STATE OF IDAHO

H. C. BALDRIDGE, Governor

BUREAU OF MINES AND GEOLOGY

ERNEST W. ELLIS, Acting Secretary

IDAHO BUREAU OF MINES AND GEOLOGY BULLETIN

ISSUED QUARTERLY—PRICE 50 CENTS

No. 13 July, 1928

CRATERS OF THE MOON NATIONAL MONUMENT, IDAHO

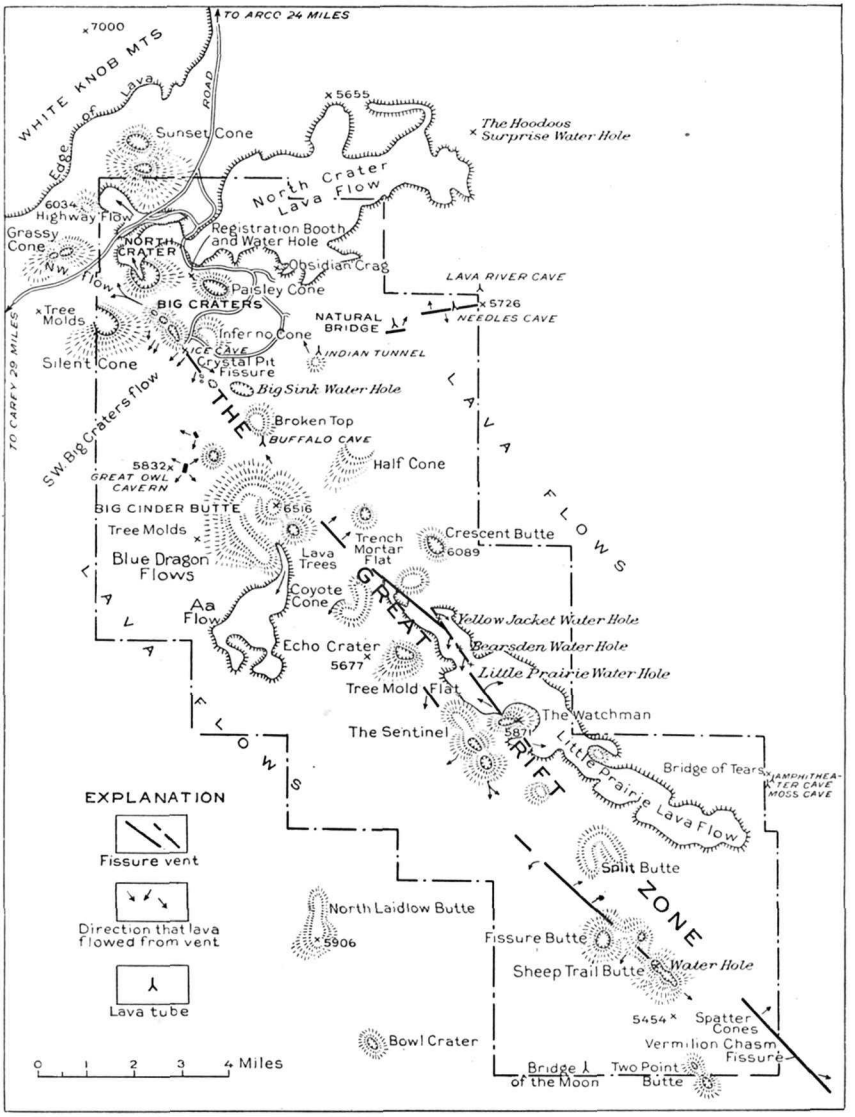
PREPARED IN COOPERATION WITH THE
UNITED STATES GEOLOGICAL SURVEY.

BY

HAROLD T. STEARNS.

UNIVERSITY OF IDAHO
MOSCOW, IDAHO

Entered as second class matter Aug. 11, 1924 at the post-office at Moscow, Idaho, under the Act of March 3, 1879.



Sketch Map of the Craters of the Moon National Monument.

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ILLUSTRATIONS.

CRATERS OF THE MOON NATIONAL MONUMENT, IDAHO

By HAROLD T. STEARNS

GENERAL VIEW OF THE AREA.

"An area of about 60 miles in diameter, where nothing meets the eye but a desolate and awful waste, where no grass grows nor water runs, and where nothing is to be seen but lava."[1] Undoubtedly Irving's description has reference to the area now known as the Craters of the Moon region of Butte and Blaine counties, Idaho. About 39 square miles[2] of this unique volcanic area was proclaimed the Craters of the Moon National Monument by President Coolidge on May 2, 1924. It is administered by the National Park Service of the Department of the Interior. The local representative is R. B. Moore, custodian of the Monument, whose address is Arco, Idaho.

The Monument is reached by a drive of 26 miles from Arco southwest along the Idaho Central Highway. It is easily accessible to tourists on the way to or from Yellowstone National Park. Upon entering the Monument the road leaves the dusty sagebrush desert and enters an area of barren black cinders and lava. Here it winds among the smooth cones and across strips of rough, fresh-looking rock. The similarity of the dark craters and the cold lava nearly destitute of vegetation to the surface of the moon as seen through a telescope gives to these peculiar features their name. The Monument comprises the most interesting and recent part of a vast lava field that covers hundreds of square miles and merges westward into the Columbia Plateau. This plateau covers about 200,000 square miles.

A marvelous view of this desolate lava waste is obtained from the summit of Big Cinder Butte, which rises to an altitude of 6,516 feet and ranks among the largest purely basaltic cinder cones of the world. To the east stretches barren black lava until it fades into the desert haze. Nothing breaks its monotony except one group of grass-covered cones which were not inundated by

1 IRVING, WASHINGTON, The adventures of Captain Bonneville, U. S. A. Hudson ed., p. 203, New York, 1868.

2 As this report goes to press the area has been increased to about 80 square miles making it the largest national monument under supervision of the National Park Service.

the floods of lava and which now stand together as a yellow island in a sea of black. Farther east rises Big Butte, the sentinel of the Snake River desert. A little beyond and to the northeast of it, seeming to float in the blue haze, are two smaller peaks known as the Twin Buttes. These peaks have been majestic watchmen on the plain since the first eruptions of lava in the Monument.

To the southeast from Big Cinder Butte extends a double line of cinder cones, many of them grass-covered and all of them vents of volcanic flows which unite farther south into one great lonely and uninhabited field of lava. Black Top Butte, the farthest in this march of cones, lies approximately 11 miles southeast of Big Cinder Butte. Still farther away are yellow grass-covered cones, and in the distance are barely discernible the snow-covered Portneuf and Bannock mountains.

Four miles to the south of Big Cinder Butte lies a chaos of cinder crags and jagged lava, surrounding a high cinder cone called North Laidlow Butte. Half a mile beyond this cone is Little Laidlow Park, a grass-covered field of ancient lava, appearing pale yellow under the bright midday sun. Farther away on the plain are low lava domes, and in the extreme distance, beyond Snake River, are pale blue mountains along the Idaho-Utah line.

To the west for about 6 miles the lava flowed against the southern spur of the White Knob Mountains, filling the valleys as if they were bays and leaving the ridges like projecting headlands in a black sea. Black and barren as it is, the lava surface has a weird scenic charm.

To the northwest there are crater pits, spatter cones, cinder cones, and lava flows, massed along the Great Rift. Many of the cinder cones are brilliant red at noon but slowly change to purple by sundown. On the tops of many of them are discernible yawning crater pits, which are especially beautiful under the lengthened purple shadows of evening. Beyond this chaotic display of volcanic features rise the granitic White Knob Mountains, covered with grass and streaked with small groves of quaking aspen, golden with autumn foliage and snuggled away in twisted ravines and canyons. Farther north are the snow-clad Sawtooth Mountains, the pride of all Idaho. This grand array of hills and mountains presents an inspiring scene and toward evening becomes pale and soft and velvety, like a staghorn in spring. To

those who tarry long these hills are "never the same, yet are always the same through each changing."

GEOLOGY

These are the Craters of the Moon as they appear today; let us turn back the pages of stone in the geologic history of this region to the time before any lava had appeared in southeastern Idaho, when the White Knob Mountains of granitic rocks, then higher than they are now, projected southward into the wide valley of the ancestral Snake River. All the rivers—Big Lost River, Little Lost River, Birch Creek, and the other streams adjacent to the area—flowed southward from the mountain canyons and joined the ancient Snake. Today these rivers sink into the lava plain at the foot of the mountains and find their way underground into the Snake River through numerous crevices and cavities in the lava.

The White Knob Mountains and their foothills slumbered peacefully and undisturbed except by stream erosion until one day, long before Egypt had a name, a tremendous fissure, now known as the Great Rift, opened on their slope. With this earth rifting there occurred a volcanic eruption that built up a long line of cinder cones, and lava flowed southward and eastward, cooling into thick, jagged flows, consisting largely of broken blocks. "Frozen" in some of these lava blocks are both large and small fragments of granitic rocks that were broken off from the roof of the lava reservoir and floated upward in the molten lava during the eruption. The lava issued at a temperature of about 2,000°F., which was too low to remelt the granitic inclusions; hence the white fragments retain their original characteristics. Numerous eruptions occurred during this epoch, but most of the flows and cones then formed are now buried by later flows. Remnants of these old cones, broken by faulting, and weathered into hoodoo-like pinnacles of cinders and spatter, form the Devil's Orchard and the field of crags south of Big Cinder Butte. In these crags occurs obsidian, or volcanic glass, which the Indians quarried to make arrow points and other implements.

For a long time the Great Rift seemed to be healed; but volcanic activity was only dormant. Eruptions broke out again with renewed vigor, and many of the large cinder cones in the chain that stretches southeastward through the center of the Monument

were formed. To this second epoch belong Sunset, Grassy, Silent, Big Cinder, Fissure, Split, and numerous other cones on the Great Rift. Most of their lava has been buried by later flows, but the cones rise above the later flows as islands. (For a list of the cinder cones giving their height and location see page 33.) The volcanic outbursts were spasmodic in occurrence but probably followed one another at short intervals. Often more than one cone was formed during a great eruption, and there is evidence that some of the cones were made by several eruptions occurring at the same place. All these manifestations of internal unrest continued throughout centuries, and the Great Rift was reopened again and again. Thus it became a great zone of weakness in the earth's crust and the center of many earthquakes.

The third and last epoch of eruption followed upon the heels of the second and may have been closely connected with it. During this epoch all the barren black lavas that are found in the area were emitted. North Crater, which is visible from the highway, was reopened and gave vent to a large billowy lava flow that moved northward and then eastward. This flow is crossed by the road leading into the Monument. Big Craters gave vent to four flows during this epoch—one to the northeast, one to the northwest, one to the west, and one to the southeast. Coincident in time with the last eruption of Big Craters the line of spatter cones along Crystal Fissure at the end of the automobile road were formed, and lava flowed eastward and westward from them. With the subsidence of the lava in the Great Rift after this eruption numerous areas on the rift collapsed, forming a chain of pit craters. Big Sink Water Hole is in one of these pit craters.

Big Cinder Butte again broke open and gave vent to a short lava flow on the north side. Two other outpourings of lava occurred in the area half a mile northwest of this breach, but the eruptions at these vents did not build cinder cones. Lava was also poured out at Indian Tunnel, at the Natural Bridge, and at Needles Cave in the area east of Inferno.

In the central part of the Monument the old cinder cone called The Watchman opened, and lava flowed out quietly from the northwest and southeast sides. Numerous other lava flows that cannot be described here occurred in the area during this time. Altogether about thirty-five cones and vents and thirty different lava flows belonging to several epochs are found in the Monument.

Many others were probably formed but have since been buried. The approximate eruptive sequence of the principal lava flows in the area is given on page 32.

NON-VIOLENT ERUPTIONS.

Many visitors to the Craters of the Moon talk about the tremendous catastrophe or awful convulsion that must have occurred in the area, but the writer found no evidence of any great explosive eruption such as occurred at Krakatoa, near Java, in 1883; at Vesuvius, in Italy, in 1906; or at Katmai, in Alaska, in 1912—tremendous explosions which spread volcanic dust for hundreds of miles. Such eruptions as these usually cause great loss of life and property. The dust from the eruption of Krakatoa was carried by winds around the earth and fell on the housetops in London. The brilliant sunsets that followed the eruption of Katmai were caused by particles of volcanic dust in the atmosphere. The character of the ejecta in this area, however, shows that the effects of the eruptions from the Craters of the Moon were relatively insignificant and were confined to the area inundated by the lava flows or adjacent to the cinder cones. The volcanic outbreaks in the Monument were all of the so-called quiet type, like those that occur at intervals at Kilauea and Mauna Loa, in Hawaii. For example, should a similar eruption occur at the Craters of the Moon tomorrow, it would be possible to stand with safety less than half a mile from the windward side of a cinder cone in eruption and to approach within a few feet of a lava flow in motion. During his visit to Vesuvius the writer descended into the crater and took photographs less than 50 feet from a spatter cone that was about 50 feet high and was hurling out clots of molten lava every three minutes. The lava flow on which he stood had been poured out only two weeks before, and paper would catch fire from the heat in the cracks of the lava crust. This spatter cone was very similar in shape to those in the row extending southeastward from Big Craters at the end of the automobile road.

The mechanism of a volcanic eruption of the type that occurred in this area may well be compared to the opening of a beer bottle. The liquid remains quietly under pressure within its bottle walls, but when the cork is removed the pressure is released and the included gas expands, causing the contents to

foam and to overflow the neck of the bottle. The first foam that runs over consists of large bubbles, but as the foaming diminishes the bubbles decrease in size, and some of the liquid runs out. However, all of the gas does not escape during the foaming period, for gas will continue to rise in the liquid for a considerable time thereafter. Like the fluid in the bottle, the magma, as the molten lava with all its included gases is called, rests in an underground reservoir surrounded by strong rock walls. It may remain in this natural container at or about the same place for a long period of time, until some force cracks open the earth's crust above the reservoir, thereby releasing the included gases. The weight of several miles of the earth's crust is immense, but as the molten magma ascends in the crack the pressure upon it becomes less and less. The included gases continue to expand as the magma rises, and when it reaches the surface there may be a tremendous foaming and frothing of the lava column. It is during this period of foaming that the cinder cones are built, the cinders being the hardened froth. After the period of intense foaming the gas bubbles decrease in size, and the heavier lava clots or spatter are thrown out. During the spatter stage or soon after it, the lava rises in the crater and either flows over the rim or escapes through a crack in the side or at the base of the cone. Like the liquid beer after the foaming period, the lava still contains considerable gas, and it is the escape of this gas as the lava hardens that forms the vesicles, or bubble-shaped holes, in the lava.

TYPES OF LAVA.

Many kinds of lava have been poured out on the surface of the earth, but they all fall into three main classes or types. One type, known as rhyolite, is poor in iron but rich in silica and consequently light-colored. It is the common lava of Yellowstone Park, and this rock and its decomposition products give the magnificent colors shown in the Grand Canyon of Yellowstone River. Another type of lava, known as andesite, is of intermediate composition, containing moderate amounts of both iron and silica, and is usually gray. This rock forms a considerable part of the volcano of Lassen Peak, California, and the lava extruded from this volcano in 1915 was an andesite. The third type, which is rich in iron and poor in silica, is called basalt. This is a dark-colored rock. It covers the Snake River Plains, forms the rim

rock along Snake River, and is the rock commonly known as lava in the Northwest. It is the only type of lava known to occur in the Craters of the Moon.

Because of the numerous queries of visitors to the Craters of the Moon as to the composition of the lava, an analysis, made by the United States Geological Survey, of a specimen of basalt collected by I. C. Russell near Big Cinder Butte is given below:

ANALYSIS OF RECENT LAVA FROM THE BIG CINDER BUTTE FLOW, CRATERS OF THE MOON NATIONAL MONUMENT, IDAHO.

[Analyst, W. F. Hillebrand.]

	Per cent
Silica	51.14
Titanium dioxide	2.41
Zirconium dioxide	.12
Alumina	13.95
Chromic oxide	None
Vanadium trioxide	Trace
Ferric (iron) oxide	2.15
Ferrous (iron) oxide	12.97
Manganous oxide	.44
Nickelous oxide	Trace
Calcium oxide	6.56
Strontium oxide	Trace
Barium oxide	.25
Magnesium oxide	2.21
Potassium oxide	2.33
Sodium oxide	3.59
Water below 105° Centigrade	.12
Water above 105° Centigrade	.22
Phosphoric oxide	1.59
Carbon dioxide	None
Chlorine	Trace
Fluorine	.10
Iron dissulphide	.15
	100.30
Less oxygen computed in place of fluorine	.04
Total	100.26

Specific gravity 2.907 at 24° C.

PAHOEHOE AND AA LAVA FLOWS

In physical characteristics the lava flows that occur in the Craters of the Moon belong to two distinct types known by the names of pahoehoe (pah-hoe'ay-hoe'ay) and aa (ah'ah). These terms are the native words used in Hawaii, where the two types were early distinguished.

Pahoehoe, which covers about half the area of the Monument, is a billowy, ropy type of lava that is filled with caverns. Its shiny blue glassy crusts make some of the flows extremely beautiful in brilliant sunlight. The ropy and wrinkled surfaces of the pahoehoe are due to the hardening of a thin crust or scum on the lava flow while the crust is being pushed forward by the flowing lava below. This motion causes the scum to wrinkle and fold very much like molasses poured from a jug on a cold winter day.

The numerous caverns that are found in the Craters of the Moon all occur in the pahoehoe lava. They are formed within the flow itself by the hardening of the surface of a lava stream. As the flow continues the side walls also stiffen and a tube is formed. The main tube forks and reforks and the lava is conducted without much loss of heat to the advancing margin of the flow through this set of ramifying tubes, which extend away from the vent in a sort of great subway system. As the slope of the land is not very steep in the Monument, only the upper or source ends of the tubes were drained out when the lava ceased flowing. A list of the principal lava tubes and their location is given on page 33. Indian Tunnel, Great Owl Cavern, and Buffalo Caves show lava stalactites formed by the dripping of the hot lava from the roof. On the walls are hardened trickles of lava. The narrow ledges parallel to the floor of the caverns are the shore lines of a subsiding river of lava. On the floor the last stream of lava with its ropy and twisted surface is usually visible. When the lava flows out of the tube there are many portions of the roof that are unstable and collapse or are shaken down by earthquakes accompanying some of the later eruptions. The natural bridges are small remnants of the tunnel roof that are left standing; the portions that are roofed over for longer distances form the caverns. The location and size of the large bridges are given on page 33.

While chemically like pahoehoe, aa lava is not smooth and billowy but is rough, jagged, and spiny. It appears to owe its origin to a different combination of gas and heat. It has been established that an aa lava stream never changes into pahoehoe although in many cases pahoehoe flows far away from their sources have changed into aa. In a few cases on record vents have given forth first pahoehoe, then aa, and finally pahoehoe again. This alternation of the kinds of lava arriving at a vent suggests that the same causes which operate on the surface may also operate in the lava conduit. These causes have not yet been definitely determined but field evidence seems to indicate that there are differences in the amorphous glassiness, heat and gas content of the aa as compared with the pahoehoe. It is the escaping gas from the doughy mass which pulls out stringers of lava and causes the spines on the aa lava. It is usually difficult for the visitor to understand how such a great jumbled

mass of lava clinkers ever could have flowed. The explanation is that the lava was in a pasty condition while in motion and floated this broken material along on its surface, continually furnishing more clinkers to the heap by granulation. Some of the fragments are pushed and rolled at the margin of the flow, and others are dragged along under the lava. The whole flow resembles slush ice in a river in the spring of the year. The Monument contains aa lava flows 25 to 100 feet thick, some of which have moved several miles out on the plain.

TYPES OF CONES

There are three different types of cones in the area—cinder cones, spatter cones, and lava cones. The cinder cones, with black, loose cindery surfaces and smooth conical profiles, are familiar to everyone who has visited the Monument. They are heaps of the lava froth or spray formed by the fire fountains that played at the time of the eruptions. Big Cinder Butte is the finest example in the area. The cinder cones, especially those in the northern part of the Monument, are elongated toward the northeast. They owe this unsymmetrical form to strong southwest winds that blew during the eruption, piling more of the cinders and lapilli on one side of the cones. Grassy Cone, North Crater Butte, and Silent Cone are all about 450 feet high. Grassy Cone is unlike its neighbors, however, in that it appears to have been formed during one great eruption. The length of time required to form this particular cone by a single eruption is of course unknown, but an interesting comparison of its size with that of a cone of the same type that has been formed elsewhere in historic time may throw some light on the subject. A little to the west of Pozzuoli, on the shore of the Bay of Naples, not far from the village of Baja, is a conical hill, composed of black cinders, which rises 440 feet above the adjacent waters of the bay. There is conclusive evidence that prior to 1538 the site of this cone was partly occupied by Lake Lucrine. The recent origin of the hill is indicated in its name, Monte Nuovo ("new mountain"). When visited by the writer in 1925 it supported a considerable growth of vegetation and resembled Grassy Cone in many respects. This cone covers an area of more than half a square mile and is comparable in volume to Grassy Cone. According to contemporary records based on testimony of eye-

witnesses, the adjacent region was affected by earthquakes for more than two years, and on September 27 and 28, 1538, the shocks occurred with maximum frequency and intensity. Judd[1] says:

"About 8 o'clock on the morning of the 29th a depression of the ground was noticed on the site of the future hill, and from this depression water, which was at first cold and afterward tepid, began to issue. Four hours afterward the ground was seen to swell up and open, forming a gaping fissure, within which incandescent matter was visible. From this fissure numerous masses of stone, some of them 'as large as an ox,' with vast quantities of pumice and mud, were thrown up to a great height, and these falling upon the sides of the vent formed a great mound. This violent ejection of materials continued for two days and nights, and on the third day a very considerable hill was seen to have been built up by the falling fragments, and this hill was climbed by some of the eye-witnesses of the eruption. The next day the ejections were resumed, and many persons who had ventured on the hill were injured and several killed by the falling stones. The later ejections were, however, of less violence than the earlier ones and seem to have died out on the seventh or eighth day after the beginning of the outburst. The great mass of this considerable hill would appear, according to the accounts which have been preserved, to have been built up by the materials which were ejected during two days and nights."

Spatter cones are formed by the smaller fire fountains. The clots of lava hurled out by these fountains were not sufficiently inflated with gas to form cinders and moved so slowly and through distances so short that instead of landing as cold cinders they fell as clots in a viscous state and adhered to one another. They built up rather steep-sided cones of small height and diameter. The line of spatter cones extending southeastward from the end of the automobile road, all of which are less than 50 feet high and 100 feet in diameter, is one of the most perfect spatter-cone chains in the world.

The third type of cone found in the Craters of the Moon, but observed by very few visitors, is the lava cone, or, more properly, the lava dome. Some of these domes are surmounted by tiny spatter cones less than 10 feet high. Lava domes differ from spatter and cinder cones in that they consist of compact lava and have a broad, flat dome shape, many of them rising only 30 to 50 feet above the surrounding country. These inconspicuous domes are formed by the continuous quiet welling out of pahoehoe lava on the surface from the same point. Because most of the lava escapes through tubes the cone is not built up very high. Great Owl Cavern, Indian Tunnel, and Needles Cave mark the sites of some of these lava domes. In size and shape and in the character of the lava extruded from it the Needles Cave dome closely resembles the dome of Maunaiki, which was formed in 1920 on

1 Judd, J. W., Volcanoes, pp. 76-77, New York, 1881.

Kilauea Volcano, Hawaii. In the early part of December, 1919, numerous cracks opened on the southwest slope of Kilauea, and on December 21 lava welled out from one of the cracks. The stream of lava from this vent continued until July 28, 1920,[1] and formed a flow 6 miles long and about half a mile wide. Part of the lava was pahoehoe, and part was aa. The fissure from which the lava issued was buried by the flow, and a lava dome 70 feet high and 1 mile across was developed over the fissure. On the summit of the dome is a small pit about 30 feet in diameter and 20 feet deep, due to the collapse that followed the eruption. This depression is smaller and less conspicuous than the one near by formed by the collapse of the roof of the lava tube through which most of the lava escaped. If this eruption had not been witnessed no one would have surmised that the lava welled out of a fissure about half a mile long. During this eruption lava escaped from four other fissures on the slope of Kilauea and formed small isolated patches of lava and another small lava dome.[2]

BOMBS.

Probably the most curious of all the lava features that are found in the Monument are the lava bombs that lie scattered on the cinder and spatter cones. These bombs range in length from half an inch to more than 13 feet and in diameter from a quarter of an inch to 3 feet. There are three classes of bombs—spindle bombs, ribbon bombs, and bread-crust bombs. Spindle bombs are those that have tapering projections on the ends of a football-shaped body. These bombs owe their origin to a clot of lava being hurled through the air with a rotational or spiral motion. Most of the best-formed bombs found by the writer were very close to their source, indicating that their flight was of short duration. Some of these bombs had long, tapering twisted ends that projected 3 to 10 inches from the main part. These long, thin strips of lava were broken off by the fall of the projectile and lie scattered on the surface. They are called ribbon bombs because of their shape. Some of the ribbon bombs owe their origin to the pulling apart of two clots of lava which traveled at a slightly different speed or in slightly different directions.

1 Hawaiian Vol. Observatory Monthly Bull., vols. 7 and 8, 1919-20.

2 Stearns, H. T., and Clark, W. O., Geology and water resources of the Kau District, Hawaii: U. S. Geol. Survey Water-Supply Paper (in preparation).

The longer ribbon bombs, such as those 2 to 13 feet in length and only a few inches wide, seem to have originated in one of two different ways. A few of them are simply lava clots that landed on the side of a cone and ran down the slope while still plastic. Weathering and the removal of the cinders adjacent to some of these long lava trickles have caused them to become detached and to lie loose on the surface like bombs. Other ribbon bombs are formed by the throwing out from a spatter or cinder cone of a large clot of very liquid lava that stretches out during its flight and falls on cinders sufficiently loose to prevent its breaking into pieces.

Bombs of a third kind are light and porous and covered with a crust or skin that resembles the crust of bread. These are known as bread-crust bombs. They are formed by a clot of lava filled with gas being hurled through the air. During its flight a skin or crust forms on the clot, and as the bomb swells owing to expansion of the included gases the skin is cracked open in many places, producing a number of small checks on the surface. In baking bread the same process can be observed. First a thin crust bakes, and then, as the gases from the yeast expand, the loaf swells and the crust is broken, showing numerous small cracks.

TREE MOLDS.

Tree molds exist in certain lava flows in the Craters of the Moon where the lava flowed slowly and at the right temperature into a forest. When the charred or partly burned wood rotted away the hole formed a perfect mold of the part of the upright tree and the branches that were buried by the lava. The tree molds range in diameter from a few inches to 3 feet and are easily distinguished from other holes in the lava because they retain the form of the tree and its branches. Many of them are 10 to 20 feet deep, the depth depending upon the thickness of the lava that surrounded the tree and the amount of rock or cinders that have fallen or blown into the mold since it was formed. The explanation why molten lava does not completely obliterate a tree is apparent to one who understands the characteristics of lava flows. It is possible to walk on a pahoehoe a short time after it crusts over and while there is still molten lava beneath, because a few inches of the lava crust cools rapidly

and is sufficient to prevent any great amount of heat from escaping. This fact is easily demonstrated by applying a hot blast from a blacksmith's forge on one side of a 4-inch crust of lava. Moreover, liquid lava at or near the temperature of solidification requires very little time to become a rock that is a poor conductor of heat. Thus within a few minutes lava that surrounds a tree becomes a shell of solid rock. Moreover, the burning started by the hot lava creates an air space or chamber between the tree and the mold which accelerates the cooling of the lava. The cooling process is further aided by the steam emitted from the sap of the tree. The writer saw trees in Hawaii which two years after they had been partly buried by lava had their upper portions uncharred and had dead leaves clinging to the branches. There is much less chance for the formation of a mold from a dead tree, for it burns so rapidly that it may be completely destroyed while the lava is still plastic.

Most of the vertical tree molds do not preserve charcoal impressions, but in some places where the tops of the trees fell on plastic lava the impression of the charred log and the delicate grain of the wood have been preserved. In places the lava was soft enough or was rendered plastic enough by the steam from the burning wood to flow into the checks or shrinkage cracks in the charred surface of the log, forming a checker pattern that is easily mistaken for bark impressions. Practically all the tree molds in the Monument were examined, but not one was found that showed bark impressions. The principal localities where tree molds have been found are given on page 34.

There are two kinds of tree molds in the area. Those of one kind, called lava trees, are common on Trench Mortar Flat southeast of Big Craters Butte. These trees rise 1 to 5 feet above the lava surface. Lava trees are formed in the same manner as the tree molds just described but in localities favorable to the draining away of part of the lava flow, or they are due to trees being buried by spatter from a spatter vent. There are in Hawaii lava trees 40 feet high which consist of thin shells of lava surrounding charred remnants of trees. The other kind is represented by the tree molds of simple type that extend downward into the lava flow. The top of the tree is sometimes found molded near by on the lava surface.

During the eruption of Etna in 1865 the lava entered a pine forest. The results of this invasion are described by Reclus[1] as follows:

"Sheaths of solidified lava were surrounding the trunks of pines, and thus showing the height to which the current of molten stone had reached. * * * Below the escarpments of the Frumento, the torrent, which was there retarded in its progress, had not contented itself with bathing for a moment the trunks of the forest trees but had laid them low. Great trunks of trees, broken down by the lava, lay stretched in disorder on the uneven bed of the stream, and, although they were only separated from the molten matter by a crust a few inches thick, numbers of them were still clothed with their bark; several had even preserved their branches. At the edge of the cheire[2] some pine trees, which had perhaps been preserved from the fire by their moisture being converted by heat into a kind of coating by steam, were surrounded by a wall of heaped-up lava, and their foliage still continued green; it could not yet be ascertained if the sources of the sap had perished in their roots. In some places rows of firs very close together were sufficient to change the direction of the flow and to cause a lateral deviation."

UNUSUAL OCCURRENCE OF WATER.

The visitor to the Craters of the Moon on a hot July day is amazed at the ice-cold water found in the most unexpected places. The temperature of the water rarely exceeds 34°F. There are three kinds of places where water or ice is found. Most of the large water holes occur in depressions in very rough, broken lava. In these depressions a considerable amount of snow collects in winter. Some of it sifts down into the crevices between the rocks and remains sheltered from the hot atmosphere during the long summer days. In addition, water during the thawing periods in the autumn or spring may drip downward into the crevices, where it is frozen by cold circulating air. During the long cold winters ice forms. Some of it melts in the summer, but in favored locations it never melts entirely away. Just as the solid lava is a poor conductor for the upward movement of heat from molten lava beneath, so it is a poor conductor for the downward passage of heat from the sun. Usually a small amount of the ice melts during the summer and forms a pool of water. On digging down into the loose rock in a water hole of this type, ice will always be found beneath the water.

Water and ice also occur in the lava caves or tubes where drafts of cold air freeze any water that percolates into them. The freezing period covers about seven months in the year, and during the remaining months there is a gradual wasting away of the ice.

1 Reclus, Elisee, The Earth, vol. 2, p. 495, New York, G. P. Putnam & Sons, 1871.
2 French for aa lava.

Even during the summer days the temperature of the interior of the caves does not rise above 40°F.; hence melting proceeds very slowly. Ice and water are also found in the deep inverted-funnel craters of the spatter cones, such as the Ice Cave. In occurrences of this type the snow accumulates in the crater during the winter and is exposed to the direct rays of the sun for only a short time each day. Thus, there results a continually increasing heap of ice. The Ice Cave, near the end of the road, is of this type and contains a heap of ice and snow about 20 feet thick. The locations of the perennial water holes are given on page 34.

Many people imagine that some uncanny, mysterious method accounts for the formation of the ice, such as impossible chemical reactions and queer volcanic phenomena. On the active volcano of Kilauea, Hawaii, where thousands of similar caves occur and where immense quantities of rain fall, no ice occurs in the caves, but the explanation is apparent, for Kilauea has neither snow nor freezing temperature. On the other hand, Mauna Loa Volcano, which rises nearly 14,000 feet above the sea, into the snow zone, contains numerous ice caves in and near the crater, and many of them are only a stone's throw from a steam vent. Ice caves do not occur anywhere in the world except where there are freezing temperatures during some part of the year.

The lava in the Craters of the Moon is so extensively fissured that no water is found in it throughout the year except where the water is perched upon an impermeable body of ice.

AGE OF THE FLOWS.

Everyone who visits the Craters of the Moon is impressed with the freshness and barrenness of the black lava flows. However, the longer the visitor remains and wanders over the lava fields the more he is impressed with the time that must have elapsed since the last eruption. The absence of soil on many of the flows is easily accounted for. All the fine dust that falls on the lava surface or results from the weathering of the crusts is blown off or sifts into adjacent cracks. This hidden soil accounts for the presence of the numerous shrubs and pines that have taken root in crevices where no soil is visible. In Hawaii many of the historic lava flows are covered with vegetation, but in the desert area on the southwest slope of Kilauea both historic and prehistoric lava flows appear equally fresh to the eye and are abso-

lutely devoid of vegetation. In the Kau Desert the growing season is the full twelve months, and the plants growing in the area are adapted by age-long selection to growing on lava rocks.

In the Craters of the Moon the vegetation has a growing season of about four months and is poorly adapted to its environment. The writer found a limber pine that had been growing in the Big Craters lava flow, which appears as black and recent as any other in the Monument. The pine took root in one of the cracks near the edge of the flow, and it had favorable conditions for growth, because the roots found their way downward into the soil beneath. This tree has fresh black lava of the Big Craters flow actually touching the trunk 2 feet above its base, and the tongue of pahoehoe in which the tree grew is split open and wedged apart by the roots. This "age tree," as it may be called, because it afforded a measurement of the minimum age of the lava, was 34½ inches in diameter and was judged to have been dead only two or three years because of the pine needles still clinging to the branches. It was probably killed by lightning, as it showed a scar where a strip of bark about 4 inches wide was peeled off from top to bottom. It was perfectly sound and showed no burning scars nor any indications of fire. A count of the annular rings of this tree shows that it lived 461 years and hence was a good-sized tree before the discovery of America. Other larger trees rotting on the lava surface near by may have been dead a hundred years. This lava was certainly extruded before these trees came into existence.

It is interesting to note Russell's impressions of the age of the flows a quarter of a century ago. He states:[1]

"No positive evidence was obtained to show that the dead trees which occur along their borders in certain instances were killed by their heat. The remnants of the craters from which the lava was poured out are tree clothed, and on the supposition that the lava outflows immediately followed the explosive eruptions which built the craters, the lava is older than the trees, many of which are fully 20 inches or 2 feet in diameter. Although it is impossible to make a well-founded estimate of the time that has elapsed since the last eruption, it seems probable that it is no more than 100 or possibly 150 years."

Had Russell cut down one of these 20-inch pines that he saw growing on the cones in 1902 he would have been surprised at their great age, for limber pines with a diameter of 20 inches would range in age from 250 to 300 years. Thus the basis of his estimate

1 Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 105, 1902.

of the age of the lava flows is in error. The writer found trees 24 to 30 inches in diameter lying on the surface of the cones. The advanced stage of decay of many of these trees indicates that they died possibly a hundred years ago; hence even the youngest cones in the area are well over 400 years old. It must take considerable time for vegetation to start on a newly formed cinder cone in this semiarid region, in which only scattered growths of trees occur to provide the necessary seeds.

The charred trees on the cinder cones and at the edge of the flows which Russell mentions were carefully examined by the writer. They bear unmistakable evidence of having been burned by a brush fire set by lightning or by man. None of them were killed by the lava or by hot cinders. Several of the largest trees that grew at the edge of the lava with their trunks touching the rock are burned only on the side away from the lava, indicating that the fire spread through brush on the cinders. Some isolated charred trees standing on barren cinders were also burned by brush fires. The ashes of the brush disappeared, leaving barren stretches of cinders between the trees. Hence, it is not permissible to conclude, as some have done, that such trees were burned by the heat from the lavas.

Resting upon the Big Craters flow on which the "age tree" grew is the glistening pahoehoe from North Crater. It has been established that this last lava flow from North Crater was not extruded immediately after the formation of the cone, as Russell supposed. However, it could not be definitely ascertained whether the black cinders on the surface of this cone were ejected after the formation of the main bulk of the cone and immediately before the eruption of the last lava from North Crater. If the vegetation on this cone was able to survive the last eruption then the vegetation which indicates that the cone is at least 400 years old is not an index to the age of the last eruption. It is therefore obvious that if the last eruption was not accompanied by the usual "fire fountains," then the lava could be either younger or older than this vegetation. There are absolutely no indications that lava has been extruded in the last century in the Monument, and the writer believes from a comparison of the flows that the last volcanic eruption occurred more than 250 years, but perhaps not more than 1000 years ago.

EARLY EXPLORATION AND INDIAN HISTORY

In 1879 Mr. J. W. Powell, formerly of Arco, Idaho, but now residing in Long Beach, Calif., visited this area. Having been offered a substantial reward for the discovery of sufficient water to supply several hundred head of cattle, Mr. Powell and Arthur Ferris explored in the early eighties the lava beds even beyond what is now the south boundary of the Monument. They were probably the first white men to visit the interior of this expanse of lava. A large stone marker built by Mr. Powell on this trip still stands near the water hole in Vermilion Chasm. A shoulder bone of a cow was found in 1926 in Buffalo Caves with the names of these two men and the date 1885 written on it. The writer visited Mr. Powell in 1926 and was surprised by his remarkable memory of the principal features in the area. Mr. Powell stated that in 1879 he interviewed Major Jim, a Bannock Indian scout, who spoke English well, regarding the time of the last eruption in the area. Major Jim replied that his great great great great father saw fire in the region. On the basis of this statement the last eruption occurred in the early part of the seventeenth century. It is not impossible that an eruption occurred in the area at that time, but it is as likely that a fumarole or steam vent could have been considered fire by the Indian. That the Shoshone Indians frequented the area is shown by the fact that during the writer's investigation hunting blinds were found in the Little Prairie aa flow on the south side of The Watchman and several obsidian arrowheads, scrapers, and other artifacts were gathered. Mr. Era Martin found a nearly complete pottery bowl near Echo Crater, and near Indian Tunnel the crescentic rock heaps that weighted down the Indian tepees can still be seen.

Furthermore, at the north entrance to the Monument, in the cinders near the edge of the North Crater flow, there formerly existed several artificial mounds that are now nearly destroyed. These mounds have been opened by several persons, but no human remains have been found in them. They consist of cinders and sagebrush in alternate layers, and it is stated by one of the Indians living on the Fort Hall Reservation that mounds of this type were used to indicate trail directions. It is said that the sagebrush was laid lengthwise in the direction of the trail, which is now faintly discernible across the lava to the southeast.

Dim trails probably used by Indians and animals alike can be discerned here and there in the cinders or in the loose material on the surface of some of the lava flows. Three or four moss-covered pieces of lava rock or cinders piled on a prominent point may mark a trail or water hole, but the large conspicuous monuments have all been erected by white persons. Because Indians frequented the region for hunting or took refuge from enemies in the numerous caves and craters, it is probable that the ancestors of the modern Indian witnessed eruptions in the area. However, to attempt to fix the date of an eruption on the basis of Indian tradition may lead to serious error. Everyone who has traveled among primitive tribes is aware of the amazing ability of such people to invent stories to explain everything to the satisfaction of the questioner. A good example of the imaginative character of some of the Indian legends is their story that a hard ledge of rock in Columbia River is the wreck of an ancient bridge built by some of their ancestors. The Indians doubtless recognized from its appearance that the lava had once been molten and hot, and hence they may not have been slow in inventing a story regarding it.

FUTURE VOLCANIC ACTIVITY

So numerous have been the eruptions along the Great Rift that the rift might be likened to a great elongated volcano without a central orifice. It seems safe to predict that another eruption may occur in this area in the not too far distant future. The period covered by the history of our country is extremely short. Before 1914 Lassen Peak was cited in several books as an example of an extinct volcano in the United States, yet in 1914 and 1915 gigantic explosions occurred there. If these same explosions had occurred in a thickly settled part of our country they might have completely obliterated cities and killed thousands of people. Thus it is impossible to say whether a volcano is extinct or only dormant. It seems unlikely that on the Snake River Plateau, where thousands of volcanic outbursts have occurred during long ages and up to very recent time, all the volcanoes should have become extinct in this last moment of time. Instead, it appears that we happen to be living in a period of repose. The next eruption may come without any appreciable warning, although it is likely to be preceded by earthquakes. The great lava plains of

Idaho, however, are very thinly settled; hence an eruption would not be likely to cause any loss of life or to destroy any great amount of property.

ACKNOWLEDGMENTS

The writer's appreciation of the warm hospitality and tireless efforts of S. A. Paisley, former custodian of the Monument, can not be too strongly expressed. Mr. Paisley accompanied the writer on many long and tedious trips across the lava beds, without recompense, in order that the less obvious, though no less interesting, features of the area could be described in this paper. During the last ten years he spent much time exploring the area, and many of the caves and water holes were discovered by him. Thanks are due to Mr. and Mrs. Era Martin for hospitality on this trip and during a previous visit to the area. Mr. Martin furnished valuable information on the early history of the area. Acknowledgments are also due to the people of Arco for their cooperation and especially to C. A. Bottolfsen, Editor of the *Arco Advertiser*.

The geologic work was greatly facilitated by the excellent topographic map made by Max J. Gleissner. This map will be published separately by the United States Geological Survey.

The writer is indebted to Dr. Norah D. Stearns for her helpful criticism of this paper, which was the more valuable because of her personal knowledge of the area; also to Dr. F. E. Wright and to several members of the Geological Survey for helpful criticism.

APPENDIX

FAUNA

The birds that are known to inhabit the area are given in the following list. This list is not complete, for doubtless many other birds visit the area in certain seasons of the year.

1. Mallard *(Anas platyrhynchos)*. In flight.
2. Geese. Variety unknown. In flight.
3. Killdeer *(Oxyechus vociferus)*. Frequents water holes.
4. Sage grouse *(Centrocercus urophasianus)*.
5. Mourning dove *(Zenaidura macroura carolinensis)*.
6. Western goshawk *(Astur atricapillus striatulus)*. Nests on top of crater rims.
7. Western redtail hawk *(Buteo borealis calurus)*.
8. Red-bellied hawk *(Buteo lineatus elegans)*.
9. Black hawk (perhaps *Bueto abbregiatus*, but has no white bands on tail).
10. Golden eagle *(Aquila chrysaetos)*.
11. Bald eagle *(Haliaetus leucocephalus)*.
12. Sparrow hawk (not identified, perhaps *Falco columbarius)*.
13. Screech owl *(Otus asio asio)*. Reported.
14. Western horned owl *(Bubo virginianus pallescens)*.
15. Clarke nutcracker *(Nucifraga columbiana)*.
16. Red-headed woodpecker. Reported.
17. Yellow hammer. Reported.
18. Western nighthawk *(Chordeiles virginianus henryi)*.
19. American magpie *(Pecappica hudsonia)*.
20. American raven *(Corvus corax sinuatus)*.
21. Crow *(Corvus brachyrhynchos)*.
22. Western meadowlark *(Sturnella neglecta)*.
23. Loggerhead shrike *(Lanius ludovicianus)*. Frequently seen sitting on sagebrush.
24. Mountain bluebird *(Sialia currucoides)*.

The first impression received by a casual visitor to the area is that animal life shuns the lavas. However, numerous mammals live in the area; the common varieties are listed below:

1. Coyote.
2. Pack rat.
3. Porcupine.
4. Chipmunk.
5. Pocket gopher.
6. Black-tailed jack rabbit.
7. Cottontail rabbit.
8. Rock rabbit.
9. Snowshoe rabbit.
10. Rock chuck.
11. Bobcat.
12. Bat.
13. Skunk.
14. Pine squirrel.

Mr. S. A. Paisley reports that a small red fox also inhabits the area. One bat caught in Needles Cave was identified by Mr. Gerrit S. Miller, jr., curator of mammals, Smithsonian Institution, as a big-eared bat *(corynorhinus rafinesquii pallescens)*. Other varieties also may live in the caves, although none were found. The lava caves are favorite places for bear to hibernate, but the number that visit the area has rapidly decreased in the last

decade. Mr. Era Martin reports that he killed several grizzly and black bears in the area some time ago. The bear cage near the automobile road was hauled in to trap a bear alive for a circus. It is stated by Mr. Martin that no bear was ever caught in it, although a bear removed the bait on several occasions. It is now the object of considerable curiosity. During the investigation numerous bear dens were found in such caves as Sunbear Cave and Moss Cave. In these two caves shallow saucer-shaped bear-beds were found in the ash on the floors. The wild parsnip on the cinder cones in the lower part of the Monument is their favorite food, and at the time of his early visits to the area the writer saw acres of these parsnips that had been pulled and dug up by rooting bear.

The skulls of antelope and mountain sheep are occasionally seen among the lavas bleaching in the sun. Formerly these animals wintered in the area. According to a statement by Mr. S. A. Paisley, a buffalo horn was found in Buffalo Caves. During the autumn of 1926 a buck, doe, and fawn lived in the timber in the crater of Sunset Cone. Several decades ago the number that ranged in the Monument was much larger. Under the protection of the National Park Service more may take refuge in the Monument. Conies are reported to inhabit the rock ledges of the craters. The little chipmunks are great travelers, for they are often seen half a mile or more out in the roughest and freshest lava away from all visible food supplies. The pack rats likewise cross the roughest lavas and inhabit the principal caves. Mr. Paisley found their nests in the bottom of Crystal Pit, one of the spatter cones at the end of the road, 80 feet below the rim of the crater. Doubtless the rats find their way into this abyss through crevices or tubes at the base of the cone. No snakes—not even the desert rattler—are found in the Monument, although they are sometimes seen at the margins of the lava beds outside. It is thought by many that the skin of snakes is not sufficiently tough to withstand travel across the rough and jagged lava.

FLORA

BY MARIE McELREATH

The scenery of the Craters of the Moon National Monument is so vastly different from that of the national parks that the tourist naturally wonders if the flowers are not different also.

The flowers are not essentially different from those in other parts of the West but their variety in this place is unusually large as compared with the remainder of Snake River desert, and the contrast of them among the black, brown, and red cinders, and the bare-looking lava flows, is striking and unexpected. The usual green of the short spring, which is characteristic of the semi arid plain, is lacking in this area of black lava flows. However, for a short period much of the area of the cinders is carpeted with white bitter root and red monkey flowers. The beauty of the blossoms of these short stemmed plants, practically obscure and often passed unnoticed at other times of the year, is accentuated by the black and drab background. Later in the hot summer when one is tramping across the fields of lava, one is agreeably surprised at suddenly coming upon the profusely blooming mock orange, clinging tenaciously to the otherwise bare lavas, or, being confronted by a deep crack, to find growing in its shady recess a beautifully green and dainty fern. On every hand are striking examples of the struggle to heal and conceal this great black scar on the face of the earth.

The trees are dwarfed because of the unfavorable conditions under which they grow. Three species are found in the Craters of the Moon but the visitor who motors around the loop road will probably see only one, the limber pine, *Pinus flexilus.* It seems better adapted to growing on the cinders than on the lava. Small stands of quaking aspen, *Populus tremuloides,* grow on the slopes of Big Cinder and Fissure Buttes where the snow lies late in the spring. The other tree, western or red juniper, *Juniperus occidentale,* is found on the lava flows at the southern end of the Monument but it is not abundant. The mistletoe that is found clinging to the limber pine is a small, scarcely noticeable, yellow-green plant, and not the white-berried and broad-leaved variety of the southern states.

If one visits the Craters of the Moon in July he is surprised at the abundance of blossoms. The mock orange, *Philadelphius Lewisii,* the state flower of Idaho, is found in the deep crevices of the lava. It is a small shrub but profuse in its blossoming. *Purshiana tridentata,* sometimes called buck brush, a shrub with dark green trilobate leaves, yellow flowers, and a rounded fruit, pointed at the tip, is the most abundant of the shrubs. Another conspicuous shrub is *Sericotheca glabrescens (Chamaebatiaria*

millefolium), mountain spray. It has a viscid stem and leaves and bears numerous panicles of small white flowers. *Ribes Hudsonianum* or *viscosissimum* is an inedible currant found near the Registration Booth. *Ribes cereum,* an edible variety, is very abundant on Little Prairie. Rabbit brush, *Chrysothamnus graveolens;* sage brush, *Artemesia tridentata;* service berry, *Amelanchier alnifolia;* and choke cherry, *Prunus melanocarpa,* are found on the cinders.

Many of the herbs on the cinders attract the attention of the traveler, whether they are is blossom or not. In June during the heat of the day, bitter root, *Lewisia redeviva,* is in full glory and surpasses all the other flowers in beauty. It is an acaulescent perennial plant with a thick, short stem, white flowers, and large orange root. In June and July the cinders are covered with patches of the red monkey flower, *Mimulus nanus,* a small annual with a reddish-purple, funnel-shaped corolla with yellow spots in the throat. The buckwheat, *Eriogonum,* is found in all kinds of places. The most common variety is *Eriogonum depressum* or *acaule,* a small plant with white leaves, a perennial root and heads of cream and sometimes red flowers. The other buckwheats are *Eriogonum aridum,* pale yellow heads that turn purple with age; *Eriogonum ovalifolium* with oval shaped leaves and a single, loose, yellow head of flowers on each scape; and *Eriogonum vimineum,* a very lacy pink flowered plant with the flowers in the axils of the leaves and not in heads.

Other flowers found in the Monument are as follows: a very pretty blue Pentstemon which has not been named; the blue larkspur, *Delphinium Nuttallianum; Senecio Howellii* and *Senecio Sphaerocephalis* (?) squaw weed or ragwort, a yellow composite; *Castelleja pinetorum,* Indian paint brush; *Crepis acuminata,* another yellow composite; *Lygodesmia spinosa,* a pale pink composite with stiff branches and spine-like scales for leaves; *Lupinus tenulus,* a purple lupine with pale green pubescent leaves; *Machaeranthera pulverulenta,* a low blue composite with a deep yellow disk; *Gayophytum ramosissimum,* a delicate finely branched plant with pale pink or white flowers, which belongs to the primrose family; *Nuttallia acuminata (Mentzelia multiflora),* sand lily, a large plant with shining white stems and numerous large yellow blossoms; *Acrolasia dispersa (Mentzelia densa),* a much smaller sand lily much like the preceding; *Potentilla biennis* and

Potentilla dichrona, two cinquefoils found on the lava; *Drymocallis pseudorupestris,* a plant much like the cinquefoils; *Erigeron nanus,* a low pale blue or white fleabane daisy; *Navarretia minima,* a small, exceedingly spiny phlox with white flowers; *Leptodactylum patens (Gilia pungens),* a larger phlox with a spiny stem and large white flowers; *Pentstemon deustus,* a small glabrous plant with dense racemes of white flowers with purple markings in the throat; *Calochortus Nuttallii,* sego or mariposa lily, the state flower of Utah, a large white lily with a dark spot in the center; *Phacelia heterophylla* and *Phacelia leucophylla,* scorpion weeds, having recurved racemes with pale lavender flowers and leaves that are strikingly veined, silky pubescent, and tinged with purple; *Chaenactis Douglasii,* false yarrow, a grey green plant with white flowers in dense clusters on a rigid stem; *Crypthantha Torreyana,* a white flowered borage covered with stiff hairs; *Oreocarya dolosa,* also a borage, like the preceding except that the flowers are in denser racemes; *Eupatorium occidentale,* Joe-pye weed or boneset, a plant bearing lavender or pink flowers and many leaves; *Coleosanthus grandiflorus (Brickellia grandiflora)* a composite which is like boneset except that it has fewer leaves on the stem; *Nicotiana attenuata,* tobacco, which has a viscid stem and a white tubular corolla and is abundant on the road near Big Craters and in Little Prairie; *Opuntia* at least two species, *Opuntia xanthostemma* and *Optuntia polycantha* the only cacti found at the Craters of the Moon; an *umbellifer,* probably wild parsnip, a low plant with yellow blossoms found on the cinders; *Agoseris sp. (Troximon)* or goat chicory, a yellow composite, which has not been identified; *Salsola pestifer,* the Russian thistle, and *Circium orthe,* Canadian thistle.

The ferns are found in the crevices in the pahoehoe lava where they have been able to gain a good foot-hold. There are three ferns found here in the Monument, namely, *Felix fragilis,* a dainty fern; *Woodsia oregana* like the *Felix* but more common; and *Polystichum scropulinum,* Christmas or holly fern, a coarse fern with broad fronds.

One finds also several grasses namely, *Bromus tectorum,* brome grass, an introduced species found in almost every kind of place; *Ericoma hymenoides,* Indian millet; *Oryzopsis Bloomeri,* rice grass; *Stipa comata* and *Stipa occidentalis,* known as spear grass, porcupine grass, or feather grass; *Melica bella,* a large grass, in-

dicative in its abundance of overgrazing, commonly known as melica grass but sometimes called rye grass; *Sitanion rigidum* and *Sitanion cinereum,* grasses with many long awns which give it a fuzzy appearance upon drying.

There are numerous interesting lichens, mosses and algae found in caves and on rocks. The most conspicuous is a large green fruticose lichen which grows on dead or dying limber pines. On the smooth spatter in the mouths of the little craters and on the pahoehoe lava, one finds a great variety of lichens; grey, green, red, orange and black. In the water holes, in the coldest water, are found colonies of green algae. A few are also found in the open moist caves. All of the deep caves that have sufficient light are heavily carpeted with moss. Occasionally one finds a plant of *Marchantia,* liverwort, growing in the niches in the pahoehoe lava.[1]

The following is a list of plants found in the area:

TREES

Juniperus occidentalis, western juniper
Pinus flexilus, limber pine
Populus tremuloides, quaking aspen

SHRUBS AND HERBACEOUS PLANTS

Acrolasia dispersa, sand lily
Agoseris sp., goat chicory
Amelanchier alnifolia, service berry
Arabis perelegans, rock cress
Artemesia tridentata, sage brush
Calochortus Nuttallii, sego or mariposa lily
Castelleja pinetorum, Indian paint brush
Chaenactis Douglasii, false yarrow
Chrysothamnus graveolens, rabbit brush
Circium orthe, Canadian Thistle
Coleosanthus grandiflorus
Collomia lineanis
Crepis acuminata
Crypthantha Torreyana, borage
Delphinium Nuttallianum, larkspur
Drymocallis pseudorupestris
Erigeron nanus, fleabane daisy
Eriogonum aridum, umbrella plant
Eriogonum depressum, umbrella plant
Eriogonum ovalifolium
Eriogonum subalpinum, sulphur plant
Eriogonum vimineum, umbrella plant
Eupatorium occidentale, boneset
Felix fragilis, brittle fern
Galium boreale, bedstraw
Gayophytum ramosissimum, baby's breath
Gilia leptomeria
Heuchera ovalifolis, alum root
Leptodactylum patens, phlox
Lewisia redeviva, bitter root
Lupinus tenulus, lupine
Lygodesmia spinosa, prairie pink
Machaeranthera pulverulenta, viscid aster

1 The identification of the majority of plants has been checked by Dr. P. A. Rydberg of the New York Botanical Gardens, New York City, to whom the author is deeply indebted. An attempt has been made to find common names for all plants and to correlate them with the text of Coulter and Nelson. In cases where two general names are given the keys differed as to the name of the plant: the first name is from "Flora of the Rocky Mountains and Adjacent Plains" by P. A. Rydberg and the second from "A New Manual of Rocky Mountain Botany" by Coulter and Nelson.

Mimulus nanus, monkey flower (*Eunanus Tolmiei)*
Mentzetia dispersa
Navarretia minima, small phlox
Nicotiana attenuata, tobacco
Nutallia acuminata, blazing star
Opuntia polycantha, cactus
Opuntia xanthostemma, cactus
Oreocarya dolosa, borage
Pentstemon deustus
Pentstemon sp.
Phacelia heterophylla, scorpion weed
Phacelia leucophylla, scorpion weed
Philadelphus Lewisii, mock orange
Philoria tenufolia, desert pink
Potentilla biennis, cinquefoil
Potentilla dichrona, cinquefoil
Prunus melanocarpa, choke cherry
Purshiana tridentata, buck brush
Ribes cereum, edible currant
Ribes Hudsonianum, inedible currant
Salsola pestifer, Russian thistle
Seriocotheca glabrescens, mountain spray
Senecio Howellii, squaw weed or ragwort
Senecio Sphaerocephalis (?), squaw weed or ragwort
Umbellifer, sp.

GRASSES

Bromus tectorum, brome grass
Ericoma hymenoides, Indian millet
Melica bella, melica or rye grass
Oryzopsis Bloomeri, rice grass
Sitanion cinereum
Sitanion rigidum
Stipa comata, spear or porcupine grass
Stipa occidentalis, spear or porcupine grass

APPROXIMATE ERUPTIVE SEQUENCE OF THE PRINCIPAL LAVA FLOWS IN THE AREA IN ORDER FROM YOUNGEST TO OLDEST.

1. Indian Tunnel flow
2. Needles Cave flow
3. North Crater flow
4. Northeast Big Cinder Butte flow
5. Southwest flow from Big Craters and Crystal Pit fissures
6. Northwest Big Craters flow
7. Cave flow
8. Owl Cavern flow
9. Little Prairie aa flow
10. Derelict flow
11. Spatter-cone flow on Sheep Trail Butte
12. Northeast Big Craters flow
13. Serrate flow
14. Sheep Trail Butte flow
15. Highway flow
16. Coyote Butte flow
17. Trench Mortar Flat flow
18. Sentinel Butte flow
19. Fissure Butte flow
20. Ancient northeast flow from Big Cinder Butte
21. Vermilion Chasm flows
22. Fissure flow northwest of The Sentinel
23. Echo Crater flow
24. Moss Cave flow
25. Grassy Cone flow
26. Sunset Cone flow
27. Silent Cone flow

PROMINENT CINDER CONES.

IN THE GREAT RIFT ZONE

NAME	Elevation above sea level.	Height above adjacent plain.	Section	Township	Range
	Feet	Feet			
Sunset Cone	6,386	590	26	2 N	24 E
Grassy Cone	6,351	450	34	2 N	24 E
North Crater Butte	6,338	440	35	2 N	24 E
Paisley Cone	6,050	350	1	1 N	24 E
Inferno Cone	6,177	300	1	1 N	24 E
Big Craters Butte	6,300	300	2	1 N	24 E
Silent Cone	6,346	450	2	1 N	24 E
Broken Top	6,060	225	12	1 N	24 E
Big Cinder Butte	6,516	800	13	1 N	24 E
Half Cone	6,041	350	18	1 N	25 E
Crescent Butte	6,089	490	11	1 N	25 E
Coyote Butte	5,907	300	19	1 N	25 E
Echo Crater Butte	5,850	250	29	1 N	25 E
The Watchman	5,871	325	28	1 N	25 E
The Sentinel	5,840	250	33	1 N	25 E
Split Butte	5,750	250	3	1 S	25 E
Fissure Butte	5,877	425	10	1 S	25 E
Sheep Trail Butte	5,617	150	10	1 S	25 E
Two Point Butte	5,471	120	23	1 S	25 E
OUTSIDE OF THE GREAT RIFT ZONE					
Round Knoll	5,631	125	27	2 N	25 E
North Laidlow Butte	5,906	350	7	1 S	25 E
Bowl Crater Butte	5,596	50	18	1 S	25 E

LOCATION OF THE PRINCIPAL CAVES

NAME	Quarter	Section	Township	Range
Unnamed	SW. ¼ SW. ¼	12	1 N	24 E
Buffalo Caves	SE. ¼ SE. ¼	12	1 N	24 E
Great Owl Cavern	NE. ¼ NE. ¼	14	1 N	24 E
Lava River Cave	SW. ¼ SW. ¼	33	2 N	25 E
Last Chance Cave	NW. ¼ SW. ¼	4	1 N	25 E
Tom Thumb Tunnel	SE. ¼ NE. ¼	5	1 N	25 E
Horseshoe Cave	NE. ¼ SE. ¼	5	1 N	25 E
Needles Cave	NW. ¼ SE. ¼	5	1 N	25 E
Surprise Cave	NE. ¼ SW. ¼	6	1 N	25 E
Dewdrop Cave	NE. ¼ SW. ¼	6	1 N	25 E
Indian Tunnel	SE. ¼ SW. ¼	6	1 N	25 E
Unnamed	NW. ¼ SW. ¼	33	1 N	25 E
Moss Cave	SW. ¼ NW. ¼	36	1 N	25 E
Sunbear Cave	SW. ¼ NW. ¼	36	1 N	25 E
Amphitheater Cave	SW. ¼ NW. ¼	36	1 N	25 E
Unnamed	NW. ¼ NW. ¼	14	1 S	25 E
Unnamed	SW. ¼ SW. ¼	15	1 S	25 E

LOCATION AND SIZE OF THE PRINCIPAL NATURAL BRIDGES

NAME	Quarter	Section	Township	Range	Height	Span
Natural Bridge	SW	5	1 N	25 E	12	30
Indian Tunnel Bridge	SW	6	1 N	25 E	60	75
Bridge of Tears	NW	36	1 N	25 E	15	40
Bridge of the Moon	SE	16	1 S	25 E	20	60

LOCATION OF TREE MOLDS

Kind of mold	Name of lava flow	Section	Township	Range
Lava trees	Trench Mortar Flat	18	1 N	25 E
Lava trees	Tree Mold Flat	28, 29	1 N	25 E
Tree molds	Northwest flow from Big Craters	3	1 N	24 E
Tree molds	Owl Cavern flow	13	1 N	24 E
Tree molds	Blue Dragon Flows	13	1 N	24 E
Tree molds	Blue Dragon Flows	26	1 N	24 E
Tree molds	Blue Dragon Flows	34	1 N	24 E
Tree molds	Black Flows	15	1 N	25 E
Tree molds	Black Flows	16	1 N	25 E

OCCURRENCES OF PERENNIAL WATER OR ICE

NAME	Quarter	Section	Township	Range
Registration Booth Water Hole[1]	NW	1	1 N	24 E
Ice Cave	SE	2	1 N	24 E
Pit Crater Water Hole	NW	12	1 N	24 E
Big Sink Water Hole	NW	12	1 N	24 E
Owl Cavern	NE	14	1 N	24 E
Hoodoo Water Hole	SW	27	2 N	25 E
Surprise Water Hole	NE	29	2 N	25 E
Doves Water Hole	SW	30	2 N	25 E
Last Chance Cave	SW	4	1 N	25 E
Yellow Jacket Water Hole[2]	SE	20	1 N	25 E
Bearsden Water Hole	NE	29	1 N	25 E
Little Prairie Water Hole	NE	29	1 N	25 E
Sheep Trail Butte Water Hole	SE	10	1 S	25 E
Ice Cave	SE	14	1 S	24 E
Ice Caves	NE	24	1 S	25 E

[1] Went dry for first time in 1928.
[2] Dry in September and October, 1926.

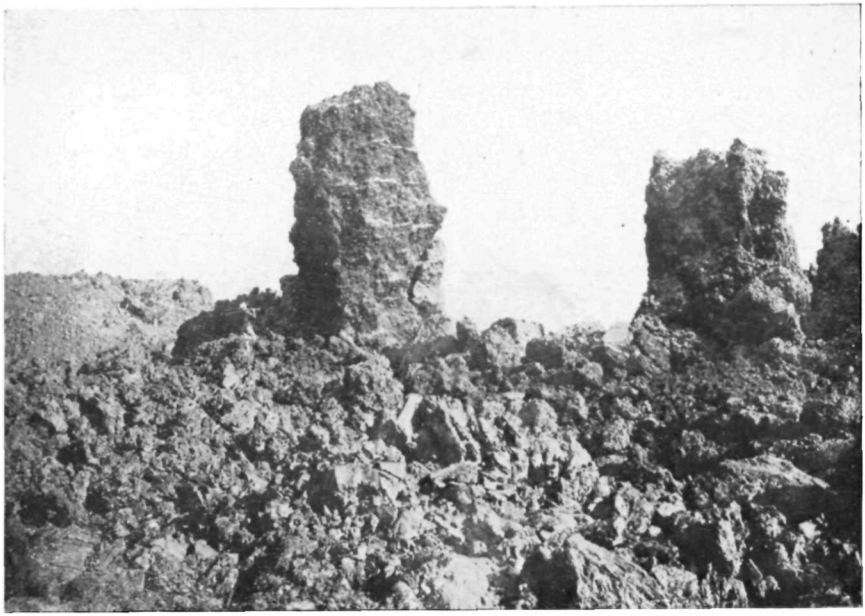
View looking southeastward from Big Cinder Butte, showing a double line of cinder cones, many of them grass-covered and all of them vents of numerous flows which unite southward into one great field of lava, lonely and uninhabited. The symmetrical crater bowl on the southeast side of Big Cinder Butte lies in the foreground. Photograph by H. T. Stearns.

A.—A chain of very symmetrical spatter cones marks the site of Crystal Fissure, near the end of the automobile road. Big Cinder Butte in the background. Photograph by H. T. Stearns.

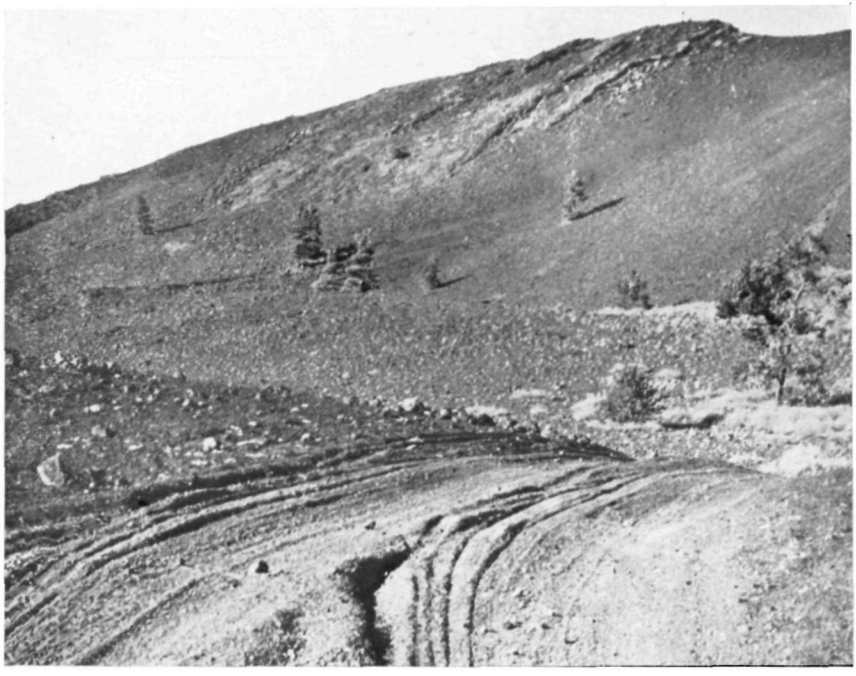
B.—Round Knoll, an ancient grass-covered cinder cone, stands as a yellow island in a sea of black lava. Photograph by H. T. Stearns.

A.—A picturesque camp made by a lone geologist on the cinders of Inferno. Photograph by O. E. Meinzer, geologist in the United States Geological Survey, who visited the Craters of the Moon in June, 1921, and made preliminary plans for a geologic survey of the area.

B.—In the central part of the Monument the old cinder cone called The Watchman reopened and lava flowed quietly from the northwest and southeast sides. Photograph by H. T. Stearns.

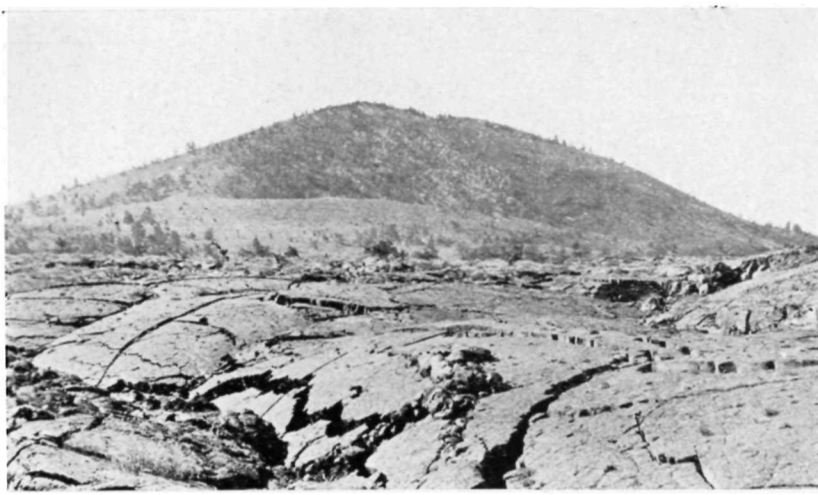


A.—Cinder crags, portions of cones floated away on the surface of a lava flow near the entrance to the Monument. Photograph by I. C. Russell.



B.—The last slop-over of lava on the slope of Big Craters Butte at the end of the automobile road. Photograph by H. T. Stearns.

A.—An extensive billowy pahoehoe lava flow from North Crater was one of the last eruptions in the Craters of the Moon. The road entering the Monument crosses this flow. Photograph by H. T. Stearns.



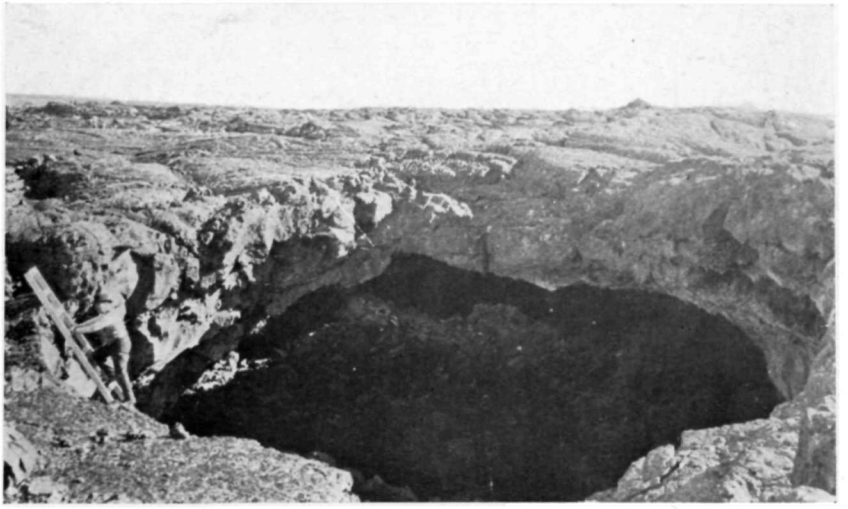
B.—Close-up view of a cracked and fissured surface of a billowy pahoehoe lava flow northeast of Big Cinder Butte. Photograph by H. T. Stearns.

The ropy and wrinkled surfaces of the pahoehoe are due to the hardening of a thin crust or scum on the flow while the crust is being pushed forward by the flowing lava below. Photograph by H. T. Stearns.

A "frozen" cascade of pahoehoe east of Surprise Cave.
Photograph by H. T. Stearns.

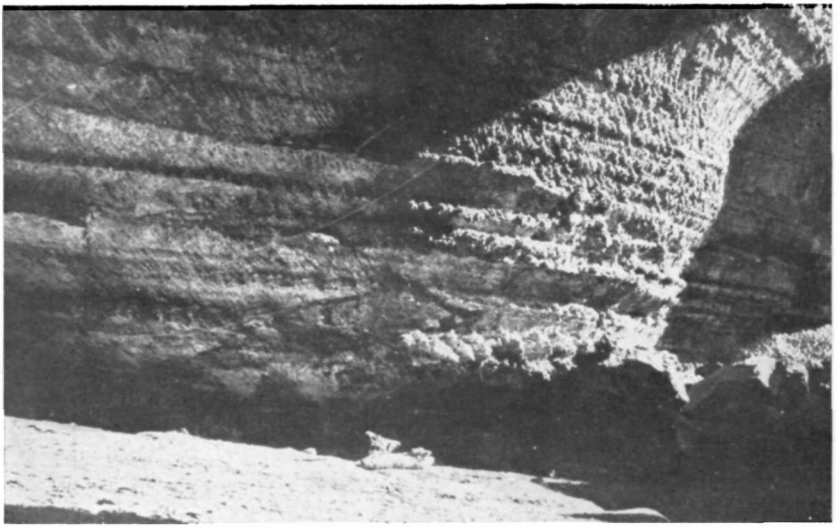
A.—Pahoehoe in places breaks up like slush ice on a river in spring. Photograph by H. T. Stearns.

B—Entrance to Great Owl Cavern, the most perfect lava tube or cavern in the Monument. A small spatter cone can be seen in the middle ground. Photograph by H. T. Stearns.



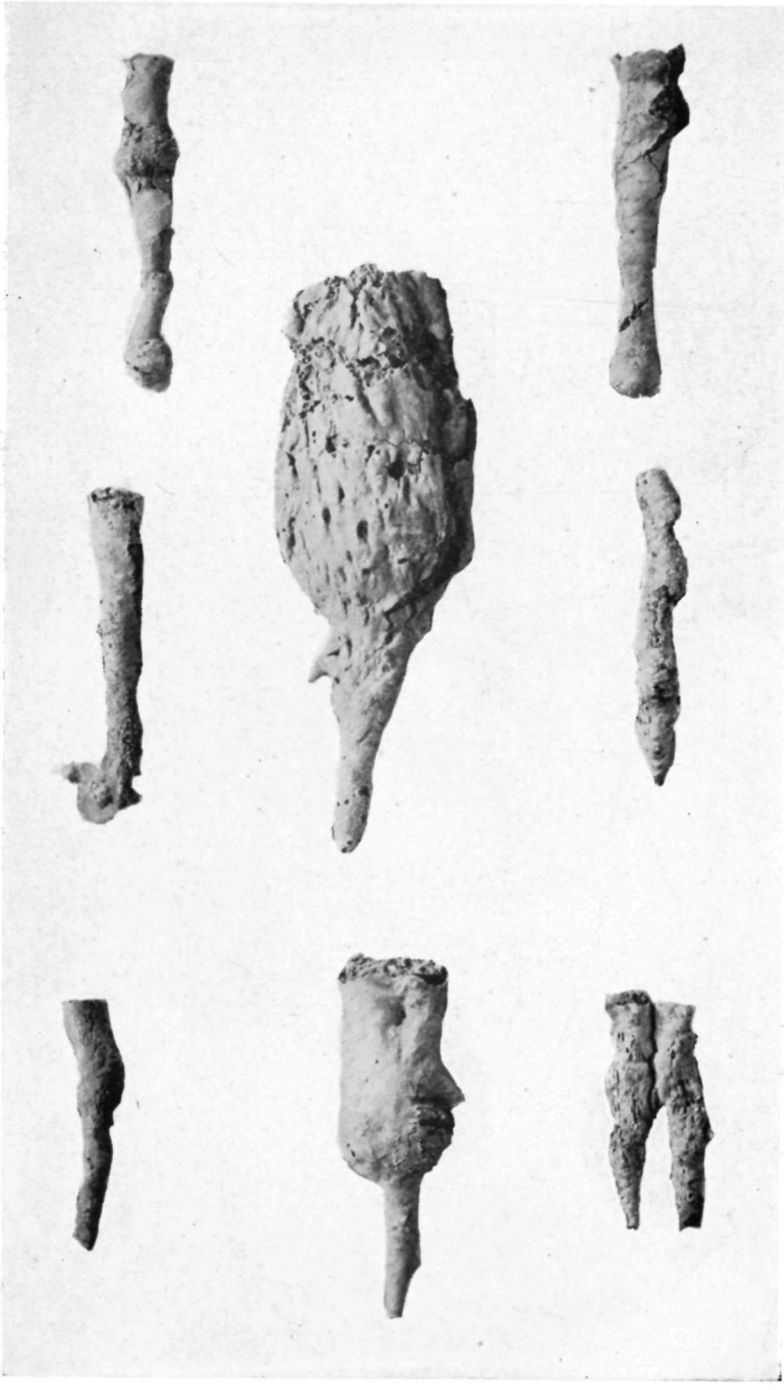
A.—Entrance to Indian Tunnel, the largest and most accessible lava tube in the Monument. Photograph by H. T. Stearns.

B.—Crescentic piles of rocks which weighted down Indian tepees are numerous near Indian Tunnel. Photograph by H. T. Stearns.

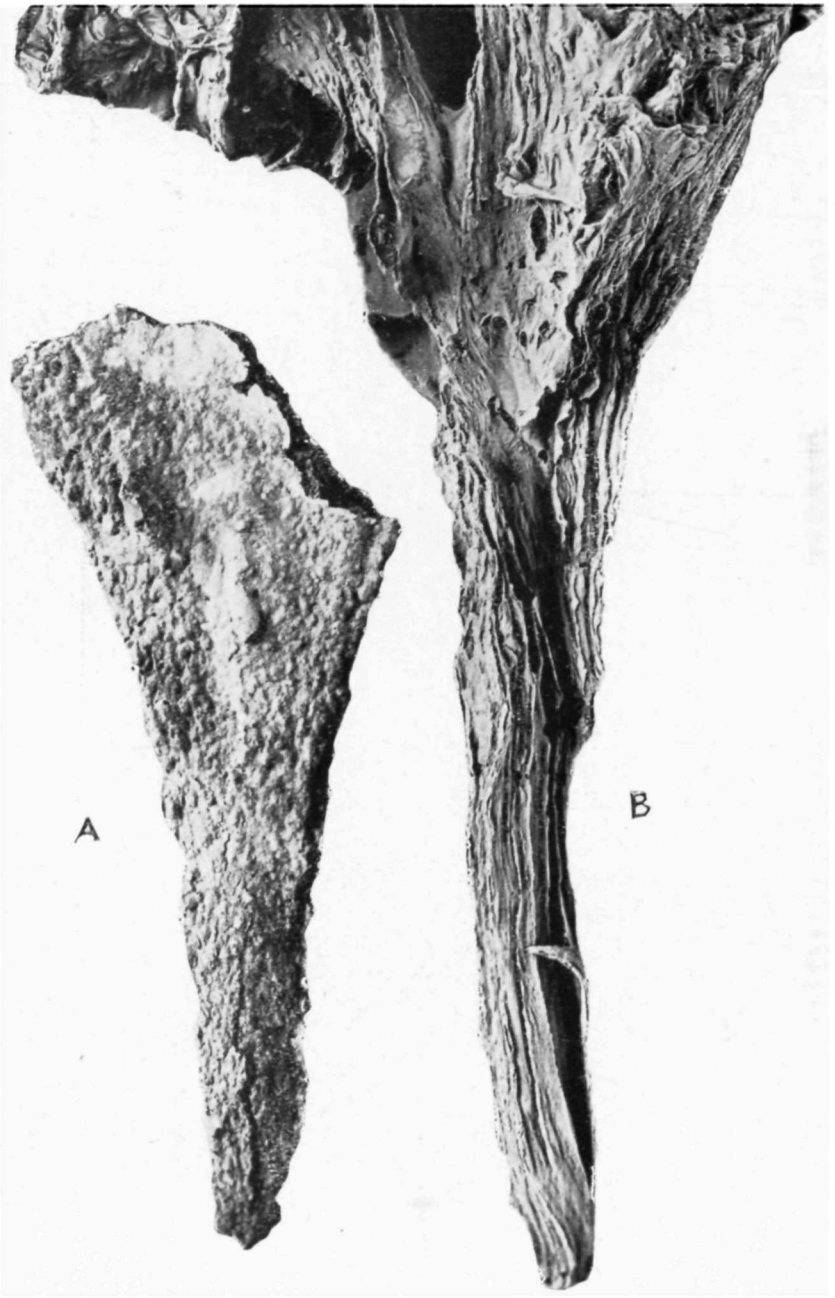


A.—The narrow ledges parallel to the floor of Buffalo Caves are the shore lines of a subsiding river of lava. Photograph by H. T. Stearns.

B.—The natural bridges are small remnants of the tunnel roof that were left standing after the collapse that followed the draining away of the lava river. Photograph by H. T. Stearns.



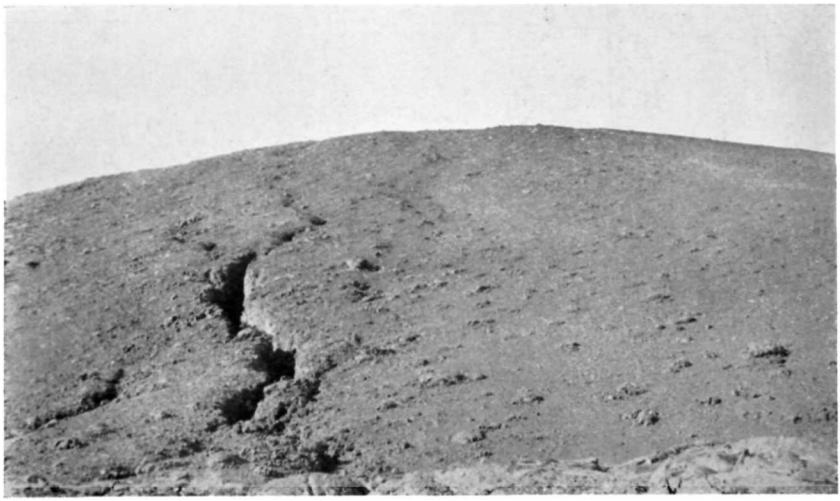
A few lava stalactites from the caves. They were formed by the dripping of the hot lava from the roofs of the tunnels. Natural size.



A lava stalactite from the under surface of the crust of a pahoehoe lava flow (B), in contrast to a lava stalactite from the roof of a lava tunnel (A). Natural size.

IDAHO BUREAU OF MINES AND GEOLOGY BULLETIN 13, PLATE XIV.

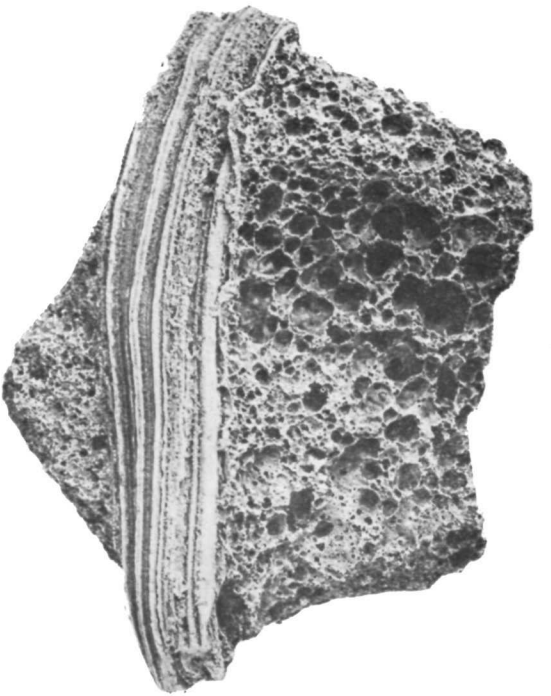
A.—The Bridge of the Moon, showing the graceful arch of a lava tunnel. Photograph by H. T. Stearns.



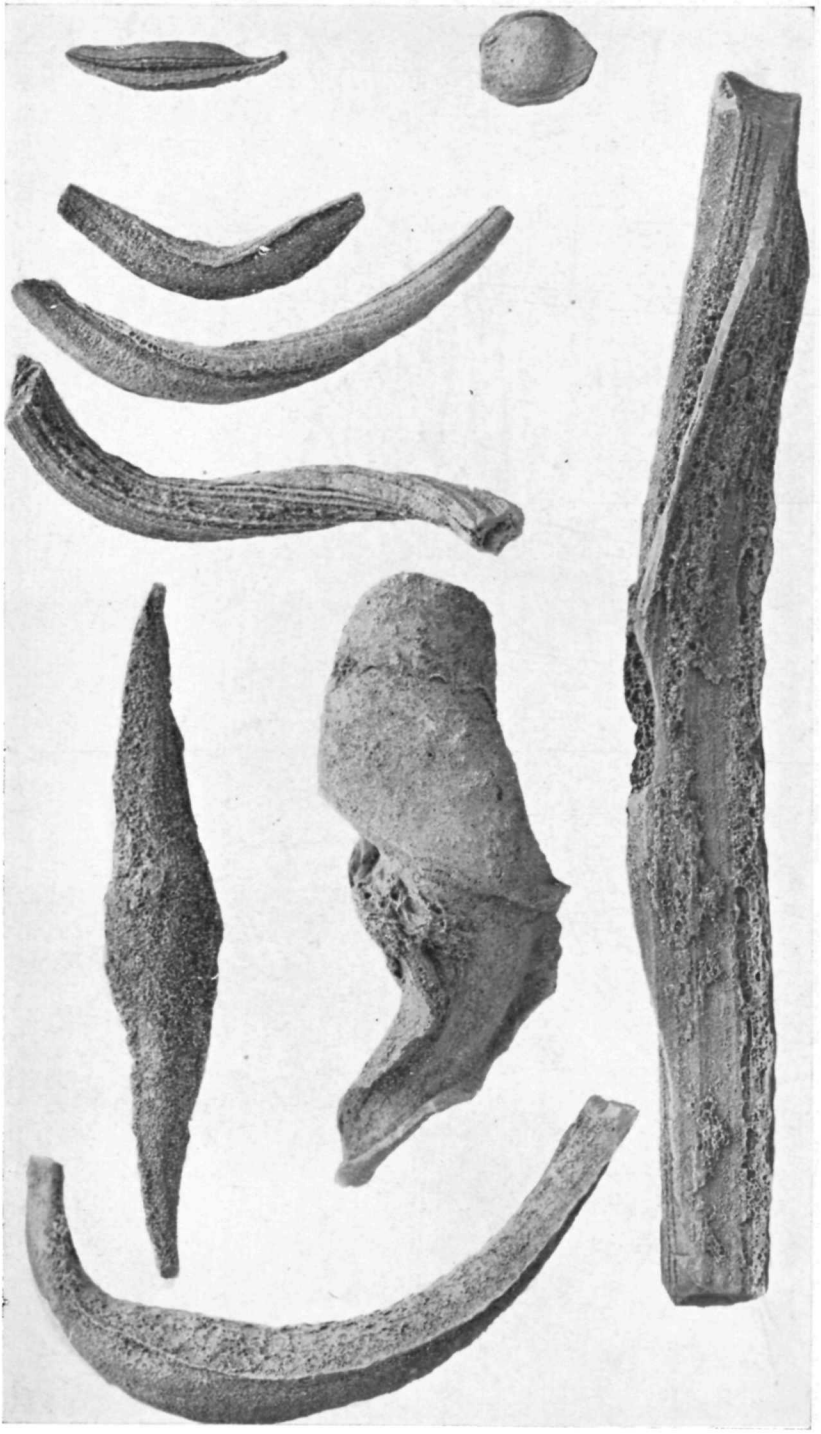
B.—Dark yawning fissures break the barren surface of Broken Top. Note the flattened bombs near by. Photograph by H. T. Stearns.

The rough, bristling, jagged kind of lava is known as aa. Walking over such rock is extremely slow and hazardous. View of the Northeast lava flow from Big Craters Butte. Photograph by H. T. Stearns.

A.—The most symmetrical cinder cone and crater bowl in the Monument is a part of Two Point Butte. Photograph by H. T. Stearns.

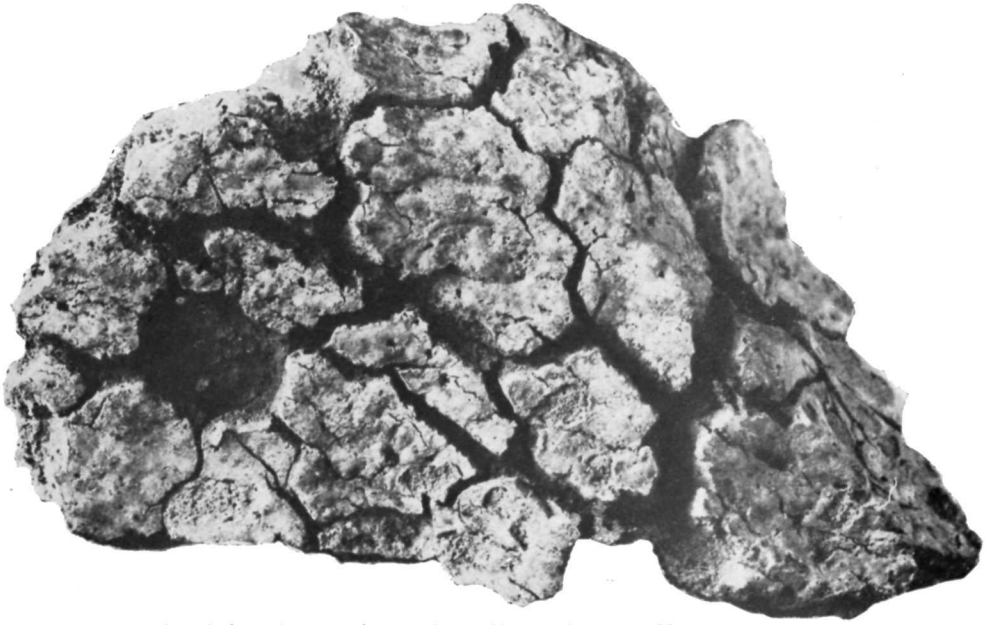


B.—A ribbon bomb "frozen" to a cinder. These long strips of lava are broken off the spindle bombs or owe their origin to the pulling apart of two clots of lava traveling at slightly different speeds or in different directions. Natural size.



Some small spindle and ribbon bombs found on the cones in the Monument. Natural size.

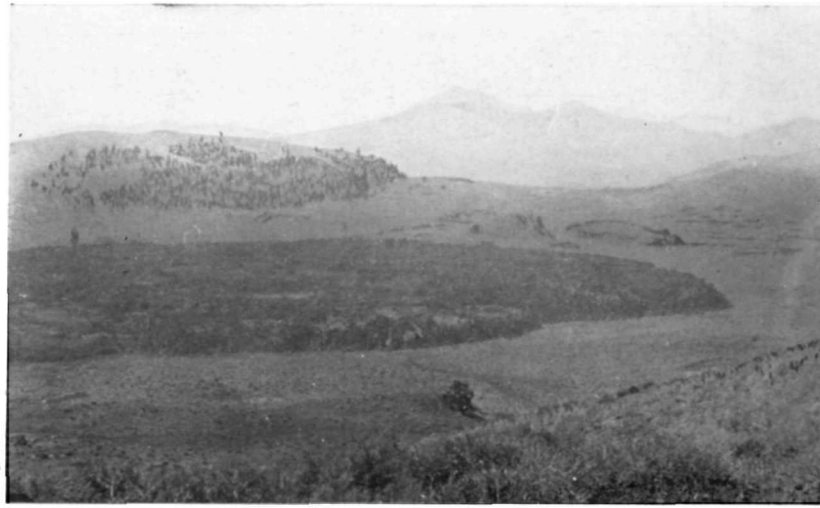
IDAHO BUREAU OF MINES AND GEOLOGY BULLETIN 13, PLATE XVIII.



A.—A bread-crust bomb from North Crater. Natural size.

B.—Lava pendants and gypsum crystals adorn the interior of Crystal Pit. Photograph by S. A. Paisley.

A.—The impressions of charred logs and the molds of the tree trunks are preserved in some places in the pahoehoe lava. Photograph by H. T. Stearns.



B.—The Highway aa lava flow as seen from Sunset Cone. Photograph by H. T. Stearns.

The lava trees are tree molds that rise above the surface of the lava flow. This one, located on Trench Mortar Flat, is formed chiefly of spatter that was ejected from an adjacent fissure. Photograph by H. T. Stearns.

Hoodoo Water Hole, in the Serrate aa lava flow, where water only 1° or 2° above the freezing point can be found on the hottest summer days. Photograph by H. T. Stearns.

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