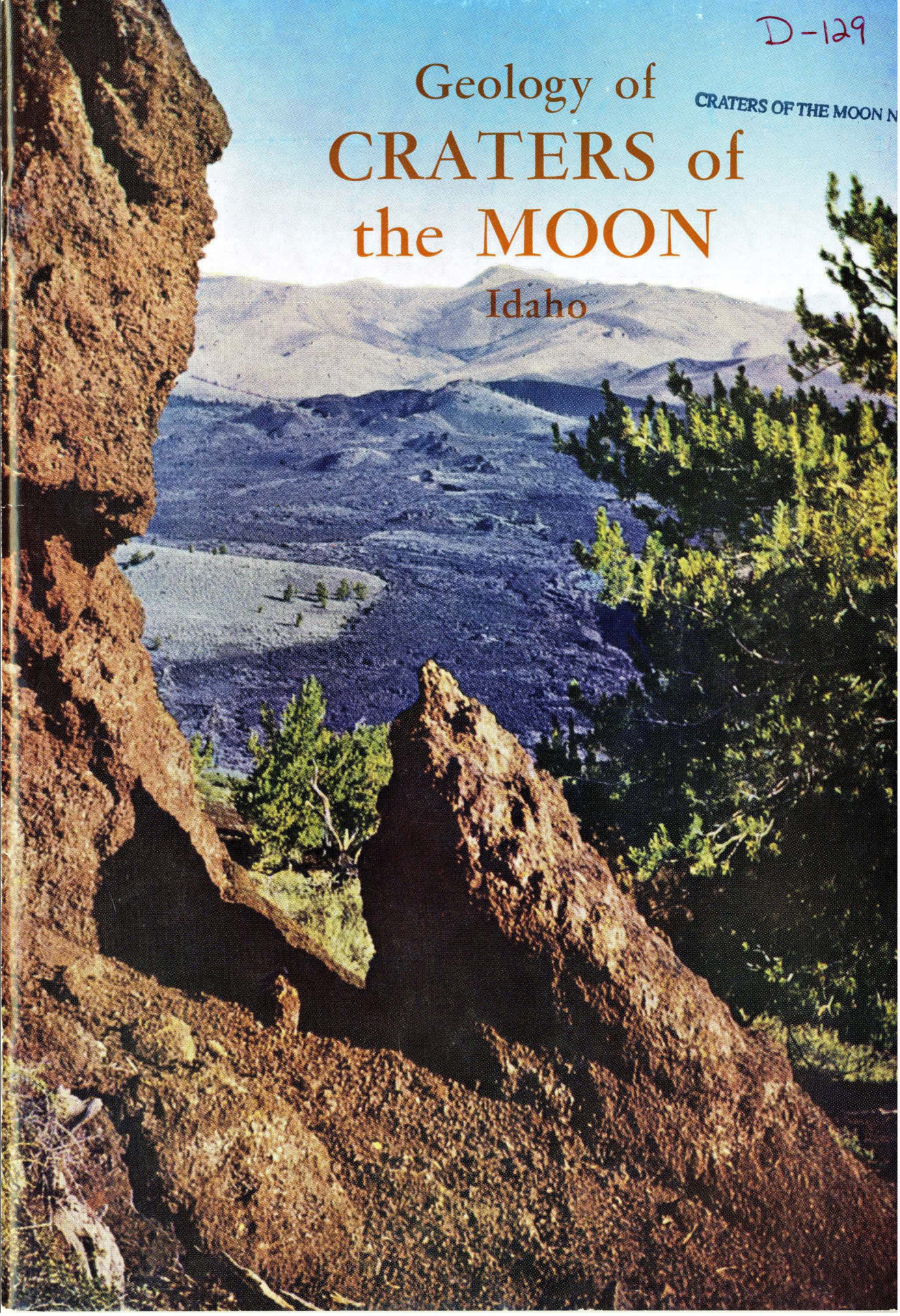
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Geology of CRATERS of the MOON

Idaho

CRATERS OF THE MOON N



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by Harold T. Stearns

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Looking northerly from Big Cinder Butte along the Great Rift with its chain of spatter and cinder cones. Pioneer Mountains visible in background. Photograph by D. C. Ochsner, National Park Service.

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GEOLOGY OF THE CRATERS OF THE MOON NATIONAL MONUMENT IDAHO



by Harold T. Stearns

ABOUT THE AUTHOR AND THIS BOOKLET.

The original survey of the Craters area was started by the author in 1921 for the U.S. Geological Survey. In 1923 he wrote a very favorable report to the National Park Service describing the volcanic features and recommending that steps be taken immediately to preserve them as a National Monument. His report and recommendations were forwarded by the Park Service to President Coolidge. The President commended the author for his recognition of the need for preserving the unique formations and, on May 2, 1924, proclaimed 39 square miles to be the Craters of the Moon National Monument.

In 1926 the survey was completed in cooperation with the Idaho Bureau of Mines and Geology and a popular summary of the geology was published by them in 1928 as Bulletin 13. The Bulletin was soon out of print but was reprinted in July 1930 with slight changes as "A Guide to the Craters of the Moon National Monument, Idaho" by Caxton Printers at Caldwell, Idaho. It included a description of the fauna and flora and ran through six editions. In 1938 a colored geologic map of the Monument made by the author was published in "Geology and Ground-water Resources of the Snake River Plain in Southeastern Idaho": U.S.G.S. Water Supply Paper 774. Detailed descriptions of the various lava features have been released in manuscript form in the open files of the U.S.G.S. in Boise, Idaho and in Washington, D.C. (See Circular 448, item No. 133, 1960) The present booklet is based on the old "Guide" with new illustrations and current data.

The author has studied volcanic terranes over a period of 40 years in many parts of the world. He mapped the geology of the Hawaiian Islands, including the active Kilauea and Mauna Loa volcanoes. After 25 years of service in the U.S. Geological Survey, he resigned to become a Consulting Engineering Geologist specializing in construction projects and water development in volcanic terranes. He now resides in Hope, Idaho.

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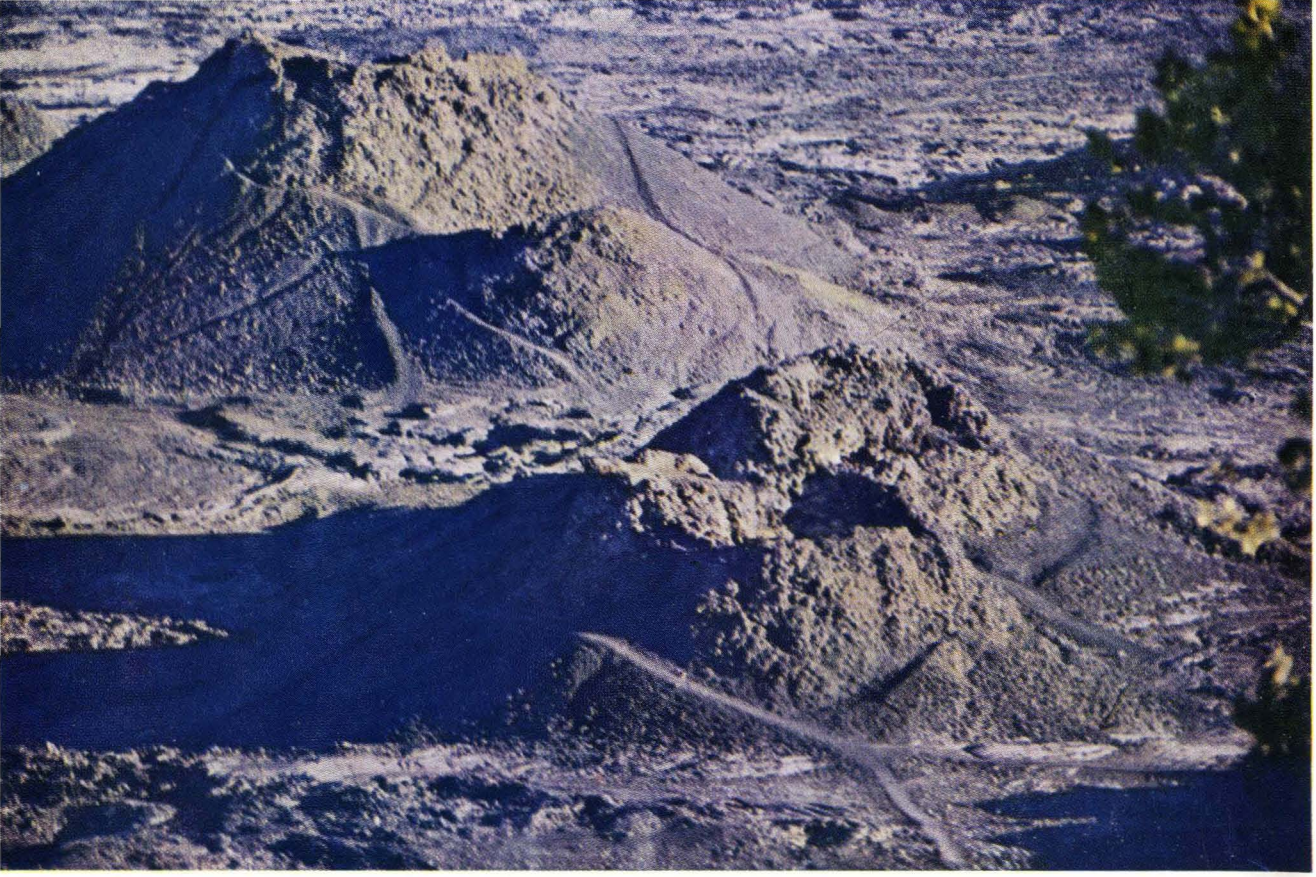
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Cinder cones, ice caves, and moonlike craters pock 75 square miles of the Snake River Lava Plain between Arco and Carey, Idaho. Here the Great Rift, a healed wound in the earth's crust, has repeatedly opened and spewed fiery rock. Yellowstone National Park lies 200 miles away.

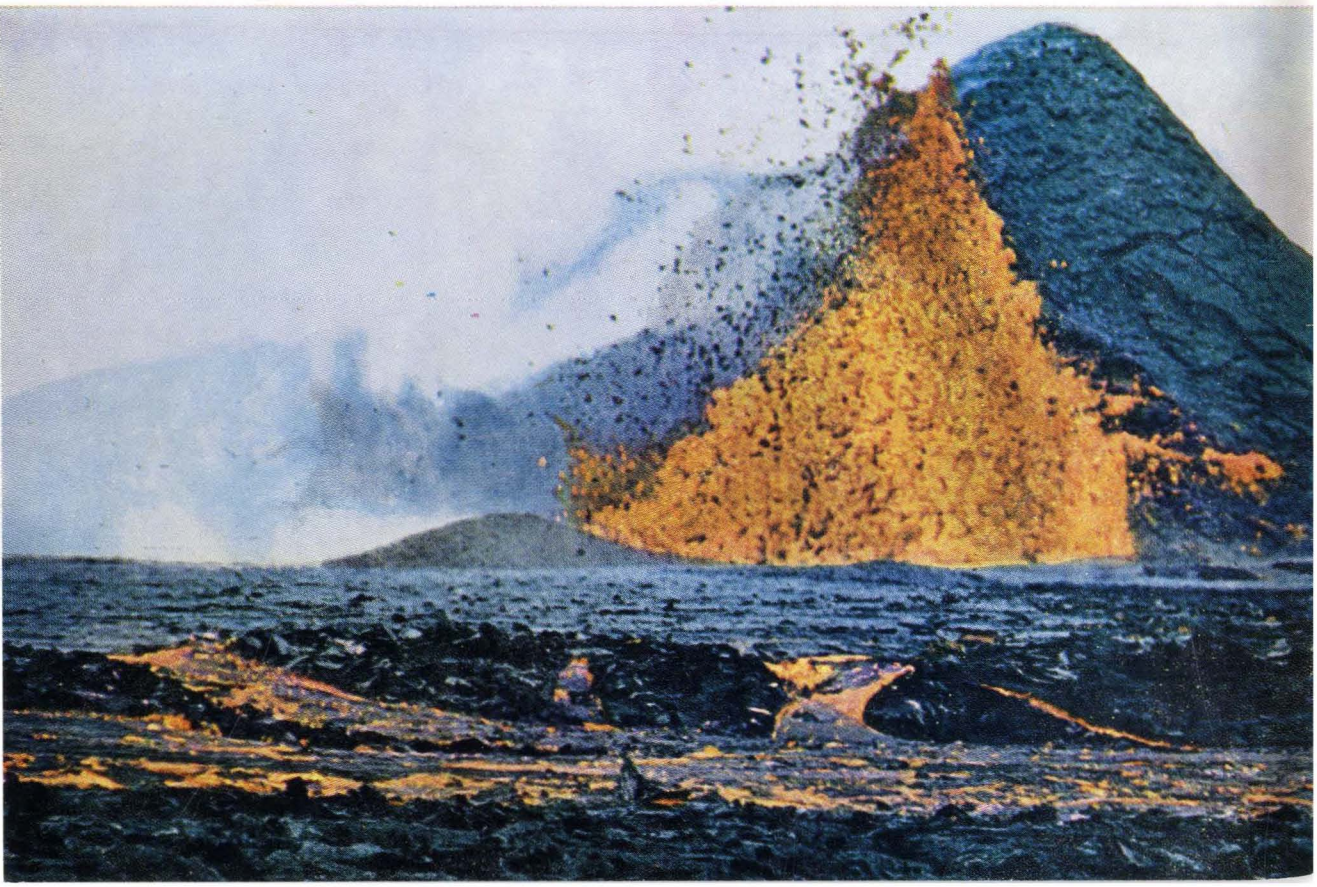
The Great Rift extends northward through the entire monument into the Pioneer Mountains but is concealed by chains of spatter and cinder cones.

Courtesy National Geographic Magazine © National Geographic Society



Crystal Pit and adjacent spatter cones were made by firefountains erupting along a fissure. Photo by Peter G. Sanchez, National Park Service.

Firefountain building a spatter cone along a fissure on the slopes of Kilauea Volcano, Hawaii, January 28, 1960. The glowing lava is typical pahoehoe with crustal cakes floating on its surface. Photo by Carter and Rackle, Honolulu.



INTRODUCTION

"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 of this unique volcanic area was proclaimed the Craters of the Moon National Monument by President Coolidge on May 2, 1924. It was subsequently increased to 83 square miles. It is administered by the National Park Service of the Department of the Interior. The address of the Superintendent of the Monument is Arco, Idaho.

The Monument is reached by a drive of 20 miles from Arco southwest along U.S. Routes 93A-20-26. 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 and contains about 26,000 cubic miles of lava.

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 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.

Extending southward from Big Cinder Butte is a chaos of cinder crags and jagged lava, which reaches as far as the high cinder cone called North Laidlow Butte, eight miles away. 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,



Airview of an extensive pahoehoe lava flow showing numerous sink holes caused by the collapse of the crust as the lava drained away through lava tubes to the lower margin. Photo by D. C. Ochsner, National Park Service.

are pale blue mountains along the Idaho-Utah line.

To the west for about 6 miles the lava flowed against the Pioneer 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 impressive Pioneer 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

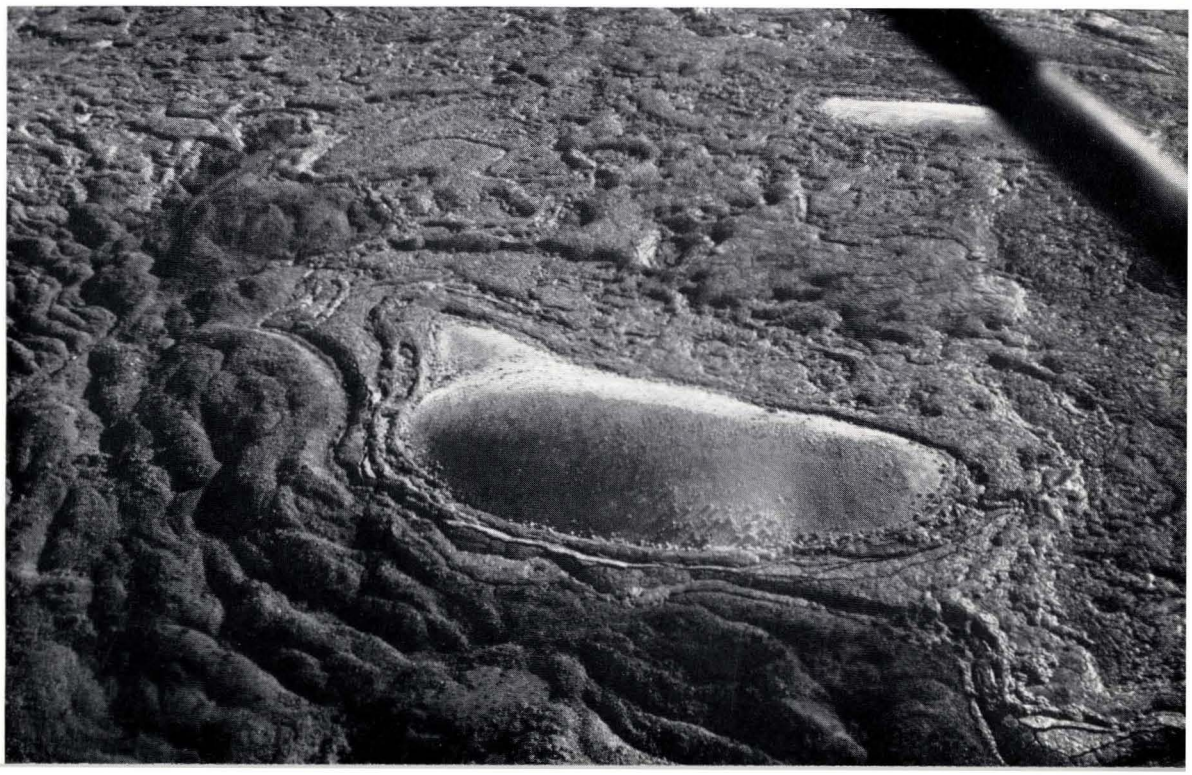
These are the Craters of the Moon as they appear today; let us turn back the pages of stone in the geologic history of this region to the time before any lava had appeared in southeastern Idaho, when the Pioneer Mountains of ancient rocks, then higher than they are now, projected southward into the wide 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 within 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.

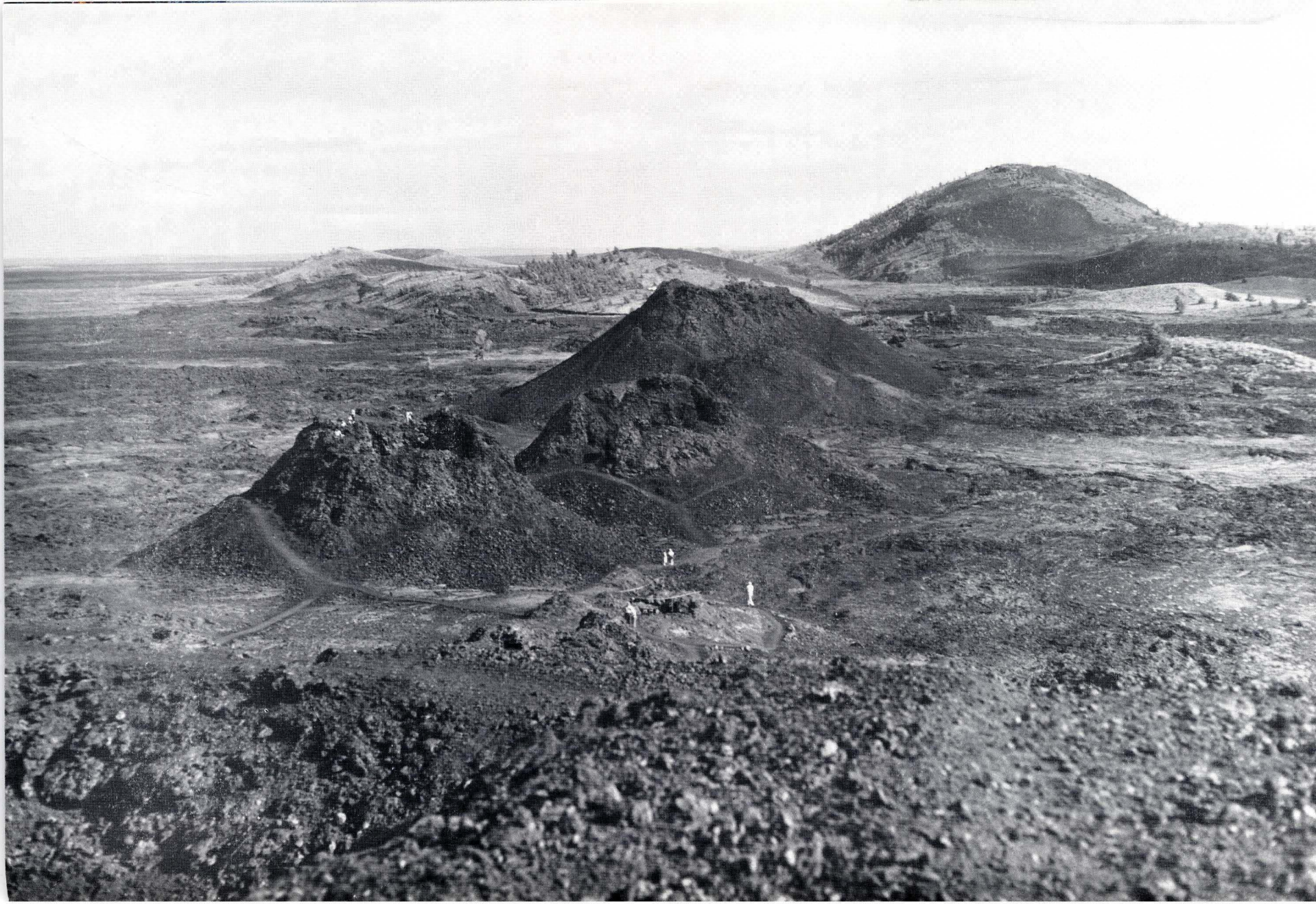
The Pioneer Mountains and their foothills slumbered peacefully and un-

disturbed 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 large and small fragments of granitic rocks that were broken 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., but did not 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 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. (See end tables for a list of the cinder cones giving their height and location.) 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

Great floods of molten lava, now congealed in giant waves, nearly innundated Round Knoll, an ancient cinder cone, which now stands as a yellow island in a sea of black. Airview by D. C. Ochsner, National Park Service.







Billowy pahoehoe near Indian Tunnel resembles the hide of an elephant. Photo by D. C. Ochsner, National Park Service.

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 was 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 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 Cone.

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



Spatter cones in the foreground and Big Cinder Butte in the right background indicate by their alignment the position of the Great Rift, a fissure in the earth's crust which has repeatedly erupted to form the Craters of the Moon. Photo by D. C. Ochsner, National Park Service.

formed but have since been buried. (See end tables for the approximate eruptive sequence of the principal lava flows in the area.)

SOURCE OF THE LAVA

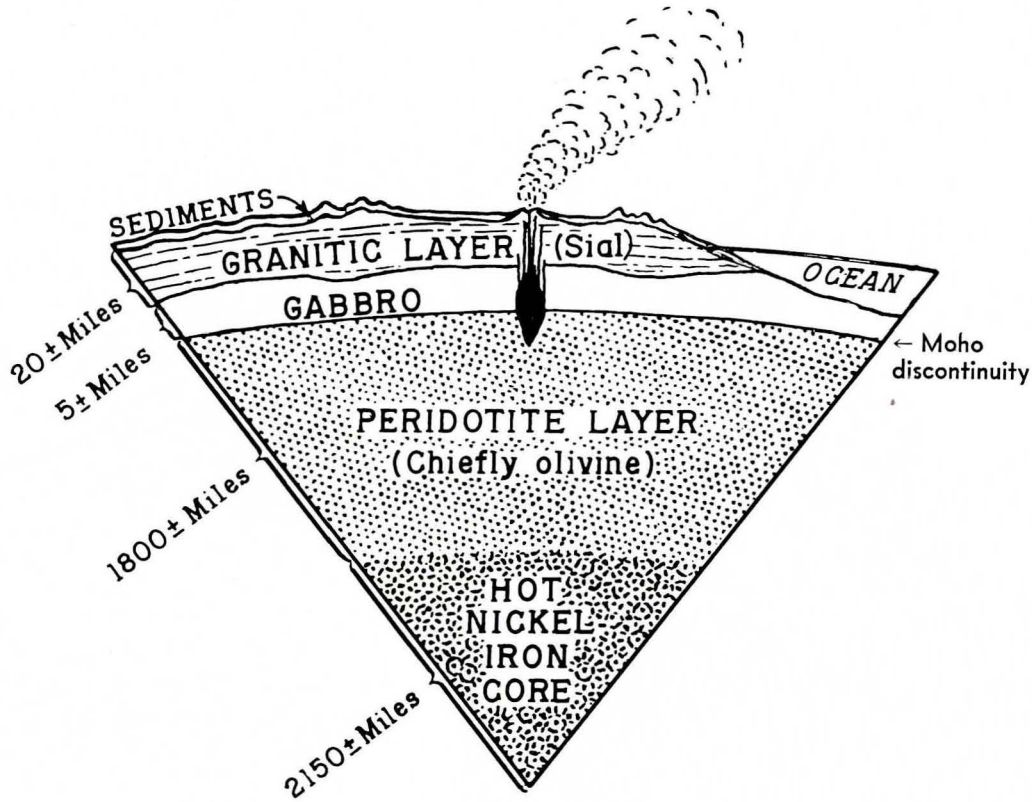
The structure of the earth and the depth from which lava originates have been determined with fair accuracy from the rate of transmission of earthquake waves recorded at various seismological stations. A section of the earth is shown in the diagram on page 7. The sedimentary layer and its associated lava flows average about 2 miles in thickness on the continents. An irregular more massive layer of granite, about 20 miles thick, lies under the sedimentary layer. The sedimentary layer may be more than 5 miles thick under the Snake River Plain because the plain has been a sinking block in which sediments and lavas have been accumulating for a very long time. By contrast the Pioneer Mountains in the north end of the Monument are on a rising block of the earth's crust and close by is the Salmon River Basin where granite is exposed at the surface. The boundary between the sinking and rising blocks is approximately along U.S. Route 93A between Arco and Carey, Idaho.

A gabbro layer 5+ miles thick underlies the granite layer. Gabbro is a coarse grained silica-poor rock commonly called black granite. It has the same composition as basalt but has a coarse grained texture caused by cooling slowly under the heavy weight of the overlying crust, just as granite is the coarse grained equivalent of rhyolite, the silicious lava common in Yellowstone National Park and in Big Southern Butte.

The Moho discontinuity is the break between the gabbro and peridotite layers. This break has gained publicity in recent years as a result of the attempt to drill to it from aboard ships. Earthquake waves behave differently when they pass from the gabbro layer to the peridotite layer, a condition believed to be caused by plastic or liquid material below the discontinuity. Rocks are at high temperatures and under great pressures at a depth of 25 miles so that a slight decrease in pressure may cause the gabbro to liquify. The liquid magma may then rise along fissures and erupt at the surface as basalt. This is what happened repeatedly along the Great Rift and elsewhere in southern Idaho in late geologic time. The eruptions have built the extensive Snake River lava plains. The relief of pressure which causes an eruption apparently is related to adjustments in the earth's crust brought about by changes in its form. Adjustments never cease and, at times of slippage, give rise to earthquakes. The rate of change is cyclical in geologic time so that some periods are times of mountain building and other periods are times of slow sedimentation. Southern Idaho at present appears to be near the end of one of the great epochs of mountain building; hence has a declining rate of volcanic and earthquake activity. However, earthquake epicenters in historic time lie close by at Hailey and more recently at Hebden, Montana on the outskirts of Yellowstone National Park.

NONVIOLENT 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



Hypothetical section showing the origin of the Great Rift eruptions in relation to the layers in the earth.

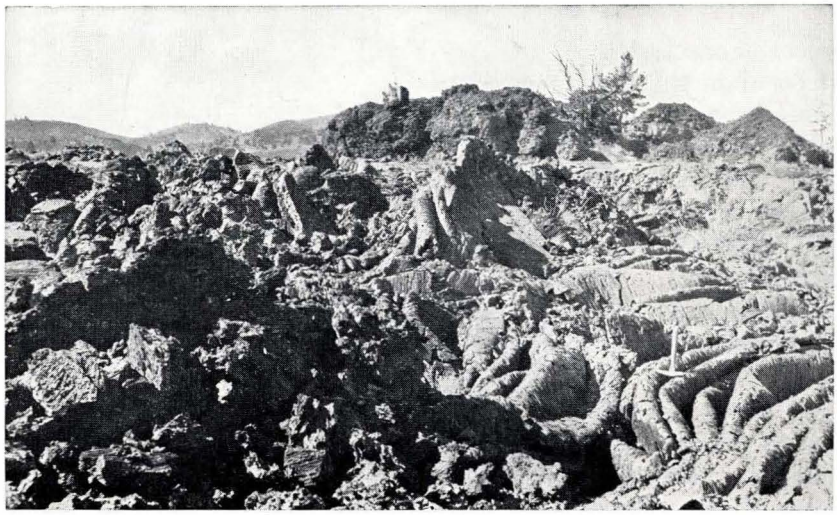
these usually cause great loss of life and property. The dust from the eruption of Krakatoa was carried by winds around the earth and fell on the housetops in London. The brilliant sunsets that followed the eruption of Katmai were caused by particles of volcanic dust in the atmosphere. The character of the ejecta in the Monument, however, shows that the effects of the eruptions at 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 where thousands of persons visit the eruptions.[2] Should a similar eruption occur in 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.

The mechanism of a volcanic eruption of the type that occurred in this area may be compared to the opening of a beer bottle. The liquid remains quietly under pressure within its bottle walls, but when the cap 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



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

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. Almost concurrently the lava flows away from the newly formed crater, either over the rim or through a channel in the side of the cone. Like the liquid beer after the foaming period,



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

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 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. The lava extruded from the volcano of Lassen Peak, California in 1915 is 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 disulphide	.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-ho'ay-ho'ay) and aa (ah'ah). These two Hawaiian words have been adopted as scientific terms to describe the two types of lava flows.

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 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. The 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 caves and their location is given in the end

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. Photo by H. T. Stearns.





Entrance to Indian tunnel, the largest and most accessible lava tube in the Monument. Photo by D. C. Ochsner, National Park Service.

tables. 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 temporary levels 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 in the end tables.

While chemically like pahoehoe, aa

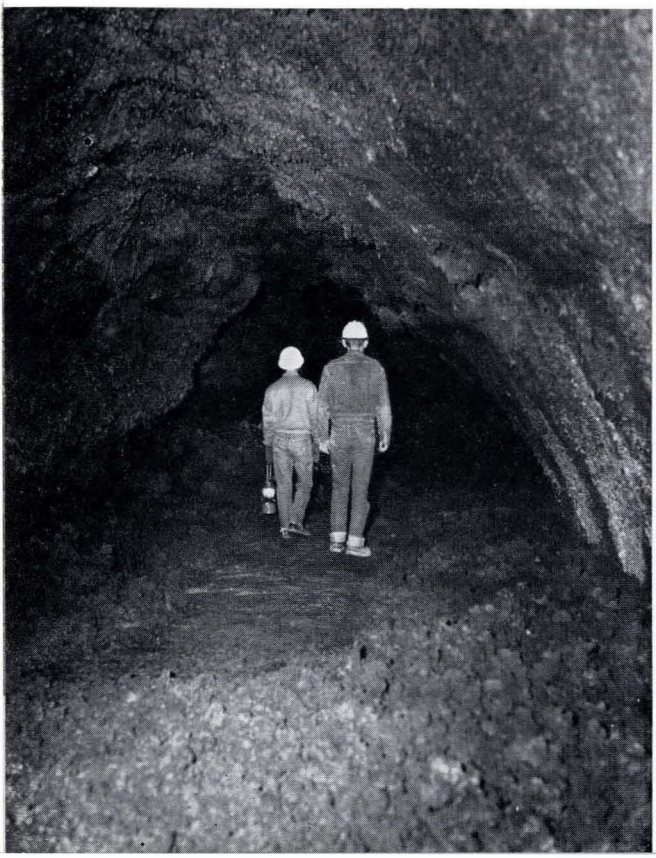
Natural bridge—remnant of a tunnel roof. Photo by R. C. Zink, National Park Service.



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 change into aa. The cause for this change has not yet been determined definitely but field evidence indicates 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

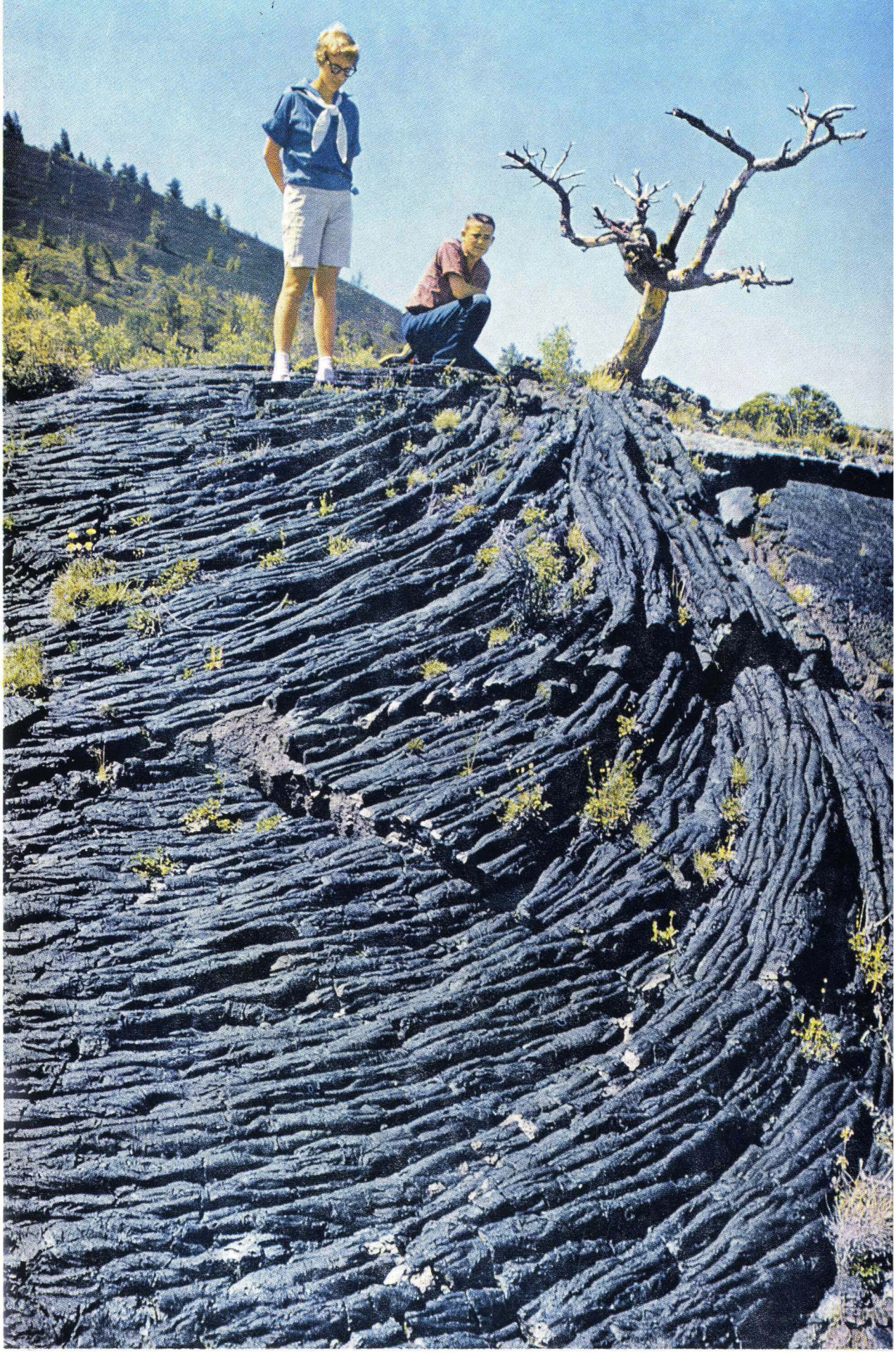
Three different types of cones occur in the area — cinder cones, spatter cones, and lava cones. The cinder cones, with black, loose, cindery surfaces and smooth conical profiles, are familiar to everyone who has visited the Monument. These cones are heaps of the lava froth or spray formed by the fire-fountains 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



Exploring Arco tunnel, one of the many caverns in the Monument. Photo by D. C. Ochsner, National Park Service.

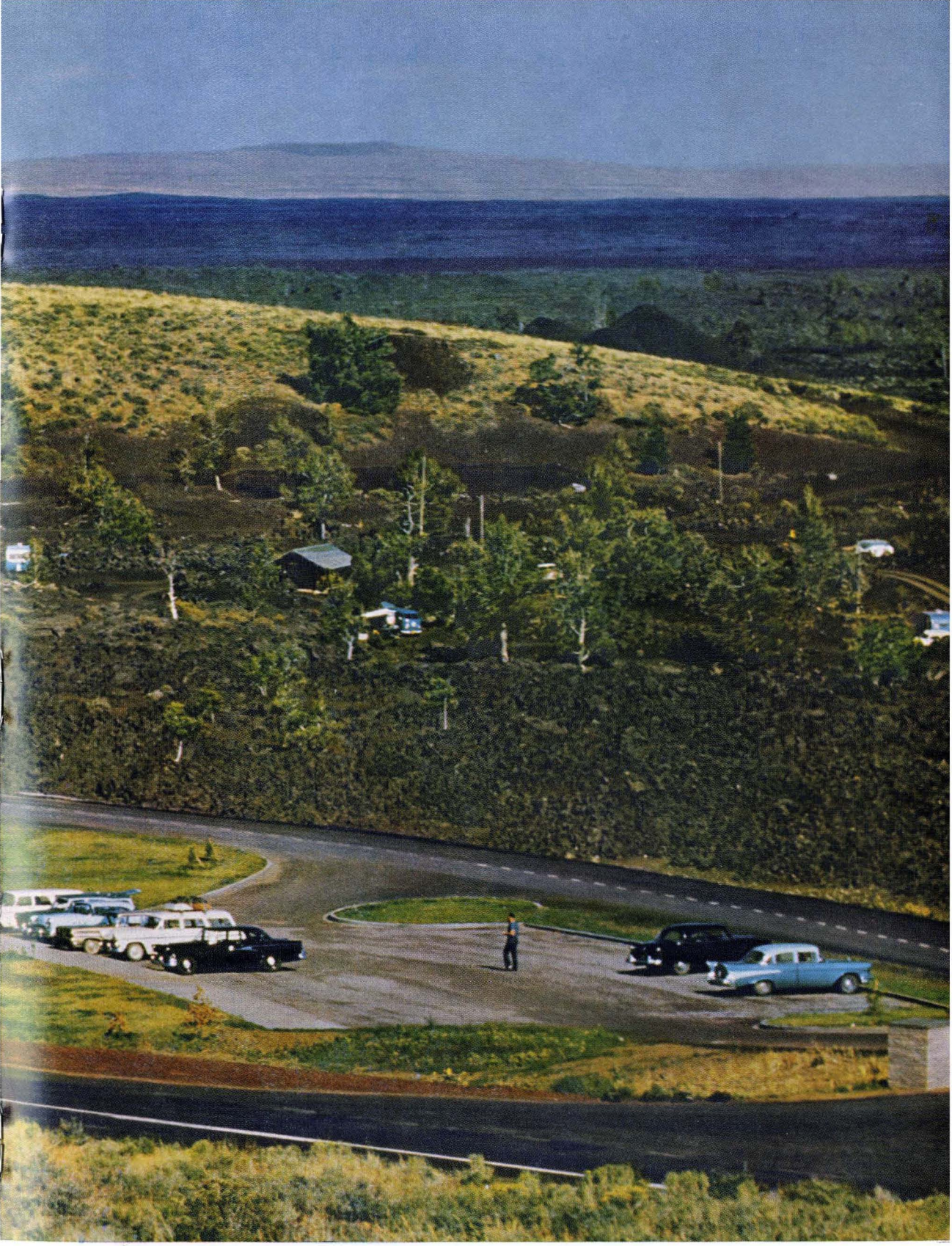
The ropy and wrinkled surface of the pahoehoe is due to the hardening of a thin crust or scum on the lava while the crust is being pushed forward by the flowing lava below. Photo by William Belknap, Jr.

Courtesy National Geographic Magazine © National Geographic Society





Big Southern Butte, 27 Miles Away, Looms Above the New Visitor Center
Sentinel of the Snake River Lava Plain, the 7,576-foot mountain served as a landmark to fur trappers and stagecoaches. It is the remnant of a very ancient silicious volcano that



antedates all the basaltic eruptions on the Snake River Plains. A campground laid amid brush and cinders stands across Loop Drive from the headquarters building. Photo by William Belknap, Jr.

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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 eyewitnesses, 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[3] 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.

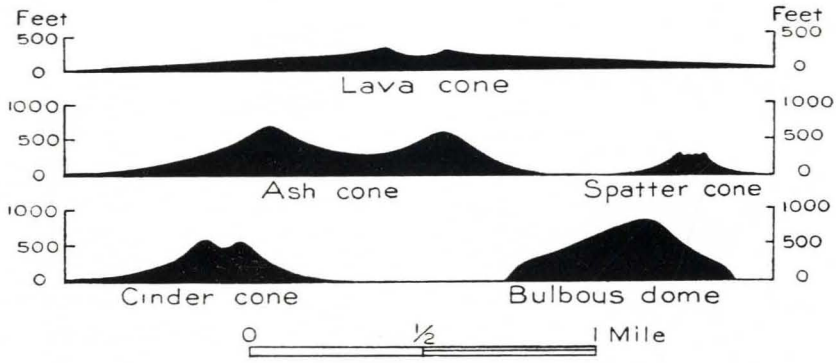
Spatter cones are formed by the smaller firefountains. The clots of lava hurled out by these fountains were not sufficiently inflated with gas to form cinders and moved so slowly and through distances so short that instead of landing as cold cinders they fell as clots in a viscous state and adhered to one another. They built up rather steep-sided cones of small height and diameter. Gypsum crystals and lava pendents adorn the interior of Crystal Cones. The crystals were deposited by exhalations after the eruption. The line of spatter cones near 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

← **A cinder crag,** portion of a cinder cone which floated away on a lava flow like a derelict ship. Photo by William Belknap, Jr.
Courtesy National Geographic Magazine © National Geographic Society



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

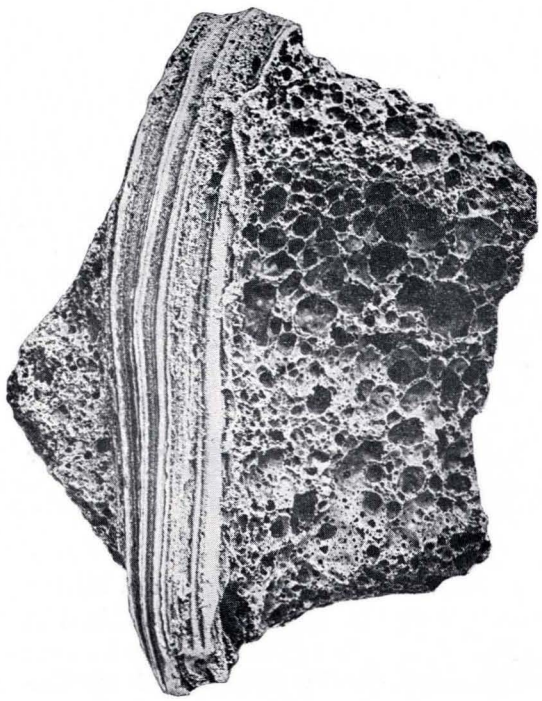


Silhouettes of various types of cones

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 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,[4] 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 nearby 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.[5]

BOMBS

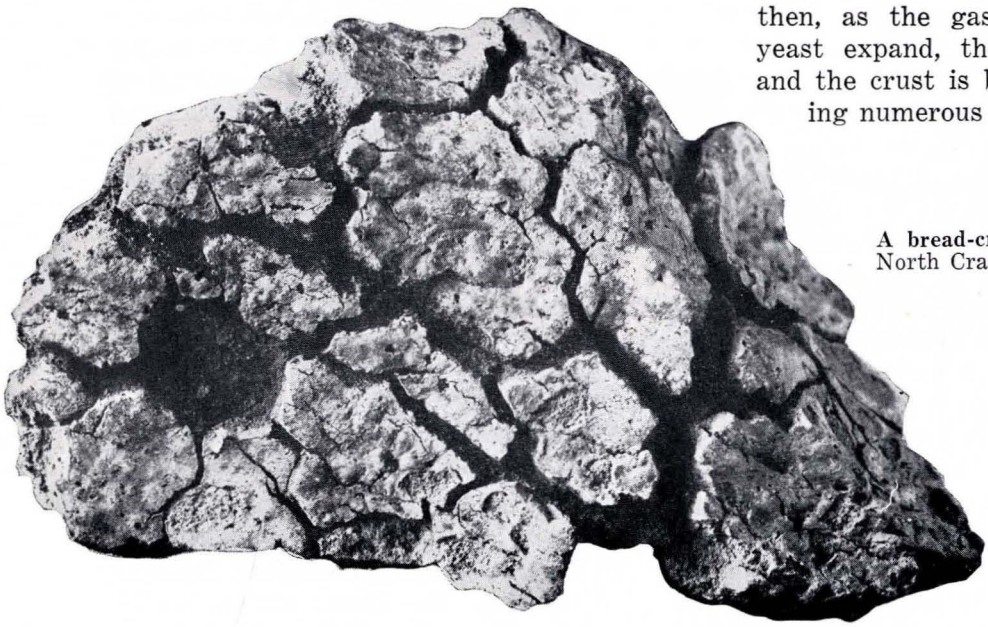
Probably the most curious of all the lava features that are found in the Monument are the lava bombs that lie scattered on the cinder and spatter cones. These bombs range in length from half an inch to more than 13 feet and in diameter from a quarter of an inch to 3 feet. There are three classes of bombs — 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 slightly different speeds or in slightly different directions. The longer ribbon bombs, such as those 2 to 13 feet in length and



A ribbon bomb "frozen" to a cinder. Actual size.

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 the 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.



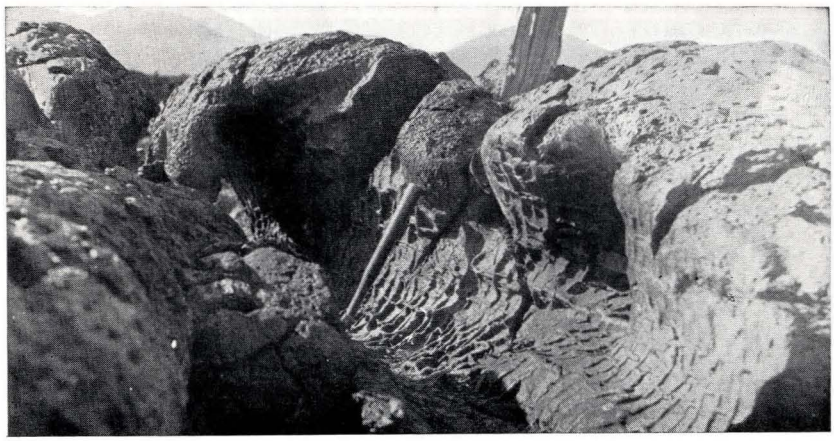
A bread-crust bomb from North Crater. Actual size.



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. Photo by H. T. Stearns.

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 has fallen or blown into the mold since it was formed. The explanation why molten lava does not completely obliterate a tree is due to the characteristics of lava flows. It is possible to walk on 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. Liquid lava at or near the temperature of solidification requires very little time to become a rock



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

that is a poor conductor of heat. Thus within a few minutes lava that surrounds a tree becomes a shell of solid rock. 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 with their upper portions uncharred and dead leaves still clinging to the banches over two years after their trunks had been partly buried by hot lava. There is much less chance for the formation of a mold from a dead tree, for it burns so rapidly that it may be destroyed completely 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 the 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 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 in the end tables.

There are two kinds of tree molds in the area. One kind, called lava trees, is 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[6] 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 [aa lava] 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

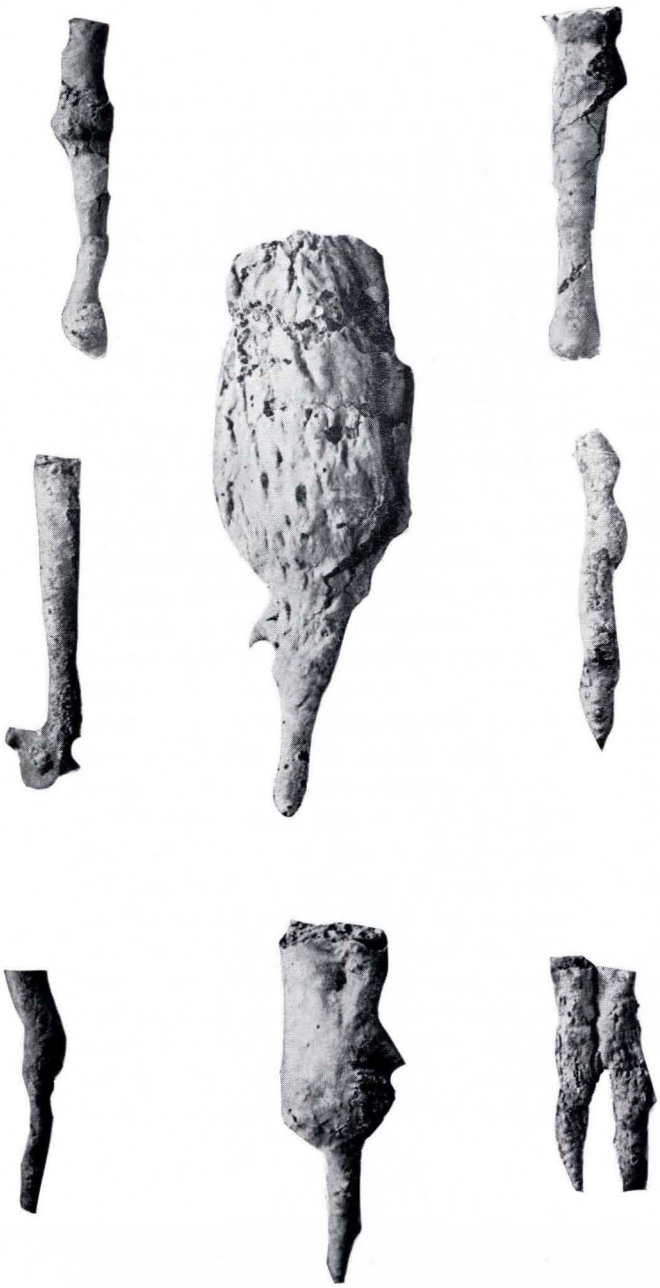
The visitor to the Craters of the Moon on a hot July day is amazed at the ice-cold water found in the most unexpected places. The temperature of the water rarely exceeds 34° F. There are three kinds of places where water or ice is found. Most of the large water holes occur in depressions in very rough, 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 the molten lava beneath, so it is a poor conductor for the downward passage of heat from the sun. Usually a small amount of ice melts during the summer and forms a pool of water. If one digs 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. 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. 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. Snow Cone is of this type and contains a heap of snow and ice about 20 feet thick in its crater. The locations of the water holes are given in the end tables.

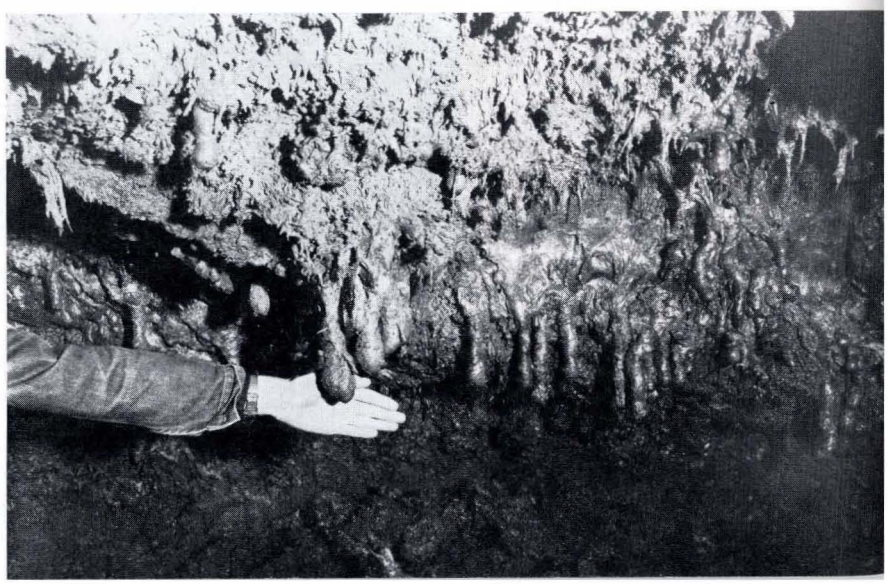
Many people imagine that some uncanny, mysterious method accounts for the formation of the ice, such as impossible chemical reactions and queer volcanic phenomena. On the active volcano of Kilauea, Hawaii, where



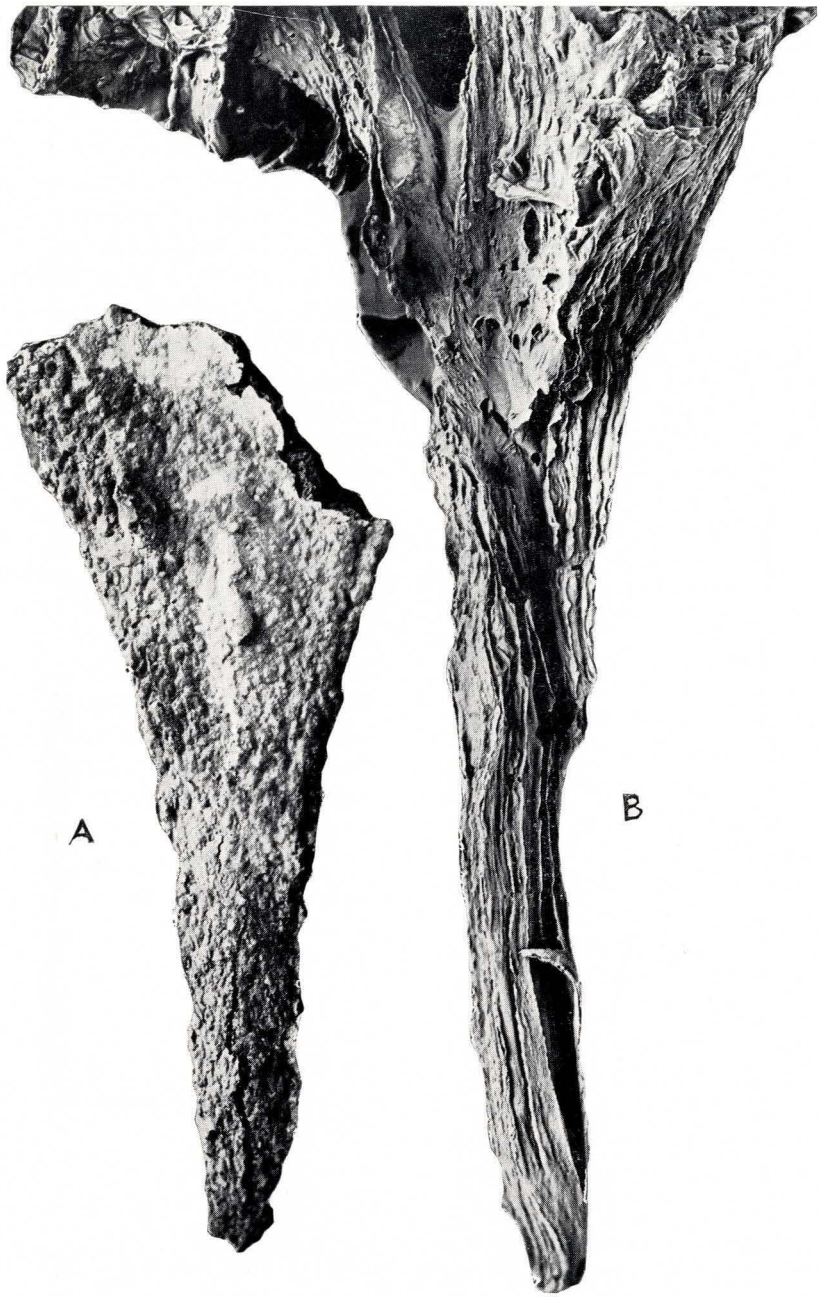
The narrow ledges parallel to the floor of Buffalo Caves mark temporary levels of a subsiding river of lava. Photo by D. C. Ochsner, National Park Service.



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



Bulbous stalactites in Arco tunnel formed by drip of lining as the lava level lowered in the tube. Photo by D. C. Ochsner, National Park Service.



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). Actual size.

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 and lava.

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 you remain and the more you see of the lava fields the more you will be impressed with the time that must have elapsed since the last eruption. The absence of soil on many of the flows is easily explained. 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 absolutely 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. The writer found a limber pine that had been growing in the Big Craters lava—a 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 into the soil deposits beneath. The pahoehoe tongue of the Big Craters flow 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 in 1902. He states:[7]

> No positive evidence was obtained to show that the dead trees which occur along their borders in certain instances were killed by the 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 range in age from 250 to 300 years. Thus the basis of his estimate 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. 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.

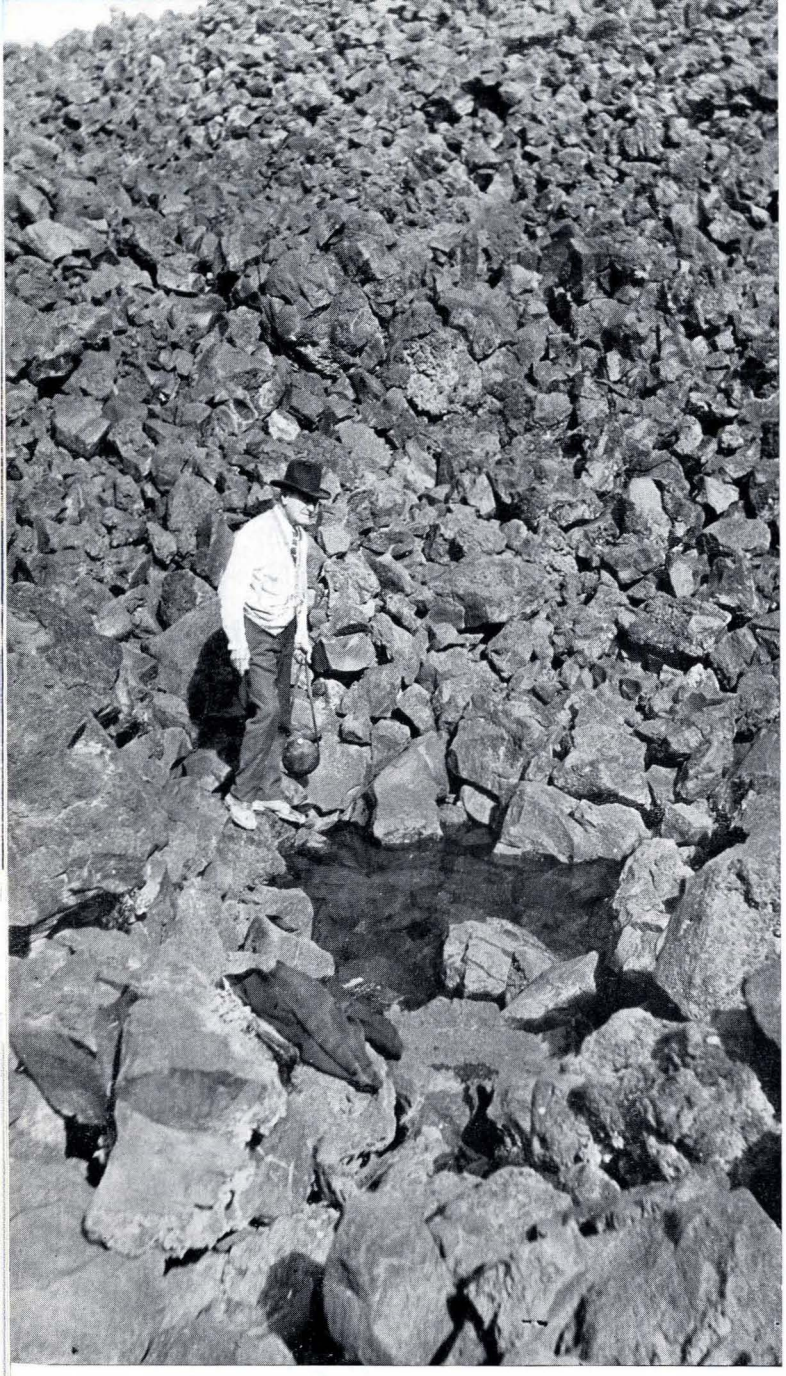
The charred trees on the cinder cones and at the edge of the flows which Russell mentions were carefully examined by the writer. They bear unmistakable evidence of having been burned by a brush fire set by lightning or by man. None of them was killed by the lava or by hot cinders. Several of the largest 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. Russell believed that this last flow from North Crater Cone was erupted immediately after the cone was formed but it appears from the degree of weathering that a considerable interval occurred between the formation of the cone and the outpouring of the glistening pahoehoe.

The "Triple Twist Tree" growing out of a crack in the North Crater Flow died in 1961 with a rotted heart. A core 16½ inches long removed from this tree by the Park Service in 1954 had 1350 years of growth as determined by a count of the annual rings by the Laboratory of Tree Ring Research at the University of Arizona. It is estimated that the tree is about 1500 years old allowing for the missing heartwood. This means that the lava is at least 1650 years old, if time is allowed for the lava to cool and soil to accumulate. The lava flow may be several times this old.

EARLY EXPLORATION AND INDIAN HISTORY

In 1879 the late Mr. J. W. Powell, formerly of Arco, Idaho, 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-grandfather saw fire in the region. On the basis of this statement the last eruption occurred in the early part of the eighteenth 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



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. Photo by H. T. Stearns.

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 are crescentic rock heaps. One theory is that these weighted down Indian tepees.

Several artificial mounds, now destroyed, existed at the north entrance to the Monument, in the cinders near the edge of the North Crater flow.



Margin of aa lava flow along the Great Owl Cavern trail in the Craters of the Moon National Monument. Photo by Peter G. Sanchez, National Park Service.

An aa lava flow crossing a road on Kilauea Volcano, Hawaii, May 21, 1955. Aa produces clinker by the forward motion of a very viscous lava which has lost most of its gases. Photo by G. A. MacDonald.





These mounds have been opened by several persons, but no human remains have been found in them. They consisted 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 people. It is probable that the ancestors of the modern Indian witnessed eruptions in the area as Indians frequented the region for hunting or took refuge from enemies in the numerous caves and craters. 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 the 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.

Note: Fred Bullard obtained a radiocarbon date of 2255±60 years before present for the Trench Mortar Flat lava flow and 2140±60 years B.P. for a pahoehoe flow at the base of The Watchman.

←

The ice caves on a hot July day never cease to arouse the wonder and curiosity of the visitor. Icicles festoon the ceiling of Boy Scout Cave. Photo by William Belknap, Jr.

Courtesy National Geographic Magazine © National Geographic Society

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[1]

NAME	Quarter	Section	Township	Range
Registration Booth Water Hole[2]	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[3]	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] Some have gone dry in recent years.
[2] Went dry for first time in 1928; near site of former registration booth.
[3] Dry in September and October, 1926.

DEFINITIONS OF VOLCANIC TERMS

Aa — a lava flow with a rough clinkery or loose blocky surface. The rock contains deflated and stretched vesicles.

Andesite — a lava generally gray in color and richer in silicon and sodium and poorer in iron than basalt.

Agglomerate — a term sometimes used for aa lava or lumps of lava stuck together while still hot in a spatter cone.

Ash — sand or dust size ejecta.

Basalt — a dark lava rich in iron and magnesium and comparatively poor in silicon; the common lava in the Monument.

Blocks — volcanic ejecta solid when thrown out and larger than 1½ inches across.

Bombs — volcanic ejecta molten when thrown out and having particular forms, such as ribbon, bread-crust, spindle, etc.

Butte — a hill rising abruptly above a plain.

Cinder cone — a mound built by small ejecta around a vent, with most of the fragments larger than ½ inch across, very vesicular, and mostly loose.

Crater — a depression at a volcanic vent.

Dike — the lava which solidified in a crack. Most are cross-jointed and with a long dimension much greater than the width. Basaltic dikes in the fissures of the Monument probably are less than 10 feet wide.

Ejecta — fragments of any size hurled out by a volcanic eruption.

Fault — a fracture in the earth's crust along which movement has occurred.

Fault scarp — a cliff formed by fault movement.

Feldspar — a light colored crystal with a complex silicate composition common in basalt.

Fumerole — a hole from which volcanic gases issue, usually lined with chemical deposits.

Igneous rocks — those formed by the solidification of magma.

Intrusive rock — a rock which congealed in a fissure or other opening below ground.

Kipuka — an island of old land surrounded but not covered by a lava flow. It can be higher or lower than the lava flow. Round Knoll is a kipuka.

Lapilli — volcanic ejecta ¼ to about 1 inch across.

Lava — either hot or solidified magma on the earth's surface.

Lava tree — a tree mold which rises above the level of a lava flow.

Lithic — stony.

Magma — liquid lava beneath the surface.

Olivine — a green crystal with a complex silicate composition common in basalts.

Obsidian — volcanic glass formed by lava chilling too quickly to crystallize. Tachylyte is the technical name of basaltic glass.

Pahoehoe — lava with a smooth or ropy surface spread chiefly through tubes and characterized by round vesicles.

Pumice — frothy or highly vesicular ejecta, chiefly glass.

Pyroxene — a dark colored crystal causing most of the dark color in basalt; it is a complex silicate.

Rhyolite — a light colored lava rock, higher in silica and poorer in iron than a basalt.

Rift — a lengthy fissure in the earth's crust.

Scoria — slaggy vesicular ejecta.

Shield volcano — a broad fairly flat lava cone having the shape of a shield. Commonly called "Lava Cone."

Solfatara — a fumerole which gives vent chiefly to sulfurous gases.

Spatter cone — a cone built by spatter around a vent. The clots stuck together when they fell.

Stalactite — cylindrical and pointed pendants that hang from the roof of a cave. In the Monument they are composed of lava which dripped while viscous.

Stalagmite — a small mound on the floor of a cave formed by the drip from a stalactite.

Tachylyte — basaltic volcanic glass. See obsidian.

Tree mold — a hole in a lava flow caused by lava making a cast of a tree trunk.

Tube — a lava cavern through which pahoehoe lava flowed.

Vesicular — having bubble holes formed by gas.

Vitric — glassy.

Volcanic rift zone — a zone of fissures from which lava has issued.

FOOTNOTES

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

2 For the reader interested in more detail regarding Hawaiian eruptions see Stearns, H. T. and Clark, W. O., Geology and ground-water resources of the Kau District, Hawaii including parts of the volcanoes of Kilauea and Mauna Loa Volcanoes: U.S. Geol. Survey Water Supply Paper 616, 194 pages, 1930 and Stearns, H. T. and MacDonald, G. A., Geology and ground-water resources of the Island of Hawaii: Hawaii Div. of Hydrography Bull. 9, 363 pages, 1946.

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

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

5 Stearns, H. T., and Clark, W. O., Geology and water resources of the Kau District, Hawaii: U.S. Geol. Survey Water-Supply Paper 616, 1930.

6 Reclus, Elisee, The Earth, vol. 2, p. 495, New York, G. P. Putnam & Sons, 1871.

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