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CRATERS OF THE MOON NATIONAL MONUMENT

Introduction

Location and Extent of Area

The Craters of the Moon National Monument, in southern Idaho lies between meridians 113° 25' and 113° 35' West Longitude and approximately between parallels 43° 20' and 43° 30' North Latitude. At the time it was studied, in 1926, it had an area of about 39 square miles but the geologic work was extended about 1 mile outside of the Monument in anticipation of an increase in size, hence the total area mapped is about 87 square miles. In 1928, the area of the Monument was enlarged to about 80 square miles. The Monument is crossed by the Boise base line and includes parts of Ts. 1 and 2 N., Rs. 24 and 25 E., and part of T. 1 S., R. 25 E. The area mapped is about 12 miles long and 10 miles wide, and lies in Butte and Blaine counties, at the foot of the White Knob Mountains on the edge of the Snake River plains. The Monument is reached by a branch of the Oregon Short Line Railroad, which runs from Blackfoot to Mackay. Arco, the nearest railroad station is 26 miles by road northeast of the Monument, and the Idaho Central Highway from Arco to Carey passes through its northern part. The Monument is about 200 miles by road west of Yellowstone Park, and about 30 miles east of Carey (see pl. 1.) At the present time there is no road approaching it from the south.

Purpose of the Investigation

The purpose of the investigation was primarily to explore this unique area and describe in detail its numerous volcanic features. A no less important purpose was the study of the structure of the flows and other volcanic forms which are so well exposed in this area in order to elucidate similar features less well preserved in the older flows of the Snake River Plains. A thorough understanding of the processes of volcanism so admirably displayed in the Monument leads to a fuller appreciation of the occurrence of ground water in the lava beds of the region as a whole. Of great interest also is the unusual occurrence of ice and water in this vast area of permeable lava. The contrast of a great heap of ice in the brilliant red throat of a fresh-looking spatter cone on a hot July day is complete and not easily for gotten. The reason why such ice is preserved and why water only a few degrees above freezing occurs in fractured lava in this dessert during the summer has always been the subject of considerable discussion. It is believed that the investigation solved this problem.

A popular account of the geology and natural history of the

Monument has already been published.[1] Practically all of the features found in the lava fields of the volcanoes of the Hawaiian Islands produced by historic eruptions and many of the volcanic forms that appear on the slopes of Vesuvius and Etna, in Italy, and among the volcanoes of Iceland are admirably displayed in this Monument. A few features are found here that excel even the best examples in other volcanic fields. It is a compact exhibit of volcanic forms almost in miniature, readily accessibly to the people of the mainland of the United States. In order to preserve this unusual volcanic phenomena for posterity, the area was proclaimed a national monument by President Collidge on May 2, 1924.

The writer's (Stearns) appreciation of the warm hospitality and the indefatigable efforts of Mr. S. A. Paisley, former Custodian of the Craters of the Moon National Monument, cannot be too strongly expressed. Mr. Paisley accompanied him on many long and tedious trips across the lava beds, without recompense and solely as a Labor of love in order that the less obvious though no less interesting features of the area could be included in this report. It is fitting to state here that Mr. Paisley has spent many days during the past ten years exploring the Monument and that many of the caves and waterholes were unquestionably first discovered by him. He exemplifies the patriotic and public-spirited characters who pioneered the Snake River Desert.

Mr. Era Martin rendered valuable help and furnished information on the early history of the area. The writer is indebted to Mrs. Martin for the gift of a number of excellent photographs of the lava. The writer is particularly grateful to them for hospitality on this trip and during a previous visit to the area. Acknowledgements are also due to the people of Arco for their kindly and willing cooperation and especially to Mr. C. A. Bottolfsen, editor of the Arco Advertiser. Mr. E. C. Eckert furnished numerous excellent photographs, several of which are used herein.

The geologic work was greatly facilitated by the excellent topographic map (pl. 16) made by Max J. Gleissner, of the United States Geological Survey, which was made possible through funds furnished by the Idaho State Bureau of Mines and Geology and the United States Geological Survey. Mr. Howel Williams kindly

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[1] Stearns, H. T., Craters of the Moon National Monument, Idaho: Idaho Bureau of Mines and Geology Bull. 13, 1928. (Out of print.) Reprinted as "A guide to the Craters of the Moon National Monument, Idaho", Caxton Printers, Caldwell, Idaho, 1930

examine the lavas in thin section and furnished the petrographic descriptions. His careful work and interest are especially appreciated. The constructive criticism of Dr. O. E. Meinzer, under whose supervision the work was done, of Mr. B. H. Lane of the United States Geological Survey, and that of Dr. F. E. Wright of the Geophysical Laboratory of the Carnegie Institution, is greatly appreciated. Dr. Meinzer visited the Monument in 1921, and first noted the remarkable fissures that characterize the Great Rift Zone, and in 1923, Dr. Wright pointed out the resemblance of the features of the Great Rift Zone to those of the rift zones in the lava fields of Iceland.

History of Exploration

In 1868, Irving[1] wrote as follows: "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." Doubtless he was describing the region which is now the Craters of the Moon National Monument. A map and early records show that in all likelihood the area was visited earlier, about 1840-45, by Father De Smet, a Belgian priest.

In 1879, Mr. J. W. Powell, formerly of Arco, Idaho, but now residing in Long Beach, California, visited the area. Having been offered a substantial reward for the discovery of sufficient water to supply several hundred head of cattle in the early eighties, Mr. Powell, with Arthur Ferris, explored the lava beds even beyond what is now the south boundary of the Monument. They were undoubtedly the first white men to explore the interior of this expanse of lava. A large stone marker built by Mr. Powell on this trip still stands near the waterhole in Vermillion Chasm. A shoulder bone of a cow was found in 1926 in Buffalo Caves with the names of these 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 places 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. It is not impossible that an eruption occurred in the area at that time. There can be no doubt that the Shoshone Indian frequented the area, for hunting blinds are found in the Little Prairie aa flow on the south side of the Watchman, and several obsidian arrow-heads, scrapers, and other artifacts were gathered in the Monument during the investigation. Mr. Era Martin found a nearly complete pottery bowl near Echo Crater, and near Indian Tunnel there can still be

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[1] Erving, Washington: The adventures of Captain Bonneville, U. S. A.: Judson Edit., p. 203, New York, 1868.

seen the crescentic rock heaps that weighted down the Indian teepees. Further, at the north entrance to the Monument in the cinders near the edge of the North Crater flow there formerly existed several low artificial mounds that are now nearly destroyed. These mounds have been opened by several persons but no human remains have ever been found in them. They consist of cinders and safebrush 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 lies lengthwise in the direction of the trail now faintly discernible across the lava to the southeast. Dim trails probably used by Indian and animal alike can be discerned here and there in the cinders or in the loose material on the surface of some of the lava flows. Occasionally three or four moss-covered pieces of lava rock or cinders piled on a prominent point mark a trail or waterhole 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 probably 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 for everyone who has traveled among primitive tribes is aware of the amazing ability of such people to invent stories to explain everything and always to the satisfaction of the questioner. The Indians doubtless recognized from its appearance that the lava had once been molten and hot, hence may not have been slow in inventing a story regarding it.

In 1901, the area was visited by I. C. Russell, of the United States Geological Survey, who wrote the first scientific account of it[1]. He called it the Cinder Buttes region and he became so interested in the remarkable bombs in the area that he revisited it in 1902, and published a second account in 1903[2]. It is evident from his descriptions that he visited only the northern part of what is now the Craters of the Moon National Monument. Sinc

Since 1901, the area has been visited by local people on hunting expeditions and from about 1910 on, Mr. S. A. Paisley, first Custodian of the Monument, made numerous trips into the area

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

[2] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: U. S. Geol. Survey Bull. 217, p. 36, 1903.

and located many of the caves and natural bridges. Mr. Era Martin, who has lived within 3 miles of the area for over forty years, discovered and marked with monuments many of the caves and waterholes. He also made the wagon road across the lava beds and constructed the concrete watering trough at Little Prairie Waterhole.

In 1921, R. W. Limbert,[1] a taxidermist of Boise, Idaho, visited the area and published an account of his trip in the National Geographic Magazine. In the same year, Dr. O. E. Meinzer, Chief of the Division of Ground Waters of the United States Geological Survey, and the writer visited the area. In 1923, the writer, accompanied by Dr. F. E. Wright, of the Geophysical Laboratory of the Carnegie Institution of Washington, again made a trip to it and published a description in the Geographical Review.[2] Because of the unique character of the region the writer was asked by the National Park Service, in January, 1924, to submit a report describing the area, delineating boundaries, and stating the reasons for its preservation as a national monument. This was done, and on May 2, 1924, the area was created as a national monument by a proclamation of President Coolidge.

In 1925, the topographic map of the Monument was made by M. J. Gleissner, of the United States Geological Survey, and during the mapping, many new and interesting features were discovered. In 1926, the writer made his third visit to the area and spent a month mapping its geology. During this work several new caves, waterholes, and other unique volcanic forms were found. So hidden are the caves and other features that many probably still remain to be discovered.

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[1] Limbert, R. W., Among the Craters of the Moon: Nat. Geogr. Mag., vol. 45, pp. 303-328, 1924.

[2] Stearns, H. T., Craters of the Moon National Monument: Geogr. Review, vol. XIV, No. 3, pp. 362-372, July, 1924.

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Geography

Climate

The climate in the Craters of the Moon National Monument is semi-arid and similar to that which prevails over the Snake River Plateau. The amount of precipitation throughout is variable because of the critical relation of the area to the adjacent mountains. The northern part lies at the foot of the White Knob Mountains, whereas the southern part lies well out on the plain and about 400 feet lower and hence lies in the path of the dry westerlies. During the the period 1892, to 1897, a precipitation station was maintained at Martin Post Office about 3 miles north of the area, a place having the same relation to the mountains as the north end of the Monument. The mean precipitation at this station for the period on record is 15.60 inches. The average annual precipitation in the area probably ranges from 10 to 13 inches, and most of it falls during the winter months in the form of snow. Slight precipitation usually occurs in the months of July and August, practically all of which accompanies thunderstorms. Records of the monthly, annual, and average precipitation at Martin during the years 1892 to 1897, as obtained from the United States Weather Bureau are given in the following table:

Monthly, annual, and average precipitation in inches at Martin, Butte County, Idaho. - Altitude 5,600 feet. (From records of the U. S. Weather Bureau)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1892 -	....	....	....	....	4.27	1.94	T.	0.02	1.70	1.42	2.10	3.32	.....
1893	1.75	1.93	2.66	1.19	0.70	0.00	0.19	0.12	0.58	0.02	1.33	1.05	11.52
1894	2.58	1.75	3.93	1.75	0.20	0.78	0.06	0.35	0.10	1.18	0.00	1.95	14.58
1895	2.65	0.15	3.10	0.66	2.17	0.50	0.55	0.30	1.25	0.00	0.40	1.16	12.89
96	3.35	0.15	2.30	0.55	3.45	....	0.40	0.10	0.24	0.55	5.10	0.20	.....
1897	0.00	2.40	3.70	0.40	....	....	T.	1.00	....	....	....	....	.....
Means	2.06	1.28	3.14	0.91	2.16	0.80	0.20	0.32	0.77	0.63	1.79	1.54	15.60

The The precipitation at Martin is somewhat greater than at Arco because Martin is about 300 feet higher. The altitude of Arco, which lies about 26 miles northeast of the Monument is about the same as that of the south end of the Monument, hence the p recipitation at both these places is proably similar. The average annual sowfall in the Craters of the Moon, based upon records at Arco is probably about 40 inches, and snow falls have been recorded in every month of the year except July and August.

The prevailing wind direction is southwest in all months of the year and high wind velocities have occurred. Stretching northeastward from Big Cinder Butte and especially prominent on the Trench Mortar

Flat lava flow, is a line of trees all blown down in the same direction. The path of the storm that swept this flat is rather well defined, but the rotten condition of the trees indicates that they were blown down many years ago.

The highest temperature recorded at Arco is 101°F., and the lowest is -41°F. The mean annual temperature is 40.8°F. A summary of climatological data for Arco for the years 1894 to 1920 is given in the table below because it approximates that of the Monument. It is pertinent in relation to the occurrence of ice and water in the Craters of the Moon National Monument that the mean minimum temperature is below the freezing point of water seven months of the year.

Summary of climatological data for Arco, Butte County, Idaho.[1] Altitude 5318 feet.

Record for the years 1894 to 1920[2]	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean maximum temp.	28.0	33.6	42.7	56.9	64.1	71.9	82.5	82.2	72.0	59.0	44.6	30.7	55.7
Mean minimum temp.	1.8	6.4	18.0	28.0	34.8	40.4	46.2	45.3	36.7	28.9	17.6	6.1	25.8
Mean temperature	14.9	20.0	30.4	42.4	49.4	58.2	64.4	63.8	54.4	14.0	31.1	18.4	40.8
Highest temperature	52	54	65	85	90	95	101	97	90	80	69	40	101
Lowest temperature	-34	-41	-20	-3	15	23	14	23	19	8	-17	-23	-41
Average number of days, 0.01 inch or more of precipitation	5	4	5	4	7	6	4	3	3	4	4	4	53
Prevailing wind direction	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
Average monthly and annual snowfall in inches	11.4	6.4	9.3	1.4	0.7	0.1	0	0	0.1	1.2	5.2	7.0	42.8
Average monthly and annual precipitation in inches and hundredths	1.10	0.51	1.00	0.64	1.45	1.19	0.60	0.47	0.66	0.62	0.63	0.76	9.63

[1] Fursnished by U. S. Weather Bureau, Boise, Idaho.

[2] From 1894 to 1910, inclusive, the values are for Lost River, about three miles northwest of Arco. For the year 1913 the values are for Moore, about seven miles northwest of Arco.

Some data on prehistoric climate based on the width of the rings of a tree on a recent lava flow in the Craters of the Moon National Monument is given on pages to . The graphs indicate successive periods of favorable and unfavorable growth which are in general indicative of greater and less amounts of precipitation. However, the important factor in tree growth is believed to be the amount of snow and the length of time it lies on the surface. Therefore, increased amounts of snowfall or a lower temperature with a consequent longer period of snow on the ground can be deduced from high peaks in the graphs. Irregularity in the variations is dominant but large cyclic fluctuations are discernible. It may be that these fluctuations correspend to those of world climate as related to sunspots and other cosmic conditions such as discussed by Douglass,[1] Huntington,[2] and others.

A discussion of the flora and fauna of the Craters of the Moon National Monument has been published in an earlier report,[3] and therefore, will not be repeated here.

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[1]Douglass, A. E., Climatic cycles and tree growth, Cargegie Pub. 289, 1919; Some aspects of the use of the annual rings of trees in climatic study, Smithson Rept. 1922, pp. 223-239.

[2]Huntington, Ellsworth, Fluduating climate of North America, Smithson Rept. 1912, pp. 383-412.

[3]Stearns, H. T., Guide to the Craters of the Moon National Monument, Idaho: Caxton Printers, Caldwell, Idaho, pp. 48-54, 1930.

of the lower ones have been partly bured by subsequent lava flows (see pl. 16). The location of the prominent cinder cones and the altitudes of their summits given in order as they extend southeast from the White Knob Mountains, which occupy the northwest corner of the area, are given in the following table.

Prominent cinder cones

	Altitude (feet)	Height above adjacent plain (feet)	Sec.	T.	R.
In the Great Rift Zone					
Sunset Cone	6383	590	26	2 N.	34 E.
Grassy Cone	6351	450	34	2 N.	24 E.
North Crater Butte	6338	440	35	2 N.	24 E.
Paisley Cone	6050	350	1	1 N.	24 E.
Inferno Cone	6177	300	1	1 N.	24 E.
Big Craters Butte	6300	300	2	1 N.	24 E.
Silent Cone	6346	450	2	1 N.	24 E.
Broken Top	6060	225	12	1 N.	24 E.
Big Cinder Butte	6516	800	13	1 N.	24 E.
Half Cone	6041	350	18	1 N.	25 E.
Crescent Butte	6089	490	11	1 N.	25 E.
Coyote Butte	5907	300	19	1 N.	25 E.
Echo Crater Butte	5850	250	29	1 N.	25 E.
The Watchman	5871	325	28	1 N.	25 E.
The Sentinel	5840	250	33	1 N.	25 E.
Split Butte	5750	250	3	1 S.	25 E.
Fissure Butte	5877	425	10	1 S.	25 E.
Sheep Trail Butte	5617	150	10	1 S.	25 E.
Two Point Butte	5471	120	23	1 S.	25 E.
Outside of the Great Rift Zone					
Round Knoll	5631	125	27	2 N.	25 E.
North Laidlow Butte	5906	350	7	1 S.	25 E.
Bowl Crater Butte	5596	50	18	1 S.	25 E.

Geology

General Character and Age of the Rocks

All the rocks in the area are igneous except one small patch of alluvium, hence it is difficult to ascertain their geologic age. The two chief kinds are basalt and andesite. The andesites are confined to the White Knob Mountains which occupy only about 3 of the 87 square miles that were mapped. They are usually assigned to the Miocene(?) but on very meagre evidence.[1] These eruptives rest on eroded surfaces of bodies of granite of Mesozoic(?) age in many places in this part of Idaho. Granite prophyry of later age has been entruded into the Miocene(?) eruptives in the White Knob Mountains.

The basalt is similar in appearance to that which makes up most of the Snake River Plains. It occurs as flows and pyroclastics and except for patches of soil here and ther, crops out over about 84 square miles of the area shown in Plate 16. The freshness of the youngest flows suggests that they are probably not over a thousand years old. The older flows, such as occupy Little Laidlow Park, in secs. 18 and 20, T. 1S., R. 25 E., may be of early Pleistocene age.

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[1]Umpleby, J. B., Westgate, L. G., Ross, C. P., Geology and ore deposits of the Wood River region, Idaho: U. S. Geol. Survey Bull. 814, p. 60, 1930.

Tertiary System

During the mapping of the volcanic features, little time was available for the study of the older rocks in the adjacent mountains which at that time were outside of the monument boundary. The few hours spent in the mountains nearby were sufficient to show that the rocks were andesite and dacite flows and intrusive granite porphry. Petrographic descriptions made by M. N. Short of the U. S. Geological Survey of four specimens collected from the foot of these mountains by Mr. S. A. Paisley for the writer are as follows:

"Specimen C-136, SW. ¼ NW. ¼ sec. 34, T. 2 N., R. 24 E. Andesite. Phenocrysts consist of large feldspar crystals up to 3 mm. diameter of equidimensional habit, togerher with a few scattered biotite plates and here and there a grain of green hormblende. The groundmass is feldspar in interlocking grains approximately 0.10 mm. diameter with a small proportion of biotite in irregular scales. The feldspar is andesine. The feldspar phenocrysts are very fresh; the feldspar of the groundmass is partly kaolinized. Some of the biotite plates are very fresh but some are partly chloritized.

"Specimen C-140, SW. ¼ SE. ¼ sec. 27, T. 2 N., R. 24 E. Andesite. The phenocrysts are andesine feldspare of equi-dimensional habit. Most of them are fairly fresh but some of them are partly replaced by secondary carbonate and epidote. Biotite phenocrysts were formerly present although never abundant. All the biotite has been completely altered. Some areas of chlorite remain but for the most part chlorite has been taken away in solution leaving rutile needles in parallel lines to record the former cleavage plates. The groundmass is feldspathic and finer grained than C-136. It is extensively replaced by tiny rounded grains of epidote. Carbonate is also abundant in the groundmass.

"Specimen C-141, Knoll in NW. ¼ NE. ¼ sec. 26, T. 2 N., R. 24 E. Andesite. Phenocrysts consist of coarse rounded plagioclase feldspar crystals. The groundmass was probably fine grained or glassy but is now so completely altered that its original character is uncertain. Serpentine predominates in the groundmass. Most of the feldspar phenocrysts are comparatively fresh; some are somewhat sericitized. In addition to the feldspar some biotite crystals, tabular in form and averaging 1 mm. long occur as phenocrysts. Very few of them are fresh. Most of them are completely chloritized. This rock appears to be an altered facies of C-136.

"Specimen C-138, SE. ¼ NW. ¼ sec. 27, T. 2 N., R. 24 E. Andesite. Similar to C-141 but fresher. Groundmass is chloritized. Feldspar phenocrysts are practically unaltered. Biotite phenocrysts are practically all altered to chlorite."

Biotite dacite crops out near the head of Little Cottonwood Creek. Howel Williams, who kindly examined microscopically a specimen from this place, describes it as a mica-andesine-dacite glass containing conspicous phenocrysts of biotite and plagioclase in a glassy siliceous base showing pronounced flow structure. Orthoclase is rare and porphyritic quartz is absent. These extrusive rocks belong to the extensive group of eruptives that occupy former valley and that have been assigned to the Miocene by Umpleby.[1] Recent work in this part of Idaho[2] indicates that the granite prophry was intruded after the Tertiary eruptives because it has been found cutting them.

Since this report was written, Anderson has mapped the geology of the basaltic cones in the White Knob Mts. that lie on the extension of the Great Rift Zone.[3]

About the middle of sec. 22, T. 2 N., R. 24 E., in the bed of Little Cottonwood Creek, is the Martin-Heslop Mine. Galena and gold-bearing pyrite in a white clayey matrix is mined at this place. The ore is separated from the matrix by a jig and hauled away from the mine in sacks.

Ejected rock fragments among the cinders on the cone indicate that rhyolite and granodiorite underlie the basalt.

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[1]Umpleby, J. B., Geology and ore deposits of Lem hi County, Idaho: U. S. Geol. Survey Bull. 528, p. 35, 1913.

[2]Umpleby, J. B., Westgate, L. G., and Ross, C. P., op. cit. p. 61.

[3]Anderson, A. L., Lava Creek vents, Butte County, Idaho: Northwest Science, Vol. 3, pp. 13-18, 1929.

Quaternary System

Alluvium

The only alluvium in the area, the fan of Little Cottonwood Creek, covers about one-fourth of sec. 27, T. 2 N., R. 24 E. It is unconsolidated and is composed chiefly of rounded and subangular granitic and andesitic cobbles and sand. During its low stages in the summer this creek flows only a few gallons a minute, and sinks into the alluvium. In the spring the creek carries considerable debris which is deposited at the edge of the lava plain at the foot of the mountains in the form of an alluvial fan. During flood stage the creek forms a pond at the edge of the lava, but fails to overflow, hence all of its load of silt, sand, and gravel is deposited in this place. The alluvial fan, however, is by no means comparable to the size of the canyon Little Cottonwood Creek has excavated, hence a considerable amount of the alluvium must be buried by the lava flows from Grassy and Sunset cones that have encroached upon the fan. This interfingering of the alluvial fans of the creeks discharging from the mountains with the basalt flows accounts for the rapidity with which water escapes from the streams into the adjacent lava. Thus, the surface water escapes into the upper lava beds while the underflow of the stream follows the gravel beds and sinks into lower lava beds. This water percolates through the cavernous lava and eventually discharges as springs in the Snake River Canyon.

Igneous Rocks

Basaltic flows and cinder cones cover approximately 34 of the 87 square miles shown in the geologic map on Plate 16. They are very conspicuous, for many of the flows are black and fresh in appearance and the cinder cones stand out as prominent features of the landscape. The basalt flows are dark bule and black and often have satiny, glassy crusts. They vary in vesicularity from scoriaceous types in which the vesicles make up over 50 per cent of the mass to dense stony lavas in which vesicles are rare or microscopic. The vesicular lavas greatly predominate. As a rule the lavas are aphanitic although occasionally phenocrysts 1/2 to 1 centimeter across are found in them.

Howell Williams, who examined some specimens from this area under the microscope describes them as follows:

> "They are without exception olivine basalts and are abnormally rich in magnetite. They consist typically of microliths of basic andesine and acid labradorite, together with granules of a colorless olivine, in a glassy matrix rendered opaque by iron ores. On the evidence of the few specimens studied, there appears to be no essential difference between the 'older' and the 'newer' lavas or between the aa and the pahoehoe flows. The dominant basalt is hyalopilitic and only exceptionally carries crystals large enough to be recognized by

the aid of a hand lens. Olivine is never distinguishable microscopically, but phenocrysts of basic andesine ($Ab_{55}An_{45}$) usually much resorbed, may attain a length of 15 millimeters as in the pahoehoe flow from North Crater and in the Little Prairie aa flow.

"Dense black basaltic obsidian (tachylyte) occurs as thin beds in the cinder crags in the Devils Orchard, and in similar crags south of Big Cinder Butte. The refractive index of a specimen from Obsidian Crag in the Devils Orchard (see pl. 16) is 1.596 which suggests a silica content of 48 per cent and an iron oxide content of 14 per cent. Tachylyte is also present as irridescent or blue skins on the surfaces of the pahoehoe flows and is then characterized by the segregation of magnetite granules about the earlier formed microliths of labradorite.

"The olivine of the basalts is present chiefly as rhomb-shaped sections or as rounded granules, varying only slightly from a millimeter in diameter. The better formed crystals are invariably elongated parallel to 'a' (100). They never exhibit alteration. The negative orientation of the mineral suggests a content of FeO exceeding 12 per cent.

"Magnetite is usually present in two generations, the earlier being represented by cubes and octahedra dispersed throughout the lavas and penetrating all other constituents. The later generation is present, as dense dust and formless granules in the glassy base. The approximate percentage of this magnetite-filled base is rarely less than 50, and is usually about 70.

"The characters enumerated above are shared by all the basalts alike, the only important differences between the various lavas being in the relative amounts and in the different sizes of the constituents. The coarsest types observed are from the pahoehoe flow of Grassy Cone (specimen C 84) and from the walls of Vermillion Chasm (specimen C 120)."

Only one analysis has ever been made of the lavas in the region, namely that of a specimen of basalt collected by I. C. Russel from near the entrance to the Monument. Its location cannot be definitely ascertained from his description, but was probably taken from one of the flows from North Crater or Big Craters. This basalt has the

position (II) III. 5. (2) 3. 4. in the quantitative classification of igneous rocks.[1] The analysis of this specimen is given in the table below with analyses of some basalts from other lava fields for comparison.

Analyses of basalts from various lava plateaus

	1	2	3	4
Silica SiO_2	51.14	49.08	48.79	50.12
Alumina Al_2O_3	13.95	13.71	11.96	13.52
Ferris (iron) oxide Fe_2O_3	2.15	1.25	2.51	3.99
Ferrous (iron) oxide FeO	12.97	13.02	12.10	9.19
Magnesium oxide MgO	2.21	4.56	5.60	5.42
Calcium oxide CaO	6.56	8.44	10.15	9.97
Sodium oxide Na_2O	3.59	3.11	2.40	2.42
Potassium oxide K_2O	2.33	1.31	0.70	0.56
Water above 105° C.	0.22	0.90	0.40	1.46
Water below 105° C.	0.12	0.20	0.65	0.14
Titanium dioxide TiO_2	2.41	3.56	4.17	2.46
Phosphoric oxide P_2O_5	1.59	0.73	0.37	0.29
Chromic oxide Cr_2O_3	None	n.d.	trace	none
Manganous oxide MnO	0.44	0.25	0.21	0.18
	[a]100.30	100.20	[b]100.59	[c]99.84

[1]Recent lava near Big Craters, Craters of the Moon National Monument, Idaho. Hillebrand, analyst. I. C. Russell, U. S. Geol. Survey Bull. 199, p. 87, 1902.

[2]The Dalles, Columbia River, Oregon. Washington, analyst. H. S. Washington, Bull. Geol. Soc. America, vol. 33, p. 779, 1922.

[3]Basalt (Tertiary) Holmatindur, Eski-fjord, Iceland; Harwood, analyst. Holmes, Mineralogical Magazine, vol. 18, p. 193, 1918.

[4]Deccan basalt Jiran near Mimach, Central India; Washington, analyst. Bull. Geol. Soc. America, vol. 33, p. 774, 1922.

[a]Includes ZrO_2, F, 0.10; FeS_2 0.15; NiO, trace; BaO, 0.25; SrO, trace.

[b]Includes CO_2, 0.41; S, 0.06; V_2O_3, 0.11; Cl, trace; NiO_2, trace; BaO, trace, SrO, none.

[c]Includes ZrO_2, none; SO_3, 0.09; BaO, 0.03.

[1]Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, p. 607, 1917.

A well drilled in Laidlow Park not far from the south boundary of the Monument penetrated 918 feet of basalt before reaching the older lavas. There is reason to suppose from the topography that the flows thicken southward and that the basalt in the northern end of the area may not exceed 200 feet in thickness.

Age of the Lava Flows

The ancient basalt flows in the area, especially those which issued from cinder cones outside of the Great Rift Zone, are tentatively assigned to early Pleistocene. The oldest of these flows, such as occupy Little Laidlow Park, are almost entirely covered with soil. This soil cover is chiefly a loess with only a small part derived from the disintegration of the underlying basalt. The accumulation of the loess is a very slow process, as shown by the deposition of only 25 feet of loess on the Hagerman lake beds since Pliocene time in a place close to the sources of supply. A loess deposit barely adequate to cover the rough surface of the basalt near the Camas Meadows has been formed since the earliest glacial stage recognized in southern Idaho.

All intermediate stages are found in the Monument between older soil covered flows and flows which are fresh, bare, and black. Locally some of the flows have thick mantles of pumice blown from and adjacent cinder cones, but this deposit should not be confused with the loess which is like rockflour and is slowly transported eastward by the wind from the desert to the west and south. The origin of the loess has never been fully determined but certainly some of it is derived from such sources as the weathering of the Tertiary lake beds, the alluvial fans and playas of small streams, the banks of Snake River, and the more violent explosive eruptions that have occurred in Idaho and Oregon in Pleistocene time.

All who have seen the latest lava flows in the Craters of the Moon area must wonder about their age and that of the last eruption. Common methods used to estimate the age of the lavas, include: amount of soil cover and vegetation; size and age of trees growing on the lavas; possible presence of trees charred by heat of adjacent lava flows; lava adhering to sagebrush; and charcoal in tree molds.

The charred trees on the cinder cones and at the edge of the flows which Russell was unable to convince himself were killed by the heat of the lava, were carefully examined by the writer. They bear unmistakable evidence of being burned by brush fires set by lightning or by men. 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 the bare cinders were also burned by brush fires. The ashes of the brush have disappeared leaving bare patches of cinders between the trees.

Limbert[1] was even more optimistic regarding the recent age of the lava than was Russell. He added that he thought perhaps some of the small spatter cones erupted in 1866, at the time of an eruption of Buffalo Hump in Idaho County, Idaho. He fixes this date of the Buffalo Hump eruption on Bancroft[2] who based it upon several old Idaho newspaper accounts, such as the Wood River Miner of September 21, 1881; the Idaho World, June 30, 1866, and the Silver City Avalanche, January 29, 1881. Unfortunately, these accounts are unreliable for it is now definitely established that no eruption occurred at Buffalo Hump in historic time. Francis A. Thomson, former Deal of the Idaho School of Mines and Secretary of the Idaho Bureau of Mines and Geology, has examined Buffalo Hump and states that there is not the least sign of an eruption. Other geologists who are familiar with the area also agree that there is no foundation for the statements of the newspaper articles.

Limbert[3] states that he found charred sagebrush near a fissure vent north of Echo Crater, but Mr. Era Martin states that he burned off the brush in this area to develop pasturage a few years prior to Limbert's visit. Limbert states also that he picked up near the same spot a piece of brush with a clot of lava frozen to it. The specimen found by Limbert either was formed by the sagebrush growing up through a hole in a lava clot, or it was a peculiar stony-like insect deposit on the brush. Lava is not sticky when it falls on anything and shows no tendency to adhere to wood. In fact it shrinks away from an object as it cools, and the brush on which it falls is generally reduced to charcoal. Mr. J. A. Harrington of Idaho Falls kindly loaned the writer a specimen of sagebrush found in the vicinity which was adhering. It was a substance closely resembling a lava clot, and, of all those who saw it while it was exhibited by Mr. Harrington, not one expressed the slightest doubt as to its volcanic origin. It was, however, a granular, cellular mass of material resembling basalt but much softer, composed of tiny particles of basaltic glass derived from adjacent weathered scoria and deposited on the wood by some insect. The material could be cut readily with a knife, had a glossy film on its surface and encircled about one-half of the wood stem which is three-fourths of an inch in diameter.

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[1]Limbert, R. W., Among the Craters of the Moon: Nat'l. Geogr. Magazine, vol. 45, p. 328, March. 1924.

[2]Bancroft, H. H., History of Washington, Idaho, and Montana, p. 396, vol. 31, 1890.

[3]Op. cit., p. 328.

In the Keaiwa lava flow, Hawaii, partly charred wood and charcoal was found adjacent to tree molds.[1] The precipitation in the area of these tree molds is not very different in amount and distribution from that in the Craters of the Moon area. Charcoal in large tree molds is known to last a century or more. It is reasonable to assume that charcoal should be found in the tree molds associated with the latest flows in the area discussed if they are only one hundred to two hundred year old. Tree molds, many of them three feet in diameter and ten to twenty feet deep are found in practically all of the recent lava flows in the Craters of the Moon except the last one from North Crater which spread out on the plain for a distance of four miles. But charcoal was not found in any of the ones examined. This recent flow from North Crater was especially searched for molds and charcoal but not one mold was found. The absence of the tree molds in this case is due to the presence of a slightly older and more extensive flow from the same crater that nearly everywhere underlies the recent flow and which probably destroyed any former vegetation. The flows which issued from several places on the sides of the Big Craters Butte in sec. 2, T. 1 N., R. 24 E. cover many square miles and appear to be about as fresh as the North Crater flow. Tree molds in these flows also were carefully examined for charcoal but none was found. It is concluded that this criterion of recency is absent in the Monument.

Magnetic method. - A magnetic method of investigation was used by the writer (Stearns) to determine the age and chronology of the flows. It has been shown by Chevallier[2] that each basaltic flow on the slopes of Etna Volcano, Sicily, has a slightly different magnetism according to the year it was extruded. It is a well established fact that because of the wandering of the magnetic poles of the earth the direction in which a compass needle will point varies slightly from year to year at any given point on the earth's surface. The amount of deviation of the compass needle away from the true geographic poles of the earth expressed in degrees and fractions thereof, is known as magnetic declination. The slight variation in the declination over a long period of years at a given place is known as the secular change. The annual change is the amount of secular change in one year. The mean declination for Arco for 1926, as furnished by the U. S. Coast and Geodetic Survey was 19° 45' E. and the annual change is a decrease of about 1' at the present time. A record of the change in declination for Pocatello, Idaho, which is located about 65 miles southeast from Arco from 1850 to 1920, as furnished by the U. S. Coast and Geodetic Survey is as follows:

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[1]Stearns, H. T., The Keaiwa or 1823 lava flow from Kilauea Volcano, Hawaii, Jour. of Geo., Vo. 34, No. 4, p. 343, May-June, 1926.

[2]Chevallier, R., L'simantation des laves de l'Etna et l' orientation du Champ terrestra en Sicile du XII-e au XVII-e sicle. Ann. Phys., Paris, Ser. 10, V. 4, pp. 5-162, July-August, 1925.

Secular change of the magnetic declination
for Pocatello, Idaho

(Latitude 42° 52', longitude 112° 26')

Year	East
1850	17° 41'
1860	17° 57'
1870	18° 05'
1880	17° 59'
1890	17° 48'
1900	17° 55'
1905	18° 09'
1910	18° 29'
1915	18° 39'
1920	18° 36'

Annual change in 1926, about 1' decrease.

It is apparent from the values of the declination given in the table above that the secular change is periodic in character. In other words, it does not go on indefinitely in one direction. Eventually a turning point is reached and a change in the opposite direction sets in. Several centuries are required for its full development, a period longer than is covered by reliable observations in the United States.[1] The values of the magnetic declination in the Monument as far back as 1800 can be estimated on the basis of existing measurements at Pocatello and known changes in this and other parts of the United States. Before, that date any statement as to the values would be very unreliable. Formerly, the Coast and Geodetic Survey expressed the secular changes of the magnetic elements by formulas, on the assumption that the changes were periodic and could be expressed in this way. If this were allowable, the early values could be obtained by computation. However, as time passed it became apparent that the formulas did not fit the new observations, and could not be considered reliable for more than a few years beyond the limit of observation, and in recent years the formulas have been abandoned.

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[1] Hazard, D. L., Magnetic Declination in the United States for January 1, 1920. United States Coast and Geodetic Survey, Special Publication No. 90, 1922.

All of the lava flows in the Monument contain iron minerals; chief among these are the magnetic iron oxide, magnetite. The compass needle is affected by the presence of magnetic (commonly dalled lodestone), and the needle of a compass often deviates from true magnetic north in basaltic lava fields. When basalt is extruded in a molten condition the lava contains in it tiny crystals of magnetite which orient themselves in the fluid material according to the earth's field of magnetism. When the lava solidifies these crystals become fixed in place and being unable to change their orientation with the secular change, they preserve throughout centuries the magnetic declination of the particular year in which the lava cooled. It is therefore, possible by measuring the declination of a lava flow to determine the year it was extruded provided the magnetic declination has been previously determined for an adjacent station. Care must be taken, however, to observe the declination only on broad surfaces of the pahoehoe crust which have not moved after they solidified. By use of an elaborate method worked out by Chevallier it is possible to observe the declination of the jagged and chaotic flows known as aa.

The observations in the present study were confined entirely to the pahoehoe flows because of the short time available. Several observations were made of the declination of the lava flows by orienting the map carefully on a broad smooth crust of pahoehoe and by then making compass readings with the alidade parallel to a north-south geographic meridian on the map. Refined readings of the compass could not be made with the equipment on hand, and it was impossible to make a large number of readings in the limited time available for field work. The results given in the following table indicate that flows may be separated from each other on the basis of their magnetism and that flows which appeared in the field to be of the same age were, on this basis, erupted at quite different times.

Observations of the magnetic declination of lava flows in the Craters of the Moon National Monument

(Mean declination for 1926 19° 45')

	Date			
1.	9/25/26	SW. ¼ NE. ¼ sec. 35, T. 2 N. R. 24 E.	Highway flow	N 0° E.
2.	Do.	NW. cor. sec. 2, T. 1 N., R. 24 E.	NW Big Crater flow	N 10° E.
3.	Do.	NE. ¼ NE. ¼ sec. 2, T. 1 N. R 24 E.	Do.	N 10° E.
4.	Do.	NE. cor. SW. ¼ sec. 35, T. 2 N., R. 24 E.	See footnote No. 1	N 15° E.
5.	Do.	NW. cor. NE. ¼ SE. ¼ sec. 35, T. 2 N., R. 24 E.	See footnote No. 1	N 15° E.
6.	10/2/26	NE. ¼ NW. ¼ sec. 10, T. 1 N. R. 24 E.	SW Big Crater flow	N 19° E.
7.	10/5/26	SW. ¼ SW. ¼ sec. 2, T. 1 N., R. 24 E.	Crystal Fissure flow	N 19° E.
8.	Do.	NW. ¼ NE. ¼ sec. 11, T. 1 N., R. 24 E.	SW Big Crater flow	N 19° E.
9.	9/27/26	NE. cor. SW. ¼ sec. 6, T. 1 N., R. 25 E.	Indian Tunnel flow	N 20° E.
10.	Do.	Center SE. ¼ SW. ¼ sec. t, T. 1 N., R. 25 E.	Do.	N 20° E.
11.	9/25/26	NE. ¼ SW. ¼ sec. 35, T. 2 N., R. 24 E.	North Crater flow	N 21° E.
12.	10/2/26	SW. ¼ SW. ¼ sec. 12, T. 1 N., R. 24 E.	Cave flow	N 22° E.
13.	Do.	S½, NE. ¼ NE. ¼ sec. 14, T. 1 N., R. 24 E.	Owl Cavern flow	N 32° E.
14.	Do.	SE. cor. NW. ¼ SW. ¼ sec. 2, T. 1 N., R. 24 E.	NE Big Crater flow	N 44° E.

[1] Observation made on broad crust slightly tilted and on small patch of lava that is not connected with any known flow and may have come from either Big Crater or North Crater.

The conclusions that can be based upon such a small number of readings are necessarily tentative but are worthy of mention. The magnetism of the flows is affected to some extent by the field of magnetism produced by the underlying flows. The precise effect of these magnetic fields could not be determined but it is believed to be small. While making the readings it was found that often within small areas of a few square yards a great variation in the magnetism of the lava existed probably due to the tilting of the blocks. Consequently care was taken to observe the magnetism only on a broad practically level crust. The agreement of the two readings, numbers 2 and 3, in the above table for the NW Big Crater flow might have been considered accidental if it had not been for a similar agreement of numbers 4 and 5, 6, 7, and 8; and 9 and 10.

The oldest appearing flow on which the magnetism was observed is the Highway flow. Its magnetic declination is due North. The North Crater and the Indian tunnel flows appear to be the two youngest. The great divergence of the reading for No. 14 on the NE Big Crater flow from all the others leads one to suspect that some local condition is responsible for it. The observation was made only a few feet from the North Crater Cone and where the flow was only a foot or two in thickness. The magnetism of the lava when it solidified may have been greatly disturbed by the adjacent magnetic materials. The flow does not appear to be much older than the other flows from the Big Craters.

The range in magnetism, excluding reading number 14, is from 0 to 32° E. Because of the readings from the flows from the south side of the Big Craters, from Crystal fissure, North Crater, and Indian Tunnel vent, which are the most recent in the Monument, fall in the middle of the table, there is indication that the secular change is periodic and that in former times the declination has been much greater than 19° E and that in still more ancient times it reached zero. Because of the absence of actual declination records for southern Idaho before 1850, and because it is impossible to estimate the declination prior to 1800, with any degree of accuracy the actual date of the flows cannot be obtained from their magnetism as was done so effectively by Chevallier on Etna Volcano in Italy. However, three conclusions are apparent from the observation, namely:

1. The boundaries of otherwise inseparable flows may be ascertained by their permanent magnetism, provided they were extruded in different periods.

2. The flow from the chain of spatter cones in which Crystal Pit is located was poured out concurrent with the flows that escaped from the southeast and southwest sides of the Big Craters. This coincidence of age was suspected by the writer but could not be proved by the usual field methods.

3. The eruptions that produced the flows from Big Craters, Crystal Fissure, Indian Tunnel vent, and North Crater were not separated by any great interval of time, and the fact their magnetism is not very different from the present declination suggests that they may have been extruded within the last thousand years.

It is certain that if this area had been inhabited by a people such as the ancient Greeks or Romans who were able to record such volcanic events instead of by Indians who could not, many of the eruptions in the Craters of the Moon area would not be dated. It is only when one compares the historic records of a newly settled region such as Idaho with the long chronological records of the Japanese or the Greeks which tell of eruptions over 2000 years ago that one realizes how many volcanic episodes may have occurred in the western part of the United States within the last millenium.

A list of the flows in the approximate order of their eruption, based chiefly upon their overlapping one another and the amount of vegetation on them, is given in the following table:

Approximate eruptive sequence of the
principal lava flows in the Craters of the Moon National Monument
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 Crater 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. Vermillion 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

facing away from the flow. The rock must have been faulted into its present position after the lava solidified because the ropy surfaces of the crust have been tilted at steep angles. From the location of the tilted block it might appear at first sight to have been caused merely by lava pouring down the slopes of the cone upon which it rests, but such an explanation is not satisfactory because there is no crater or sign of a vent at the foot of the escarpment and the ropy crusts do not indicate that it flowed from Broken Top. There remains therefore, the explanation of uplift after the flow had cooled. The mechanics of the faulting are not clear unless the whole of Broken Top has been tilted toward the southwest. Some evidence indicating that such occurred is found in the numerous deep cracks on the southwest side of Broken Top, in the lava filled trench on its west and southwest sides, and the presence of a fault escarpment facing northeast on the northeast side of Big Cinder Butte in line with this trench and from which lava has flowed.

Cause of the Faulting. - All of the faults in the lava with the exception of the ones which form the Highway Craben, are parallel to the trend of the fissure vents and cones of the Great Rift Zone and are intimately connected with volcanic action. From some of them lava has issued. Whether this faulting was caused by the rising magma or was produced by some other stress is not known. Certainly much of the minor cracking and faulting is connected with the collapse following the subsidence of the lava column. By many faulting has been considered the mechanism which released the magma and allows it to reach the surface. By others the lava is held responsible for the earth rifting and is itself the active agent. A study of the faults in the Craters of the Moon Monument throws but little light on this interesting subject. The original faulting which determined the position of the Great Rift on the plains of Idaho, is believed to be associated with earlier epochs of mountain building and the lava is thought merely to have followed this predetermined path to the surface.

Geologic History

The earliest event in the geologic history of the area that can be interpreted from the rocks is the extrusion of andesites and dacites filling valleys eroded in Paleozoic sediments in the White Knob Mountains. Concurrent with this eruptive period, granitic intrusions penetrated and deformed the ancient Paleozoic sediments and older flows. According to Umpleby[1] this epoch of granitic intrusion was accompanied by uplift, followed by a long period of erosion during which the Idaho peneplain was developed. This peneplanation has been variously dated from Eocene to Miocene. Along with these early eruptions thousands of feet of ash and sediment were deposited in the ancient Lake Payette and later during the Pliocene in Lake Idaho, both extensive lakes occupying Snake River Valley. The lake beds thus formed, which are so conspicuous in the Snake River Canyon, do not crop out in the Craters of the Moon area and a well 1,110 feet deep near the south end of the area did not penetrate them.

Then came the Pleistocene epoch during which glaciers formed on the high peaks to the north. They apparently failed to reach the area, although the higher peaks in White Knob Mountains were probably ice capped. Sometime during this epoch eruptions occurred for the first time on the southern slope of these mountains and basic lava poured out from a SE-NW fissure. Unlike many of the other fissures that have opened in the Snake River Plains, this fissure, a line of weakness in the earth's crust persisted after the first eruption and was opened and reopened by numerous eruptions from that time on. Intermittent volcanic activity along the

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[1] Umpleby, J. B., Geology and Ore deposits of the Mackay region, U. S. Geol. Survey Prof. Paper No. 98, p. 38, 1917.

fissure produced many cinder cones and lava flows. However, the lava was not always extruded from the same fissure. When earlier cracks were sealed by solidified dikes, new fissures opened a few feet from the old ones and parallel to them, so that the vents do not occur in a straight line but fall into a zone half to a mile wide and about 12 miles long, as shown in figure 8. This is the Great Rift Zone.

Figure 8 - Diagram showing the location of the vents in the Craters of the Moon area.

Extending three miles south of Grassy Cone is a line of nearly buried cinder cones that indicate the existence of a short branch from the Great Rift. A few small vents have poured out lava about a mile east of the Great Rift. They are intimately connected with it and represent minor diverging fissures. (See pl. 16) The older cinder cones which lie several miles away and which appear to have no connection with the rift have been shown in Plate 16 by a separate color.

The Great Rift Zone is an unusual volcanic feature within the continental boundaries of United States. Since most of the basalt of Idaho has been erupted through fissures it is remarkable that the phenomena of the Great Rift Zone has not been found elsewhere in Idaho. Instead, in other places on the Snake River Plains after the extrusion of the lava the rift has permanently healed leaving practically no surficial evidence of its existence. The reason why eruption after eruption has occurred along the Great Rift and not elsewhere is not readily explained. In Iceland and in Hawaii where similar lavas are often extruded, permanent rift zones are the rule rather than the exception and the great volcanoes of Kilauea and Mauna Loa are fed by lava that rises through definite and narrow rift zones.[1] It follows that the persistence of the Great Rift Zone in the Monument makes it a logical site for future volcanic activity in Idaho.

The sequence of eruptions along the rift cannot be worked out exactly, but it appears to have been unbroken by any long period of repose. Because lava and cinders were not extruded along the entire rift during each eruption recent cinders and lava overlie older cones and flows in some places and much more recent ones in other places. This gap in the continuity of the eruptions in any given place, however, is only local for during the same time interval eruptions occurred along other parts of the rift.

[1] Stearns, H. T., and Clark, W. O., Geology and water resources of the Kau district, Hawaii: U. S. Geol. Survey Water-Supply

In general, the eruptions seem to fall into three epochs. The oldest cones and flows are nearly everywhere buried by later volcanics products. Remnants of these old cones, broken by faulting and weathered down into fantastic hoodoo-like crags of cinders and spatter, from the Devils Orchard and the field of crags south of Big Cinder Butte and The Sentinel. Most of the tachylyte or basic volcanic glass is found in these crags. The lava flows of this cycle are practically all buried.

Then there appears to have been an interval of time during which the Great Rift healed. After this period of repose the rift again opened and emitted the products of the second or intermediate epoch. Many of the largest cinder cones, such as Sunset Cone, Grassy Cone, Paisley Cone, Inferno, Big Cinder Butte, The Watchman, The Sentinel, Fissure Butte, and Split Butte, were formed at this time. Many of the lava flows of this epoch are now buried. These volcanic outbursts, like the preceding, were spasmodic in occurrence, but probably followed one another at short intervals. Often more than one cone was formed during a single eruption and there is evidence that some of the cones were made by several eruptions occurring at the same place.

The third or last epoch closely followed the second and may have been intimately connected with it. During this epoch of volcanism all of the black and bare lavas were erupted. North Crater was reopened and gave vent to a large pahoehoe flow that spread eastward over the plain. The cone in which the Big Craters are situated was probably entirely formed in this epoch. It gave vent to flows to the northeast, northwest, southwest, and southeast. All of them were not coincident in time but the flows to the south and those from the fissure marked by the Crystal Pit cone chain were all extruded at the same time. Indian Tunnel, Natural Bridge, and Needles Cave vents also poured out lava about this time. The great and extensive flows of this epoch broke out chiefly in the northern part of the area, but some of the old cones farther south such as Big Cinder Butte, The Watchman, and Sheep Trail Butte belched forth cinders and lava again.

So numerous have been the eruptions along the Great Rift Zone that the rift might be likened to a great elongated volcano without a central orifice. Because the periods of repose have probably lasted several centuries and because numerous eruptions have occurred along the rift in the past 2,000 years, it seems possible that other eruptions may occur in this area. The written history of our country is extremely short. Until 1914, Lassen Peak in California had been included in several books as an example of an extinct volcano in the United States, yet in 1914 and 1915,

explosions occurred there, which, had they taken place in a thickly settled region, might have caused serious loss of life and property. Thus it is impossible to say whether a volcano or recent volcanic area is extinct or only dormant. It seems unlikely that on the Snake River Plains where thousands of volcanic outbursts have occurred in Pleistocene and Recent time, all the volcanoes should have become extinct in this last moment of time. Instead, it appears as though the repose period between eruptions was simply growing longer with the decline of volcanism, and that we happen to be living in one of these periods. The next eruption may come without appreciable warning, although it is likely to be preceded by seismic disturbances. The great lava plains of Idaho, however, are very thinly settled, and an eruption is not likely to cause loss of life or to destroy much property.

Volcanic Features

The Great Rift Zone

The source of the lava was a reservoir of unknown size and depth some miles below the crust in this part of Idaho. Many geologists think the original source of the lava lies in a basaltic substratum about 11 miles below the earth's crust. Whether the lava ascended directly to the surface from such a substratum or proceeded upward from a large pod-shaped reservoir that lay several miles above is unknown. Regardless of the depth and shape of the supplying reservoir, the lava rose through the upper part of the crust along several well defined fissures parallel to each other and confined to a narrow belt known as the Great Rift Zone.

In the Great Rift Zone there are found no less than 55 craters or cones that have given vent to lava, in addition to 14 fissures bordered by spatter or marked by chains of spatter cones. (See fig. 8.) The number of buried vents would probably add considerably to this total. The localization of these vents along a well defined rift is a significant fact and bears an important relation to the origin of the Snake River Plains. For many years it was contended that the great lava sheets of Idaho poured out of huge fissures which masked themselves completely and that the few solitary cinder cones were unequivocally of secondary origin.[1]

Russell,[2] in his exploration of the lava plains of Idaho recognized and described numerous cones and craters and reached the conclusion that the great lava plains were built up by numerous lava flows from inconspicuous cones, both in the mountains and on the plains, that were essentially fed through tubular vents and which differed chiefly from the great volcanic cones with a single central orifice such as Vesuvius by being less violent and much shorter lived.

Thoroddsen[3] describes numerous fissure eruptions in the great lava plains of Iceland which have formed cone chains and fissures bordered by spatter. Most of these eruptions were preceded by earthquakes and produced immense floods of lava. The Great Rift Zone is similar in appearance, in the kind of lavas extruded, in its location on a plain, and in its origin, to many of the rifts of Iceland. Fissure eruptions producing similar cone chains and lava flows occur on the flanks of Vesuvius in Italy. Such fissures are formed on Vesuvius only at the time when the central orifice is nearly filled with lava or during great catastrophic eruptions. The fissuring of the cone of Vesuvius which is largely composed of fragmental material, at these particular stages is thought to be due to the rupturing of the cone by the immense pressures exerted by the confined lava column. The results produced are similar to the eruptions on the plains of Iceland except that the lines of cones and flows on Vesuvius are on the steep sides of the cental cone and are considered a secondary phase in the eruptive history of the volcano, whereas in Iceland they are usually isolated on a plain unassociated with any central volcano and are frequently the first and only outbursts of the volcanic forces at that place.

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[1] Geikie, Sir Archibald, Geological sketches at home and abroad, pp. 237-238, 242-245, N. Y., 1882.

[2] Russell, I. C. Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 63, 1902.

[3] Thoroddsen, Th., Iceland: pp. 106-110, 1905.

Intermediate between the fissure eruption of secondary importance on Vesuvius and the isolated fissure eruption of an Iceland lava plain are the fissure eruptions on the slopes of the great lava domes of Kilauea and Mauna Loa volcanoes in Hawaii. Lateral eruptions from these volcanoes produce cone chains and fissures bordered by spatter similar to those on Vesuvius, in Iceland, and in Craters of the Moon National Monument, but occur on the surface of a lava dome which is intermediate in slope between the steep cone of Vesuvius and the lava plains of Iceland. The fissure eruptions on these two Hawaiian volcanoes are confined to narrow fundamental rift zones and control by their intersection the location of the central vents. Thus, these rifts antedate these two volcanoes and because of eons of continued activity along them they are permanent and not accidental like the fissures on the slopes of the Vesuvian cone or ephemeral like the fissures of the lava plains of Iceland or Idaho. A plain was built in Idaho instead of a huge basaltic dome such as Kilauea or Mauna Loa, not because of lack of the volume of the material extruded but because the fissure vents were not permanent and persistent as they are in the rift zones of the Hawaiian volcanoes. The shifting of the fissures and their associated vents in Idaho was a complicated process and may have resulted from many causes. Chief among these causes is the structure of the beds underlying the volcanic plain and the widespread rather than localized faulting that has occurred in the basement structure of this plain adjacent to the Rocky Mountains.

Cinder Cones and their Flows

The cinder cones in the area are conical heaps of lapilli and cinders, the froth of the lava column. The smooth arciformed profile of these cones as shown in figure 9 is a characteristic

Figure 9. - Properties of Crescent Cinder cone and Needles cave lava dome.

feature that enables one to distinguish them from other types of cones even at a considerable distance. The principal cinder cones and the flows associated with them are described in the following pages, in their order of occurrence southeast from the mountains.

Sunset Cone. - Sunset Cone has an elevation of 6,386 feet above sea level and rises about 590 feet above the plain. As shown in Plate 17A, its slopes are mostly grass covered although a few bare patches of black cinders occur here and there. Large fir and pine trees grow in its two large craters. Like most of the large cinder cones it was formed by several eruptions. The last one formed a deep crater on its western slope and the beautiful red and purple shades of the scoria of the walls gives this crater its name. The crater rim is crescent-shaped and its lack of symmetry is attributed to the strong winds that blew at the time of the eruption. An undrained depression about 50 feet deep forms the bottom of the crater. On the northeast side of the cone is the other crater which has been breached on the east by the lava discharged from the vent. Cinders from this vent form a thick mantle on the projecting spur of older rock to the northwest. The lighter lapilli that formed during the eruption was carried a mile or more by the wind and deposits several feet in thickness accumulated in the gulches of the mountains along the road northeast of Sunset Cone.

The main flow from Sunset Cone breached the crater on the northeast side at 5,830 feet and spread eastward on the plain in the form of pahoehoe. The flow is covered by considerable loess, soil, and sagebrush and belongs with the older lava which is not completely differentiated because part of it lies beyond the area. It is exposed over an area of at least three square miles and some of it has been buried by the North Crater flow.

Grassy Cone. - The summit of Grassy Cone rises about 450 feet above the plain to the south of it. The cone is approximately half a mile wide and a mile long with its long axis southwest-northeast. The shape was evidently determined by strong winds blowing during the eruptions. On the northeast side is a stand of firs and aspen, but otherwise the cone is covered with grass

and brush only. Unlike Sunset Cone it seems to have been formed during a single great eruption. While the length of time required to form this particular cone by a single eruption is of course unknown, it is interesting to compare its size with a cone of the same type that has been formed elsewhere in historic time.

A little to the west of Puzzuoli on the shore of the Bay of Naples and not far from the village of Bath, Italy, is a conical hill composed of black cinders which rises 440 feet above the adjacent waters of the Mediterranean. 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 by the name of the hill bears, Monte Nuova, or "New Mountain". When visited in 1925 it supported a considerable growth of vegetation and resembled Grassy Cone in many respects. It covers an area of more than half a square mile and is comparable in volume to Grassy Cone. According to records obtained from witnesses the adjacent region was affected by earthquakes for more than two years and on the 27th and 28th of September, 1538, the maximum frequency and intensity of the shock occurred. According to Judd,[1]

> "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 afterwards tepid, began to issure. Four hours afterwards 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 mount. 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."

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[1] Judd, John W., Volcanoes, p. 76-77, N. Y., 1881.

On the summit of Grassy Cone are two craters. The easter and larger one is over 100 feet deep and 400 feet in diameter. In it grow a few good sized trees. To the west is a smaller crater about 60 feet deep and 100 feet in diameter which is one of the most symmetrical crater bowls in the area. A narrow valley-shaped depression occurs on the northwest slope which changes to a spur of lava near the base of the cone. The depression is due to ejecta being carried away by the lava which broke through the cone at this place and the spur is a constructional form produced by the accumulation of the lava extruded.

The Grassy Cone pahoehoe flow which escaped through a hole in the side of the cone is exposed over several square miles to the north and west. (See pl. 16) Soon after it escaped from the cone the flow crusted over and the lava continued to flow through tubes. Several small caves, parts of these tubes, are found in the flow and doubtless many others occur but are obscured by the soil and brush that grow upon the surface. Rising as an island about 50 feet high in the Grassy Cone flow in the NE $\frac{1}{4}$ sec. 34, T. 2 N., R. 24 E., is a small cone of cinders and spatter that has been completely surrounded by the lava. The Grassy Cone flow is approximately the same age as the Sunset Cone flow and is overlain by the Highway flow and the Northwest Big Crater flow.

North Crater Butte. - A mile south of Sunset Cone lies North Crater Butte which rises about 440 feet above the lava flows to the north of it. It is somewhat over half a mile in diameter and like the other cones the greater bulk of the material is piled on the northeast side of the former vent. The height of the cone above the plain has been diminished considerably by burial since the eruption, for in every direction the pyroclastics of this eruption pass under later lava flows. The western portion of the cone is rent with fissures and trenches and the entire north side of the cone has subsided from 30 to 50 feet into the Highway Graben. On its slopes were found numerous bombs and a great variety of ejectaments which are described further on p. . The slopes are nearly destitute of vegetation although a few old stunted pines reaching a diameter of 20 inches grow on the crater walls. The crater has been breached on the north by an early lava flow, hence the rim now forms a great horseshoe about 100 feet high on the west side and 400 feet high on the east as shown in Plate 17c. North Crater has given vent to at least two flows and perhaps three.

The youngest lava flow from North Crater is chiefly pahoehoe lava and is shown on Plate 16 as North Crater flow. It is not improbable that this flow which resembles the 1921 lava flow from Halemaumau, the active crater of Kilauea, welled out quietly from

an opening in the floor of North Crater without the ejection of cinders or spatter. Its surface is entirely free from cinders or other ejecta and in most places has a blue glassy crust. At first a lava lake was formed with after filling the crater basin overflowed through the breach on the north rim. It flowed about half a mile northward and then was dammed and diverted towards the east by the Highway fault escarpment. It then flowed eastward over a rough aa flow for a distance of about $3\frac{1}{2}$ miles and spread out as a sheet in places over a mile wide. The altitude of the head of the flow is 5,920 feet, and the terminal margin 5,650 feet, hence it has a gradient of about 77 feet to the mile.

When viewed from the summit of the crater rim where the gradual northern slope of the flow is not apparent, it seems as if the lava flowed into North Crater instead of out of it. (See pl. 17c.) Studding the surface of this flow to its most distant margin and forming a train extending outward from North Crater are numerous cinder crags shown in pl. 18c, ranging from a few feet to 75 feet in height and varying in size from that of a small shed to that of a good sized house. Thse crags are composed entirely of spatter and cinders such as make up cinder cones, and a few show distinct bedding such as characterizes the internal structure of cinder cones. They are therefore, quite different in origin from the great heaps of aa so frequently seen on the lava flows in Hawaii. Russell[1] long ago established that they were transported. Surrounding the crags are moat-like depressions five to eight feet deep formed by the failure of the viscous lava to fit tightly against them. Russell[2] thought the crags had been transported in this pahoehoe flow and that the moats were formed by the crags depressing the "viscous surface on which they rested in the same manner that a brick might depress the surface of pitch". Field evidence does not sustain this explanation. If these crags had been floated away from North Crater in the pahoehoe the train of crags should end at the terminal margin of this flow. Quite the contrary is found, however, for stretching away to the very foot of Round Knoll nearly a mile and a half beyond the end of the flow is a great train of cinder crags which form the fantastic Hoodoo Rocks. (See pl. 16)

The cinder crags which lie beyond the North Crater pahoehoe rest on the Serrate flow, a glassy thick aa lava which also came from North Crater. Because it underlies the pahoehoe and is

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[1] Russell, I. C., Geo. and Water Resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, p. 83, 1902.
Idem, Geology of Southwestern Idaho and Southeastern Oregon, U. S. Geol. Survey Bull. 217, p. 39, 1903.

[2] Idem, Bull. 217, p. 40, 1903.

somewhat weathered, it was probably erupted several centuries before the North Crater pahoehoe lava. It is evident, therefore, that this thick aa lava flow shoved and pushed along the crags into their present position long before the pahoehoe welled out. Such a transportation of extraneous masses is incompatible with the subterranean method fo flow which characterizes the spreading of pahoehoe lava and can only be explained by the glacier-like motion of the aa. Furthermore, the farther away from the source the crags are seen the more they are crushed and jumbled because of being shoved and pushed into position by the aa lava. If they had been floated on a viscous fluid in the manner described by Russel they should be intact even near the termination of the flow. Further evidence of the method of transportation is afforded by the finding of occasional blocks of the glassy aa belonging to the older flow in the moat-like trough surrounding the crags which rise as islands in the pahoehoe. Also, within a few feet of many similar crags in other flows in the area vertical tree molds are found in the lava surrounding the crags. The fact that these molds have not been tilted is indisputable evidence that trees were growing on the now buried portions of the crags, before they were surrounded by the pahoehoe. The moat-like trough is therefore, due to the upper part of the pahoehoe failing to fit closely around the crags because of its viscosity. Thus the crags are a special type of kipuka[1] not commonly seen in the lava streams. Similar troughs of various depths surround all other kipukas that rise above the surface of the lava streams of the Monument.

All of the crags in the youngest North Crater pahoehoe were not carried away from North Crater. Lithologic evidence suggest that they have several different sources. The cinder crags were definite bedding planes in the lava near North Crater were in part transported from North Crater and in part are crags nearly in situ resulting from the breaking up of an old cinder cone by collapse. Many of the crags in sec. 36, T. 2 N., R. 24 E., are large and weathered and contain bands of tachylyte which are similar to those found in Obsidian Crag in the Devils Orchard in the same section. The crags in the Devils Orchard were produced by the breaking down of ancient cinder cones by weathering a process aided perhaps by collapse. These crags cover over half a square mile. The crags to the north in sec. 36, partly buried by the North Crater pahoehoe flow, clearly belong with the Devils Orchard crags. The larger ones do not appear to have been moved appreciably. Extending toward Round Knoll from this group is a well defined train of crags that appear to have been transported from this place.

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[1] Kipuka, Hawaiian for "The Hole" is the name applied in the Hawaiian Islands to an old island-like area surrounded by a lava flow. This is the dagala of the Sicilians.

A quarter of a mile north of North Crater Butte at the foot of the Highway fault escarpment is a narrow path of lava half a miles long and an eighth of a mile wide that appears to be older than the youngest North Crater flow which rests upon it. (See pl. 16.) The magnetism of this flow is different from that of the youngest pahoehoe flow from North Crater and its rusty brown crust is readily distinguished from the blue glass crust of the pahoehoe which overlies it to the south. This small patch comprises both aa and pahoehoe. It is later than the Highway flow because angular blocks of talus from the Highway flow cliff which beheads the Highway lava flow have been transported on its surface. It is not connected with any other flow and whether it is a part of the great Serrate flow to the east or whether it is a part of a small later flow from North Crater, could not be determined.

The Serrate flow shown in Plate 16 is one of the largest lava flows in the area. It is exposed over about four square miles and before partial burial by the North Crater pahoehoe it probably covered at least six square miles. The flow cannot be traced directly to its source but the train of cinder crags and the slope of the surface of the flow indicate that it issued either in the Highway Graben or poured out of North Crater. If it came from either of these places it must have had a width of a quarter of a mile near it source and a total length of $5\frac{1}{4}$ miles. It has a maximum width of 2 miles near its margin. Near Grassy Knoll where no later lavas lap upon it this flow has a thickness of over 50 feet and comprises angular block of glassy lava, which in places grade into tachylyte. The surface is exceedingly irregular and the depressions between the heaps of blocks are usually 20 to 30 feet deep. This rugged surface of loose and poorly balanced jagged blocks makes traveling over it extremely slow and hazardous.

It is possible that all of this lava did not come from North Crater, for there is a prominent pile of lava blocks near the center of sec. 16, T. 2 N., R. 25 E., that may be a lava prop. The term prop is used by the Dutch for a mushroom-sahped dome of aa lava directly over a vent, without a central depression. Matteucci[1] describes a similar structure formed on Vesuvius between 1895 and 1898 as a cupola lavica. Some of the Puys of Auvergne, France, are

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[1]Matteucci, Sur les Particularities de l' Eruption du V'suve, Comptes-Rendus, vol. 129, p. 65-66, 1899; Sul Solle vamento edogeno di una Cupola lavica al Vesuvio, Rendicent. Accad. Scienze Fisiche e matemat. Mapoli, vol. 37 p. 285 et seq., 1898; Se al Sollevamento endogeno di una Cupola lavica al Vesuvio fossa aver contribute la sol indicazaions del Magma, Bollet. Soc. Geol. Poma, vol. 21, p. 413 et seq., 1902.

said to have originated in this way. A similar monticle was formed in Santorin, on the island of Giorgios, off the coast of Greece in 1866. Numerous props have been formed in Java in historic time. One was erupted in Galunggung crater in 1918, and on Merapi volcano one was in progress in growth in 1924. Such dome-shaped masses of lava are not uncommon in the United States. They have been seen in the Paulina Mountains near Bend, Oregon, in the Medicine Lake Caldera in northern California, and on the summit of the Cascades in Oregon. In 1915, a lava prop was formed on the summit of Mt. Lassen, California. The term prop is used because of the lack of an English term and because these forms have been so admirably described by the Dutch.

The Serrate flow is remarkable also for the number of diorite includsions that have been brought up from the basement below. These xenoliths range in diameter from a fraction of an inch to a foot or more, and are not appreciably altered at their edges. Howel Williams who examined specimens of these inclusions under the microscope identified them as angular inclusions of coarse grained hypersthene quartz diorite. They show no alteration as a result of being bathed in the hot basalt. Most of them has a gneissic structure.

On the surface of the flow or in the interstices between the blocks is considerable loess and also fine pumiceous material derived from the cinder cones to the southwest. In places a few stunted pines grow on its surface although as a whole it is black and bare. Lava flows from vents to the south lap upon it, hence the flow is grouped with the older ones. It is distinctly younger than either Grassy or Sunset flows and in many places it can be found resting upon the latter. Its stratigraphic position is at the top of the series in which it has been placed.

Highway flow of lava - Resing on the Grassy Cone flow and on the cinders of Sunset Cone in sec. 35, T. 2 N., R. 24 E., is the Highway flow. It is a black and bare aa flow covering an area of about half a square mile. It flowed from the south and terminated with a steep margin 35 to 40 feet high as shown in Plate 19a. It has been beheaded by the Highway fault so that it can no longer be traced to its source and the part south of the fault has been buried by recent flows. Its relation to existing topography indicates that in all probability it came from North Crater or an adjacent vent. It is not a part of the Serrate flow because it does not have on its surface the cinder crags which are so characteristic of this rugged flow. Moreover, the Serrate flow is believed to have issued after the Highway Graben was formed. The Highway flow near the fault cliff rests upon an older flow which also is displaced by the Highway fault and of which only a long narrow sliver remains on the southeast side of Grassy Cone.

Silent Cone. - Half a mile southwest of North Crater Butte is Silent Cone, which rises about 450 feet above the adjacent lava plain. It is about a mile long and half a mile wide and is composed entirely of cinders. The original height must have been greater for it is completely surrounded by later flows. Its surface is well clad with vegetation and from all appearances it is about the same age as Sunset Cone. Its crater is a quarter of a mile wide and is breached on the north so that its rim forms a horseshoe with the highest point about 400 feet above the crater floor. About 300 feet south of the crater rim is a small bowl-shaped crater about 150 feet in diameter and 40 feet deep. On the southeast side there is a remant of a crater rim that faces towards the southeast and is much older than Silent Cone. Less than a mile southwest of Silent Cone, the recent flow from the Big Craters is found resting on an old soil-covered aa flow which probably came from this cone. As this lava lies almost wholly outside of the area it was not studied.

Paisley Cone. - Half a mile due east of the summit of North Crater is Paisley Cone. It rises about 350 feet above the plain and covers nearly a square mile. It is decidedly elongated to the northeast owing to strong southwest winds at the time of its formation. Doubtless before the extravasation of the North Crater flow the lighter lapilli were to be found a considerable distance farther to the northeast. There is an undrained depression about 50 feet in the bottom of its crater which is a quarter of a mile wide and nearly half a mile long. The highest point of the rim is about 300 feet above the lowest part of the crater. Very little lava seems to have been erupted from this cone although a narrow strip of lava lies on the south side of it nearly obscured by cinders. Superimposed on the northwest rim of Paisley Crater is what appears to be part of the rim of a smaller and later crater. In this smaller crater is a mass of very jagged and rough aa of which seems to have issued in a very viscous state and formed a mushroom-shaped mass of lava about an eighth of a mile in diameter. In the rough lava of this prop is the basin of the former Registration Booth Water Hole. The perennial water of this hole disappeared suddenly in 1927.

On the north side of Paisley Cone about 50 feet above the road there crops out highly oxidized red cinders that are a part of a very ancient crater rim. The bedding in this outcrop dips steeply toward the south or into Paisley Cone which indicates that the focus of this eruption was about an eighth of a mile north of the outcrop and that Paisley Cone mantles a much older vent. This conclusion is further supported by the presence of numerous weathered cinder crags, remnants of older cones, in the Devils Orchard on the northeast side of Paisley Cone.

Big Craters Butte. - Between Paisley Cone and Silent Cone is Big Craters Butte, a cinder cone surmounted by the Big Craters. This cone rises about 300 feet above the plain and covers slightly less than a half a square mile. Its size, however, is not comparable to its importance, for it has given vent to immense floods of lava and has been the site of numerous eruptions. On its summit is a line of five craters linked together in a crater chain. (See pl. 16.) Two other craters are found on the summit making a total of seven. Its northern and southern slopes have been rent by fissures that have poured out lava. The cone is elongated in a northeast-southwest direction and was built over a fissure having the same trend. The preponderance of the ejectamenta are piled on the northeast side of the line of craters owing to the winds that prevailed at the time of the eruption. Its slopes are sparsely covered with vegetation although good sized pine trees have lived and died within its craters. The southernmost crater is about 30 feet deep and about 50 feet in diameter. Northwest of this one is a much deeper crater separated from the next and largest of the Big Craters by a low divide. The largest crater is only an eighth of a mile wide but it is an undrained depression almost 200 feet deep. This dark yawning crater pit with its beautiful purple and black slaggy walls is one of the scenic features of the Monument especially when these colors are intensified by the refle ction of the brilliant colors of the desert sunset. On the north side of this crater as shown in Plate 19B, about 40 feet above its bottom is discernible a narrow ledge of black lava about five feet thick. This ledge has an origin similar to that of the Black Ledge that surrounded the active crater of Kilauea for so many years. It is the shore line of a former lava lake. There are at least six different lava flows that were erupted from Big Craters Butte. Of this number two have issued from a fissure on the northwest slope, three from the west side, and one spilled over the rim of one of the summit craters and flowed southeast.

The northeast flow issued from a fissure on the southwest side of the cone and flowed for half a mile to the northeast and stopped near the site of the former Registration Booth Waterhole. It is only about an eighth of a miles wide at its widest point and at no place attains a thickness of over 25 feet. It is a mixture of pahoehoe and aa and is devoid of vegetation but is covered with cinders from some later eruption. From its rusty brown weathered crust and the deposit of cinders on the surface it appears to be the oldest flow from theBig Craters that is traceable to its source. After the extrusion of this lava, fumeroles existed along the fissure from which it extruded long enough to color the rocks brown, yellow, and red. Subsequent to the fumerolic activity faulting occurred which cracked the lava into numerous blocks. The downthrow to the west was sufficient to develop a vertical escarpment 10 to 20 feet high, striking northwest. These same faults displace the west side of North Crater Butte.

The Northwest flow from the Big Craters escaped from the side of the cone through three tubes. The absence of cinders on its surface shows that it is later than the one from the Northeast side flow. It flowed northwest about a mile to the foot of Grassy Cone and then forked. One stream flowed northeast from this place and the other went toward the southwest. (See pl. 16.) The northeast stream is partly buried by the last flow from North Crater, hence the distance it flowed in that direction is unknown. The southwest stream extends a short distance beyond the area mapped. Southward this stream merges so imperceptibly with the Southwest Big Craters flow that its boundary was not determined in the time available.

An interesting lava streamlet left the main flow near the source and cascaded over the rim of North Crater. (See pl. 16.) This cascade is only about six feet wide and ends in a mass of talus blocks belonging to the crater rim. It could not be determined definitely whether this lava stopped in the talus or passed under the North Crater flow. Viewed from the opposite crater rim it looks as though the last lava flow that poured out of North Crater was fed by this little lava cascade from the Northwest Big Craters flow, but sufficient evidence was found to show that this did not occur.

The part of the Northwest flow between North Crater and Silent Cone is exceedingly rough and is shown by the contours on Plate 16 as aa lava. It is not all aa lava, however, for some of it is made up of cakes of pahoehoe crust turned up on end by motion subsequent to the formation of the pahoehoe. The general appearance of the aa part of the flow is shown in Plat 19c. The pahoehoe portions farther out on the plain are smooth and billowy. The average gradient of the flow in the first two miles is 105 feet to the mile. One hundred and fifty feet of this fall occurs in the first half mile, and this steep gradient doubtless caused the toppling over and tilting of the pahoehoe blocks which makes the rough surface in this part of the lava stream.

Near the base of Grassy Cone are several cinder-covered patches of ancient lava that occur as kipukas in the flow. Several cinder crags with moat-shaped depressions around them occur west of Silent Cone. The presence of vertical tree molds in the Northwest Big Craters pahoehoe lava surrounding the crags indicates that trees grew on the crags before they were surrounded by the lava, hence these crags have not been floated on the pahoehoe as postulated by Russell. The surface of the Northwest Big Craters

flow is black and practically bare of vegetation. However, in a few places small pine trees on inch or two in diameter can be found on it and in the cracks in its margin near the crags grow a few large pines. One of these was felled and found to be about 361 years old. (See p. 47.) This flow is therefore at least that old.

Three flows have escaped from the southwest side of Big Craters Butte. (See p. 16.) The northernmost of these flows issued from a crack in the cinders at the edge of a small crater over 25 feet deep on the northwest side of the summit chain of craters. This flow is covered with ejectamenta and within a few hundred feet passes under later flows from the Big Craters. The cinders on its surface indicate that it is older than the other southwest Big Craters flows. From its appearance it is believed that this lava was extruded about the same time as the Northeast flow.

Southwest of the largest crater near the base of the cone are four lava tubes, the subterranean channels through which the summit craters discharged their lava to the southwest. (See pl. 16.) From the roof of this cave hang many delicate needle-like lava stalactites. These flows have spread out on the plain to the southwest and merge imperceptibly into the Northwest Big Craters flow and the Crystal Fissure flow. Most of the surface of the flow is exceedingly rough although a few large patches of aphoehoe are seen intermingled with the aa lava. The black, bare, chaotic surface of these flows remind one of Thoroddsen's[1] description of the view of the Odadhraun, the Great Icelandic lava field:

> "The weirdness of desolation itself. As far as the eye can see, the surface of the earth resembles a gigantic stiffened corpse, petrified, black as the night."

The Southeast Big Craters flow is unusual among those in the Monument because it poured over the rim of the crater and coursed down the slope without breaching the rim. This lava flow is only about 6 inches thick on the surface of the cone and can be traced up the slope of the cone and over the rim and down the crater wall for a considerable distance. It resulted from the overflow of the lava lake which existed temporarily in the crater. The crater rim was not breached because it had walls sufficiently strong to withstand the pressure of the molten lava. The lava which overflowed must have been highly charged with gas for it is very vesicular and scoriaceous. The coating of the inside of the crater wall is a veneer left as the lake subsided.

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[1] Thoroddsen, T., Explorations in Iceland during the years 1881-98, Geogr. Journ. Vol. 13, p. 270, 1899.

Inferno Cone. - Inferno Cone rises about 300 feet above the adjacent plain. It is greatly elongated to the northeast due to the strong winds that blew during the eruption that produced it. Because of its bare black surface strewn with bombs it appears to be a very recent cone. This bareness and fresh appearance is due however, to the lapilli and cinders that fell on it later during the eruptions that formed Big Craters Butte. The numerous bombs which lie scattered on its surface were derived from the same source. Near its summit there are bright red, tightly packed, bedded cinders that are not extraneous and which point to its antiquity. It appears to form the northeast rim of the crater nearly half a mile in diameter which has been almost entirely filled with recent flows. The kipuka of cinders west of Crystal Pit is another remanant of the rim of this ancient crater. The flows from Crystal Fissure have cascaded over the slope of this kipuka.

Broken Top. - Broken Top, an ancient cinder cone, rises about 225 feet above the plain. Nearly all traces of its former crater have been destroyed by subsequent faulting which has depressed the southwest side of the cone and opened gaping fissures 10 to 20 feet deep and several feet wide on its southeastern slope. One of these fissures is shown in Plate 18B. The southeastern side of the cone is bare of vegetation and on it are scattered numerous large flattened bombs, some of which are three feet in diameter. The other slopes are practically covered with vegetation. The lack of vegetation on the southwest slope appears to be wholly due to exposure to the strong southwest winds. If any flowed from this cone it is now entirely buried by subsequent lava.

Big Cinder Butte. - Big Cinder Butte rises to an altitude of 6,516 feet above sea level and nearly 800 feet above the plain. It covers about 2 square miles and is by far the largest and highest cone. (See pl. 16.) It is a compound cone resulting from numerous eruptions separated by long intervals of time. It merges to the southeast with Coyote Butte and on the east with Half Cone, and from the size and history might become the chief vent in the Great Rift Zone if eruptions continue in this area. This immense cinder cone has clearly been built over a northwest-southeast fissure which is now masked to a large extent by cinders. (See pl. 16.) The cone culminates in two peaks, the higher one on the east side of the fissure and the other, 305 feet lower, on the west side.

A spur of the cone extends toward the north for half a mile and is made up of three small united cones, each one surmounted by a crater. Two of the craters are open to the west but the southern one is a symmetrical crater bowl.

Much of Big Cinder Butte is covered with vegetation except small areas of loose cinders swept bare by the wind. The history of the cone is long and complicated and only later events can be deciphered.

Extending southeast from Big Cinder Butte nearly to Coyote Butte, is a line of red cinder crags surrounded by later lapilli. The crags are weathered remnants of an ancient line of cones which have been in eruption during the early activity of Big Cinder Butte. Less well preserved is a belt of crags a quarter of a mile wide extending south from Big Cinder Butte. Toward the south these crags are surrounded and perhaps in places transported by an aa lava flow. They merge one into the other so gradually that it is impossible to determine exactly where the lava begins and the cinder crags end.

The crest of Big Cinder Butte is a part of the rim of a crater which has been breached on the southeast side. This rim borders a former crater three-quarters of a mile long and nearly half a mile wide and in places it is over 600 feet above the bottom of the crater. Inside of this large amphitheatre is a smaller crater an eighth of a mile in diameter, also breached on the southeast side. A short aa stream has flowed out from it. A quarter of a mile east of this crater at an altitude of 6,000 feet is the symmetrical crater bowl over 50 feet deep shown in Plate 15B.

The northeast slope of Big Cinder Butte has been cleft by a fissure from which lava has been erupted and along which subsidence has occurred. Along the fissure is a deep, steep-sided trench bordered by spatter. A few feet from this trench and somewhat higher in elevation is a nearly circular crater. A little southeast of it is a second crater bowl. The material in the walls of this crater is different from that of any others in the Monument because it does not consist of bedded cinders. Instead there crops out on its walls, even bedded, fairly compact brown tuff. The tuff consists of shards of glass and indicate an explosion of sufficient intensity to disrupt the froth of the lava colum into minute fragments. Much of the crater is filled with debris so that it is not feasible to determine the thickness of the tuff or whether any beds of cinders are intemingled with it.

Parallel to this line of craters on the spur projecting northwest toward Broken Top is a line of small spatter cones covered with bombs of all sizes and shapes. In this line of vents is a small crater bowl ten feet deep and about 25 feet in diameter, on the township line bounding the east side of the N.E. $\frac{1}{4}$ sec. 13, T. 1 N., R. 24 E. In this tiny crater is a small round patch of pahoehoe that welled up in the crater and solidified without overflowing. It is an example in miniature of the hardened lava lakes which form the floor of Kilauea-Iki and Keanakakoi craters on Kilauea Volcano, Hawaii.

Three fairly recent flows have issued from vents on Big Cinder Butte but the number of older flows cannot be ascertained because some of them are buried. A blue-crusted billowy pahoehoe flow issued from the fissure through on the northeast side of Big Cinder Butte and flowed northward completely covering the depression enclosed by the two north spurs of Big Cinder Butte and Broken Top. The surface of the flow is nearly level with no pronounced piling up at the source, hence the flow may have formed a great lava lake in the depression before it crusted over. The flow is nearly bare of vegetation and the margin is abrupt and in places is made up of tessellated pahoehoe cakes 10 to 15 feet square which stand nearly perpendicular, especially south of Broken Top. The northwest part of the flow overlies the aa that entered through the gap west of Broken Top, hence it is later than the Crystal Fissure flow. It also overlies the ancient pahoehoe in the low gap south of Broken Top and the old lava that crops out on the southwest side of Broken Top both of which may be parts of the same flow. In the NE. ¼ sec. 13, T. 1 N., R. 24 E., there is a small stream of lava only about 20 feet wide which spilled over the rim of a spatter cone near by. It passes under the Big Cinder Butte flow.

The Derelict Flow breached the southeast rim of the inner or nested crater on Big Cinder Butte and flowed southwest for a mile and a half. It consists entirely of pahoehoe and the dark rugose crags of cinders on its surface look like derelicts on a lava sea. Some, if not all, of the crags are in situ and are remnants of old weathered cones forming kipukas in the flow. The relative age of this aa is difficult to ascertain, for it overlies only one other flow and that came from the same vent. This older flow covers several square miles to the southwest and is almost entirely pahoehoe. Although the lava cannot be traced directly to a source, it is believed to be coeval with the formation of the large breached crater on Big Cinder Butte. To the northwest it merges imperceptibly with other pahoehoe flows that came from the north.

Extending south from the old belt of cinder crags east of Derelict flow, beyond the area mapped, is a massive, glassy aa flow that either came from a new obscured vent on the south side of Big Cinder butte or pushed out as a viscous mass in the center of sec. 36, T. 1 N., R. 24 E.

Half Cone. - Half a mile northeast of Big Cinder Butte and with its slopes covered with pumice largely derived from vents on Big Cinder Butte is Half Cone. It rises nearly 350 feet above the adjacent plain and is only the southern rim of a much larger crater. All traces of the flow from this cone are now buried and later lavas from other sources have filled its crater. The lava which surrounds it supports considerable vegetation and the topography indicates that it came from a vent on the northeast

side of Big Cinder Butte or the south side of Broken Top. Half a mile south of the summit of Half Cone is a small unnamed cinder cone covering an eighth of a square mile and rising about 100 feet above the plain. It is surmounted by a small crater from the floor of which rises a small cone formed during the last phase of the eruption. This cone is a kipuka in later flows and is bordered on the east by the ancient pahoehoe that encompasses Half Cone and on the west by the Trench Mortar Flat flow.

Crescent Butte. - About a mile southeast of half Cone is Crescent Butte which rises 490 feet above the adjacent plain. Its crater bowl is breached on the north side leaving the rim in the form of a great crescent. The highest point on the rim is 340 feet above the bottom of the shallow undrained depression in the center of the crater. The surface of the cone is partly covered with vegetation and its flow, if it had any, are entirely buried by later lava. Its western slopes merge into the cinder plain and all possibilities of determining its relative age are thereby removed. It is older than all the adjacent flows and although perfectly preserved was probably formed concurrent with some of the ancient flows in the area. A profile of this cone along a line traversing the cone from southwest to northeast is shown in Figure 9.

Figure 9. - Profiles of Crescent cinder cone and Needles Cave lava dome.

On the south side of the cone on the cinder plain there is a crater about 40 feet deep with a low and inconspicuous rim that appears younger than Crescent Butte. If any lava ever issued from this cone, it is now entirely buried.

Coyote Butte. - One mile southeast of Big Cinder Butte and nearly the same distance from Crescent Butte rises Coyote Butte. Its summit is 5,907 feet above sealevel and about 300 feet above the plain. The entire cone is composed of cinders and covers a little less than one half a square mile. The two summits for parts of the rim of a crater about a quarter of a mile in diameter on the north side of which poured forth the Sawtooth Lava flow. On the south side of the butte there is a shallow depression marking the site of another eruption.

The Sawtooth lava flow derives its name from its sharp and bristling surface. It is one of the largest lava flows in the Monument and is undoubtedly the largest aa flow. It issued from the north crater of Coyote Butte and flowed southward for over six miles, extending beyond the area mapped. Its maximum width is about a mile and a half and its minimum width is not less than a mile.

Numerous inclusions of diorite were found in this flow. One of these, a white granular angular inclusion (Spec. C125) was examined under the microscope by Howell Williams who describes it as an aplitic modification of quartz diorite occurring in vesicular tachylyte.

At its source the flow is covered with cinders from eruptions of adjacent cones and also with considerable vegetation. Southward the lava thickens, becomes more chaotic, its surface is more bare and black and has only a few scattered trees on it. It affords an admirable example of the variation in the freshness of a single lava flow and illustrates how on a desert an ancient aa flow with large interstices can remain black and bare for thousands of years. The northern part was subjected to thick pumice and ash falls. Having a less porous surface it became covered with vegetation, and assumed a very ancient appearance. The Sawtooth flow evidently destroyed considerable grazing land for it invaded Little Laidlow park, a grass-covered area and isolated North Laidlow Butte as a kipuka. Its western boundary was not mapped in detail. The eastern margin near the south end is indistinguishable from a thick aa flow from the Sentinel. The great thickness of the Sawtooth flow and the fact that it consists of large blocks jumbled together in a chaotic mass make a proposed road to Little Laidlow Park and to the southern cities of Idaho difficult and expensive.

Echo Crater Butte. - A little over a mile and a half southeast of Coyote Butte is Echo Crater Butte, which rises about 250 feet above the plain. On its summit are three linked craters, of which the northwestern one is the largest and deepest. During part of the investigation a camp was maintained on the floor of this crater and by constructing a small dug-way it was possible to haul the equipment and baggage into it by team. The camp was sheltered to a large degree from the winds by the crater walls, and the large dead pines on the talus slopes at the foot of the walls afforded ample wood. Water, however, had to be hauled from Little Prairie Water Hole, a mile away. This crater is an undrained depression nearly 100 feet deep and the crater rim in places rises about 300 feet above the crater floor. A quarter of a mile northeast of it is an oval knoll that appears to be the top of a nearly buried cone. Another cone remnant occurs about the same distance southeast of Echo Crater and near by are other crag remnants. On the top of the most prominent crag is a stone blind formerly used by the Indians in hunting. At the foot of this crag numerous potsherds have been found.

Extending away from the east side of Echo Crater is a shallow trough-like depression through which lava escaped from the crater.

The Echo Crater lava flow is nearly buried with pumiceous soil and supports a good growth of brush and grass. It is clearly one of the ancient flows but is original extent cannot be determined because fresh black lavas from the north have partly buried it. It is overlain also by the Little Prairie aa flow in the vicinity of Echo Crater. It is partly pahoehoe and partly aa and it is exposed over at least three square miles.

The Watchman. - A mile and a quarter southeast of Echo Crater is The Watchman, an old cinder cone which rises about 325 feet above the adjacent lava plain. When viewed from either the southeast or northwest the wide saucer-shaped depression on its summit is very conspicuous and divides the cone into two parts. The crater rim is low on the southeast and northwest sides so that the undrained depression is only about 40 feet deep. With the exception of two black patches of spatter, the slopes are entirely covered with brush interspersed with a few scattered pines. The two patches of spatter lie on the southeast and northwest slopes of the cone and are distinctly younger than the main mass. Dark, bare flows have welled out on the fissures from which this spatter was ejected and unite on the south side of the cone to form the Little Prairie aa flow. These two eruptions are accidental features on the slopes of The Watchman for, as these fissure vents continue out on the plain, they are very clearly a part of the Little Prairie fissure vent. It is significant that the fissure erupted spatter and lava all the way from the base of the northwest side of the cone to the rim of the crater. Lava failed to break out in the old crater of the Watchman, but again broke out on the southeast slope of the cone. (See pl. 16.) This gap in the line of eruption of the fissure is apparently due to the former feeder of the Watchman being sufficiently strong to withstand the stresses which fissured the cone. The earlier lava flows from The Watchman cannot be identified but doubtless some of the lava to the southeast issued from it.

The Sentinel. - Half a mile southwest of The Watchman is The Sentinel, a cone which rises about 250 feet above the plain. Between the Watchman and the Sentinel is a low gap through which an old Indian trail passes. The Sentinel is a quarter of a mile long and half a mile wide and the northwest-southeast trend of the cone is due to it being built over a fissure. Along the crest of the cone are five distinct craters formed evidently during at least two eruptive cycles, for there is striking difference in freshness between the northern ones and the southern ones. The southern crater is breached on the south side where a lava stream has flowed out. On the south side of the cone is a spur composed largely of old red cinder crags apparently the weathered remnants of an ancient cone.

The oldest lava flow from the Sentinel escaped through the west side and spread southward over the plain. It is partly covered with soil and supports a heavy growth of sage brush. The boundaries are no longer discernible for the flow has been nearly buried by the Sawtooth flow on the west and a later flow from the Sentinel on the east. The part of the flow that is exposed forms a peninsula-shaped Kipuka about three miles long extending southward from the vent. The end of this peninsula is a broad undrained depression 60 feet deep covering over half a square mile and almost entirely surrounded by a wall of aa lava from 10 to 40 feet high. (See pl. 16.)

A later flow also has issued from The Sentinel. It was extruded from the south side of the cone through a large lava tube. At the head of the flow is a cave 50 feet wide, 50 feet long, and 20 feet high. The remainder of the tube is either collapsed or the caves in it are not accessible. The course of this former lava river is now seen as a pronounced steep-sided trench extending for over half a mile from the vent and of sufficient size to be shown by the contours on Plate 16. This lava flow is old also and has considerable soil in it which makes it impracticable to determine its boundaries. It spread southward with a gradient of about 50 feet to the miles, and about two miles from the source accumulated as rough aa which merges with the Sawtooth Flow forming an extensive field of bristling block lava two miles wide and extending a few miles south of the area mapped.

Split Butte. - A little over a mile southeast of the Sentinel is Split Butte which rises about 250 feet above the plain. The cone is covered with vegetation and belongs with the group of older cones. The crater opens to the southeast apparently in the direction lava flowed from it. It is not certain, however, whether the lava which occupies this breach is lava from Split Butte or a later flow which has entered the crater from Fissure Butte and buried the Split Butte flow. The butte is a kipuka for later lavas lap up on its slope.

Fissure Butte. - A mile south of Split Butte is Fissure Butte which rises about 425 feet above the plain. It covers about half a square mile and has a pronounced trend northwest to southeast owing to a later fissure eruption building a spur to the northwest from the mass of the main cone. Subsequent eruptions along an extension of this fissure to the southeast has joined Sheep Trail Butte to Fissure Butte. On the western side of the cone is a large undrained bowl-shaped crater. The highest point of the rim is about 375 feet above the bottom of the pit. Movement along a fissure which passes over the eastern side of the butte has caused a subsidence of the east side. Another trough an eighth of a mile east of this fissure shows the same type of displacement.

The flows from Fissure Butte are nearly obscured by later ones. An extensive flow extruded from the south side merges to the south with flows from Sheep Trail Butte. It may have been poured out simultaneously with the Sheep Trail Butte lava for the place of issue is at the junction of the two cones. This lava is older, however, than the south flow from The Sentinel for both are overlain by it. The Fissure Butte flow is fairly well covered with vegetation and soil in the northern parts but to the south it becomes black rugged aa. The later lava flows belonging to this cone welled out of the fissure that lies mostly on the plain and that only incidentally affected Fissure Butte.

Sheep Trail Butte. - Adjoining Fissure Butte on the southeast is Sheep Trail Butte which rises about 150 feet above the plain. It covers about half a square mile and its surface is black and bare although a few large scattered pines grow on its slopes. The bare surface is probably not an indication of recent age in this particular case, because the surface is composed of loose cinders which are covered with trails that converge at the water hole in one of the craters in its summit. These trails and the twisted horns of the mountain sheep indicate that this was a favorite place for animals to congregate in the past and the lack of vegetation is very likely due to overgrazing and to trampling of the surface by animals.

On the summit of the cone are three linked undrained crater bowls along a northwest-southeast fissure, the general trend of the Great Rift. Around the southeast crater are a series of narrow concentric rings of cinders due to periodic collapse following the intermittent subsidence of the lava column after the eruption.

Along a fissure on the saddle between this butte and Fissure Butte is a line of driblet or spatter cones that have short flows extending away from them. The surface near the cones is rent with gaping cracks caused by an eruption which formed the spatter cones and flows at a much later time than the main bulk of the cone. The ejecta from these small spatter cones were confined to a very limited area and can hardly be considered the cause of the bareness of Sheep Trail Butte. This small eruption on the saddle between the two buttes has been shown on Plate 16 as a member of the youngest series of lava flows in the Monument but this stratigraphic position is tentative only because it is not improbably that is occurred simultaneously with the extrusion of the lava from the fissure which cleaves Fissure Butte.

Earlier flows have issued from the northeast and southeast sides of Sheep Trail Butte. The northeast flow supports a considerable growth of vegetation and is evidently the older of the two. Its lateral extent is unknown because of partial burial by subsequent flows from vents to the northwest.

The southeast flow from Sheep Trail Butte started out as pahoehoe and near the source there are two small caves marking the site of a lava tube that fed the flow. The tube starts from a pit 100 feet wide and 200 feet long and about 50 feet deep formed by collapse immediately following the draining away of the lava. About half a mile to the southeast the flow changes to aa and in this chaotic part is a wide lava channel 25 feet deep formerly occupied by a lava river. This flow extends beyond the southern end of the Monument and its boundaries become lost in the black lava field that lies to the southeast.

Two Point Butte. - Standing as a kipuka in the lava from Sheep Trail Butte is Two Point Butte. It rises 120 feet above the plain and lies a mile south of Sheep Trail Butte. It is older than Sheep Trail Butte and appears to be about coeval with Fissure Butte and many of the old cones in the Great Rift Zone. The Butte is made up of two cones on which there are three craters in linear arrangement. The norther cone is the smaller of the two. It is perfectly round and has on its summit the very symmetrical crater bowl about 50 feet deep shown in Plate 17B. The lavas from this butte are entirely buried by subsequent flows.

Outside of the Great Rift Zone there are only three cinder cones that lie in the Monument area, namely, North Laidlow Butte, Bowl Crater, and Round Knoll. All of these cones were in eruption before or in the same epoch as the older cones in the Monument. Some of the cinders on the summit of Round Knoll are coated with minute black magnitite crystals. Besides these cones there are weathered remnants of a line of partly buried old cones that appear to be built over an ancient branch fissure of the Great Rift extending southward from Grassy Cone. (See pl. 16.)

Spatter Cones and Fissures and their Flows

In addition to the lava flows that have issued from cinder cones, other important lava flows in the area have excaped from fissures which are marked on the surface by trenches bordered by spatter or by coalescing spatter heaps. Some of the spatter heaps from very symmetrical cones. This type of fissure eruption is common on the slopes of most basaltic volcanoes. It is not, however, a common type of vent in the lava fields of Idaho and probably nowhere else on the Snake River Plains are they so well preserved and so numerous as in the Monument. A primary requisite in the formation of fissure vents bordered by spatter is the arrival at the surface of lava containing only a relatively small amount of excess volatile components as compared with the lava that is erupted from the cinder cones. The difference in the amount of the gases causes the lava column to froth violently to form cinder cones in one case, whereas in the other case the expansion of the lava as it reaches the surface is sufficient to eject spatter only. Lava spatter as a whole is less vesicular than cinders and consequently is heavier. Fissures bordered by spatter and fissures marked by chains of spatter cones may appear very different in the field, but they both result from only slight variations in the mechanism of the eruption. In the case of the fissures bordered by spatter, the ejection of the lava is more or less continuous along the entire length, whereas in the case of the chain of spatter cones the jetting of the lava becomes confined to certain points along the fissure and the spatter accumulates around the vents as small heaps. The two conditions may occur simultaneously along different part s of the fissure or the chains of spatter cones may be the last phase of the eruption. A crack along which there is continuous jetting may become clogged in places and localized jection may take place at certain definite and easy exists. A third variation in the machaism of fissure eruptions of this type of lava also occurs in the area. If the lava wells out in a very fluid state from a fissure without frothing sufficiently to produce spatter, a low lava dome will be formed which often obscures the fissure from which the lava was extruded. Fissure eruptions have produced chains of cinder cones also in the area. In a few cases both chains of cinder cones and spatter cones were formed during the same eruption. The features resulting from a fissure eruption may differ vastly in size and shape, and the variations are best explained by changes in the volume of the volatile components in the erupting magma.

The driblet cones, the fissures bordered by spatter, and the lava flows associated with them, are described in the following pages as they occur in order from north to south. The northermost fissure is between North Crater and Big Craters Buttes and gave vent to the Northeast Big Craters flow. (P.)

Crystal Fissure. - At the end of the automobile road on the southeast side of Big Craters Butte is the remarkable chain of steep sided spatter cones shown in Plate 20A marking the site of a fissure half a mile long. The 11 spatter cones in the chain range in height from about 5 to 50 feet. The first of the spatter cones is known as the Ice Cave. It stands about five feet above the adjacent lava and is made up of clots of lava that adhered to each other when they fell. The throat of the cone, dark red in color, is descended by means of a wooden ladder. It is about 8 feet in diameter at the top but enlarges downward. The original depth of the pit was about 35 feet but it is now partly filled by a heap of ice and snow. With a light, one can enter a small cave about 20 feet long extending north from the bottom of the pit. On the roof and walls of this cave there are many long red stalactites and on the floor short red stalagmites. The next spatter cone in the chain has a very symmetrical form and a sharp rim surrounded an irregular funnel-shaped crater about 30 feet in diameter and 50 to 60 feet deep. About 10 feet below the rim, it is constricted to a narrow opening a few feet in diameter. Below this opening, according to Russell[1] who descended it, the throat again expands giving the cone in vertical section an hour-glass form. At the bottom of the cone are two openings 15 feet wide and 10 to 12 feet high that are mouths of lava tubes through which lava excaped.

Counting the Ice Cave as a spatter cone, Crystal Pit is the seventh spatter cone southeast in the cone chain. It is less conspicuous than those to the northwest of it but is unique because of its deep pit. Formerly this crater was thought to be bottomless because of, although the rumbling of the stones dropped into it could be heard for several moments, the stones were not heard to hit bottom. This phenomenon can be explained by the sound waves echoing inside of the jug-shaped crater long after the stone had hit the bottom, and doubtless the echoes drowned the sound

[1]Russell, I. C., Geology and water resources of the Snake River Plain of Idaho., U. S. Geol. Survey Bull. 199, p. 81, 1902.

of its impact against the bottom. The opening on the top of Crystal Pit is about three feet in diameter. The circular throat is unchanged in size for the first 25 feet and resembles a well with walls of adhering lava trickles. Abruptly, it opens downward into a large chamber about 60 feet deep, making a total depth of 80 feet for the inverted funnel-shaped crater of this spatter cone. About 10 feet above the bottom is a ledge about 5 feet wide which apparently was formed by the lava crusting at this elevation. Subsequent subsidence of the lava column left this ledge at the shore line. Two tube-like caves lead away from the chamber at different elevations. One of these tubes is inaccessible without a ladder because it opens from the side of the crater wall. The other is about 60 feet long and opens to the north from the floor of the crater. These tubes are where the magma escaped to feed the margin of the flow. The rest of the pit bristles with the sharp red lava pendants from three to six inches long that resulted from the dripping of the molten lava at the cessation of activity. Covering many of these stalactites and parts of the walls and floor are scintillating white gypsum crystals. The average crystal is about an eighth of an inch long and is bounded by well developed crystal faces. They adhere to one another forming clusters several inches long. The gypsum was deposited by the gaseous emanations that accompanied the closing phase of the eruption. It is one of the most common salts deposited at volcanic vents.

Wide and extensive streams of black fresh-looking lava have welled out from Crystal Fissure, the fissure marked by this cone chain. The boundaries of its flows cannot be distinguished because lava from the Big Craters merges imperceptibly with them. It is evident from the feeding channels that lava flowed from the fissure to the west, and southwest, south and east. The eastern stream is shown in Plate 20B. One short stream entered the gap between Broken Top and the north sput of Big Cinder Butte. The eastern flow is mainly aa, but the one that flowed southwest is largely pahoehoe. At least three different lava currents took a westerly course from it. The middle stream forms a cascade over the slope of a cinder cone remnant in the NE. $\frac{1}{4}$ sec. 11, T. 1 N., R. 24 E. An eighth of a mile west of the southern end of the cone chain is a small spatter heap of a low dome of pahoehoe. This may be only a hornito or secondary vent developed over a lava tube but it is shown in Plate 16 as a vent because of the large amount of pahoehoe lava that has issued from it.

Trench Mortar Flat Fissure. - Trench Mortar Flat Fissure is on the southeast side of Big Cinder Butte and nearly two miles in a direct line southerly of Crystal Fissure. It is a shallow trench

5 to 10 feet deep and about 20 feet wide, bordered on both sides by spatter. Its original depth may have been somewhat greater but subsequent eruptions on adjacent cones have deposited considerable pumice and cinders in it and on the surface of its flow.

The remarkable lava clot with adhering lapilli, shown in Plate 20C was found on the surface of the lapilli that form a broad undulating plain an eighth of a mile southwest from Trench Mortar Flat Fissure. It is seven inches long and four inches wide, and in no place over half an inch thick. If the adhering lapilli were removed, it would average about an eighth of an inch in thickness. Much of its upper surface is shiny and glazed bulging here and there with blisters with paper-like shells. The color varies from dark red to black and the interior is black and filled with spherical vesicles. To its under surface adhere numerous small lapilli, and the mold of some form of vegetation can be seen. (See pl. 20C.) The upper surface is undulating as a result of molding over the lapilli. It is so fragile that one cannot believe it has been exposed any great length of time at the surface because this area has been pastured extensively during the last decade and such fragile clot would have been broken easily if stepped upon. It is probably this this clot was buried during the eruption by lapilli and cinders soon after its ejection and has only recently been exposed by the wind. Within a few feet of it, and scattered over the rest of the flat grow sagebrush and scattered pines which indicate that it was not ejected in recent time. Moreover there are no fresh looking vents nearby. Such a clot is hurled out at a high temperature during an eruption, falls in a very liquid condition, and flattens out by the impact. The writer has described similar clots from the Kilauea eruption of 1823 that molded the grass on which they fell.[1] A careful search failed to discover other clots in this area, a fact which further substantiates the idea of recent uncovering.

It is possible that the short crack about three-quarters of a mile northeast of Trench Mortar Flat Fissure, on a short spur of Big Cinder Butte in the NE. $\frac{1}{4}$ sec. 13, T. 1 N., R. 24 E., was formed at the same time as Trench Mortar Flat Fissure. The surfaces of the little spatter cones that mark the line of this fissure eruption are strewn with bombs a fraction of an inch to three feet in diameter. These bombs are more perfectly developed and more numerous than in any other place in the Monument and are

[1]Stearns, H. T., The Keaiwa or 1823 lava flow from Kilauea Volcano, Hawaii: Jour. of Geol., Vol. 34, No. 4, p. 345, 1926.

described on page . A narrow stream of pahoehoe spilled over the rim of one of these spatter cones and flowed to the west but within a few feet in passes under the Northeast Big Cinder Butte flow.

The Trench Mortar Flat flow is remarkable for its thinness, being in many places less than a foot in thickness. In this respect it differs from all the other lava flows in the Monument and is very similar to the Keaiwa flow of 1823 from Kileuea.[1] The lava is extremely scoriaceous and some portions of it are almost pumiceous. It is exposed over an area of about half a square mile to the northeast of the fissure from which it flowed. Formerly it was more extensive, for the end of it is now overlain by a later lava flow from the north. In the Trench Mortar Flat flow within a hundred yards of the source, are a number of lava trees which rise from 2 to 5 feet above the crust of the flow. It is the resemblance of these lava trees to the trench mortars of the Civil war period that give this flat its name. They are described in detail on page .

Little Prairie Fissure. - Half a mile in a straight line southeast from Trench Mortar Flat fissure is Little Prairie Fissure which extends southeast from near coyote Butte to the south side of the watchman. The fissure extends southeast for about two miles, but it is not traceable on the surface for this entire distance. It occurs as five segments, the intervening parts being probably buried by subsequent lava. The segements all trend in the same direction and are parallel to one another but they are offset on echelon. Only the extremeties are in actual alignment.

Parallel and adjacent to the fissure are numerous cracks. These cracks divide the surface into narrow strips, some of which have subsided a few feet. In many places the cracks are so open and occur so close together that it is impossible to cross them on horseback.

It cannot be definitely ascertained whether all of these fissures erupted simultaneously. The physical character of the lava suggests that the southernmost fissures may be somewhat later than the northern. Although all of the fissures are bordered by spatter, no well defined spatter cones occur along them. At Bearsden Waterhole, in the middle part of the fissure however, one small ill-defined spatter cone occurs. Collapse, following the subsidence of the lava in the fissure has developed a trench in places over 100 feet deep. The north end is 35 feet deeper than the southern end. The southern part passes up the northwest slope of the Watchman to the crater rim where it dies out.

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[1] Idem., pp. 336-351.

It reappears, however, on the southeast slope of The Watchman and ends within a few hundred feet. Yellow Jacket, Bearsden, and Little Prairie water holes which are described in detail on page occur along this fissure.

Lava welled out along nearly the entire length of Little Prairie Fissure and flowed southeastward for a distance of 5 miles. This flow is shown in Plate 16 as the Little Prairie aa flow. The highest source of this flow is 270 feet above the terminal margin; hence the gradient is 54 feet to the mile. It is the narrowest flow in the Monument, ranging from an eighth to half a mile in width. At tis source the lava is pahoehoe and is partly covered with spatter thrown out from the fissure but elsewhere it is aa 10 to 15 feet thick. A large number of tree molds were found in the flow near the fissures.

Parallel to the Little Prairie Fissure and half a mile to the southwest, a narrow fissure about an eighth of a mile long bordered by spatter, has given vent to a flow that extended southward. Its original extent is unknown for all except about half a square mile of it is buried by later flows. (See pl. 16.)

Fissure Butte Fissure. - Extending northwestward from Fissure Butte is a prominent fissure over a mile long and in many places 100 yards across and over 50 feet deep. It is bordered on the west side by spatter, but on the east side, except for two small patches, the spatter was carried away by two lava streams as fast as it was ejected. The eruption was subsequent to the formation of Fissure Butte, for it cracked open the northeast slope and the accompanying subsidence depressed the east side. A short fissure which may have erupted concurrently with the Fissure Butte fissure occurs in the saddle between Fissure and Sheep Trail Buttes. This eruption has already been described on page .

An eighth of a mile northeast of Fissure Butte fissure is a line of about a dozen partly collapsed spatter cones which apparently erupted simultaneously with Fissure Butte fissure. The flow from these spatter cones mingles with those from Fissure Butte fissures, and together they cover several square miles. A very rugged stream of aa lava forms a narrow tongue about a mile long between Fissure Butte and Split Butte. Elsewhere the boundaries are determined only with difficulty, the lava being partly covered with vegetation and merging imperceptibly with adjacent flows.

Vermillion Chasm. - Vermillion Chasm is in the southeastern corner of the area mapped. As shown in Plate 21A, it is primarily a trench bordered by spatter, with a few well-formed spatter cones on its floor. Its width from rim to rim varies from a few feet to several hundred, and the spatter heaps that form the rims in places rise 50 feet above the floor. The distribution of the rim spatter indicates that fire-fountains played along its entire length with the last sputtering phases of the eruption forming the small spatter cones on the floor. One of these spatter cones in the northern part has a crater about 4 feet in diameter and 6 feet deep, with walls lined with dark red stalactites. The cone rises less than 5 feet above the floor of the trench and in outline resembles the low sinter cones formed by the geysers in Yellowstone Park. Four or five other incomplete spatter cones occur near by.

Farther south along the fissure occur still other spatter cones, one of which is 30 feet deep and contains ice and water. Another spatter cone with a crater 3 feet in diameter lies farther southeast along the fissure. A rock dropped into it can be heard falling for a couple of seconds, hence the pit may be 70 feet or more in depth. About half a mile southeast of this pit is a chain of spatter cones which do not rise over 15 feet abo ve the adjacent plain. Chimney-like craters, a few containing ice, exist in these cones.

Although some lava has flowed from Vermillion Chasm in all directions, definite streams have flowed only from its east side. They merge southward with the aa from Sheep Trail Butte, and considerable work would have to be done to determine their boundaries.

Several other spatter cones occur in the Monument, namely near Owl Cavern and Needles Cave, and are described in the following pages under the lava domes with which they are associated.

Lava Domes

When lava wells out quietly from a fissure or tubular vent, a lava dome is formed. Such domes are so low and have such a gradual slope that they form insignificant features on the landscape. The profile of a typical lava dome in contrast to the profile of a cinder cone is shown in Figure 9. Only eight domes occur in the Monument. (See pl. 16.) The presence of tubes leading away from the dome is the usual surface criteria that the dome is located over a vent. Obviously such tubes must have started at a place where the lava welled out. In places crateral depressions occur on their summit resulting from collapse at the cessation of extrusion.

Cave Dome, in the SW. $\frac{1}{4}$ sec. 12, T. 1 N., R. 24 E., is a small lava dome with a small heap of spatter on its summit. Pahoehoe spread out on the adjacent plain from this place through radiating tubes. The boundary of the flow is indeterminable on the west side of the dome because it merges with flows of similar appearance from the north.

Great Owl Cavern Dome, half a mile south of Cave Dome in the NE. $\frac{1}{4}$ sec. 14, T. 1 N., R. 24 E., gave vent to a flow characterized by a blue glass crust half an inch thick, that spread out for several miles to the south. The distribution of most of the lava occurred through Great Owl Cavern. The flow wupports very little vegetation and merges on the west with the Southwest Big Craters flows and on the south with the Big Cinder Butte flows. Russell named these flows the Blue Dragon Flow because of their beautiful blue glassy crust. On top of Great Owl Cavern Dome are two small spatter cones less than 20 feet high.

A mile east of Inferno Cafe on the line between secs. 6 and 7, T. 1 N., R. 25 E., is Indian Tunnel Dome. A triangular piece of this dome covering nearly an eighth of a square mile collapsed at the close of the eruption and now forms an undrained depression about 30 feet deep. Extending northward from this depression is Indian Tunnel, the main lava tube through which lava escaped. The freshness of the lava that makes up the dome indicates that it is one of the youngest flows in the Monument. The boundaries of the Indian Tunnel lava flow are indeterminable and it is possible that the eruption at this dome was simultaneous with that of the adjacent domes.

Four domes are located outside of the Great Rift Zone and are described in the following pages.

A little over half a mile east of Indian Tunnel Dome in sec. 5, T. 1 N., R. 25 E., is Natural Bridge Dome. Lava welled out of this vent and spread out over the adjacent plain through a tube which has since collapsed on the summit of the dome and now forms a narrow trench an eighth of a mile long. The lava is fresh and merges imperceptibly with the Indian Tunnel flow.

Less than a quarter of a mile northeast of the Natural Bridge Dome is Needles Cave Dome. It covers over a square mile and its profile is shown in Figure 9. On the west side are two spatter cones, one 5 feet and the other 20 feet high. The larger spatter cone has collapsed on the west side and it is possible to enter the crater throat through this gap. The crater is about 15 feet deep and has a pile of debris on the bottom derived from the collapsed side. A small cave near the summit of the dome has many sharp needle-like stalactites in it, hence the name. (See pl. 22C.) Other caves occur on the slopes of the dome indicating that the lava escaped through several radiating tubes. The lava flows appear to be slightly older than those from the Natural Bridge and the Indian Tunnel domes.

The size and shape of the Needles Cave Come and the lava extruded from it closely resembles that of the dome of Maunaiki that was formed in 1920 on the southwest slope of Kilauea Volcano. In the early part of December 1919, numerous cracks opened in the southwest Rift Zone and on December 21 lava welled out from one of the cracks. The lava poured out until the 28th of July, 1920[1], and formed a flow six 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 a mile across developed over it. 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. However, this crater is smaller and less conspicuous than the adjacent depression formed by the collapse of the roof of the 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 welled out from four other fissures on the slope of Kilauea and formed small isolated patches of lava and another small lava dome.[2]

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[1]Monthly Bull. of the Hawaiian Vol. Observatory, 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 616, p. 80, 1930.

Needles Cave Dome probably was not formed all at one time. It appears that lava welled out at an earlier date in the vicinity of Tom Thumb Tunnel for the lava in which this cave exists is overlain by the Needles Cave lava. Furthermore, after the collapse which formed the entrance to the Lava River Cave a tongue of lava cascaded into the west side of the depression near the entrance.

Two miles north of Needles Cave Dome, in the NE. $\frac{1}{4}$ sec. 29, T. 2 N., R. 25 E., is a low dome of pahoehoe lava that appears to be a vent. In the depression nearly 100 feet deep on its summit occurs the Surprise Water Hole. Lava from this vent overlies the Serrate flow.

About a mile and a half northeast of Split Butte near the margin of the fresh black lavas in the Little Prairie Kipuka, is Moss Cave Dome, in the NW. $\frac{1}{4}$ sec. 36, T. 1 N., R. 25 E. It is largely covered with soil and vegetation and its flow is almost entirely buried by subsequent lavas from other vents. Moss Cave is located on the summit of this dome. Amphitheatre Cave and Sunbear Cave also are parts of the tubes through which the lava from this dome spread out on the plain.

Another unnamed dome in the SE. $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 11, T. 1 N., R. 24 E., is described on page .

Pit Craters

A type of craters different from that which is found on cinder cones occurs in the Monument. In sec. 12, T. 1 N., R. 24 E., several yawning craters form a chain around which are no cinders or spatter. Lava Cascade, the largest, is oval in shape, about 50 feet deep, and over a quarter of a mile long. To the northeast are several others just as deep but about 50 to 100 feet across. In their walls are exposed horizontally bedded basalt. It is at once evident that these craters originated by collapse. In the case of Big Sink, lava flowed from the vent before the collapse took place and the absence of cinders and spatter is accounted for by the absence of any explosive phase accompanying the extrusion of the lava. Some of the other craters to the northeast do not seem to have been the source of lava and represent collapse only. They are similar to the pit craters on the volcanoes of the Hawaiian Islands and were probably formed by magma fluxing a hole in the earth's crust, contemporaneously with the Crystal Fissure eruption. Small pit craters often resemble pits formed by the collapse of tubes because both are formed by collapse without the extrusion of lava but it is evident that they have a very different origin.

Detailed Features of the Flows

Both pahoehoe and aa flows are found in the area. The pahoehoe comprises streams of lava with broad, relatively smooth surfaces that spread out like thick tar as shown in Plates 17C and 21B. The aa in contrast, has a rugged surface made up of jagged and bristling blocks, as shown in Plate 19C. The two kinds of lava are variations of the same magma and differ in physical form only, for pahoehoe streams as they spread out on the plain sometimes change into aa. The aa flows, however, never change into pahoehoe although elsewhere during a few historic eruptions aa and pahoehoe have been alternately extruded from the same vent. It seems therefore that alternations in the type of lava arriving at the vent can occur whereas revisions in the lava stream once it has started flowing on the surface do not occur. The alternations in the type of magma reaching the surface are easily accounted for by the arrival at the vent of a fresh supply of lava from a different depth. The fact that aa can form from pahoehoe, but once formed, cannot revert to its latter condition while flowing as a lava stream implies that critical factors have been dissiplated that cannot be regained. The two things that are lost by every lava stream as it moves away from the vent are heat and volatile components. The critical factor, however, seems to be not the amount of these two constituents, but their interacting relationship. Thus as the temperature lowers less gas can be held in solution by the lava, and vice versa, the escape of the volatile constituents dissipates the heat. Both kinds of lava, however, are known to have practically the same temperature when extruded, hence it seems likely that a certain equilibrium is maintained between the volatile constituents and the temperature in pahoehoe which when destroyed results in the aa form. Emerson[1] states that "it would seem that the controlling factors in determining the final appearance of a lava flow are essentially mechanical, such as the thickness and viscosity of the flow, and its velocity at the time of crystallization." This conclusion does not seem adequate to explain the aa and pahoehoe here. Since all of the flows spread out upon a uniformly sloping plain the velocity or rate of movement would be similar for flows of comparable viscosity. Since the viscosity of a lava flowing on a plain determins primarily the thickness of the flow when it solidifies, it follows that the thickness of the flows is an index to the viscosity. The aa flows are not consistently thicker than the pahoehoe flows, hence one must conclude that the viscosity of the two types did not differ appreciably when extruded. Thus, with the viscosity the same, the velocity of the lava streams on this plain must have been sufficiently alike so that velocity was not a controlling factor in the formation of aa or pahoehoe. The increase in the thickness and viscosity of the lava is an effect and not a cause, and is one that results from a loss of temperature or gas content.

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[1]Emerson, O. H., The formation of aa and pahoehoe: Amer. Jour. Sci., Vol. 12, p. 114, Aug. 1926.

Aa Flows

Extensive aa flows occur in the Monument and cover a large part of the area west of the Great Rift Zone. They are shown on Plate 16 by zigzag contours. Serrate, Little Prairie, Southwest flow from Big Craters, and Sawtooth flows, are the important aa flows. The aa flows vary in thickness from 10 to 50 feet and are all extremely rough and jagged. Locally some of the flows are 100 feet thick. It is difficult for many who visit the area to imagine that these basalts ever flowed. The surface of these sheets consists entirely of loose and acicular blocks which make walking across them slow and difficult. These jumbled masses of lava clinkers solidified as separate blocks before they came into their present position. They either floated along on a pasty lava mass during its flow, or pushed and rolled along at the margin. Similar blocks are also dragged along beneath the flow. The characteristic feature of the aa blocks is the short sharp spines on their surface. The spines are caused by the gas pulling out a stringer of viscous lava as it escaped from the block. Similar spines formed in the same way can be seen on some of the stalactites from the caves. (See pl. 22C.) It was observed that the roughness of the surface of the blocks and the number of spines on them decrease as the blocks become more glassy. In fact the surfaces of the blocks which are nearly obsidian in the Serrate flow are smooth and devoid of spines. Since the imprisoned volatile content of the glassy forms of lava is usually higher than in the stony types the rapid cooling evidently excludes the opportunity of the gases to escape and form spines.

Pahoehoe Flows

The largest area of pahoehoe is found on the east side of the Great Rift Zone. In fact, practically all of the lava on this side is pahoehoe except the Serrate flow, a short aa stream from Crystal Fissure, and the Little Prairie aa. It was extruded chiefly during the eruptions that formed the lava domes. On the west side of the Great Rift the largest tract of pahoehoe occurs near Big Cinder Butte, and makes up the Blue Dragon flows. The blue crust which gives these flows their name is a variety of basaltic glass formed by the rapid chilling of a skin of the surface of the lava. It varies from a thin film to half an inch in thickness and in color from a dull rusty blue through many shades of blue to a golden brown. In places the crust has a beautiful irridescent sheen. This type of crust is usually separated from the underlying lava by a parting plane developed during cooling by the lava below shrinking away from it; hence the glassy crust often lies as loose fragments on the surface of the flow as a result of trampling or by mechanical weathering.

It is the parting and breaking away of this crust from the flow that produces part of the popping and snapping sound that occurs when pahoehoe flows are solidifying. All of the pahoehoe of the Blue Dragon flows does not have the blue crust, and all of the blue crust is not confined to this one area. It is a common feature in the area and occurs on most of the fresh pahoehoe. The reason why one part of a pahoehoe flow has the blue crust and the other part does not, and why it does not occur universally on all pahoehoe flows, is unknown. It may be that the climatic conditions such as air temperature and precipitation during its formation are the determining factor. It seems probably also that when the ebullition of the volatile constituents from the surface of the flow is slight, glass is found instead of a scoriaceous crust. The blue crust is very brittle and relatively much more unstable than the main lava mass, hence it weathers much more rapidly. For this reason it is rarely found on the older flows in the area.

The relatively smooth and swelled forms which make the undulations on the surface of a pahoehoe flow are due to several causes. The large dome-shaped hummocks 10 to 50 feet long and 10 feet wide, known as pressure domes, are formed by the buckling of the crust by subsequent movement of viscous lava below and by subsidence of the crust during the later stages of the flow. Not uncommonly lava will squeeze out through the cracks in the tessellated surfaces of these domes which indicates that they are formed while the lava is still molten below.

One of the most interesting and characteristic features of the surface of the pahoehoe flow and one never found on an aa stream is the ropy structure. These waves of "frozen motion" are admirably displayed in the Monument as shown in Plate 21B. These ropy and wrinkles surfaces are caused by the freezing of a thin crust or scum on the lava flow while the crust is being dragged along by the flowing lava below. In some cases the pahoehoe crust, broken and tilted by subsequent motion of the flowing lava as shown in Plate 21C forms a rugged surface which is often mistaken for aa. Some very fine lava cascades formed by the lava freezing as it spilled over a precipice are to be seen in the area as shown in Plate 22A.

In many places along the sides of cracks in the pahoehoe crust and especially numerous near the vents are yellow and brown stains marking the sites of former fumeroles. The stains are caused chiefly by the magnetite of the crust being converted by steam into hydrous iron oxide.

Lava Tubes or Caves. - Tubes occur in pahoehoe but are never found in aa. They lie entirely within the flows themselves and are caused by the solidification of the surface of a lava stream and subsequent drainage of the underlying lava. As the flow continued, the side walls also solidify and a tube is formed which entirely confines the underground river of lava. During the spreading of pahoehoe the main tube forks and reforks as the lava moves out on the plain so that little or no molten lava is in sight during a flow. Thus, the lava is conducted without much loss of heat to the advancing margin through a 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 Crater of the Moon area only the upper or souce ends of the tubes drained out when the lava ceased flowing. Consequently, in the area lava tubes are found only near the sources of lava.

Often one lava tube will have several skylight entrances and be divided into several caves by parts of the roof falling in. The number of the caves is therefore not an index to the number of tubes. Since the larger tubes divide and subdivide into an infinite number of smaller ones, many caves occur in the same tube system. The principal caves in the area and their location are given in the following table and the striking features of most of them are described.

Location of the Principal Caves

Name	Quarter	Section	Township	Range (East)
Unnamed	SW. ¼ SW. ¼	12	1 N.	24
Buffalo Caves	SE. ¼ SE. ¼	12	1 N.	24
Great Owl Cavern	NE. ¼ NE. ¼	14	1 N.	24
Lava River Cave	SW. ¼ SW. ¼	33	2 N.	25
Last Chance Cave	NW. ¼ SW. ¼	4	1 N.	25
Tom Thumb Tunnel	SE. ¼ NE. ¼	5	1 N.	25
Horseshoe Cave	NE. ¼ SE. ¼	5	1 N.	25
Needles Cave	NW. ¼ SE. ¼	5	1 N.	25
Surprise Cave	NE. ¼ SW. ¼	6	1 N.	25
Dewdrop Cave	NE. ¼ SW. ¼	6	1 N.	25
Indian Tunnel	SE. ¼ SW. ¼	6	1 N.	25
Unnamed	NW. ¼ SW. ¼	33	1 N.	25
Moss Cave	SW. ¼ NW. ¼	35	1 N.	25
Sunbear Cave	SW. ¼ NW. ¼	36	1 N.	25
Amphitheatre Cave	SW. ¼ NW. ¼	36	1 N.	25
Unnamed Cave	NW. ¼ NW. ¼	14	1 S.	25
Unnamed Cave	SW. ¼ SW. ¼	15	1 S.	25

Buffalo Caves are at the edge of a lava flow at the foot of the south slope of Broken Top. They received their name for a buffalo horn found in one of them. The eastern one is amphitheater shaped and is about 25 feet long and 20 feet high. It is well lighted by sunlight during the late afternoon and the narrow parallel shelves of lava scoring the walls from top to bottom shown in Plate 22B are the successively lower shore lines of the lava river that now forms its floor. On the west side the tube divides into four smaller ones at different levels. None of these cave can be explored for over 100 feet because they either become too narrow to crawl through or else are cluttered with loose blocks from the roofs and walls. Cool drafts of air blow through some of them indicating that although reduced in size, they continue farther and perhaps contain ice. They were discovered in 1885 by J. W. Powell and Arthur Ferris.

Great Owl Cavern is on the summit of the Great Owl Cavern lava dome. Near by are two driblet cones. If they resulted from gas and lava spatter being ejected from the roof of the cave they are hornitos. However, their secondary origin is not necessarily proven by this association with the lava tube for they also lie over a former lava vent and may have been caused by escape of lava from the fissure feeder. It is possible to descend into the cave through a nearly circular opening 30 feet in diameter in the roof by means of a rope ladder 25 feet long. The walls of the entrance pit are overhanging so that the ladder swings and twists in mid air as one descends on it. On the floor of the cave directly under the entrance or skylight is a pile of loose and poorly balanced rocks which fell from the roof at the time it collapsed. On a ledge not far below the opening is usually found a pair of great horned owls which are often seen perched in the shadows with glaring cats-eyes. Yellow jackets and pack rats inhabit the cave.

Great Owl Cavern is the most symmetrical lava tube in the Monument and is remarkable because of the preservation of so many original features in its interior. In many tubes formed in historic lava flows the original features of the interior are destroyed by the collapse immediately following the withdrawal of the lava or by subsequent earthquakes. The cave has a nearly uniform diameter of about 45 feet and a total length of nearly 400 feet. The entrance occurs near the north end of the cave, consequently most of the cave lies to the south of the entrance and is so dark that lights are necessary. The southern part extends away from the opening on a long tangent whereas the northern part ends abruptly within about 75 feet in a slightly overhanging wall under on e of the spatter cones.

On the floor and forming an arched fill 2 to 4 feet high and 8 to 10 feet wide is the last river of lava with all of its ripples "frozen" before it could completely drain away. This arched floor and vaulted roof gives the cavern the appearance of a sinuous railroad tunnel, with a ballasted fill on its floor.

Sloping toward the edges of the lava river from a narrow ledge a few inches wide parallel to the floor and about 3 feet above it, are smooth strips of lava about 6 inches thick and 2 feet wide which border both sides of the tube. Parallel cracks 2 to 4 inches wide, 6 inches deep, and 4 to 10 inches apart run the entire length of the cave in these bordering strips. Directly above them on both sides of the cave are narrow ledges only a few inches wide. The ledges mark the old shore lines and the strips are parts of the ledge that subsided as the lava stream contracted and partly drained away while cooling. A similar feature is seen along the small creeks in northern United States during the fall months. It is produced by a sluggish creek first freezing over. Later in lower stages the ice settles leaving a rim along the banks slightly above the level of the ice covering the main part of the channel and separated from it by sloping strips of ice. Just as one sees along such a shore places where cakes of ice have slid and gouged the mud beneath them, so one can see along the shore in Owl Cavern, cakes of lava that slid on the pasty lava beneath, grooving the walls of the cave.

The walls are covered with a lava veneer 2 to 3 inches thick. As the walls are curved the lava of the veneer dripped from the overhanging parts and formed short lava stalactites while on the lower part trickles ran down to the shore line resembling runs of paint. On the west side of the cave, about 20 feet from the entrance are two holes in the veneer about 1 foot in diameter made by segments peeling off after the lava subsided. Between these two holes the veneer has pulled away from the wall about 2 inches but failed to tear completely away and fall. On the west side of the cave at the entrance is a shell of veneer only an eighth of an inch thick that peeled away from the wall but is still hanging from it. When tapped gently with the blunt end of a folded knife it rings like sheet iron. In places the veneer is covered with gypsum which peels off in sheets sometimes 6 inches in diameter and less than a sixteenth of an inch thick.

The roof of the cave is covered with short stalactites formed by the liquid lava dripping from it. Only a few short stalagmites occur in the cave and they are confined to the floor adjacent to the walls. Three stalactites collected from this cave are shown in Plates 22C and 23A.

Specimen D in Plate 22C is quite heavy and contains numerous small round vesicles. Its original glazed surface is now coated with a white substance, presumably gypsum. On the white coating are small patches of a green colored material that did not occur in sufficient quantities to be determined. The surface of the stalactite is covered with innumerable small pimple-like protuberances produced by expanding gases during its formation. Stalactites D and G in Plate 23A are examples of the small and slender forms that occur in the cave. They have the usual glazed surface of such stalactites. The one lettered G is nearly hollow. The stalactites on the roof of this cave are all short and are the primary forms resulting from the usual dripping of the lava of the roof. There were no long slender, hollow, secondary types nor any loose glazed blocks on the floor such as sometimes develop from secondary fusion resulting from the burning of lean gases in the cave immediately following the draining out of the lava.

About 100 feet south of the opening there is a branch cave that extends at a low angle upward toward the west and ends abruptly. Near the south end of the main tube a small amount of ice was found on September 26, 1926. A small basin of water occurs about 25 feet north of the opening in a little depression in the floor. It was almost dry on September 26, 1926. This cave was discovered by the topographic party of the United States Geological Survey in 1925.

Lava River Cave is one of the tubes on Needles Cave Dome. It was discovered in 1925 by Mr. S. A. Paisley and the writer (Stearns). It is 400 feet long, 40 feet wide, and 8 to 20 feet high. The natural skylights in its roof illuminate it sufficiently so that an artificial light is not necessary. The currents and ripples in the lava river that solidified on the floor are exceedingly well preserved. The roof is adorned with stalactites. The one labelled B in Plate 22C is from this cave. It is 4 inches long and quite heavy. The interior of the stalactite is black, aphanitic, and vesicular. The vesicles do not form a band around the periphery of the stalactite, however, like they do in those collected from other caves. The original surface of the pendant was glazed but is now covered with a shiny white mineral probably gypsum that has penetrated through the surface glaze and partly filled the vesicles in the center of the stalactite. It has two teat-like swellings on it. Here and there on the floor and in niches on the walls are piles of a fluffy white salt similar to that which was identified from Indian Tunnel as being thenardite. (See page .) Near the south entrance to the cave is a cascade of later lava. A small natural bridge is located about 100 feet south of this cave.

Last Chance Cave, on Needles Cave Done, was discovered and named by Mr. Paisley about 1923. It is the easternmost cave where water can be obtained, hence its name. The entrance is a hole in the roof of the lava tube and it is possible to descent on the loose rocks heaped on the floor. The cave extends about 60 feet east and 125 feet west of the opening. The western part opens into two chambers, the walls of which are lined with soft green moss. Ordinarily the cave contains ice and water but it was dry in October 1926 owing to the exceedingly low precipitation during the preceding winter. The maximum height of the cave is about 30 feet and on the roof are some particularly well formed lava stalactites. Mr. Pairsley states that during the spring montsh, huge icicles over 6 feet long form in this cave.

Tom Thumb Tunnel is on the Needles Cave Dome a few hundred feet northwest of Last Chance Cave. It is 90 feet long, 8 to 12 feet wide and 5 to 10 feet high. The small size of the cave accounts for its name. It was discovered and named by Mr. Paisley in 1922. It is believed that this cave is at a or very near a vent.

Horseshoe Cave is only a few hundred feet northwest of Tom Thumb Tunnel. Its name comes from its shape which is due to the forking of a lava tube. A massive column of veneered lava rock separates the two tubes. The east cave divides into two caves one above the other. In the lower one there is usually water but the cave was dry in October 1926. Mr. Paisley who first discovered it states that as late as June of 1926 massive icicles five feet long hung from the roof of the cave.

Needles Cave is about an eighth of a mile northwest of Horseshoe Cave. It lies over the lava vent which formed the dome. It was discovered by Mr. Paisley and students of the Pocatello Polytechnical School. It is entered through a west-facing hole. Within a few feet the main tube subdivides into a number of smaller ones which can be explored for only about 30 feet because of their small size. The roof is covered with innumerable needle-like stalactites 1 to 2 inches long. Stalactites F and H in Plate 23A were collected from the roof of this cave. The small size and needle-like form is quire apparent from the illustrations. The one labeled H is a twin stalactite with a dull grey surface and nearly hollow interior. The one labeled F has a stony appearance and a smooth dull gray surface which like H is not glazed. Its interior is filled with minute round vesicles. The point of this specimen is broken off. Clinging to one of the stalactites in this cave was found a bat identified as a big-eared bat, Corynorhinus rafinesquii pallescens.

Surprise Cave is in the Indian Tunnel tube system and is part of a lava tube which opens to the northeast from a collapsed area of pahoehoe. The entrance is only about 4 feet in diameter and the loose blocks at the opening make it difficult to enter. The aperture can be enlarged, however, with only a little labor. The cave is about 100 feet long and near the north end of it there is a chamber about 40 feet high which is caused in part by the falling of blocks from the roof and in part by exposure of another tube above.

Some of the stalactites from this cave are short and stubby while others are long and needle-like. The longest stalactite known to occur in any cave in the Monument formerly hung from the roof of this cave. Originally it was about 10 inches long but only 6 inches of it now hangs in place. By looking back toward the entrance from near the rear of the cave an excellent silhouette of the bristling roof is obtained. The sharp and formidable stalactites and the valuted roof resembles a huge shark's mount with row after row of serrate teeth. A few stalactites collected from this cave are shown in Plates 22C, 23A, and 23B. Stalactite A in Plate 23B is 5 inches long and quite dense. On its surface is a crack apparently produced by slight swelling of the interior after the surface had cooled. It is covered with a gray glaze that forms a skin which can be flaked off. The surface is sparsely covered with a white mineral. The opposite side of this stalactite is covered with low ridges which converge at the point. The core of the stalactite is blue black in color and is aphanitic and vesicular. Many of the vesicles are between 2 and 5 millimeters in diameter. Surrounding the core is a band a quarter of an inch wide of very vesicular lava with a brownish black color. Stalactite A in Plate 22C is remarkable for the sharp and jagged points which terminate it. These projections were apparently formed by the volatile constituents pulling out the viscous lava as they escaped. On the surface of the stalactites are others about a quarter of an inch long that point upward or what was toward the roof of the cave before it was removed. These projections are similar to the spines on aa lava and appear to have originated in the same way as the terminal points of the stalactite. The center of the stalactite is practically solid with the vesicles arranged in crude concentric rings about it. Specimens A, B, E, in Plate 23A illustrate some of the other forms of the stalactites in this cave. Stalactite C is cracked open from the top to bottom caused by the bursting of the shell accompanying the inflation of the interior.

Dew Drop Cave is about an eighth of a miles southeast of Surprise Cave and is a part of Indian Tunnel tube. It is only a short cave and while it usually contains the largest pool of water of any cave in the Monument, only a few small pieces of ice were found in it during September 1926.

Indian Tunnel is the name applied to a long lava tube on the Indian Tunnel Dome. Holes in the roof let in sufficient daylight for the cave to be explored without the aid of artificial light. Parts of the roof form the natural bridges which are described on page 78. The tube extends for at least half a mile north of the lava vent which poured out the Indian Tunnel flow and its path is marked by a series of rocky trenches and caves. Dew Drop and Surprise caves are parts of this lava tube and other unnamed caves are found along it. The north entrance is a hole in the roof the the lava tube about 50 feet in diameter and about 40 feet deep. A wooden ladder about 25 feet long reaches from the surface to this pile of rock. (See pl. 24A.) Indian Tunnel receives its name from the fact that Indians camped near by. Numerous crescentic piles of rock near this tunnel formerly weighted down Indian teepees. Indian Tunnel is not as interesting as most of the other caves because much of its floor is cluttered with debris fallen from the roof. It is one of the most accessible large caves in the area. The total length of the cave was not measured but it maximum width is about 75 feet and its maximum height about 60 feet. Wherever the floor of the cave is exposed its exhibits ropy structure. In one place several parallel ledges on the walls of the cave indicate the periodic subsidence of the lava river. On the ledges and in many other sheltered spots where water dripped from the roof and was caught and evaporated are small piles of fluffy white flour one to two inches high. Mr. W. T. Schaller of the U. S. Geological Survey determined this flour-like substance to be the mineral thenardite. It consists chiefly of sodium sulphate with traces of potassium, calcium, chlorine, and water.

Moss Cave on the summit of the Moss Cave Dome together with Sunbear and Amphitheatre caves, was first discovered by Era Martin but was named and first described by Limbert.[1] The entrance to Moss Cave is a hole about 3 feet in diameter. The cave enlarges downward from this small hole like an inverted funnel. Stalactites hang from the roof but are largely concealed by a luxuriant growht of moss. The floor is covered with loess that has sifted through

[1] Limbert, R. W., Among the Crater of the Moon, Natl. Geogr. Mag., Vol. 45, p. 319, 1924.

the holes and crevices in the roof. The number of lapilli found in the loess are too numerous to have drifted into the cave during eruptions from cones in the Great Rift, hence it is believed that this cave is the interior of a small spatter cone, the lapilli being formed there. The funnel shape of the cave further indicates this origin. The cave is infested by pack rats but contains no visible water.

Sunbear Cave, a few feet east of Moss Cave, is about 150 feet long, 30 feet wide and 8 to 10 feet high. The entrance is so small it is necessary to crawl on hands and knees to enter, but the cave enlarges inward. The opening is partly choked up with debris that fell in during the collapse and from wind blown ash. In the fine ash on the floor of the cave are numerous saucer shaped beds made by bear. Sunbear Cave runs toward Moss Cave and apparently is tributary to it. Although there is no open connection between them. A few feet northwest of the entrance to Sunbear Cave is a smaller cave 75 feet long.

Amphitheater Cave is a little farther east in this line of caves. It can be entered only with difficulty because of the small opening, and nearly vertical drop of 10 feet to the floor. The cave has roughly the form of an amphitheater and the floor slopes steeply up to the northwest. A stage-like platform 25 feet across and 10 feet long at the southeast end is caused by the tube dividing into two tubes, one above the other. The upper one is sealed at the end of the platform but the lower one extends about 100 feet toward the southeast. The roof is covered with lava stalactites. Around the western side of the amphitheater-shaped chamber are rock ledges which are successive shore lines produced by the lava river in subsiding. The last lava river to flow through the tube solidified where it entered the chamber thus sealing the northwest end of the cave.

Stalactites. - A few types of stalactites from these caves have been described in the preceding pages, and are illustrated in Plates 22C, 23A, and 23B. Another form of stalactite is found in the Monument. The arched and warped crusts of the pahoehoe flows often exhibit an array of delicate red stalactites on their under surfaces. They are formed while the lava beneath the crust was still viscous and resembled "pulled dough". Specimen B in Plate 23B was collected from the under surface of the crust of the northeast flow from Big Craters. It has a dull purplish red color on the outside but has a black and aphanitic interior, containing numerous large oval vesicles stretched parallel to the long axis of the stalactite. The surface corrugations caused by the stretching of the lava when viscous converge

at the point. During the stretching some small strips were partly torn away from the stalactite and folded back on themselves. The stalactite is 6½ inches long.

Natural Bridges. - All of the natural bridges in the Monument are narrow strips of roofs of lava tubes that remained standing after the collapse of the adjacent parts of the tube. For this reason their span is in proportion to the size of the lava tube over which they form a roof. Only 4 natural bridges are of sufficient size to warrant description. Natural Bridge is on the summit of the Natural Bridge Dome in the SW. ¼ sec. 5, T. 1 N., R. 25 E. It has a span of 30 feet and is 12 feet wide and about 12 feet high. It is a part of the roof of the lava tube which distributed the lava from the natural Bridge Dome. Indian Tunnel Bridges are parts of the roof of Indian Tunnel lava tube. The largest one has a span of about 75 feet and a height of about 60 feet and is the larges in the Monument. The Bridge of Tears, in the Moss Cave tube system, is 75 feet long, 8 to 15 feet high and has a span of about 40 feet. Its original height was greater but the floor of the tube beneath the bridge has considerable soil on it and is cluttered with rock. The Bridge of the Moon is a smooth symmetrical arch over a tube leading away from the main east-west tube at this place. It is by far the most symmetrical bridge in the Monument as well as the most inaccessible. The maximum span of this bridge is 60 feet and the arch is 20 feet high and 60 feet wide. The rock heap at the south side of the arch obscures an otherwise unobstructed view of the breat area to the south and should be removed as soon as this part of the Monument is made accessible. This is not the "Bridge of the Moon" figured by Limbert.[1] The natural bridge shown by him is the Arco Natural Bridge that is situated on the slope of the limestone ridge near Arco Pass 10 miles east of Arco and 36 miles from the Craters of the Moon National Monument. A table of the location and size of the important natural bridges is given below:

Location and Size of the Important Natural Bridges

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

[1] Limbert, R. W., Idem., p. 325.

Tree molds. - Molds or shells of lava formed around trees that were surrounded by flows are frequently seen in the area. The location of most of them are shown in Plate 16. They usually occur near the margin of the flows where the lava was sluggish and on the point of cooling, or on steep stopes where it drained away rapidly. Two kinds of tree molds are found in the area, namely, those with shells that rise above the surface of the flow and those which form cylindrical holes in the lava. The former are called "lava trees" in the Hawaiian Islands and this name has been found useful to designate similar molds in the Monument.

The principal localities where tree molds have been found are given in the following table:

Location of Tree Molds

Kind of mold	Name of lava flow	Section	Township (North)	Range (East)
Lava trees	Trench Mortar Flat	18	1	25
Lava trees	Tree Mold Flat	28 & 29	1	25
Tree molds	NW. flow from Big Craters	3	1	24
Tree molds	Owl Cavern flow	13	1	24
Tree molds	Blue Dragon flows	13	1	24
Tree molds	Do.	26	1	24
Tree molds	Do.	34	1	24
Tree molds	Black flows	15	1	25
Tree molds	Do.	16	1	25

Two large groups of lava trees occur in the Monument. One is found in the pahoehoe on Trench Mortar Flat. The resemblance of the molds to the trench mortars used in the Civial War gives this flat its name. Another large area of lava trees discovered in 1926 is situated northwest of The Watchman on Tree Mold Flat. The molds of the lava trees on Trench Mortar Flat range from a few inches to 3 feet in diameter. None of them rise over 6 feet above the surface of the flow although many of them have partly fallen down. The holes formerly occupied by the trees extend below the surface of the lava flow but none are over 10 feet deep. The original depth of these holes was greater but they have been partly filled up with loose rock and cinders since they were formed. The shells vary in thickness from 2 inches to a foot and most of them consist of a relatively dense lava bordered on the outside and inside by bands of vesicular lava.

A typical lava tree on Trench Mortar Flat is shown in Plate 24B. The lava trees on this flat all tilt toward the northeast in the direction the lava flowed. The molds were carefully examined for charcoal but none was found. No bark impressions occur on the inside surface of the molds although numerous holes which are molds of branches are found. Some of the branches molded by the lava are oly an inch in diameter. The lava trees are confined to the area adjacent to the fissure from which the lava issued. The molds close to the fissure have a composite origin. The lower part of the mold was made by the lava solidifying around the tree. The upper parts, however, consist entirely of spatter thrown out from the fissure which fell on the tree and piled up around the trunk on top of the flow. In a few of them it is evident that the clots piled up in the crotches of the tree and became attached to each other before the wood burned away. This type of lava tree closely resembles in form the driblet spires seen on the flows in Hawaii that are formed by small lava jets piling up spatter over a small vent. The presence of the large hole with its branches however indicates that the driblet piles on Trench Mortar Flat are formed by spatter accumulating on and around trees.

The lava trees farther away from the fissure are caused by the lava forming a solid shell around the tree during the first hours of the eruption. As the flow subsided, it left the solidified shell or mold projecting above the surface. The outside of some of these molds were grooved by the crusts of the flow scratching the viscous exterior of the shell as the lava subsided. Lava trees 20 to 40 feet high formed by lava pooling around trees and later subsiding are found in some of the lava flows on Kilauea Volcano. There, in 1924, dead trees, some of them as small as 3 inches in diameter, were still standing in their lava molds close the the fissure where lava had been extruded in the previous year. The part of the tree not surrounded by the lava was not burned, and withered leaves still clung tenaciously to the branches. In 1931, some of the tree ferns had sprouted from their partly charred stumps and a little of the spatter still hung in the crotches of the trees.

The lava trees on Tree Mold Flat near the Watchman are in the flow from the adjacent Little Prairie Fissure. They are not as prominent as the lava trees on Trench Mortar Flat but are much better preserved and more numerous. Many of the molds on this flat are 3 feet in diameter and although the shells rise only a few feet above the surface of the flow many of the molds are over 10 feet deep and one measures 18 feet. Because so much of the trees had been submerged by the lava excellent molds of the trunks with their branches are preserved. In one place the lava buried a tree up to the base of a large branch. The mold of the under part of the branch is well exposed in the crust of the lava and forms a branch from the top of the trunk mold.

The presence of these tree molds indicates that in the past even when eruptions were frequent trees 3 feet in diameter had time to grow on one flow before they were destroyed by another. Since pine trees require about 400 years to attain a diameter of 3 feet in this area it is not unlikely that, had this area been visited in the past by man, it would not have looked very different from what it does today with clumps of trees here and there on kipukas rising out of black and bare lava flows.

Tree molds which form wells below the general lava surface are also numerous. They were found only in the pahoehoe but because similar molds occur in aa in other regions, they will doubtless be found some day in the aa in the Monument. The largest group of tree molds occur in sec. 3, T. 1 N., R. 24 E., in the northwest flow from the Big Craters. This group is readily accessible for it lies only a few hundred feet southeast of the highway. (See pl. 16.) About a dozen molds occur in this group. All are close to small, old cinder crags which indicate that the trees grew on the crags before they were surrounded by lava. The molds occur in thick hummocky pahoehoe as nearly vertical holes 1 to 2 feet in diameter and from 5 to 12 feet deep. They are almost perfectly preserved and have very little loose rock in them. One of the molds is inclined about 45 degrees from vertical, probably because the tree was pushed nearly over by the sluggish lava. On the surface near by is the mold of the top of a tree with its branches that fell into the molten lava after the trunk had burned in two. The grain of the wood as shown in Plate 24C is perfectly molded in the lava as well as check marks of the charred log.

About an eighth of a mile southeast of this group of tree molds near where the same lava laps upon Silent Cone, is a vertical tree mold and two log molds. Near a crag north of these molds there is an unusual mold. A log $2\frac{1}{2}$ feet in diameter had been buried 2 feet beneath the surface of the flow. Subsequently a wide crack opened in the flow through the mold. It is now possible to crawl down into the crack and see the mold of the charred log extending away from both sides of the crack. This mold indicates that trees and logs completely buried by the lava may form hollow molds.

In the Blue Dragon lava in the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 13, T. 1 N., R. 24 E., 3 vertical tree molds form depressions in the pahoehoe about 3 feet deep and from 1 to 2 feet in diameter. The original depths were greater because loose fragments of rock now partly fill them. A few feet south of these vertical molds there is

the mold of a log 15 feet long in the crust. The small holes branching out from it are molds of the branches of the tree. In one place the lava completely covered the log and this part now forms a small tube a foot in diameter and 16 inches long. The usual check-work pattern formed by lava flowing into the shrinkage cracks of this charred log as shown in Plate 25A is here admirably displayed. Between these checkmarks is the delicate pattern of the grain of the wood molded in the lava. (See pl. 24C.) Such delicate molding as was done by this viscous and sluggish pahoehoe at the margin of the flow is not a simple process. It can be seen from Plate 25A that the mold of this log and especially the relief of the check marks, increases in detail from the upper edge of the mold downward to what was formerly the under surface of the log. There is field evidence that the fluidity of the lava is increased by the addition of steam from the vaporization of the sap in the burning log. It has been established by laboratory experiments that the fluidity of a melt is partly dependent upon the amount of water present and it appears that this is a natural example.

Very intricate and delicate molds have been obtained from a quarry in an aa lava flow on Etna Volcano in Sicily. These molds indicate that as the wood burned, it cracked open to the very center and the lava filled the cracks even where they were only a 64th of an inch wide. The cast as it now appears after the charcoal has disappeared, is a series of thin partition-like segments radiating from a common center. These unusual tree molds were formed near the bottom of the lava stream where stumps of trees had been buried and then slowly burned. The lava was clearly a viscous type and the extreme local fluidity as evidenced by these molds must have been induced by the absorption of the vapor given off by the burning stump.

Not one of the molds examined showed the impression of the bark of the tree because apparently the dry bark burns at the instant it comes in contact with the lava. In the Hawaiian Islands where the trees have mosit barks, molds of the bark and of fern leaves have sometimes been observed. During the eruption of Etna in Sicily, in 1865, the lava entered a pine forest, and it is described by Reclus[1] as follows:

> "----- sheathes 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,

[1] Reclus, E., The Earth, G. P. Putnam and Sons, New York, Vol. s, p. 495, 1871.

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 mositure 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 source 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."

An aa branch of the 1920 lava flow from Kilauea entered a patch of woods and in several instances pushed over trees or snapped them off a few feet above the ground without burning them. The tops of many of the trees with their leaves intact were pushed along on top of the flow without being burned. It has already been pointed out that an aa flow, especially near the margins, usually consists of a wall of loose blocks which are shoved forward by the movement of the lava farther up stream. It is mainly because the advancing margins of aa lava flows smash down the trees rather than surround them that tree molds in the lava aa are less common.

Ejectamenta

The usual ejectaments, - cinders, spatter, and lapilli, that accompany the eruption of basalt are all found within the Craters of the Moon area. Except in one crater the comminuted glass such as characterizes catastrophical explosions is absent. Among the ejecta are many peculiar forms, chief among which are the volcanic bombs. There are also block of grans diorite, rhyolite, and other rocks which had been brought up from the underlying basement. Magmatic bombs, are plentiful on the slopes of most of the cones and near certain spatter cones. They vary in length from a fraction of an inch to over 13 feet and in diameter from an eighth of an inch to 3 feet. There are three general types, namely, spindle or spiral bombs, ribbon bombs, and bread-crust bombs.

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[1] French for aa lava.

Spindle Bombs

The spindle bombs are those which have ear-like projections on the ends of a football-shaped body like the one shown in Plate 25B. They are the "unipolar" and "bipolar spindle" bombs described by Reck.[1] These bombs originate from a clot of viscous lava being hurled through the air with a rotational or spiral motion. They have a smooth glassy skin, ususally corrugated, and a fairly dense interior. The corrugations converge toward the projecting ears. Both black and red bombs are sometimes found on the same cone. Small vesicles in the interior are often arranged in lines which show the effect of the twisting of the mass. The "ears" often arranged in lines which show the effect of the twisting of the mass. The "ears" may extend straight out from the bomb or may be curved upward or may be folded back toward the center of the bomb. The length of the ears found seldom exceeds 3 inches but most of them must have been originally longer because they terminate abruptly instead of tapering out. The small pieces of broken off from these ears form one kind of ribbon bomb. Some of the bombs were sufficiently plastic to adhere to the cinders on which they fell. Most of the symmetrical and well formed bombs of this type were found within 50 feet of their source indicating that their flight was a short duration and with low velocity. Large number of these bombs formerly existed on the surface of the spatter cones south of Broken Top and on Big Cinder Butte but many of the finest have been carried away or broken. Russell[2] has described the spindle bombs from this area in detail.

Ribbon Bombs

Ribbon bombs,[3] as the name imples, are long slender ribbons of lava. They vary in size from strips of lava smaller than a pencil to heavy masses 8 inches in diameter and 13 feet long. Howel Williams kindly examined some of these small ribbons in thin section and describes them as follows:

> "The ribbon bombs examined from the vicinity of Big Cinder Butte are essentially composed of alternating layers of darker and paler tachylyte, poor in microliths, the layers being elongated parallel to the length of the bombs."

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[1]Reck, Hans, Physiographische Studie uber vulkanische bomben, Erganzungsband zur Zeitsch. f. Vulk. P. 111, 1915.

[2]Russell, I. C., Idem., Bull. 199, p. 75; Bull. 217, p. 40.

[3]These are the Bond Bombe of Reck.

Ribbon bombs originate in several different ways. The small slender ones a fraction of an inch thick and several inches long like those shown in Plate 25B are chiefly the ends broken off the ears of spindle bombs. Others are produced by the pulling apart of molten clots while in transit. Therefore, they are similar in origin but considerably heavier than Pele's hair, the threads of glass spun by the lava fountains of Kilauea and Mauna Loa volcanoes in Hawaii. Similar volcanic spun glass was doubtless produced by the lava fountains in the Monument but because of the fragile character, the threads decompose within a few years, hence they have long ago disappeared. Some of the ribbon bombs must have fallen on plastic cinders or collided with them in the air for the ribbon bombs shown in Plate 25C was found nearly buried in a scoriaceous clot.

The larges ribbon bomb in the area is one described and figured by Russell[1] on the west side of Big Cinder Butte. It measured 13 feet in length and its maximum diameter is only 8 inches. Bombs nearly as long were found also an eighth of a mile south of Broken Top and on Split Butte. These long bombs seem to have originated as lava clots that fell on the side of a cone and ran down the slope while still molten. Weathering, and the removal of the cinders adjacent to them has caused them to become detached and to lie loose on the surface like bombs.

Bread-Crust Bombs

Bread-crust bombs are found on many of the cones and are particularly numerous near the Big Craters. They are usually several inches in diameter and balls a foot or more in diameter are not rare. They are very light in weight as compared with any of the others of equal size. Their interiors are extremely vesicular and scoriaceous. The vesicles vary in size according to the dimensions of the bomb, and invariably increase in diameter toward the center. The outer surface is a skin of the same material containing fewer and smaller vesicles and covered with a network of open cracks resembling the crust of bread. They are formed by a clot of lava filled with gas being hurled through the air. During the flight, a skin or crust freezes on the clot which cracks open as the bombs swell with inflation of the included gases forced out of solution as the interior solidifies. The process which causes the structure of the bomb as well as its appearance is similar to the expansion of bread dough by gases from the yeast during baking.

Bread-crust bombs are found on most of the cones, and many lie scattered on the south slope of Broken Top. The latter are

a somewhat modified form of the bread-crust bomb for they fell in a sufficiently plastic state to be flattened by the impact as shown in Plate 18B.

Among the ejectaments on some of the cones, especially North Crater Butte, a variety of accessory and accidental ejecta was found. Some of the accidental ejecta have bread-crust surfaces and were apparently inflated by the heating they have undergone. Howel Williams examined several of the accidental ejecta from North Crater in thin section and states:

> "Among the ejecta (Specimens C 56 and C 57) are fragments of an extremely light and minutely visicular ryolite obsidian of which one specimen has a pale brick red nucleus surrounded by a buff colored break-crust skin."

Some of the accidental ejecta like the one shown in Plate 26A exhibit a breadk-crusted skin a quarter of an inch thick. The crust has a gray color under which is an orange pink zone half an inch thick. The interior of the bomb is pale pink and gray and extremely vesicular.

Occurrence of Water

The part of the Craters of the Moon area covered with basalt is entirely devoid of streams, and the rocks which cover the surface are so permeable that no well defined stream channel has yet developed. This is in strong contrast to the White Knob Mountains, which extend into the northwest corner of the area shown in Plate 16. These are composed of nearly impermeable rocks and are furroughed with deep gullys and canyons. Little Cottonwood Creek, the only perennial stream in the area occupies a canyon about 500 feet deep. It rises near the northwest corner of sec. 22, T. 2 N., R. 24 E., and flows woutheastward in a canyon which is in line with the Great Rift Zone. This coincidence suggests that the position of the creek was determined by the same structure which determined the position of the Great Rift Zone.

On September 28, 1926, Little Cottonwood Creek was flowing about 25 gallons a minute near the Martin-Heslop lower mine. Above the mine the flow is a little less because some water sinks through the roof of the mine and later excapes at the portal farther downstream. Several small springs feed the creek. The one just a short distance above the mine and the other about a mile above are the largest springs in the canyon.

In 1930, President Hoover proclaimed the land where one of the springs issues a part of the National Monument and an appropriation was made by Congress to pipe the water to the entrance. An analysis of the water is given on page . The water appears to be supplied to the upper springs through crevices in the biotite-dacite which occupies the head of the valley. During September, 1926, the entire creek disappeared into the alluvium near the mouth of the canyon. During freshets, however, the creek is reported to form a small pond at the edge of the lavas. The water from this pond that does not excape by evaporation, sinks into crevices in the basalt. During the summer time the flow of the creek dwindles, most of it being transpired by the vegetation along its bank. It is stated by Mr. Paisley that the flow is appreciably less in the late afternoon than early in the morning as a result of evaporation and transpiration. It is an important stream even through it is small in size because it is the only water available for a distance of many miles sufficient to suppy the future needs of the Monument.

Water in Cracks

Water and ice are found in some of the deep cracks in the area. The principal waterholes of this type are given in the following table:

Waterholes in Cracks in Lava Rock

Name	Quarter	Section	Township	Range (east)
Yellow Jacket Waterhole	SE.	20	1 N.	25
Bearsden Waterhole	NE.	29	1 N.	25
Little Prairie Waterhole	NE.	29	1 N.	25
Ice Cave	SE.	14	1 S.	25
Ice Caves	NE.	24	1 S.	25

Yellow Jacket Waterhole was dry in October 1926, but usually contains water throughout the year. It is in the talus in the bottom of the Little Prairie Fissure and is supplied by melting ice.

Bearsden Waterhole is about half a mile southeast of Yellow Jacket waterhole in the same fissure. A small spatter cone about 5 feet high developed at this place during the Little Prairie Fissure eruption. When the lava subsided a crater 30 feet in diameter and about 25 feet deep was formed. In order to find the water it is necessary to descend into the crater and walk northwest into a narrow cave about 15 feet long. Both ice and water were plentiful in it during October 1926. Many packrats infest the crater and polute the water. The water has a temperature of about 34°F. during the summer months and is fed by the adjacent heap of ice. The waterhole is described here because the cave it occupies is neither a tube nor a crater. It is merely a small part of the main Little Prairie Fissure roofed over by spatter. Between Yellow Jacket and this waterhole several small patches of ice, some of which were 30 feet below the surface, were found in shady recesses in the cracks.

Little Prairie Waterhole is about an eighth of a miles southwest of Bearsden Waterhole in the Little Prairie Fissure. The crack is 8 to 10 feet wide and 35 feet deep and occurs in massive pahoehoe. The water in October 1926, was about 3 feet deep and underlain by an unknown thickness of ice. The ice extends in both directions along the crack and helps supply the

water in Little Prairie waterhole. It forms in this crack in the same manner as it does in the lava tubes although circulating cold air currents during the winter are an important factor in its accumulation. This area is rent with innumerable crevices and cracks resulting from the disturbance accompanying the eruption and it is evident that water would not remain in this fissured rock unless it was perched on ice. The pool of water and the ice are both completely shaded by a narrow roofed over portion of the crevice, hence they are never exposed to the direct rays of the sun.

Several years ago Era Martin placed a small motor-driven lift pump in this waterhole and built a concrete watering trough near by in order to water cattle. He found that in an eleven day period one summer the waterhole was pumped completely dry. This fact indicates that the pool was only a local perched supply derived from the ice and not from percolating ground water. In october 1926, 6 head of horses were watered from it for over a week without appreciable drawdown. It is the largest perennial waterhole in any of the crevices and maintains a temperature of 34°F. even on the hottest days. This water is less polluted than others mainly because of the large supply for rats are numerous. The low temperature of the water is certainly not conductive to the growth of bacteria and the water is not injurious for drinking purposes.

The Ice Cave in the SE ½ sec. 14, T. 1 S., R. 25 E., is similar to the Bearsden waterhole. Ice and water occur in a crack extending from northwest to southeast through a small spatter cone in the main Vermillion Chasm Fissure.

The Ice Caves in the NE. ¼ sec. 24, T. 1 S., R. 25 E., are on the same Vermillion Chasm Fissure three quarters of a mile southeast of the Ice Cave described above. The ice occurs in a crevice connecting a chain of spatter cones and is practically inaccessible.

Water in Craters

Water, snow, and ice are found in some of the craters. The principal perennial water supplies occurring in craters are given in the following table.

Principal Waterholes in Craters

Name	Quarter	Section	Township	Range (east)
Ice Cave	SE.	2	1 N.	24
Pit Crater Waterhole	NW.	12	1 N.	24
Big Sink Waterhole	NW.	12	1 N.	24
Sheep Trail Butte Waterhole	SE.	10	1 S.	25

The Ice Cave in the SE. ¼ sec. 2, T. 1 N., R. 24 E., is in the first spatter cone of the Crystal Fissure cone chain. It is the best known, for it is at the end of the road. Covering the bottom of the throat of this spatter cone about 20 feet below the surface is a conical heap of ice and snow 10 feet thick in the middle and 15 feet in diameter at the base. Near the edge of the ice is a small pool of water. The amount of ice in this crater has not changed appreciably since Russell visited in 1901.[1] The bottom of this driblet cone is in the shadow of its walls except for about an hour each day, which is not long enough for the sun to melt much of the snow of the previous winter.

Pit Crater Waterhole is in an elongated pit crater about 35 feet deep near the end of the Crystal Pit Fissure. A perennial pool about 2 feet wide and a foot deep exists in the loose talus in the bottom of this crater. It is supplied by melting ice that fills the interstices of the adjacent lava blocks. The ice is replenished annually by cold, circulating air freezing the water that percolates through the crevices. A narrow trail leads to this waterhole. It is one of the few waterholes exposed to the direct rays of the sun and doubtless considerable water escapes by evaporation. It is a favorite watering place for birds and insects.

Big Sink Waterhole in the next pit crater to the southeast is similar to Pit Crater Waterhole in appearance as well as in origin. It is slightly shaded, however, by huge blocks of lava. On October 5, 1926, it had a temperature of 33°F. when the adjacent air temperature was 70°F. Green algae flourish in this water.

Sheep Trail Butte Waterhole is under a shelving ledge of scoriaceous lava in the loose cinders in the northernmost large crater in the summit of Sheep Trail Butte. It is the only perennial waterhole in loose cinders in the area. On October 12, 1926, it had a temperature of 33°F. which clearly indicates that it is

[1]Russell, I. C., Idem, Bull. 199, p. 81.

supplied from melting ice. Moreover, it must be perched on ice in the interstices of the cinders beneath it, for they are too permeable to prevent the water from sinking. On October 12, 1926, only a few inches of water were under the shaded part of the ledge but Mr. Paisley who has visited the waterhole in several different years, states that it was exceptionally low at this time and that ordinarily animals can drink there. The existence of ice below the surface of these cinders would never be expected, because when visited they were hot from the noonday sun. However, as late as July 14, 1926, Mr. Paisley found considerable ice 2 feet below the surface in the interstices of the cinders of North Crater while making an excavation. Ice evidently forms in sufficient amount in the frost zone in the shaded areas of the cinder cones to remain from year to year. Where conditions are favorable water derived from this ice supplies water holes.

Main Water Table

The 1,110-foot well near the south end of the Monument encountered water in the basement rocks beneath the basalt at 1,104 feet. The water rose about 20 feet. This well indicates that water will be recovered only at great depths from rocks below the basalt. The results of other drilling in Laidlow Park makes it doubtful if a water table in the usual meaning of the term underlies this area. The failure of a 1,700-foot well a little farther west to encounter water indicates that water occurs only here and there in crevices in the acid eruptives underlying the basalt. The precipitation is low in the Monument and although a large percentage of it may become ground-water recharge, still the water probably cascades rapidly toward the south through the permeable basalt and joins the main underflow of Snake River Valley.

Summary

The Craters of the Moon National Monument comprises an area of about 80 square miles of recent lava features in southern Idaho at the foot of the White Knob Mountains about midway between Carey and Arco in Butte and Blaine counties, Idaho at the north edge of the Snake River Plain. The Monument is essentially a plain sloping southeast from an altitude of 6,000 feet at the upper end, to 5,400 feet at the lower end. Traversing the plain from northwest to southeast is a line of cinder cones, craters, and fissures which are massed along the Great Rift Zone. The Monument is undissected by erosion and presents the unmodified volcanic features of a recent volcanic area. Big Cinder Butte, the highest cone in the area, rises 800 feet above the adjacent plain. The area is only sparsely covered with vegetation and many of the flows and a few of the cones are black and bare.

The lava flows are all basaltic and are superimposed upon Cretaceous(?) grano-diorites and Tertiary acidic eruptives. The basaltic lavas and the associated pyroclastics cover about 84 of the 87 square miles of the area mapped. They range in age from Pleistocene to Recent and some of the youngest flows may not be much over 250 years old. Faulting has caused several relatively recent escarpments and is though to have determined the location of the Great Rift Zone. Eighty eight vents and 39 lava flows are distinguished on the surface in this small area, a number which indicates that the Snake River Plains was not built up by a few great lava floods but is an accumulation of lava sheet upon lava sheet. The mechaism of eruption and the resulting volcanic products are not different from those in other basaltic areas except the accumulation of the erupted products was not confined to the vicinity of any single orifice. The eruptions produced cinder cones, spatter cones, lava domes, and fissures bordered by spatter. An unusual feature of the eruptions was the long continued activity along the same set of fissures thereby building up the Great Rift Zone and its associated volcanic features.