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NOTES

ON THE

GEOLOGY OF SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON

BY

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NOTES ON THE GEOLOGY OF SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON.

By Israel C. Russell.

INTRODUCTION.

During the summer of 1902 I made a rapid reconnaissance through portions of southwestern Idaho and southeastern Oregon for the purpose, principally, of ascertaining in what localities, if any, the geological conditions are favorable to obtaining flowing water by drilling wells. This search was more successful than had been hoped, and a preliminary report on the artesian basins discovered has already been published.[a] The explorations referred to were in continuation of similar work done the preceding summer in southern Idaho, a report on which was published as Bulletin No. 199 of the United States Geological Survey. The aim of the present paper is to put on record such observations relating to the general geology of the region traversed as it is thought may be of interest, more particularly to the people of Idaho and Oregon, and also in certain instances serve to supplement the report referred to on artesian conditions.

During the reconnaissance I was assisted by Mr. Scott Turner and Mr. Robert H. Dawson, students of the University of Michigan. Our journey began at Boise, Idaho, on July 6, and ended at the same place on September 6, 1902. The route followed was planned so as to traverse as many as possible of the valleys of southwestern Idaho and southeastern Oregon, in which rich agricultural land is plentiful and where artesian conditions are most likely to be present. Portions of Canyon and Owyhee counties, Idaho, and of Malheur and Harney counties, Oreg., were examined; but it is not to be understood that anything like a geological survey of the immense territory included in these counties was undertaken. This paper is simply an account of observations made during a rapid reconnaissance, principally in the way of supplementing the study of artesian conditions, and should not be judged in any other light.

[a] Water Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

CLIMATE AND VEGETATION.

The leading characteristics of the climate of the portions of Idaho and Oregon here considered are: Small precipitation; generally cloudless skies; hot, dry summers; and moderately cold winters, during which there is some rain and snow, but not enough to make the mean annual precipitation large. Something of the nature of the prevailing climatic conditions may be judged from the following data, compiled from the report of the United States Weather Bureau for 1900, which pertain to localities within or near the region here discussed.

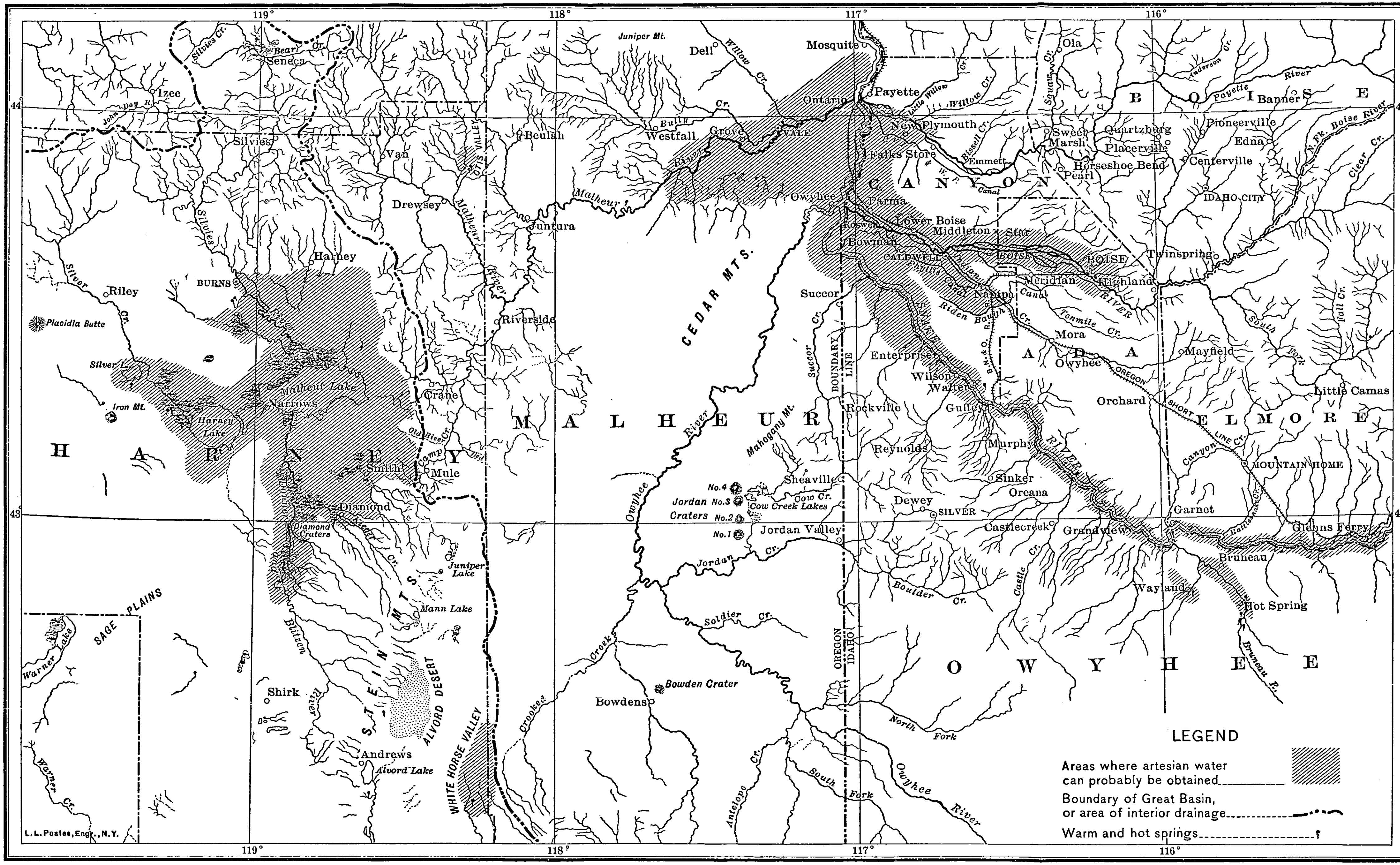
Weather records for the year 1900.

Locality.	Precipitation.	Temperature.			Killing frost.		Snow.
		Minimum.	Maximum.	Mean.	Last in spring.	First in autumn.	
	Inches.	*Deg. F.*	*Deg. F.*	*Deg. F.*			*Inches.*
Boise, Idaho	12.77	11	104	52	Apr. 23	Oct. 23	20.1
Garnet, Idaho	8.11	14	------	------	Apr. 26	Oct. 25	------
Payette, Idaho	10.60	10	104	53.7	Apr. 13	Sept. 25	19.8
Baker City, Oreg	13.84	−1	95	47.3	May 29	Sept. 26	27.8
Burns, Oreg	6.57	1	99	46.1	May 16	Aug. 8	------
Silver Lake, Oreg	7.34	0	98	46.4	(a)	(a)	12.8
Vale, Oreg	9.21	8	101	49.4	May 26	Sept. 18	15.5

[a] Temperature below 32° F. every month.

All the localities mentioned in the above table are situated in valleys. On the mountains cooler and more humid atmospheric conditions prevail. The snowfall is light in the valleys and, like the mean annual precipitation, increases with elevation, but not in a direct and simple ratio. The general climatic conditions of both Idaho and Oregon vary in a conspicuous manner at different localities. In Idaho the northern and more mountainous portion of the State is much colder and more humid than the intensely arid southern portion. In Oregon aridity is the prevailing condition in the southeastern and central parts of the State, with increasing humidity toward the west and northeast. The portion of each State here described, while characteristic of its most arid valleys and most desolate mountains, must not be considered as representative of the entire political division of which it forms a part.

The most conspicuous effect of increase in elevation on climatic conditions in the region discussed is an increase in precipitation, particularly in snowfall. While in spring and early summer the snow lingers on the mountains long after it has disappeared from



SKETCH MAP OF PORTIONS OF OREGON AND IDAHO SHOWING, APPROXIMATELY, ARTESIAN AREAS

Scale

0 5 10 20 30 40 miles

the valleys, there is but one mountain range in the region on which it remains throughout the year. On Stein Mountain, Oregon, snow banks occur in the shelter of northward-facing cliffs in midsummer, and severe snowstorms occur as late as the first week in July and as early in the autumn as the middle of September. It is principally the melting of the usually abundant snow on this mountain range that feeds the many streams which flow from it into the adjacent valleys.

On account of the small rainfall in the valleys, agriculture is impracticable without irrigation. Throughout much of the region agricultural pursuits are restricted also on account of the liability of frost, particularly in the more elevated valleys where other conditions, such as the composition and texture of the soil are favorable.

At one time both valleys and mountains throughout southern Idaho and adjacent portions of Oregon were clothed with nutritious bunch grass, but now to a great extent these natural pastures are nearly ruined, owing to overgrazing. The valleys are treeless, except for the occasional cottonwoods along the immediate margins of streams, and the hills and lower mountain slopes are for the most part devoid of timber.

Throughout southern Idaho and over the greater portion of Oregon east of the Cascade Mountains, the plant which is most characteristic is the sagebrush (*Artemisia*). In common with nearly all of the arid region of the United States, the area discussed is a sagebrush land. At no locality along the route traveled is one beyond recognizable distance of this ubiquitous grayish-green shrub, except while crossing the barren mud plains left by the desiccation of ephemeral lakes or while standing on the summit of Stein Mountain. Although the sagebrush imparts a dreary monotony to the valley and lower mountain slopes, every traveler who lives out of doors is indebted to it for fuel. Not only does the sage replenish the explorer's camp fire, but to a considerable extent it is the ranchman's wood pile. Where it grows sturdily there is rich land, which needs only irrigation to make it highly productive.

The first tree to make its appearance when increase in elevation brings about greater precipitation is the juniper. Mingled with the scattered juniper trees, and usually beginning at a somewhat greater elevation than their lower limit, are thickets and groves of mountain mahogany. These grayish-green trees when growing wide apart frequently attain a height of 20 to 30 feet and look not unlike olive trees. They add much to the beauty of the land, or, perhaps more accurately, detract in a marked way from the desolation of the lower mountain slopes. In the deep stream-cut valleys they frequently form almost impenetrable thickets. On many of the lower mountains, as Mahogany Mountain in Oregon, for example, they constitute almost the only arboreal vegetation. Above the lower limit of the juniper and the mountain mahogany in certain favored ranges pines and firs appear and occasionally form valuable forests. The scarcity of trees throughout the arid portions of the two States visited is indicated by the fact that along the route traveled pines and firs are only seen at a distance. It is almost literally true that a traveler over the route referred to, about 600 miles in length, is never beneath the shade of a tree, unless it is one which has been planted and irrigated. The Lombardy poplar is usually chosen as a shade tree in villages and about farm houses and to serve as a wind-break on the borders of orchards and gardens. So adverse to tree growth are the climatic conditions that in the region covered by the reconnaissance there are only two areas to be seen which are dark with forests.

Castle Rock, a prominent crag situated in the northwest portion of Malheur County, Oreg., is on the southern border of an extensive forest of pines, firs, juniper, mountain mahogany, and other trees, and from its commanding summit the mountains to the northwest are seen to be black with evergreens. In autumn the somber tone of the mountains is relieved by dashes of golden yellow, mostly in the gulches on the lower mountain slopes, which mark groves of aspens. Again, from the hills and mountains near Harney and Burns, in Harney County, Oreg., a splendid forest may be seen mantling the gradually ascending mountain to the northwest. It is in this extensive forested region that Silvies River has its source. One of the most noticeable features of this forest, a part of which has recently, and very judiciously, been set apart as a forest reserve, is the absence, so far as can be judged from distant views, of burned areas within it. On account of the remoteness of the forests of eastern Oregon from railroads, they have not as yet been encroached upon by lumbermen and still preserve their primeval beauty.

One interesting feature in connection with the distribution of trees on the mountains which rise from an arid region is the occurrence in certain instances of two "timber lines." There is an upper limit of timber growth, the true timber line, the position of which is determined principally by the severity of the climate and especially by the prolonged cold and icy gales of winter. There is also a lower limit, determined principally by lack of moisture, below which trees are absent. Each of these borders of the mountain forests is in many instances sharply defined. On lofty mountains surrounded by arid valleys, when seen from a distance, there is frequently present a dusky band appearing not unlike the shadow of a cloud, midway up their rugged slopes. The band of shade crosses bold crests and deeply sculptured valleys, but on both its upper and lower margins is somewhat more extended in the gorges and ravines than on the intervening ridges. The upper limit of tree growth, or the "cold timber line," as it may be termed, as is well known, declines in elevation when traced from equatorial toward polar regions.

In Mexico the upper limit of tree growth has an elevation of about 17,000 feet; in California it has an elevation of approximately 12,000 feet; on the slopes of Mount St. Elias, in Alaska, it is at an altitude of 2,500 feet; while in northern Alaska and northern Canada it reaches sea level. In the far North it becomes the continental timber line, and to the north of it are the treeless barren-grounds and tundras. The lower limit of tree growth, or the "dry timber line," is highest where the climate is most arid, and becomes lower and lower when traced to regions enjoying greater humidity.[a] In regions where precipitation in the valleys is too scanty to permit trees to grow, the mountains may perhaps rise above the lower or dry timber line and become forest clothed. If the mountains are sufficiently lofty, they may rise above the upper timber line, in which case their summits will be bare of trees, but perhaps rendered glorious by fields of gorgeous alpine flowers. In regions of extreme aridity the lower limit of tree growth, as determined by aridity, may be so high that it meets the similar upper limit, as determined by temperature, and even the most lofty mountains will be bare of trees from base to summit. A conspicuous illustration of the rise of the lower limit of tree growth until it meets the upper limit at which arboreal vegetation can survive is furnished by the White Mountains in western Nevada, which, although over 13,000 feet high, are bare of trees from base to summit. In general, then, the mountains of the arid region in west-central North America, of which the portions of Idaho and Oregon under consideration form a part, are in many instances bare of trees because they fail to reach above the dry timber line; others, in general more lofty, are encircled with a belt of forest; while still others, perhaps even higher than those having a belt of trees between the two timber lines, are barren, for the reason that the dry timber line rises until it meets the cold timber line.

These conditions are well illustrated in southeastern Oregon. The mountains northwest of Harney and Burns, probably from 5,000 to 7,000 feet in elevation, are clothed with a fine forest of pines and other coniferous trees, while Stein Mountain, about 100 miles distant to the southeast, and rising to an elevation of over 9,000 feet, is, with the exception of scattered groves in the deeper canyons, without trees. The mountains northwest of Burns and Harney are sufficiently lofty to reach above the lower limit of timber growth or the dry timber line, and on their higher portions are completely forest clothed, but do not have bare peaks rising above the cold timber line. Stein Mountain is bare at the summit on account of severe climatic conditions, and the region from which it rises is so arid that the dry timber line meets the cold timber line, and even an encircling belt of forest is ab-

[a]There is another condition which at times becomes dominant in limiting the distribution of trees, namely, excess of humidity, as on the borders of swamps, lakes, etc., and it may be found convenient to recognize a "wet timber line" in addition to those referred to above.

sent. On Stein Mountain a few pines, firs, junipers, and cottonwoods grow in the deep canyons on its western slope, and at a few localities along the border of the small streams which descend its precipitous eastern escarpment. In each of these instances the elevation is well below that of the cold timber line, and water for natural irrigation is supplied by streams.

The snow line on mountains, or the lower limit of perennial snow, like the upper and lower limits of arboreal vegetation, is determined by climatic conditions, mainly temperature. The snow line marks approximately the elevation at which the mean annual temperature is at the freezing point, namely, 32° F. The snow line, like the cold timber line, is high above the sea in equatorial regions, and declines toward the poles. In the Andes, near the equator, the snow line has an elevation of about 17,000 feet; in the high sierra of California, it is at an altitude of about 14,000 feet; on the southern slope of Mount St. Elias it has an elevation of 2,500 feet; and in the Arctic Archipelago it reaches sea level. The snow line is higher than the cold timber line, and between the two lies the belt of alpine flowers.

In southwestern Idaho and adjacent portions of Oregon none of the mountains are sufficiently lofty to reach the snow line, although Stein Mountain, the highest and finest range of the region, makes a near approach to the necessary height, and, as already stated, snow banks are found on its higher portion throughout the summer, but for the most part only in the noontide shadow of northward-facing precipices.

TOPOGRAPHY.

The portions of Idaho and Oregon under consideration have broad and, in general, flat-bottomed valleys, separated by abrupt and deeply sculptured hills and mountains. The valleys so situated that the streams formed in or traversing them can discharge into lower valleys or join Snake River are usually trenched by stream channels and canyons, but the valleys from which there is no escape of the surface water are level floored and either contain lakes or the desiccated beds of transient water bodies. The valleys for the most part owe their existence to the upraising of the bordering hills and mountains. Their generally flat bottoms are due to the breadth of the folds or irregular dome-like elevations and depressions resulting from movements in the rocks and to the partial filling of the depressions by lacustral and stream-deposited débris.

The greatest valley of the region is the one through which Snake River flows. This, as was described in a previous report,[a] extends from east to west across the entire width of southern Idaho, and includes an area of about 1,200 square miles in Malheur County, Oreg. This valley, known also as the Snake River Plains, is underlain by lacustral and stream deposits and by extensive sheets of basaltic

[a] Bull. U. S. Geol. Survey No. 199.

lava. The fine, light-colored sediments, mostly of Tertiary age, are best developed in southwestern Idaho and the adjacent portion of Oregon, while the associated lava sheets are more continuous and apparently more numerous in southern Idaho east of Ada County. This difference in the rocks is accompanied by marked contrasts in the topography. The vast smooth plain through which the Snake River flows has been deeply trenched by that river from American Falls westward, and where the walls of its canyon are of basalt they stand in bold cliffs, and if sedimentary beds are present beneath a surface sheet of basalt, there occurs along the borders of the plateaus a characteristic feature common in many areas in Oregon. The sheets of resistant material, with weak strata beneath, give origin to rim rocks, as they are locally termed; that is, precipitous and frequently vertical escarpments, surmounting more gentle slopes which are sheathed with débris derived from the crumbling margin of the protecting layer (Pl. XVI). The details in the valley sides present great variety, dependent on the number of alternating strong and weak beds, and their variations in thickness. Where the strong, resistant rocks greatly predominate, the valley sides due to erosion are bold, and if canyons have been excavated they are characteristically narrow, with nearly vertical walls. Where weak, easily eroded rocks predominate, other conditions being the same, the valleys are wide and have flaring sides, perhaps with a few vertical steps, marking the positions of resistant beds, and narrow canyons with vertical walls are absent. Where all the rocks cut through in the excavation of a canyon or valley are soft or weak, as for example where lava sheets are absent, and only lacustral beds, stream deposits, or beds of volcanic dust and lapilli are present, the valleys have widely flaring sides which are sculptured into a great variety of details, owing to the action of rain, rills, and usually ephemeral streams. The results just indicated, which depend mainly on rock texture and composition, or perhaps more strictly on the varying degree of resistance rocks offer to mechanical and chemical erosion, are modified, as is well known, by differences in the way the earth's surface is being sculptured, dependent on climatic conditions, elevation above sea level or the base-level of erosion. In the portions of Idaho and Oregon under consideration the climatic conditions are essentially the same throughout, but the elevation and the position of the rocks are markedly different from locality to locality.

MOUNTAINS.

The entire region here considered may be designated as mountainous, and although at present not enough is known of the underlying structure to permit a detailed description of the manner in which even the more prominent elevations were produced, it is apparent that two types of mountains are present.

The Owyhee Mountains, in southwestern Idaho and the adjacent portion of Oregon, consist of a broad dome-shaped mass, composed of sheets of igneous rock and thick deposits of Tertiary lake and stream sediments, but as indicated by the débris in the stream beds leading away from the central part of the extensive uplift, quartzite and granitic rocks are present in its higher portion. The great dome, from a cursory examination of a part of its bordering slopes, has been deeply dissected by streams and given a rough surface.

Similar to the Owyhee Mountains in their general features are the mountains of the northern portion of Malheur and Harney counties, but too little is known of that region to permit one to speak with confidence, even of the larger features in the structure. It is evident, however, that great erosion has taken place, and that all the secondary features, or those which give diversity and picturesqueness to the scenery, are due to the weathering of the uplifted rocks and the erosive work of streams.

Mahogany Mountain, in the east-central portion of Malheur County, Oreg., is a long, narrow, sharp-crested ridge, trending northeast and southwest, and presenting a bold escarpment to the northwest and a much more gentle, but still steep slope to the southeast. The rocks of which it is composed are to a considerable extent, at least, rhyolitic tuffs, which occur in well-stratified beds and are resistant to the agencies of erosion. Beneath the beds of tuff there are probably soft Tertiary lacustral and stream deposits, and the entire series is inclined downward to the southeast at angles varying from perhaps 10° to 15°. In short, this uplift has the characteristics of the Basin ranges of Utah and Nevada, and, as appears from the evidence in hand, may be considered as a ridge produced by the upheaval and tilting of the rocks on one side of a break; that is, the mountain is due to the tilting toward the southeast of an elevated fault block. Erosion has roughened the slopes of the mountain, but not enough to conceal the leading features due to uplift. It is clothed with picturesque groves of mountain mahogany, whence its name.

The most prominent mountain in eastern Oregon, and by far the most conspicuous of all the elevations of a region embracing many thousands of square miles in Idaho, Oregon, and Nevada, is Stein Mountain, in the southeastern portion of Harney County. This conspicuous uplift rises to a height of about 9,000 feet above the sea, by aneroid measure, and about 5,000 feet above the desert plain in Alvord Valley at its east base. It is a long, narrow range, trending in general about northeast and southwest, but its crest line is somewhat curved. On the east, in its highest and most characteristic portion, it presents a remarkably bold escarpment, and on the west it slopes gradually down to the valley in which Harney and Malheur lakes are situated. The crest line of the uplift is near its eastern border, the descent on the east being precipitous and seemingly almost vertical, while the west slope, from 20 to 30 miles in length, has an inclination varying from about 3° at the crest line of the mountain to less than 1° at a distance of 15 miles, and continuing to decrease still farther westward. Southwest of the highest portion of the uplift the rocks of which it is composed are bent into a broad, gentle syncline that widens out to the northwest and passes beneath Harney and Malheur lakes. The longer axis of this synclinal trough pitches to the northwest and the inclined basin produced by the faulting and folding is drained by Donner and Blitzen River.

Stein Mountain is thus a typical monoclinal block of large size. The entire length of the uplift is in the neighborhood of 100 miles, but its extremities have not been closely examined. It is apparent that the main part of the eastward-facing cliff, forming the highest portion of the uplift for a distance of over 20 miles, is a fault scarp, along the base of which recent movements have taken place, as is indicated by the occurrence of hot springs and fresh breaks in alluvial deposits. During a visit to this region in 1882[a] I believed this fault to continue far to the north, but more detailed study must be made before this can be considered as fully established. It may be that at the north the Stein Mountain fault scarp merges with a similar eastward-facing cliff, which may be interpreted as being due to the erosion of an anticline. To the east of the great line of cliffs referred to there are other monoclinal ridges, which, so far as the evidence now in hand is concerned, may be interpreted as remnants of a deeply eroded anticline, instead of evidence of extensive faulting, as previously considered.

The rocks of which Stein Mountain is composed are principally basalt, in well-defined sheets. The basalt, as is well known, was poured out in a molten condition, either from fissures, forming what are termed massive eruptions, or, what is more probable, from well-defined volcanic vents, as has happened in many instances in the same general region in recent times. The age of the Stein Mountain basalt is probable Middle Tertiary, and it seems to be a part of the great succession of widely extended lava flows, termed in a general way the Columbia River lava. In the highest and grandest portion of the mountain the layers of basalt are in many instances separated one from another by layers of coarse yellowish sandstone, varying in thickness from 4 or 5 to about 15 feet. In one section, obtained while climbing the east face of the uplift, which overlooks Alvord Desert, seventeen of the sheets of sandstone referred to were observed. The basaltic layers average perhaps 60 to 75 feet in thickness, and a large number are present. The entire thickness of the great pile of widely extended sheets of basalt is about 5,000 feet.

On the west side of Alvord Desert, and for a distance of about 10

[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431-464.

miles along the east base of the highest portion of Stein Mountain, there are fine exposures of sedimentary rock, mostly shale, beneath the basalt composing the main mass of the mountain. These sediments have not, as yet, yielded fossils, but are probably of early Tertiary age. Their exposed thickness is over 1,000 feet. On the west side of Stein Mountain, in the vicinity of the east borders of Malheur and Harney lakes, there are, again, good exposures of sedimentary rocks and of tuff, but these are younger than the Stein Mountain basalt. A detailed study of this region can not fail to furnish most instructive results as to the succession of rocks which underlie a great portion of eastern Oregon and the neighboring parts of Idaho and Nevada, as well as typical illustrations of the manner in which the earth's crust throughout the same region have been bent and broken and otherwise deformed.

Traversing the immensely thick succession of basaltic sheets, in the east face of Stein Mountain, there is a number of nearly vertical basaltic dikes, ranging in thickness from about 15 to 60 feet. These dikes are horizontally columnar in their central portion and are well exposed in several instances for distances of a thousand feet or more in the walls of nearly vertical cliffs. These dikes, as is well known, are due to the filling of fissures with molten rock injected from below. The slow cooling of the intruded magma resulted in producing joints which define the sides of the usually six-sided, horizontal columns, which forms such a conspicuous feature of the parts of the dikes now exposed. The horizontal columns appear not unlike the steps of great stairways in the walls of the cliffs traversed by them, and a person climbing the mountain finds it convenient to utilize them as stepping stones, since in some instances they furnish the easiest means of ascent.

Since the upheaval of Stein Mountain it has undergone a large amount of erosion, and deep canyons have been excavated in it, especially on its western side. From the head of Donner and Blitzen River northward to Kieger Creek, a distance of about 25 miles, each of the principal westward-flowing streams, six in number, is situated in a deep canyon of its own making. The boldest and most characteristic of these excavations is the one occupied by Kieger Creek. This creek has its ultimate source at the crest line of the uplift, which, it will be remembered, is on the east margin of the tilted block forming the mountain, and flows westward in a steep-sided canyon that for a distance of about 8 miles is over 2,000 feet deep. The walls of this canyon, like all the other profound trenches cut in the west slope of the mountain, have been excavated in gently dipping beds of basalt. None of the westward-flowing streams, however, so far as known, has cut through the basalt so as to expose the rocks on which it rests. The canyon of Kieger Creek exhibits well-marked contrasts on its two sides. The north wall is a continuous and remarkably smooth escarpment of basalt, concealed in large part by talus, while the south wall is broken by several deep alcoves or side canyons, between the mouths of which there are prominent and in some instances remarkably picturesque pinnacles and buttresses of black basalt. The scenery of the south wall is remarkably fine, and derives its principal geological interest from the fact that the bottoms of the side alcoves open out into the main canyon to which they are tributary, at a generally uniform horizon, at least 800 feet above its bottom. To use a name recently introduced into geographical literature, the alcoves referred to are hanging valleys, or valleys which have been occupied by and owe their leading characteristics, as is now generally conceded, to the work of small glaciers tributary to a much larger ice stream. The main canyon of Kieger Creek is broad bottomed, with a well-defined U-shape in cross section, due in part, however, to steep talus slopes on its side. In brief, the shape of the canyon is such as is usually attributed to the work of a stream-like glacier. There is an absence of well-marked lateral moraines on the canyon's sides, and no polished or striated rock surfaces were observed. In spite of the incompleteness of the records, however, it seems safer to conclude that the canyon was occupied at one time by a small glacier of the alpine type. Four or five small tributaries joined the main glacier on its south side, each one being situated in a lateral alcove about 1 mile in length. These lateral alcoves have the characteristic shapes of glacial cirques, and at the head of each one snow banks at the present time are found throughout the summer. With but a slight change of climate, prolonging the winter conditions and increasing the snowfall, these lateral alcoves would again be occupied by glaciers. There is an absence of glacial records on the bold summit portion of the mountain between the deep canyons trenching its gentle west slope, and it appears that even during the Glacial epoch the balance of atmospheric conditions was only favorable to the accumulation of snow to such an extent as to supply small local glaciers in the deeper valleys. Evidently the mountain was deeply trenched by the westward-flowing streams before the Glacial epoch, and the canyons excavated at that time were subsequently modified in a small way by glacial ice. None of the canyons referred to, excepting the one excavated by Kieger Creek, was closely examined, but from the descriptions given by residents of the region it seems that several of them, including the one in which the principal tributary of Donner and Blitzen River rises, may have been modified somewhat by glacial ice. Stein Mountain, it will be remembered, is an isolated uplift, and the highest elevation in eastern Oregon or the neighboring portions of Idaho and Nevada. It is also the only mountain in that great region, so far as we now know, that bears evidence of having been formerly occupied by glaciers.

VALLEYS.

The valleys of southern Idaho and southeastern Oregon are in general broad with nearly flat bottoms and either trenched by stream channels or smooth from side to side. The features due to stream erosion are found in the valleys which have an avenue of escape for their waters, such, for example, as discharge to Snake River, but some of those which are not completely inclosed are, on account of the aridity of the climate, not scored with stream-cut channels. The smaller streams from the uplands, on entering a valley, flow less rapidly than in the upper portions of their courses owing to the flattening of their channels. More than this, evaporation decreases the flow, and furthermore, also, as the streams enter the arid valleys soil moisture becomes less and there is percolation away from a stream channel instead of into it, as is normally the case in humid regions. For these various reasons the streams drop a large part and in many instances all of the material they bring from the uplands, and thus broaden the valley bottoms and tend to give them even surfaces. The material brought out of the usually narrow valleys and canyons in the uplands and spread over a wide area in the valleys ranges in physical character from coarse gravel and even large stones and bowlders to fine sand and the finest of silt. The coarser material is deposited for the most part near the base of the bordering uplands, but under exceptional conditions sometimes is carried far down the stream channels, while the finer material, owing to the subdividing of the streams in the valleys, and the presence of distributaries on alluvial cones, is spread out over a broad area. By this process deep accumulations have been formed over the valley floors. It is to this method of deposition that the richness of the soils in the valleys of Idaho and Oregon, in common with nearly the entire arid region, is due. The streams from the uplands which fail to reach through drainage lines to the sea not only deposit their visible loads of sand, silt, etc., but their invisible loads as well—that is, the material they bring from the higher portions of their courses in solution. This process is carried on not only by the ephemeral streams, but to a considerable extent, as is well known, by the perennial streams, since the latter, while flooded, in many instances widely overspread their dry-season channels.

In southwestern Idaho and in the northern portion of Malheur County, Oreg., the broader valleys are to a great extent floored with fine, nearly white silt and volcanic dust—the sediment of Lakes Idaho and Payette—deposited in Tertiary time, and in these instances it is sometimes difficult to distinguish the older deposits from the stream-deposited silts laid down on them at a later date. In fact, the material in each instance, to a considerable extent, is essentially the same, since modern streams have eroded the Tertiary terranes and redeposited the loads thus acquired on adjacent surfaces.

Throughout many of the valleys of southeastern Oregon the underlying formation is fine silt and volcanic dust, essentially the same as the material just referred to as having been deposited in Lakes Idaho and Payette. Conspicuous examples of such deposits occur in the valley of the Owyhee where Jordan Creek enters it, about the eastern and southern margins of Malheur and Harney lakes, and in many other localities. The picturesque badland sculpturing of the lacustral deposits in the valley of the Owyhee is represented on Pl. XVIII.

In general, as may be gathered from the statements just made, the valleys of the region examined are floored with the deposits of Tertiary lakes and by modern alluvium washed in from the adjacent uplands. Another process of filling is through the action of the wind. Considerable removal and redeposition of fine material is now going on, and in certain localities notable accumulations of sand and dust can be easily traced to this cause. Still another process of valley filling, which results in giving depressions remarkably level and conspicuously persistent surfaces, is by the accumulation of rock fragments, such as lapilli and volcanic dust blown out of volcanoes during explosive eruptions, and the overflow of highly liquid lava from volcanic vents, as will be explained later in describing some of the recent volcanoes of the region under consideration.

The wide distribution of fine alluvium over valley floors by ephemeral streams necessitates a delicate adjustment of climatic and topographic conditions such as is seldom seen except in regions of small rainfall. Before man disturbed the balance of natural conditions, many of the valleys of Idaho and Oregon became deeply filled with fine, usually yellowish or nearly white rock débris, and only faint stream channels, if any at all, could be distinguished on the surfaces of the deposits during the seasons of extreme desiccation. The uplands and valleys alike were clothed with an open growth of vegetation, consisting largely of bunch grass. On the uplands and hillsides the grasses serve to bind the soil together, but less completely and efficiently than is usually the case in humid regions where a continuous sod is present. In the valleys, owing to the absence in many instances of stream channels in the deep alluvium, soil moisture was held near the surface at least during a considerable part of the dry season, and grasses, notably the coarse rye grass, grew luxuriantly. This delicate balancing of conditions, a result of a long period of adjustment, was seriously disturbed when stock was introduced and grazing on the natural pastures was carried on extensively. The introduction of large numbers of sheep, especially, has resulted in the nearly complete destruction of the bunch grass over vast areas, and in consequence the surface run-off from the uplands has been rendered more rapid and rills have been formed where previously the rain water soaked into the ground and percolated slowly away. The more rapid surface run-off has caused the hillsides to be deeply gullied, much of the soil has been swept into the lowlands, and on account of the increased strength of the surface streams the débris taken in suspension and redeposited is coarse as well as more abundant than formerly. Destructive denudation is thus in process on the hillsides and an equally destructive deposition taking place in the valleys. Owing to overgrazing the grasses do not have an opportunity to mature their seeds and scarcely to sprout from the old roots, and the destruction of the natural pastures is thus for several reasons going on at an accelerated rate. One result of the quicker transfer of the surface waters from the upland to the valleys is the excavation of channels, frequently from 5 to 20 feet deep, in valley floors, where, previous to the change referred to, the water spread out over the surface and deposited fine silt instead of eroding as at present. The cutting of channels has, in many instances, resulted in a far more complete subdrainage of the valleys, and in consequence has caused the disappearance of the rye grass which formerly flourished in them and its replacement by sagebrush. A conspicuous illustration of the process just outlined is furnished in the broad-bottomed valley of Willow Creek, northwest of Vale, in the northern part of Malheur County, Oreg. This valley, previous to the introduction of stock in excessive numbers, is reported to have been without a dry-season stream channel, and to have been clothed over great areas with a luxuriant growth of rye grass, which was mowed each year for hay. Now, owing to the more rapid escape of the rain water falling on the upland, a stream channel 8 or 10 feet deep has been excavated for a distance of a score of miles through the central part of the valley. In summer this freshly cut channel is dry and contains only occasional pools of water, and the rich land adjacent to it is so completely subdrained that the meadows of rye grass have disappeared and been replaced by sagebrush.

The cause for the recent changes just referred to is, as stated, overgrazing. The lands that have suffered, but more particularly the uplands, belong to the Federal Government, and are considered as free pastures. The reason for the ruin that has been wrought is the greed of the people owning stock. The remedy is the prohibition of free grazing on public lands. Now that practically all the land which can be irrigated, excepting through the use of artesian water and by the construction of storage reservoirs, such as can only be built by State or national aid, has passed to private owners, it seems desirable that the remaining land, and especially the hills and mountains, should be placed on the market at such a figure and under such conditions that they can be acquired in large tracts and cared for as private pastures. The beneficial influences of such a system are already shown, although illegally and in defiance of Federal laws, by the extensive tracts of Government land that have been inclosed with fences by numerous individuals and stock companies. If the grazing lands pass to private owners the interests of such owners would be to decrease and otherwise regulate the degree to which they are grazed, and to conserve and regenerate the rapidly vanishing grass crop.

HYDROGRAPHY.

DRAINAGE SLOPES.

In reference to drainage the portions of Idaho and Oregon traversed during the reconnaissance of 1902 present two principal divisions. All of the part of Idaho visited, together with Malheur County and the northeastern part of Harney County, Oreg., belong to the drainage system of Snake River, a branch of the Columbia, the waters of which are discharged into the Pacific Ocean. This region is thus a portion of the Pacific slope of North America. The principal part of Harney County, however, sends no water to the ocean, but is a part of the great region of interior drainage termed the Great Basin. The dividing line between these two great hydrographic provinces, in the region under review, is indicated by a broken line on the map forming Pl. I.

STREAMS.

The principal streams tributary to Snake River are the Owyhee and Malheur rivers. The Owyhee rises in the bold mountains of Owyhee County, Idaho, and the adjacent region on the west which lies in Oregon, and has the same general topography and climate. It flows for the most part through a succession of narrow defiles cut in resistant igneous rocks, but at times its canyon opens out into park-like valleys where soft lacustral sediment permitted easy excavation. One of these wide reaches eroded by the stream is situated where Jordan Creek joins it. Here there is a beautiful valley about 6 miles long and 2 miles wide, the east and west borders of which are picturesque cliffs. The rocks are principally evenly stratified lacustral sediments of Tertiary age which are light colored and in part of a delicate-green tint. Some idea of the marvelous rain and wind sculpture on the bold wall of this little stream-eroded basin may be gathered from Pl. XVIII. The bottom of the valley is sagebrush land, a small portion of which is now under irrigation. At the lower end of the valley the soft lacustral deposits are absent, and the river has cut a narrow canyon about 200 feet deep with vertical wall through dense igneous rock. A favorable site is here furnished for a storage reservoir, in which the abundant winter waters of the Owyhee might be retained for use on the parched plains near Snake River. This site is certainly worth careful investigation by engineers, and as I have been informed by settlers in the region, is but one of several similar localities along the Owyhee where storage dams might perhaps be constructed to advantage.

The Owyhee River, in the lower portion of its course, after passing through a narrow, irregular, steep-sided canyon in the Cedar Mountains and emerging into the broad valley excavated by Snake River, is bordered by flat lands, where the soil is rich. All of its water in summer is used for irrigation.

The Malheur River derives by far the greater part of its water from its branches, which come in from the northwest and have their sources in the forest-covered Strawberry Mountains. Its principal tributaries are perennial streams, but in summer all of the water which reaches the main channel is used for irrigation along the lower 40 miles of its course, and great areas of desirable land still remain uncultivated. As in the case of Owyhee, the Malheur demands careful study from hydraulic engineers, with the view of storing its winter flow for summer use.

A feature of special geographical interest in the case of the Malheur is the fact that it has lost fully one-third of its former drainage basin, owing, judged by the observations, to the occurrence of a lava flow which dammed its channel in the vicinity of Mule, in Harney County, between Stein Mountain and the Crow Creek Hills. It is to this lava dam, which obstructs the old river bed for a distance of about 30 miles, that Harney and Malheur lakes are due. The surface of the lava is only about 10 or perhaps 15 feet above the normal level of Malheur Lake, but the broad, flat-bottom valley to the west of the obstruction permits of the spreading out of the waters which reach it until evaporation counterbalances the inflow, and the lakes produced have never risen sufficiently to discharge across the lava sheet which retains them.

The portion of the former channel of Malheur River now floored with a sheet of recent lava is situated about 6 miles north of Mule, and leads from the broad basin of Malheur Lake eastward to Camp Creek, at present the extreme southern branch of Malheur River. The level-floored valley is about 1 mile wide near Mule, with bold bluffs on each side, and the essentially level lava sheet now forming its bottom is not broken by a stream channel until a point about 6 miles from Camp Creek is reached. Near the terminus of the lava stream its surface is rugged and presents numerous ridges like those so common in the Snake River Plains. The valley is treeless, but is covered with a strong growth of sagebrush.

The failure of Malheur Lake to rise and overflow the low lava dam which confines it is evidence that the climate of the region has been arid since the obstruction was formed. The ponding of the waters above the lava dam and their failure to rise and cross it caused the entire region now drained by Malheur and Harney lakes, about 4,500 square miles in area, to be removed from the Pacific slope drainage and added to the Great Basin.

The principal streams in the region draining to Malheur and Harney lakes are Silvies River, which rises in the forest-covered mountains to the north of Burns and Harney, flows south, and empties into Malheur Lake; and Donner and Blitzen River, which has its head branches on the west slope of Stein Mountain, flows northward, and also enters Malheur Lake. Of these two important streams, Silvies River is much the larger. Each of these streams is utilized to its full capacity for irrigation, but there are seemingly favorable conditions for storing their abundant winter run-off and thus increasing their efficiency, not only for agricultural purposes, but as sources of power. Of the numerous small streams which rise on the elevated borders of the Malheur-Harney basin, and flow toward its center, there are none which reach the lakes in summer. Some of the small streams referred to, as Rattlesnake Creek near Harney, and Cow Creek, in summer barely enter the broad flat-bottomed basin to which they flow and there expand and are lost in natural meadows. In the majority of instances, however, the smaller streams from the mountains flow only during the rainy season or when the snow on the uplands is melting; they become dry in summer.

East of Stein Mountain there are several basins, aggregating about 1,500 square miles in area, from which there is no outflow of water. The largest of these is the one in which Alvord Desert is situated. Alvord, Mann, and Juniper lakes occupy other similar desert valleys. This region is a part of the Great Basin, and all the water which reaches it is evaporated. The streams are small and wherever land is available are fully utilized for irrigation.

Such information as I have been able to gather concerning Snake River and its tributaries, in the portion of its course represented on the accompanying map (Pl. I), is contained in Bulletin No. 199 of the United States Geological Survey. A much more detailed account of the river, however, and of the water resources generally of southern Idaho may be found in the reports of the State engineer of Idaho.

SPRINGS AND ARTESIAN WELLS.

Some account of the warm and hot springs and of the artesian wells in the portions of Idaho and Oregon examined in 1902 has been presented in a preliminary report on the work of that season,[a] and only a brief summary of the results reached in this connection seems desirable at this time.

It is to be understood that the streams briefly described above, like most streams the world over, are fed by rains or melting snow, but to a great extent owe their water supply to seepage from the bordering uplands. The seepage referred to is sometimes sufficiently concentrated at definite localities to form hillside springs, the temperature of which throughout the year is approximately the same as the mean annual temperature of the locality where they are situated. In the region under consideration this may be taken as approximately 50° F., although in certain localities, as at Burns, Oreg., it is perhaps 2° lower.

In addition to hillside springs, there are at numerous localities, as indicated approximately on the map (Pl. I), springs of warm or hot water, which rise from deep sources, presumably in most instances

[a] Water-Sup. and Irr. Paper U. S. Geol. Survey No. 78, 1903.

through fissures. These springs range in temperature from a few degrees above the mean annual surface temperature up to the boiling point of water for the elevation at which they occur, and vary in volume from a mere seepage to several cubic feet per second. Good examples are furnished in Idaho by the hot springs about 4½ miles east of Boise, the hot spring about 7 miles east of Mountain Home, the warm spring 1 mile west of Walters Butte, the copious hot spring at Enterprise, and the several springs of warm water near Sands. In Oregon hot springs occur at Vale, where one has a temperature of 198½° F., so far as known the hottest in the region; in Warm Spring Valley between Vale and Westfall; at Beulah; from 1 to 3 miles southwest of Burns; near Silver Lake; on the southeast border of Harney Lake; a few miles northeast of Malheur Lake; in Alvord Valley on the west border of Alvord Desert; near Andrews; and in Whitehorse Valley. Such data as are available concerning these numerous fountains of heated waters are presented in the Preliminary Report on Artesian Conditions,[a] already referred to.

The chief interest in reference to these warm and hot springs aside from their direct utilization for irrigation, baths, cooking, warming houses, etc., is the bearing they have on the question of obtaining artesian water. Every fissure spring is essentially a natural artesian well, but in most instances the conduits through which the water rises are obstructed and much lateral flow or leakage presumably results. The question as to the best way of improving such springs and of increasing their flow presents itself to everyone who examines them. In a few instances efforts have been made in this direction which are highly promising. Wells drilled in the vicinity of the hot springs near Boise have been conspicuously successful, and the capital of Idaho now has an excellent supply of both hot water—temperature from 125° F. to near boiling point—and of water with a temperature of from 60° to 70° F. derived from artesian wells. Other successful artesian wells have been drilled in the vicinity of hot springs in Bruneau and Little valleys, Idaho, and again at Vale, Malheur County, Oreg. The well at Vale is, however, not utilized except for bathing, on account of the large amount of mineral matter in solution, much of which is deposited in the casing of the drill hole and leads to its obstruction.

The water of this artesian well, or, perhaps more accurately, developed hot spring, should be analyzed in order to learn its medical or other properties, and experiments made with reference to preventing the precipitation of mineral matter. The precipitation is apparently due to the cooling of the water as it rises, and by insulating the casing this could no doubt be decreased and perhaps prevented. Then, too, if the waters prove of value, tools for cleaning the well could easily be provided and the obstructions formed within it removed as frequently as necessary.

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[a] Water-Sup. and Irr. Paper U. S. Geol. Survey No. 78, 1903.

ARTESIAN BASINS.

The study of the geological structure—that is, the positions the stratified rocks occupy—together with the information furnished by springs and drilled wells, has shown that there are four basins in southwestern Idaho and southeastern Oregon which may be expected to yield flowing water when wells are put down. In two of the basins referred to drilled wells have already proved the presence of subsurface water under sufficient pressure to cause it to rise to the surface and overflow when the drill holes are properly cased. The four basins referred to have been described in the Preliminary Report on Artesian Conditions already mentioned, and are indicated approximately on the map forming Pl. I. They have been named the Lewis, Otis, Harney, and Whitehorse artesian basins. Their combined areas below the artesian head in each instance is estimated at approximately 2,000 square miles. While it is not to be assumed that all of this area can be irrigated by means of artesian wells, the conditions are such as to warrant the careful testing of each basin and a judicious development of its water supply.

The Lewis artesian basin, situated along Snake River, between Glenns Ferry and Weiser, and including Bruneau and Little valleys and the lower portion of Boise Valley, has an area below the known artesian head of not less than 1,000 square miles. Wells have been put down in it at several localities, as in Bruneau Valley, Little Valley, and near Guffey, Central, and Enterprise, in Idaho, and at Ontario, in Oregon. These wells are from 200 to somewhat more than 1,000 feet deep, and with one exception—near Central—are all successful so far as demonstrating the presence of artesian conditions is concerned, and in the majority of instances furnish a strong surface flow of water. The water in all cases in which temperature measurements have been made is warm and in general ranges from 60° to 100° F. The exceptional well at Vale, which is strictly speaking a developed hot spring, has a temperature of 198½° F. The artesian wells near Central and Enterprise exhibit an increase in their temperature gradients—that is, the rate of increase in temperature with depth—as the large hot spring at Enterprise is approached. This and other similar although less definite instances indicate that the Lewis artesian basin is supplied in part at least by water rising through fissures from a considerable depth.

The greater number of borings that have been put down in the Lewis artesian basin were drilled with the hope of obtaining petroleum. In this respect they were failures, although they attained a more desirable result in demonstrating the existence of artesian water. The reasons for the failure to discover petroleum and the conditions which lead to the accumulation of that substance will be discussed later.

The Otis artesian basin, in the region drained by Otis Creek, about 6 miles northeast of Drewsey, Oreg., has not been tested with the drill, and will merit the name here given it only after such demonstration. The reasons for predicting the presence of subsurface water under pressure are the basin-like structure the rocks exhibit and the presence within the basin of strong springs of warm water. The area throughout which it is probable that artesian water can be had is in the neighborhood of 20 square miles.

The Harney artesian basin embraces the extensive region draining Malheur and Harney lakes, and as shown by its geological structure may be expected to yield flowing wells throughout an area of perhaps 1,000 square miles. Two drill holes, one near Harney and the other near Burns, have been put down and have demonstrated the existence of subsurface water under sufficient pressure to force it to the surface where wells are drilled to the requisite depth and properly cased. The artesian head, as indicated by these wells, has an elevation of about 4,100 feet. The thickness of rocks involved in the formation of the basin, however, probably exceeds 10,000 feet, and water-bearing horizons at a greater depth than those now known may reasonably be expected to be present. Several warm and hot springs in the Harney basin, as already mentioned, lend support to the prediction that success will follow a careful exploration of the basin with the drill where the surface elevation is less than that of Harney or Burns.

The Whitehorse artesian basin is located about 20 or 25 miles east of the higher portion of Stein Mountain, and includes the valley in which the former military post known as Whitehorse was located. Here again the geological structure and the presence of warm springs are sufficiently strong indications to warrant a careful exploration with the drill with the hope of obtaining a surface flow of water. The artesian head, as shown by the warm springs about 6 miles south of Whitehorse ranch, is well above the flat lands of the valley's bottom. The area throughout which one is seemingly justified in predicting success in case wells are drilled is not less than 30 square miles.

The four artesian basins briefly described above contain about 2,000 square miles of rich agricultural land, throughout which the conditions justify the opinion that flowing water may be obtained. It does not follow from this that all or even the greater part of the tracts referred to can be irrigated, as it is to be presumed that the water supply will not be adequate to meet all the demands that will be made upon it. The expense involved in drilling a well, and the certainty that the water supply even under the most sanguine expectations which may seem warrantable is not inexhaustible, make it imperative that there should be the strictest economy in the use of the water and rigid restrictions with reference to its waste. Suggestions in this direction have been offered in the Preliminary Report on Artesian Conditions, to which the reader is referred for a more detailed record of the facts available concerning the artesian basins of the region under review and the best means to be employed in the development and care of their water resources.

LAKES.

As previously stated, the portions of Idaho and Oregon shown on the accompanying map (Pl. I) have undergone long erosion, since the youngest of the more extensive geological formations occurring there were spread out as lacustral sediments or lava flows, and during or since these same formations were folded and faulted. As a result of such a well-advanced stage in topographical development, the land would be expected to be well provided with drainage channels, cascades and waterfalls should be rare, and all lake basins should have been either filled with sediment or drained on account of the cutting of channels by their overflowing streams. These expectations are fulfilled throughout the greater part of the region referred to, and the exceptions are due to special occurrences which are seemingly accidents, and which have interrupted the normal course of events. The so-called accidents referred to are of two classes, namely, lava flows, and decrease in precipitation accompanied by an increase in the rate of evaporation. Locally conditions dependent on each of these causes have acquired control in the processes of stream erosion and denudation, and lakes appear in situations where they would otherwise be absent.

There are three localities in the region under consideration where lakes are present, all of which are in Oregon. These are on Cow Creek, a branch of Jordan Creek, in the eastern part of Malheur County, where the Cow Creek lakes are situated; the Harney Valley, in Harney County, which is occupied in part by Malheur, Harney, and Little Silver lakes; and Alvord Valley, also in Harney County, and east of Stein Mountain, where there are about 8 lakes during rainy periods, most of which evaporate to dryness during summer seasons.

COW CREEK LAKES.

In the valley of Cow Creek, about 12 miles northwest of Jordan Valley village, there are several small lakes, with markedly irregular outlines. These lakes are due to the damming of the waters of Cow Creek by recent lava flows. As will be described later, not less than four small volcanic craters of recent origin, which it is convenient to term the Jordan Craters, occur in what was previous to their formation a well-drained valley. The craters referred to are situated approximately on a north-south line, a little to the west of the former course of Cow Creek, and from each crater have been poured out what may be truthfully stated to be immense lava flows, in comparison with the size of the craters from which they came. Each of these flows acted as a dam to the waters of Cow Creek and led to the formation of one or more lakes. The most characteristic example of the lakes formed in this way is the most northerly in the series, which is held in check by the last lava flow from the Jordan Craters. This lava sheet has an area of about 50 square miles and entered the channel which Cow Creek had eroded through a previous lava sheet. The recent lava flowed up the old canyon for about a mile and now terminates with a low, irregular slope. The lava forms a dam, above which a lake about 4 miles long has been caused to form. The lake extends into lateral valleys so as to have an irregular outline, but on an average is perhaps half a mile wide. During high-water stages it overflows across basalt and supplies other lakes to the south. In summer it is lowered by evaporation, leaving broad areas exposed about its eastern and northern borders. These lands are covered with wild grass, and form natural meadows from which several hundred tons of hay are cut each year. The lake has never been known to evaporate to dryness, and is only slightly alkaline. Its water, as is common with many playa lakes (that is, lakes which evaporate each summer so as to leave large portions, or as is most common, their entire beds, exposed as mud plains or playas), is always turbid with fine silt in suspension.

South of the lake just described, which is the largest of the series of which it is a member, there are seven or eight other similar water bodies and several small ponds. The irregularities of these lakes and ponds and their indefinite or rather variable number are due to the fact that the water fluctuates in volume, and as the surface of the lava, which is in part submerged, is irregular, marked changes in the outlines and in the number of lakelets to be seen occur between the rainy and dry seasons. The more southern of the Cow Creek lakes, like the one at the north, fluctuates greatly in volume, and in summer leaves broad natural meadows exposed on its eastern border, from which large quantities of naturally irrigated wild grass are cut each year. Cow Creek, south of the lakes in which it is ponded, flows through an irregular, ill-defined channel, and near Jordan Creek its waters are utilized for irrigation.

About the Cow Creek lakes the creek which supplies them flows through a rather deep canyon which is joined by well-defined branches, thus demonstrating that the process of stream adjustment and of erosion was well advanced before the Jordan Craters sent out lava which invaded the medial portion of the valley it entered, and buried its previous stream-sculptured surface.

The Cow Creek lakes furnish a fresh and unmodified illustration of the effects of lava flows on drainage, and present typical examples of lava-dammed lakes. Other lakes of the same character occur about the Diamond Craters, at the west base of Stein Mountain, in Harney County, but are much less extensive, and in fact swamps instead of open water mark the presence of obstructions to the escape of the surface waters. The Bowden Crater, as will be described later, also sent out a broad lava sheet, which obstructed the drainage and caused a lake to form, but in this instance the outflowing stream has cut a drainage channel, and the lake, which once existed, has been drained.

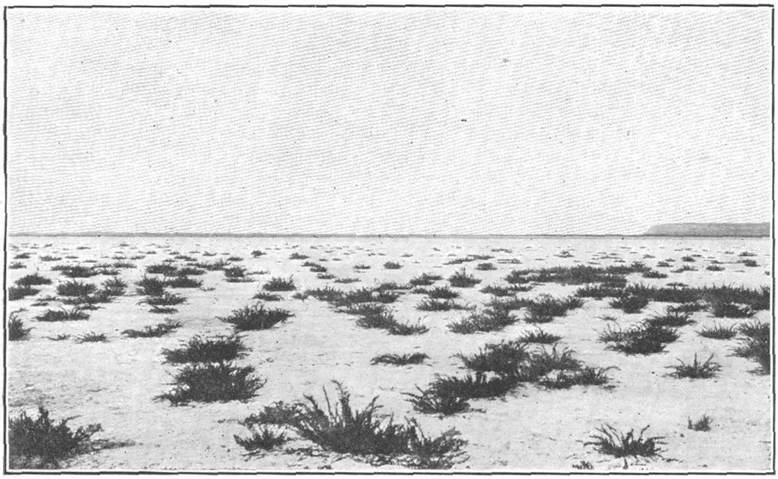
MALHEUR AND HARNEY LAKES.

These two water bodies, situated in the central part of Harney County, present several features of geographical interest. Harney Valley is situated in an arid climate and is one of the many valleys in the region of interior drainage termed the Great Basin which now fail to send streams to the ocean. Malheur Lake is flat bottomed, with low, indefinite shores, and although fluctuating greatly in area with seasonable changes in precipitation and the rate of melting of snow on the neighboring mountains, is probably at no time over 10 feet deep in its deepest part. When most broadly expanded it is about 23 miles long by 5 or 6 miles wide and has an area of approximately 135 square miles, but as it is bordered on nearly all sides with swamps, and large areas even in its central parts are occupied by rank growths of tules and other aquatic plants, its precise area would be difficult of determination even if surveys were made for that purpose. Its water supply comes mainly from Silvies River, which rises in the forest-covered mountains to the northwest and has a length, not including its minor bends, of about 75 miles, and from Donner and Blitzen River, the sources of which are on Stein Mountain, 50 or 60 miles to the southeast. Before their waters were utilized for irrigation these streams probably never failed, even in summer, to send a large volume of water to the lake. In addition, there are several streams which reach the lake only in winter, and a few springs, which add in a small way to the lake's resources.

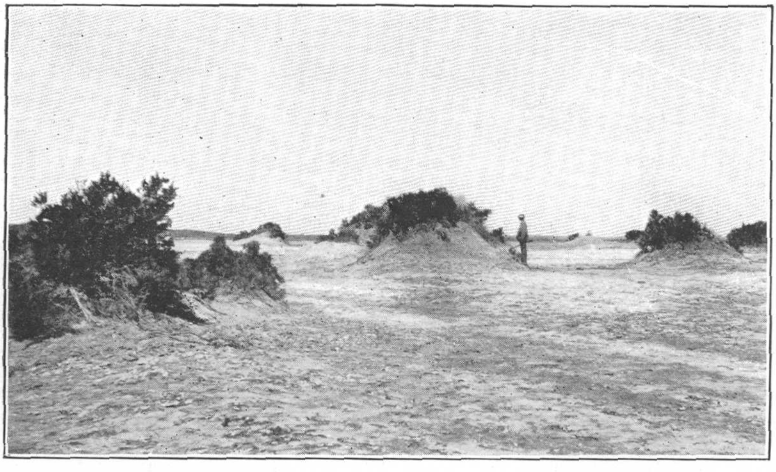
Harney Lake, situated southwest of Malheur Lake, is rudely circular, with a diameter of about 10 miles and an area of from 50 to 60 square miles. Its northern and western shores are low and gently sloping, but the water line is well defined, and swamps are absent. On the southeast side of the lake cliffs rise precipitously from its margin during high-water stages, and near the shore the waters have a considerable though as yet unmeasured depth. Judging from the appearance of the lake when seen from adjacent hills, and from the ineffectual attempts to sound it made by fishermen, it is to be expected that a depth varying from 50 to 100 feet throughout a large portion of its central and southwest portions will be discovered when an accurate survey is made. A large volume of water is contributed to the lake by Silver Creek, which in midsummer, when its supply comes entirely from springs in the lower portion of its course, discharges about 10 cubic feet of water per second. In winter and spring Silver Creek is greatly extended headwards and becomes a drainage channel for a region 80 or 100 square miles in area. At such times it is a veritable river with a broad, swift current, and discharges a great volume of water into the lake at its mouth. There are also ephemeral streams which flow to Harney Lake during the rainy season, and hot springs on its border make some contribution to its water supply.

None of the springs rising in the neighborhood of Malheur and Harney lakes, it may be noted, are highly charged with mineral matter in solution, and all their tributary streams are of clear, sweet water, unless it is in late summer, when they are greatly reduced in volume by evaporation.

Malheur and Harney lakes are without outlet, except that during high-water stages the former sometimes overflows into the latter through a recently formed channel. The two lakes during their winter stages are separated by a narrow irregular ridge of sand dunes, which extends westward and borders Harney Lake for several miles. These dunes are composed of quartz sand, blown up from the shore of the lake during low-water stages by the prevailing westerly winds, and make a conspicuous range of hills in general about 100 feet high, in part grass covered, with steep-sided basins among them. Previous to the formation of these hills of wind-drifted sand the basins of Malheur and Harney lakes were not separated one from the other, at least during high-water stages, and but one lake existed. The water in this lake at the locality where the basin is now divided was shallow and during summer seasons, or at intervals of unusual desiccation, the bottom was exposed. During such a low-water stage, as seems evident, the winds drifted the exposed sands and formed a ridge which divided the preceding water body into two lakes. This was before white men visited the region. It is reported that during an unusually high-water stage in 1877, and aided, as I have been informed, by a furrow plowed for the purpose, the water of Malheur Lake broke across the ridge of sand referred to above and rapidly scoured out a channel leading to Harney Lake. This channel is now about a quarter of a mile long, 30 to 40 yards wide, and from 6 to 10 feet deep. At the time of my visit, August 6, 1901, the channel was dry and the water of Malheur Lake had shrunk until only a few hundred acres to the south of The Narrows (a constriction in the lake near its southern end, now crossed by a bridge) were flooded; the water of Harney Lake had also been diminished by evaporation so that the lake's surface was from 8 to 10 feet below the ridge of sand and gravel marking its preceding winter stage. The gravel ridge or beach line referred to was about on a level with the highest point in the newly formed channel, but the ridge, it will be understood, marks the upper limit of the waves generated during storms and not the usual level of the lake. In summer, when Malheur Lake is low, nearly the whole of the portion of its basin south of The Narrows is dry and converted into a playa over which broad areas are white with alkaline salts, or overgrown with the familiar plant of alkaline valleys known as *Salicornia* (Pl. II, *A*). Nearly every winter season, as I have been informed by persons living in the vicinity, Malheur Lake rises and overflows into Harney Lake. Each lake is alkaline, but, owing to the delicate adjustment described above, Harney Lake is more strongly charged with mineral matter in solution



A. SOUTH SHORE OF MALHEUR LAKE, OREGON. SALACORNIA GROWING IN ALKALI.



B. EOLIAN MOUNDS ON BORDER OF PLAYA, NEAR IRON MOUNTAIN, OREGON.

than its companion which occasionally discharges into it. A sample of water from Harney Lake collected August 5, 1902, gave the following results on analysis:

Analysis of the water of Harney Lake, Oregon.

[Analyst, George Steiger.]

	Parts per million.
Silica, SiO_2	28.7
Aluminum, Al	None.
Iron, Fe	None.
Magnesium, Mg	6.8
Calcium, Ca	None.
Sodium, Na	3,604.5
Potassium, K	192.8
Carbon trioxide, CO_3	2,974.7
Hydrogen, H (required in formation of bicarbonate)	32.3
Sulphuric anhydride, SO_4	773.3
Chlorine, Cl	2,771.3
Bromine, Br	None.
Iodine, I	None.
Boracic acid, B_4O_7	92.8
Total	10,477.2

Specific gravity, 1.081.

NOTE.—Reaction strongly alkaline. The computation shows that no free carbonic acid is present above that required to form bicarbonates.

Judging from the analysis given above, the most abundant salts contained in the lake waters are sodium chloride or common salt, sodium carbonate or bicarbonate, and sodium sulphate. Potash and borax are present, but as the total amount of saline matter in solution is only 1.04 per cent by weight, the lake waters can not be considered as being of commercial value. The low degree of salinity, and the absence of iodine and bromine, together with the low percentage of magnesia, furnish evidence that the lake as it exists at the present day is not the result of a long period of concentration by evaporation.

The water of Malheur Lake is a weaker saline solution than its companion, as it is being freshened by overflow. While this renders it evident that it is of no economic importance, so far as its contained salts are concerned, it is of interest in reference to the proposed use of its water for irrigation, as it is not too highly saline for that purpose. The manner in which Malheur Lake is contributing its salts to Harney Lake, by the process of occasional overflow described above, is also of much interest to geologists, as it illustrates one method by which a lake may be freshened, while at the same time a companion lake is growing more and more saline. [a]

[a] The occasional outflow of water from Malheur Lake into Harney Lake, from which it escapes solely by evaporation, is a counterpart on a small scale of the process, now well advanced, by which the Caspian Sea is being relieved of a part of the saline matter it holds in solution. The Caspian is an inclosed lake, 181,000 square miles in area, the waters of which vary in chemical composition in different parts, but remote from the mouth of the Volga and other tributary streams contain 0.6494 per cent of total salts in solution. On the east side of the Caspian there is

The inner slopes of the valley in which Malheur and Harney lakes are situated are not scored with old beach lines or terraces, as is the case in so many of the similar valleys of the Great Basin. This is consistent with the low elevation of the old river channel leading eastward from the valley to the headwaters of Malheur River. As already stated, the present hydrographic basin of Malheur and Harney lakes was formerly a part of the Malheur River drainage system, and was cut off by a lava flow which entered the channel of the former and greater Malheur River. On account of the small precipitation and active evaporation in the region above the broad lava dam, the water in the basin thus cut off has never been able to rise sufficiently to cross the obstruction which retains it. The evidence thus furnished, tending to show that Malheur and Harney lakes are not remnants of a former large water body, is also in harmony with their chemical composition. Their present degree of salinity indicates but a comparatively short period of time since the dam which retains them was formed. The lava sheet referred to is, however, covered with a thin soil, and supports a rank growth of sagebrush, indicating that it is much older than the very recent lava flows about the Diamond, Bowden, and Jordan craters, to be described later.

SILVER LAKE.

In the valley of Silver Creek, about 11 miles northwest of Harney Lake, there is a small, shallow water body, termed Silver Lake, and sometimes referred to as Little Silver Lake to distinguish it from another and larger water body of the same name situated in Lake County, Oreg. The basin in which Silver Lake is situated is broad and flat, with indefinite boundaries, and during high-water stages becomes a wide expansion of the creek which flows through it. In summer the creek ceases to flow, and the lake is kept from evaporating to dryness by the contribution received from a hot spring on its southern border.

Several basins along the somewhat indefinite course of Silver Creek between Silver and Harney lakes become flooded in winter and completely desiccated in summer. When dry the floors of these shallow basins become absolutely barren mud plains or playas, some of which are 3 or more miles across. These yellowish floors of dried mud are sufficiently hard in summer to be crossed with a loaded wagon with-

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a bay, about 100 miles in diameter, known as the Karaboghaz, or "bitter lake," which is connected with it by a strait 450 yards wide and 5 feet deep. The Karaboghaz has no inflowing streams and no outlet. The climate is arid, and on account of the loss from its surface by evaporation a current sets into it from the Caspian at a rate of from 1½ to 3 miles per hour. As computed by Van Baer, the amount of saline matter carried by this current is 350,000 tons per day. The Caspian is thus losing saline matter probably at a greater rate than it is being supplied, and the water of the Karaboghaz has been concentrated to such an extent that it is a saturated solution, and contains something like 24 per cent of saline matter, and from it common salt is being deposited. An instructive example is thus furnished of one method by which a saline lake may be relieved of its salts, and of one method also by which saline matter is concentrated and deposited in a solid form.

out leaving more than a faint trail. Their smooth surfaces are usually intersected in every direction by a network of shrinkage cracks, and about their borders there is in some instances a white incrustation of saline matter, which is left as the water which seeps down from the neighboring uplands is drawn to the surface by capillary attraction and evaporated. The characteristic vegetation about the borders of these and many other similar playas in the Great Basin region is the common greasewood. This shrub frequently attains a height of 4 to 6 feet, and, like most desert plants, grows in isolated clumps. These bushes encroach on the playas, and occupy an advanced picket line, where the conditions leading to survival or death are nearly evenly balanced. One result of this delicate adjustment is that during the periods when the playas are desiccated the wind blows away the dried sediment from between the clumps of bushes, and also drifts fine débris about them, so that rudely circular mounds are formed, which in many instances are 8 or 10 feet high and from 12 to 20 feet in diameter. (Pl. II, *B*.) The roots of the greasewood serve to retain the material forming the mounds, and the obstruction to the wind afforded by their branches also tends to preserve them. That the mounds are dependent on the greasewood for their preservation is well shown by the fact that when the bushes die the mounds soon disappear. In some instances a complete sequence can be observed, from large mounds crowned with a vigorous growth of greasewood through similar mounds on which the bushes are dead, and from those to others partially denuded by the wind, in which only the roots of the plants which formerly grew in them can be found, and from these again to low, indefinite hillocks on the desert, and even flat, circular areas which reveal the former presence of a mound solely by the fact that the surface is slightly softer and perhaps a little more moist than the broad, flat area about it. Although greasewood mounds of the nature just described are seemingly transient features of the borders of playas, they might, in certain situations, survive a change to more humid climatic conditions and the areas they occupy, becoming grass covered, be transformed into "mound prairies."

THE LAKES OF ALVORD VALLEY.

At the foot of the precipitous eastward-facing escarpment of Stein Mountain there is a well-defined valley, trending in general about northeast and southwest, which is fully 75 miles long, and about 8 miles wide in its widest part. This valley was evidently at some former time a part of a river system, but the topgraphic history of the extensive region of which it is a representative part remains to be deciphered.

In the widest part of Alvord Valley, and east of the highest portion of Stein Mountain, is situated Alvord Desert. This is a mud plain or playa throughout most of the year, but in the winter and spring it becomes covered with a few inches or possibly 1 or 2 feet of water and transformed into a lake, which when fully expanded covers an area of between 50 and 60 square miles. The water supply for this winter lake is furnished principally by the small streams which descend the precipitous east face of Stein Mountain, but a small contribution is made by a hot spring on its southwest border. In summer the desiccated bed of the lake is a smooth, even, hard mud plain, crossed in every direction by a rather fine network of small shrinkage cracks. Scattered over the smooth and frequently glossy surface there are, at intervals usually of several rods, fragments of rock, some attaining a diameter of perhaps an inch. The manner in which these angular fragments reached their present resting place is obscure, but it is probable that they were transported and deposited by floating ice. Frequently on clear, hot summer days the delusive effects of the mirage relieve the desolate monotony of the desert and the surface is seemingly flooded with water. To the south of Alvord Desert and in the same valley or basin is another and smaller playa lake, known as Alvord Lake, which is supplied during the wet season by Trout Creek, and also receives the waters from a constantly flowing hot spring.

North of Alvord Desert the valley adjacent to the east base of Stein Mountain becomes narrow, its general width being about 2 miles, and the streams from the bordering mountains have deposited large alluvial cones, some of which extend entirely across the depression and meet the débris on its eastern side. In this manner the valley has been divided into a number of shallow basins, four of which hold small playa lakes, of which Juniper and Mann lakes are representative examples.

The basin in which Juniper Lake is situated was formerly more deeply flooded, as is shown by beach lines about its borders, and contained a lake about 7 miles long, 2 to 3 miles wide, and 100 feet deep. About the little valley in which Mann Lake occurs there are also faint beach lines which show that it formerly contained a lake approximately 150 feet deep and about 4 miles long and 2 miles wide. Several of the small basins between the sharp-crested ridges to the east of the two lakes just mentioned are occupied by mud flats in summer and by ephemeral lakelets in winter.[a]

FLUCTUATIONS OF LAKES AND EFFLORESCENCES.

The lakes of Harney and Alvord valleys, and other places described above, are similar in many ways to a large number of lakes scattered

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[a] As the facts concerning a few of the inclosed lakes of Oregon here presented may perhaps lead the reader to wish to continue the study further, references are given to some of the more accessible reports, books, etc., bearing on the subject:

Russell, I. C., Geological history of Lake Lahontan: Mon. U. S. Geol. Survey, vol. 2, 1885.

Russell, I. C., Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, 1889, pp. 261-394.

Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

Russell, I. C., Lakes of North America, 1895.

throughout the Great Basin, but occurring principally in its northern half. The reason for the presence of more lakes in the valleys of the northern than in similar inclosed basins in the southern part of the Great Basin, is evidently due principally to a slightly greater mean annual precipitation and a slight decrease in evaporation as one journeys from the south toward the north in that region. The lakes of southeastern Oregon furnish an instructive contribution to the study of the delicate balancing of conditions referred to, and illustrate the manner in which mountains may become the controlling condition on which depend the existence of the lakes in neighboring valleys. For example, if mountains had not been upraised about the Harney Valley to act as condensers and give origin to streams, it is evident that the basins of that region would not have had lakes developed in their deeper portions.

Another feature in which the portion of Oregon here considered is representative of the Great Basin in general is the deep filling in the valleys. In a region which has no outflowing streams, all the material brought from the bordering or included uplands and mountains by the rain wash, rills, brooks, etc., is deposited in the valleys. For this reason the depressions normally become deeply filled with stream-deposited alluvium and with the sediments spread out in lakes. These two processes of deposition are frequently in operation at the same time, and it is extremely difficult in many instances to determine from a study of the accumulations whether they were made by flowing or by still water. In general the valleys throughout the Great Basin have been deeply filled with fine silt-like material having a light-yellow color, deposited in part by streams and in part in lakes. The valleys have thus been given nearly level floors in their central parts, and on their borders slope upward in gentle curves to meet the bordering hills and mountains. This is the case in the Harney and neighboring valleys, and the surface deposits of fine silt form rich soil, which needs only water to make it highly fruitful.

In a region devoid of outflowing streams all of the material brought to the valleys by streams in solution—their "invisible loads"—as well as all of the débris they carry in suspension—their visible loads—is left as the waters evaporate. Hence not only the lakes of such regions are characteristically alkaline, but the soils are apt to contain easily soluble salts. Within each inclosed basin there is an assorting and concentration of saline matter, and as frequently happens the lower lands are strongly alkaline. At times, as the waters evaporate, surface incrustations or efflorescences are formed, consisting principally of common salt, sodium sulphate, sodium carbonate, etc., but in rare instances they also contain boracic acid, and are valuable as sources of borax.

Several of the small playas in southeastern Oregon are covered in summer with white incrustations of the nature just described. A sample of one of these from near Dog Mountain, about 6 miles west of Narrows, gave the following result on chemical analysis:

Analysis of efflorescence from near Narrows, Oreg.

[Analyst, George Steiger.]

Insoluble in hot water	1.25
Sodium oxide, Na_2O	47.49
Water, H_2O (of crystallization)	10.08
Sulphuric anhydride, SO_3	11.76
Chlorine, Cl	2.90
Carbon dioxide, CO_2 (carbonic acid gas)	26.33
Boracic acid, B_2O_3	.28
Total	100.09

PROXIMATE COMPOSITION.

Insoluble in hot water	1.25
Sodium carbonate, Na_2CO_3	55.91
Sodium bicarbonate, $NaHCO_3$	5.98
Sodium sulphate, Na_2SO_4	20.88
Sodium chloride, NaCl	6.17
Sodium biborate, $Na_2B_4O_7$ (borax)	.46
Water, H_2O (of crystallization)	9.44
Total	100.09

Judging from the above analysis, the efflorescence from which the sample examined was obtained, if in sufficient quantity and commercially accessible, would be of value for the sodium carbonate and sodium bicarbonate it contains, but not for its borax.

Every surface incrustation of the nature described above, when of sufficient quantity to be of commercial value in case it contains sodium bicarbonate, borax, etc., should be carefully sampled and a representative portion analyzed. In every playa also auger holes should be bored for the purpose of discovering if deposits of valuable salts exist below the surface. The clays and silts in a playa should also be tested, as they may have absorbed sufficient borax or other salts to make them of commercial value.

GEOLOGY.

RECENT VOLCANOES.

Some account of the recent but now extinct volcanoes of southern Idaho was presented in my report on field work done in 1901,[a] and additional data in this connection were obtained during the reconnaissance which furnishes the basis of the present report. In 1902 the Cinder Buttes, the most instructive group of recently extinct volcanoes thus far discovered in Idaho, were revisited, and three separate centers of recent volcanic activity in southern Oregon, not previously

[a] Bull. U. S. Geol. Survey No. 199.

known to geologists, also examined. The facts observed in connection with these four modern and still well-preserved volcanoes or groups of volcanoes, when taken in connection with the studies already made of many other similar examples in the same region, not only contribute to a better understanding of volcanic phenomena in general, but aid in an important way in the interpretation of the records of the far more extensive lava flows of greater age in the same region.

The more instructive features of the recent volcanoes of Idaho, described in the report referred to above, may be briefly summarized as follows: The lava extruded is in all instances a dark basic rock, and may all be classed as basalt. In physical characteristics it ranges from compact, columnar rock to highly scoriaceous and even pumice-like material. The lava was extruded from the volcanic conduits in two ways: part, and by far the larger part, flowed out in a highly liquid condition and spread widely over the surface before cooling and hardening, and part was blown into the air as angular fragments or as clots, bombs, etc., which fell on the adjacent surface and built more or less conspicuous elevations. The material extruded in each of these ways presents many variations in its physical condition, dependent on secondary influences.

Of the lava which flowed out in streams two principal varieties may be recognized; one division includes the rocks formed by the cooling of the molten material on land, which, although at times highly scoriaceous, especially at the surface of the sheets, is in general a dense, compact rock, and on account of the formation of joints as it cooled is frequently columnar; the other division contains the lavas which entered surface water bodies and became expanded and "shredded," or shattered by the resulting steam explosions. The lava which was blown into the air presents an interesting series of forms, ranging from angular fragments produced by the shattering of the material after it had become cool and rigid, through clots, bombs, lava cakes, etc., formed of more and more plastic lava, to splashes of the magma which were still highly liquid when they fell.

From the two principal variations in the manner in which the volcanoes discharged their lava, two types of elevations about the mouths of their conduits resulted. The explosive eruptions led to the building of lapilli and cinder cones, a considerable range in the forms produced resulting from the degree of rigidity or plasticity of the projected fragments and the extent to which they cooled before striking the surface. These elevations are usually steep sided and contain depressions or craters in their summits, and as a class may be termed cinder cones. The lava overflows occurred for the most part quietly, without explosions, although in general, as it is believed, following explosive eruptions which opened the volcanic conduits for the free discharge of the molten rock which rose later and was poured out in such volume that the extruded material cooled in a mound above the orifice from which it came and flowed outward in all directions, forming what it is convenient to term lava cones. The cinder cones are high in reference to their diameters, with steep and normally concave slopes, while the lava cones are usually low, with gentle and at times convex sides and immensely expanded bases.

One of the most notable facts connected with the volcanoes in question is the vastness of the lava fields spread out about them in comparison with the size of the cinder or lava cones found at the summits of the conduits from which the material came.

On the surfaces of the lava flows there are two principal features, which are dependent on the ratio between the motion of the lava and the degree of rigidity of the crust formed on its surface as cooling progressed. When the cooling and stiffening of the surface occurred without marked disturbance from the flow of the still liquid material beneath, smooth, swelling, convex surfaces resulted, which at times were wrinkled and even forced upward into hollow folds. These folds show the characteristics of pahoehoe, as such surfaces are termed in the Hawaiian Islands. (Pl. XII, *A*.) When, however, the underflow beneath a brittle crust caused it to become fractured, and the fragments thus produced were tossed about in much the same manner that the cakes of ice in an ice jam are crushed together and piled up, a rugged surface, simulating what is termed *aa* in the Hawaiian Islands, resulted. (Pl. XII, *B*.)

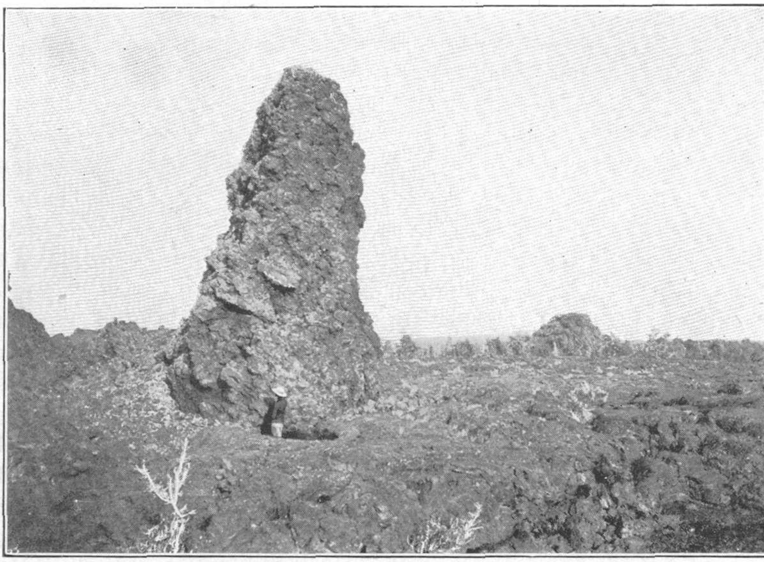
The numerous instructive features just referred to, which were described and discussed in some detail in the report on the observations made in 1901,[a] were found in the crater and lava flows of southeastern Oregon examined in 1902, and still other phenomena belonging to the same general category were observed. The reexamination of the Cinder Buttes enabled me to verify and extend the results previously recorded.

CINDER BUTTES.

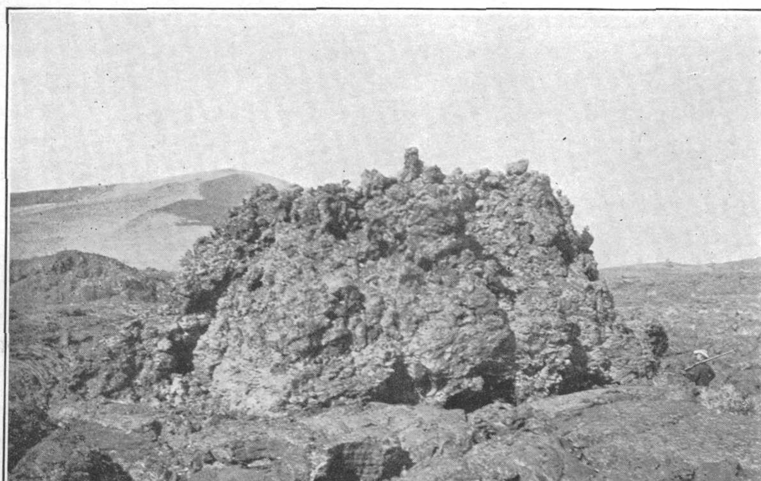
The Cinder Buttes are situated on the west side of the Snake River Plains, about 70 miles west of Blackfoot, Idaho. They are not conspicuous on account of size, as the highest crater in the group rises but 600 feet above the adjacent plain, but are remarkable for the vast amount of lava that flowed from them and for the many instructive details they present in reference to the behavior of volcanoes which erupt basic and easily fusible lava.

The additional facts concerning this most interesting group of craters and lava flows, at least in a measure supplementing the account of them already published,[a] relate principally to the floating away of large fragments of a ruptured tuff cone on the surface of the outflowing lava stream, a greater variety in the volcanic bombs occurring about the crater than was previously known, and the occurrence of

[a] Bull. U. S. Geol. Survey No. 199.



A.



B.

CRAGS OF TUFF ON LAVA FLOW, CINDER BUTTES, IDAHO.

distinct beds of compact lava in the walls of cinder cones, due to the running together and hardening into a single mass of many splashes of liquid lava, etc.

Breached cinder cones and crags of tuff floated on lava streams.—There are several well-defined craters built of lapilli and scoria among the Cinder Buttes, which were breached by the lava that escaped from them, and in one instance of this nature large masses of the parent crater were floated away on the surface of the lava stream which escaped through an opening in its wall. The floated masses range in general from 20 to 50 feet in diameter and from 40 to 50 feet or more on a side. They occur in a well-defined train, extending down the lava stream which escaped from a breach in the parent crater for a distance of about 2 miles. The masses are always angular and are bounded by rough surfaces that have resulted from fracture. They consist of reddish tuff, formed by the partial consolidation of lapilli, or of adhering clots of lava that were plastic when they were brought together. In color and composition they correspond with the portion of the cinder and lapilli cone still remaining intact, and differ from all other rock in their vicinity. They are in striking contrast with the black, generally smooth but in places wrinkled or fractured lava surface on which they occur. About the base of nearly every one of the crags the surface of the sustaining lava is depressed so as to form a moat-like trough which completely encircles it. Some of the features just described, including the depressions encircling the bases of the crags, may be recognized in the accompanying photographs. (Pl. III.)

It is of interest to note that the surface of several of the lava streams about the Cinder Buttes, for a distance of a mile or two from their sources, has subsided since it hardened, owing to an outflow of the still liquid lava from beneath a rigid crust. The amount of this subsidence is in several instances from 50 to 70 feet. As a result of such subsidence in the central part of a lava stream its marginal portions are sometimes left stranded, and a precipitous broken escarpment, facing the subsided area, borders the portion of the stream from which the lava outflowed. On the border of a lava stream which has been lowered at times large blocks of the stranded crust slope downward toward the subsided area.

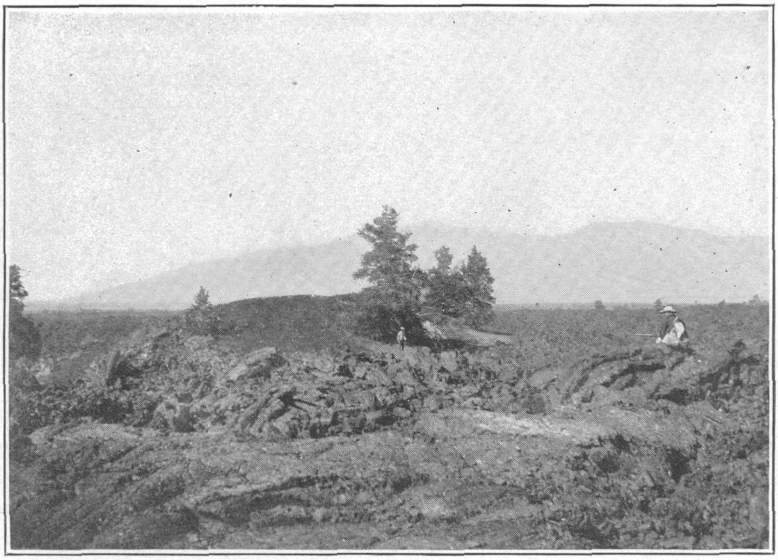
In the case of the Northwest lava flow, i. e., the one on which the crags of tuff, etc., described above, occur, there has been a subsidence of the surface of the flow throughout the first mile or more of its course, and a lowering of the crust formed on its central part of 50 to 70 feet. A portion of the flow, a square mile or more in area on the west side of the stream, was left stranded by this subsidence at a higher level than the surface of the lava, which continued to flow to the north.

From the facts briefly described above it seems evident that the crags of tuff, etc., on the surface of the Northwest lava streams are fragments of the breached crater from which the lava came, and that they were floated on the surface of the plastic lava. The floated fragments are composed of rock which, on account of its porous and usually scoriaceous condition, is lighter than the usually compact lava on which they occur, but they depressed the viscous surface on which they rested in the same manner that a brick might depress the surface of pitch. The floated fragments were not carried to the end of the lava flow, for the reason that a crust was formed on the stream of molten rock from beneath which the still liquid material escaped. Owing to the outflow beneath, the crust remained stationary and with its freight of tuff was gradually lowered to the position it now occupies. That the crags to which attention has been directed are not islands in the lava stream is clearly shown by comparing them with well-characterized occurrences of that nature, one of which is shown on Pl. IV, *A*. The stranded blocks of lava about an island in a lava stream which has subsided are inclined away from it, as may be seen in an example of this nature shown in the photograph just referred to. In such instances the result is much the same as may be observed on the borders of a river which has subsided after a sheet of ice had formed on its surface; in instances of this nature, as is well known, cakes of ice left stranded on the banks of the stream are inclined downward toward its center. About the islands in a lava stream which has been lowered by the outflow of the liquid rock from beneath a solid crust, the portions of the crust left stranded slope away from the central part of the island and nothing resembling the moat-like depression observed about the floated crags described above is even suggested.

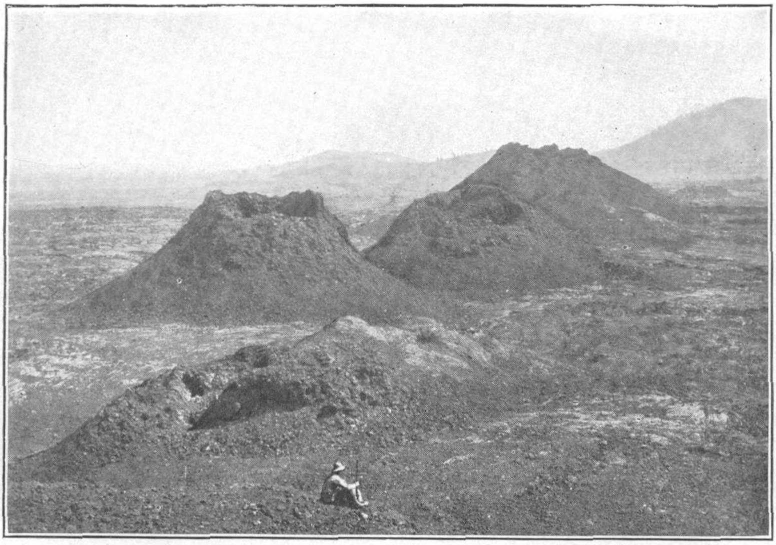
In some instances observed about the Cinder Buttes, the subsidence of the central part of a lava appear to have been so gentle that the surface sheet of stiffened but still somewhat plastic material was not seriously broken, and still remains in the condition of pahoehoe. At other times a more rapid lowering of the surface, or the presence of a rigid and brittle crust, caused a large amount of fracturing and the heaping up of the pieces produced so as to make a characteristic *aa* surface. About the bases of the floated crags on the Northwest lava flow, described above, typical examples of each of these classes of lava surfaces are to be found. In some instances the crags rise from smooth, swelling, and frequently corrugated pahoehoe surfaces, and at other places are surrounded by the chaos that is characteristic of *aa* surfaces.

Volcanic bombs.—The volcanic bombs strewn about the Cinder Buttes are so abundant that in several instances they form a large part of the material of which the craters are composed and present several well-characterized varieties.

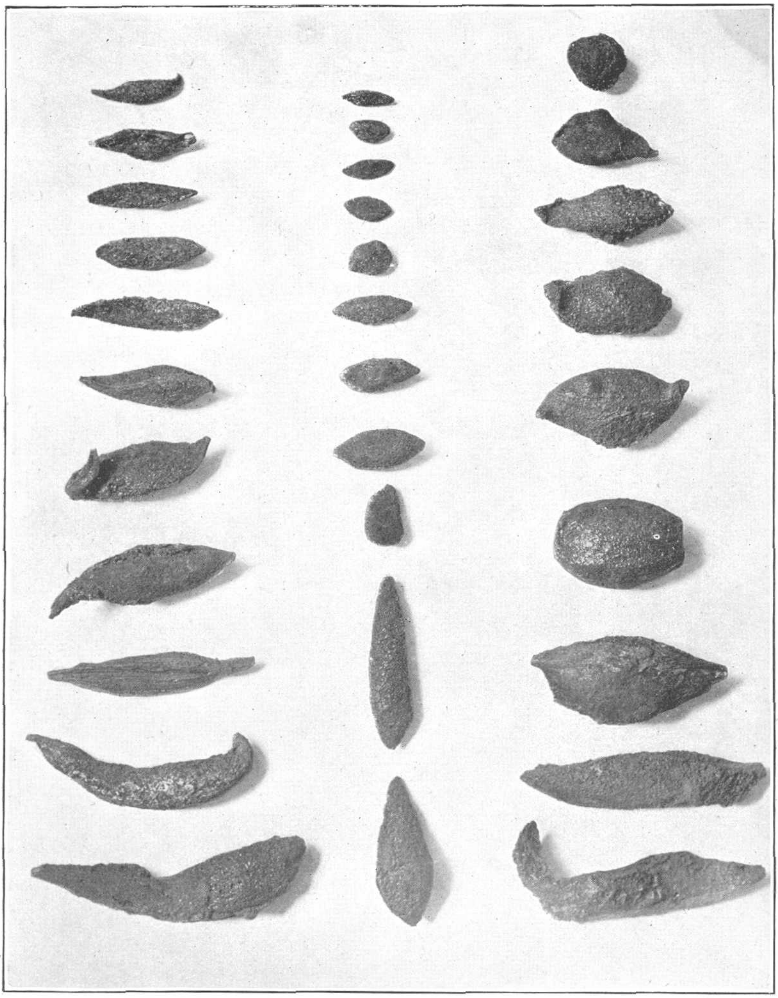
The term "volcanic bomb" is usually employed to designate the class of projectiles blown out of volcanoes, which, on account of their



A. ISLAND OF LAPILLI IN LAVA STREAM, CINDER BUTTES, IDAHO.



B. SCORIA AND BOMB CONES, "THE ICE WELLS," CINDER BUTTES, IDAHO.



VOLCANIC BOMBS, CINDER BUTTES, IDAHO.

Four-tenths natural size.

revolving about an axis during their flight and while still plastic, assumed more or less regular spherical or ellipsoidal shapes. Typical examples of such bombs, ranging in form from nearly perfect spheres to elongated oval bodies with projections or "ears" at the ends of the longer axis, were obtained in abundance. The central body as well as the projections in those examples are marked by spiral lines and ridges, produced by the rotation of the mass while yet hot and viscous or plastic. Illustrations of such forms which preserve unmistakable evidence of having rotated while yet plastic are presented on Pls. V–VI. The bombs which most nearly approached the typical shapes just referred to range in size from less than an inch in length to masses that are 9 feet long and 12 feet in circumference in the center. In addition to the bombs with characteristic spherical or ovoid shapes, many other forms, some of them conspicuously irregular, were noted.

In some instances, as illustrated on Pl. VI, a mass of plastic lava, after being fired into the air and acquiring the common "foot-ball" shape, seems to have fallen straight downward, and the projecting ends or ears, being still plastic, were bent inward and perhaps flattened on the central portion of the mass. A great variety of bombs of this description, with recurved and infolded ears, was observed. Examples are also common of masses of lava which were projected into the air, and on falling acquired a pear-shaped or tear-drop form. These bodies, which seem to have fallen straight downward, as is indicated by their shapes, are of all sizes up to 2 feet or more in diameter. In many instances the tapering end is curved, or even folded down onto the body of the bomb, so as to produce shapes curiously like certain varieties of squash with curved necks. These pear-shaped and squash-shaped bombs were in many observed instances evidently still plastic when they struck the ground, as is shown not only by the fragments of lapilli, etc., adhering to their lower surfaces, and partially embedded in their outer crusts, but by a bulging at the base or flattening due to a change of shape on striking.

In addition to the bombs with more or less symmetrical forms, due to masses of plastic lava cooling and stiffening while rotating in the air or falling from aloft, there are many irregularly shaped bodies which originated in a similar manner. These are frequently greatly elongated, loosely twisted shreds, perhaps several feet long and only a few inches in transverse diameter in the thickest part. One of the most bizarre of these irregular forms is represented on Pl. VIII. This ram's horn-like body of dense light-colored lava measures 13 feet in length and 8 inches in diameter in the thickest portion. It lies on the west side of the highest of the Cinder Buttes, about one-third of the way from its base to the top, and was hurled through the air to a distance of about one-half mile. On striking, it was still sufficiently plastic to become indented by the stones on which it fell, some of which still adhere to its lower surface. On account of its plastic consistency it did not break when it fell, but has since been fractured, probably on account of changes of temperature.

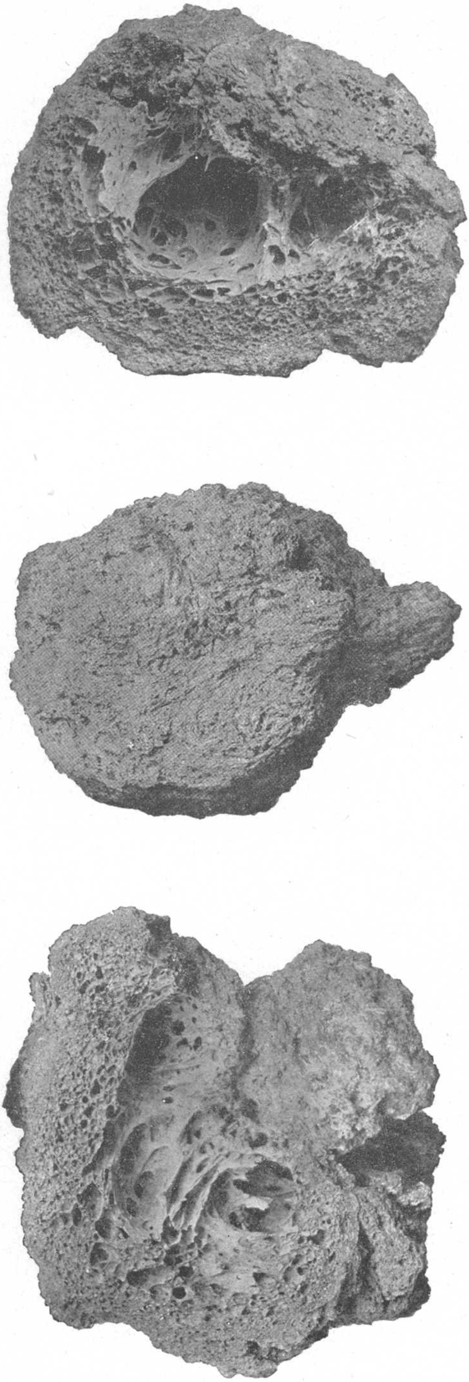
Many projectiles, either complete or more or less shattered, of the same general character as the one shown on Pl. VIII, occur about the Cinder Buttes, and in most if not all instances they are composed of dense, compact, light-colored rock, which on freshly fractured surfaces looks not unlike hard-burned stoneware and resembles the material forming the immediate borders of basaltic dikes or, the whole of very thin dikes of similar character. It is evident that the lava forming the irregular shred-like bombs cooled quickly from a liquid or highly plastic condition, and that the steam and gasses contained in the original magma escaped, for the most part, without leaving vesicles.

When the bombs are broken so as to expose their interiors they present at least three well-defined variations in structure. Certain ones, including the elongate, twisted forms described above, are compact throughout or exhibit only irregular and, frequently, much extended cavities, such as steam or gases leave in cooling lava, and are either light, and in fact almost white, or glossy black in color. In sections at right angles to the longer axis something of a spiral arrangement of the steam cavities, cracks, etc., is apparent, and on their exterior there is more or less evidence of the influence of rotation while the mass was still plastic. The bombs having these characteristics seem to have been formed of highly plastic or nearly liquid lava, from which the contained steam and gases escaped freely.

Bombs of a second variety, characterized by their rudely spherical shapes, rough exteriors, and highly vesicular and frequently nearly hollow interiors, but without surface crusts, spiral lines or ridges, or projecting ears, occur in abundance, especially in the walls of parasitic cones or what may perhaps be termed driblet cones of large size. These rough spheres range in diameter from a few inches up to 2 feet or more, and the walls of the large cavities within frequently present the appearance of "pulled dough," as if marked expansion of the steam cavities had occurred while the material was viscous. (Pl. VII.) The bombs of this variety are sometimes flattened and bear on their under surfaces impressions of the material on which they fell. At times they adhere one to another, and in some instances were sufficiently plastic to flow after coming to rest. The occurrence of these bombs in chimney-like piles, about openings in lava streams, and in the walls of the so-called ovens to be described later, indicates that they were tossed out of openings in the crusts of lava streams, but did not make any considerable journey in the air. They form a connection between projected clots of vesicular lava, such as are commonly termed "cinders," and true bombs, which were thrown to a considerable height and cooled while rotating.

VOLCANIC BOMB, CINDER BUTTES, IDAHO.

Four-tenths natural size.



VOLCANIC BOMBS, CINDER BUTTES, IDAHO.

Three-tenths natural size.

VOLCANIC BOMB, CINDER BUTTES, IDAHO.

Length, 13 feet; greatest diameter, 8 inches.

The third common type of bombs includes those which are cellular within—the vesicles diminishing gradually in size from center to circumference—and inclosed in a thin rind or crust. In some instances there is a thin layer of cellular lava on the outside of the hard rind, but more frequently the surface is smooth, glossy black, and in many examples broken by shrinkage cracks which have been widened by the expansion of the material within after a thin surface crust had formed. (Pl. X, *A*.)

The interior structure of these bombs closely resembles that of certain bombs found on Ascension Island and described by Charles Darwin. In order to show this resemblance more definitely, a figure of a partial section of one of the bombs referred to, published by Darwin,[a] is reproduced on Pl. IX by the side of a similar specimen from the Cinder Buttes. In each case there is a conspicuous and gradual increase in the size of the vesicles in the central scoriaceous mass, from the inner side of the inclosing rind to the center. The explanation of this peculiar internal structure advanced by Darwin is as follows:

> This structure is very simply explained, if we suppose a mass of viscid, scoriaceous matter to be projected with a rapid, rotatory motion through the air, for while the external crust, from cooling, became solidified (in the state we now see it), the centrifugal force, by relieving the pressure in the interior parts of the bomb, would allow the heated vapors to expand their cells; but these being driven by the same force against the already hardened crust would become, the nearer they were to this part, smaller and smaller or less expanded until they became packed into a solid, concentric shell. As we know that chips from a grindstone can be flirted off when made to revolve with sufficient velocity, we need not doubt that the centrifugal force would have power to modify the structure of a softened bomb in the manner here supposed. Geologists have remarked that the external form of a bomb at once bespeaks the history of its aerial course, and we now see that the internal structure can speak with almost equal plainness of its rotatory movement.

As stated in my report on a reconnaissance in Idaho in 1901,[b] the observations then made concerning the cellular bombs strewn about the Cinder Buttes are not in harmony with the explanation quoted above. Later studies serve to strengthen this conclusion and to lend additional support to the hypothesis advanced in the bulletin referred to. In brief the explanation of the cellular condition of the bombs in question, and the increase in the size of the vesicles they contain from beneath the crust to the center, which apparently best satisfies the observed facts, is that masses of steam-charged lava, tossed into the air from pools of liquid rock in craters, cooled quickly at the surface and formed a dense crust, which prevented further escape of steam from within, and as the lava continued to cool, the change gradually progressing from the circumference inward, there was an

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

[b] Bull. U. S. Geol. Survey No. 199.

extrusion from the cooling lava of steam or gases previously held in solution in the molten rock. The regeneration of steam or gases in this manner would tend to expand a bomb, thus leading to a cracking of the first formed crust and a widening of the cracks, as is illustrated on Pl. X, *A*. The change referred to would also favor the formation of larger and larger vesicles within a bomb as the cooling and stiffening of the material composing it progressed. In addition to the facts referred to tending to support the hypothesis here restated, it may be noted that the bombs seen about the Cinder Buttes which show the internal structure, neither in their forms nor in their surface markings exhibit evidences of rapid rotation, and moreover occur on the crests and inner slopes of craters or in situations that do not indicate a long aerial flight. The impression that one gains from seeing large numbers of these bombs in the position in which they fell is that they are formed of masses of plastic lava which were tossed out of craters with only sufficient rotary motion to give a spherical form, but were not fired high in the air and did not acquire the spindle shape with twisted projections at either end, so characteristic of bombs that rotate rapidly while cooling.

Bombs of the various external shapes and with the wide range in interior structure described above occur in great numbers about the Cinder Buttes, and in fact furnish a very considerable portion of the fragmental material of which they are composed. Mingled with the bombs in the walls of many of the craters, as previously described,[a] are great quantities of thin, nearly flat, cake-like masses of lava, which were formed by the cooling and hardening of small bodies or splashes of lava that had been projected into the air and were still liquid when they fell. These flat cakes furnish illustrations of one extreme of the many variations presented by the material thrown out by volcanoes during explosive eruptions; a series which includes scoria, clots, several varieties of volcanic bombs, and angular fragments, such as lava blocks, lapilli, volcanic dust, etc. This wide range in the products of volcanic explosions in reality presents an orderly sequence, dependent on the degree of fluidity, plasticity, or rigidity of the material at the time it was blown into the air.

If the material forming the summit portion of the column of lava within the conduit of a volcano becomes rigid before steam explosions beneath cause it to be fractured and the fragments blown into the air, angular blocks of lava, lapilli, dust, etc., are produced. If the material is plastic or viscous, clots may be blown out, and cool as scoriaceous masses, or so-called cinders, which have rough, irregular, but not fractured surfaces. If such clots are projected high in the air and cool while rotating, bombs result. Should the lava be still more thoroughly fused at the time it is projected into the air, it may still be liquid on striking, and form lava cakes, or even spread over the

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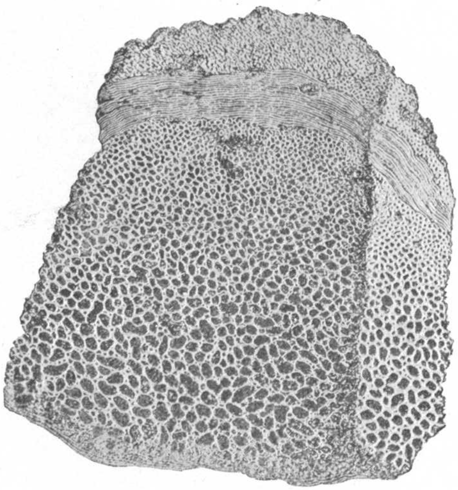
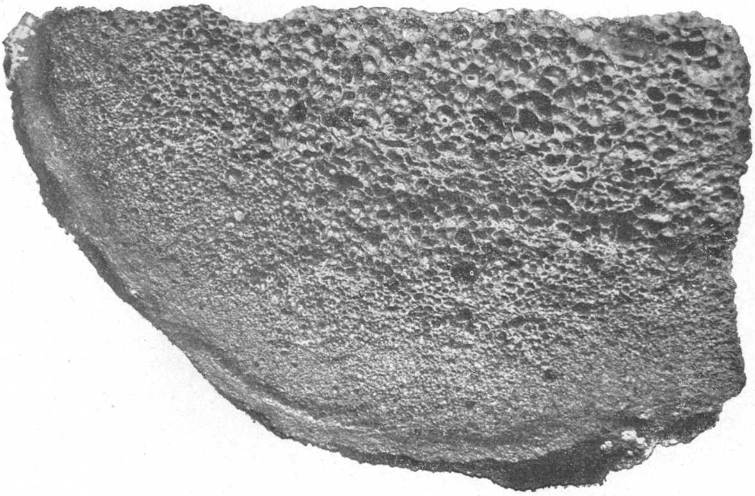
[a] Bull. U. S. Geol. Survey No. 199.



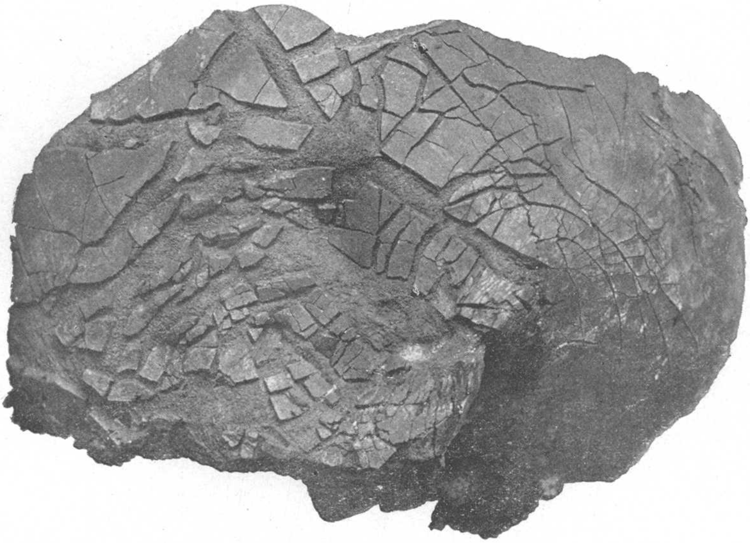
A.



B.

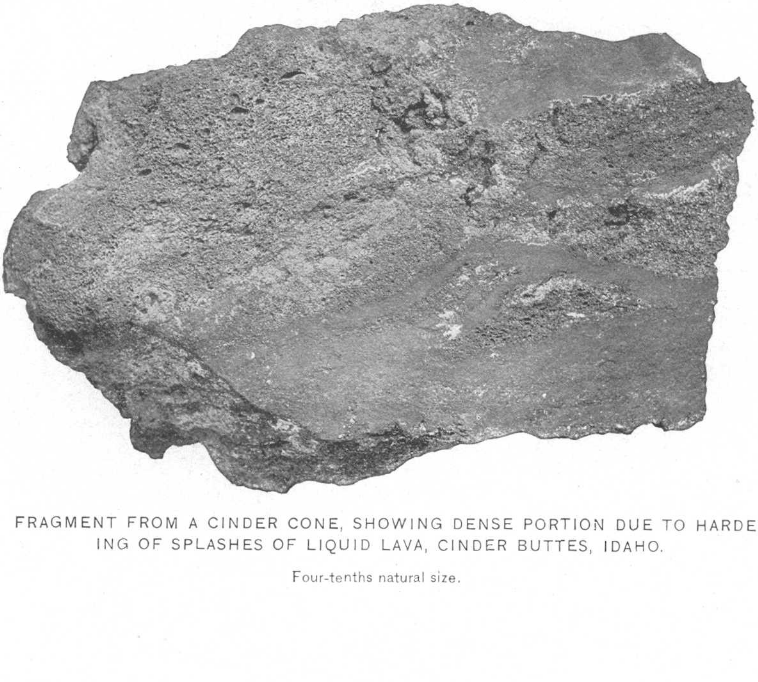
SECTIONS OF VESICULAR VOLCANIC BOMBS.

Fig. *B* is one-third natural size.



A. CRACKED SURFACE OF VOLCANIC BOMB, CINDER BUTTES, IDAHO.

Four-tenths natural size.



B. FRAGMENT FROM A CINDER CONE, SHOWING DENSE PORTION DUE TO HARDENING OF SPLASHES OF LIQUID LAVA, CINDER BUTTES, IDAHO.

Four-tenths natural size.

surface and, additional material of the same character being supplied, form tile-like sheets. This entire sequence is admirably illustrated by the projectiles which accumulated to form the Cinder Buttes.

The occasional presence of balls of dense lava on the surfaces of lava flows, described by J. D. Dana in the case of certain lava streams in the Hawaiian Islands, and observed by me in Idaho,[a] as well as the presence of analagous spherical masses of lava in the crater walls of certain of the Cinder Buttes, suggest, as a tentative hypothesis, that during the boiling of lava in a crater, masses of fused rock may become cooled, and, owing to rotation produced by the movement of the molten or plastic material about them, acquire a spherical form before being blown out or carried away by outflowing lava. The compact, rough-surfaced, spherical balls sometimes found about volcanoes appear to have originated in some such manner, and not from the rotation of plastic material projected into the air.

The sequence of events in the history of the Cinder Buttes, as recorded by the accumulations of projectiles still remaining and by the extensive lava flows which were discharged from the same volcanic vents, is briefly as follows: The eruptions in a large number of instances began, so far as can be judged from the evidence now available, with explosions which caused considerable quantities of cool and rigid lava in the form of lapilli, dust, etc., to be projected into the air. Later came similar violent discharges of plastic lava which formed scoria and volcanic bombs, and later still, liquid lava was ejected. This fell before cooling, and spreading over the surface where it struck formed lava cakes. Following these explosive discharges, or accompanying the later ones, great volumes of highly liquid lava were poured out. This lava was extruded quietly and flowed over the surface of the surrounding plain so as to form sheets many square miles in area. The close of the eruptions, in several instances at least, was not characterized by a return of the conditions which produce explosions, but the outflow of liquid lava decreased gradually and finally ceased, the craters being left with nearly level floors of highly vesicular rock having the surface characteristic of pahoehoe.

Lapilli cones, cinder cones, etc.—The term cinder cone is commonly used to designate the piles of projectiles which have accumulated about volcanic vents, irrespective of their precise character. While the cones and craters referred to are in general composed of irregular scoriaceous masses of lava, usually referred to as "cinders," it will be seen from the brief description given above of the wide range in the nature of the projectiles of which they are composed that several varieties of "cinder cones" should be recognized.

When angular fragments of hard lava, such as blocks of rock, lapilli, dust, etc., are blown out of volcanic vents, they usually fall about the opening from which they come and accumulate in a conical pile

[a] Bull. U. S. Geol. Survey No. 199, p. 114.

with a depression or crater at the summit. The outer slopes of these cones frequently form angles of 30° to 35° with a horizontal plain, the angle being essentially the angle of repose of the fragments of which they are built, but their profiles are concave instead of straight lines. The reason for the downward curves presented by the sides of such cones is not definitely understood, but seems to depend on the fact that the structures are built of fragments of different sizes and shapes. Vertical sections through such piles commonly show, as is well known, two series of beds, one series dipping away from the crater in the summit, and forming the outer slopes of the cones, and the other series dipping from the rim of the crater toward its bottom. The junction between these two series of opposite-dipping beds in the rim of a crater is not a sharp angle, as sometimes represented, but a curve, convex upward. The cones referred to are symmetrical when built of fragments projected vertically, unless the influence of the wind in carrying the material in one direction more than another made itself felt. Cones or craters built of angular fragments with surfaces produced by fractures are sufficiently distinct from the similar structures built of other kinds of projectiles to be specially designated, and may with propriety be termed *lapilli craters*, or lapilli cones in case a depression in the summit of the pile is absent.

When the material projected into the air from a volcanic vent is plastic, and falls in irregular clots and rough scoriaceous masses, it frequently forms steep-sided piles with chimney-like openings within. Owing to the frequently large size of the masses which fall, their rough surfaces, and also to the fact that they are in many instances still plastic when they come to rest, the slopes of the structures produced, both on the outside and within, are commonly steep, and in some instances are nearly vertical, but the outer slopes of these hollow piles are normally less steep than the walls of the openings within. Piles of congealed clots of this nature present several instructive variations. At times they are steep-sided chimney-like forms, such as are illustrated on Pl. III. In other instances their encircling walls are contracted at the top so as to leave only small openings, and in extreme examples of this nature a complete roof is formed by the adhering of the clots blown out, and a beehive or oven-like structure results, such as is shown on Pl. XI. The chimney-like elevations produced in the manner just referred to have been designated driblet cones by J. D. Dana, but for the entire series of cones, craters, etc., built of scoriaceous or cinder-like clots of lava the term cinder crater or cinder cone seems appropriate.

For the sake of avoiding a lengthy discussion of the classification of elevations produced by the accumulation of volcanic projectiles about the vents from which they were blown out, I may briefly state that in certain instances well-characterized volcanic bombs form the greater portion of an elevation with a crater in its top, and in some instances similar elevations are composed principally of lava cakes formed, as already explained, by the cooling of splashes of liquid lava after coming to rest. Examples of cones or craters formed exclusively or in large part by the two methods just cited, however, are so rare that special names for them do not seem to be necessary.

It frequently happens that a volcanic hill or mountain is composed of projectiles of all the classes considered above, as, for example, when large angular blocks of lava are ejected, together with lapilli and dust, and at some time in the life of the volcano plastic or liquid lava is blown into the air and forms scoria, bombs, lava cakes, etc. Such composite cones or craters built of the products of explosive eruptions are illustrated by several characteristic examples among the Cinder Buttes.

There is one feature of lapilli and scoria cones which does not seem heretofore to have attracted attention. Interbedded with the fragmental material in the walls of such craters there are sometimes irregular sheets of compact and usually reddish lava, ranging in thickness from a few inches or less to many feet, and presenting all variations in extent from a few square inches to several hundred square yards, and resembling true lava flows. These compact layers occur both in the outer and inner slopes of a crater, and at times a single bed in one part belongs with the steeply sloping layers of the inner cone, and changing its dip in the part beneath the crater's rim, passes into the outward-dipping series of beds. As may be seen at the Cinder Buttes, such beds of compact lava sometimes contain scoriaceous masses, and on their edges become thin and terminate irregularly in accumulations of lapilli or scoria. Some of these features may be recognized in the small sample from the wall of a cinder cone, shown in Pl. X, *B*.

The range in size of the compact beds just described, the presence in them of scoriaceous masses, and the manner in which they terminate, etc., show that they are due to an accumulation of liquid or highly plastic splashes and clots of lava, which united one with another as they fell. In harmony with this explanation is the fact that in many instances a sheet of lava of the nature under consideration is completely inclosed in lapilli or scoria. In sections of lapilli and scoria cones to be seen among the Cinder Buttes numerous examples of interbedded sheets of compact lava may be seen which are due to the running together of liquid or highly plastic splashes and clots in the manner just explained, and similar occurrences were seen elsewhere, particularly at the Jordan Craters described below.

The notes presented above are intended as a supplement to the more general account of the Cinder Buttes contained in Bulletin No. 199 of the United States Geological Survey, and I trust will be followed by a detailed survey of that unique region. In the publication just referred to, several isolated craters and groups of craters situated in southern Idaho are described, and the list of these recent volcanoes is here extended by an account of three similar centers of eruption in southeastern Oregon.

JORDAN CRATERS.

In the east-central part of Malheur County, Oreg., and from 18 to 20 miles west of the Idaho-Oregon boundary, there are four recently extinct volcanoes, which are here termed, collectively, the Jordan Craters. They are situated to the north of Jordan Creek, and to the west of its tributary known as Cow Creek. The four craters referred to are nearly on a line bearing a little west of north and are approximately 3 to 5 miles apart, although the distance of the one at the north from its next neighbor is somewhat greater than the spaces between the others in the series. While but four recent craters are here referred to, there are certain rounded hills to the west of the south end of the series which are probably of volcanic origin, and perhaps represent ancient craters, but these have not yet been examined.

Three of the four craters referred to—that is, all but the most northerly in the series—are situated in a valley, and the lava which flowed from them spread in all directions and built up lava cones with broad bases and low surface slopes. Each crater rises about 500 feet above the plain, but by far the greater part of this elevation is gained in the broad, low lava slopes surrounding the small buttes which mark the centers of eruption. The central elevations are in general about 150 feet high, and are composed of lava which occurs mostly in thin sheets. There is an absence of scoria in detached clots and of lapilli or other ejected material, such as is blown into the air during explosive eruptions. In short, they are elevations formed by the cooling and hardening of lava which overflowed from the summits of volcanic conduits in all directions, so as to form low cones with immensely expanded bases. When seen in profile, especially at sunrise or sunset, they are at once recognized as typical examples of what I have ventured to term lava cones in distinction from elevations built by the accumulation of projectiles.

The central and summit portion of each of the Jordan Craters is usually circular, with steep outer slopes, and in one instance contains a crater-like depression. This cavity in the summit of the cone, as in the case of many similar lava cones in Idaho and Oregon, is due to the falling in of a dome-like structure composed of thin lava sheets, the subsidence being caused by the escape of still liquid lava laterally from beneath a rigid crust.

It is convenient to designate the Jordan Craters by numbers, beginning at the south end of the series and proceeding northward. A brief examination serves to show that No. 1 is the oldest in the series; next in age is No. 3, then No. 2, and last and youngest of all, No. 4. Their relative ages are shown by the degree to which their surfaces are weathered and the extent to which they are covered with soil and vegetation. The slopes of the oldest crater are smooth, with but few rocky crags visible, and are covered with soil mostly of eolian origin, in which a strong growth of sagebrush, etc., is conspicuous. Crater No. 3 is less completely concealed beneath accumulations of atmospheric dust than No. 1, and is less densely overgrown with sagebrush, while No. 2 presents a rough surface of hard black lava, on which pressure ridges are conspicuous, although notable quantities of atmospheric dust have accumulated in the depressions, and bushes and bunch grass grow in cracks and crevices on seemingly bare cindery crags and ridges.

While Craters Nos. 1, 2, and 3 are instructive on account of the many square miles of lava poured out from them and the various stages reached in its change to smooth pasture land, the chief interest of the general locality centers about Crater No. 4, at the north end, the youngest of the series.

Crater No. 4.—This very modern crater, unlike its companions, came into existence on a somewhat steep-sloping hillside, which was trenched by erosion channels previous to the volcanic outburst, and the great flood of extruded lava flowed away in one principal direction. Owing to the freedom afforded for the escape of the lava down the slope below the orifice from which it came, a large portion of the cinder and lapilli crater, built during an early stage in the history of the volcano, has been spared, and furnishes important evidence as to the general sequence of events, which, as it now appears, normally accompany the building of lava cones.

Crater No. 4, as it exists to-day, is in part a cinder and lapilli cone, and in part a lava cone, and extending over an area of about 50 square miles on its southeastern side is a black lava field entirely bare of vegetation (Pl. XII, *A*). Although differing conspicuously in its details from the associated craters in the same series, the one here considered was evidently built in the same manner as its companions, but owing to its being located on a sloping surface, the products of the earlier stages of the eruption which built it were not buried by the great effusion of highly liquid lava poured out later, as was the case in numerous observed instances, where similar eruptions have occurred on a plain.

Throughout about one-half of the periphery of the cinder and lapilli cone forming Crater No. 4, the older rocks, consisting mainly of Tertiary rhyolite, are without a covering other than a thin layer of soil, to within a distance of 800 or 1,000 feet of its base. This fact suggests that some evidence may perhaps be obtainable as to the nature of the break or opening through which the eruption that built the crater reached the surface. The testimony in this connection, however, is meager. On the hillside, where the crater is situated, and extending in an essentially straight line from it, both to the north and south, there is a faint escarpment averaging perhaps 15 feet in height, and facing east. This escarpment has the general appearance of a fault scarp, but is by no means certainly of that nature. The only unquestionable evidence of a break in the rocks on which the crater stands is furnished by a row of about 12 driblet cones, situated in a line extending west from the principal center of eruption and up the slope of the hill at right angles to the faint escarpment referred to above. The portion of the break on which the driblet cones are located, situated at a distance of about 1,000 feet from the center of the main crater, shows no evidence of a differential movement of its walls. There is then but slight evidence of a shattering or faulting of the country rock preceding or following the birth of the volcano.

The portion of the original pile of cinder and lapilli remaining at Crater No. 4 is highest on the south side of the crater, where it rises about 100 feet above its outer base and somewhat more above the irregular pit it partially inclosed. The cone has lost much of its symmetry, owing to the falling of its inner surface, and on the south side of the crater presents a fairly good section of outward-dipping layers of lapilli and of compact reddish lava. The compact layers referred to are among the more interesting features of the section, and while having the appearance of lava flows which descended the outer slope of the lapilli and scoria cones when it was but partially completed, are in reality due to the flowing together and cooling in one mass of many splashes of liquid lava. This mode of origin of the dense compact layer is shown by it containing angular fragments of lapilli and by small, isolated, lenticular masses of the same nature completely embedded in lapilli, with which it forms a complete gradation. More than this, the surrounding surface of rhyolite, adjacent to the base of the cinder and lapilli cone, where not concealed beneath lava flows, and to a distance of about 800 feet, is thickly strewn with reddish clots of lava, which were liquid when they fell and in general ran together, so as to form a tide-like sheathing to the surface. This material spattered out of the crater and falling well beyond, its base is of the same character as the layer of dense lava built into its wall and covered by subsequent showers of lapilli. The preservation of the rough, angular pavement, composed of congealed splashes of lava about the crater, which fell in a liquid condition, thus serves to explain the history of at least certain compact layers in the walls of the cinder cone, the most noticeable of which has a thickness of between 10 and 20 feet. Similar compact, usually reddish, layers of lava in cinder cones have been observed at the Cinder Buttes and elsewhere, as already explained, and are evidently a common feature of the walls of cinder and lapilli craters built by volcanoes which discharged highly liquid lava.

After a small cinder and lapilli crater had been built by the volcano under discussion, it is evident from the records still remaining that liquid lava rose within it and breached its wall, both on its west and southeast borders. The lava which escaped westward was small in amount and now forms a pool-like sheet of black pahoehoe about 600 feet across. Some of the lava in this pool, however, came from the crack mentioned above, along which there is situated a row of driblet cones. After the opening of a breach in the west side of the crater the opening was partially closed by a discharge of lapilli, but not rebuilt to its former height. On the southeast side of the crater the portion of its wall which has disappeared includes about one-third of its original extent, and through the break there was outpoured a flood of lava which inundated an area of about 50 square miles. The lava cooled in the breach it had formed in thin sheets, so as to produce a steep-sided ridge, which completely occupies the break and unites with the remaining fragments of the lapilli and cinder cone at each end. This ridge of lava is of the same nature as the walls of typical lava cones, being formed of thin sheets of highly vesicular rock, each one seemingly formed by the congealing of a thin overflow from the crater and succeeded by another similar overflow, until a steep ridge composed of overlapping lava sheets was produced. The main discharge of lava took place beneath the crust thus formed, after the manner so common in highly liquid lava streams, and escaped through tunnels.

The final drawing off of the molten material, which once filled Crater No. 4 up to the level of the top of the rim of congealed lava on its eastern side, allowed the crust of scoriaceous and ropy pahoehoe lava formed within it to subside, and although in part broken it still rests at the bottom of the irregular pit it left about 100 feet lower than its former position. Since the subsidence of the floor of the crater there has been some tumbling in of its unsupported walls, but the cakes of corrugated lava on its floor are still to a large extent unconcealed.

The rise of liquid lava within a cinder and lapilli cone, as in the example just described, the building of a raised rim in the breach in the crater walls composed of fragmental material, and the subsequent lowering of the lava crust formed on the pool within the crater are all features which are found in numerous volcanoes in Idaho and Oregon which built lava cones. The greater number of the lava cones that have been examined, however, are situated on generally plain surfaces, and the floods of outwelling highly liquid rocks, which were extruded from them, spread in all directions, and the cinder and lapilli cones, which probably in all the instances referred to were formed at an early stage in the eruptions, were completely destroyed or buried. In the instance here considered, however, owing to the inclination of the surface on which the volcano originated, the lava extruded flowed almost entirely in one direction, leaving a large portion of the preceding cinder and lapilli cone intact. No. 4 of the Jordan Craters is thus in part a cinder and lapilli cone and in part a lava cone. Had the slope down which the lava flowed been steeper it is probable that the liquid rock would have flowed away too quickly for a lava ridge to have been formed about the pool in the summit of the conduit from which it came, a condition illustrated by the Martin lava stream and other similar outwellings of lava in mountainous regions described in Bulletin No. 199.

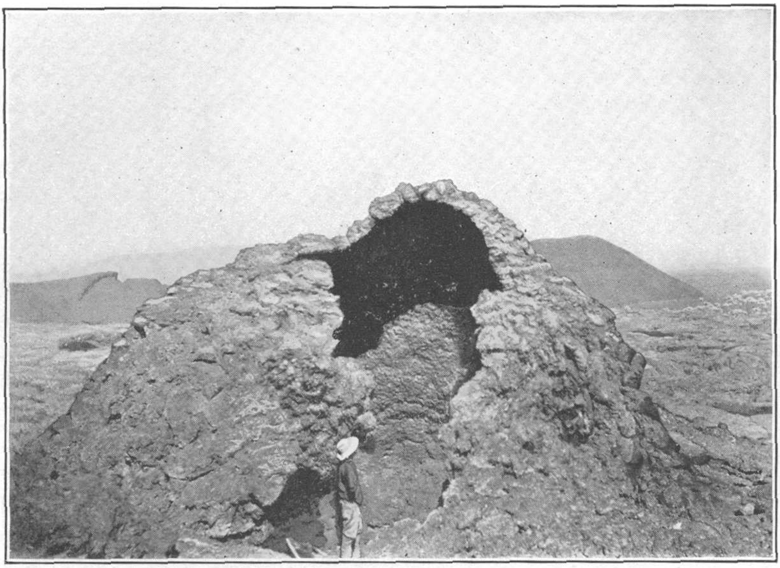
Driblet cones and "ovens."—The extrusion of liquid or highly plastic lava from cracks or other openings in the crusts formed on lava, as in the craters of certain of the Hawaiian volcanoes, has been described by J. D. Dana,[a] and the hollow cones, towers, etc., produced by drops or clots of ejected material which adhered one to another, have been designated driblet cones. Interesting examples of structures of this general nature occur along the fissure mentioned above, which extends westward from the most northern of the Jordan Craters.

Situated on the fissure referred to are 10 or 12 oven-shaped piles of lava clots, some of which are more or less confluent, so that a definite count is impracticable. These piles are nearly circular, with rounded summits, and range in height from 15 to probably 25 feet, and are hollow within. Some of the examples are still unbroken, and are either completely roofed over or have rudely circular openings at the top, while others are broken and prevent free examination of their interiors. One characteristic example, shown in Pl. XI, *A*, is about 20 feet high on the exterior, between 40 and 50 feet in diameter at the base, and within contains a symmetrical level-floored chamber, with dome-shaped roof, measuring 14 feet in diameter at the bottom and 17 feet in height. The walls of this "oven" are about 12 feet thick at the base, and diminish gradually toward the roof, which is from 4 to 6 inches thick. This beehive-like pile, and others similar to it, are plainly of the nature of driblet cones, but on account of their shapes may perhaps be termed driblet ovens. Their formation, as has been explained by Dana in reference to similar structures observed in the Hawaiian Islands, is due to the blowing out of plastic lava from an orifice and the piling up of the adhering clots about the place from which they came. The hollow chimney-like forms thus produced were gradually contracted at the top until, in some instances, they became completely roofed over. On the interior of these structures the lava hangs in pendant stalactite-like masses, usually of a deep-reddish color, and from a few inches to 2 feet or more long.

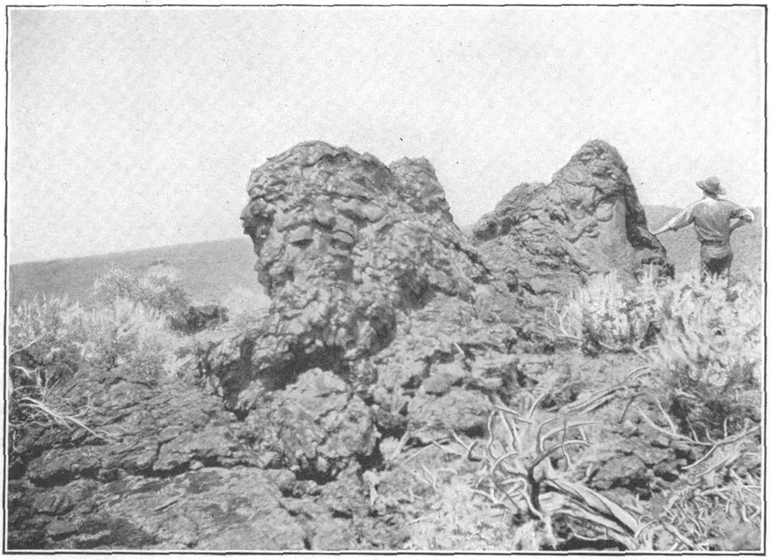
Examples of similar driblets cones of smaller size occur on a lava flow that came from the Diamond Craters, to be described later, two of which are shown on Pl. XI, *B*. Driblet cones are also present at the Cinder Buttes, but in this case are chimney-like piles, termed on a previous page parasitic cones. One example at the Cinder Buttes, however, now partially destroyed, has the oven-like shape so characteristic of the example present at the Jordan Craters.

Lava "gutters."—About the bases of the driblet ovens associated with Crater No. 4 of the Jordan series, and also at the east base of the crater itself, there are localities where lava flowed in narrow

[a] Characteristics of Volcanoes, New York, 1890.



A. DRIBLET CONE OR OVEN, JORDAN CRATERS, OREGON.



B. DRIBLET CONE, DIAMOND CRATERS, OREGON.

streams down moderately steep slopes and made for itself well-defined channels. These channels are, in general, about 3 feet wide, 3 to 4 feet deep, with the crests of their bordering ridges elevated about 3 feet above the adjacent surface, and from 50 to 150 feet long. One example of these troughs or gutters, situated at the south base of the driblet cone shown on Pl. XI, *A*, is about 50 feet long, 14 to 16 inches wide, and $3\frac{1}{4}$ to $4\frac{1}{4}$ feet deep; the crests of the bordering ridges are, in general, 3 feet above the adjacent surface. Near its distal extremity the trough is completely roofed over, as may be seen in the illustration just referred to. The largest example observed is situated on the east side of Crater No. 4, and is about 150 feet long, 3 feet wide, with well-defined walls, which rise approximately 3 feet above the neighboring surface. These and other similar gutters usually begin abruptly at their upper ends and retain a nearly uniform width and depth to near their distal extremities, where their walls become lower and the troughs merge with broadly expanded, low, dome-shaped elevations on a general pahoehoe surface. In some instances the liquid lava, as it flowed through one of these gutters, became cooled at the surface so as to form a crust, which was left as a slightly arched roof above a tunnel as the still-liquid lava beneath flowed out. These gutters with roof are in fact tubes or tunnels. In the instance shown in Pl. XIV, a well-defined gutter was formed, in which the lava flow decreased until the surface of the current was about 3 feet below the crest lines of the inclosing ridges; a crust was then formed, and the lava below it flowed out, leaving a roof spanning the gutter throughout its length.

The mode of formation of lava gutters seems to be that a narrow stream of liquid lava cools at its margins and forms a slight ridge, more lava spreading laterally over this ridge, in turn cools and stiffens, and then adds to its height, and so the process continues until a well-defined gutter with raised borders is formed. These parallel ridges on the borders of a narrow, high-grade lava torrent are in a measure analogous to the natural levees built by alluvial-depositing streams.

Lava flow.—The lava from Crater No. 4 of the Jordan series, as already stated, flows southeastward over a previously stream-eroded surface. The lava, just after leaving the crater from which it came, formed a stream 545 yards wide, and increasing rapidly in width reached a distance of about 8 or 10 miles. The entire flow is by estimate between 50 and 60 square miles in area. The average depth may perhaps be taken as approximately 100 feet. These statements, it must be remembered, are rough estimates, as no surveys have been made, and no maps of the region are available. The lava as it advanced was guided in a conspicuous way by the preexisting topography, and in several instances progressed short distances up lateral valleys tributary to the main depression down which it flowed. One of these small offshoots went nearly due north for one-half mile up a small stream valley until its progress was checked by the rising gradient. In places the fresh, black lava is bordered by rims of older rock, showing that small canyons in the preexisting surface had been nearly filled. Near the eastern limit reached by the lava it ascended the small canyon of Cow Creek for about 1 mile, and on cooling formed a dam, which now retains the largest and most northern of the Cow Creek lakes, as has been described on a previous page. About its southeastern margin there are several other lakes.

This great lava stream or lava sheet came from a small crater, termed above Crater No. 4, the bottom of which is approximately 300 feet across. Seemingly the actual conduit must be of still smaller diameter. This effusion of highly liquid lava, with only mild explosions at the beginning of the discharge, is a typical illustration of the manner in which many extensive lava sheets of Idaho, Oregon, and Washington were poured out. The lava from Crater No. 4 seems to have progressed mainly by flowing beneath a stiffened crust, and in this manner was prevented from cooling quickly, thus permitting it to advance far and spread widely. Tunnels in the lava were produced by the outflow beneath the crust formed on its surface, and in certain places, as near the source of the stream, the roofs of such tunnels have fallen in, leaving irregular pits with overhanging walls from 50 to 70 feet deep.

In many portions of the lava flow pressure ridges and domes like those so common in the immense lava sheets about the Cinder Buttes, in the older sheets of Snake River lava, and at other places, are well displayed. A photograph of one of these domes, situated near the northern border of the lava sheet, and midway between its source and the most northerly of the Cow Creek lakes, is reproduced on Pl. XV, *A*. A similar ridge on a lava sheet of somewhat older date, which came from the Diamond Craters, is shown on Pl. XV, *B*. That the lava in each of these instances was horizontal before being pressed up into dome-like ridges, is shown by the corrugation on the surface of the dome, to be seen in Pl. XV, *A*, and of the columnar structure in Pl. XV, *B*.

DIAMOND CRATERS.

A group of recently extinct volcanoes which it is convenient to term the "Diamond Craters" is situated in the east-central part of Harney County, Oreg., about 6 miles west of Diamond post-office. The craters, about 20 in number, occupy an area of about 5 square miles, and are surrounded by at least 30 square miles of rough lava which flowed from them.

The Diamond Craters are situated near the base of the long west slope of Stein Mountain, and came into existence after the land over which they discharged their lava had been deeply dissected by erosion. The lava entered the valleys and canyons and obstructed the drainage so as to cause swamps to form. A significant fact in this connection is that the basins above some of the lava dams are still unfilled and have never been occupied by water bodies except ephemeral or playa lakes. This evidence seems to show that the climate of the region has been as arid as at present ever since the lava streams obstructed the drainage.

The Diamond Craters are of two types, namely, lapilli cones and lava cones, the lapilli cones situated in the southwest and the lava cones in the northeast portion of the group. The lapilli craters are mostly low, and range in size from one measuring about 2,500 feet across to small conical piles of brownish débris. Within the largest crater there are hills and mounds of lapilli of the same character as the material forming its encircling rim, but rising to a height of from 50 to 75 feet above it. This great accumulation of fragmental material presents an uneven surface consisting of hillocks and crater-like hollows and bears evidence of the occurrence of weak explosions in a crater so abundantly charged with débris that it could not clear itself. From analogy with streams, the volcano may be said to have been overloaded with débris. The fragmental material was blown up into hills, and crater-like pits opened in it, but the escaping lava did not have sufficient force to eject it from the crater.

The hills and rings of lapilli among the Diamond Craters present many variations. Some are simple conical piles of the normal type, with depressions in their summits; in others lava rose and, breaching the inclosing wall, overflowed. In one instance the lava, after rising in a crater and outflowing, was drawn off beneath the crust formed on its surface and within the bowl of lapilli, about 600 feet across, causing the crust to fall in and leaving a black, irregular gulf 30 feet deep, and one lapilli ring or crater has another, composed of the same kind of material, within it, thus recording two stages of activity. In one instance a small crater is composed of compact, spherical lava balls or bombs, ranging in size from about 2 inches to the size of small shot. These bombs are rough, of a dull-red color, not cellular, and exhibit no evidence of rotation excepting their well-rounded shapes. Bordering the lapilli craters on all sides are the broad, rough surfaces of recent lava fields, which in most instances are covered to some extent with sagebrush and other vegetation.

To the north of the lapilli craters and merging with them as topographic forms are rounded hills composed of lava sheets, which furnish examples of lava cones. The highest of these hills rises about 400 feet above the adjacent plains and is the highest and most conspicuous summit in the group of which it is a member. This central dome is about 1½ miles in diameter, and so far as is indicated by the exposures is composed throughout of lava sheets, which occupy its summit and descend its sides in all directions to the surrounding plain. There is no true crater to be seen, but at the summit of the hill there is a gulf, due to the falling in of a large block of lava of which the surface of the hill is composed. This gulf has a nearly vertical wall from 40 to 70 feet high, runs about east and west, is from 500 to 800 feet across, and fully 2,000 feet long. Within it are several irregular ridges formed by the edges of large tilted blocks of the fallen crust. The lava exposed in the walls of the break is irregularly columnar, and the topmost layer, which arches over the summit of the hill, is about 40 feet thick. This sheet is continuous from one side of the hill to the other, passing over the summit, but in the central part of the dome thus formed the rock is highly scoriaceous and the bedding less distinct than at the sides. From the gulf in the summit of the hill branching fractures extend down its sides to the east and southeast, and in part these radiating breaks are gulfs produced by the subsidence and tilting of large blocks of the surface layer. To the north of the hill just described there are other elevations of a similar nature, but lower and less broken, and about the group there are rough lava flows, which came from it and spread over the previously eroded land. On one of these lava sheets there are small driblet cones, two of which are represented on Pl. XI, *B*.

The interpretation of the facts in reference to the domes of lava briefly described above seems to be that from certain of the Diamond Craters, which were probably lapilli cones like those of that nature still remaining, great quantities of lava were extruded in a liquid or plastic condition, which buried or carried away the preceding craters of lapilli and, thickening about the opening from which it came, built up rounded hills. The outwelling lava flowed down the sides of the hill and a thick crust was formed on its surface. After this, the outflow continued beneath the stiffened surface, and finally, when no more lava rose from the conduit beneath, a considerable portion of the surface crust fell in, leaving the black gulf now forming such a conspicuous feature of the summit and eastern side of the largest dome. The smaller lava cones or domes to the north of the principal cone were less fractured than the main one of the series, and retain nearly all of their constructional features unmodified by either fracture, subsidence, or erosion. In fact but slight changes by erosion are anywhere visible throughout the entire group of craters.

The rounded hills of lava among the Diamond Craters are, as may be judged from the description just given, examples of lava cones, and are similar to many other elevations in Idaho and Oregon, which were produced in each case by the escape of lava in large volume from a volcanic conduit. The chief differences between the lava cones here considered and those of the normal type are the prominence of the rounded central hills and the comparatively small extent of the surrounding lava fields with which they merge. The usually characteristic profile presented by lava cones, consisting of long, gentle slopes leading up to a low central flat-topped butte, is not present. In this connection it may be suggested that the lava poured out to form the hills referred to was less liquid and did not flow away so readily, as in many other similar instances, but thickened in a more conspicuous manner than normally about the openings from which it came.

In the formation or lava cones, as is the case with the flow of lava streams generally, an important condition, and the one which makes it possible for a small hill to form with a sheet of lava extending completely over its summit, is the subsurface flow of liquid or plastic lava beneath a stiff crust. The degree to which lava escapes in this manner from a deep accumulation determines the extent to which its surface will be fractured and the amount of surface change which will result from the subsidence of fragments of the crust.

BOWDEN CRATER.

Situated in the south-central part of Malheur County, Oregon, and about 6 miles northeast of the former post-office of Bowden, there is an isolated volcanic crater surrounded by an extensive lava flow, which it is convenient to designate the Bowden Crater.

The region about Bowden Crater is composed largely of Tertiary lacustral deposits, and was deeply eroded before the eruption which built the crater. The region, in fact, had all of its present erosion features at the time referred to, and has been but slightly modified since the volcano ceased to be active.

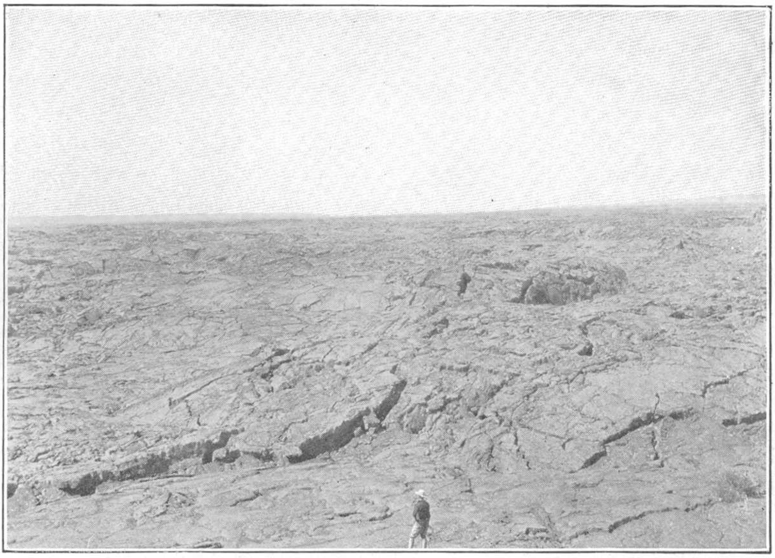
Bowden Crater and the lava flow about it are composed of basalt. There is, so far as observed, a complete absence of the products of explosive eruptions, such as lapilli, volcanic bombs, etc. The crater rises 600 feet by aneroid measure above the plain at the margin of its lava flow, but the lava flow and crater merge with each other, and the rise from the outer margin of the lava to the base of the cone in the center of the broad, black, desolate tract of fresh rock is exceedingly gradual. The upward slope for the first 3 or 4 miles is less than 1°; then for about 2 miles it gradually increases to perhaps 2° or 3°, and on the sides of the central and circular elevation becomes about 10°. The height of the central elevation above the surrounding lava is approximately 200 feet. The walls of the crater are of lava of the same general character as that forming the extensive sheet about it, but is perhaps somewhat more scoriaceous. The raised rim of the central elevation inclosed a steep-sided circular basin, 600 feet in diameter and about 40 feet deep. The bottom of the depression is level floored and consists of fine light-colored silt, most probably of eolian deposition. During the wet season this depression is converted into a shallow lake, which evaporates to dryness in summer.

When standing on the summit of Bowden Crater no other similar elevation is in sight, and no other volcanic vent has as yet been discovered nearer than the Jordan Craters, situated about 30 miles to the northeast. It is thus evident that the surrounding lava flow came entirely from this single and relatively small center of eruption. The lava flow referred to surrounds the crater on all sides, but extends farthest to the northwest, or in the direction of drainage of the region before the lava was spread out. The area of the lava field is by estimate fully 100 square miles. The thickness, on the supposition that it was spread out on a nearly level plain—which was apparently the case—varies from but a few feet at the margin to about 400 feet at the center. The surface of the lava is rough, and many pressure ridges are present, particularly within a radius of 2 to 3 miles of the crater. Considerable weathering has occurred, and in general the entire lava flow, as well as the sides and bottom of the crater, is overgrown with sagebrush, bunch grass, and other vegetation. On its southern border the lava field dammed Rattlesnake Creek, and caused a lake of considerable size to form. The bed of this lake has been filled to a depth of at least 40 feet with fine alluvium, and, owing in part also to the lowering of its outlet by erosion, is now dry and occupied by natural meadows of rye grass.

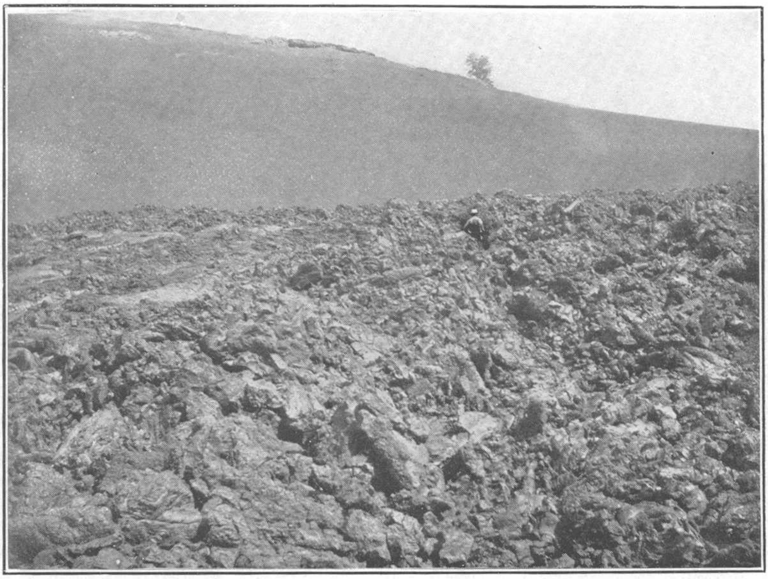
Bowden Crater, as may be judged from the facts just mentioned, is a typical and most instructive example of a lava cone of the variety having a crater at the top. This crater is circular, and not an irregular gulf, produced by the breaking and partial subsidence of a dome of lava, as in the case of the highest of the Diamond Craters. The precise manner in which the crater's rim was built up is not clear, but apparently it was formed by the radial overflow of lava in thin sheets. The central part is perhaps due to a drawing off of the molten rock which once occupied it, through tunnels in the surrounding lava. It is possible, in this and other similar instances, that a circular cinder rim was formed about the summit of the conduit from which the lava rose by the cooling and running together of splashes of liquid lava. Craters formed in this manner would furnish a connection between those composed of lapilli and scoria and true lava domes, like the highest of the Diamond Craters.

SUMMARY.

The various phases of volcanic eruptions illustrated by the Cinder Buttes and by the Jordan, Diamond, and Bowden craters are such as pertain in general to volcanoes which, for the most part, discharge highly liquid lava. At each of these volcanic centers it seems that the first eruptions were of the explosive type, and that the elevations produced by the accumulation of projectiles—whether solid, plastic, or liquid—first formed were, to a considerable extent, and in some instances completely, buried by the subsequent quiet effusion of vast quantities of liquid lava. Among the more interesting of the minor phenomena associated with them are the craters which were built of ejected angular fragments which were blown out from the cooled and rigid lava at the summits of the volcanic conduits, and similar struc-

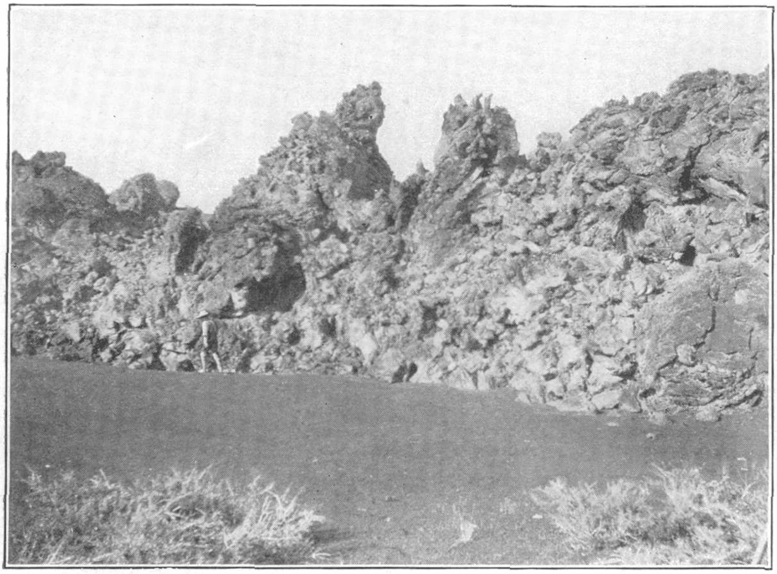


A. FISSURED PAHOEHOE LAVA, JORDAN CRATERS, OREGON.



B. AA LAVA SURFACE, CINDER BUTTES, IDAHO.

A.



B.

MARGINS OF LAVA FLOWS, CINDER BUTTES, IDAHO.

tures formed of material which was ejected in various conditions ranging from extreme viscosity to liquidity, and which formed scoria, bombs, lava cakes, and splashes of lava which became confluent after falling. The elevations built by the accumulation of such projectiles range, as has been stated, from lapilli cones or craters, due to the piling up of solid angular fragments, through similar craters composed in part or perhaps wholly of clots of plastic lava, volcanic bombs, and lava cakes to driblet cones and "ovens." The range in angle of slope on the exterior of these structures is from the neighborhood of 30° for the loose angular fragments to nearly vertical for the adhering clots; the range in slopes of the interior of the crater walls is about the same as for the exterior. When the driblet cones are roofed over, their inner slopes, both on the outside and within, pass beyond the vertical and approach the horizontal.

The lava flows also present a wide range in the resulting details, such as typical pahoehoe (Pl. XII, *A*) with corrugated surfaces, and even hollow folds due to the influence of an underflow beneath a plastic crust, and equally typical *aa* (Pl. XII, *B*), due to the breaking of a rigid crust on account of the energetic flow of still liquid lava beneath it. The occurrence of lava gutters (Pl. XIV) and the presence, in numerous instances, of prominent pressure ridges on the recent lava sheets (Pl. XV, *B*) are also instructive features. The thin margins of liquid lava streams and the conspicously abrupt and rugged extremities of highly viscous lava flows are illustrated on Pl. XIII.

All the material extruded from the volcanoes described above is basalt, and represents the more easily fusible of lavas.

In many ways these modern volcanoes serve to illustrate the nature of the far larger outporings of molten rock which, on cooling, formed the Snake River Plains and the still vaster, but, in part at least, somewhat differently erupted Columbia River lava. In a general discussion of volcanoes the Cinder Buttes, etc., may be considered as representing volcanoes of the quiet type, or such as erupt without energetic explosions, but their periods of activity were in all cases, so far as can be judged, initiated by explosions sufficiently violent to blow out projectiles, which on falling formed conspicuous elevations. They may be considered, therefore, as furnishing a connecting link between volcanoes of the explosive and those of the quiet type. These intermediate examples indicate, as has long been recognized, that the classification of volcanoes under two types, viz, explosive and quiet, is largely for convenience and that no sharply defined boundary separates the two.

TERTIARY FORMATIONS.

Besides the products of recent volcanoes, briefly described in the preceding pages, there are, in the portions of Idaho and Oregon under consideration, widely extended sheets of rock which may be classified according to their mode of origin in two broad groups of terranes, one of which includes the rocks composed of material that was deposited by water and the other the rocks which have cooled from a molten condition. The former includes the material laid down in lakes and by streams, aided in each case in a minor way, no doubt, by the transporting action of the wind; and the latter embraces the various products of volcanoes or volcanic rocks, and the similar magmas which have cooled in fissures, below the earth's surface, forming dikes. These more general groups of rocks are naturally subdivided in reference to mode of origin, composition, etc., as is indicated in the following table:

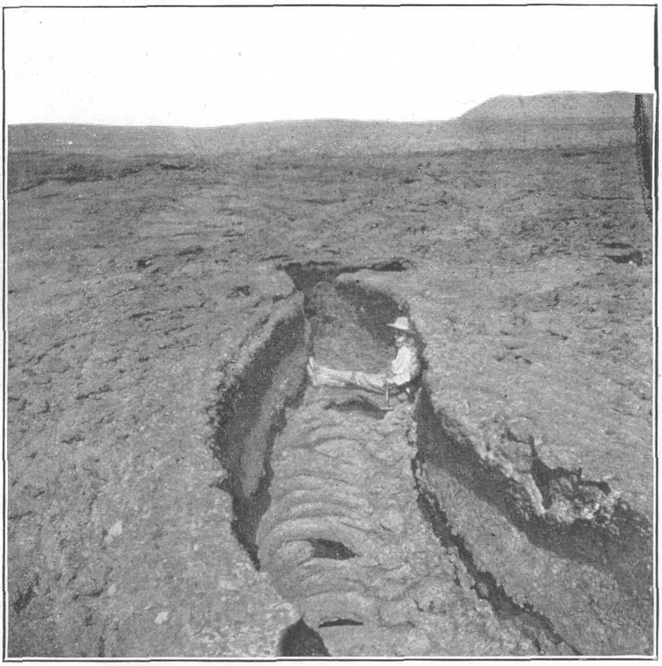
1. Sedimentary rocks	Conglomerates, sandstones, shales, unconsolidated gravel, sand, clay, etc. (together with beds of volcanic dust and volcanic gravel or lapilli).		
2. Igneous rocks	a. Volcanic rocks	Lava flows	Basalt.
			Rhyolite.
		Fragmental products of volcanoes.	Basaltic scoria, bombs, lapilli, etc.
			Rhyolitic lapilli and dust.
	b. Dike rocks	Magmas like the molten material discharged by volcanoes, but which cooled in fissures below the earth's surface, forming dikes.	

All the rocks referred to above are placed provisionally in the Tertiary division of geological history, excepting, as already noted, in the case of certain of the products of volcanoes which are of later date, and belong to the Pleistocene and recent times. The sedimentary rocks of Tertiary age also grade into more recent deposits of similar character and like mode of origin. At present it is impracticable to designate any well-defined boundary between either the volcanic or sedimentary rocks of the Tertiary and the similar terranes of more recent origin. While terranes older than the Tertiary are certainly present beneath the areas occupied by rocks of that age, they are believed not to be exposed at the surface along the route followed during the reconnaissance which furnished the data for this report.

SEDIMENTARY ROCKS.

The stratified rocks of the region examined—or those composed of fragments of older rocks, spread out in layers or strata by the waters of lakes and streams—comprise conglomerate or pudding stone, sandstones, soft, highly calcareous, usually nearly white, shales, and loose gravel, sand, white volcanic dust, and dark usually yellowish volcanic gravel or lapilli. These beds were for the most part deposited in lakes, and belong to the Tertiary division of geological history.

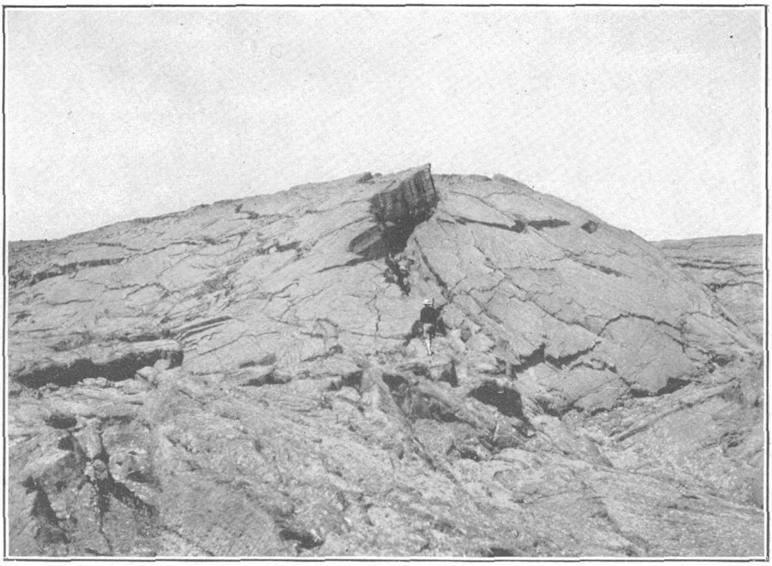
Examples of the conglomerate and sandstone referred to may be seen in the hills near where the Owyhee joins Snake River, in the isolated hills near Vale, and in the conspicuous bluffs to the southeast of Malheur and Harney lakes, as well as many other localities. These



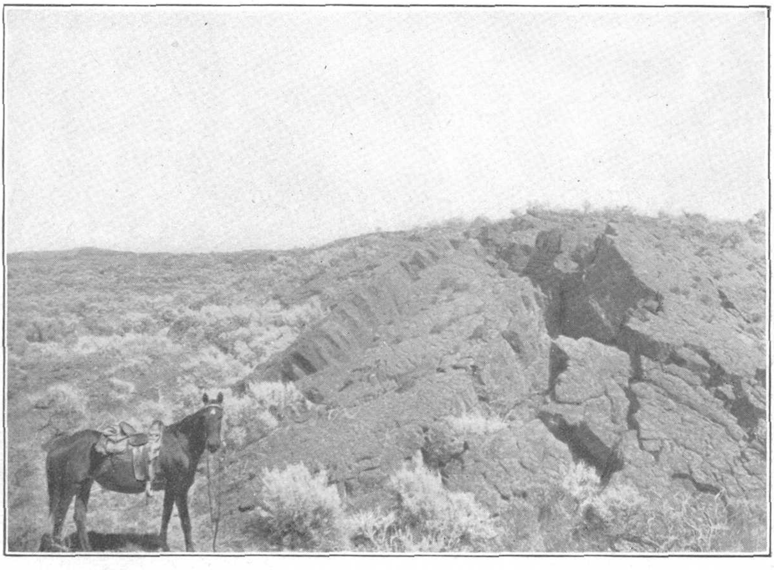
A.

B.

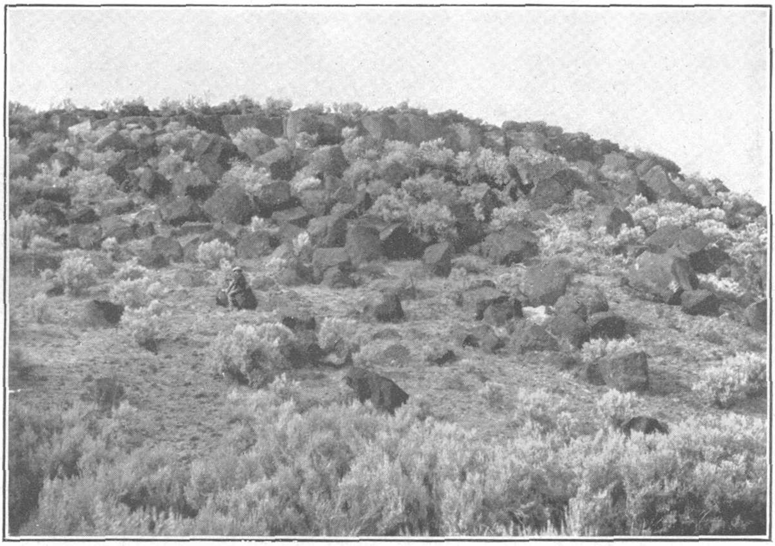
LAVA GUTTERS, JORDAN CRATERS, OREGON.



A. PRESSURE DOME IN RECENT LAVA, JORDAN CRATERS, OREGON.



B. PRESSURE RIDGE IN RECENT LAVA, DIAMOND CRATERS, OREGON.



A. WEATHERING OF THIN SHEET OF BASALT ABOVE SOFT STRATA, MULE, OREG.

B. WEATHERING OF THICK SHEET OF BASALT ABOVE THICK BEDS OF SOFT MATERIAL, SNAKE RIVER CANYON, OPPOSITE ENTERPRISE, IDAHO.

rocks are usually dark yellow, but occasionally, as near Narrows, are nearly white, and in some instances are sufficiently compact to be used for building stone. Associated with the layers of consolidated pebbles and sand just referred to, and having a wide extent in both Idaho and Oregon, are soft unconsolidated light-colored shales and marls and thick beds of nearly white sand and light-colored clay. Beds of this general nature aggregating more than a thousand feet in thickness underlie the Snake River between Glenns Ferry and Weiser and form the conspicuous white bluff along each side of that stream. Similar beds occur also in the lower portion of the valley of Malheur River and beneath the rim rocks of the canyons on the west slope of Stein Mountain. Light-colored and in part greenish shales outcrop on the west side of Alvord Valley, where they pass beneath the sheets of basalt, forming the bold eastern face of Stein Mountain. Fine exposures of rain-sculptured lacustral sediments, usually of a peculiar light-greenish tint, occur on the border of Owyhee River, near the mouth of Jordan Creek (Pl. XVIII). Similar beds are present also in the mountains of Owyhee County, Idaho, and are a southward extension of the thick sediments exposed along Snake River. This same formation extends northward from Snake River and is exposed near Boise and in the valley of Payette River. From its abundant exposures along the last-named stream it has been named by Waldemar Lindgren the Payette formation.

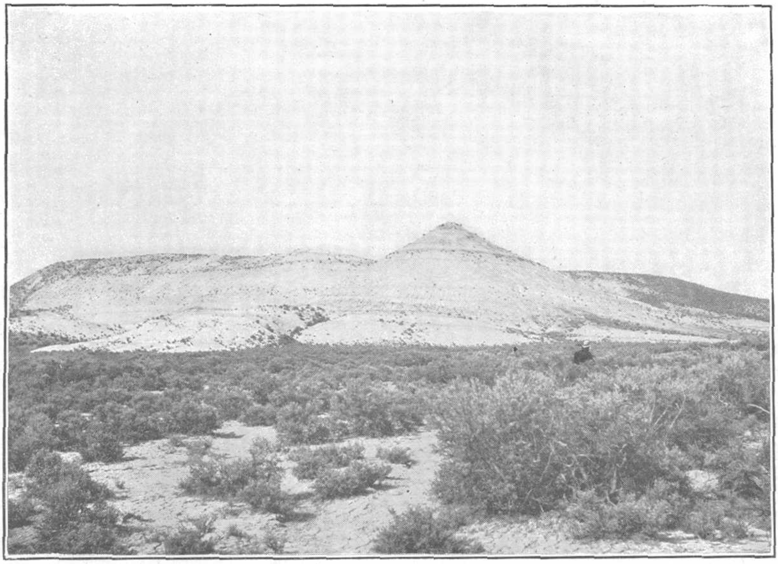
While the Payette formation has a wide extent in Oregon, and possibly reaches to the John Day River, where other similar beds outcrop and have been independently named, it is not positive that all the exposures of similar material as far south as Harney and Silver lakes were deposited in the same lake basin. The lacustral sediments beneath the basalt of Stein Mountain reveal a thickness of fully 1,000 feet, and, as seems probable, are of older date than the Payette formation.

Interbedded with the sandstone and shale, of the formations just mentioned, and frequently forming a considerable and at times seemingly the major part of their thicknesses, are beds of exceedingly fine white volcanic dust. This dust was blown out of volcanoes while in a state of violent eruption, and, falling in lakes, or being washed into them by streams, became interbedded with other sediments or intimately commingled with them. Examples of pure white volcanic dust from 10 to 20 or more feet thick may be seen in the hills on the lower course of Owyhee River, a few miles south of Owyhee, and are also splendidly exposed near Beulah (Pl. XVII). Outcrops of material of the same nature, conspicuous on account of their whiteness, occur beneath the rim rock near Diamond, in the borders of the small valleys in the northern portion of Owyhee County, Idaho, as well as at a large number of localities in the bluffs bordering Snake River.

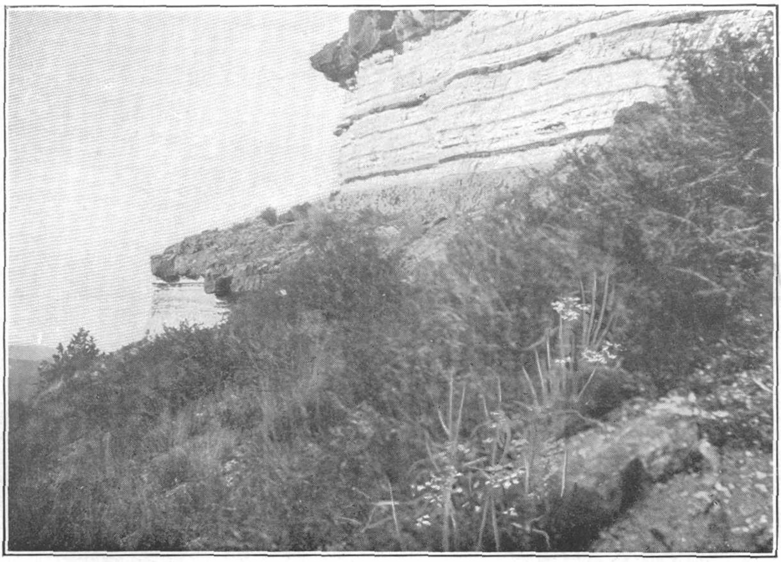
An interesting fact in connection with the stratified beds briefly described above is that they contain the bones of animals which are now extinct, but which lived in large numbers in and about the ancient lakes in which the sand, clay, volcanic dust, and other rocks now exposed and eroded into hills and valleys were deposited. In these same beds, but most abundant in the thinly laminated white silts and sheets of fine volcanic dust, occur fossil leaves, frequently in great abundance, and less commonly the fruits of the plants to which they belonged. These plant remains differ from the vegetation living on the earth to-day, and reveal the nature of the luxuriant forests that flourished in the now arid portions of the far West during the Tertiary period of geological history. The fossil bones and impressions of leaves and fruits referred to are of great scientific interest, as they furnish evidence in reference to past climatic changes and the gradual evolution of life on the earth, and also enable geologists to determine the relative age of the beds in which they occur.

Small collections of beautifully preserved fossil leaves were obtained from beds of fine white silt near Beulah, in the northwestern portion of Malheur County, Oreg., and from well-exposed and in part indurated sediments of Lake Payette, on Succor Creek, in Oregon, about 2 miles west of Rockhill, in Idaho. These specimens have been studied by F. H. Knowlton, paleobotanist of the U. S. Geological Survey, from whose manuscript report the following facts and interpretations of their meaning have been taken:

"The fossil plants collected contain, in addition to several species not as yet described, examples of broad-leaved trees, such as the oak (*Quercus*), of which there are several species, maple (*Acer*), plane tree or buttonwood (*Platanus*), willow (*Salix*), together with representatives of the bearberry (*Barberis*), wax-myrtle (*Myrica*), senna (*Cassia*), and others. The genera of plants represented are nearly all still living in America, but the species and varieties differ almost wholly from their modern descendants. The genera named above, as will at once be recognized by the inhabitants of the arid portions of Idaho and Oregon, are not now characteristic of that region. The leaves discovered in the rocks indicate that the trees and plants on which they grew required a more humid and in general less changeable climate than now prevails where their fossil remains are entombed. The nearest analogy of the flora they represent is seemingly furnished by the varied and beautiful vegetation of the Lower Mississippi Valley. Among the most conspicuous of the leaves spread out in the fine-grained lacustral sediments, in which they have been preserved for countless years, as if in the presses of an herbarium, are broad, strongly-veined, deeply-lobed leaves of an ancient maple, and in association with them are finely preserved winged seeds belonging to the same genus and possibly the same species. Several species of oak, etc., show that the uplands were clothed with hardwood trees, inter-

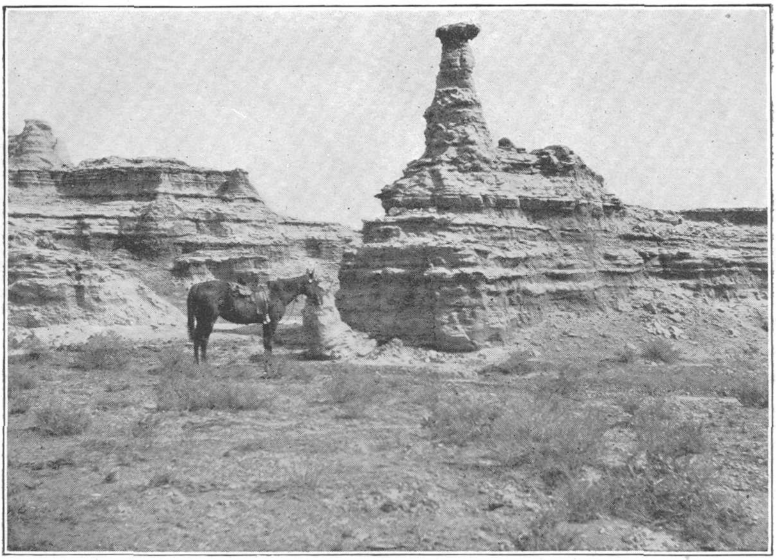


A.

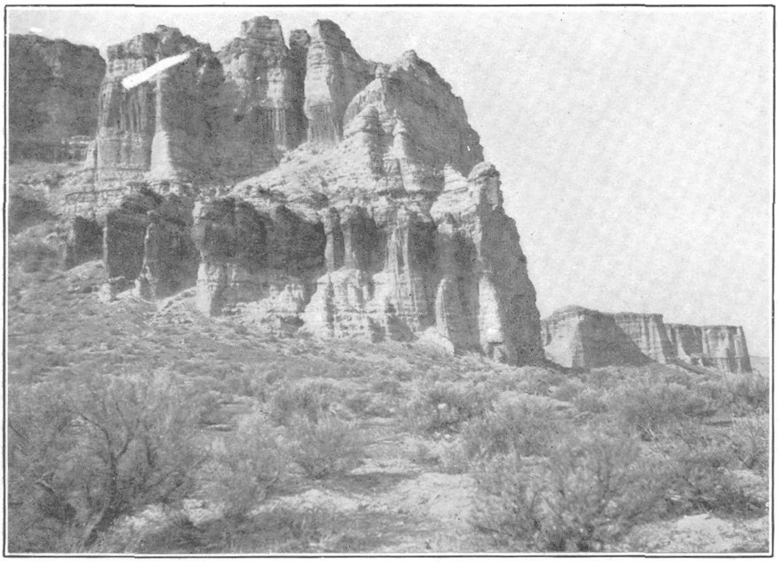


B.

EXPOSURES OF VOLCANIC DUST OF TERTIARY AGE, NEAR BEULAH, OREG.



A.



B.

EXPOSURES OF TERTIARY LAKE BEDS, OWYHEE RIVER, OREGON.

spersed among which were evergreens, as may be judged from the evidence furnished by impressions in the rocks of the cones of *Glyptostrobus*, a genus of conifers not now found living in America, but still surviving in China." The species from this varied and beautiful flora identified by Knowlton are as follows:

From Beulah: *Acer*, sp.?; *Cassia obtusa?* Knowlton; *Glyptostrobus?* species probably new; *Salix dayana* Knowlton; *Salix perplexa* Knowlton. From Succor Creek: *Acer* sp. ? *Berberis simplex* Newberry; *Myrica lanceolata* Knowlton; *Quercus breweri* Lesquereux; *Quercus consimilis* Newberry; *Quercus simplex* Newberry; *Quercus* sp. near *Q. idahoensis* Knowlton; *Platanus aspera* Newberry; *Sapindus* sp. ? and several apparently new species.

From the evidence furnished by these fossils, it appears that the plant-bearing beds on Succor Creek are a part of the Payette formation, named and described by Waldemar Lindgren,[a] which is now placed in the Upper Eocene instead of Upper Miocene as formerly.[b] The plant-bearing beds at Beulah are younger than the Payette, and, although the evidence is not all that could be wished, are referred to the Upper Miocene (corresponding with the Mascall beds of Merriam, in John Day Valley, Oregon).

The significance of the fossil plants catalogued above can perhaps be best suggested to the general reader by directing attention to an instructive, but now nearly forgotten, essay on the ancient lakes of the western portion of the United States, by J. S. Newberry,[c] one of the distinguished pioneers who made known the marvels of the Pacific mountain region.

The graphic pen picture given in the following quotation applies to the now arid valleys of Idaho and Oregon, in which the plant-charged sediments of ancient lakes are preserved, and should serve to awaken a deep interest in the minds of the people inhabiting that region in reference to the history of the land of their birth or adoption.

> The pictures which geology holds up to our view of North America during the Tertiary ages are in all respects but one more attractive and interesting than could be drawn from its present aspects. Then a warm and genial climate prevailed from the Gulf to the Arctic Sea. The Canadian highlands were higher, but the Rocky Mountains lower and less broad. Most of the continent exhibited an undulating surface, rounded hills and broad valleys, covered with forests grander than any of the present day, or wide expanses of rich savannah, over which roamed

[a] Descriptions of the Payette formation, together with discussions as to its geological age, may be found in the following publications by Waldemar Lindgren: The mining districts of the Idaho Basin and the Boise Ridge, Idaho: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 617–736; The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 65–256; The gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1902, pp. 551–776.

[b] The evidence which necessitated a revision of the conclusions presented in the papers by Lindgren, just referred to, in reference to the geological position of the Payette formation, is presented by F. H. Knowlton in Bull. U. S. Geol. Survey No. 204.

[c] The ancient lakes of Western America; their deposits and drainage: Preliminary report of the U. S. Geol. Survey of Wyoming and portions of contiguous Territories, by F. V. Hayden, Washington, 1872, pp. 338–339.

countless herds of animals, many of gigantic size, of which our present meager fauna retains but a few dwarfed representatives. Noble rivers flowed through plains and valleys, and sea-like lakes, broader and more numerous than those the continent now bears, diversified the scenery. Through unnumbered ages the seasons ran their ceaseless course, the sun rose and set, moons waxed and waned over this fair land, but no human eye was there to mark its beauty nor human intellect to control and use its exuberant fertility. Flowers opened their many-colored petals on meadow and hillside and filled the air with their perfumes, but only for the delectation of the wandering bee. Fruits ripened in the sun, but there was no hand there to pluck nor any speaking tongue to taste. Birds sang in the trees, but for no ears but their own. The surface of lake or river was whitened by no sail nor furrowed by any prow but the breast of the waterfowl, and the far-reaching shores echoed no sound but the dash of the waves and the lowing of the herds that slaked their thirst in the crystal waters.

Life and beauty were everywhere, and man, the great destroyer, had not yet come; but not all was peace and harmony in this Arcadia. The forces of nature are always at war, and redundant life compels abundant death. The innumerable species of animals and plants had each its hereditary enemy, and the struggle of life was so sharp and bitter that in the lapse of ages many genera and species were blotted out forever.

The herds of herbivores—which included all the genera now living on the earth's surface, with many strange forms long since extinct—formed the prey of carnivores commensurate to these in power and numbers. The coo of the dove and the whistle of the quail were answered by the scream of the eagle, and the lowing of herds and the bleating of flocks come to the ear of the imagination mingled with the roar of the lion, the howl of the wolf, and the despairing cry of the victim. Yielding to the slow-acting but irresistible forces of nature, each in succession of these various animal forms has disappeared, till all have passed away or been changed to their modern representatives, while the country they inhabited, by the upheaval of its mountains, the deepening of its valleys, the filling and draining of its great lakes, has become what it is.

IGNEOUS ROCKS.

Volcanic rocks.—The rocks which came from volcanoes are by far the most conspicuous of any of the formations in southwestern Idaho and adjacent portions of Oregon, and are apparently of greater extent and thickness than the associated sedimentary beds. They may, with sufficient accuracy for the purpose in hand, be classified as basalt and rhyolite, but a more critical study than has as yet been practicable will perhaps show that each of these divisions, and particularly the one here termed rhyolite, includes material that can with greater propriety be otherwise classified.

Both the basalt and the rhyolite present two conspicuously different phases, due to the manner in which the material was spread out on the earth's surface. In each case the rock while molten was in part extruded by volcanoes so as to form sheets which, in many instances, flowed far and wide over the surface of the land before cooling; and in part the lava while yet in the conduits cooled sufficiently to become rigid and was shattered by steam explosions. The fragments thus produced were blown into the air and widely distributed through the action of the wind, as sheets of volcanic dust, volcanic gravel, or lapilli, and angular fragments frequently of considerable size.

The basalt was spread over the surface of the land mostly in a molten and even highly fluid condition, and the beds of fragmental material produced are relatively small; while the rhyolite to a great extent was shattered at the time it was erupted, and the resulting beds of fragments were probably of greater extent and thickness than the sheets of the same material which were spread out as lava flows. This difference in the behavior of the volcanoes from which the comparatively fusible basalt was erupted, and of the volcanoes from which the more refractory rhyolite was discharged, is of much significance in reference to the nature of volcanoes, but can not be discussed at this time.

The basalt is a black, compact rock, but is frequently cellular on account of the presence of steam cavities, and in many localities is columnar. In the region under review it occurs in widely extended sheets which in general vary in thickness from about 20 to 80 feet. Fine examples may be seen all along Snake River, but more especially on the northern side of its canyon, in the canyon of Bruneau River, and in the hills and mountains of Malheur and Harney counties, Oreg. The finest exposure of basalt in the region visited by me in 1902, if not the most remarkable in the world, is to be seen in Stein Mountain. The eastern slope of that splendid mountain is composed of the broken and eroded edges of sheets of basalt, which dip westward at an angle of about 3° and present an aggregate thickness of not less than 5,000 feet. Between the sheets of basalt, as already noted, there are in at least 18 instances beds of coarse sandstone, varying in thickness from a few inches to 6 feet. Where the beds of sandstone occur the sheets of basalt are in general about 60 feet thick. From this and other similar evidence the total number of lava flows which occur in Stein Mountain is estimated at between 80 and 100.

The widely extended sheets of basalt just referred to, like the sedimentary beds with which they are intimately associated—the sheets of basalt and the beds of sandstone, shale, clays, etc.—belong principally to the Tertiary period of geological history and, as seems evident, form the lowest member of the widely distributed formation termed the Columbia River lava. Volcanoes have been active, however, in Idaho and Oregon at intervals from the time the oldest sheets of basalt were poured out in a molten condition down to almost the present day, as is shown by the Cinder Buttes, Jordan Craters, and other volcanic features already briefly described.

The rhyolite, like the basalt, occurs both as massive sheets, formed by the cooling of molten rock, and as fragmental deposits, which also form well-defined beds. Of the layers of rock originating in these two ways, the sheets composed of angular fragments, now in many instances firmly cemented, and forming a rhyolite tuff, are far more numerous and more extensive than the associated rhyolitic lava sheets. The beds of white volcanic dust described above as forming a part of the sedimentary deposits are composed of the finest of the fragments blown into the air by the volcanoes from which came the material now forming the sheets of rhyolite and of rhyolitic tuff.

The compact massive rhyolite is lighter colored than basalt, and in Idaho and Oregon is usually purplish on fresh surfaces, but weathers to a rich brown or red. It contains conspicuous crystals and grains of quartz, feldspar, and other mineral, and hence usually appears spotted. Frequently the crystals and grains referred to exhibit a linear arrangement, such as would be produced by a flowing motion in the glassy base in which they were embedded. At times the molten material cooled too quickly for crystals to form and produced a compact black glass, termed obsidian, fragments of which occur thickly over hundreds of square miles in eastern Oregon.

The rhyolitic tuff is composed of angular fragments of the rock just described, which, in most instances, are firmly cemented, so as to form sheets that are nearly, if not fully, as resistant to atmospheric conditions as the rock which cooled from fusion without being shattered, and frequently forms "rim rocks" on the sides of canyons and valleys.

Extensive exposures of rhyolite and of rhyolitic tuff occur in the mountains on the northeast side of Harney Valley, sometimes termed the Crow Creek Mountains. The conspicuous rim rocks on each side of Rattlesnake Creek, near Harney, are of rhyolitic tuff, while certain of the beds lower down in the walls of the same canyon, usually cavernous on the weathered outcrops, are of rhyolite, which has a peculiar concentric or spherulitic structure. Again, in the bluffs of Silvies River, to the west of Burns, the edges of a thick sheet of compact tuff are well exposed, and similar rock has a wide distribution in the forest-covered mountains in which Silvies River rises. Other outcrops of tuff and of compact rhyolite occur about Silver Lake at Iron Mountain and in the Mahogany Mountains. The conspicuous rim rocks in the vicinity of Diamond are composed of tuff, and similar rock has a wide distribution in the hills near Smith and Mule.

An interesting fact in connection with the sheets of rhyolite and of rhyolitic tuff in southeastern Oregon is that they are younger than much of the basalt of the same region, and overlie it. There have been eruptions of basalt also since the youngest observed sheet of rhyolite or of rhyolitic tuff was spread out, as rim rocks of basalt above the thick deposits of rhyolitic tuff are of common occurrence.

Dike rocks.—The molten magmas which rise in volcanoes and in part overflow, so as to form lava sheets, also in part cool below the surface in the conduits of volcanoes and in fissures. Many distinctive features in the rocks produced from the same molten magma arise in this way, which it is unnecessary to consider at this time.

Both the basalt and the rhyolite which form such extensive outflows in Idaho and Oregon came to the surface through openings, as fissures, for example; and below the present surface it is to be expected that there are many fissures in which molten rock has cooled so as to form what are termed dikes. A few dikes were observed in the bold eastern face of Stein Mountain, and indicate what may be present in other localities. The dikes referred to are nearly vertical, vary in width from 20 to 60 feet, and are horizontally columnar. As is well known, dikes have frequently led to the hardening of the walls of the fissures they occupy, and for this and other reasons their presence in an artesian basin might introduce serious difficulties in the way of obtaining flowing wells. If in drilling a well the locality chosen should chance to be directly above a dike, it is probable that the well would be a failure, even if the difficulty of penetrating the usually compact and hard rock of the dike could be overcome. Where the country rock is concealed beneath deep sheets of soil, alluvial deposits, etc., it is frequently impossible to detect the presence of a dike in the rocks beneath the surface covering, unless they are encountered in drilling or making other excavations. So far as can now be judged, however, the dikes in the artesian basins described in this report are not numerous, and the chances of striking them in drilling are small. A greater danger lies in the fact that they may cut a water-bearing stratum, so as to prevent the percolation of water through it.

STRUCTURE.

By geological structure is understood, in part, the positions occupied by stratified or bedded rocks in the earth's crust. For example, sandstone, shale, etc., originally laid down in horizontal sheets, are now found to be inclined, folded, and in many instances occupy a vertical position.

The rocks, both sedimentary and volcanic, which underlie southwestern Idaho and southeastern Oregon, were at the time of their formation spread out in nearly horizontal layers, but subsequently they have been depressed in one locality and raised in another, and in certain instances crushed together so as to form great upward and downward folds. In other instances they have been broken along nearly vertical planes, and the portion of the strata on one side of the break upraised or depressed in reference to the corresponding strata on the opposite side; that is, have been faulted. Examples of the gentle tilting of previously horizontal sheets of rocks throughout great areas are furnished in the broad Snake River Plains between Glenns Ferry and Owyhee. North of Snake River the rocks are now gently inclined upward to the north, but south of the river the same beds rise when followed southward, and in the Owyhee Mountains are more than a thousand feet above the position the same strata occupy beneath Snake River. This uptilting of stratified beds is well displayed in the hills near where Snake River first crosses the

Idaho-Oregon boundary. These remnants of formerly much more widely extended strata indicate the great amount of denudation that has occurred throughout an extensive region.

Broad and comparatively gentle elevations and depressions of the once horizontally stratified rocks occur also in other portions of the region examined, as, for example, in the neighborhood of Harney and Burns. The rocks beneath the extensive valley in which Malheur and Harney lakes are situated slope upward in the hills and mountains about the borders of the basin, as is well shown in the walls of the canyons on the west side of Stein Mountain, in the Crow Creek Mountains, on the border of the canyon of Rattlesnake, in the hills to the west of Burns, and at several other localities in the same region. In general, all about the Harney Basin—as it is convenient to term the great depression in which Malheur and Harney lakes are situated, and of all of the country drained by them—the rocks are upraised. This basin, however, is not a simple saucer-shaped depression, but has irregularities, and is due to the association of several upheavals and depressions. The broad, gentle undulations in the rocks just referred to are, in some instances, a hundred or more miles across, and are promising structural features in reference to the hope of obtaining an artesian water supply.

In addition to the broad and usually somewhat indefinite swells and depressions referred to above, and others of similar nature but of smaller size, are certain well-defined upward folds or anticlines, and equally characteristic downward folds or synclines. These are similar in shape and analagous in the manner in which they were produced to the folds or corrugations that may be made by pushing one side of a pile of rugs toward its center, or, on a still smaller scale, by forcing together the sides of a pile of newspapers so as to compress them into folds. In the region under consideration there are several examples of such folds, but, as is commonly the case on all land areas, the relief of surface produced in the manner referred to has been greatly modified by erosion. The upward folds particularly have been cut away, leaving for the most part only their basement portions.

A striking illustration of a great upward bend, involving bedded lava sheets with an aggregate thickness of fully 5,000 feet, and also a great but unknown thickness of stratified sedimentary deposits beneath them, is furnished by the northern portion of Stein Mountain and the several parallel—nearly north-south—ridges to the east of it, and north of Alvord Desert. The larger features of the rugged belt of country referred to are seemingly due to the erosion of a great anticlinal fold, the longer axis of which trends about northeast and southwest, but this conclusion is here stated tentatively, as sufficient time was not available for more than a hasty examination of a part of the region. The hard layers of compact basalt in the truncated remnant of the fold now form the sharp-crested ridges to the east of Juniper and Mann lakes, which have a gentle surface slope on one side and a steep escarpment on the other.

A characteristic example of a broad downward fold or syncline may be seen from the summit of Stein Mountain on looking southwest over the region drained by Donner and Blitzen River. The longer axis of this basin trends in a north-south direction, and is inclined downward or pitches northward.

Accompanying the deformation of rocks, breaks sometimes occur, and the edges of the broken layers on the opposite sides of a fracture are upheaved or depressed with reference to each other. In this and yet other ways what are termed faults are produced.

Breaks in the earth's crust of the nature just referred to, when they affect the relief of the surface, produce bold escarpments. The strata frequently dip away at gentle angles, thus producing what it is convenient to term monoclinal ridges or mountains—that is, elevations with steep descents on one side and gentle slopes, corresponding closely with the inclinations of the component beds, on the other. Examples of such monoclinal mountains are furnished, as seems evident from such studies of them as it has been practicable to make, by Stein Mountain and Mahogany Mountain, in Oregon.

MINERAL RESOURCES.

PETROLEUM.

Search for petroleum has been carried on in the valley of Snake River in southwestern Idaho and adjacent portions of Oregon, but these attempts have proved failures so far as the discovery of the material sought is concerned. In all of the instances referred to that have come under my notice, it is evident that little if any study of the geological conditions was made previous to drilling, and little if any appreciation of the conditions governing the accumulation and storage of petroleum seems to have been entertained by the persons who "promoted" the various oil ventures. As much time and money has been spent in the region mentioned in fruitless attempts to discover petroleum, and as additional efforts will no doubt be made in the same direction, more conservative methods may perhaps be favored if a plain statement of the general principles pertaining to the occurrence of petroleum, and of gas with which it is commonly associated, be laid before the reader.

CONDITIONS FAVORING THE NATURAL STORAGE OF PETROLEUM AND ROCK GAS.

The geologist in searching for oil and gas pools, as subterranean accumulations of petroleum and natural or rock gas are commonly termed, must of necessity be guided mainly by the physical properties of these substances; by the occurrence of water, with which they are commonly associated; and by the characteristics of the strata in which they occur. An attempt is here made to state in nontechnical language the conclusions that have presented themselves in reference to the natural storage of petroleum and gas, as search for these substances has been carried on in various parts of the world. No originality is claimed for what follows, as it is simply a rearrangement of widely current knowledge.

The physical properties of petroleum, gas, and water are well known, and of these properties the ones of special significance to the geologist are their specific gravities. The specific gravity of petroleum in most all instances is below 1—that is, it is lighter than an equal volume of water. The range in specific gravity for American petroleum is from about 0.771 for the highly liquid yellow or amber-colored varieties to 0.945 for the thicker and frequently black material, valued principally as a lubricant. The only instance known, so far as the writer is aware, of petroleum which is heavier than water is that obtained at Zante, in Greece, which has a specific gravity of 1.02. Natural gas is far lighter than the lightest petroleum, its density being about one-half that of air. The principal physical differences between petroleum and gas are those that constitute the distinction between a liquid and a gas. The gas has the property of indefinite expansion, and when put under pressure diminishes in volume, at the same time acquiring greater expansive energy or tension.

It is the occurrence in nature of petroleum and gas with these widely different physical properties, and each of them lighter than water, with which they are usually associated, that the geologist has to consider. Not only this, but attention needs to be given to the occurrence of these substances singly or together, and of one or both of them in association with water. The physical properties of petroleum and gas thus determine some of the conditions on which success in the search for commercial quantities of these substances depends.

If water, petroleum, and natural gas be placed in a corked bottle and the receptacle be allowed to rest for a brief time, they arrange themselves in the order of their respective specific gravities, the water being at the bottom, the petroleum next above, and the gas at the top. This conclusion is self-evident, and there is no reason for thinking that the law it illustrates is violated when the three substances named are present in a cavity in the earth, or what is much more common, contained in the pores of a loose-textured rock. Then, too, the water present in the rocks is never pure, but contains more or less mineral matter in solution, and not infrequently it is highly saline. Its specific gravity is, therefore, greater than if it was pure, and its ability, under certain conditions, to displace petroleum and cause it to rise is correspondingly increased.

The displacement by water of petroleum contained in the pores of rock has certain limitations, however, which at times become important. Petroleum in porous rocks adheres to the surfaces with which it comes in contact, this tendency being greater in the heavier than the lighter varieties, and may be only in part or not at all displaced by water. If the oil refuses to flow under the pressure of water, however, it can not be separated except by methods which at present are commercially impracticable.

Another important consideration in reference to the occurrence of petroleum and gas in the interstices of rocks, is the porosity of the rocks themselves. It has been shown by wide experience that water, petroleum, and gas, as they occur in the rocks, are generally contained in the small interstices and minute cavities between the grains or crystals, and not in caverns or open fissures. This is the nearly universal rule, not only in reference to water in artesian basins, but also for petroleum and gas in practically all the areas where they occur. Although cistern-like bodies of these substances may exist, they are certainly rare, and their presence beneath the surface can not be foretold. Their accidental discovery by the drill is a lucky chance.

The porosity of rocks varies through all degrees, from loose sand, which may absorb one-half or more of its own volume of oil, to dense, compact quartzite, granite, and limestone, which are practically impervious.

The three substances under consideration are contained in porous rocks in the same manner that water is held in a sponge or in a brick, and in the same manner, also, that water passes through a sponge or may be forced under pressure through a brick, so petroleum percolates or flows through porous rocks.

The conditions under which water, petroleum, and gas exist in porous rocks may be illustrated by packing a bottle with sponges and pouring in water and petroleum; the water, being heavier than the petroleum, will evidently find its way to the lower portion of the receptacle, and the petroleum will gather above it. If the bottle charged in this manner is placed in a warm room, or a gentle heat be applied to hasten the process, some of the petroleum will evaporate and form a gas, which will rise above the oil. If the application of heat is continued, more and more gas will be generated, and a strong gas pressure be produced. The application of the principle thus demonstrated will be considered later.

The porosity of rocks varies, as stated above, but those most commonly charged with petroleum or gas so as to act as reservoirs are sandstone, conglomerates, and certain open-textured limestones. It must not be concluded, however, that these are the only rocks that may act as storage reservoirs in this connection; any rock that has an open texture, from whatever cause, may serve the purpose. A rock may be crushed and so filled with crevices as to permit of the ready percolation of liquids; even volcanic rocks with an open scoriaceous texture might fill the rôle. In general, also, the rocks which permit of the passage of petroleum and gas are permeable by water.

The impervious rocks met with in stratified beds, which are the usual ones containing water, petroleum, and gas, are mainly shale and clay. These rocks were once in the condition of mud and silt, and are composed of very small fragments, and, moreover, on account of their consistency, are rendered compact by pressure and are frequently impervious even to gases.

The porosity of rocks thus depends on the size and shape of the grain, or crystals of which they are composed, and on the nature and amount of the cement which unites the grains; the smaller the grains and the more perfectly they are cemented together, the less the size of the interspaces between them. Pressure tends to compact the granules of rocks, and the smaller the granules the more thoroughly they may be made to fit together. The search for petroleum and gas, therefore, demands a study of the rocks in reference to their porosity. As will be shown below, the most favorable conditions, so far as rock texture is concerned, occur when a thick layer of open-textured rock, say coarse sandstone, is covered by a layer of fine-grained rocks like shale. An additional reason why sandstone and certain limestones make favorable reservoir rocks, and shales efficient covers for the reservoirs, is because the sandstones and limestones are rigid, and if fractured or jointed the cracks remain open unless the beds are under excessive pressure, while the shales, if fractured, tend to flow, even under moderate pressure, and thus close the fissures.

The source of the water with which nearly all rocks near the earth's surface are more or less thoroughly charged, is primarily the rain, although essentially all stratified beds were deposited in water and for that reason were at first water charged, but this primary water has in most instances been flooded out by subsequent underground percolation.

The source of the petroleum, as conceded, I believe, by all geologists, is organic matter contained in the rocks, but other theories to account for its presence have been suggested. The chemistry of the change undergone by organic matter when excluded from the air is not well known, but the evidence seems conclusive that plant or animal remains buried in the rocks, usually in the presence of saline water, undergo a slow spontaneous change at low temperatures, one result of which is the production of petroleum. A higher degree of heat hastens the process, but within moderate limits seemingly does not vary the nature of the result.

Petroleum at ordinary surface temperature evaporates and gives origin to inflammable gases, and an increase in temperature hastens the change, but, except at what may be termed a high degree of heat, does not vary the nature of the result. What is of special interest to the geologist in this connection is that the evaporation of petroleum and the production of gas go on at the ordinary temperatures observed in the surficial portions of the earth's crust. As light, highly liquid petroleums evaporate, they become more and more dense and change to heavy oils; still greater loss by evaporation leads to the production of highly viscous substances, like mineral pitch; and a further change in the same direction furnishes a large variety of solid hydrocarbons.

In a general way, then, petroleum furnishes natural gas as a "distillate" and viscous and solid hydrocarbons as residues. This is as far as we need attempt at present to penetrate the wide and but partially explored field of the origin and chemistry of petroleum and its derivatives.

If we assume, as stated above, that petroleum is derived from the organic matter contained in rocks, then it follows that we may expect to find it in sedimentary rocks of any geological age which were deposited after life appeared on the earth. This conclusion is abundantly sustained by the many discoveries of petroleum and gas that have been made in rock ranging in age from the lower Paleozoic to the Tertiary and even recent time. Any series of stratified rocks, therefore, so far as its geological age is concerned, may be expected to yield hydrocarbons in one form or another, and, as has already been suggested, even igneous and metamorphic rocks may serve as reservoirs.

Fluids and gases contained in subterranean chambers, or in the interstices of porous rocks, are first of all subject to the force of gravity. Water in porous rocks will descend under the pull of gravity and displace lighter fluids, as well as gases, thus causing them to rise if avenues for escape are available. Petroleum alone, in a porous rock, will descend and seek the lowest attainable position, although the thicker varieties, owing to their high degree of viscosity, would move sluggishly.

Hence, water, petroleum, and gas in a porous rock will, as already stated, arrange themselves in the order of their respective specific gravities, the water being at the bottom and the gas at the top, and the water will be subjected to the pressure of the lighter substances resting on it. When porous rocks charged with the three substances named are confined by impervious beds, so that an escape for the gas is impossible, the water and the oil must be pressed on by the gas, owing to its tension or expansive force; and should gas continue to be generated, it will acquire such a tension as to exert a great pressure on the fluids imprisoned with it. The fluids and gases contained in the rocks may therefore be subjected to gas pressure which, as is well known, may equal thousands of pounds to a square foot.

When a porous rock is inclosed between two impervious beds and the series is inclined, the natural arrangement of the three substances under consideration will be the same as just stated, but under certain conditions the petroleum and gas may be brought under hydrostatic pressure. To illustrate the requisite conditions for producing hydrostatic pressure, reference is made to the following diagram, which represents a section of the earth's crust, say, 20 miles long and 1,000 feet deep, where the rocks have been gently folded. In the section two bodies of shale are shown, with an included layer of porous sandstone. If the sandstone is charged with petroleum and gas generated in the shales beneath, or possibly in its own mass, it is evident that these light substances will in part be flooded out by water entering where the layer comes to the surface in the eroded fold at the right. Under such conditions indications of petroleum and gas should occur at *a*, of the nature of springs of these substances or as a general exudation of heavy oil, since the freedom of escape would facilitate evaporation of the petroleum and its consequent concentration. The petroleum in the porous layer beneath the unbroken fold *b* would be above the water and subjected to a pressure equal to the height of the water in the porous layer above the base of the petroleum. An "oil pool" would therefore form beneath the fold *b*, which would be subject to the pressure of the water in the higher portion of the same bed. The outcrop of the porous bed, where it receives water, may be scores or hundreds of miles distant from the oil pool, and the height of the source of water supply scores or hundreds of feet above the

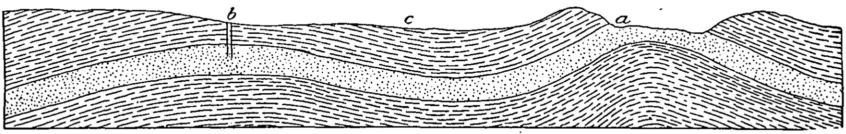


FIG. 1.—An ideal geological section illustrating the manner in which petroleum and natural gas accumulate in anticlines, and also the origin of hydraulic pressure on such "pools."

reservoir on which it presses. Gas generated from the petroleum in the oil pool beneath *b* would collect above it and form a gas pool, also under hydrostatic pressure. In computing the pressure exerted by water in cases like the one just cited, account must be taken of the density of the water, since, if highly saline, its weight will be materially increased. Under the conditions just assumed the oil and gas pools beneath *b* may enlarge until their bases extend laterally below the downward fold between *a* and *b*, when a limit would be reached, as an avenue of escape through the porous bed to the outcrop at *a* would then be furnished.

Under the conditions shown in fig. 1 a well drilled at *b* and reaching the porous layer would yield gas under pressure, which would escape without diminution of pressure until it was exhausted, providing the porous bed was sufficiently open textured to admit of the ready flow of water through it, otherwise the gas might escape more rapidly than the water could flow in, so as to maintain a constant pressure. After the gas had passed off the petroleum would rise in the well to a little above the level of *a*, depending on its specific gravity, and the gas well would be transformed into a "pumping" oil well.

Great variations in the general conditions illustrated above occur in nature. The locality *a* may be much higher than the surface at *b*, in which case the gas first escaping would be followed by a flow of petroleum, and when that failed, water would follow and form an artesian well. Under the conditions shown in fig. 1, wells put down between *c* and *a*, with the hope of finding either petroleum or gas, must evidently result in failure.

Another source of pressure which may be brought to bear upon fluids and gases in a porous rock has been suggested, namely, the weight of the overlying rocks, but this hypothesis may evidently be discarded unless, after the rocks have been charged with water, petroleum, or gas, the weight of the superimposed strata causes compression, which diminishes the volume of the interstices in the porous bed. Such a change might evidently take place, but in general must be of such small amount in comparison with other causes of pressure on the contained fluids and gases that it need not be considered.

Geologists have found that it is not a scarcity of petroleum or gas that makes the occurrence of commercial quantities of the substance so valuable, but their concentration into what are termed "pools" or natural reservoirs. In this concentration the position in which the

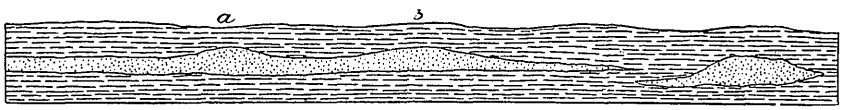


FIG. 2.—An ideal geological section illustrating the manner in which petroleum and natural gas may be concentrated in horizontal beds.

layers of rock in the earth's crust occur is in the highest degree important.

Stratified rocks, when first formed, were in nearly all cases essentially horizontal, but, owing to subsequent movements in the earth's crust, are now in many instances variously inclined, folded, and broken. In strictly horizontal beds it is evident that the conditions for concentrating the petroleum and gas they may contain are unfavorable. This, however, is not equivalent to saying that horizontally bedded rocks are of necessity destitute of oil and gas pools. For example, as in the section shown on fig. 2, the upper surface of a porous bed inclosed between two sheets of shale may be irregular, and the elevations in its upper surface might supply conditions similar to those furnished by an upward fold. In the diagram, oil and gas might accumulate at *a* and *b* under gas pressure and be of sufficient volume to yield valuable returns. Again, in horizontal, impervious beds there may occur irregular, porous, masses of rock—as sandy patches in shale or porous regions in limestone, for example—which would serve as reservoirs, and on becoming charged with petroleum and gas yield one or the other of these substances, according to the shape of the pool and the place where it chanced to be penetrated in boring. An illustration of such a possibility is shown to the right in fig. 2.

The influence of an inclination of the strata and of folds has already been briefly considered, but the importance of structure, to use a general term to designate the position in which the beds occur, is so important in the concentration of oil and gas into productive pools that it needs to be well understood by all who search for these substances.

In many regions the rocks are crumpled or corrugated into a series of up and down folds, termed, respectively, anticlines and synclines, as shown in fig. 1. Under the structural conditions there indicated it is evident that if petroleum and gas occur in the dotted stratum, assumed to be a porous sandstone between two thick beds of shale, and water is present, the petroleum will accumulate beneath the anticlines, and if evaporation occurs, as is the rule, gas will be generated, and both gas and hydraulic pressure will be present. These anticlinal folds, it will be remembered, have a length usually much greater than their width, and may measure scores of miles in their various dimensions. The longer axes of the folds may be horizontal or inclined, or pitch toward one end or the other. If the axes are horizontal it is evident that a well put down anywhere along the crest of a fold, as at *b* in the above cross section, should admit of a flow of gas followed by a rise of oil in the well, or its discharge, fountain-like, at the surface, according to the pressure. Should the anticlines have a pitch, however, one end of the fold being depressed or the other elevated, with reference to a horizontal plain, then it is manifest that the petroleum and gas would be concentrated near the upper portion of the pitching anticline and the area of the resulting "pool" consequently lessened. Other complexities of structure may be present, as, for example, where one series of folds crosses another series, thus producing conditions favoring the accumulation of several relatively small pools. Sometimes the rocks, instead of being folded into long, narrow anticlines, are elevated in certain regions so as to assume dome-like forms. A broad, low dome in a series of oil and gas charged beds, with the requisite succession of porous and impervious strata, would form the ideal conditions for the concentration of the substances named.

The conditions briefly explained above form the basis of the well-known "anticlinal theory" of the occurrence of oil and gas pools, so ably worked out by Prof. Edward Orton in Ohio and Prof. I. C. White in Pennsylvania and West Virginia.

A variation of the conditions just considered occurs when the strata are gently inclined over broad areas, and the rocks are bent along certain axes without being folded so as to form true anticlines, but produce flat terrace-like areas in a region of gently-inclined beds. Such "terraces" or "arrested anticlines" occur in Ohio and have been described by Professor Orton. For example, oil-bearing rocks about 2,500 feet thick enter the Macksburg oil field, dipping gently southeast, at a rate of 20 to 30 feet to the mile, but they suddenly cease their descent and for about 3 miles there is no appreciable fall. The amount of territory included in the terrace appears to be 15 or 20 square miles. Beyond this the regular dip is resumed. It is difficult to understand how the petroleum and gas are retained in a "terrace" if it is really horizontal, but the conditions regulating the storage of these substances are so delicately adjusted that a difference of a very few feet in the height of the top of the porous layer may determine the success or failure of a well drilled to it. The difficulty of ascertaining the actual position of the surface of the porous layer when gently inclined is shown by the fact that a thickness of a thousand feet or more of overlying strata has frequently to be penetrated to reach the necessary rock. It is well known, however, that the nearly flat areas, as the drill shows them to be, in certain regions where the rocks are gently inclined in the same direction on each side, sometimes contain commercial quantities of liquid and gaseous hydrocarbons.

In the above consideration of the influence of structure and texture on the storage of petroleum and gas we have assumed that water is also present in the rocks. While this is the normal and practically universal condition, yet it may happen that water is absent from a porous layer containing the other two substances named. In the absence of water, petroleum would accumulate in the downward folds or would descend until arrested by an impervious stratum, and gas would occupy the remainder of the porous bed. An increase in the amount of gas would be accompanied by an increase in pressure. Under these scarcely to be expected conditions, a well penetrating a syncline would yield oil under gas pressure which might be great, while a well drilled in the course of an adjacent anticline would yield gas only, the oil not rising unless the relation of the well to the inclination of the porous layer was such that the oil itself could produce "hydraulic" pressure. In such a case the flow of petroleum would not be followed by water, and when the outflow ceased the well would still be filled with petroleum.

Certain modifications or limitations of the general principles above stated need to be kept in mind by persons searching for commercial supplies of petroleum and gas, lest valuable pools of exceptional character be overlooked.

One of the exceptional conditions referred to is the absence of a pervious stratum to act as a reservoir or receiver. For example, a bed of shale which is impervious to water may be of such a texture as to permit of the slow percolation of petroleum and the ready passage of gas. Should such an oil-charged shale occur in thick masses, as in the Cretaceous system in the great plateaus, without interbedded porous beds and not having an impervious cover, the gases generated would pass off, leaving heavy petroleum, which would descend to the bottom of the generating layer or until it was arrested by an impervious stratum. A well drilled in such a bed should furnish petroleum, but not under pressure. A small but long-continued yield by pumping might be expected, the petroleum slowly percolating into the well from the adjacent country rock in much the same way that an ordinary surface well is supplied with water. Under the conditions just postulated, but petroleum as well as water being absent, a well might yield a moderate but long-continued supply of gas.

Another consideration which may perhaps have economic importance is that the presence of petroleum, especially the heavier varieties, in a porous rock retards the passage of water. The outcrop of a porous bed, in which heavy oil has been produced by the evaporation of a lighter variety, might seal the pores of the rock and thus prevent the inflow of water, and therefore the cessation of the outflow of petroleum. These results might come about especially in a warm climate and modify the conditions under which petroleum and gas are usually stored. The formation of solid hydrocarbons in porous beds and in fissures is but a further step in this same direction. Bodies of petroleum-bearing sandstone or other rocks above the surface drainage of a region might, on account of the formation of viscous or solid hydrocarbons in their superficial portions, be made to yield heavy oil if penetrated by horizontal wells.

The opening of fissures communicating with the surface above an oil pool is considered fatal to it as a reservoir of commercial value, but if the oil is not under hydraulic pressure or if the pressure is not sufficient to cause it to overflow and be replaced by water, the petroleum may not rise in the fissure, or if it does rise not reach the surface, and on evaporating, seal the breach and renew the conditions favorable for natural storage. Fissures filled with solid hydrocarbons may therefore be considered as favorable indications of the presence of oil pools in their vicinity. While the conditions under which petroleum and its derivations occur in nature are simple and easily understood, the application of theory to practice is beset with difficulties and uncertainties. The information that is wanted is the texture of the rocks, the order of their occurrence, and their structure at a depth of several hundred or perhaps several thousand feet below the surface, and this, too, when the surface is usually covered with vegetation and soil, alluvial deposits, and possibly a thick sheet of glacial drift. While the geologist is better able than anyone else to judge of the conditions to be expected within the earth's crust, it must be confessed that the only practicable way to secure the desired facts in untried regions, is in many instances, to put down test wells at what seem the most favorable localities. One important duty of the geologist is to discourage ventures in regions where the rocks are so greatly disturbed and broken that gas or water-tight reservoirs can not exist, or when other conditions such as the metamorphism, preclude the probability of success. The conditions which have led to the accumulation and storage of petroleum and gas are in general the reverse of those which lead to the accumulation of water in artesian basins. The most promising localities in the search for relatively light hydrocarbon, are in upward folds or anticlines and the most favorable localities for storing water in the rocks under pressure are in downward folds or synclines. This difference in the conditions leading to accumulation of oil and water, as an effort has been made above to explain, is due to the differences in the specific gravities (or weight of equal volumes) of the substances named. If a fluid heavier than water should be present in the rocks, the other conditions considered being the same, the water would be forced upward and would accumulate in anticlines, and the most favorable localities for searching for artesian water would be in the upward folds, instead of as now, in the downward folds.

APPLICATION.

In attempting to apply the principles just considered in Idaho and Oregon, it is evident that the search for petroleum should be confined to regions where the rocks have been but moderately disturbed, and in such regions drill holes should be put down in the crests of anticlinal folds. The downward folds or synclines should be avoided, as water is everywhere present in the rocks and all the downward folds may be expected to be filled with it. Experience in southern Idaho has fully sustained these deductions, and much time and expense might have been saved if they had been given proper consideration when the search for petroleum began. All of the drill holes thus far put down with the hope of obtaining petroleum are located in broad synclinal basins, and in nearly all instances have resulted in obtaining a surface flow of water. Even after several artesian wells had been obtained, the drilling of holes for petroleum was continued in the same basin, as in Snake River Valley, between Guffey and Weiser, and uniformly with the same result. Although there has been a total failure to obtain petroleum, what in the end will prove to be a much more valuable result, so far as the development of the region is concerned, has been secured, namely, the demonstration of the value of the Lewis artesian basin.

While the region crossed by Snake River in western Idaho and the adjacent portion of Oregon, in the vicinity of Owyhee, Vale, and Ontario, is a broad syncline, nearly flat in its central portion, it does not follow that the entire region is a single great fold. There may be secondary wrinkles, and beneath the small upward folds, if such are present, petroleum and gas might occur, and be under the pressure of the water in the broader and in general trough-shaped depression.

The only locality in the Snake River Valley in western Idaho, so far as I can judge from the explorations I was enabled to make, at which one would be justified in drilling for the purpose of prospecting for petroleum, is the southern part of Canyon County, in the vicinity of Pickles Butte. I was not able to visit the region referred to, but views of it obtained from a distance suggested that the rocks there rise into a small anticline, the longer axis of which trends about northwest and northeast. A careful study of the region referred to should show whether an anticline is present or not, and if discovered a drill hole put down to a depth of 1,000 or 1,200 feet would furnish a crucial test as to the presence of petroleum or gas. So far as can be judged, the Payette formation, which, together with sheets of basalt, underlies the Snake River Plains, is notably free of organic matter, and the chances seem to be that even if anticlines or other conditions favoring the storage of petroleum or gas are present, but little hope of obtaining commercial quantities of these substances can reasonably be entertained.

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 217.]

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