present flat slopes like the roof of a house, with an open fissure along the top. The steeply inclined sides of these Λ-shaped ridges frequently carry well-defined corrugations, which were formed when the surface of the cooling lava was horizontal.

The similarity between the large ridges on the surfaces of the older sheets of the Snake River lava and the hollow folds, corrugations, etc., observed at the Cinder Buttes, leaves no room for doubting that the former, like the latter, were produced by lateral pressure in the surface portion of a lava flow. The ridges on the old flows are large because they were formed in lava that had flowed far over a nearly level plain, and had formed thick crusts before they were forced up into ridges. As is shown by the small corrugations, hollow ridges, etc., on the surface of the recent lava flows, there is a direct relation between the thickness of the stiffened crust that forms as lava cools and the size of the arches that may be produced in it by lateral pressure. In the case of the old lava flows referred to the crust had become 10 feet or more thick before the arching occurred, and correspondingly broad ridges were produced. When the lava at the surface was still sufficiently yielding to be stretched by a force slowly applied, it was not ruptured, but by far the greater number of the large ridges are cracked, showing that the surface had become too rigid to yield by stretching to the force applied. The extreme case, where the crust had become solid, is illustrated by the flat-sided or roof-like ridges.

The large ridges and dome-shaped elevations on the surface of the older sheets of the Snake River lava have attracted the attention of previous observers. They are referred to as follows by F. H. Bradley:[a] "Whatever the source [referring to the lava of the Snake River Plains], the material had evidently become quite viscid; for, at some points, where it ran over small inequalities of the surface beneath, it now stands in low mounds, which could not have been the case if it had been very fluid. That these mounds were not all formed by an undermining and sinking of the surrounding masses, to which some of them have very properly been referred, is proven by the tapering shapes of the closely fitting blocks which form the arch. But there is still room for study on all these points."

That the explanation suggested in the above quotation is not admissible, at least in a large proportion, and, I believe, in all the instances observed by me, will appear, I think, from the comparison with the more recent forms of a similar nature presented above. Moreover, characteristic domes and "cracked ridges" occur near Shoshone Falls, etc., on the immediate border of Snake River Canyon, where the lava is from 500 to 700 feet thick. In the walls of the canyon, as already stated, sections of the ridges are exposed, which show that they are either hollow arches above flat lava sheets, or else the folds die out gradually below. No clearer evidence could be presented to show that they were not produced by viscid lava being drawn over eminences, even if such an occurrence was known to be possible.

In the production of wrinkles, corrugations, hollow ridges, etc., as just described, we have examples of the changes produced in a still-yielding crust under the influence of a force slowly applied, arising

[a] Sixth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., Washington, 1873, pp. 204-205.

from the flow of the subcrustal lava. Cases where the crust became fractured have also been cited. All this implies slow cooling and a gradual passage of the lava from a fluid through a viscid to a solid state, accompanied by a gentle flowing motion in the more slowly cooled subsurface portions of the lava streams. Should the crust congeal rapidly so as to form a thin or comparatively thin rigid sheet, while motion still continues, it is evident that it would become fractured and the blocks thus formed variously displaced; that is, an aa surface would be produced.

Aa.—The presence on the Martin lava stream of angular blocks of basalt frequently united into a coarse breccia has already been mentioned. In that instance an example is furnished of a lava stream having swift motion, owing to a high gradient. A similar occurrence throughout areas of many square miles, where the surface is generally level, may be seen over the lava streams which flowed away from the Cinder Buttes, and especially in the middle portions of their course. The areas here referred to have the characteristics included by Dana under the term aa.

On the great lava flood which spread northward from near the northern base of the highest of the Cinder Buttes, but not from the volcano which built that eminence, the breaking of the surface begins within less than a mile of its source, and continues broadening to the northward as far as the eye can reach from the most commanding of the neighboring elevations. The surface of this stream is a chaos of angular blocks of scoriaceous lava, which at times are heaped in piles 10 to 15 or more feet in height. In many instances large cakes of lava stand on edge, and are prominent landmarks from afar. The blocks of lava sometimes have wrinkled and corrugated surfaces, showing that they existed as pahoehoe before they were broken and displaced. In some places, in the midst of a broad area composed of fragments, there will be a small tract, usually depressed below the level of the general surface, which is smooth and unbroken and presents the features due to motion while yet plastic.

The general explanation of the origin of the aa surfaces, as is well known, is that a hard crust was formed on the lava while yet in motion, and that the friction of the still liquid portion beneath caused the crust to break. The fragments, being in most cases vesicular, were lighter than the liquid lava and were carried along by it. The analogy between such a lava stream and a river covered with cakes of ice is very close. In the case of a gently flowing lava stream, like a broad river covered with cakes of ice, the floated lava blocks are generally horizontal and only occasionally turned on edge. When the flow is stronger, as when the gradient down which the lava progresses is moderately steep, the lava cakes become heaped together and great confusion results. In such instances the piled-up lava blocks resemble an ice jam or an ice pack on arctic seas. The congealing of a lava stream when covered with floating blocks of its own disruptured crust is similar to the refreezing of a river on which there are ice flows and ice jams. The submerged portions of the lava blocks are thus united by the hardening of the liquid or plastic lava in which they are immersed, and a breccia is formed. This second crust, however, is sometimes ruptured and the fragments of breccia are displaced and tossed about.

The fact that in the production of an aa surface a hard crust is first formed, which is ruptured owing to the flow of still liquid lava beneath it, is again indicated by striations or grooves on the under surface of the crust fragments. These markings are frequently several feet long, have a width of several inches, and are usually straight. At first glance they resemble glacial scorings, but there is no polishing. The origin of these grooves can be traced to hard fragments carried by the underflow and pressing against the still plastic lower surface of the floating crust. At times a ragged kernel or fragment of rock is found at the end of a groove, showing that at last its motion was arrested and it stuck fast.

As already suggested, whether a pahoehoe or an aa surface will be produced on a lava stream is determined by the ratio between rate of cooling and the rate of motion. But this ratio is not the same for different lavas. When a lava sheet cools without motion, neither a characteristic pahoehoe nor an aa surface is produced. Many of the older sheets of Snake River lava illustrate this; they are simply plane surfaces, composed of either vesicular or compact granular basalt.

The explanation of the origin of aa adopted above was not accepted by Dana,[a] who suggests that the breaking of a lava crust may be due to moisture derived from the rocks over which lava flows and leading to quicker cooling in certain areas than in others. Such an occurrence, however, even if proved to exert an influence, seemingly introduces a variation into a more general process, without supplanting the controlling conditions.

LAVA CAVES.

In the production of an aa surface, as already stated, a rigid crust formed on the surface of a lava stream, becomes broken by the flow of the still liquid lava beneath. If the crust is of sufficient strength, however, not to be broken by the underflow, the lava beneath may flow out so as to leave a cavern. As is well known, this has occurred in many instances. Examples of this class of caverns occur in the lava that came from Black Butte, near its source, where it had formed by its own upbuilding a considerable gradient, but none were observed intact in the nearly flat lava fields about the Cinder Buttes,

[a] J. D. Dana, Characteristics of Volcanoes. New York, 1890, pp. 242-244.

although certain steep-sided depressions are there present which perhaps represent such caverns, whose roofs and sides have fallen in. These sunken areas vary in length up to 200 or 300 feet, and are from 50 to perhaps 70 feet wide and 40 to 50 feet deep. Their bottoms and sides are strewn with large blocks of their fallen roofs. Lava caves of the nature here considered occur at several localities in the older sheets of Snake River lava, but are not known where the Snake River and its tributaries have excavated canyons in the nearly level sheets. One was visited by me, on the eastern slope of Notched Butte, about 4 miles south of Shoshone, and several of large size are reported to occur about 6 miles northwest of the same town, where lava descended from the mountains before reaching the adjacent plain. The cavern on the side of Notched Butte was entered through an opening formed by the falling in of a part of its roof. The portion open to inspection is 300 to 400 feet long, 25 to 30 feet wide, and is partially filled with blocks that have fallen from the under surface of its cover. The height of the opening at present is from 6 to 10 feet. In continuation of the portion of the cavern still remaining, there is a depression about 15 feet deep which is crossed at one locality by a natural bridge formed of a portion of the roof still in place.

The interiors of such caverns present various details, due principally to the drip of the lava while yet hot and mobile. The falling in of the thick roofs of this variety of lava caverns is evidently not in all cases due to a sudden collapse. The cave referred to, on Notched Butte, has been enlarged upward by the falling of blocks from the under side of its roof, and I think none of the original under surface of the arch remains. This process continuing, openings will finally be made to the surface, and more or less gradually the entire roof will fall. The cause of the displacement of blocks from time to time from the roof of such a cavern is difficult of explanation. The only agency that can be appealed to as generally active is change of temperature, but this can not be considered as important in caves with roof 20 to 40 or more feet thick, as is frequently the case, until openings have been made. The temperature of caverns situated at such depths is generally uniform. The only other agency that I can suggest is earthquake shock. That earthquakes may have occurred in the region where Notched Butte is situated is shown by the presence of faults in the Snake River lava, as will be described later.

From what is known concerning lava caves due to outflow of still liquid or plastic material from beneath a rigid crust, it appears that the controlling condition favorable to their formation is a sufficient gradient to permit the subsurface lava to flow, but yet not of such steepness as to cause a current which would shatter the crust in the earlier stages of its formation. A delicate adjustment between rate of cooling and rate of flow is also necessary. The caves should be expected to occur where the gradient is gentle, but still sufficient to insure a draining away of the lower portion of a lava stream after a crust too thick and strong to be wrinkled or broken by the friction of the underflow has formed. The underflow must evidently produce a current of restricted width, for if broad, the arch left would fail to support its own weight and subsidence would occur, probably resulting in the production of a more or less characteristic aa surface. The length of the tunnel does not seem to be confined within narrow bonds, and it may extend for miles, in the direction in which the lava stream flows. The presence of the caves is not suggested at the surface unless a sagging of their roofs has occurred. The caves in cross section show a flat arched roof resting on vertical side walls and nearly flat floors.

The formation of lava caves of considerable size by the arching of a still somewhat plastic lava crust, due to lateral pressure caused by an underflow, has already been described. Their presence is indicated at the surface by an arched ridge, rising above the adjacent and usually flat surface. Within the caves, as a rule perhaps, the arch of the roof springs from the flat floor and vertical side walls are absent; there are exceptions to this, however, and in such instances there has probably been an outflow of material as in the formation of the variety of caverns noted above. The roofs are relatively thin from having been forced up into true arches, which are more perfect structures from an engineering point of view than the flat-topped roofs left by an outflow of lava from beneath a thick crust. These caverns are elongate, their length being at right angles to the direction of flow of the lava stream which produced them. A characteristic feature of the interiors is the roughness of their roofs, which, as already stated, have the appearance which is produced by the pulling apart of a highly viscous substance. This appearance is more pronounced on the roofs than on the floors, owing to the fact that the separation took place when the nearly solid crust rested on still plastic material below, which settled to an even surface. In addition to the "pulled-dough" forms in the roof, there are sometimes pendent stalactite-like masses formed by the congealing of lava, which was at first sufficiently fluid or plastic to drip.

There is still another variety of lava caverns due to the blowing out by escaping steam of still liquid or highly plastic lava through openings in a solid crust. The chimney-like openings in the parasitic cones described on a previous page are examples of "vertical caverns" which have recesses opening from them at their bottoms. The claim that the horizontal enlargements are due to the cause suggested requires confirmation, but the cones built of clots of lava, scoriaceous bombs, etc., contain far more material than the vertical openings within them could have furnished. This is apparent when it is remembered that the vertical shafts are principally in the built-up portions of the "chimneys," and hence the material blown out must have been supplied in large part by the horizontal galleries to which the vertical shafts lead.

In some instances parasitic or "driblet" cones, are closed at the top so as to form beehive-like piles. These peculiar structures, built of adhering clots of lava, sometimes contain circular rooms that are 15 to 20 feet in diameter and 15 or more feet high. Their floors are usually flat and their arched sides and ceilings are hung with pendent masses of lava which cooled as it dripped.

DEPRESSIONS IN THE SURFACES OF LAVA SHEETS.

The falling in of cavern roofs so as to produce open depressions in the surface of a lava stream has already been referred to. This has been a common occurrence on the younger flows, such as those about the Cinder Buttes, Black Butte, etc. These holes, pits, trenches, etc., are frequently 15 to 20 feet in diameter and 10 to 20 or perhaps 50 feet deep, but ragged gulfs of much greater dimensions are also present, especially on Black Butte. In some instances they are several times as long as wide, or have a linear arrangement showing that the roof of a long subterranean gallery has fallen in throughout a considerable part or perhaps the whole of its length, or else given way in places, producing several pits. When the fall of a cavern roof has occurred recently its fragments may be recognized in the confused pile of débris at the bottom of the depression left, but more frequently quantities of dust or soil have been blown and washed in, and bushes, taking root, conceal the dislodged fragments.

In a few instances the roofs of caverns have been known to fall, and the liability of such an occurrence makes traveling over the younger lava fields somewhat dangerous. I have been informed that only a few years ago, in the portion of the lava flow south of Cinder Buttes, a team of horses and a wagon broke through a cavern roof and went down with the blocks that fell.

On the surfaces of the older lava flows, now mostly covered with a fine yellowish soil, pits and steep-sided depressions of the nature just described are rare and seemingly wanting. The reason for this is, apparently, that they have been filled with wind-borne débris. On the surfaces of the older flows there are, however, occasional shallow depressions from a fraction of an acre to several acres in extent which are bordered in part or wholly by ridges of lava. These depressions are, in many instances, occupied by water during the rainy season and transformed into shallow, ephemeral pools, of the variety termed playa lakes. In summer the water evaporates, leaving mud flats or playas. The depth of the fine silt-like material occupying these depressions is known from borings, in one instance, to be about 40 feet. It thus appears that there are depressions in the surfaces of the older lava sheets which are analogous to those in the younger lavas, and are probably also of similar origin.

MARGINS OF LAVA FLOWS TERMINATING ON A PLAIN.

The principal variations in the character of the margins of lava sheets which expand on a plain are determined by the plasticity or rigidity of the lava. If the lava is highly plastic, or liquid, it terminates in a low frontal slope, having the characteristics of pahoehoe; in such instances it may thin out to a feather edge, only a few inches thick, with local extensions here and there, which are highly scoriaceous within and have oval and frequently wrinkled surfaces. When lava becomes thick and viscous, and especially if blocks formed by the breaking of a rigid crust are inclosed by it, its flow is retarded and its margin presents a steep slope. In such instances the distal end of a lava stream frequently terminates in a nearly vertical escarpment 20 to 30 feet or more high. Each of these variations is admirably illustrated about Black Butte, in the valley of Big Wood River, where in places the lava advanced onto a plain and terminated in a feather edge of pahoehoe; again, to the northeast of the butte, the side of a lava flow when seen from below appears as a rugged wall of angular blocks, about 30 feet high. From a comparison of numerous examples which have come under my notice it appears that streams of acid lava usually terminate in steep frontal slopes, while basic lavas, if in the condition to produce pahoehoe, have thin margins, and if aa is present, form rugged bordering slopes.

MARGINS OF LAVA TERMINATING AT THE MOUNTAINS.

Where the great southward-flowing lava stream from the Cinder Buttes met the deeply indented border of the mountains, interesting topographic changes resulted. The lava, as previously stated, was highly fluid when extruded, and flowed with almost the freedom of water. On the plain it spread out and formed what may be termed a lake of liquid rock. The western shore of this lake for a distance of fully 30 miles in a straight line is formed by steep mountain slopes and presents the general features that would be seen along the shore of a lake occupying the Snake River Plains. The margin of the lava is approximately a contour line. The difference in elevation of the surface of the lava in a distance of 30 miles is about 1,000 feet. Probably considerably more than one-half of the descent occurs in the first 10 miles after leaving the Cinder Buttes. In the southern two-thirds of the flow no eye can observe that it is not a perfect plain. The liquid rock entered the mouths of the valleys in the mountains which open out into the Snake River Plains and extended up them various distances, dependent on their gradients. Where the ascent was gentle it flowed up them 5 or 6 miles before being checked by the rise of the land. The ridges between the mountain valleys became capes and headlands, and the peaks at their extremities were, in a few conspicuous instances, converted into islands. About 10 miles southwest of the Cinder Butte the lava was partially checked by a ridge of quartzite projecting well into the plain, but crossed it at a saddle and descended as a cascade about 200 feet high on its southern side. This lateral offshoot of lava formed a stream which, at the crest of the cliff down which it cascaded, was about 600 feet wide. During its maximum it was 30 to 35 feet higher than the surface now remaining, and left a ridge of angular fragments resembling a lateral moraine on each side of its course. Below the cascade the lava expanded and reunited with the portion of the main flow which went around the end of the cape and extended a mile or more up a lateral valley. An elevation near the end of the ridge across which the lava flowed was left as an island or a steptoe. Another saddle, now crossed by a wagon road, about 500 feet farther up the crest of the ridge than the lava cascade, was barely reached by the lava, which, however, did not flow down the southwest slope, but congealed after forming tongues of pahoehoe, which had started to descend. In a few other instances, between the Cinder Buttes and the southward-projecting mountain spur south of Carey, islands of quartzite rise through the fresh black lava.

The wagon road between Carey and Martin follows for nearly the entire distance—about 40 miles in a straight line—the immediate border of fresh lava fields, including all its sinuosities. This road, between the two places named, is fully twice as long as a straight line connecting them. It enters nearly all of the lateral valleys as far as the lava extended, and winds about the ends of nearly all the mountain spurs that project into the plain. The highway is held rigidly to this course—almost a contour line—by the precipitous mountain slopes on one side, and by a wall of rugged lava, frequently 15 to 20 feet high, on the other. In this narrow, trench-like depression some fine material, together with fallen blocks of stone, has served to grade the roadway. As the Cinder Buttes are approached, the material forming the roadbed shows a change in character, becoming finer and consisting mainly of lapilli and volcanic dust. Between the Cinder Buttes and the neighboring mountain the road passes over an extensive bed of coarse, scoriaceous lapilli or "cinders," which from its appearance has been reported to be "natural coke." The dust and lapilli were ejected from the Cinder Buttes during their explosive eruptions, and showered down on the adjacent mountains within a radius of about 10 miles, but are wanting on the more recent lava flows. The thick accumulation of dust in the roadway was washed down from the adjacent mountain sides.

Where a tongue of lava extended up a lateral valley it frequently presents a ridge of aa on its immediate border, and, in numerous instances, all along its margin there are ridges with open fissures in their crests, produced by lateral pressure on a thick and nearly rigid crust. In numerous instances, also, the lava, after entering the mouth of a lateral valley and perhaps extending 3 or 4 miles from the border of the main flow, and hardening at the surface, receded, there being an outward underflow. In such instances broad, shallow basins, with rough surfaces, were formed, margined on their border adjacent to the older rocks (mostly quartzite) by ridges 10 to 15 feet high. These ridges are usually arches, or inclined blocks, produced by lateral thrust, but in addition there has been a withdrawal of the lava from beneath the floor of the basins. The explanation of this phenomenon seems to be that the lava after entering a lateral valley, and cooling so as to form a crust usually 3 to 5 or more feet thick, receded, being allowed to flow out, because the main lava flow across the mouth of the valley had been lowered by its onward progress.

In some instances lava streams originating in the mountains, as described on a preceding page, and flowing down lateral valleys before reaching the Snake River Plains, expanded in the broader portions of their courses, and were later, in part, drawn off by an underflow, leaving their hardened crusts stranded. An example of this nature occurs in the valley of Lava Creek, about 1 mile above Martin. The lava stream which came down the valley of Lava Creek, as already described, formed cascades in the upper part of its course, but farther down expanded and became about 1 mile wide. About the western margin of this broader portion of the lava stream there is now a ridge consisting of pressure domes and tilted lava blocks, bordering a broad, flat-bottomed depression. In this instance also there was a withdrawal of the still-molten rock from beneath the rigid crust, the edge of the crust being left stranded. The phenomenon here referred to is similar to that which produces lava caves by the outflowing of liquid lava from beneath a rigid crust, but the area of hardened lava left unsupported from beneath was so great that it could not sustain its own weight, and it collapsed and became broken.

The basins just described might become occupied by water and thus be transformed into lakes, but I am not aware of an instance in which this has happened. Apparently the bottoms of the basins are too much fissured to retain water, unless a considerable amount of silt were deposited on them.

The encroachment of recent lava flows on the bases of the mountains has exerted an important influence on the surface drainage. The lava entering the mouths of valleys sometimes formed dams, which held their waters in check and caused lakes to form. An instance of this nature is furnished by Lava Lake, situated at the entrance of Fish

Creek Valley. The eastern wall of this water body, which is about 200 or 300 acres in area, is formed by a wall of aa and pressure ridges; its western shore is composed of alluvium washed from the mountains.

When the lava that entered a lateral valley terminates in a thin edge the alluvium from the mountains usually extends out upon it, concealing its actual margin, and no lake results.

The reason why more lakes are not present about the border of the lava is twofold: First, on account of the small rainfall the streams are usually weak and disappear in summer, and are unable to form perennial lakes even under favorable conditions; and, second, the lava is fissured and nonretentive.

As will appear later, the changes produced in the topography where the recent lava flows from the Cinder Buttes meet the mountains seem to explain many similar changes, frequently on a far grander scale, produced by the lava flows which came from much older craters.

RELATIVE AGE OF THE LATER LAVA FLOWS.

As has been stated, at least six large streams of lava flowed from the Cinder Buttes at a recent date. Among these certain differences in age are readily distinguished. In reference to three of the main flow, namely, the two most westerly on the north side and the great stream which was supplied from two sources on the south side of the buttes, no tangible differences in age have been recognized. Each of these three great flows is as fresh as if it had congealed and come to rest but yesterday. The lava appears black to one walking over it, but at a little distance, and in certain stages of illumination, has a light-gray appearance as if uniformly and lightly covered with dust. That this appearance is due to dust, however, seems improbable, as it does not reveal itself on close inspection. This surface "bloom," whatever its cause, is certainly an indication of youth, as it is absent on lava flows known from other reasons to be older. These recent flows are totally bare of soil, lapilli, volcanic dust, etc., and only to a slight extent have lichens taken root upon them. No positive evidence was obtained to show that the dead trees which occur along their borders in certain instances were killed by their heat. The remnants of the craters from which the lava was poured out are tree clothed, and on the supposition that the lava outflows immediately followed the explosive eruptions which built the craters, the lava is older than the trees, many of which are fully 20 inches or 2 feet in diameter. Although it is impossible to make a well-founded estimate of the time that has elapsed since the last eruption, it seems probable that it is no more than one hundred or possibly one hundred and fifty years.

Next older than the three lava streams just referred to, so far as one can judge, is a stream which skirts the base of the highest of the buttes on its western side and expands on the plain to the southward. This was a strong flow, although smaller than the ones just referred to as being of decidedly recent date, and presents remarkable examples of large swells and stream-like pahoehoe ridges crossing one another. The lava, although bare and still fresh in general appearance, has evidently lost the bloom of youth, and its surface shows some indications of weathering. The most interesting feature in this connection is the presence on the surface of the smooth pahoehoe swells of a thin, deep-blue incrustation or film of the nature of "desert varnish."[a] The thin films designated by this term occur on rocks which are exposed to an arid climate, and seem to be due to the solution by absorbed water of some of the material forming them, and to its transfer, through the action of capillarity as surface drying takes place, to the surface, where it is precipitated. The examples of desert varnish described by Gilbert and Diller are of various shades of brown deepening to black, and are due to a film of iron and manganous oxides. In the present instance the surface film is a strong, deep blue, closely similar to earthenware colored with cobalt. The color is a decided cobalt blue, but, as chemical tests show, is not due to that metal. Attempts to separate enough of the film to serve for analysis have failed, and it may be a physical rather than a chemical phenomenon. That the color is of the nature of a desert varnish and not due to oxidation as the lava cooled, in a way similar to the changes occurring on the surface of steel and other metals when highly heated and allowed to cool, is seemingly shown by its presence on exposed surfaces and the upper portions of the sides of fissures and its absence on the walls of cavities unless they were broken at about the time the lava hardened. The color is deepest near the borders of crevices and becomes lighter on the surfaces between the cracks. In many instances long, sinuous, stream-like ridges emerge indefinitely on the surface of the lava stream, become prominent for a distance of perhaps 10 to 30 feet and then disappear beneath other ridges or swells formed by similar local outbreaks of viscous lava. These ridges are covered with a network of small shrinkage cracks, the borders of which are deep blue and the central parts of the interspaces light blue or gray. The appearance of these tessellated serpent-like forms is frequently striking. Their comparison to scaled reptiles, although fanciful, is suggestive of their appearance. In my notes I have termed the lava stream bearing these unique forms the Blue Dragon lava flow.

The opposite neighbor of the Blue Dragon lava flow, or the third recent lava stream on the north side of the Cinder Buttes, counting from the west, is not as extensive as the other streams which went northward, although it presents a typical pahoehoe surface fully half a mile in length. This stream, although still young, bears evidence of

[a] A term proposed by G. K. Gilbert, and more fully explained by J. S. Diller in The Educational Series of rock specimens, Bull. U. S. Geol. Survey No. 150, Washington, 1898, pp. 389-391.

having been longer exposed to the atmosphere than any of those mentioned above. The smooth swells and ridges are still bare and preserve all their corrugations, pressure ridges, etc., intact, but their surfaces have lost their freshness, and a little soil has been concentrated in the hollows and crevices. A striking feature of this generally bare lava surface is the presence upon it of pine trees, which seem to spring from the naked rock. The trees, some of which are 20 feet high, are gnarled and deformed, showing plainly in their contorted forms that their struggle for existence is severe. In many instances the cracks in which the trees have taken root are so small that they escape notice unless searched for. The trees are immediately surrounded on all sides by bare corrugated lava. In some examples a tree rises from the intersection of two cracks, where the opening is a little larger than elsewhere and a little more soil has been caught, showing how persistently the vegetation has sought for a foothold. The pines are scattered at intervals over an area of several square miles, being grouped in small groves in the hollows. They extend to the bordering banks of lapilli where, finding less adverse conditions, they are of larger size.

The soil gathered in the crevices and depressions of the lava is evidently not derived from the disintegration of the lava itself, which, as stated, still retains even the smaller details of its original surface, and is hard and black. A surface covering of lapilli and volcanic dust is absent, although the bordering hills are composed of such material, and it is evident that no explosive eruptions have caused showers of rock fragments to fall on the lava stream. This is a suggestive fact, as the volcanoes a mile or two to the west sent out their great lava streams after the one here considered was formed. The tuff cones from which they came, and the widely extended surface sheet of lapilli and dust on the adjacent mountains, so far as can be judged, must also be of much later date. The reason why the tree-covered lava stream escaped receiving a shower of lapilli and dust seems to be that the wind carried the material, which was blown out by what must be considered more recent volcanoes, in other directions.

The soil in the crevices and hollows, in which the pines referred to have taken root, is apparently composed of ordinary atmospheric dust brought by the wind, a process which is still operative.

RELATION OF THE CINDER BUTTES TO OLDER VOLCANIC ERUPTIONS.

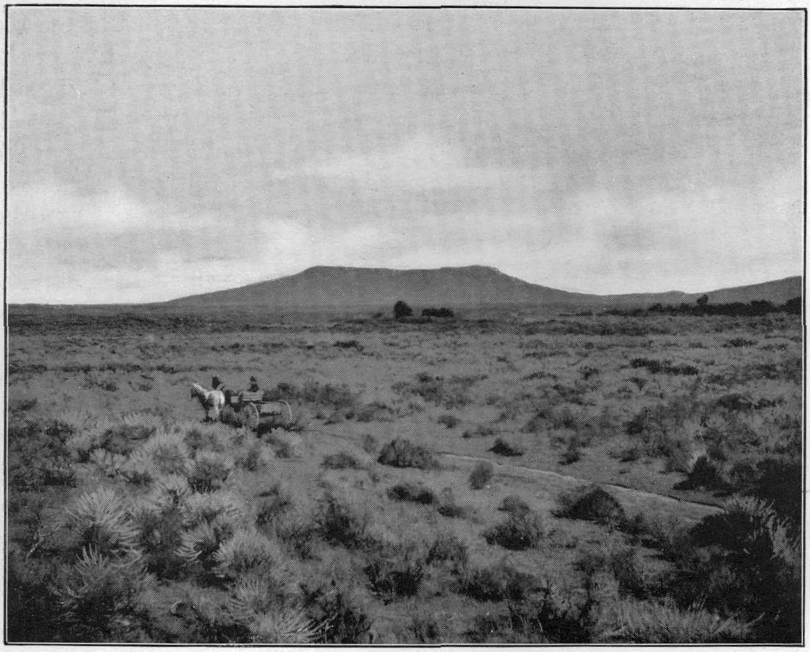
To the east of the tree-covered lava streams described above, still other local lava flows are present. Some of these can be readily traced to the craters from which they came, but they are now almost completely soil covered and clothed with shrubs and grass, and in part with trees. About these and extending far beyond the reach of vision, even to an observer standing on the highest of the Cinder Buttes, are the vast plains underlain by still older lava sheets, but now completely soil covered over hundreds of square miles. The occasional dome and pressure ridges on these older lava flows are black, the edges of the fissures in them yet sharp, and the corrugations on their surfaces still clearly distinguishable. It is evident, therefore, that the soil concealing all but their more prominent rugosities is not derived from the disintegration and decay of the underlying lava. The nature, mode of origin, etc., of this widely extended surface sheet will be discussed later.

The phenomena connected with Cinder Buttes—which are comparatively small volcanic cones, or fragments of cones, built of scoriæ, lapilli, bombs, etc., by explosive eruptions, and which later sent out truly immense volumes of highly liquid lava, which spread widely over the adjacent plain, and added another sheet of basalt to those previously formed, etc.—are all of recent date, and assist in interpreting the records of the still greater and much older eruptions, which formed by far the larger part of the Snake River Plains. Additional assistance in this same connection is furnished by other but less remarkable volcanoes, also of recent date, which rise above the surface of the same vast lava plains.

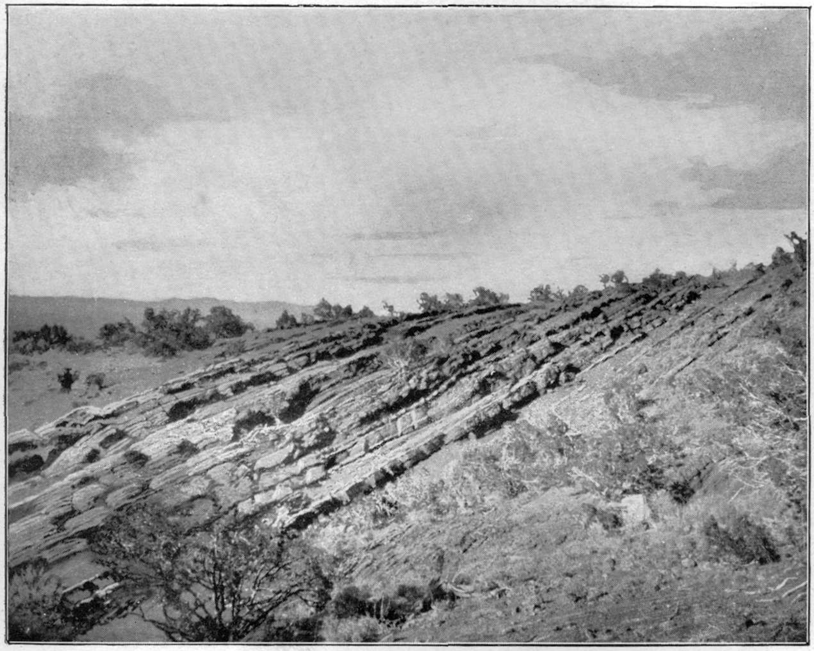
Market Lake craters.—About 6 miles northeast of the town known as Market Lake there are two conspicuous buttes, which rise from 500 to 600 feet above the surrounding plain. The smaller of the two, situated to the north of its companion, shown in Pl. XVI, *A*, has an oval base measuring, approximately, 1 by 2 miles, in its principal diameters, and at the top is about 3,000 feet across from north to south and 2,000 feet in a transverse direction. It has a well-defined crater in its summit, still about 150 feet deep, although containing much material blown or washed from the encircling wall. A secondary crater is stated by Bradley[a] to occur on the northwest portion of the main crater, which has a diameter of 200 or 300 feet. The cone is grass covered and bears a scattered growth of small juniper trees. It is composed almost entirely of yellowish lapilli, now loosely consolidated into tuff, which is well stratified, as is shown in Pl. XVI, *B*, and has both the inward and outward dips so common in tuff cones. The beds forming the outer slopes are well exposed on account of wind erosion and dip away in all directions from the crater's rim, at angles in general of about 20°, but flatten near the base, where they appear to become nearly horizontal. On the inner side of the craters the beds of lapilli are inclined downward toward its center at angles of from 25° to 30°.[b] Contained in the tuff are a few angular masses of scori-

[a] F. H. Bradley: Sixth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, p. 210.

[b] Bradley suggests that the material composing these volcanic cones was deposited in water, and that a lake formerly existed on the Snake River Plains. My own observations failed to confirm either of these suggestions. The stratification of the tuff forming the craters is of the same character as that which is known to occur in many other cinder and tuff cones not formed in water, and calls for no special explanation. No evidence of the presence of a lake on the surrounding plains since the craters were built has been obtained.



A. MARKET LAKE CRATER, IDAHO.



B. STRATIFIED LAPILLI, MARKET LAKE CRATER, IDAHO.

aceous basalt and occasionally waterworn pebbles of quartz and of dense igneous rock resembling diorite. In certain layers of the tuff and intimately mingled with small angular fragments of scoriaceous, glassy basalt, there are large quantities of angular quartz grains and other fragments, which appear to be feldspar. In some layers the sand grains far outnumber the lapilli fragments, and if the material did not occur in the walls of a crater it would certainly be taken for a bed of sandstone containing a limited amount of lapilli. The non-volcanic included material indicates that the conduit of the volcano was opened through coarse gravel, such as Snake River is now spreading out near at hand, and finer sediments, probably lake beds, consisting largely of sand.

The moderately compact tuff is sufficiently soft at a depth of a few feet below the surface to be cut with an ax and has been quarried at an adjacent locality on the bank of Snake River for building purposes. There are several houses in Menan built of rough-dressed blocks of this stone.

The plain about the base of the butte is smooth for a distance of 1,000 to 2,000 feet, on account of the lapilli blown and washed down from its sides; outward from this belt, except on the south, where alluvial deposits laid down by Snake River have modified the surface, is a rough plain of basalt with only a thin covering of wind-deposited material in the depressions.

The crater of the larger of the two cones, as stated by Bradley, is of somewhat greater size than that of the one just described, but is not so deep. The two volcanic cones are united at their bases and are undoubtedly of about the same age and moderately recent. Although comparatively young lava flows form the neighboring plain, it is not apparent that either of the volcanoes gave origin to a lava stream.

Kuna Butte.—Rising from the Snake River Plains about 17 miles northwest of Mountain Home, and 7 miles west of Cleft, as indicated on fig. 1, is an isolated cinder cone, 230 feet high, known as Kuna Butte, shown on Pl. XVII. This conical elevation, rising from a nearly level and seemingly limitless plain, is a conspicuous object and a prominent and well-known landmark throughout a region several hundred square miles in area.

The butte is composed mainly of scoriæ and lapilli, but, so far as can be distinguished beneath the soil and drifting sand about its base, did not give origin to a lava flow. Lava was blown out in a highly plastic condition, however, as is shown by irregular, flattened cakes of highly scoriaceous basalt at the summit, which are 3 or 4 feet across and several inches thick. At the top of the cone there is a remnant of a once comparatively large crater, the walls of which have now fallen in, and its crest has become rounded and notched by erosion. There is a suggestion of compact lava in a gully on the northeast slope, and possibly a summit overflow of liquid lava did occur, but the subsequent downwashing of lapilli has concealed the evidence in this connection which may formerly have been present.

From the summit of Kuna Butte four other similar but smaller conical elevations may be seen on the plain to the southwest, at distances of 4 to perhaps 10 miles. These appear to be cinder cones marking the sites of once active volcanoes.

Crater rings near Cleft.—Three miles south of Cleft, and, as indicated on the map forming fig. 1, at the top of a broad, low elevation

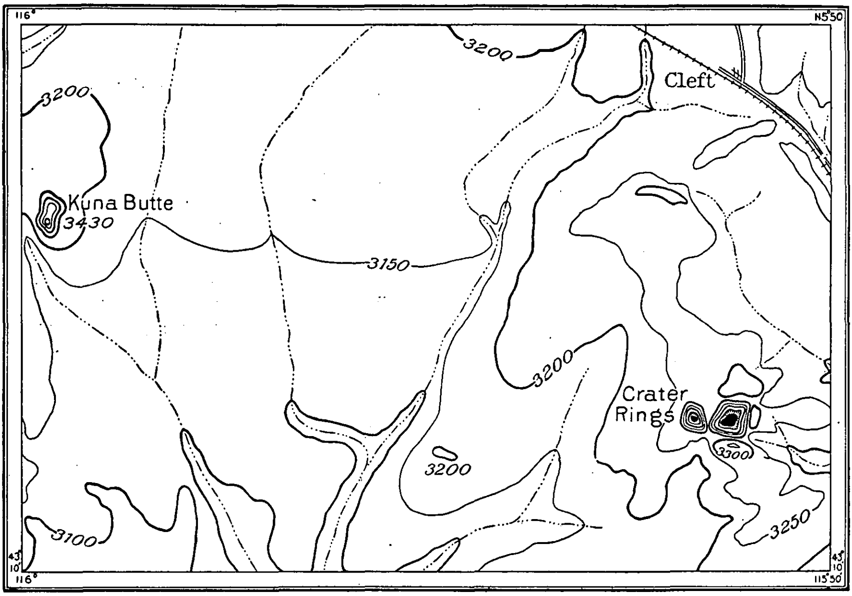


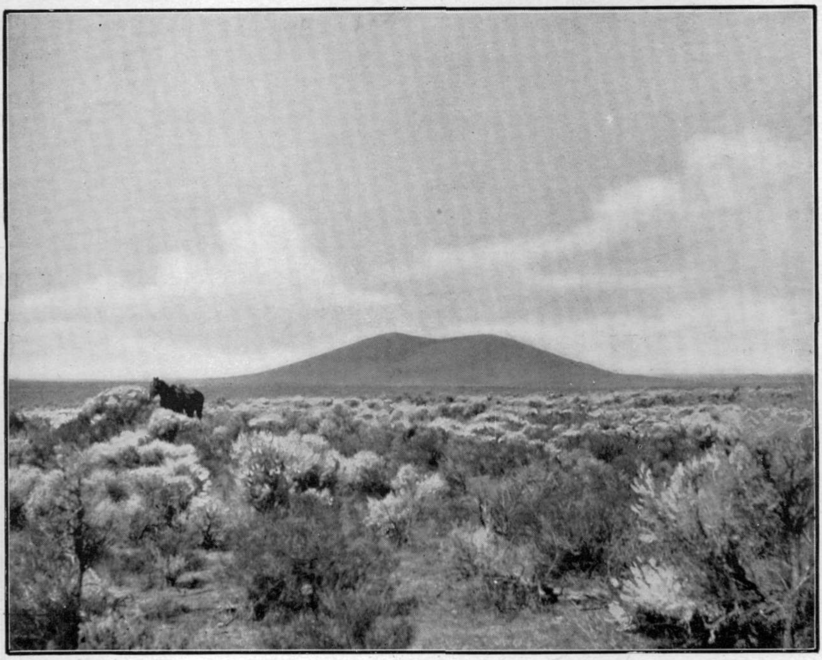
FIG. 1.—Map of crater rings near Cleft. Scale, 1 inch = 2 miles; contour interval, 50 feet. Dotted lines indicate stream channels; figures give elevation above the sea.

on the featureless plain, there are two circular depressions with vertical inclosing walls, but without elevated rims. These pits are evidently to be classed as crater rings,[a] which are generally considered by geologists to owe their origin to volcanic explosions.

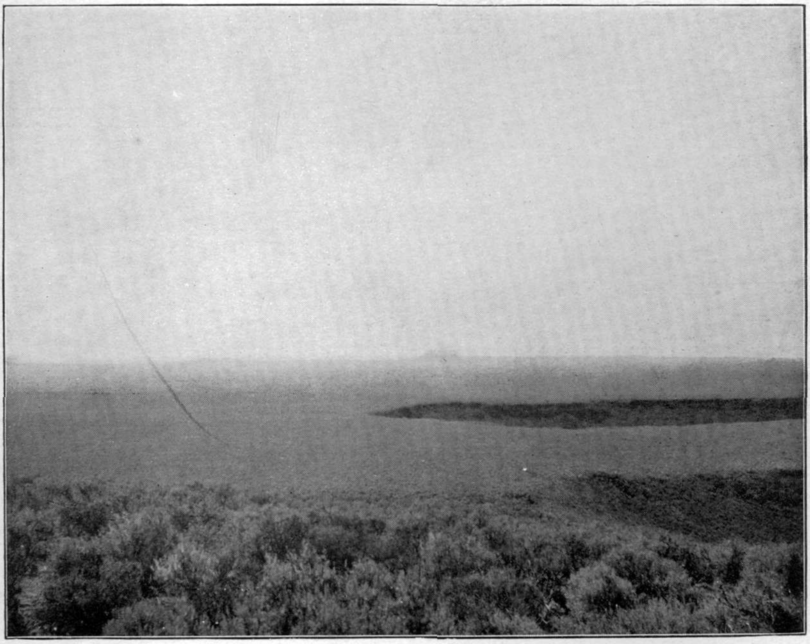
Each of these rings has a level floor composed of fine yellowish soil, like that covering the adjacent plains, and no crags or solid rock of any kind occur within them.

The smaller of the two pits, situated to the west of its companion, has a diameter, measured across its level floor, of about 800 feet. The inclosing cliffs, with conspicuous talus slopes, are 200 feet high, and present the appearance of the wall of a canyon cut in horizontally bedded sheets of massive and, in part, columnar basalt. The summit of the wall of the depression is surrounded, to use an expressive term current in the Far West, by a "rim rock" of black lava. Some of

[a] J. W. Judd, Volcanoes. New York, 1881, pp. 170–176.



A. KUNA BUTTE NEAR CLEFT, IDAHO.



B. CRATER RINGS NEAR CLEFT, IDAHO.

Kuna Butte in the distance.

these features may be distinguished in the photograph reproduced in Pl. XVII, *B*.

The larger of the pits is less markedly circular than its neighbor and about 1,100 feet in diameter at the bottom. Its walls are approximately of the same height as those of the smaller pit, but less continuous. There are two breaks in the rim rock, one on the northeast and the other on the southwest, down which a horseman can easily ride to the plain at the bottom. About the outer border of the larger pit, and in general a few rods away from its brink, there are irregular piles of lapilli with indefinite shapes, the higher ones forming broad hills that rise perhaps 50 feet above the adjacent plain.

The fact that these circular pits are depressions in a broad plain, composed of horizontally bedded and relatively thick sheets of basalt, indicates that they were formed after the basalt had cooled and hardened. The presence near them of considerable but not conspicuous deposits of lapilli—although there are no cinder cones or other evidence of explosive volcanic eruption nearer than Kuna Butte, 7 miles distant—indicates that the fragmental material was blown out of the pit near which it occurs. The amount of this material in sight, however, is far too small to refill the adjacent depression if transferred to it; and is absent or concealed by more recently deposited soil from about the smaller depressions. The tentative explanation that these facts indicate is that two small volcanoes formerly existed where the crater rings now occur, and probably built cinder cones similar to Kuna Butte, and that later explosions occurred, which blew away the piles of fragments and enlarged the conduits above which they have been deposited. This suggested explanation, adopted from the studies of others in reference to similar crater rings elsewhere, is not entirely satisfactory, however, as in case such explosions as suggested did occur, we should expect to find blocks of lava torn from the walls of the conduits in the process of enlarging them, scattered over the surrounding surface. More than this, the two circular pits are less than 1,000 feet apart, and unless the explosions which produced them occurred simultaneously, one would be expected to be more or less completely filled by the débris from its neighbor. That an explosive eruption occurred in the case of the larger pit, however, is evident from the lapilli piles referred to. The only alternative hypothesis suggested by these depressions, and by others elsewhere, some of them several miles in diameter, is that the walls of the volcanoes broke away and fell in on account of the withdrawal of the supporting lava formerly filling their conduits, after the manner in which the great crater-like depressions in the summits of certain Hawaiian volcanoes are known to have been enlarged.

Although it is necessary at present to leave these crater rings without a definite explanation, it is hoped that the facts recorded may supplement observations in other similar instances, and thus assist in a small way in reaching a proper understanding of the series of similar depressions in volcanic regions in various countries.

OLDER CRATERS AND LAVA FLOWS.

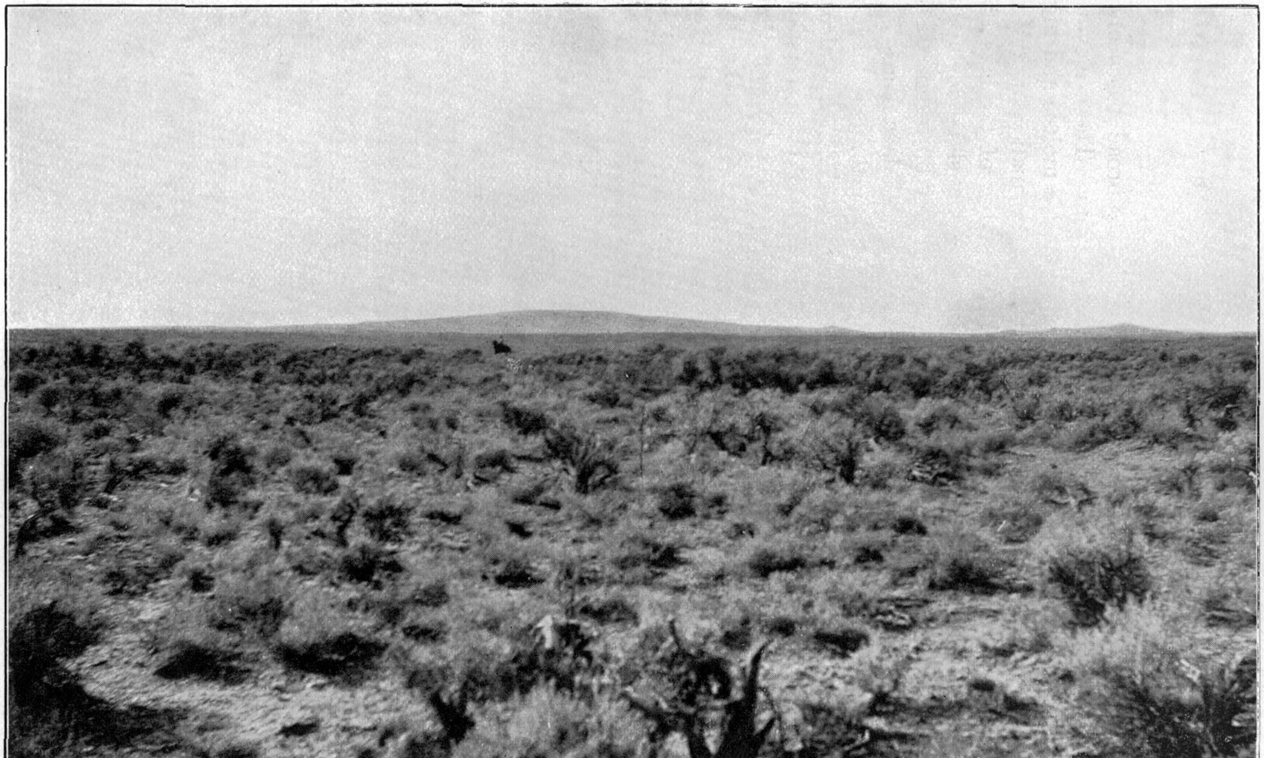
LAVA CONES.

The occurrence of low cones with immensely broad bases on the Snake River Plains has already been referred to. These elevations are composed almost entirely of lava extruded in a molten and highly fluid condition, seemingly from a comparatively small vent, and owe their height mainly to the cooling and thickening of the lava about the place of emergence, so as to form the necessary slope down which it could continue to flow. As these mounds or low buttes are distinct from cinder cones, I venture to suggest the name "lava cones." An example of recent date is furnished by Black Butte, described on a previous page. Their characteristic shapes (Pl. XVIII) have already, perhaps, been sufficiently well described not to require repetition. They occur usually at wide intervals over the Snake River Plains, especially to the east of Shoshone and to the south of Big Butte. Owing to their distance apart and the absence of water in the region where they occur, only three were visited by me. The most characteristic of these is Notched Butte, 4 miles south of Shoshone. This is a conical elevation with gently sloping sides, 250 feet high, with a nearly flat top, but broken so as to present notches when seen from a distance. The sides are formed of lava sheets in which there are caves due to the flowing out of still molten rock from beneath a thick, rigid crust, as already explained. The summit is formed of highly scoriaceous lava. There is evidence of considerable explosive violence at the top in the form of scoria in clot-like masses, mingled with thin sheets of vesicular lava. Evidently a shallow crater once existed at the summit. A connection between cinder and lava cones is thus shown, and the two are but extremes of a single process. When explosions predominated cinder cones were built, either with or without lava flows; and when the lava predominated a lava cone resulted.

Lava cones are evidently more enduring structures than cinder cones, and for this reason perhaps seem to have been the type of volcanoes that furnished most of the old lava sheets now occurring beneath the Snake River Plains.

LAVA SHEETS.

The fact that the Snake River Plains are underlain by lava sheets throughout perhaps eight-tenths of their area is indicated on the map forming Pl. I. The number of sheets can not be even approximately determined, but at several localities in Snake River Canyon four have



LAVA CONE, SNAKE RIVER PLAINS NEAR ARCO, IDAHO.

been seen in single vertical sections, with lake beds or other deposits between. The total, however, considering the whole area, is no doubt many times this number. The various sheets are not of the same extent, but overlap. The thicker portion of the pile is seemingly in the broadest part of the basin to the south of Big Butte, but this can not be proved, as no canyons exist there, and no drill holes have as yet been put down. From the mouth of Salmon River westward, the manner in which various sheets terminate unequally is well shown. That is, the lower sheets which extend farther south than the southern margin of the surface sheet are exposed in the canyon walls.

The sheets cut through by Snake River are, in general, comparatively thin, the range in thickness being from 20 to 40 feet; but in the deeper portion of the canyon, for about 10 miles below Shoshone Falls, about 500 to 700 feet of basalt are exposed, in which the thickness of the individual sheets seem to be greater, in general, than the measures just stated, but the various layers are united in such a way as to render it difficult to determine their precise number.

The basalt shows considerable variation in its physical condition, being at places vesicular and again compact. Usually, the layers are obscurely jointed and columnar, the columns being vertical, but at times the columnar structure is pronounced, as is shown on Pls. VIII, *B*, and IX, *A*. No doubt some variation in mineralogical and chemical composition occurs, but enough study has not been given to this phase of the subject to permit of drawing general conclusions.

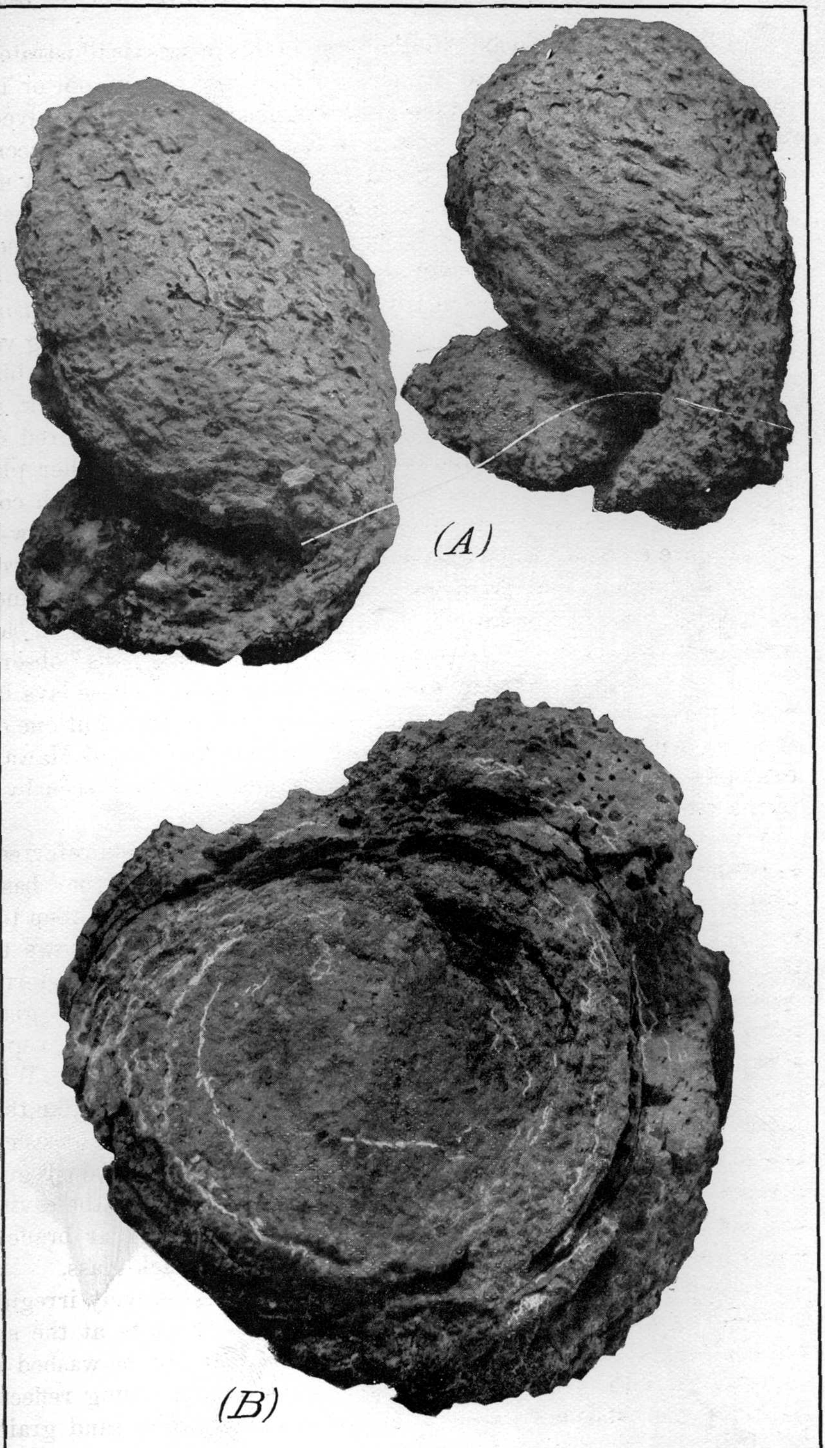
LAVA STREAMS THAT FLOWED INTO WATER.

In the north wall of Snake River Canyon, from Bliss upstream to above the mouth of the Salmon River, there are abundant exposures of the eroded border of a lava sheet and at certain localities near Hagerman, of two lava sheets, which present conspicuous contrasts between the basal and central or upper portions. In these instances, while the upper and central parts of a lava sheet are granular, compact, or perhaps moderately vesicular, its lower portion is open in texture and composed of irregular fragments, some of which are extremely rough on the surface and within are open and cellular, resembling somewhat a mass of irregular twigs of glassy lava compressed into a moderately compact mass. This peculiar structure, incapable of being accurately described, and presenting many variations, is imperfectly shown on Pl. XIV, *A*. In many instances this material forms rounded masses resembling a pillow folded on itself, as is shown on Pl. XIX, *A*. The lower surface of such a "pillow" is sometimes nearly flat, but more frequently it is concave and when found in place is seen to have taken the form of the upper surface of a similar mass on which it rests. These folded masses clearly indicate a rolling up of the still plastic lava. Another step in this process is illustrated by spindle-shaped bodies 6 to 8 inches in diameter and a foot or more long, which in some examples have a scoriaceous core, involved in several layers of stony or glassy lava (Pl. XIX, *B*). The concentric white lines in this example are due to involved grains of sand. A more pronounced occurrence of the same nature is shown by oval or nearly spherical bowlder-like masses from a few inches to 2 or more feet in diameter, which are excessively hard and compact. The inner portions of these spherical masses are composed of stony basalt, usually containing kernels of olivine, which are covered with a coating varying from half an inch to an inch or two in thickness, of black, glassy lava. The outer crust in some places has a smooth, black, glittering surface, like bottle glass which while fused was poured over an irregular surface and allowed to cool quickly. In other places the surface coating of glass is rough and of a dull-brownish color. These balls, together with the less completely rolled-up pillow-like masses, are embedded in a coarse breccia consisting mainly of irregular glassy kernels, but frequently containing also angular fragments of compact granular basalt (Pl. XX). The spherical masses of basalt just described appear to be analogous to certain "lava balls" observed by Dana[a] in lava streams of the Hawaiian Islands. These lava balls are stated to be commonly from 3 to 5 feet in diameter, but one contains at least a thousand tons of rock. Even the normal Hawaiian examples, however, are larger than the largest specimen seen by me in the walls of Snake River Canyon.

While the upper and central portions of the lava sheets referred to are composed of compact, granular, and frequently columnar basalt, usually more or less vesicular, their basal portions have an open texture, and consist mainly of glassy material. This contrast shows that the upper portion cooled slowly so as to form what may be termed normal basalt, while the basal portion cooled quickly. The glassy portion is not scoriaceous and has the appearance of obsidian, especially when examined under a microscope with reflected light. While this glass is characteristically cellular, the openings are not like those produced in scoriaceous lava by the expansion of steam or gases contained in the magma while still hot and plastic, but they are irregular cavities due to a force acting from without. The walls of the cavities and the rough, glassy offshoots and the extremely irregular branches about them are not vesicular, but are composed of black glass.

Another instructive fact is that the cellular, excessively irregular masses of glass, although black within, are nearly white at the surface. This is due to a thin incrustation which can not be washed off or removed with strong acids. Under a microscope, using reflected light, the incrustation is seen to be composed of white sand grains,

[a] J. D. Dana, Characteristics of Volcanoes, New York, 1890, pp. 10–11, 241.



A. PILLOW-LIKE FOLDS IN LAVA STREAM THAT ENTERED WATER.
B. SECTION OF SPINDLE-LIKE ROLL OF LAVA FROM A LAVA STREAM THAT ENTERED WATER.

partially embedded in the black glass. In many instances, also, the interiors of cavities are lined with similar material, and at times masses of sand or clay are completely inclosed in the cellular, glassy lava.

All of the facts enumerated unite in indicating that the lava while yet molten entered water and was quickly cooled, hardening to a glass, and that the steam generated blew the still plastic material into shreds and excessively irregular branching forms. As the upper surfaces of the lava sheets are not glassy and do not show the other characteristics referred to, it appears that the waters which the still hot lava entered were shallow. The still plastic material in numerous instances was rolled or folded into spindle-shaped and pillow-like forms, and even into spherical and oval balls, the surfaces of which in contact with water cooled quickly to a glass and the part within developed large crystals of olivine and other minerals. All stages in this rolling-up process, from folded masses to complete spheres, are illustrated. The still plastic lava, coming in contact with the sand at the lake bottom, adhered to it, thus giving the black glass a white surface, and in many instances masses of sand and clay became involved in the basal portion of the flow. The characteristics here accounted for pertain to the lava which was fluid or plastic on entering water and was distended and variously modified by the steam generated, but not shattered. In other instances the rock was broken into angular fragments and a breccia produced. When this occurred it appears that the lava, although still hot, had lost its plasticity on entering the water and was fractured instead of being blown into shreds and similar branching forms.

When a lava stream enters water it is evident that a connected series of products should be expected, ranging from compact or what may be termed normal lava to lava that has been shredded, as it were, by steam explosions acting on it from the exterior, and from normal lava again to coarse and fine breccia, the controlling condition being the degree of plasticity or rigidity of the magma. Between basic and acid lava it is to be expected that the former would be the more apt to furnish cellular, torn, and ragged masses or be rolled into balls; while the latter, owing to its less fusibility and greater brittleness when solid, would be the more apt to become shattered.

The coarser breccia observed in connection with the steam-blown basalt in the walls of Snake River Canyon is composed of angular fragments of normal granular basalt, but the smaller fragments are glassy. The finer breccia resembles closely the tuff formed of lapilli blown out by steam explosions from volcanoes, but there seems to be a difference between the two, although I am not sure it can be readily recognized. Lapilli are characteristically and perhaps always scoriaceous, while the fragments produced by the contact of hot lava with water may not be scoriaceous, and in the case of lava streams that have progressed far are normally compact. Either lapilli or the fragments produced by contact of hot lava with water may be glassy, but such fragments, at least in the tuff cones of Idaho that have been examined, are rare, while in the breccias produced by hot lava entering water they are common.

In association with the lava sheets cut through by Snake River there are immense beds of fragmental material sometimes 100 to 160 or more feet thick, and traceable for several miles, which resemble closely the tuff about the Market Lake and other craters. In fact, they seem to have the characteristics of compacted lapilli or tuff, but again simulate the fragments produced by contact of hot lava with water. In which of these two ways the material referred to was principally produced I am not sure, but incline to the opinion that in the main it resulted from volcanic explosions and is a true tuff.

When a breccia is produced, including at times cellular lava and the "lava balls" referred to, the interspaces are completely filled with what was once sand or mud, and the mass is, as a whole, compact and essentially impervious to water; but when the cellular and steam-torn rock occurs, it is open in texture and in a condition to permit of the flow of water through it. These differences are significant in connection with the occurrence of springs and in reference to the possibility of obtaining artesian water. The truly wonderful springs at what is termed The Thousand Springs (Pl. III), for example, pour out of a cellular lava of the nature described above. Near Hagerman, at two localities, tunnels or horizontal wells have been excavated in the basal portion of the lava flow and a strong outflow of water has been obtained.

The facts presented above seem to indicate that whenever a lava stream flows into water there will be steam explosions and a great disturbance of the bottom over which the lava flows. Remarkable examples of results of this nature may be seen in the northern wall of Snake River Canyon, about a mile upstream from the mouth of Salmon River, and near the Riverside ranch, where the involved and steam-torn lava and the associated breccia contain fragments of clearly recognizable stratified clay and masses of sand of all sizes up to 5 or 6 feet in diameter. Other exposures of the bases of lava streams, however, seem to show that lava may flow over a lake bottom without disturbing it or producing scarcely any discernible change in it.

An instance of the nature just referred to occurs in the east wall of the canyon of Canyon Creek, about a mile above its junction with Snake River. At this locality the rim rock of the canyon is formed by a lava sheet between 30 and 40 feet thick, which rests on fine, white, thinly laminated lake beds, of which about 12 feet in thickness are exposed. The lava, owing to wind erosion, projects about 10 feet beyond the soft beds beneath, and its bottom is well exposed. The base of the lava is a flat, but moderately rough, surface, composed of cellular,

SECTION OF A LAVA STREAM THAT ENTERED WATER, BLISS, IDAHO.

glassy basalt, while the upper part is granular and irregularly columnar. Involved in the glassy material forming the base of the sheet of basalt are a few small masses of soft, white, sandy clay, like the bed beneath. This indicates that the basalt flowed into a lake, and at its base was quickly cooled to a glass, which was expanded and made cellular by the steam generated. The striking feature of the exposure is that the soft white lake beds on which the lava rests are not hardened and are undisturbed, the lamina being still horizontal, even to the contact with the lava. Some of these features may be recognized in the photograph reproduced on Pl. XXI. The only change is a slight yellow stain, perceptible to a depth of 5 or 6 inches from the surface of the contact downward. This discoloration may have been produced subsequent to the coming of the lava and due to weathering.

The characteristics just described occur not at one small exposure only, but at several throughout a distance of about 600 or 800 feet. How a sheet of lava 30 to 40 feet thick could advance over a bed of soft unconsolidated sandy clay, which was evidently covered with water, without disturbing it in the least degree, is difficult to explain. Possibly the lava sheet may have advanced by sending out small thin streams of liquid rock of too little weight to disturb the beds on which they rested, which were later overridden by the main flow, but that such was the case is not apparent in the internal structure of the lava itself.

IRREGULARITIES IN THE THICKNESSES OF LAVA SHEETS.

An interesting fact in connection with the lava sheets exposed in section in the walls of Snake River Canyon below Shoshone Falls is that in several instances they exhibit conspicuous variations in thickness while their surfaces remain essentially horizontal. The obvious explanation of this is that the surfaces over which the lava flowed were irregular.

Examples of the phenomena referred to occur in the north wall of Snake River Canyon in the southeast portion of Ada County, where, as already stated, the rim rock forming the brink of the canyon, and usually having a thickness of 30 to 40 feet, thins to a few feet, and for a space a mile or more long is wanting. The beds of lapilli which occur normally below the sheet of basalt rise and protrude through it so as to form low mounds which rise higher than the adjacent surface of the lava. In this instance the lava flowed against a hill of lapilli, probably completely surrounding it, and became thin and finally failed to cover the lower terrane on account of an elevation on the general surface over which it advanced.

Again, in the neighborhood of the mouth of Rattlesnake Creek there is a sheet of lava 40 feet thick which for a distance of 2 or more miles forms a conspicuous terrace on the north side of the canyon.

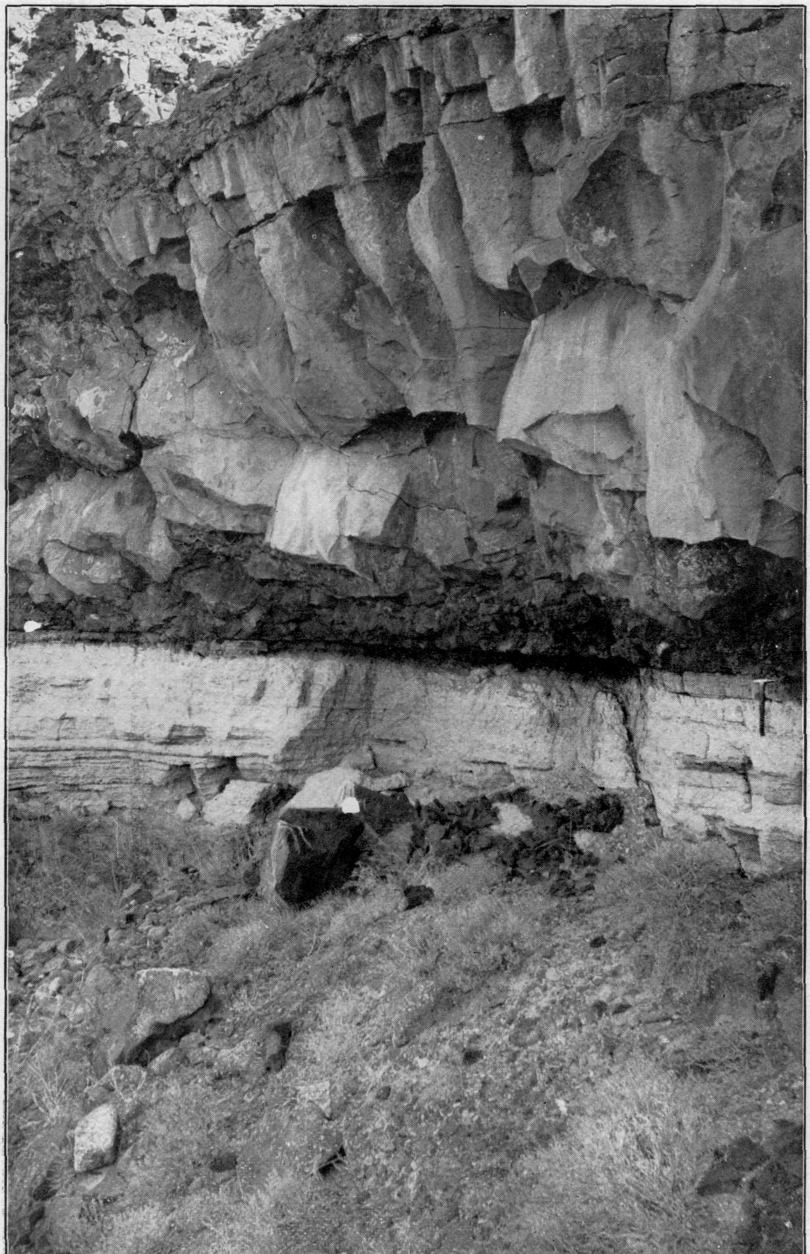
Farther downstream, just below the mouth of Rattlesnake Creek, this sheet of lava thickens abruptly to at least 175 feet—the river having not as yet cut through its entire depth—and south of the river it thins abruptly to a feather edge and disappears. This lava sheet must have advanced over a generally plane surface in which there was a depression at least 135 feet deep. The depression was filled by the lava which flowed beyond it, and an essentially level surface was produced. The lava where it is thin has a glassy structure and bears other evidence of having flowed into water, but where it is thick such characteristics are wanting in the part exposed. From the facts observed, it is surmised that the lava entered a lake, in the bottom of which there was a marked depression which became filled with lava, or else flowed over an eroded land surface the hollows in which were occupied by water. Where the lava sheet was thin the changes produced on coming in contact with water affected it throughout its entire depth, but where it was thick the upper portion cooled slowly and assumed the appearance of lava which has cooled on land.

The study of the lava sheets that advanced over surfaces having hollows or depressions in them has not been carried far enough to show whether they entered lakes in all instances or not. Sometimes the lava rests on waterworn gravel, and this and other facts suggest that it advanced over a previously stream-eroded land surface and entered the valleys where it became thicker in case the depressions were filled, and also came in contact with the waters of streams. The results of these two sets of conditions would be much the same, so far as the appearances to be observed in the walls of canyons subsequently excavated through the lava and associated beds are concerned. In the case of a lava sheet entering a broad lake, however, one would expect that the beds beneath it would be fine clays or sand, and in the case of a lava-filled stream valley coarse gravel and bowlders would be apt to be present. But such a correlation can not be relied upon implicitly, since lakes may have broad areas of pebbles and bowlders adjacent to their margins and bars of similar material extending far from shore, while rivers may flow through broad valleys floored with fine flood-plain deposits which are indistinguishable in most ways from even the finest sediments of lakes.

CHANGES PRODUCED IN LAVA SHEETS AFTER COOLING.

OPEN FISSURES AND FAULTS.

The surfaces of the recent lava sheets about the Cinder Buttes are crossed in several instances by open fissures, from a fraction of an inch to several inches and in some cases a foot or more wide, which have opened since the lava hardened. Possibly these are due to stresses generated by the contracting of the lava on cooling, but at



LAVA RESTING ON UNDISTURBED LAKE BEDS, CANYON CREEK, IDAHO.

one locality to the north of the highest of the buttes a block of recent lava measuring several hundred feet in diameter has been elevated and sharply tilted, thus indicating that movements in the older rocks beneath the recent surface sheets have taken place.

In the summit of Black Crater there is a gulf, not of the nature of a crater, but of an open cleft, in the walls of which the edges of thin layers of lava are broken across and well exposed. This gulf is by estimate 300 feet across and 100 feet deep, and traverses the summit of the butte in a northeast-southwest direction. In its bottom there is black, scoriaceous lava which rose after the fissure was opened, and now forms a pahoehoe floor. This large fissure joins another, or, perhaps more accurately, two others at its southwest extremity. These branching fissures, 20 to 30 feet across, traverse the flanks of the butte irregularly and in their walls expose admirable sections of the thin-bedded, highly scoriaceous lava of which the crater is composed. In this case it is evident that the crater has been badly shattered, not by a steam explosion, for there are no blocks of lava or fragments of the nature of lapilli scoria, etc., about the openings, but owing to an overflow of still liquid lava from beneath, or by an earthquake.

Similar open fissures occur also in certain instances in the older sheets of Snake River lava, and are evidently of recent origin.

At Cleft the surface of the surrounding nearly featureless plain is formed by a sheet of massive, vesicular lava having a rudely columnar structure, which is broken by a fissure having several branches that run nearly east and west and can be traced for fully a mile. The fissure is from 5 to 10 feet wide, and is loosely filled with large blocks of basalt which have fallen from its side. The blocks rest against the sides of the cleft and support one another, leaving large open spaces into which a person may easily descend at least 40 feet, and it is evident that the opening is much deeper. The supported lava blocks in places form a series of floors, beneath which a person can clamber for distances of several hundred feet, as in a long, narrow cave; light from above being excluded by the roof formed of dislodged blocks. Other similar open fissures of still greater extent and depth are reported as occurring about 2 miles west of Cleft. In each of these instances there has been no displacement of the rocks forming the walls of the fissures, and to a person standing even a few yards to one side of a break no suggestion of its presence is visible on the surface of the plain. These fissures are of the same character as those sometimes formed during earthquakes, but instead of being due to earthquake shocks, they were produced, I am inclined to believe, by other causes, and at the time of their formation caused shocks or vibration in the rocks beneath the adjacent region.

About 1 mile east of Cleft the principal open fissure changes to a fault, the heaved side of which stands on a vertical escarpment of basalt from 10 to 25 feet high. It trends east and west and can be distinctly traced for half a mile or more. A view of a portion of this wall is shown on Pl. XXIII, *A*. This fault scarp faces south, and the adjacent portion of the sheet of obscurely columnar basalt that was broken across, and upraised, has a slight dip to the north. There is no open fissure at the base of the escarpment, for the reason, probably, that the change in the topography produced by the fault caused the line of fracture to become occupied by a small stream which flows during the winter or when snow is melting.

The open fissure at Cleft, which changes to a fault when traced eastward, belongs to a series of recent faults, which are best displayed in the portion of the Snake River Plains that lies between 5 and 9 miles north of Mountain Home and between Canyon Creek on the west and Rattlesnake Creek on the east. The northern margin of this broken tract of old lava is formed by the precipitous southern or southwestern border of rugged mountains of rhyolite. In the area just referred to there are five principal faults, each trending about east and west, and presenting steep and in part vertical scarps of basalt facing south. The heaved block, the broken edge of which forms a bold escarpment, looking like a wall when seen from the south, is in each case inclined downward to the north and maintains a uniform or slightly decreasing dip to the foot of the next escarpment. The height of these walls varies from a few feet at their ends to 40 or 50 feet and in several localities reaches 150 feet or more. The most northerly of the series is close to the base of the mountains, and appears in the wall of the canyon cut by Canyon Creek as a broad, irregular cleft. The mountain face is itself a vast fault scarp, as has already been stated, and it is probable that a recent movement along this break in the nature of an elevation of the block forming the mountains has caused the comparatively small faults in the lava forming the adjacent portion of the plain.

The displacements to the north of Mountain Home are admirable examples of step faults, as they are termed—that is, a series of nearly parallel breaks or cracks—separating the rocks they traverse into long narrow blocks which are tilted in one direction. The breadth of the gently tilted blocks in the instance before us is in general about 1,000 feet. The faults are not perfectly parallel, but in some instances unite or branch, maintaining, however, a general east-west direction, and generally coincide in trend with the great escarpment forming the border of the adjacent mountains. Some of the faults in the basalt extend east of Rattlesnake Creek, but were not followed in that direction. On the west the escarpments decrease gradually in height, and in most, if not all, instances die out on reaching a dome-like elevation in the basalt, described below, through which Canyon Creek has cut a narrow, steep-walled canyon.

Other faults, belonging to the series briefly described above and connecting it in a general way with the fault and open fissures near Cleft, occur on the west side of Canyon Creek, 5 miles northwest of Mountain Home. At the locality referred to there is an irregular but rudely triangular hill, as it would appear on a map, measuring about a mile on each side, the surface of which is inclined to the northwest. It is bounded by precipitous escarpments from 300 to 400 feet high on its eastern and southern border. The form of this prominent elevation and the character of its precipitous borders facing eastward and southward show that it is an elevated block bounded in part by faults. The elevated tract is composed of stratified basalt, as is shown particularly in its southern escarpment, which is more clearly due to faulting than its steep eastern face. The fault scarp on the south side of the hill dies out when traced westward, but is succeeded by other escarpments bordering another and lower hill, the structure of which is obscure.

The fault scarps to the north of Mountain Home are associated with other topographic forms, due to movements in the lava beneath that portion of the Snake River Plains.

South of the locality where Canyon Creek leaves the mountains of rhyolite, in which its two principal branches have excavated deep, flaring canyons, and enters a narrow gorge with vertical walls of columnar basalt (Pl. X, *B*), there has been an upward bending of the sheets of lava so as to form what may be described as half of a low, elongated dome or broad-pitching anticline. The longer axis of this elevation runs approximately northeast and southwest, or, in a general way, at right angles to the great escarpment forming the border of the adjacent mountains, and also normal to the direction of the small faults in the basalt between Canyon and Rattlesnake creeks. The arching of the basalt is most pronounced at the base of the mountains, where it is perhaps 3 miles broad, and dies out southward in a distance of about 4 miles, where it meets the triangular hill referred to previously. Canyon Creek follows the longer axis of the elevation and has cut a canyon in it which is 150 feet deep adjacent to the mountains and which decreases southward. On leaving the short canyon cut in the dome the creek becomes a surface stream and is spreading out an alluvial fan. The nature of the pressure which arched the lava in the manner just described was not determined. Seemingly it had no clear relation to the movements which produced faulting in the adjacent portion of the plain. Relief from pressure in one instance was obtained by an arching of the strata, while in the other instance breaks occurred. One of these breaks, however, as noted above, cut the fold near its northern end and was certainly of later date than the upraising of the arch. Then, too, the longer axis of the fold is at right angles to the trend of the neighboring faults, which would not be expected if one movement was responsible for each class of deformations.

The broad gentle depression of the strata beneath the Snake River Plain, previously referred to as the Bruneau artesian basin, involved several sheets of lava, which were gently bent in common with the associated beds of lacustral and perhaps in part river sediments. Further attention will be given this broad syncline in the second part of this paper.

ROCK DISINTEGRATION AND DECAY.

Under the climatic conditions now prevailing, which no doubt with minor variations have been in continuance for a long period of time, rock decay is progressing but slowly, while rock disintegration, through the action of changes of temperature, freezing of water, etc., is much more rapid. Mountains of quartzite are practically buried beneath their own débris, the fragments showing but little change from the unaltered parent rock. Mountains of granite are still more deeply sheathed with fragments of their own rock, but in this case much chemical alteration is manifest. The surfaces of basaltic lava sheets long exposed are covered with loose, rounded stones, usually of a rich-brown color, to a depth in most instances of not more than a foot or two. Between the weathered stones there is in certain regions, but not generally, a soft, rich-brown soil that has resulted from the decay and disintegration of the basalt itself, together with fine dust deposited by the wind. The amount of decay, however, that even the oldest sheets of basalt now exposed have undergone is but small. Many old lava sheets, owing in part, perhaps, to their having been covered by protecting layers now removed, still retain their characteristic surface markings, such as corrugations, pressure ridges, etc., in what may be termed a legible condition. While such markings are perhaps not an infallible sign that they were formed at the actual surface of a lava flow as already noted, their presence over large areas must be taken as evidence that such is the case. Perhaps the most conspicuous and general change that the exposed crags and rim rocks of basalt have experienced is due to the action of wind-carried dust and sand. The rocks usually have a smoothed appearance, approaching a polish, and their surfaces are characteristically pitted with small, somewhat shell-like hollows, or shallow depressions, with smooth interiors. The depressions are probably due in part to the flaking of the rocks on account of sudden changes of temperature, but the polishing is to be ascribed to the friction of wind-blown particles. These surface features, however, are never so conspicuous or well executed, one may say, as many well-known examples where quartzite, fine-grained limestone, etc., have been long exposed to the drifting sands of deserts.

The general conclusion in this connection is that the Snake River lava has suffered but slight changes, far too slight in fact to account for the presence of even the thin layer of soil that forms the actual surface over the several thousands of square miles of the lava-floored plains. The comparatively slight alterations referred to seem to mean either a very slow rate of change in response to atmospheric agencies, or else but a short exposure of the rock. The first of these reasons is not certainly true, but the second is plainly evident in a large number of instances.

In reference to progress made in disintegration and decay a comparison of the Snake River lava with the Columbia River lava is of interest. The lower sheets of lava beneath the Snake River Plains, as previously stated, are of approximately the same geological age as the main mass of the Columbia River lava, but the upper sheets of the Snake River lava are very much younger than any part of the basalt included in the Columbia River lava. In harmony with this conclusion is the fact that the extensive sheets of basalt in southern Idaho, although exposed to essentially the same climatic conditions that exist on the plains of the Columbia, are but slightly decayed; while the Columbia River lava at many localities and over areas embracing hundreds of square miles is so decayed to a depth of 40 to 60 or more feet that it is in the condition of clay, and can be molded in the fingers.[a] These facts sustain the conclusion derived from fossils, that the Columbia River lava is far older than the main portion of the similar formation in southern Idaho.

CANYONS AND WATERFALLS.

The streams which rise among the mountains bordering the Snake River Plains and flow across them bring silt, sand, gravel, and other deposits from their upper courses, and with these have cut deep channels even in the hard and nearly level lava sheets. The master stream is Snake River. As that strong stream lowered its bed the rate of flow of its tributaries was increased and they deepened their channels also, but could not cut below the level of the controlling stream. While the stronger tributaries, such as Salmon and Bruneau rivers, were enabled to deepen their channels at the same rate as the master stream, and at their mouths have essentially the same surface level as the Snake, and enter it as slack-water streams, the weaker tributaries, like the numerous creeks in Elmore and adjoining counties, could not work so fast, and now in several instances enter the master stream with swift currents, and have falls near their mouths. The weaker streams, however, which flow through soft material near their

[a] The surface changes of the Columbia River lava are described in the following reports: I. C. Russell, Water-supply and Irrigation Paper U. S. Geol. Survey No. 4, 1897, pp. 57–68; Water-supply and Irrigation Paper U. S. Geol. Survey No. 53, Washington, 1901, pp. 42–51.

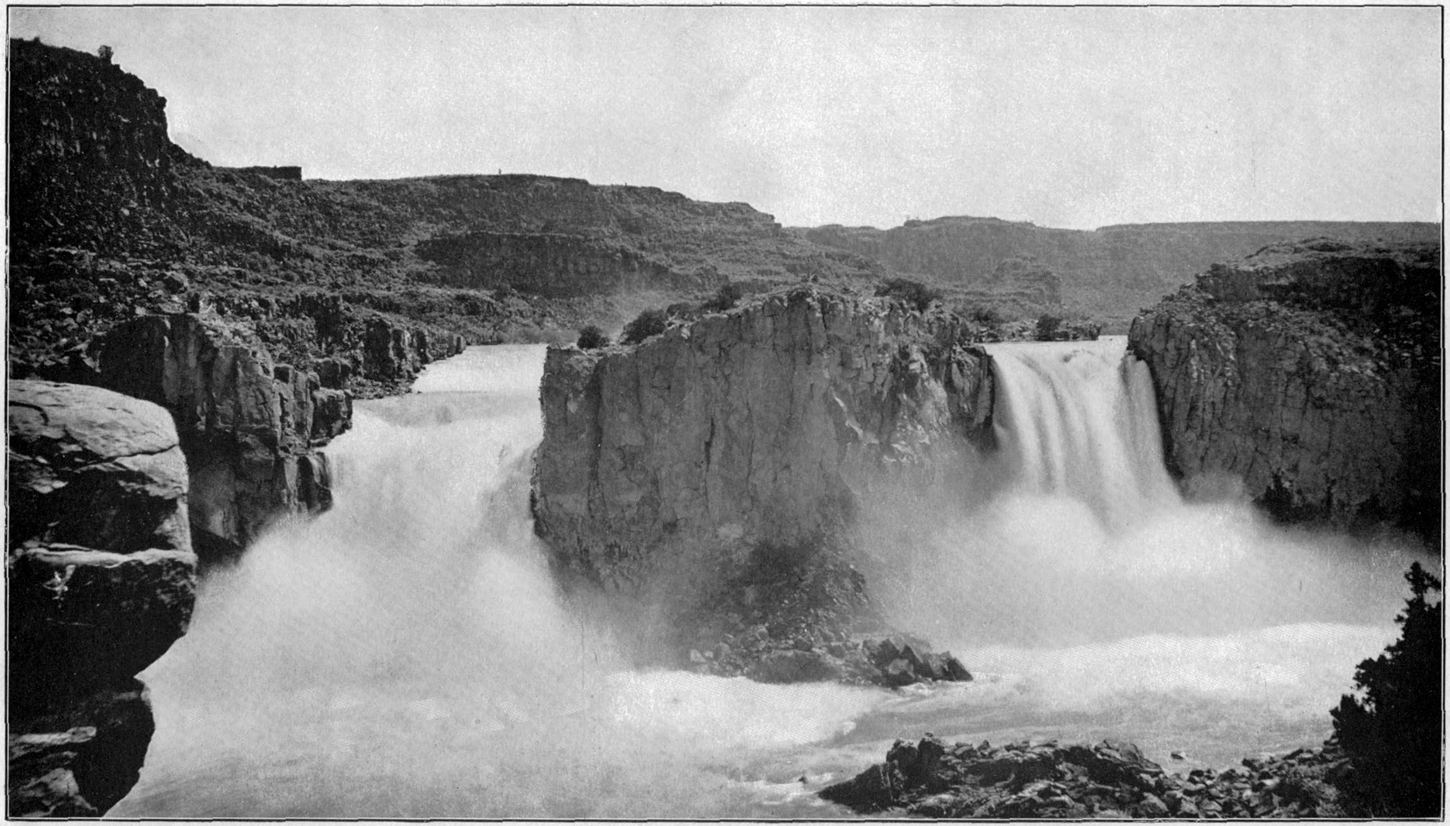
mouths, like Bennett, King Hill, and other creeks, have been able to keep pace with the down-cutting of the Snake, which is still working on hard basalt at several localities below the point where these tributaries enter.

The result of the concentration of energy in narrow belts at the bottoms of the streams has been to dissect the portion of the Snake River Plains situated west of American Falls, and to form a great system of canyons, with broad uneroded and nearly flat areas between. This portion of the region furnishes admirable examples of what has been termed young topography. Within this region, however, where the soft lake beds are not protected by a surface sheet of lava, as over great areas in the northern portion of Owyhee County, even weak and ephemeral streams have been able to advance rapidly with their work, and much more mature topographic forms occur.

In the broader and most characteristic portion of the Snake River Plains, lying north and west of Snake River and east of Little Wood River, the surface is uncut by streams, and is still a vast uneroded plain. This tract, about 10,000 square miles in area, is an admirable illustration of a new land formed by lava outflows. It has been left with its original or constructional surface, in part because of its actual youthfulness, as measured in years, but it also owes its preservation more definitely to the small rainfall, which fails to supply the streams coming from the north and west with sufficient water to enable them to reach Snake River. This failure is due in part to the open structure of the lava itself, which favors subterranean rather than surface drainage. In this connection consideration must be given to the fact that the Snake in its upper course is supplied with more sand, gravel, and other material than it can carry across the plains, where its gradient becomes less than in the mountains to the east, and deposition and the formation of broad alluvial fans and gravel flood plains on the surface of the lava are in progress.

As the portion of the Snake in southwestern Idaho, where it flows over soft sands and clays, is from 2,200 to 2,500 feet above sea level, it is evident that a sill of hard rock exists lower down stream, which has regulated the depth to which the river has been able to deepen its channel in these soft deposits. Below the mouth of the Payette the Snake flows through one of the most magnificent canyons in North America, one exceeded in grandeur of scenery only by the Grand Canyon of the Colorado. Although this region has not been carefully studied and is, in fact, almost entirely unknown to geologists, such information as is in hand indicates that a mass of resistant rock has been elevated athwart the course of the Snake, and that the task of sawing a canyon through the obstruction is still in progress.

Without wishing to invite the reader to take too comprehensive a view of the later geographical history of the region under discussion, one



TWIN FALLS, SNAKE RIVER, IDAHO.

other general principle which has influenced the erosion of the Snake River Plains may perhaps be cited.

Snake River, as stated, is spreading out coarse deposits in the portion of its course above American Falls, and it may reasonably be asked why is it that the same stream lower down its course has been enabled to excavate a deep canyon. The reason is evidently that owing to an increase in gradient in the portion of its channel below where it is laying aside its load, its rate of flow is increased and its capacity for work consequently augmented.

The scenery of Snake River Canyon presents many variations, dependent largely on the nature of the rocks cut through and especially on the presence or absence of lava sheets. Where alternating, nearly horizontal layers of soft lake beds and hard lava occur, the deepening of the canyon has been retarded by the hard layer and accomplished mainly by the recession of cascades and waterfalls. It happens that the river in its course across southern Idaho passes from a region where lava sheets are thick with but little soft material between them—as, for example, from American Falls to the foot of the deep, narrow canyon below Shoshone Falls—to a region where the lava sheets in general become thinner and are separated one from another by soft lake beds. When the stream in its downcutting flowed over a nearly level sheet of basalt to its edge it quickly deepened its channel in the soft beds encountered and a fall was produced. Such a fall would recede at a rate dependent on several conditions, but mainly on the thickness of the lava sheet and the depth of the channel below the cascade. In the main, the canyon of Snake River has been produced by the recession of a series of waterfalls of the nature just cited, and the process is still continuing. Each of the falls and rapids in the river is due to the presence of a resistant sheet of lava, in the border of which a notch of greater or less length has been cut. Where the lava sheet is thick, as at Twin Falls and Salmon Falls, a precipitous descent results; where the lava sheet is thin or composed of several thin layers of varying resistance, a succession of small leaps or a rapid is produced, as is the case to-day at several localities.

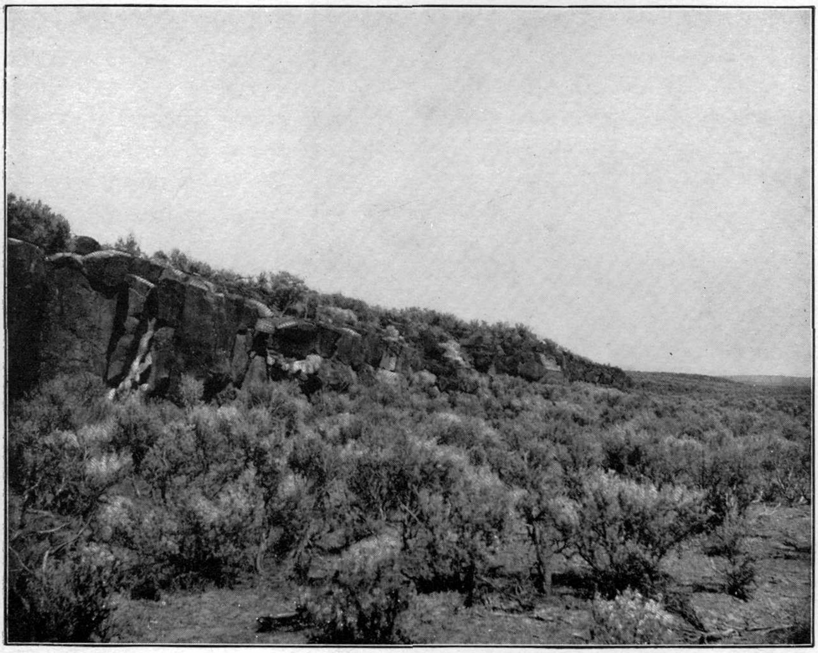
An exception to the rule just stated occurs in the case of Shoshone Falls, the highest and grandest of all the leaps Snake River makes. The river is here deepening its channel, mainly through horizontally bedded basalt, with a mass of rhyolite beneath. The surface of the lower and harder rock was not a plane, as are the lava sheets, but is irregular, and a series of rapids was probably formed which developed into a single great fall. The fall has receded about 5 miles in the rhyolite and at present, judging from the height to which the rhyolite above the falls rises into the lava, is as high as it will ever become. As the fall continues to recede it will probably decrease in height, and when the obstruction that causes it is cut across, will resume the characteristics due to thick lava sheets.

The principal variations in the topography of the canyon walls, from Shoshone Falls westward, depend on the relation of the lava sheets to associated clays, sand, etc., interstratified with them. Where the lava predominates the canyon is narrow with precipitous walls, as in the portion of its course for about 15 miles below Shoshone Falls. When only a thin surface sheet of lava is present the canyon has flaring sides, margined above by a vertical rim rock. If two or more sheets of lava are present, with soft beds of considerable thickness between the adjacent sheets, two or more rim rocks similar to the higher one will occur, their strength depending on the thickness of the lava. If a sheet of lava separated from the highest sheet of the same nature by a thick deposit of soft beds is present, a broad outer canyon, with flaring sides, and a summit rim rock will usually be developed, in the bottom of which there will be a smaller, inner canyon. When, as most frequently happens, the lava sheets occur only on one side of the canyon, i. e., on the northern side, the characteristics just referred to, with numerous variations, are there present, while the other side is less definitely canyon-like and usually presents less well-defined topographic forms.

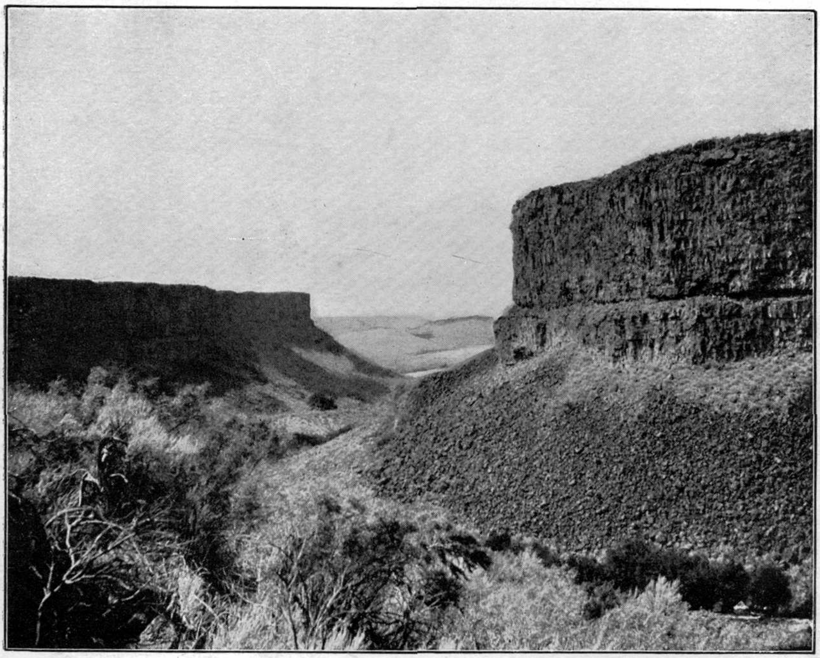
The slopes formed of soft material below the broken edge of a thin lava sheet are usually strewn with blocks of lava that have fallen from above, and may be completely sheathed with such talus (Pl. VII, *A*). The profiles of these slopes are sometimes concave, as when the talus is too thin to preserve the soft beds beneath and erosion curves are produced, but may be nearly straight when the slope of the talus is the predominant factor, or become convex when the material beneath is resistant and weather curves predominate.

The broken edges of thick sheets of basalt resting on soft deposits, especially if the latter are also thick, are apt to break away in larger blocks than in the formation of a talus, and landslides result. Excellent examples of landslides of the nature just referred to occur for several miles on each side of Snake River above the mouth of Canyon Creek.

The principal features of the walls of Snake River Canyon, described in the last three paragraphs, it must be remembered, are such as are most pronounced and become accentuated owing to the prominent part played by certain special conditions, but many other variations occur which are not essentially different from those known elsewhere in the arid region, except in detail. There is one class of exceptional topographic forms, however, which becomes especially conspicuous in the wall of the Snake River Canyon, the like of which, so far as I am aware, has not been observed in other regions. I refer to certain remarkable alcoves or branches from the main canyon which are not due to the work of surface streams.



A. FAULT SCARP OF BASALT NEAR CLEFT, IDAHO.



B. LITTLE CANYON, LOOKING SOUTH INTO SNAKE RIVER CANYON, IDAHO.

SPRING-FORMED ALCOVES ON THE SIDES OF CANYONS.

At Blue Lakes, about 5 miles below Shoshone Falls, where the walls of Snake River Canyon are about 700 feet high, and nearly vertical, except for the talus lodged against their bases, there is a tributary canyon-like alcove in the north wall which is about 2 miles long, and about 2,000 feet across at the top and which heads in a semicircular amphitheater with vertical walls about 300 feet high. There is no stream entering the alcove from the surface of the neighboring plain, but springs discharging probably several hundred cubic feet of water per second boil up in the amphitheater at its head. One of the striking features in this alcove is the small quantity of talus at the bases of the bordering cliffs. This is most noticeable in the semicircular expansion of the alcove at its head. In the view of the Blue Lakes alcove presented on Pl. XXIV some of the features referred to may be recognized.

On the north side of Snake River Canyon, about 2 miles above the mouth of Salmon River, which comes into the Snake from the south, the canyon wall is again nearly vertical and about 300 feet high, and there are two side branches, known as Little and Box canyons. These are similar in all their leading features to the Blue Lakes alcove, and, like it, are lateral openings from the main canyon. They are also without surface streams entering them from the plain above. Box Canyon is approximately 3 miles long, and Little Canyon is perhaps a mile less in length. Each of these secondary canyons or alcoves has vertical walls about 200 feet high. There are comparatively small talus slopes along their sides and practically none at the base of the wall encircling their heads. At the head of each alcove there is again an immense spring. The stream issuing from Box Canyon has a volume of about 1,000 cubic feet per second, and the stream from Little Canyon is perhaps one-third as great. A view in Little Canyon looking out into Snake River Canyon is reproduced on Pl. XXIII, *B*.

Malade River, which is formed by the union of Big Wood and Little Wood rivers, in recent years has become dry in summer, owing to the demands made on its tributaries for irrigation. The river, as I was informed, was dry a few miles below where its two branches unite, late in August, 1901, but on crossing its canyon, where it emerges into Snake River Canyon, I found a roaring stream of clear water 8 feet wide and fully 4 feet deep discharging by estimate about 3,000 cubic feet of water per second. All of this water is contributed by springs in the lower 4 miles of the canyon. The main supply, as I have been informed by Mr. N. Uhrlaub, comes from a great spring which rises at the foot of a precipice in the canyon, and which causes a cascade in the Malade when water comes from the upper part of its course in winter and spring. The volume of the spring referred to is reported to be not less than 1,500 cubic feet per second. The canyon of the Malade throughout the lower 4 miles of its course is similar to the Box and Little Canyon alcoves, but its walls are higher, and during portions of each year, and perhaps continuously during certain years, it receives a stream at its head from the plain above.

The water flowing from each of the four alcoves just described is clear, but has a bluish color and a slight opalescence, due to finely divided white silt-like material in suspension. It is this fact which has suggested the name for the small spring-fed lakes in Blue Lakes alcove. These pools and others fed by springs in and near the four alcoves referred to have white bottoms composed of clean white sand, which is brought to the surface of the springs themselves.

The four side canyons or alcoves referred to thus have many similar features and without question have been produced by similar agencies. One conspicuous feature in each is a sheet of basalt from 200 to 300 feet or more thick. No exposures of the material on which the basalt rests are known to me, but as the springs are bringing out white silt and fine white quartz sand it is evident that beds of similar material exist beneath the basalt.

The origin of the side canyons which receive no surface streams, such as Little and Box canyons and the one in which the Blue Lakes are situated, is plainly due to the action of the great springs which come out at their heads. The lower portion of the canyon of the Malade has a like history, modified by the fact that a surface stream is also concerned in the work. The great springs undermine the basalt by removing the soft material on which it rests. Thus blocks of the usually more or less vertically jointed rock break away and fall into the spring, and sooner or later sink into the soft bed beneath, as the emerging waters remove the silt and sand from beneath them. By this process vertical walls without talus slopes are produced. This process continuing, the cliff recedes, leaving a side cut or alcove in the wall of the main canyon, which becomes lengthened into a lateral canyon. The process would seem to be cumulative, as the farther the head of a side canyon receded the greater would be the tendency of the escaping waters to converge toward it. The marked tendency to an enlargement into an amphitheater, observable especially at the head of the Blue Lakes alcove, is apparently due to this cause.

It is to be expected, under the hypothesis just suggested, that as the head of a spring-formed alcove recedes the wall formed would be always vertical and kept fresh in appearance by the fall, from time to time, of portions of its face; while the sides of the older portion of the cut produced would become more or less encumbered with talus. The truth of each of these inferences is abundantly sustained by observation. The precipices partially encircling the great springs at the heads of the alcoves visited are not only vertical and either without

BLUE LAKE ALCOVE, LOOKING SOUTH INTO SNAKE RIVER CANYON, IDAHO.

or nearly free from talus, but are so fresh in appearance that the last blocks to fall from them must have been detached during the past few years, while the sides of the canyons through which the great springs discharge their waters have at their bases talus slopes (Pl. XXIII) which extend well toward the centers of the gulf between them. The Blue Lakes are retained by dams composed of talus blocks.

In considering the origin of alcoves of the type of Little Canyon, etc., the question arises, Why should not landslides be caused by the undermining of thick sheets of basalt by springs in the same manner that a river cuts under the border of a similarly thick sheet of resistant rock? The answer to this query is that the fall of individual blocks of comparatively small size, so as to form a talus, and the breaking away and descent of large masses, as in landslides, are in reality but extremes of a single process. Large blocks of such dimensions as to be termed landslides are not caused to fall by the undermining performed by springs, evidently because the action is too local. The fact that large alcoves are not more frequent along the side of Snake River Canyon, as at The Thousand Springs, etc., where water is pouring out, is because only exceptionally strong springs can undermine thick lava sheets so as to initiate and continue the process described when the other essential conditions are most favorable. At The Thousand Springs the water emerges from the open basal portion of a lava sheet and above a thick layer of compact tuff which stands in a vertical cliff, and no approach to the formation of an alcove is to be seen. Several of the smaller springs which come to the surface in the canyon wall from beneath relatively thin sheets of lava, as in the vicinity of Hagerman, are situated at the heads of reentrants in the canyon walls. These reentrants are of the same general character as the larger alcove, being produced by large springs, but the extension headward has been small. In these instances the water-bearing layer is cellular basalt and the beds beneath stratified clay.

The necessary conditions, then, for the production of large alcoves which have otherwise a generally straight alignment, and which furnish no surface tributaries to the stream in the main canyon, are the presence of a surface or superior sheet of compact rock of very considerable thickness, and beneath this a stratum of unconsolidated fine sand, silt, etc., of fully as great thickness as the overlying stratum, and an abundant water supply in the unconsolidated stratum. The conditions are still more favorable if the superior sheet of compact rock is vertically jointed. The initial step in the process is the escape of the water at some locus of discharge forming a spring sufficiently powerful to carry away the material composing the porous stratum. The necessity for a thick bed of fine sand or other similar material beneath the canyon-forming layer is shown by the fact that blocks falling from the cliffs in order to form an alcove are not carried away, but are engulfed in the stratum beneath, space being furnished by the removal of the fine material by the spring.

In the process now going on in the enlargement of the Blue Lakes alcove, etc., a portion of a thick stratum of sand is being replaced by a deposit of angular blocks of lava. Possibly the mode of origin of certain ancient breccias may here be indicated.

The spring-formed alcoves on the side of Snake River Canyon are unique topographic features, because the combination of conditions necessary for the production of such recesses or lateral cuts in the border of a plateau is of rare occurrence.

LOST RIVERS.

In connection with the following brief account of a striking peculiarity in the hydrography of the Snake River Plains, the reader is invited to refer to the map forming Pl. I. As there indicated, not a single tributary reaches Snake River from the high and rugged mountains lying west of its course between Malade River and Henrys Fork, a distance in a straight line of 200 miles. Several of the eastward-flowing streams which rise in the mountains referred to are of considerable volume and reach the margin of the lava-covered plain bordering Snake River, but fail to cross it. Examples of such streams, named in order from northeast to southwest, are Camas, Beaver, Medicine Lodge, and Birch creeks and Little Lost and Big Lost rivers. When the snow is melting each of these streams advances onto the plain for distances varying, in the several cases cited, from 10 to 50 miles, but shrinks back in summer and ends indefinitely soon after leaving the valley tracts. In certain instances, as in the case of Camas and Birch creeks and Little Lost and Big Lost rivers, the waters spread out on the marginal portion of the plain during the period of their greatest elongation and form shallow lakes. These lakes are ephemeral, however, and although renewed each spring, with one exception become dry each summer, leaving smooth mud plains or playas. The exception is furnished by Camas Creek, which expands to form Mud Lake, which fluctuates in area from month to month and when largest is from 40 to 50 square miles in area. It was dry in the summer of 1891 and lower during the summer of 1900 than at any time during the preceding nine years. In September, 1900, the bed of Camas Creek was dry for a distance of 20 or 30 miles adjacent to its distal extremity, although, as indicated by a well, there was an underflow beginning at a depth of 20 feet. Mud Lake was then shrunken so as to leave a mud flat from a few to several miles broad about its borders.

The streams just referred to emerge from valleys deeply filled with alluvial material and during high-water stages bring to the plain large quantities of material held in suspension or rolled along their bottoms. The coarser portions of this, the "visible loads" of the streams, are deposited in the mouths of the tributary valleys and on the border of the great plain, so as to form alluvial fans; while the finer portion is carried farther, and, in case of the stronger streams, deposited principally over the bottoms of temporary lakes. The weaker streams, which disappear either by evaporation or by percolation, deposit the fine sand and silt they bring down from the mountains in a broad fringe about the outer margins of their low, widely expanded alluvial fans. In these several ways an attempt is being made, as one may say, to upgrade the lower portions of the stream channels, so as to enable the waters flowing down them to cross the plain. The principal reason why the streams have done this is because their water supply is insufficient. But, if properly graded water-tight channels could be provided there is no doubt but that the stronger streams, such as Camas Creek and Big Lost River, would be enabled to reach Snake River during the time the snow is melting on the mountains from which they flow and perhaps live throughout the summer. In addition to the light rainfall, therefore, other adverse conditions must be present. Chief among these is the fact that the lava covering the plain across which the streams naturally tend to flow is not smooth and level as it appears to be when seen from a distance, but rough, irregular, and undulating.

The waters are ponded, and before they can accumulate in sufficient volume to overflow the obstructions and continue on their course their expansion to form lakes leads to an increase in evaporation, which at a certain stage equals the inflow. That is, the inflow is spasmodic, but evaporation continues so long as the lake basins contain water, although fluctuating with temperature, strength of the wind, etc., and the quantity of water delivered to the lake basins each year, or during a period of several years, is all evaporated or lost by percolation. Allowing for the conditions just mentioned, however, there is still evidence that the popular belief that the waters sink into the lava and that the streams are "lost" beneath the surface is well founded. When the waters of Little Lost River are expanded so as to form a lake, I have been informed by observant residents of the region that there is at a certain stage an escape through fissures.

The surface portions of the lava sheets covering the plains are broken and jointed, so that water if spread over the land would immediately sink from sight. This is indicated also by the fact that few if any surface rills or brooks are formed on the plains during rains or when their covering of snow is melting, but this may be due to the absorbent nature of the soil. In order that streams may cross such a surface it is necessary that the openings in the rocks should first be closed. The streams are active in this direction, as is to be seen where they are spreading out alluvial fans and silting up lake beds, but the task is not far advanced. The processes now in action, given time enough, will lead to the upgrading of the plain so as to fill the cavities and fissures in the lava and enable the stronger streams to advance over it and possibly to reach Snake River. As is well known, a stream charged with sediment will seal the openings in its channel, even if flowing over a thick stratum of bowlders and loosely compacted stones, and form for itself an aqueduct through which it can flow without material loss by percolation. Admirable illustrations of this process are furnished by the "lost rivers," but the difficulties to be overcome are great, and the task undertaken is not far advanced.

The sources of supply of the large number of strong springs referred to on a previous page, which gush out from the north wall of Snake River Canyon between American Falls and Bliss, are the streams which come from the mountains to the north and are "lost" on reaching the plains, together with the rain and water furnished by melting snow which comes directly to the broken surfaces of the plains themselves.

The environment of the "lost rivers" which, coming from the west, reach the Snake River Plains to the east of the Malade but fail to pass them, is not conspicuously different from the combination of conditions influencing the lives of the streams to the west of the Malade which do reach the Snake during a portion of each year, except as noted below. To the east of the Malade the lava sheets forming the surface of the plains are in part of recent origin and a sheet of soil has not as yet been spread uniformly over them, and besides, they are still in the position in which they were spread out; that is, their surfaces, although rough, are essentially horizontal. To the west of the Malade, however, the lava sheets are comparatively old, are covered quite uniformly with soil, and besides have been bent into a broad, gentle trough, the axis of which runs in a generally east-west direction. The streams from the mountains to the north emerge upon a smooth plain, which is tilted gently in their direction of flow, and which in a large number of instances they have been enabled to cross. Another favorable condition is that the mountains northwest of Mountain Home are composed largely of granite, which furnishes an abundance of material of such size that it can be transported by even weak streams, and which are then in a condition to upgrade their course across the plain.

An important factor, however, which determines the existence of lost rivers is climate, as is shown by the fact that none of the streams to the west of the Malade until Boise River is reached, in spite of their favorable environments, are perennial. They all shrink in summer to such an extent that they barely emerge from their mountain valleys. The Malade is the only stream in the whole of southern Idaho from Henrys Fork, within 12 miles of the west boundary of the Yellowstone Park, to the Idaho-Oregon line, a distance measured along Snake River of fully 450 miles, which, rising in the mountains to the north, reaches that river in summer. Even the Malade, on account of the demands made on its tributaries for purposes of irrigation, now becomes dry for a period each year.

The marked exception furnished by the Malade to the prevailing character of the neighboring streams, when the influence of irrigation is not considered, at once suggests that some exceptional circumstance favors it. The reason for this exception is not difficult to discover. The Malade is formed by the union of Big Wood and Little Wood rivers. Each of these streams has been turned aside in recent times by a lava flow, and the two caused to unite. By their union they form for the region in which they flow an exceptionally strong river. The fact that each of the main branches of the Malade has been turned aside from what we are justified in assuming would be its natural course is at once suggested by an inspection of a map on which the drainage of southern Idaho is shown. On leaving the mountains they turn abruptly southwestward instead of continuing southeastward, as would seem to be their natural course. The reason for this in the case of Little Wood River is the presence of a recent lava flow in the mountains across the mouth of the valley down which the stream flows. In the case of Big Wood River the lava stream from Black Butte filled its former channel and caused it to take a new course. Had it not been for these "accidents" each of the streams would have maintained its independence, and most probably would have been "lost" on the plains in the same manner as in the other instances cited.

The region that the two streams just referred to would have crossed in order to reach Snake River had they not been turned aside has as yet not been closely examined, and it will be of interest to discover whether abandoned channels or alluvial deposits occur there to confirm the hypothesis of recent deflections here presented.

UPGRADING STREAMS.

In the case of the "lost rivers" of the Snake River Plains, instances are furnished of upgrading in which the process has not advanced far enough to permit the streams engaged in the work to cross the flat tract they invade and reach larger drainage channels. On the east side of the same flat region, however, there are numerous streams that have been more successful. Examples of this are furnished by the South Fork of Snake River, the Blackfoot, and Portneuf rivers, and probably other streams, which have their sources in the mountains of southeastern Idaho and adjacent portions of Wyoming and flow northwestward. There are no "lost rivers" in this region, although many of the smaller streams become dry in summer. The reason for this contrast between the streams reaching the Snake River Plains from the north and those coming in from the southeast is twofold—the former are not only smaller as a rule than the latter, but have a far broader tract of flat land to cross before reaching the main waterway. The streams from the southeast, coming from high mountains, are well supplied with material in suspension, and have been enabled to upgrade their courses across the comparatively narrow tract of flat country, and thus reach the main channel of discharge without being ponded. Perhaps the best illustration of this, and the only one which can here be noticed, is furnished by the South Fork of Snake River.

As may be seen on inspecting the map forming Pl. I—or better, the General Land Office map of Idaho, from which it was in the main compiled—the South Fork on emerging from the mountains, to the east of Market Lake, splits up into a number of distributaries, which join the North Fork independently. The meaning of this is that the South Fork, being overloaded, has built up an immense alluvial fan on the border of the Snake River Plains, on which it subdivides. The conditions, as previously remarked, are unusually favorable for irrigation, and the natural subdivision of the river has been increased in recent years by the construction of canals. The alluvial fan built by the South Fork has not only deflected the North Fork and caused it to make a curve to the west, but has checked its flow and compelled it to drop the material it was previously enabled to carry and so assist in forming a broad alluvial deposit. The North Fork has been partially dammed by the material deposited in its course, and now widely overspreads its banks during high-water stages. This tendency to form a lake was greater before the construction of extensive irrigating works and railroad embankments than it is now, for a lake was formed each year, which during certain periods was perennial. This Market Lake, as it was named early in the exploration of Idaho on account of the abundance of game in its vicinity, in now prevented from becoming flooded, and its bed is under cultivation.

Much more space could be given to the study of the upgrading being carried on by the streams that join the Snake from the southeast, but enough has probably been stated to illustrate the marked contrast that exists between them and the "lost river" on the western portion of the basin which they enter. The conspicuous difference in these two representative instances, it will be seen, is one of degree. Of the many factors involved in a river's development, a few or perhaps some definite one controls the result in certain instances, while others become prominent and perhaps assume the lead in other cases.

In reference to the process of upgrading, it will be rightly assumed from the statements already made that all the streams emerging from the mountains onto the lava-formed portions of the Snake River Plains are now or at some time in their history have been engaged in spreading out gravel, sand, silt, etc., over the surfaces of the nearly flat lava sheets that they have to cross. In this manner much of the soil of the plains has been formed.

SOILS.

As was stated in the introductory portion of this paper, the Snake River Plains are, as a rule, soil covered. The principal exception is where the recent lava is present. Where lava sheets of considerable antiquity are still at the surface, however, their roughness, especially the pressure domes and ridges which occur upon them, is not always concealed by the nearly universal sheet of fine débris in which the desert shrubs are rooted.

ALLUVIAL SOILS.

One source of the soil covering the lava sheets has already been described, namely, the alluvial deposits made by streams flowing down from the mountains. About the border of the plains, and extending out for many miles toward their central part in certain instances, the surficial covering is composed of coarse material of the same lithological character as the rocks forming the neighboring mountains. A gradation from coarse to fine is easily traced as one leaves the mountains and journeys out upon the plain. In making such a journey it will be noticed that at first the alluvial fans, stream terraces, etc., are pronounced, but as one proceeds they flatten out and become more and more indistinct, and at a distance, in general, of 8 or 10 miles from the bordering upland the plain is flat and has an even surface of soft yellowish-white silt-like material, broken only by occasional crags of basalt, or the summits of pressure ridges. Far from the channels of streams, and where even the courses of the ephemeral distributaries of wet-weather creeks and brooks are no longer distinguishable, the light-colored soil continues, and not infrequently and over continuous areas embracing several hundred square miles forms an even, unbroken surface. The origin of the soil at localities distant from all stream channels is the most interesting problem that this surface covering presents.

The surface of the plains at a distance from the mountains, and from the channels of streams, inclusive of those dependent on unusually heavy rains, presents two quite well-marked characteristics. To the west of Malade River the broad, seemingly level interstream spaces are smooth and have a gentle downward inclination to the south. It is evident that if the ephemeral streams from the mountains to the north had sufficient volume they might easily continue across this space, which varies in width from 10 to 20 or more miles, and deposit fine sediment upon it. To the east of the Malade, and over nearly all of the eastern half of the Snake River Plains, the surface is undulating, and there is no direction in which surface water could flow for many miles without being ponded. This rolling surface, however, is covered with a sheet of soil similar in its physical characters to that forming the surface of the smoother plains lying farther west. Although there is a suspicion that the soil on the smooth plains, especially when their surfaces are inclined in the direction in which streams from the mountains would flow if precipitation were sufficiently abundant, was deposited by the distributaries of ephemeral streams, it is evident that the rolling plains could not have been covered with a sheet of fine material in this manner. As is explained below, the soil on the rolling plains, which have in fact the typical aspect of rolling prairies, is decidedly different from the rocks beneath, and, as is plainly apparent, has not been formed by the disintegration and decay of the underlying basalt. It has manifestly been deposited on the lava from above, and must therefore have been spread out beneath a lake which occupied the Snake River Basin at a recent date, or else it was laid down under conditions essentially the same as those now existing. That a lake has not been present over the greater part of the lava-covered region lying east of the Malade since the surface lava sheets were spread out is shown by the absence of beach lines and other similar phenomena. The soil must therefore have been deposited from the atmosphere.

ÆOLIAN SOILS.

One method of studying the nature of soils is to sift them and thus separate the grains of uniform size. The results obtained in this manner from two samples of soil from the Snake River Plains are presented below. No. 1 is from a locality about 8 miles southeast of Shoshone Falls and is a representative of the soil covering the smooth plains. No. 2 is from a locality about midway between Arco and Big Butte, where the surface is rolling and has never been crossed by streams. Each sample was taken about 1 foot below the surface. No. 3 is a sample of the lacustral deposit which covers a great area in the northern part of Owyhee County, and is introduced here for comparison. It will be referred to later.

Mechanical analyses of soils and lacustral deposit from Snake River Plains.

	No. 1.	No. 2.	No. 3.
	Per cent.	*Per cent.*	*Per cent.*
Retained on a 20-mesh sieve [a]	0.0	5.7	0.0
Retained on a 50-mesh sieve	5.0	4.0	4.5
Retained on a 100-mesh sieve	6.5	5.5	10.5
Retained on a 200-mesh sieve	4.5	8.5	6.0
Passing through 200-mesh sieve	82.8	76.0	79.0

[a] Number of meshes per linear inch.

The material retained on a 20-mesh sieve, in the case of sample No. 2, contains about 5 per cent of easily recognizable vegetable fibers, and in the fractional parts of each sample coarser than that which passed through a 200-mesh sieve similar vegetable fragments are present. Probably 3 to 4 per cent of each sample consists of vegetable débris.

The soil represented by sample No. 1 is of a light-yellowish, nearly white color, and resembles the loess of the Mississippi Valley and other regions. The particles composing this sample, larger than those passing through a 200-mesh sieve, when examined with the aid of a microscope, are seen to consist of small grains loosely united and well rounded, probably on account of the slight attrition necessary to cause the material to pass through the sieves used. When these rounded grains are lightly rubbed in water, they immediately disintegrate. The same result is attained by placing them in weak hydrochloric acid, the spontaneous separation being accompanied by a brisk effervescence. The residue obtained after treating with acid, when examined under a microscope, is indistinguishable from the grains composing 82.8 per cent of the original sample, which pass through a 200-mesh sieve. The coarser particles are thus shown to be aggregations of the finer grains present, loosely cemented by some carbonate, probably of calcium. The grains which pass through a 200-mesh sieve, as well as those obtained by treating the larger particles present in the original sample with acid, when examined under a microscope, are seen to be angular and subangular and mostly without color. From their appearance, resistance to acids, and other tests, they have been shown to be almost entirely grains of quartz. No shreds of glass, such as are characteristic of volcanic dust, were observed. Thus, as indicated by a mechanical analysis, the soils are composed essentially of exceedingly fine quartz sand, with a minor amount of some cementing material, probably calcium carbonate. This conclusion is sustained by a chemical analysis, the results of which are here presented.

Chemical analysis of soil from near Shoshone Falls, Idaho.

[Analyst, W. F. Hillebrand.]

	Per cent.
Silica, SiO_2	52.43
Alumina, Al_2O_3	7.10
Ferric oxide, Fe_2O_3	2.63
Titanium dioxide, TiO_2	.38
Manganous oxide, MnO	Trace.
Calcium oxide, CaO	14.60
Potassium oxide, K_2O	1.7
Sodium oxide, Na_2O	.93
Magnesium oxide, MgO	2.93
Carbon dioxide, CO_2	12.40
Phosphoric oxide, P_2O_5	.20
Water, H_2O	4.96
Total	100.31

Judging from both the mechanical and chemical analyses just given, it seems that the soil consists essentially of exceedingly fine quartz sand, to which a small percentage of calcium carbonate, together with some vegetable matter, has been added. One interesting result of the chemical analysis is the small amount of sodium found.

The soil represented by sample No. 2 is brown in color. This is due in part to organic matter, but does not wholly disappear when a sample is heated to redness. The particles which will not pass through a 200-mesh sieve are aggregations of smaller grains, but are not readily disintegrated by rubbing and do not fall to pieces when treated with hydrochloric acid, and besides there is but slight effervescence when acid is used. The material passing through a 200-mesh sieve and that obtained by the partial breaking up of the coarser particles when rubbed appear under the microscope to be about the same as the grains composing sample No. 1, but are much more frequently colored. The larger part of the grains consists of quartz, but a considerable number are dark colored or opaque and indeterminate. Judging from these facts, the soil represented by sample No. 2 consists mainly of fine quartz sand, colored and in part cemented into grains by some substance not readily soluble in acid, and, as indicated by qualitative chemical tests, consisting probably of ferric oxide. The opaque indeterminate grains are possibly volcanic lapilli.

Near each of the localities where the samples referred to above were taken, as is the case throughout the soil-covered lava sheets beneath the Snake River Plains, there is an abrupt and conspicuous change from the soil to the lava and not a gradual transition from one to the other. It is evident from this, as well as from the mechanical and chemical analyses given above, and the composition of the lava, so far as known, that the soil is not derived, to an appreciable extent, from the rocks on which it rests. In many sections seen the soil is essentially homogeneous from top to bottom, excepting that much more organic matter, usually in the form of readily recognizable vegetable fibers, is present at the surface than at a depth of a few feet. Also, as previously stated, the soil mantles both the smooth and the rolling portions of the plains, and occurs also on the sides and summits of ancient lava craters.

Judging from all the facts in hand, it is evident that the fine, usually light-yellow soil covering the Snake River Plains at a distance from the mountains is mainly and essentially a dust deposit laid down by the wind. The dust is derived to some extent from the mountains, where naked cliffs, bare talus slopes, etc., furnish material for wind transportation, but of more importance is the fine sediment deposited by ephemeral streams which spread out on the marginal portions of the plains and leave all of the débris brought by them from the mountains. Another and possibly the source of the most abundant supply is the bare surface of the extensive lacustral deposits in southwestern Idaho. The prevailing winds, which are westerly, on crossing these lake beds, cut as they are into bad lands, become charged with dust, which is carried eastward and finally deposited. That much of the æolian sand was derived from this source is also indicated by a comparison of it with the material forming the lake beds. A characteristic sample of the finer of the lacustral deposits, when subjected to a mechanical analysis in the manner already described gave the results presented in column No. 3 of the table given on page 136. As respects the size of the constituent particles, it will be seen that there is no conspicuous difference between the soils numbered 1 and 2 and the lacustral deposit. When the latter is examined under a microscope it is seen to be composed largely of fine angular and subangular grains of quartz sand, identical with those composing the principal part of the soils; the portions caught on 50- and 100-mesh sieves also are loosely cemented fragments of the same material, as in the case of the soil sample No. 1. This similarity is, in fact, so close that it suggests another hypothesis, and one which I considered and abandoned while in the field, namely, that the waters of the Pliocene lake which occupied the western part of the Snake River Plains extended far eastward, and that much of the fine yellow soil to the east of Malade River is a remnant of the sediment deposited in it. To what extent the soil in question is really lacustral sediment not removed and redeposited by the wind is difficult to determine, as the passage is indefinite from the area where lacustral conditions were clearly present at the west to the area at the east where there is an absence of evidence of the former presence of a lake after the surface lava sheets were spread out.

No doubt much of the dust derived from the lake beds referred to, and from the fine alluvial deposits is carried far beyond the borders of the Snake River Plains, but it is only in situations where other deposits are not being formed and where freedom from removal by rain wash is assured that the characteristic æolian soil can be expected to occur. The grasses, sagebrush, etc., growing on the plains serve to entrap the dust and preserve it from being again removed by the wind.

In addition to the sources of supply of dust cited above, the fact needs to be borne in mind that volcanoes of the type of the Cinder Buttes, Market Lake crater, Kuna Butte, etc., contributed large quantities of volcanic dust and lapilli to the surface covering of the neighboring portions of the plains. Where this material is present in considerable quantity the soil is brown, but when æolian dust or lake beds predominate the soil is a characteristic light yellow, and is frequently nearly white. It is the fine, homogeneous, light-yellow soil that is generally present on the broad plains at a distance from the mountains.

SAND DUNES.

In general, sand dunes are absent from the Snake River Plains, but at a few localities some notable examples are present. In Snake River Canyon, to the south of the river and about 8 miles below Glenns Ferry, there are sand drifts of considerable size, which are conspicuous on account of their gray color, smooth bare slopes, and undulating crest lines. Again, in the extreme northeastern portion of the plains, between Camas Creek and Henrys Fork, there is an area of many square miles occupied by drifting sand which has partially buried a range of hills known as the Sandhill Mountains. This great deposit of wind-blown sand was visited by F. H. Bradley[a] in 1872, who described it as reaching a height of 250 to 300 feet on the hills and forming a barren belt about their sides and bases. To the west of the hills it covers a tract of country several miles wide, some of the drifts being from 100 to 150 feet high. This interesting region still awaits careful study.

In many localities on the Snake River Plains where conspicuous sand drifts do not appear there is evidence that considerable surface material, mostly quartz sand, is traveling in the direction of the prevailing winds. The roads are sometimes rendered impassable by these small dunes. The manner in which the sagebrush checks the force of the wind and causes sand drifts to start suggests that if a tract about 100 feet wide should be cleared of brush on each side of a road, so as to give the winds a clear sweep, the sand obstructions would be removed.

It is a noticeable fact that the well-defined dunes on the Snake River Plains are composed of sand from which practically all fine particles have been removed. The dust does not collect in drifts and ridges to a notable extent, but is deposited as an even sheet which, although thickest in the depressions, occurs on hillsides as well. The reason for this difference in the manner in which dust and sand is laid down is not apparent and would be an interesting subject for investigation.

Along the border of flood plains of streams tributary to Snake River, and also on the surfaces of abandoned flood plains now forming terraces along the larger stream, water-laid soils occur. They are coarse or fine, according to the strength of the currents to which their deposition is due. Usually a variety of rock fragments is present, as along Snake River, but in the case of small streams there is less diversity and the débris is of the same character as the rocks forming the region whence the streams flow. Between Mountain Home and Boise the flood plains of the streams flowing from the mountains to the north are composed of angular granitic sand. Far out on the plain, where ephemeral streams expand and at times form playa lakes, the

[a] Sixth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, pp. 211-212.

surface is covered with fine yellowish silt, composed almost entirely of fragments of quartz, and not distinguishable from true æolian soil.

RESIDUAL SOILS.

On the mountains of southern Idaho and on the steptoes which rise through the lava of the Snake River Plains there is usually an abundance of fine material forming a soil mantle which agrees in the nature of its constituent fragments with the rocks on which it rests. In many instances there is a gradation from fine soil, with occasional angular rock fragments into the solid rock beneath. These are typical examples of residual soils.

SUMMARY.

The soils of southern Idaho are of two classes—sedentary and transported. Of the transported soils, there are again two principal subdivisions—wind deposited and water deposited. Of the wind-carried or æolian soils there are two principal varieties, one consisting mainly of fine quartz sand and the other of volcanic dust and lapilli. Of the water-deposited soils there are again two varieties—those laid down in lakes, principally in southwestern Idaho, and those deposited by streams. The principal part of the soil covering the plains at a distance from the mountains and outside the canyons is of æolian origin, and consists mainly of fine quartz particles.

CHEMICALLY FORMED SUBAERIAL DEPOSITS.

A surface efflorescence of alkaline salts, etc., is unknown on the Snake River Plains. In a few localities, however, on the flood plains of streams—as, for example, along the border of Snake River to the west of Shoshone Falls—the nature of the plants indicates an alkaline soil, and in a few instances white surface incrustations are formed during the summer season. These incrustations, as is well known, are due to surface evaporation. The water from below rises, owing to capillary attraction, as the surface is dried, and being in turn evaporated, leaves its contained saline matter. Without attempting an extended discussion in this connection, it may be stated from observations made in Idaho and elsewhere that soils do not become alkaline if well underdrained; but if there is an abundance of subsoil water it will be drawn to the surface during long-continued droughts and evaporated, leaving the salts it previously held in solution at the surface. The obvious suggestion furnished in this connection by natural conditions is that irrigated land should be well underdrained.

Although what are commonly termed alkaline incrustations are absent from the soils occurring on the Snake River Plains, there is an analogous substance frequently present. I refer to the white deposit to be found almost everywhere on the under sides of loose stones or in the upper portions of basaltic outcrops when covered with loose stones, sand, soil, etc. These incrustations are perhaps most commonly only an inch or two thick, but at times have a depth of several inches, and not infrequently a layer of rock fragments 6 to 8 or more feet thick will be solidly cemented with similar material, forming a breccia. In some localities the surface portion of a bed of pebbles is similarly cemented into a conglomerate. Less frequently the white deposit is largely free of other material, visible to the eye, and forms a subsurface layer of hard, yellowish-white rock 3 to 4 or more feet thick. In certain instances, again, the cavities in the surface portion of a sheet of lava will be filled with similar material.

The most striking peculiarity of these deposits, aside from their white or yellowish-white color, is their occurrence just below the surface, and their absence at a depth of a few feet. As they occur on loose stones, and in surface deposits generally, it is obvious that they are of recent origin, and are probably still forming. This material, as shown by partial analysis, consists essentially of calcium carbonate, and agrees both chemically and in mode of occurrence with similar deposits widely distributed in arid regions.

As to the way in which these lime deposits are formed, it is evident from their mode of occurrence, composition, etc., that they are of the nature of efflorescences. Rain water on percolating downward and more or less completely saturating the soil and upper portion of the rocks beneath is drawn upward again by capillary attraction as the surface dries. Why the deposit formed should consist principally of calcium carbonate is less clear, but the fact seems to be due to the removal and carrying to a distance of the more soluble salts during the downward passage of water. The lime incrustations occur where there is free underdrainage, and the water drawn to the surface is the portion supplied by the occasional rains, which was absorbed by the rocks. The lime deposit is thus washed during each rain and a part, no doubt, removed, but in arid regions a residue remains. Similar incrustations occur, especially in gravel deposits in humid regions, but they are thin and by no means of as common occurrence as in arid regions. There is thus a delicate balancing of conditions: With slack underdrainage, alkaline efflorescences are formed when surface evaporation is active; with free underdrainage, the more soluble salts are removed, and if surface evaporation is active, lime incrustations are deposited; with more abundant rainfall and less surface evaporation, all the material dissolved by percolating waters is carried away.

That the lime deposits referred to are derived in part from the soil is shown by the presence of cemented grains, as has been described in connection with the two soil samples, of which mechanical analyses have been given. In fact deposits of lime 3 or 4 feet thick, which seem to be homogeneous throughout, when digested in acid leave a residue consisting of fine grains of quartz sand, like that composing the bulk of the æolian soils. In such instances it seems that the deposit formed has become so great that the fragmental character of the subsoil is obscured and it appears to be a compact, homogeneous bed of lime.

Not all of the lime deposited as a surface incrustation, however, comes from the soil. The cavities in the outcrops of basalt are frequently filled with similar material, as well as the spaces between blocks of basalt where no soil or but very little is present. Much of the lime in such situations must have come from the basalt itself.

An interesting result of the concentration of lime near the surface, suggested by the occurrence of loosely cemented kernels and sand grains in the samples mechanically analyzed, is that by this process the soil is rendered more resistant to wind erosion, and therefore has a greater tendency to remain in place. The chemical precipitates thus assist vegetation in holding the dust which is spread over the land by the wind.

The surface incrustation just described is sometimes in sufficient abundance to be of commercial importance, and would yield a good lime on calcination, but would probably in all cases contain considerable quantities of sand or rock fragments. Unless these foreign bodies were in considerable abundance, however, they would not detract from the value of the lime for all purposes for which it is ordinarily used.

The deep-blue film described on a former page as occurring on the surface of one of the less recent lava flows among the Cinder Buttes may here be referred to as being due to the process just considered. The blue substance is apparently of the nature of a "desert varnish," and owes its presence on the surface of the lava to the evaporation of water drawn from within the lava itself. The evaporation of the water has seemingly brought about a chemical precipitation of some of the material leached out of the lava and produced a deposit that is practically insoluble in water and hence is not removed by rain. By a similar process the upper surfaces of many of the millions of smooth cobbles of quartzite strewn over the surface of the lake beds in the northern portion of Owyhee County have been rendered dark yellow or brown and occasionally black. This is also a desert varnish, which no doubt is due to a precipitation of salts of iron or manganese on the upper surfaces of the stones; their lower surfaces are not "varnished."

It thus appears that two varieties of surface deposits resulting from the same general process must seemingly be recognized; one produced below the actual surface exposed to the sky and the other on the exposed surface. The deposits produced below the surface, in many instances at least, consist of substances (most frequently calcium carbonate) which are sparingly soluble and which most probably owe their accumulation to direct precipitation of material previously held in solution, while the deposits produced on exposed surfaces result from chemical precipitation and are not dissolved by beating rain. These two varieties of surficial deposits, due most conspicuously to the action of atmospheric agencies, frequently occur together, but the most characteristic examples are found in separate localities. The far-reaching process here touched upon, by which a concentration of sparingly soluble substances is brought about on rock surfaces or in their surficial portions while more soluble substances are carried away in solution, produces various changes dependent on the resultant, so to speak, of the several conditions or agencies involved. Not only do soils and flat-rock surfaces experience the changes referred to, but talus slopes and the faces of precipices are similarly acted on. In some instances along the border of the canyon of Idaho the aprons formed of dislodged fragments at a depth of a foot or two below the surface are firmly united with a calcareous cementing material, which includes dust particles. The faces of bold escarpments of tuff, consisting largely of fragments of glassy basalt, which occur on each side of Snake River from 1 to 2 miles above the mouth of Salmon River exhibit a surface hardening which has led to conspicuous changes through the erosive action of dust- and sand-charged winds. The resistant surface has been broken in many places, and the softer material beneath scooped out so as to form alcoves and grotto-like recesses of various shapes and sizes. The appearance of the rugged grotto cliffs, as they might be termed, is most peculiar and interesting.

Possibly a suggestion in reference to the wide influence of the process of subaerial precipitation just referred to may not be out of place. The formation of subsurface deposits, desert varnishes, etc., depends, as has been stated, on atmospheric conditions, and occurs, as might easily be shown, on a large variety of rocks. Probably there is no rock that is sufficiently resistant not to yield to the action of percolating water and, under the requisite climatic conditions, become hardened at the surface. The marked difference in results produced in arid and humid climates has been referred to. In arid climates absorbed water is drawn to the surface on account of capillary attraction induced by surface evaporation, and precipitation results, but when there is free underdrainage the more soluble portions of such precipitates are removed in solution. In humid climates all the material dissolved out of the rocks is normally carried away in solution, and rock decay progresses with comparative rapidity. In regions having an arid climate, as is well known, rock decay progresses slowly, and the principal method by which denudation is initiated is rock disintegration, or the breaking of the rocks into fragments through the influence of changes of temperature, freezing of absorbed water, etc. The conspicuous differences resulting from the same process when the conditions are varied, so frequently exhibited in the delicate adjustment observable throughout nature, are here well illustrated. Under humid climates rock solution leads to widespread and frequently deep rock decay, and surface terranes are rendered soft and readily crumble. The ultimate result, so far as most rock species are concerned, is a reddish clay or terra rossa. Under an arid climate most rocks become hard at the surface and not only do not crumble on account of the removal of material in solution, but by its reprecipitation at or near the surface are rendered resistant to mechanical agencies, such as the wind, which tend to wear them away. The colors of the rocks are not generally conspicuously altered by this process, and the color of the fragmental products are such as are inherent to the parent rocks. The soils are light colored, usually light yellow, and terra rossa is absent.

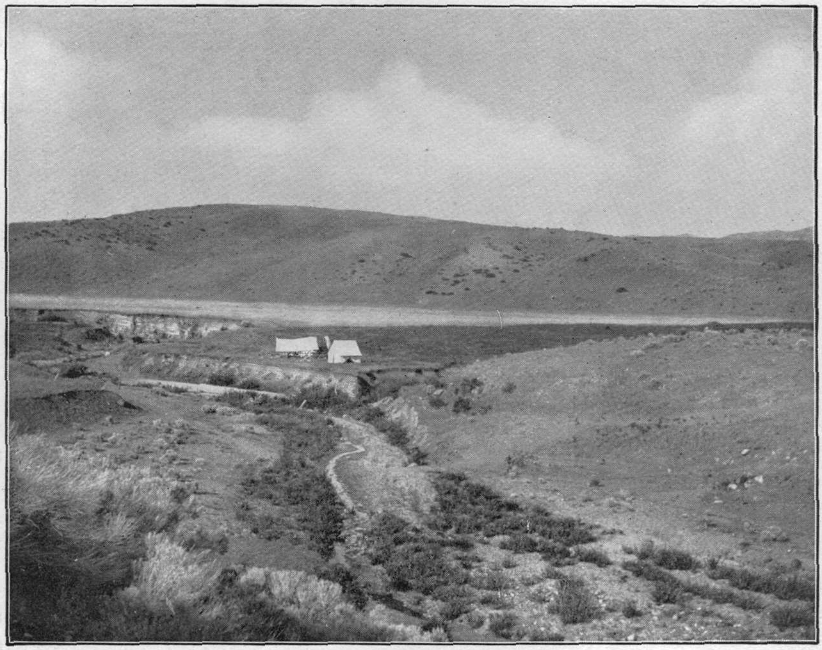
RECENT SOIL EROSION.

Reference has been maae on a previous page to small valleys in the area underlain by the Boise granite, which are so deeply filled with débris that they have no surface streams, all of the water that comes to them being absorbed by the unconsolidated material forming their floors. The valleys of this description were, up to within about 15 or 20 years, much more numerous than at present. A recent change has occurred which has caused fresh stream channels to appear in previously streamless depressions, gulches, etc., and even on hillsides formerly completely soil-covered. The change referred to is well known to ranchers and others, and is said to have been begun about 1880. At present there are numerous lateral depressions and gulches, branching from the larger valleys, which have fresh channels cut in their floors and in the sides of the adjacent hills, that are from 10 to 15 or more feet deep and a mile or more long, with perhaps several branches, but which previous to the date just given are known to have had smooth, unbroken contours. In several instances well-traveled roads have been crossed by these gullies, necessitating a wide detour to get about a steep-sided gulch from 10 to 15 feet deep. It does not require historical evidence, however, to show that the gullies referred to are recent. They are fresh cuts, with nearly vertical walls of loose earth, and at their heads begin abruptly. Each rain that comes is assisting in their extension and enlargement. At certain localities, which are unfortunately numerous, cultivated fields have been cut across by gulches formed during the last few years, which are still being enlarged. A photograph of one of these is presented on Pl. XXV, *A*. One conspicuous result of the more complete drainage of valley bottoms by modern rill channels is the dying out of formerly luxuriant meadows of wild grasses and their replacement by sage brush. The rapid erosion in progress is destroying much of the finest land in the mountain valleys lying north of the Snake River Plains, and its prevention is an exceedingly important problem, which demands immediate attention.

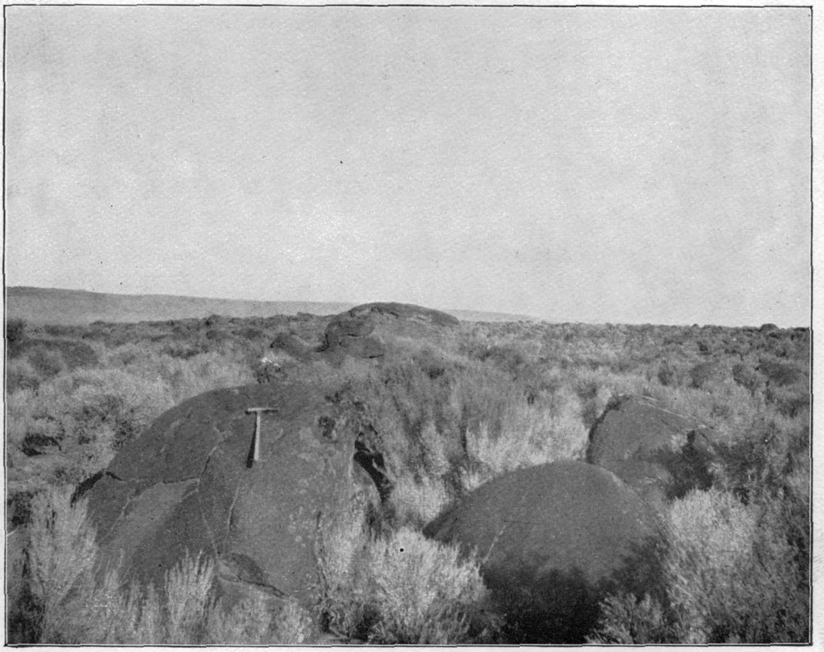
The beginning of this recent erosion is correlated with the introduction of sheep in large numbers into the country, and is but another phase of the widespread destruction for which sheep raising on a large scale is responsible. The cause of the washing is mainly the destruction of the once abundant bunch grass by the close grazing of sheep.

It might, perhaps, be thought that if sheep raising could be discontinued or properly controlled the destructive washing of the land incident to it under certain combinations of soil and climatic conditions would be arrested, but the process of erosion once started is difficult to stop, and will continue even if the sheep were removed. Successful attempts to check the work of rills where they are rapidly deepening their channels have been made by a method that is simple and efficient. Near the barrack at Boise small dams placed in the streams, with suitable precautions against erosion on account of the plunge of the water, have led to the deposition of gravel and sand and caused it to form broad fields, which will no doubt in time be cultivated. Under this method, however, erosion still progresses above where the water is ponded and the destruction continues, and will necessitate the building of additional dams lower down the stream courses or an increase in the height of those already constructed. Probably the best method of checking the work of the rills and brooks is to plant trees in them, and especially the planting of cottonwood, willows, etc., in belts across the channels where widest. By systematic attempts of this character much of the damage that threatens can be cheaply and efficiently checked.

One result of the cutting of channels through previously completed flood plains which are under cultivation, as in the example shown on Pl. XXV, is the more complete subdrainage of the portions of the fields remaining, thus necessitating additional irrigation. In many such instances the construction of willow dams sufficient to check the flow of the water and cause deposition would also lead to lateral percolation from the streams, which would be equivalent to subirrigation. The destruction by recent rill erosion is not confined to the upland valleys, but, by reason of the immense amounts of gravel and sand swept down to the larger streams, causes them to spread out sheets of this material on their flood plains, which bury the vegetable mold and greatly impair and even destroy the agricultural value of the land.



A. RECENT STREAM EROSION NEAR HOWELL, IDAHO.



B. WATER-WORN MASSES OF BASALT IN SNAKE RIVER CANYON NEAR HAGERMAN, IDAHO.

PART II.—WATER RESOURCES.

INTRODUCTION.

SURFACE AND SUBSURFACE WATER.

The water supplied to land areas comes from the atmosphere and in part flows over the surface and in part sinks below the surface. What relation the surface "run-off" shall bear to the underflow depends on a variety of climatic, topographic, and geologic conditions.

Of climatic conditions one of the most important is the rate at which water is supplied. If, for example, the same amount of water is precipitated in an hour, as during a torrential rain, that at another time falls in several hours during a gentle rain, the ratio of the run-off to the amount of water sinking into the earth is far greater in the first than in the second instance. The length of the periods between rains, rate of evaporation, etc., are also important factors in the process of dividing the water that reaches land areas into surface and subsurface portions, but need not be discussed at this time.

Among topographic and geologic conditions of interest in this connection the principal ones are surface slope and the porosity or fissured condition of the surface rocks, including the sheet of rock waste which generally forms the surficial layer of the land. The degree of slope varies from vertical to horizontal. On cliffs and steep slopes generally the run-off is large in proportion to the amount of water that is absorbed, while on plains there may be no means of surface escape and all of the water precipitated may sink into the rocks or be evaporated. The degree of porosity varies from that of compact rocks, which are practically nonabsorbent, to that of loose soils, sands, etc., which drink in all the water that falls upon them. The more compact rocks are frequently fissured or jointed and thus afford an easy downward passage for all of the water reaching their surfaces.

In southern Idaho the annual precipitation is small and occurs at intervals, and although in part descending as torrential rains, a much larger portion is furnished by gentle rains and by the melting of snow. The climatic conditions thus favor the absorption of the water by the rocks rather than surface run-off. The same result is favored also by the presence generally of a thick sheet of porous rock waste, especially in the mountains and foothills, and by the porous or fissured condition of the rocks forming the surfaces of the plains. On the Snake River Plains there is practically no run-off, all the water reaching them from the atmosphere not evaporated or absorbed by plants disappears below the surface.

The run-off is contributed directly to surface streams, but these would be intermittent, flowing only during and immediately following rains or the melting of snow and ceasing to flow during intervening periods, were it not for the return to the surface of previously subsurface waters. This return is accomplished in part by seepage from the sides and bottoms of valleys, and in part by springs. The manner in which water is retained for a greater or less time by porous and fissured rocks and rock waste and returned more or less gradually to the surface thus becomes important in the study of both the surface and subterranean water supplies. It is to the subsurface or subterranean waters that attention is here invited.

The water absorbed by porous material, such as constitutes soils, sand dunes, etc., is in part returned to the surface by passing upward, owing to what is termed capillary attraction, as the surface dries, and in part through the action of plants in absorbing water through their roots and transpiring it through their leaves. The latter process is an important adjunct to direct evaporation, and in densely plant-covered regions the quantity of water so passing into the air is frequently greater than that escaping by direct evaporation, even from freely exposed water surfaces. The water not removed by evaporation or by plants is in part retained as soil moisture, and if there is an excess above what the soil can permanently hold as a film on the surface of the particles composing it, such excess descends or moves laterally, under the influence of gravity, to a lower position and is available for the supply of springs. Water entering fissures in rocks evidently has, in general, greater freedom to flow than that in porous material, and in many instances is also an important source for the supply of springs.

The force which causes subterranean water to flow is the same that controls the movements of surface streams, namely, gravity, but certain modifications due to difference in temperature, capillarity, etc., fully discussed by King,[a] will not be considered at this time.

SPRINGS.

Four varieties of springs may for convenience be recognized, namely, hillside, canyon, fissure, and cavern springs, the classification being by reference to types and with the understanding that more or less intermediate gradations occur between well-characterized examples. In the case of each variety there is a wide range in volume, the minimum in each case being what is termed seepage.

[a] A highly instructive discussion of the way in which water percolates through porous material may be found in a paper on the "Principles and conditions of the movements of ground water," by F. H. King, in the Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, 1899, pp. 59-294.

HILLSIDE SPRINGS.

Examples of this type occur where thick beds of porous material, such as sand, loose-textured soil, disintegrated rock, etc., occur on the border of valleys or form uplands on which precipitation takes place and the water percolating downward through the interspaces in the receiving layer meets a less pervious layer and flows laterally along its surface, becoming more or less concentrated, and emerges at or near the base of an escarpment as a stream. The presence of a retentive layer in the uplands bordering a depression, at a horizon above its bottom, however, is not essential. As is well known, when precipitation is sufficiently abundant the subsoil is saturated below a certain horizon. During heavy or long-continued rains the soil and subsoil may be saturated from the surface downward, although under certain conditions there is a lower limit to saturation above the base of the porous layer. After the supply of water at the surface ceases the upper limit of saturation or the "water table," as it is termed, subsides. The water table is not a plane, but an undulating surface, which rises beneath hills and is depressed beneath valleys. As water escapes by seepage, or when more concentrated, as springs, the water table is lowered and at the same time flattens, tending to become a plane surface where it subsides below all surface depressions. So long as the water table is above the bottom of a surface depression, such as a valley, hillside springs are possible.

These conditions are indicated in fig. 2, which is an ideal vertical section across a valley with a stream flowing down it, excavated in porous material.

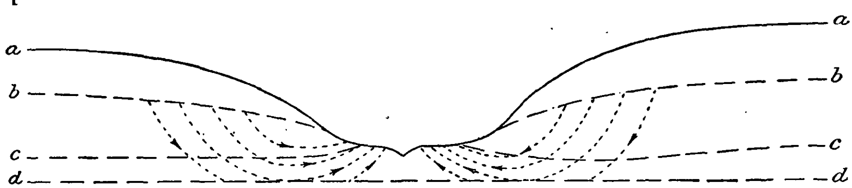


FIG. 2.—Section showing relation of hillside springs to water table.

The water falling on the surface *aa* penetrates downward, and at a certain stage after the supply ceases the upper surface of the saturated subsoil may be assumed to have the position *bb*. At such a stage the water flows toward the valley along the courses indicated by the dotted lines and escapes most commonly by seepage, but if concentrated in more definite channels forms springs. Should the water table be depressed to the line *cc*, the springs would cease to flow and lateral seepage from the stream occupying the valley would occur. Under these conditions the surface of saturation is higher beneath the valley than beneath the adjacent uplands. So long as a stream continues to flow, unless its bed is impervious, the water table can not be depressed below its bottom.

When the stream bed is dry, however, as so frequently happens in arid regions, the water table may subside below the bottom of its bed, or to *dd*, and become a plane surface; or, as really happens for various reasons, may disappear, there being no saturated subsoil layer.

Owing to variations in the conditions on which the lives of hillside springs depend, they commonly exhibit seasonal variations in volume, and perhaps also in temperature.

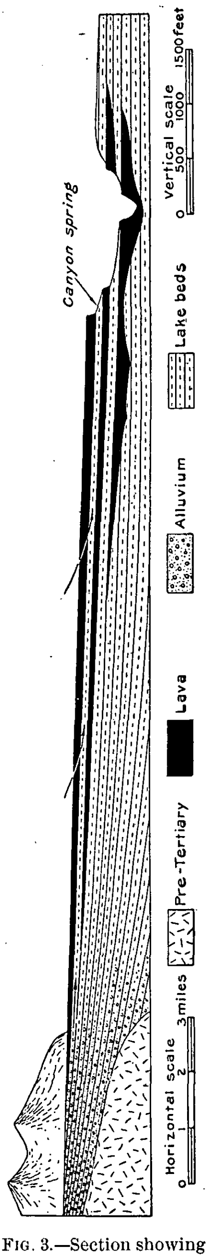


FIG. 3.—Section showing conditions favoring the occurrence of canyon springs.

CANYON SPRINGS.

When water disappears beneath the surface of the land, it may enter pervious stratified rocks and flow through them for long distances, finally emerging where the water-carrying beds have been cut across by erosion or in other ways furnished with openings through which water may escape from them. One of the most common methods by which this result is attained and one abundantly illustrated in southern Idaho is by the excavation of canyons in nearly horizontal stratified rocks, some of the larger of which are water charged. Although at times having essentially the same characteristics as hillside springs, the type here referred to, in numerous conspicuous examples, depends on markedly different conditions. The water is conducted to a distance through pervious beds having impervious floors, and may or may not be covered by impervious layers. Owing to freedom of escape even when an impervious cover is present, the water is not usually under pressure except such as results from retardation due to friction of flow. There is no storage reservoir as in the case of fissure springs, described below, and if the source of supply fails the springs run dry.

While the underground courses of the waters supplying hillside springs are commonly short, being measured usually by rods, the journeys of the waters feeding canyon springs may be long, and in many instances are measurable in miles or tens of miles.

The conditions favoring the occurrence of canyon springs are illustrated by the section forming fig. 3, which, although ideal, indicates in a general way the mode of origin of the copious springs in Snake River Canyon, which are the type of the class under consideration.

At the left of the diagram an attempt has been made to indicate the presence of a mountain valley deeply filled with alluvium, beyond which rises a deeply sculptured, bordering mountain spur. The gravel in the valley extends beneath the plain, perhaps merging with lake beds, and forms a porous layer which is underlain by an impervious bed and covered by a lava sheet. This is a special case, to be sure, but the beds beneath the plain may be of any nature, the essential feature being that one of them is so situated as to become water charged and to slope toward a canyon which is cut below its base. The bed above the pervious layer in the case of the Snake River Plain is composed of fissured lava, and permits all the water falling on it to have ready access to the porous bed beneath. In fact the fissured basalt at times furnishes the pervious bed, being underlain by a water-tight stratum. Water coming to the exposed portion of the pervious bed in the mountains descends into it, as does also the water supplied to the surface of the plain, as is indicated by arrows. Where the pervious bed appears in the side of a canyon, springs emerge.

The lost rivers of southern Idaho contribute to the support of the springs in Snake River Canyon, but this source of supply is augmented by the precipitation on the adjacent plain. The flow is constant, owing to the retention of the waters in porous beds, being in part supplied by hillside springs in the mountains, but the flow is regulated more largely by the extent of the water-charged beds. In general, canyon springs are perennial and exhibit no seasonal changes in volume or temperature.

FISSURE SPRINGS.

If a pervious layer of the nature of those supplying canyon springs is not cut by erosion, or in some other way furnished with means of escape for its contained waters, it is evident that it may become water filled. The water at any point in the porous bed will then be subject to the pressure of water at higher levels, and be forced in any direction in which an opening may occur. In nature such means of escape are sometimes provided by fissures. If a fissure leads from such a reservoir to the surface and the pressure on the water is sufficient, a fissure spring results. The conditions which lead to the occurrence of fissure springs are seldom, if ever, exposed so as to be studied in detail, and are presumably varied. In many instances it is probable that a porous stratum is absent, and the water finds its way through intersecting fissures. However diverse the conditions, it is evident that the water which rises and overflows is under pressure, and that a reservoir is present. By this it is not meant that anything like a cavern necessarily or commonly occurs. Usually porous rocks play the rôle of a reservoir. Fissure springs, like all other springs, are dependent on precipitation for their water supply, but owing usually to the small size of the conduits leading to the surface, in comparison to the volume of the reservoir, they are perennial and do not fluctuate in volume or temperature with seasonal changes. Like canyon springs, those of the type here considered are supplied from a distance and may exist in arid regions. They are frequently of common occurrence where broad sheets of stratified rock have been broken, and especially where faults occur. Owing to the depth from which their water frequently rises its temperature is often high. Springs of this type are common in the Great Basin, and occur also throughout the similarly disturbed region about it. In southern Idaho numerous examples are present, as is shown by the several warm and hot springs known.

CAVERN SPRINGS.

In limestone regions especially, water percolating through the rocks, on finding its way initially through fissures and joints, dissolves the rocks and opens out galleries. These galleries, such as Mammoth Cave in Kentucky, for example, may have lakes in them, or the water may flow freely; in either case a spring is formed where the water emerges in a neighboring valley. If a subterranean lake is present it may supply a conduit with water under pressure, and give origin to a fissure spring. With or without a lake present, springs in the sides of valleys may be found which simulate canyon springs. Caverns originating in any manner may exert an influence on subterranean drainage in the ways just suggested.

Cave springs are not known in southern Idaho, and further discussion of the conditions on which they depend need not be indulged in at this time.

Similar to cave springs are the streams which sometimes gush out of glaciers, but these have no connection with the subject in hand.

TEMPERATURE.

In all springs the temperature of the water is regulated by the temperature of the rocks from which it is derived.

In this connection certain well-known facts may be restated. The seasonal variations in temperature in temperate regions extend downward into the earth to a depth of about 50 feet, and at that depth there is a horizon of no seasonal variation which has a temperature corresponding with that of the mean annual temperature at the surface. Below this stratum of no seasonal variation the temperature increases with increase in depth, at the rate in general of about one degree Fahrenheit for each 60 feet.

Hillside springs, being of local origin and the waters supplying them not descending deeply, usually have about the mean annual temperature of the region where they occur. At Boise this is approximately 50° F. In summer such springs are colder and in winter warmer than the air. They may in fact have a temperature even in summer but little, if any, above that of freezing water, as, for example, where a soil or the surface sheet of rock waste becomes deeply filled with ice during winter, which melts slowly during summer, and yields nearly ice cold water. Hillside springs supplied with water which descends to a depth of less than about 50 feet may be expected to fluctuate somewhat in temperature from season to season, but are not quickly responsive to surface changes. Those which derive their water from a depth of approximately 40 to 60 feet and are of sufficient volume not to be sensibly altered in temperature on nearing the surface will show no seasonal variation. Canyon and cave springs perhaps, as a rule, are supplied with water which has descended more than 50 feet into the earth and possibly may have reached a depth of several hundred feet, and their temperatures should, therefore, be somewhat higher than the mean annual temperature of the region where they emerge, but they will not be characterized by a high degree of heat unless they come from abnormally warm or hot rocks. In the typical canyon springs in southern Idaho the temperature is about 60° F., or 10° above the mean annual temperature, and shows no seasonal variation. In these and other similar instances, however, in which springs are supplied by subterranean drainage, particularly of broad sheets of pervious rocks, there may be some addition of hot water rising through fissures in the rocks beneath. That is, fissure springs may contribute to the supply of subterranean streams in the same way that they do to surface streams.

Fissure springs are supplied from depths ranging from a few score feet, or even less, to hundreds of feet, and come to the surface with all variations in temperature, from that of the mean annual temperature of the region where they occur up to the boiling point for the elevations where they emerge. Those of sufficient volume and manifest freedom of flow indicate closely the temperature of the rocks from which they are supplied, and the depth of their source can thus be approximately determined, if the rate of increase of temperature with depth for the locality is known. The rise of temperature with increase in depth below the stratum of no seasonal variation, however, is not the same in different regions, and may be greatly modified by local causes, such, for example, as the presence of still hot volcanic rocks below the surface. The hot springs in Clover Creek Valley, near Blanche, and again the hot springs at Soda Springs, Bannock County, Idaho, are situated near volcanic craters that were recently active, and no doubt derive their heat from hot volcanic rocks at no great distance below the surface. The temperature gradient beneath the Snake River Plains, as indicated by the meager data in hand, is above the normal. As will be shown later (p. 173) the wells along the Oregon Short Line Railroad give an increase in temperature of 1° F.

for each 45 feet below the stratum of no seasonal variation. The canyon springs also, on the supposition that the rate of increase of heat with depth is normal, indicate a higher temperature than would be expected from the depth of the localities where they emerge below the level of the adjacent plains.

Chemical changes, as well as movements in rocks, may also produce abnormally high temperatures, which might be imparted to the waters of any of the types of springs enumerated above, but which are most apt to be felt by fissure springs.

The phenomenon of a hot and a cold spring near each other, which sometimes occurs, can be easily explained by reference to the diagrams given above. A hot fissure spring supplied from a deep source may evidently occur near a cold hillside spring, the association of the two being simply accidental.

There is much that is interesting in the chemistry of spring water, and in the way in which hot springs especially deposit material—most commonly calcium carbonate and silica—on reaching the surface, but this phase of the study can not be considered at present.

SIMILARITY BETWEEN SPRINGS AND WELLS.

Each of the varieties of springs enumerated above is represented by wells.

The ordinary wells, especially in humid regions, are supplied by percolation from the adjacent portions of the porous beds they penetrate, and are similar to hillside springs. When they are supplied at a depth of about 50 feet below the surface their temperature, when inclosed, is approximately that of the mean annual temperature of the locality where they occur. The water in them rises and falls with variations in the position of the water table, and if the surface of saturation sinks below their bottoms they become dry. Deep wells, usually obtained by drilling, which penetrate pervious strata in which the water stands at a definite horizon and which in many instances, as is frequently stated, can not be lowered by pumping, are homologous to canyon and cave springs. The water is either not under pressure or not under sufficient pressure to cause it to rise to the surface, and has a constant temperature which is somewhat higher than the mean annual temperature of the locality. Artesian wells are essentially artificial fissure springs, and have a constant and frequently a high temperature.

RELATION OF SPRINGS TO CLIMATE, TOPOGRAPHY, AND GEOLOGY.

In addition to the fact that all springs are dependent on precipitation for their water supply, there is a relation between the amount of water supplied and the topographic and geological conditions which determines what variety of spring will result.

In humid regions the subsoil is normally saturated below a certain depth (the water table) and hillside springs are of common occurrence. In such regions, also, water is nearly everywhere obtainable by means of wells of small depth. In arid regions the subsoil is, as a rule, not saturated, owing not only to downward percolation, but also to the drying of the surface and the passage upward of absorbed water, through capillary action; and surface wells are not successful and hillside springs are practically absent. In both humid and arid regions either canyon or cave springs are possible, the control passing to topographic conditions; that is, the depth to which the rocks are cut by canyons and valleys determines whether the water contained in previous strata or caverns shall outflow or not. In humid regions the general lowering of the surface by denudation keeps pace more or less closely with the downcutting of stream channels, and deep canyons do not result, except under certain highly special conditions. The valleys, as a rule, have flaring sides, and are encumbered with débris which tends to mask the presence of springs. Although springs of the type of canyon springs do occur in wet regions, they are not common or characteristic. In arid regions, however, high above sea level, which are crossed by rivers rising in well-watered uplands, deep canyons with vertical or nearly vertical walls may be produced, and it is in such instances that canyon springs reach their most typical development. In a large section of the arid region, namely, the Great Basin, canyon springs are absent for the reason that the streams are not permitted to excavate deep channels. In the Great Basin the valleys are being filled or upgraded, and no removal of material from the basin occurs, except in a small way through the agency of wind, and this is probably compensated for by the dust brought in in a similar manner.

Fissure springs are possible when water exists in pervious rocks under sufficient pressure to force it to the surface if an opening is provided. Such openings are produced by movements in the earth's crust, and regions not affected by breaks or faults, although water-charged beds may exist beneath them, are without fissure springs. Fortunately the rocks beneath large portions of the arid region have been broken, and the characteristic springs, particularly in the Great Basin, are due to this cause.

The favorable result of a combination of climatic, topographic, and geologic conditions is illustrated by the fact that canyon and fissure springs are not dependent on the precipitation in the immediate vicinity of the localities where they occur, but their waters are conducted underground perhaps for hundreds of miles without loss by evaporation, and may rise in a desert locality and give origin to an oasis. But for the fortunate combination of conditions referred to, much of southern Idaho, in common with nearly all of the arid region west of the Rocky Mountains, would be far less suitable for habitation than it is at present, and much of it would be practically impassable to travelers.

DEVELOPMENT OF SPRINGS.

The conditions on which the several varieties of springs described above depend at once suggests methods by which their flow may be increased, or new springs produced. This matter will be considered later in more detail, but I may call attention briefly to the self-evident fact that to increase the flow of a hillside or canyon spring the proper method would be to imitate nature and excavate tunnels or horizontal wells. As fissure springs rise through more or less vertical openings, it is obvious that in order to obtain water from subterranean sources where it exists under pressure vertical wells must be put down. Such *artificial fissure springs* are termed *artesian wells.*

ARTESIAN WELLS.

REQUISITE CONDITIONS.

The governing and qualifying conditions pertaining to artesian wells have been described by many writers, and are noted in a previous report relating to Idaho,[a] and need not be repeated here except in a very general way, to serve as an introduction to what follows.

The presence of water in a pervious stratum is usually dependent on the exposure of a portion of the bed at the surface, so that it may receive the direct precipitation from the atmosphere or be charged by percolation from surface rock waste, seepage from streams, etc. A pervious bed may also become water charged by leakage from other beds, as has been explained by Chamberlin.[b] The geological conditions which lead to the filling of pervious beds so inclosed that the water can not escape from them, at least not freely, are various. The conditions most frequently occurring are illustrated by what are known as artesian basins and artesian slopes.

In an artesian basin the strata containing one or more pervious beds—we will assume, for simplicity, that but one is present, with a water-tight bed above and below—have the form of a basin, at some portion of the rim of which the pervious bed comes to the surface and receives sufficient water to saturate it. An illustration of this structure may be had by spreading a layer of sand over the interior of a saucer and placing another saucer within it, both vessels being in an upright position. If water is poured into the lower saucer until the spaces between the sand grains are filled and a hole is drilled in the bottom

[a] I. C. Russell, Water-Supply and Irrigation Papers U. S. Geol. Survey No. 54, 1891. Bibliography on p. 130–131.

[b] T. C. Chamberlin, The requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125–173.

of the upper dish, the water will rise through it. In such an experiment the saucers represent the impervious and the layer of sand between them the pervious beds in an artesian basin. These conditions are indicated in the following ideal cross section of an artesian basin, in which the pervious bed *A* is water charged from the rain falling on its exposed rim and percolates downward until the bed is saturated to the impervious rocks *B*. A hole drilled at any point, as *D* or *E*, within the basin will permit the water to rise, owing to the presence of water at higher levels, and to overflow at the surface, providing the elevation where the hole is made is below the level of the lowest point in the rim of the basin by means of which the water is enabled to overflow. The upper limit of saturation in the pervious bed is termed the artesian head. In the diagram this horizon is indicated by the line *CF*, and water will rise and overflow within the basin at any locality where the surface is below this level.

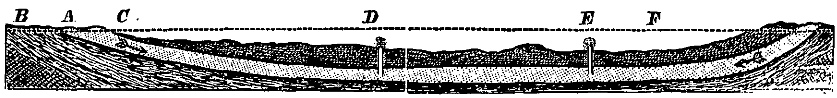


FIG. 4.—Section of an artesian basin.

Artesian basins are usually produced by a gentle downward bending of rocks containing alternating beds of pervious material, such as sand or sandstone, and impervious beds, such as clay and shale. There are many qualifying conditions, however, as has been shown by Chamberlin in the article referred to above.

The essential condition which causes water to rise and overflow in the case of an artesian well is that it shall be under sufficient pressure. In order to insure this condition, however, a complete basin need not be present. This is indicated in fig. 5, showing wedge-shaped pervious beds so exposed at the top as to become water charged and inclosed below in impervious material. Such an occurrence might be termed an "artesian wedge."

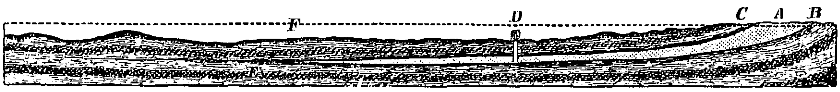


FIG. 5.—Section of an artesian wedge.

In each of the two illustrations just given the pervious beds are saturated and the water contained in them is essentially at rest; that is, hydrostatic pressure is what causes a portion of the water to rise. In order that a well may continue to flow with undiminished pressure, it is evident that the supply must be renewed.

Hydrostatic pressure in a saturated stratum, or reservoirs, is not the only cause, however, by which wells may flow. Another method of flow is illustrated by what is known as an artesian slope.

Water flowing through an inclined pervious bed meets with resistance due to friction of flow. If the pervious bed is included between two impervious beds, as, for example, in the ideal section shown in fig. 6, and a hole is drilled from the surface down to the water-charged layer, as at *x*, the friction of flow between *x* and *g*, where the water naturally escapes, may be sufficient to retard the current and cause the water to rise in the hole and possibly overflow. The reason is simply that the resistance met by water rising in the hole drilled at *x* is sufficiently less than the resistance between *x* and *g* to permit it to rise to the surface. The moving force in this instance, as in an artesian basin, is hydrostatic pressure. This matter has been discussed in the report on Nez Perce County, referred to above, where reference to other papers on the same subject may be found.

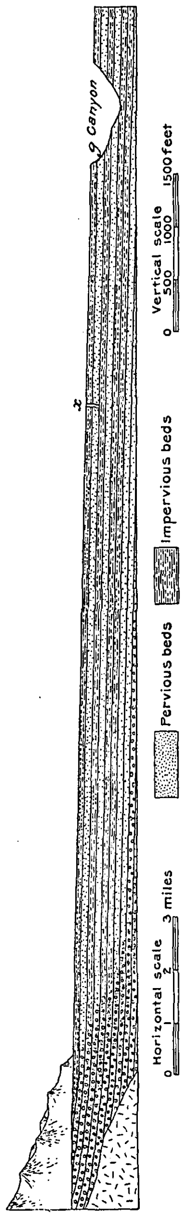


FIG. 6.—Section of an artesian slope.

In the case of an artesian basin the pervious layer is essentially a filled reservoir, and the water is at rest until an opening is made in drilling a well; in the artesian slope the water is flowing. These statements, to be sure, need to be qualified to be strictly accurate, but they express the leading difference referred to. The success of wells drilled so as to tap an artesian slope depends not only on the quantity and permanence of the water supply, but on the degree of resistance the water meets with in passing through the permeable stratum. The greater the resistance within certain limits, the higher the water will rise in wells leading to the surface.

It is not to be understood that all of the various ways in which subterranean water may be brought under pressure so as to be available for artesian wells have been enumerated. On the contrary, the only attempt here made, is to cite certain well-known principles for use later.

AVAILABLE WATER ON SNAKE RIVER PLAINS.

The most serious economic problem which confronts the people of southern Idaho is how to obtain water for irrigation and for town and household purposes. The soil is almost universally of good quality, level land that could be easily tilled is abundant, the sunshine is brilliant, the temperature favorablē, but the critical condition, and the one that controls not only agriculture, but settlement for any object, is the prevalent scarcity of water. Under these conditions, water is more valuable than land. In fact, land, however well situated and however rich, is valueless for farming purposes unless water can be brought to it.

The water available for irrigation may be conveniently classified under three heads, namely, surface streams, springs, and wells. Direct precipitation, averaging as it does less than 3 inches during the growing season, is too small to permit successful agriculture without irrigation, except, possibly, in certain localities where the soil is of such nature as to absorb and retain the winter supply.

SURFACE STREAMS.

The greatest source of water supply for the Snake River Plains, and the one first to be utilized, is to be found in the streams which, rising in the neighboring mountains, flow to or across them. The quantity of water reaching the plains in this manner and the various ways it can be most economically diverted and used for irrigation have been investigated by the State engineer of Idaho, and the conditions existing are described and discussed in a series of reports. One of these, the biennial report for the years 1899 and 1900, by D. W. Ross,[a] is remarkable for its breadth of view and thoroughness, and will prove invaluable not only to individuals and companies directly interested in irrigation, but should serve as a guide to the legislature of Idaho in framing wise laws to govern the uses to be made of the scant water supply.

The central plain of southern Idaho has an extent of about 20,000 square miles. The surface streams available for irrigating this great tract are Snake River and its tributaries, together with the "lost rivers" which fail to reach the main drainage channel. While considerable portions of the plains are rocky and entirely unsuited for agriculture, and other portions, also large, are too high above the streams to be irrigated, there remains more good land which can be reached by canals than can be brought under cultivation by the use of the water carried by all the streams during the growing season.

All of the smaller streams that reach the Snake River Plains from either the north or south have been fully utilized, except the Bruneau River, which in summer still discharges about 400 cubic feet per second into Snake River. The waters of Snake River above American Falls are largely utilized, about 211,000 acres being irrigated, of which about 200,000 acres are in the valley proper. The great waste of water that accompanies the irrigation of this land is forcibly stated by Ross. In spite of the large demands made on Snake River in the

[a] Biennial Report of the State Engineer to the Governor of Idaho for the year 1899-1900: [Boise] 1901, pp. 1-101, 6 plates and 3 maps.

portion of its course referred to, a minimum of over 5,000 cubic feet per second continues on below Montgomery Falls. From American Falls westward to the Idaho-Oregon boundary Snake River is in a canyon, and practically no use is made of its waters for irrigation. On Boise River, from the point where it emerges from the canyon portion of its course, just above Boise, to its mouth, many canals have been constructed for the diversion of its water, and 61,000 acres of land are irrigated, but much good land remains for which there is at present no water available. This is the largest tract of land under irrigation in Idaho. Payette River is utilized in a similar way and made to water 28,000 acres of land.

The utilization of the easily available water supply of the surface streams has thus far been made principally by individuals and small companies. The development of this branch of the water resources in a more comprehensive and economical way, based on a thorough understanding of the conditions, has recently attracted attention, but is not yet fully initiated. This broader view of the problem has been grasped by the State engineer, and comprehensive plans for its elaboration have been outlined. The larger tract of land, which, so far as engineering questions are concerned, can be watered by diverting Snake, Boise, and Payette rivers, as shown on the maps accompanying the report of the State engineer just referred to, is about 1,800,000 acres. Such measurements of these rivers as are available, however, indicate that not over half of this area, or, in round numbers, 1,000,000 acres, can be supplied with the requisite amount of water during years of average precipitation. Great fluctuations in the amount of water flowing through the river channels during the growing season, however, occur from year to year, and the amount of land that can be continuously cultivated without loss during years of minimum precipitation is probably much less than the area just stated. Including also the smaller streams, an estimate shows that when all available water in surface streams is economically used about one-twelfth, or, we will assume, 8 per cent of Snake River Plains can be cultivated. It must be remembered that this is a rough estimate, based on insufficient data, but I believe it is too liberal. A safer estimate, considering all the difficulties and uncertainties attending large irrigation schemes, is probably that one-twentieth, or 5 per cent of the portion of the Snake River Plains where favorable soil conditions occur, may ultimately be irrigated from surface streams.

The lessons of public interest which the study of the surface streams clearly indicates may be briefly stated as follows:

First. Water being highly valuable and an inheritance of the people in common, the strictest economy in its use should be obligatory. No more water should be used than is essential to proper cultivation; but in this connection a natural adjustment will no doubt in part be reached, since water above a certain definite quantity skillfully applied is injurious to crops, and brings about cumulative difficulties in the way of concentrating alkaline salts in the soils.

Second. The canals and ditches, and in fact the entire practice of irrigation, should be under the control of a skilled and efficient engineer, in order that water may be applied to the best land in proper quantity, all of the available supply utilized, and loss by evaporation and seepage reduced to a minimum.'

These conclusions, although sufficiently obvious in the abstract, become painfully apparent to one traveling through even the most productive portion of southern Idaho. It is safe to say that less than one-half of the service is obtained that the waters now flowing through canals and ditches might render under skillful management. Waste is everywhere conspicuous. The ignorance, carelessness, and greed of the people are disheartening to one who endeavors to point out additional sources of water supply. Obviously the first and paramount duty of the people, not only in Idaho, but generally throughout the arid regions, is to employ economically the water now available in surface streams.

An increase in the supply of water flowing through surface streams during the growing season, as has been pointed out by Ross and others, may be had by storing the water which runs to waste between the seasons when it is needed for irrigation. It is in this direction that the greatest addition to the amount obtainable by diverting streams is to be expected. For this purpose suitable reservoir sites must be available, situated where they can be filled during the winter season, and where desirable land exists at lower levels over which the water can be spread. This again is an engineering problem of high order, and one beset with difficulties and dangers. Some attempts have already been made in the direction of storing the winter flow of the streams, but not always wisely or well, and much more is to be expected. The cost of such enterprises is usually great, and it is evident that many favorable plans will have to wait until increase in population and greater demand for farm products justify the large initial expense.

When all of the water furnished by streams during the growing season has been judiciously applied in irrigation, and all of the flood water that it is practicable to store in reservoirs is made available, there will still remain extensive tracts of excellent agricultural land unprovided for. Besides the need of water for irrigation, there is a great and constantly increasing demand for water for town and household purposes. With the hope of supplementing the surface supply attention has been directed to subsurface waters. The chief purpose of the reconnaissance here reported on was to ascertain, so far as the time available would permit, what can be expected from this source. The water supply beneath the surface may for convenience be considered under two separate headings, namely, springs and wells.

SPRINGS.

The water reaching the surface from subterranean sources through natural conduits within the area embraced in the Snake River Plains forms canyon springs and fissure springs. Hillside springs are practically absent, and cave springs are unknown.

CANYON SPRINGS.

Springs of this type occur on Snake River principally between Shoshone Falls and the mouth of Bruneau River, where the stream has cut deeply into the lava sheets and associated sedimentary beds across which it flows. They are confined to the northern side of the river for the reason that the geological conditions on which their existence depends are not present on its southern side. Although much use is now being made of these springs for irrigation, far more water is supplied than is utilized, and the vast source of power they furnish is entirely unemployed. More than this, by excavating horizontal wells or tunnels the water may in numerous instances be made to flow at localities where it will be of greater service than at present.

An attempt to indicate the value of the numerous springs that gush from the north side of Snake River Canyon in their order from Shoshone Falls westward is here presented, but their full importance can only be determined by a detailed survey.

At Blue Lakes the water issuing from large springs situated principally at the head of a side alcove opening from the main canyon is, as already explained, utilized for the irrigation of extensive orchards, which are highly productive.

Below Blue Lakes to the point where the surprisingly great outflow of water occurs at The Thousand Springs, a distance of about 18 miles, there are a few small ranches, which are watered from springs. Although this portion of the canyon was seen by me only from above, I judge there are a number of localities where the water supply could be greatly increased or made to issue at a higher level, and thus be of greater service than at present. This means that not only the flat land due to deposits from the river can be irrigated, but also much of the rough talus slopes. The planting of trees and vines, not in straight rows, but here and there among the fallen blocks of rock, must be practiced in order that the great possibilities of the canyon may be fully developed.

The most remarkable springs of Snake River Canyon begin about 2 miles above where the Salmon River comes in, and extend westward to Bliss, a distance of about 18 miles. Throughout this portion of the canyon springs occur in large numbers, and many of them are of great size. The astonishing volume of the springs which have led to the existence of Box, Little, and Malade canyons has already been referred to. From a locality about 1 mile up the canyon of Snake River, about the mouth of Box Canyon, numerous springs gush out at various elevations up to about 220 feet. It is probable that all of the water issues from a single pervious stratum beneath the rim rock which sharply defines the brink of the canyon, and in descending through the abundant talus appears and disappears perhaps several times. The position of the highest line of springs is plainly marked by the upper limit of vegetation. Half a mile below the mouth of Little Canyon, near the level of the river at its lowest stage, an immense spring of wonderfully clear water of a delicate bluish color rises through a bed of clear white sand, and for this reason is named Sand Spring. This great spring is situated in a slight reentrant of the canyon wall, which indicates the nature of the beginning of a spring-formed alcove.

Opposite the mouth of Salmon River, springs which come to the surface from beneath a lava sheet which has been weathered back from the canyon wall about half a mile have been diverted and are now used to irrigate several small ranches. A picturesque fall which these waters make in descending into the canyon is known as the Snow Bank. This is the east end of the truly marvelous Thousand Springs, where in the space of about half a mile countless streams of water gush out from the canyon wall, in part at an elevation of 185 feet, but decreasing when traced westward to about 75 feet. The aggregate discharge of these springs is estimated to be 20,000 cubic feet per second. The springs show no seasonal variation. Their temperature is 62° F. The water comes from the cellular basal portion of a lava sheet which, as previously explained, was in part shattered and in part "shredded" by steam explosions, and descends over a cliff composed principally of compact volcanic lapilli. The immense water power that could be easily utilized here awaits development. Only a small fraction of the water pouring out and descending in picturesque, foaming cascades is now utilized for irrigation.

A novel plan for raising a portion of the water to the plain above, where there is a great tract of fine land available for irrigation, has been attempted by the Idaho Hydraulic and Pneumatic Irrigation Company, of which Mr. A. Ferguson, of Hagerman, Idaho, is chief engineer. The leading features of the plant, now nearing completion, is a large completely inclosed iron tank, or air separator, resembling a steam boiler, situated at the base of the cliff, into which, near its base, water is conducted from about 180 feet above by means of a large iron pipe or penstock. The water escapes from the tank in part through a standpipe connected with it near its bottom and rising to a height of about 40 feet, and in part through a smaller pipe leads from the tank, also near its base, to the summit of the canyon wall. The operation of the plant is this: The water in rushing down the penstock carries air with it, which separates in the tank and rises to the top, where it is under the pressure of the water in the large escape pipe, 40 feet high. The air pressure thus obtained forces water up the smaller pipe leading to the top of the canyon wall. This pneumatic engine, if such it may be termed, is claimed to be automatic in its operations, and therefore economical when once installed. It has not as yet been put in actual use so far as irrigation is concerned, although it has been made to discharge a stream of water on the plain above where it is situated, and its efficiency remains to be demonstrated.

Near the western end of The Thousand Springs water emerging at an elevation of about 75 feet on the canyon wall has been conducted across the river by Mr. I. A. Heron, in a pipe 12 inches in diameter, supported on a ¾-inch wire cable, which rests on crossed timbers planted in the river's bottom. The penstock leading to the pipe has a fall of 40 feet and delivers about 600 cubic feet of water per second on the south bank of the river. About 300 acres of land are under irrigation. An instructive experiment in connection with this plant was made in attempting to use a pipe placed on the bottom of the river. It was found, however, that air carried into the pipe by the water rushing down the penstock supplying it collected in the pipe at its upward bends on the river's bottom and caused it to rise and break.

Just below The Thousand Springs, Snake River makes an abrupt bend to the south, returning again to its westward course about 7 miles farther downstream. On its southern side the river is cutting into a prominent bluff of nearly white sand clay and on its northern side it is bordered by a large body of land, which, for the most part, has a gentle slope. This "Hagerman bend" contains by estimate about 14 square miles, nearly all of which can be irrigated from springs. The northern wall of the canyon continues westward from The Thousand Springs, and does not follow the bend of the river, for the reason that the stream, after having cut through two or more upper lava sheets and a thick layer of sand and clay below, discovered a southward-dipping sheet of lava which deflected the current toward its left bank. At the base of each of the two upper sheets of lava strong springs pour out and are extensively utilized for irrigation. They emerge, however, at too low a level to be available for use on some of the higher terraces, and to obviate this difficulty in part two tunnels have been excavated in the lava with remarkably successful results.

One of these tunnels, on Dan Jones's ranch, about 2 miles northeast of Hagerman, is 140 feet long, and discharges about 5 cubic feet of water per second. A second tunnel, about 100 yards eastward, is approximately 200 feet long and delivers about 4 cubic feet per second.

Each of these tunnels is in the open-textured basal portion of a lava flow, and the water rises through fissures or other openings in their bottoms. This fact shows that water exists under some pressure in rocks below the floors of the tunnels. The water has a temperature of 62° F. and issues at a horizon approximately 60 feet below the level of the surface of the plain to the northward.

Large springs occur at several localities from Hagerman to Bliss. In fact, there is what may be truthfully termed a continuous chain of springs along the north side of Snake River Canyon from about 2 miles above the mouth of Salmon River westward to Bliss. Included in this series are the springs of Little and Box canyons, Sand Springs, the Snow Bank, The Thousand Springs, the numerous springs and the two flowing tunnels near Hagerman, and a large number of strong springs between Hagerman and Bliss.

These springs issue from at least four, and perhaps more, strata. Those in Little and Box canyons and Sand Spring come from a stratum consisting largely of fine white sand which is overlain by a thick sheet of lava. The large springs supplying the Snow Bank come from above this same stratum of lava and from beneath a higher sheet, the margin of which has been weathered back from the canyon's border. The Thousand Springs issue from the lower portion of the lava sheet, over which the water supplying the Snow Bank cascades. This lava sheet, when traced westward to the end of The Thousand Springs escarpment, declines somewhat rapidly, the true dip being to the southwest, and passes beneath the agricultural land at Hagerman Bend. That the stratum is water charged is shown by a large fissure spring at the base of a small fault which supplies in part a creek flowing eastward and emptying into Snake River about a mile above Salmon Falls. This fissure spring, as well as the passage of the water-charged layer which supplies The Thousand Springs, beneath Hagerman Bend, is strong evidence that artesian wells would be successful if put down near Hagerman, and probably at any locality in Hagerman Bend. The depth of the water-charged layer is not great, but increases from the northeastern portion of the bend toward the southwest. A test well put down at Hagerman to a depth of 500 or 600 feet would probably yield flowing water.

The lava sheet in the escarpment to the north and northeast of Hagerman is higher in the rock series than the one supplying The Thousand Springs. It is probably the same one from which the water flowing over the cliffs at the Snow Bank emerges, but in the intervening space, about 3 miles in a straight line, has been weathered far back from the canyon's brink, and was not followed in the field. While the springs downstream from Hagerman all the way to Bliss, including the great springs in Malade Canyon, may come from the same layer that furnishes the water at the two tunnels described above and the large springs in their vicinity, a detailed study would perhaps show that two or more water-charged layers are present. Before the relation of all the springs can be accurately determined and the best way to develop them pointed out it will be necessary to have an accurate topographic map of the region.

In the bottom of Snake River Canyon near Bliss the water-charged stratum which supplies the springs upstream passes below the level of the river, on account of a gentle westward dip, and springs are rare for a distance of about 40 miles. The reason for the general absence of springs in this section of the canyon is not only the greater depth of the layers which yielded water near Hagerman, the continuation of which to a considerable distance west of Bliss, however, is not positively known, but also the deep dissection of the portion of the plains lying north of Snake River. So far as I am aware, springs are absent or nearly so in Snake River Canyon between the mouth of Kinghill Creek to a locality several miles below the mouth of Rattlesnake Creek. North of the river in this section creeks, about eight in number, have cut deep canyons, which would prevent a water-bearing stratum above the level of the main stream from conducting its waters to the Snake River Canyon. It is to be expected, judging from the topographic and geologic conditions, that small springs occur in the canyon of the lateral streams, such as Alkali, Cold Spring, and Bennett creeks, but as to the fulfillment of this predication I am not informed.

West of the mouth of Rattlesnake Creek, and near the point where Canyon Creek joins Snake River, large springs again occur. In that region there is a broad, uneroded plain leading from Snake River Canyon to the mountains north of Mountain Home. The canyon of Canyon Creek is short, and does not furnish an exception to the statement just made. For a distance of about 2 miles or more above the mouth of Canyon Creek soft sand and beds of gravel occur beneath the lava forming the upper portion of the canyon wall, and strong springs come out of the talus slopes and landslides encumbering the portion of the canyon's border below a prominent rim rock. These springs appear at a horizon about 500 feet below the top of the canyon, and have a temperature of 69° F., or about 7° F. higher than the water of The Thousand Springs. The water of some of the springs referred to is used for the successful irrigation of orchards. Far more service could be obtained from the springs, however, by tracing up the water that emerges through talus to the horizon where it issues from a pervious stratum, and excavating horizontal wells. By this means a larger volume of water could be had, and at such elevation that it could be used over a much larger area than is at present possible.

Canyon springs occur again, below the mouth of Canyon Creek, in the southeastern portion of Ada County, at Chapman's Ranch. They discharge somewhat less than 2 cubic feet per second, and are now used for irrigation. Other similar springs are near, but are not utilized. These springs come to the surface through talus and above a stratum of yellowish lapilli. Their temperature is 69° F. An excellent opportunity is here furnished for excavating horizontal wells, and there is an abundance of land near at hand suitable for irrigation. It is safe to say that not only the springs at Chapman's ranch but the neighboring spring a few hundred yards to the east could be developed so as to yield much more water than they now deliver.

The portion of Snake River Canyon from Chapman's ranch westward to the Idaho-Oregon boundary has not been visited by me, and what the conditions are in respect to the presence or absence of canyon springs is unknown.

In Bruneau Valley, near Hot Spring post-office, a number of large hot springs come to the surface and are utilized for irrigation. The temperature of one of these is 109° F. Still more remarkable springs occur from 5 to 6 miles up Hot Spring Creek, where its canyon is narrow. One of the springs has an estimated volume of 4 cubic feet per second, and a temperature of 109° F. While the high temperature of these remarkable springs suggests that they come from deep fissures, no other evidence that such is the case was obtained during my hasty visit. The canyon or valley in which they occur is fully 1,000 feet deep, and there is little doubt but that they are of the canyon-spring type, but for the most part they rise in the bottom of a canyon instead of issuing from its sides. In places, however, as on Hot Spring Creek, they gush out from the canyon wall at an elevation of approximately 100 feet above its bottom. These springs, although developed to some extent by vertical borings, as will be described more fully later in connection with the records of other artesian wells, can easily be made to yield far more water than they do at present.

The marked success that has attended the excavation of the two horizontal wells near Hagerman, and also the concentration of the outflow of water secured by a similar method at The Thousand Springs, is highly encouraging to the hope that a great development of the canyon spring described above may be attained.

There need be no hesitation in concluding that results similar to those just referred to may be had at a large number of localities. Wherever a canyon spring appears, there is an opportunity to increase its flow and in many instances to obtain water at a higher level than it now comes to the surface, for the reason that the water usually issues from talus and the true source is concealed. The main difficulties are the clearing away of the fallen blocks of stone that encumber the lower portions of the canyon walls, and the discovery of the edge of the water-bearing stratum. In some places the murmur of the water in flowing through the talus will assist in doing this. Where such a guide is absent, pits should be sunk at various horizons, beginning where the water is known to be present and extending up the canyon walls until the outcrop of the supplying layer is discovered. In some instances it will be more economical to begin at the top of a talus slope, above a spring, and clear away the stones in a descending direction, thus avoiding the danger of working at the bottom of a loose mass of débris.

When the precise horizon at which tunnels should be excavated is learned, it will serve to indicate where other similar excavations in the same neighborhood should be made, but such deduction can not be carried to a distance, for the reason that the lava sheets exhibit great and frequently abrupt changes in thickness. As previously explained, while the surface of a lava sheet may be horizontal, or essentially so, for many miles, its bottom may be markedly irregular. Another suggestion which may be of value is that the water escaping into a canyon from its walls flows over the surface of an impervious stratum. If, then, a bed of clay or compact lapilli (which in Snake River Canyon is usually dull yellowish, with black glass-like grains) is encountered in excavating, it is evidence that water, if present, will occur at the summit of the bed.

It need scarcely be mentioned that where fissure springs occur low in a canyon, and even in the central part of a flat-bottomed valley, as they do at times, the escape of the water being perhaps through fissures of small depth, vertical instead of horizontal wells must be excavated or drilled in order to increase the flow. Some assistance in reference to choosing a location for a horizontal well, method of development, etc., may be had by consulting a previous report[a] relating to the Columbia River lava, and associated formations.

FISSURE SPRINGS.

Fissure springs are not abundant in the portion of southern Idaho examined by me, and, so far as can be judged from the report of others, are of rare occurrence throughout the entire extent of the Snake River Plains. The Boise Hot Springs, situated on a fault 4½ miles east of Boise, are of small volume, and have a temperature, as stated by Lindgren in the Boise folio,[b] varying from 120° F. to near the boiling point. The belt of faulting on which these springs are located, extends for several miles in a southeast-northwest direction, and near it and about midway between the springs and Boise artesian wells, described later, yield a large volume of water with a temperature ranging from 75° to 170° F.

About 8 miles northeast of Mountain Home, a mile south of the

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[a] I. C. Russell, Geology and water resources of Nez Perce County, Idaho, Water-Supply and Irrigation Paper No. 54 U. S. Geol. Survey, 1891.

[b] Geologic Atlas U. S., folio 45.

line of displacement which defines the junction of the Snake River lava with the rhyolite of Mount Bennett, there is a small group of hot springs, rising through lava. For the sake of brevity, I shall term them the Mountain Home hot springs. Their combined discharge is about 2 cubic feet per second and their range in temperature is from 103° to 167° F. The water from this group of springs forms Hot Spring Creek, which flows to Bennett Creek.

Small springs, with a temperature of 131° F., occur at the right or southern banks of Snake River, about 4 miles above the mouth of Salmon River. The water rises through recent alluvium deposited by the river, and the true orifice from which it comes is not visible. Most probably there is a fissure in the solid rocks beneath the alluvial floor of the valley. A small warm spring, known as Poison Spring, occurs in the canyon of Salmon River, about 8 miles above its junction with Snake River Canyon.

Near the head of Little Valley, about 9 miles west of Bruneau, there is a small hot spring, which rises through soft, white lake beds (probably sediment deposited in Lake Idaho) which has a temperature of 101° F. Five drill holes, put down to a depth of 40 feet in the immediate vicinity of this spring, resulted in a marked increase in the outflow. The discharge is now about one-half cubic foot per second. The wells are not cased, and there is reason to believe that larger holes, with proper casing, would lead to a greater discharge.

In reference to the development of fissure springs, the fact should be borne in mind that the water in most instances rises through nearly vertical cracks, and may not have great freedom of discharge. When the water rises through stratified sedimentary beds or lava sheets, the chances are that there is great lateral dispersion or leakage, only a small part of the discharge that comes from the more deeply seated portions of the fissure actually reaching the surface. In general, fissure springs are similar to uncased artesian wells, but owing to probable irregularities in the fissures and the many chances they are exposed to of becoming clogged, it is to be presumed their surface outflow, in many instances, can be increased.

In the case of each of the warm or hot springs mentioned above, to which may be added a mud spring situated northwest of Mountain Home, and on the Overland road midway between Dry and Canyon creeks, there is no doubt that an increase and possibly a great discharge can be secured by drilling vertical wells. Such wells should be put down within a few feet of the springs, and continued, if practicable, to the depth indicated by the temperature of the spring water unless success is attained at less depth. In the case of Mud and Mountain Home hot springs the pioneer drill holes should be put down to the south of the spring in each case, and about 50 feet from it. The reason for this is that most probably these springs are situated on faults, which incline downward to the south at a high angle in reference to a horizontal plane. The depth to which it would be justifiable to continue drilling in the case of the Mountain Home hot springs, as indicated by their temperature, is about 5,000 feet. This is on the assumption that the temperature gradient in the Snake River lava is one degree for each 45 feet, as indicated by the wells along the Oregon Short Line Railroad. This assumed gradient will no doubt be found incorrect when more observations are available, but it probably indicates the minimum depth to which drilling would have to be carried to reach the stratum from which the water rises in the spring referred to. There is, however, a chance that an open fissure that will yield an abundant supply of water will be struck at less depth. The drill hole put down for the purpose of developing these and other similar springs should be at least 6 inches in diameter, and thoroughly cased, to prevent all possibility of an escape of water on the outside of the casing. In seeking to develop springs in this manner when water, even in small amounts, of the same temperature as that rising in the spring is encountered, it will probably be desirable to explode a charge of dynamite in the hole with the hope of so shattering the rock that a free communication with the cracks through which the spring water rises may be obtained.

It is scarcely necessary for me to urge that efforts should be made to develop the Mountain Home hot springs, since there is abundant land near them which could be irrigated. It may be found, however, that they are of more value for bathing purposes, or even for furnishing warm water in Mountain Home, than for irrigation; but even if these demands are not assured, there is sufficient justification for their development for irrigation purposes. The conditions at Mud Springs are less favorable than at the Mountain Home hot springs, but are sufficiently promising to warrant a trial.

In brief, I may state that wherever warm or hot springs rise on the Snake River Plains an attempt should be made to enlarge them and to prevent their waters from escaping by percolation. By this I mean that an open pipe should be provided in which the water may rise, in place of the fracture provided by nature, and that the space between the outside of the pipe and the inner surface of the bore hole at the bottom of the pipe should be packed so as to prevent leakage. This suggestion is made with the understanding that the pipe has been put in place after all necessary tests have been made for the purpose of discovering precisely where the water enters the bore hole. The lower end of the pipe should be just above that locality.

A spring developed in the way suggested, when a surface flow of water is obtained, becomes an artesian well. Probably in most cases of this nature, however, the water does not come from a well-defined artesian basin or artesian slope, but from irregular and what may be termed accidental fissures. A fissure spring may, however, be due to the leakage of either an artesian basin or an artesian slope, and is at least a sure indication that water in a subterranean reservoir of some kind exists under sufficient pressure to force it to the surface. In an arid region every such indication should be tested in case the water can be utilized.

Three miles north of Mountain Home, and at an elevation of about 110 feet above the town, there is a spring known as Bennett Spring, near which a drill hole 6 inches in diameter has been put down to a depth of 50 feet, all in basalt. The casing of this well is defective and water rises both within and around it, as well as from natural openings near at hand. At the time of my visit, August 2, 1901, this imperfectly developed spring was discharging about one-half cubic foot per second. The temperature of the water was 55° F. From the assumed temperature gradient given above the depth from which the water rises is judged to be about 225 feet. The water is not only cool, but, so far as one can judge by tasting, is of excellent quality. Mr. Bennett, the owner of the well, informed me that it flows continuously, but that the supply decreases in summer; other persons have stated that it sometimes becomes dry, and expressed the belief that it is fed by seepage from the Mountain Home reservoir or its feeding canal. In reference to this last statement, I would say that the natural conditions indicate that an escape of water has occurred for many years, and that most probably the spring is due to a weak discharge of water from a shallow fissure.

On account of the favorable location of the Bennett Spring, the excellence of its water, etc., it is highly desirable that an effort be made to increase the flow. The present drill hole should be tested in order to learn how much water it will deliver when all leakage is stopped, and then deepened to at least 225 feet. By suitable tests the most favorable water-bearing horizon could then be determined, and, if desirable, the rocks at that horizon should be shattered by an explosion of dynamite. With the information thus gained, if favorable, several other holes should be drilled within a radius of 200 feet of the present well. It is not improbable that this spring can be made to yield sufficient water for the present needs of Mountain Home.

WELLS.

For convenience, we may classify wells as, first, surface or earth wells, deriving their water by percolation from the surface sheet of rock waste, usually shallow and represented by the ordinary house wells of humid regions; second, rock wells, usually deep, penetrating the unaltered rocks beneath the surface sheet of rock waste, if any is present, and obtaining from pervious strata water which may be under some pressure, but which does not rise to the surface; and third, artesian wells, from which there is a surface overflow.

SURFACE WELLS.

On the Snake River Plains ordinary surface wells, such as are common in humid regions, are seldom possible. Where streams coming from the mountains have spread out flood plains or alluvial fans surface wells, however, are sometimes successful, the water supply being furnished by the outward percolation from the streams themselves and not by direct precipitation on the adjacent surface. Such wells are situated, for the most part, in canyons and stream-cut valleys. Their depth is regulated by the height of the surface at the locality chosen above the bed of an adjacent stream.

A modification of the process just referred to is to be seen where water is spread over the land for purposes of irrigation. In such instances a part of the irrigation water sinks below the surface and may saturate the subsoil. When the soil and subsoil are porous a large amount of subsurface water is stored more or less permanently in this manner, and furnishes a supply for surface wells. On isolated ranches wells fed by surface water from irrigation are not, perhaps, objectionable, but when towns are supplied in this manner a serious disarrangement of sanitary conditions results. One instance of a town which depends on shallow surface wells for water for household uses, and where the adjacent gardens and fields are irrigated, is furnished by Mountain Home. This town has a population numbering about 550; many of the houses are surrounded by gardens and orchards; the subsoil is gravel; there is no sewerage system; shallow cesspools are numerous and mostly in an insanitary condition; numerous stables and poultry yards are present, and the surface is flooded from time to time for purposes of irrigation. The water, after standing on the surface, in part percolates downward into the gravelly subsoil, which is underlain by an impervious stratum, and which is penetrated by wells ranging in depth, usually, from 15 to 20 feet. A more insanitary arrangement could scarcely be devised, yet Mountain Home is a typical example of many communities in the arid region. Strange as it may seem, practically no attempt is made in the majority of these towns to insure sanitary conditions.

As previously pointed out, ordinary surface wells are analogous to hillside springs. As the subsoil in arid regions is not saturated by direct precipitation, hillside springs are absent, and surface wells are not as a rule practicable.

ROCK WELLS.

The conditions which favor the occurrence of canyon springs also insure the success of deep wells which reach a water-bearing stratum. In the Snake River Plains, where deep borings have been made, water has generally been obtained. It is usually under pressure, so that it rises some distance up the drill holes. Reference is not here made to flowing wells, which will be considered later.

Examples of wells which penetrate the stratified deposits beneath the Snake River Plains are furnished by those drilled by the Oregon Short Line Railroad between Pocatello and Caldwell. A list of these wells, with their depth, has been kindly furnished by W. H. Bancroft, vice-president and general manager of the Oregon Short Line Railroad. The height to which the water rises and the temperatures recorded are from observations made by Mr. Scott Turner.

Well records along Oregon Short Line Railroad.

Location of well.	Total depth.	Depth of water.	Temperature.
	Feet.	*Feet.*	*Degrees F.*
Wapi	250		
Minidoka	425	375	55
Kimama	325	265	56
Owinza	401	341	54
Bliss	483	430	70
Cleft	450		73
Bisuka	390		
Owyhee	600	530	70
Mora	380		
Nampa	114	40	61.5

The success of these and other deep wells is good assurance that water can be had over large portions of the Snake River Plains if pumping can be resorted to. Near canyons the depth at which springs appear in their wells or bottoms indicates the depth at which rock wells would be successful, but the springs must, in most instances, be on the same side of a canyon as the site of the proposed well. If no springs occur in the canyon, wells located on the adjacent plains must be continued to a horizon below the canyon bottom before water can be expected to flow into them. Owing to irregularities in the thickness of the lava sheets, no accurate prediction can be made as to the depth to which a well should be carried at a distance from canyon springs, but in general can perhaps be assumed to be not less than 300 or 400 feet. It would not be surprising if in the broad plain tract, in the central part of which Big Butte is situated, rock wells would be successful at a depth less than that just stated, or from 150 to 200 feet, but no tests have been made to show the truth of this assumption.

An instructive result, based on the temperature of the water in the wells in the above list, is that the increase in temperature with depth is greater than the normal. As indicated by the data given (but not including the well at Nampa), the temperature gradient beneath the Snake River Plains is approximately 1° F. for each 45 feet below the stratum of no seasonal variation. This high rate probably indicates that the lava sheets have not as yet completely cooled, but in part the abnormally high temperature may be due to fissure springs rising beneath the lava, and contributing to the water supply of canyon springs and of rock and artesian wells.

ARTESIAN WELLS.

A considerable number of artesian wells in northern Idaho are now flowing, but data concerning only a portion of them have as yet been procured.

BOISE.

Included with an account of several artesian wells situated in the Boise quadrangle, and described by Lindgren in the Boise folio,[a] are those which supply Boise. These are located near the immediate border of the Snake River lava and are highly suggestive as to the possibilities in other similar situations.

There are two groups of wells near Boise—one in Hull Gulch, 1½ miles north, and the other about 2 miles east of the city. The first group consists of eight wells, six of which are reported to be 400 feet deep, and one 619 feet, but some changes were made during the summer of 1901, the results of which are not at hand; their combined flow is about 670 gallons per minute. The water is cold and of good quality. The second group consists of three wells, ranging in depth from 394 to 455 feet, which discharge about 550 gallons of water per minute, having a temperature of 170° F. This water is conducted to Boise in pipes and extensively used for heating purposes, baths, etc. Other hot wells are located in the same vicinity; they are described in the Boise folio.

The unique water supply of Boise, consisting of both hot and cold water, furnished by flowing wells at small expense, makes it highly important to learn whether similar conditions exist near other towns. The only other town similarly situated in reference to geological conditions is Mountain Home, some statement concerning the water supply of which has already been made, and to which more attention will be given later.

BRUNEAU VALLEY.

In the upper portion of Bruneau Valley there are three flowing wells, each 2½ inches in diameter, which, together with the numerous hot springs of the same region briefly described above, show that an abundance of water exists at a moderate depth under sufficient pressure to cause it to rise to the surface if openings are provided.

On W. N. Roberson's ranch, about 2 miles north of Hot Spring post-office, and on the west side of the valley, a drilled well having a

[a] Geologic Atlas U. S., folio 45.

depth of 240 feet delivers about 7 gallons of water per minute, having a temperature of 109° F. This well is within a few feet of a large hot spring having the same temperature, the flow of which was not diminished when the well was drilled. The elevation of the surface at this point, by aneroid, is 2,750 feet. The section passed through, as reported from memory by Mr. Roberson, is as follows:

Section 2 miles north of Hot Spring post-office.

	Feet.	Inches.
Light-colored sandy clay (lake beds)	236	......
Granular black layer, like basalt (volcanic lapilli?)	......	10
Blue clay	4	......
Black lava	......	(a)
Total depth, about	240	10

a Several.

The water is used for household purposes and for irrigation.

Nearly opposite the well just described, on the east side of the valley and at an elevation approximately 50 feet higher, a well drilled to a depth of 230 feet, on land belonging to Mr. A. H. Pence, resulted in a small surface flow.

On Mr. B. Whitson's ranch, situated on the eastern side of the valley, about 3 miles north of the two wells just mentioned, where the surface elevation is by aneroid 2,750 feet, a well 700 feet deep discharges about one-third cubic foot of water per second. The temperature is reported to be 90° F.

These three wells derive their water from different depths, and seem to indicate that water under pressure exists in at least three disconnected pervious layers, or else that a source of supply more deeply seated than has been reached by any of the drill holes yet made charges porous beds above it through fissures. The abundance of hot springs in the same vicinity apparently favors the latter hypothesis.

As will be shown below, the artesian wells in Bruneau Valley are within the border of a large structural basin, which it is convenient to designate the Lewis artesian basin.

LITTLE VALLEY.

Near the head of Little Valley, 9 miles west of Bruneau, there are five flowing wells, which range in depth from 150 to 215 feet, each drilled with a 2½ inch bit, and poorly cased. The water is of good quality; temperature is about 67° F. The flow varies somewhat with seasonal changes, being greatest in winter and spring and least in summer and fall. In most instances the pipes have become clogged and the discharge is small. One of the stronger of these wells delivers in August a gallon of water in seven minutes, and is said to discharge about a gallon per minute in winter. Neighboring springs have various temperatures, ranging from 56° to 59° F.

These shallow wells, some of which began to flow when a depth of 60 to 70 feet was reached, are in a broad, deeply alluvial-filled valley and evidently depend for their water supply on an alternation of pervious and impervious beds in the alluvial deposits. The source of the water of the several cold springs is, no doubt, the creeks which flow from the mountains southward, but the wells must be supplied from a deeper source.

Little Valley is situated within the Lewis artesian basin, and at a lower level than the surface at the flowing wells near Hot Spring post-office, in Bruneau Valley, but the wells referred to above do not furnish a test of what may be termed the true artesian condition.

The partially developed hot spring in the upper portion of Little Valley, described above, is about a mile east of the shallow artesian well just referred to, and presumbly derives its water from a deep source.

ROCK CREEK HILLS.

In the valley of Rock Creek, about 3 miles south of Rock Creek post-office, Cassia County, on Mr. E. M. Crockett's ranch, a 6-inch well put down in 1899 has a depth of 275 feet. The water rose at first to a height of about 20 feet above the surface, but owing to leakage due to imperfect casing has since ceased to flow. The water stands about 3 feet below the top of the well.

Half a mile south of the Crockett well, on Jones Brothers' ranch, two wells drilled in 1899, each 6 inches in diameter, imperfectly cased, now discharge about 2 cubic feet of water per second. The temperature is about 75° F., but was not measured. One of them is 90 feet deep, and the other, 30 yards distant, 115 feet deep.

The three wells on Rock Creek are situated in a deep canyon-like valley among hills of stratified rhyolite, where the rocks have been considerably disturbed. No structural artesian basin is definitely known to be present, but further study may show that this region is an extension eastward of the Lewis artesian basin. Springs are numerous in the same region and supply Rock Creek, which flows throughout the year to below Rock Creek post-office, where its water is all used for irrigation.

The geologic conditions in the Rock Creek Hills are closely similar to those in the rhyolitic mountains to the north of Mountain Home, where springs are also abundant, and the success of the wells drilled at the former locality suggests that equally favorable results should be expected on Long Tom and Syrup creeks and about Mount Bennett.

In the neighborhood of the Rock Creek Hills several borings have been put down, with various results. More or less definite reports concerning them are here presented:

At Rock Creek post-office a 6-inch drill hole 300 feet deep failed to reach water under sufficient pressure to cause it to rise to the surface. Water stands about 40 feet below the top of the well and is pumped. The well is imperfectly cased, and no adequate tests of the pressure of the water have been made. It seems probable that if this well should be properly cased a surface flow would result.

Near Dry Creek, about 10 miles east of Rock Creek post-office, and about one-half mile from the foothills to the south, a drill hole, situated near a warm spring, is reported to have a depth of between 200 and 300 feet, and to discharge a small amount of warm water. Judging from reports, this well is on the Snake River Plains, where the surface rock is basalt.

About 4 miles west of Rock Creek post-office, on the McMullen ranch, near the border of the Snake River Plains and adjacent to the Rock Creek Hills, a 6-inch well, 50 feet deep, is reported to discharge a small stream of warm water. About 10 miles farther west what is known as Wild Horse well is said to be 75 feet deep and to furnish a small supply of warm water.

Of the several flowing wells in and about the Rock Creek Hills, I was enabled to visit only the three on Rock Creek, but the success of these and the surface discharge from the others referred to is evidence that water exists under pressure beneath a region many square miles in area. Whether or not there is a continuous water-charged stratum in this region at a moderate depth beneath the surface is not demonstrated, but the facts in hand are such as to justify a thorough test. It is highly desirable that the well at Rock Creek post-office and also the wells east and west of that locality should be continued downward several hundred or possibly 1,000 feet, in order to determine positively the actual conditions.

There is a vast amount of fine land about the Rock Creek Hills, and the indications are that artesian water can be had for the irrigation of a considerable portion of it.

UNSUCCESSFUL WELLS.

In addition to those places at which the flowing wells briefly described on the preceding pages were obtained, attempts have been made to obtain flowing wells at various other localities, principally, so far as I am aware, on the northern border of the Snake River Plains. Thus far these attempts have all been unsuccessful.

At Shoshone, a well was drilled in 1890, with the hope of obtaining flowing water for town purposes, to a depth of 280 feet, all in lava, but no water was reached.

At Gooding, 16 miles west of Shoshone, a drill hole is reported to have been put down in 1890 to a depth of 155 feet, which, after passing through lava, entered clay; water rose to within 110 feet of the surface. Again, one-fourth mile south of Gooding, a drill hole 185 feet deep passed through lava and entered clay; whether water was reached or not, was not learned.

At Lee's ranch on Slater Creek, approximately 25 miles northwest of Mountain Home, and near the northern border of the Snake River lava, a well put down in the bottom of the small valley cut by the creek, has a depth of about 85 feet, but failed to reach water.

At Howe, on Little Lost River, a well drilled through lava to a depth of 200 feet reached water under sufficient pressure to cause it to rise 25 feet or to within 175 feet of the surface. The casing of the well is defective, and to what height the water would rise if proper care were taken in making a test is not known.

IMPERFECT CASINGS.

The inferences to be drawn from the several artesian wells and unsuccessful borings referred to in the past few pages are by no means so instructive as they would be if the pressure of the water met with in most instances were known. So far as I am aware, none of the artesian wells now flowing and none of the wells in which water rose some distance but failed to reach the surface are properly cased. Lack of care in this respect has caused failure, or but trifling returns, where a strong flow of water can be easily and cheaply obtained. The methods employed to prevent leakage in artesian wells are briefly described in my report on Nez Perces County, already referred to, and in several of the books and papers cited in it, but can not be repeated at this time.

LEWIS ARTESIAN BASIN.

From near the mouth of Clover Creek westward, at least as far as the eastern boundary of Ada County, the Snake River lava and associated sedimentary beds have been bent into a broad, gentle downward fold or syncline, the longer axis of which has a nearly east-west trend, and pitches very gently westward. The strata forming this basin underlie the plains both north and south of Snake River, and judging from what is known concerning the way in which the formations were deposited, or poured out as molten lava, the pervious beds, if any are present, are in a position to be charged with water from the mountains bordering the portion of the Snake River Plains referred to on the north and south. These conditions are such as produce artesian basins, and, so far as can be judged from the observed facts, this basin should yield flowing wells, providing the requisite succession of pervious and impervious beds is present. The only direct evidence we now have on this point is the meager records of the drilled well in Bruneau Valley. The wells referred to show not only that pervious beds occur beneath impervious beds, but that water under sufficient pressure to force it to the surface is present. Several hot springs also suggest the same conclusion.

My judgment, based on all the facts accessible, is that the Lewis artesian basin is of large size and well worth careful testing by means of the drill. The extent of the basin west of Elmore County is unknown, and the assumption that it is a closed basin and reaches the Idaho-Oregon boundary is based on a general knowledge of the geology of southwestern Idaho and the fact that Snake River below Weiser is flowing over impervious rocks older than the Payette formation.

As to the height to which the water will rise in the artesian head, the only basis for judgment at present is the surface elevation at the flowing wells in Bruneau Valley. None of these wells, so far as I have been able to learn, are tightly cased, and they probably do not show the full height to which water would rise under more favorable conditions. By aneroid measures, the artesian head shown by the wells in Bruneau Valley is, as previously stated, at an elevation of about 2,750 feet above the sea. The method of measuring by means of aneroid barometers, the only one I was enabled to employ is, as is well known, defective, and the elevation just given may be a hundred feet in error. With the assumed height to which water will rise, artesian wells may be expected to be successful at any locality west of the mouth of Clover Creek at least as far as the eastern boundary of Ada County and the southward prolongation of that line across Owyhee County, where the surface elevation is less than 2,750 feet. The land which is below this level is situated in the canyon of Snake River in Bruneau and Little Valley. So far as can now be judged, there is no hope that water under sufficient pressure to rise to the surface of the plains bordering the canyon and valleys just named, is present, but this is a matter that should be determined by experiment.

In order to test the predictions based on geological structure, etc., a pioneer well should be put down, with all the well driller's skill that can be commanded, at the most favorable locality, and a careful record kept of the strata passed through. It is unnecessary to add that the pressure of each water supply reached should be accurately measured. Favorable places for such a test well occur at several localities in the vicinity of Snake River, between the mouth of Clover Creek and the east boundary of Ada County and in the lower portion of Bruneau Valley. I would name, especially, Glenns Ferry and Bruneau. In the absence of accurate topographic maps, it is impossible to state at what depth water should be reached, but what is scarcely more than a guess places it at between 500 and 700 feet. The demand for water is so great, however, and the conditions, so far as can be judged from a hasty reconnaissance, are seemingly so favorable, that the people who are interested in the development of this region can well afford to continue drilling to a depth of 1,000 or 2,000 feet, unless water is sooner reached. To make a complete test, drilling should be continued until the Snake River lava and its associated lacustral beds are passed through. Beneath these formations it is probable that the drill will strike either granite, rhyolite like that which forms Mount Bennett and the Rock Creek Hills and which appears also at Shoshone Falls, or quartzite. When the drill reaches rock like any of them, or some other rock clearly distinct from the Payette formation or the Snake River lava, the possibilities for obtaining artesian water will have been exhausted. Deep drilling is also justified for the reason that the sheets of lava which supply the great springs in the vicinity of Hagerman dip gently westward, as may be seen between the mouth of Clover Creek and Bliss, and pass beneath the region included in the Lewis artesian basin. As the continuation of a lava sheet after it disappears from sight is uncertain, it can not be said from definite evidence that the open, water-charged lava sheets referred to have a wide extent west of where they dip beneath the level of Snake River, but there is a possibility that they extend far and are abundantly water charged. The manner in which the sheets of basalt in the western portion of the Snake River Plains vary in thickness is an important matter in reference to the search for artesian water, but one concerning which no predictions seem possible. This and other qualifying conditions can be discovered only by the use of the drill.

SHOSHONE ARTESIAN SLOPE.

Judging from surface elevation and the nature of the rocks exposed in the north wall of Snake River Canyon between Shoshone Falls and Bliss, the strata of lava, associated lacustral deposits, etc., beneath the plain to the south and southwest of Shoshone slope from the mountains toward Snake River. Coupled with this fact is the marvelous outpouring of water from the north wall of Snake River Canyon between Shoshone Falls and Bliss. This water, although no doubt supplied in part by precipitation on the surface of the Snake River lava, comes mainly from the mountains to the north. The great springs referred to are fed by lost rivers and by the water which disappears by percolation on the northern border of the Snake River lava sheets. There is thus evidence of a strong underflow beneath the lava plain to the south and southwest of Shoshone. For these reasons I venture to term the region referred to the Shoshone artesian slope, although the name will be justified only when the drill demonstrates that the water is under sufficient pressure to cause it to rise to the surface.

The nature of an artesian slope has already been explained, and persons familiar with the conditions existing in the triangular area, containing some 400 square miles, having Shoshone, Bliss, and Shoshone Falls at its corners, will, I think, agree with me in the conclusion that they are sufficiently favorable to the hope of obtaining flowing water to be deserving of a thorough test. The rise of the water in a hole drilled in the covering layer of an artesian slope depends on the friction of flow in the water-bearing layer below the site chosen. The less pervious the layer, down to a certain indefinite limit, the higher the water will rise with a given slope. In the case of the pervious beds beneath the "Shoshone triangle" there is a remarkably free passage for the water. On the other hand, the volume of water is great, and this perhaps more than counterbalances the adverse condition resulting from freedom of natural escape, and favors the hope that water would rise to the surface if drill holes properly cased were put down. There is the same necessity for an impervious cover to the water-bearing stratum in an artesian slope that there is for an impervious layer above the pervious bed in an artesian basin. In the "Shoshone triangle" the covering bed, as indicated in Snake River Canyon, is basalt, but above the lowest known water-bearing bed there are at least three strata of lava, and sedimentary beds may occur between these. The presence of such beds has not been proved from observation, but the fact that the water forming the springs along Snake River comes from three separate pervious beds is sufficient evidence that practically impervious rocks occur between them.

I have dwelt on these *probabilities* at some length in order to place the reader who is familiar with the "Shoshone triangle" in a position to judge for himself whether the chances of obtaining flowing water are sufficiently good to warrant making a test. In my judgment it would be worth while to put down a pioneer well to a depth of 700 or 1,000 feet, at a distance over 6 miles from the brink of Snake River Canyon, anywhere in the triangular area referred to where broad tracts of fine land occur. The locality chosen should be at as great a distance as possible from elevations like Flat Top and Notched buttes, which indicate the position of old volcanic vents.

POSSIBILITY OF OBTAINING FLOWING WELLS IN ALLUVIAL DEPOSITS.

As has already been stated, the border of the Snake River Plains is covered in part by alluvium brought down by streams from the adjacent mountains. There is reason for believing also that similar deposits were formed from time to time between the successive eruptions that furnished the Snake River lava. In such alluvial deposits generally an alternation of pervious and impervious beds occurs. The pervious beds have in a general way the shape and associations described on a previous page under the term "artesian wedges."

The conditions here referred to may be expected to occur at any of the localities where streams flowing from valleys in the mountains emerge onto the border of the Snake River Plains. In order to form "artesian wedges" of sufficient size to be of value as a source of water supply, the alluvial deposits need to be of considerable extent and thickness and to occur at the mouths of valleys down which there is a considerable flow of water. These conditions are best fulfilled, so far as I have been able to learn, where the valleys of the "Lost River country" open out on the Snake River Plains. In the lower portions of the valleys through which Big Lost River and the similar streams as far to the northeastward as Beaver Creek emerge onto the plains, the conditions are such as to warrant the drilling of wells to a depth of at least 500 feet in the hope of obtaining flowing water.

In the valleys just referred to there are deep accumulations of alluvium and fine examples of alluvial fans. At the mouth of each lateral gorge along the sides of these valleys there are local alluvial fans, which unite with a similar deposit in the main valley. The bottoms of the valleys of Big Lost and Little Lost rivers, Birch Creek, etc., are occupied by immense compound alluvial fans which extend far out onto the Snake River lava and there expand widely. Similar alluvial deposits were no doubt formed during the intervals between the eruptions that spread out the Snake River lava, and such deposits beneath the surface lava sheets and interbedded with the subsurface sheets are in a position to become water charged. For these reasons it seems worth while to search for water under pressure on the border of the Snake River plains, adjacent to or in front of the entrances of the lateral valleys referred to. One such attempt has already been made at Reno, as has been stated, and water under pressure was discovered, which did not rise to the surface. This test, however, was imperfect, as the drill hole was not properly cased, and, although counted a failure, is really encouraging. It is not to be expected that water will rise through a hole 200 feet or more deep drilled in the Snake River lava, unless it is properly cased, for the reason that the lava is largely cellular, broken by joints, etc., and would allow water to escape laterally.

Another similar locality, but less favorable than those just referred to, where the conditions hold out some hope that flowing water may be obtained, is at Mountain Home. At that place there is a broad alluvial fan laid down by Canyon and Rattlesnake creeks, which may contain an alternation of pervious and impervious beds. The conditions are not especially favorable for charging the pervious beds if such are present, with water, but the urgency for a water supply at Mountain Home is such that tests of the artesian conditions beneath and in the vicinity of the town should be undertaken. I venture to recommend that a row of borings be made at intervals of 1,000 feet along an east-and-west line passing through the northern portion of Mountain Home. Each of these borings should be continued until solid black lava (basalt) is reached. This will probably be at a depth of 150 or 200 feet. If such borings are unsuccessful, one of them, near the town, should be continued until the sedimentary beds, such as sand, gravel, clay, etc., presumably occurring beneath the highest sheet of lava, are passed through and the drill enters the next lower lava sheet.

No one can predict with certainty what results will follow such a series of tests as is here recommended, but there is a chance of success. Other suggestions in reference to a water supply for Mountain Home may be found on pages 171 and 172.

PROBABILITY OF THE PRESENCE OF WATER BENEATH THE EASTERN PORTION OF THE SNAKE RIVER PLAINS.

The largest track of waterless country in Idaho is comprised in the portion of the Snake River Plains lying to the north and west of Snake River, above Shoshone Falls. This region, measured roughly, is from 150 to 170 miles long, and from 30 to 50 miles wide, and within it there is but one perennial spring—the one at Big Butte, which discharges about one gallon of water per minute. A portion of the northeastern margin of this immense tract, it is hoped, can be watered from storage reservoirs on Henry Fork, but by far the greater part is beyond the possibility of irrigation from surface streams. In reference to subsurface water but little that is encouraging can be said.

The portion of the Snake River Plains here referred to is floored with lava, which was poured out from many vents, and is still in essentially horizontal sheets. The rocks are not cut by streams so as to form canyons, nor are there other exposures by means of which the character of the strata beneath the surface can be judged. One can only surmise what the subsurface conditions are from analogy with the somewhat deeply dissected western extension of the same formations. This analogy and the general principles pertaining to the manner in which broad basins may become filled or partially filled with alluvial deposits, lacustral sediments, and lava flows favor the assumption that beneath the broader portion of the Snake River Plain (as, for example, between Kimama and Big Butte), there is a succession of lava sheets and sedimentary beds. The lava, although in part in broad sheets, consists mainly of local flows which overlap and are probably relatively thin. Thicknesses of from 50 to 150 feet are to be expected. The sedimentary beds, if laid down as alluvial deposits, will be thickest about the border of the basin and will thin out and become finer in texture toward their center, and, if deposited in lakes, will be thicker in their central part and become thinner and coarser in texture toward their margins, there merging with alluvial deposits. From these considerations it is to be expected that an alternation of pervious and impervious beds is present. The rocks, however, have not, so far as the surface sheets are concerned, been bent into a basin shape, and there is no evidence of the presence of an artesian basin. While the surface is essentially level, the few measurements of elevation available indicate that there is a descent of approximately 25 feet to a mile from the region of Big Butte southwestward. Under favorable subsurface conditions this would produce an artesian slope which might yield flowing water on drilling.

The presence of such an artesian slope has been tested in part by wells along the line of the Oregon Short Line Railroad at Wapi (250 feet), Minidoka (425 feet), and Kimama (325 feet), which fail to furnish flowing water, but yield a supply that is raised by pumping.

As may be judged by the statements of probabilities made above, it is almost impossible to obtain data by means of which a judgment can be formed in reference to the chances of obtaining water in the region referred to. The evidence is negative and so far as it permits one to form an opinion does not favor the hope that flowing wells can be obtained. While there is but little if any hope of obtaining artesian water, it is probable that "rock wells," that is, wells in the solid rock but not flowing wells, drilled to a depth of from 300 to 500 feet, would reach water. As there is an immense tract of excellent grazing country in this portion of the Snake River Plains, it is probable that it will be found practicable to establish cattle ranches there, the necessary water supply being obtained by pumping from rock wells. There is a report current among stockmen and sheep herders who visit the region lying southwest of Big Butte in winter to the effect that flowing water comes to the surface at one locality. This report is well worth investigating, for the reason that a single watering place in such an immense pasture would be of great value.

CONCLUSION.

My reconnaissance led to the following general conclusions in reference to the future development of southern Idaho:

1. The surface water supply at present available is largely wasted, and can by proper economy be made to yield two or three times the service now obtained from it.

2. Every effort should be made to divert and utilize surface streams. In this connection, it is evident from the work of the State engineer and from personal inspection that it is practicable to use for irrigation the entire summer flow of all the streams reaching the Snake River Plains.

3. The next largest source of water supply after the flow of the streams in summer has been fully employed is by means of storage reservoirs. The sites of such reservoirs have in part been indicated by the State engineer and the hydrographic division of the United States Geological Survey.

4. Drill holes should be put down at the localities suggested on a

previous page for testing the artesian conditions in what has been termed the Lewis artesian basin, and also in the probable artesian slope lying southwest of Shoshone as well as in the "Hagerman bend."

5. At Mountain Home the Bennett well should be developed and drillings made in the alluvium on which the town is situated. The Mountain Home hot springs can also be developed and their water piped to the town if desired. Drill holes put down along Syrup, Long Tom, and Rattlesnake creeks in the mountain portions of their courses would serve to increase the flow of these streams. Storage reservoirs are possible on these same creeks. Where Canyon and Rattlesnake and other similar creeks leave the mountains, the escape of their water by percolation can be checked in some instances by putting in dams reaching to the solid rock beneath the alluvium.

6. Every fissure spring in southern Idaho is a warrant that water under pressure exists beneath the surface, and in many instances these openings can be made to deliver a greater flow than at present.

7. On the broader portion of the Snake River Plains, west of Blackfoot and elsewhere, rock wells are possible, but flowing water is probably not obtainable.

8. It is self-evident that there is but little if any use in attempting to put down the test wells suggested, unless the work is done by a skilled and conscientious driller, under the direction of a competent engineer. Each water-bearing stratum should be tested in order to determine the pressure under which the water exists, and the quantity available. *Each well should be properly cased.*

Flowing wells supplied by artesian basins or "artesian wedges" should be closed when the water is not being used. The reason for this is that the supply is being drawn from a reservoir that is not inexhaustible. Flowing wells, however, supplied by artesian slopes, and those which are essentially developed fissure springs, should be open continuously in order to keep the artificial opening clear and also because the water will otherwise escape by natural openings and no economy would result from closing the drill holes.

9. Lastly, it is painfully apparent that the control of the water supply, both for irrigation and other uses, and the sanitary inspection of towns and of isolated houses, should be placed in the hands of a competent engineer. While this suggestion is perhaps in a measure impracticable, as the private ownership of water is not likely to be relinquished and people will claim the privilege of living as they choose even though the death rate is higher than it should be, yet the present waste of water is so great and the prevalent ignorance or disregard of the laws of health so general that centralization of control or general education of the people is imperative.

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