Recent Volcanism at

AMBOY CRATER

San Bernardino County, California

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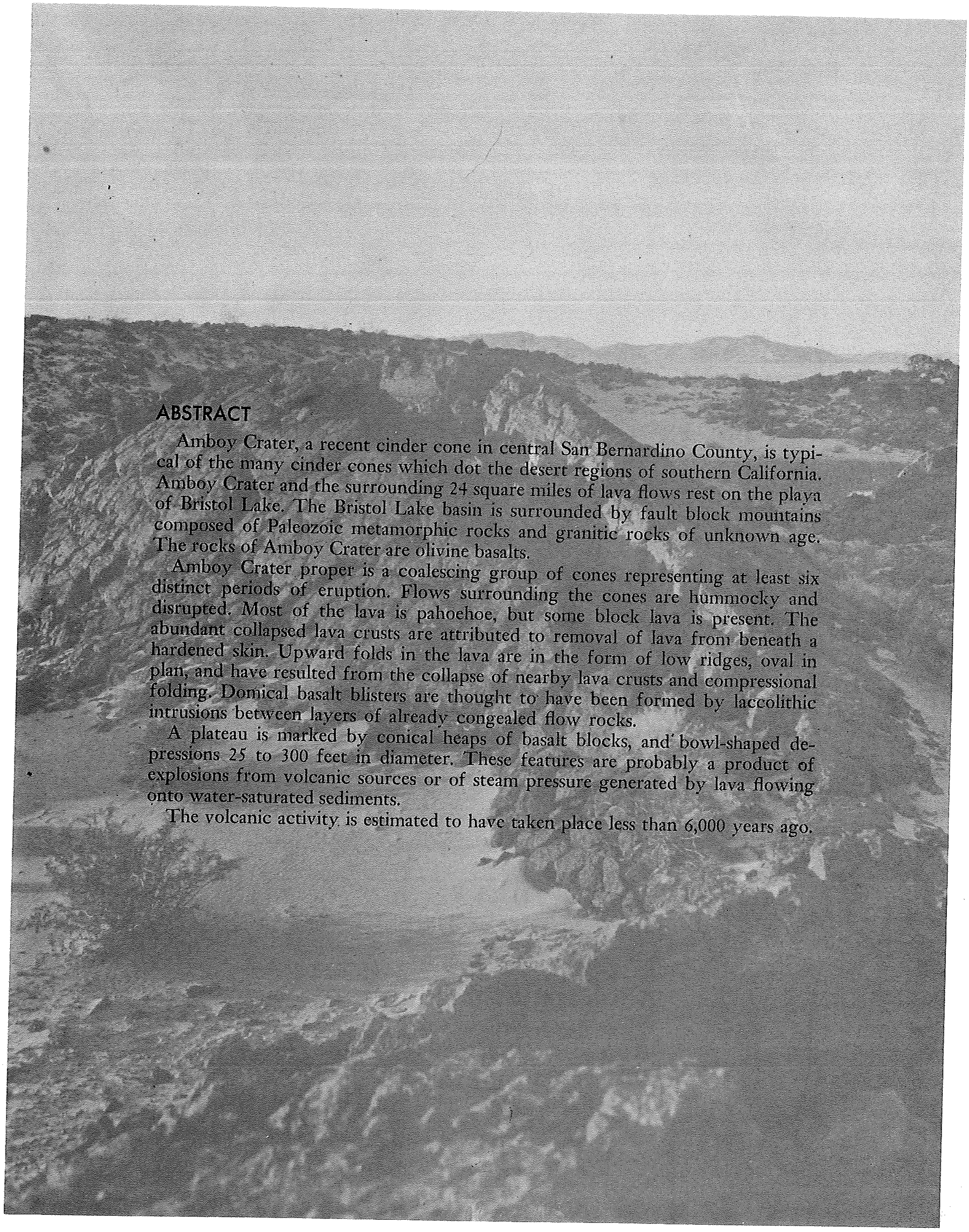

ABSTRACT

Amboy Crater, a recent cinder cone in central San Bernardino County, is typical of the many cinder cones which dot the desert regions of southern California. Amboy Crater and the surrounding 24 square miles of lava flows rest on the playa of Bristol Lake. The Bristol Lake basin is surrounded by fault block mountains composed of Paleozoic metamorphic rocks and granitic rocks of unknown age. The rocks of Amboy Crater are olivine basalts.

Amboy Crater proper is a coalescing group of cones representing at least six distinct periods of eruption. Flows surrounding the cones are hummocky and disrupted. Most of the lava is pahoehoe, but some block lava is present. The abundant collapsed lava crusts are attributed to removal of lava from beneath a hardened skin. Upward folds in the lava are in the form of low ridges, oval in plan, and have resulted from the collapse of nearby lava crusts and compressional folding. Domical basalt blisters are thought to have been formed by laccolithic intrusions between layers of already congealed flow rocks.

A plateau is marked by conical heaps of basalt blocks, and bowl-shaped depressions 25 to 300 feet in diameter. These features are probably a product of explosions from volcanic sources or of steam pressure generated by lava flowing onto water-saturated sediments.

The volcanic activity is estimated to have taken place less than 6,000 years ago.


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RECENT VOLCANISM AT AMBOY CRATER, SAN BERNARDINO COUNTY, CALIFORNIA

by Ronald B. Parker

INTRODUCTION

Amboy Crater, a complex basaltic cinder cone in central San Bernardino County, California, is 75 miles east of Barstow on Highway 66, and 3 miles west of the town of Amboy. The cone is surrounded by approximately 24 square miles of lava flows. Field studies were carried out in 1953 and 1956. Mapping was done using aerial photographs and U. S. Geological Survey topographic maps as a base.

The writer is indebted to Mr. Yee and Mr. Crowl of Amboy for their help in transportation in the field. Thanks are extended to Professors Howel Williams and G. H. Curtis of the University of California, Berkeley for their help and encouragement. Some of the field expenses were defrayed through the graduate research fund of the University of California. Chemical analyses were paid for by the University of California.

Geologic Environment

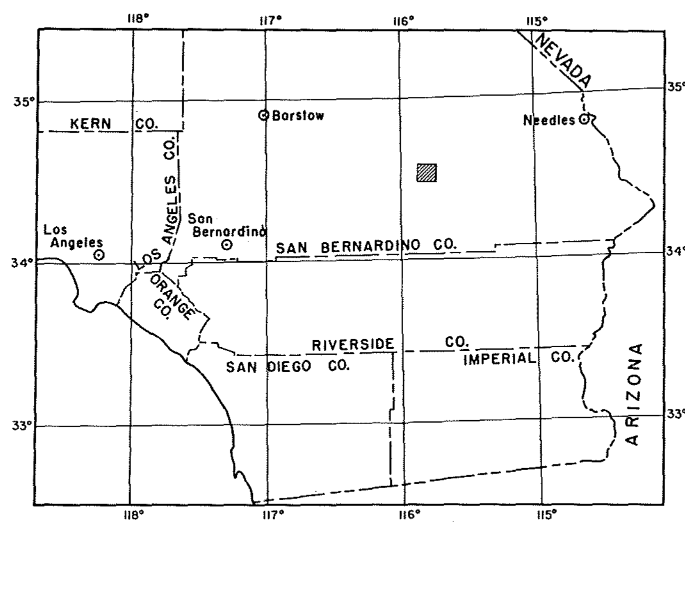
The Amboy Crater area is one of a number of centers of recent volcanic activity which lie on broad alluviated valleys and playas in the central part of San Bernardino County. Pisgah Crater and Sunshine Cone near Hector, some 40 miles west of Amboy, are described by Gardner (1940, pp. 286-288).

Eight miles west of Amboy Crater is a small cinder cone, Siberia Crater, which is not associated with visible lava flows. It is approximately 100 feet high and is surrounded and partly buried by recent alluvium. Siberia Crater is deeply dissected by erosion, and now consists of a semicircular ridge concave toward the north. The degree of denudation enables the observer to see that the cone is made wholly of ropy, almond-, and ribbon-shaped basaltic bombs which are filled with abundant inclusions of foreign rocks which include dunite, lherzolite (olivine, enstatite, diallage, spinel), and granitic rocks (see also Brady and Webb, 1943, pp. 405-406). Another basaltic cone north of Siberia—Dish Hill—is of composite type, and is made up of alternating layers of bombs and cinders, and flows. It is about 300 feet high and 1,000 feet in basal diameter. Both Pisgah Crater and Dish Hill have served as sources of commercial volcanic cinders.

Areas in the Lava Hills and Bristol Mountains to the north and west of Amboy Crater are covered by acid volcanic rocks including perlite, rhyolite, tuffs and tuffaceous sediments. These rocks are of late Tertiary age (Chesterman, 1957, pp. 443-444). Gardner (1940, p. 289) says that the rhyolitic flows in the Newberry Mountains are Pleistocene, and suggests correlation with the Bristol Mountain series. The sources of the Bristol Mountain acid volcanic rocks are in close proximity to the bodies themselves (C. W. Chesterman, personal communication).

Pre-Tertiary rocks in the Bristol Mountains are primarily plutonic igneous rocks, and Paleozoic sedimentary and metomorphic rocks. Porphyritic granite and quartz monzonite are common. Dioritic types are widespread, but are not as abundant as the more felsic varieties. Quartz-muscovite-feldspar pegmatite and aplite are commonly associated with the felsic rocks. Dolomite and contact metamorphic rocks (at dolomite-granite contacts) are

FIGURE 1. Map showing the location of the Amboy Crater area.



Frontispiece (opposite page). Amboy Crater from the air—view east of north. The bomb field is northeast of the cone (upper right). *Photo courtesy of Spence Air Photos.*

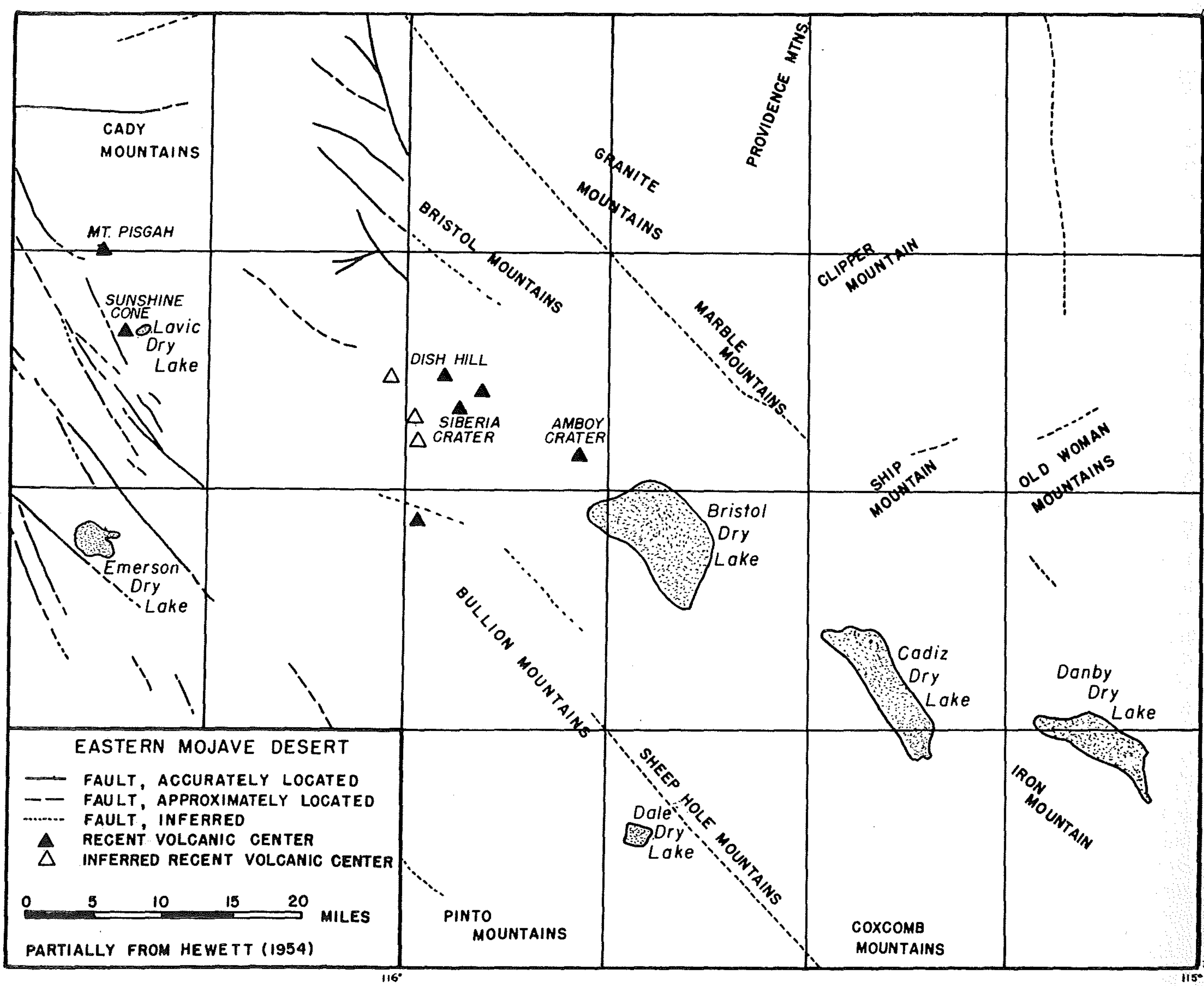


FIGURE 2. Map showing the location of centers of recent volcanism, and their relationship to faults in the eastern Mojave Desert. The distribution of the volcanic centers does not appear to be related to the fault pattern.

present. Marble and pelitic schist are common in the Marble (Iron) Mountains to the east. Mining activity is confined at the present time to prospects for a variety of metallic ores, and the perlite deposits mentioned above. The extensive saline and gypsum deposits of Bristol Lake are described by Gale (1951) and Ver Planck (1952, p. 47).

Physiography

The Amboy Crater area is within the physiographic province termed the basin and range province, the main features of which are generally attributed to faulting. The ranges are thought to be block mountains bounded by faults along which the inter-range basins have subsided with respect to the elevated mountain blocks. This simplified picture is modified by erosion, the filling of basins with alluvium, and some thrust faulting. The distribution of centers of recent volcanism, and of faults in part of this province, is shown in figure 2. A site of volcanic activity is commonly supposed to coincide with a weak place in the crust, such as a fault or the intersection of faults. Most of the centers shown in figure 2 do not bear out this simple relationship—but many more faults than are shown doubtless exist.

The Bristol Lake basin is probably a graben (a fault trough), but its shape has been modified by alluvial fan and outwash plain deposits from the mountains to the north and south. The drainage from these highlands is now confined to the basin itself, no outlet to the sea being in evidence. Darton (1916, p. 153) and Blackwelder (1954, p. 36) proposed that Bristol Lake is part of a Pleis-

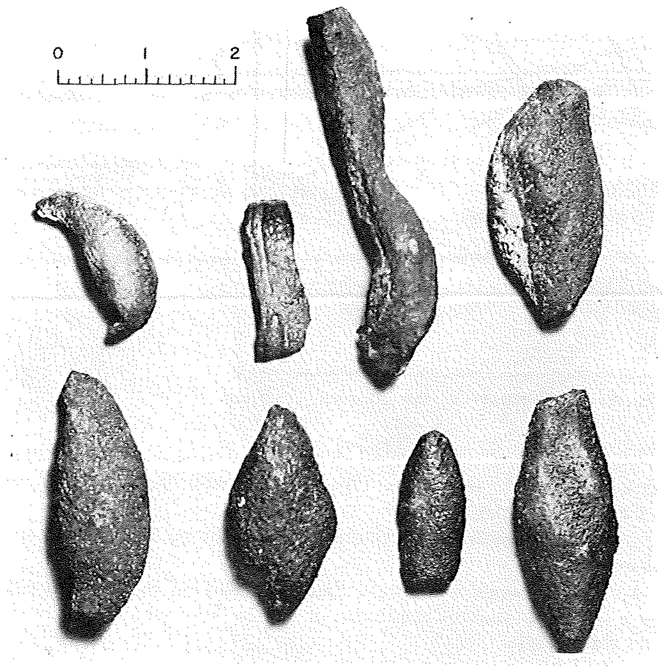
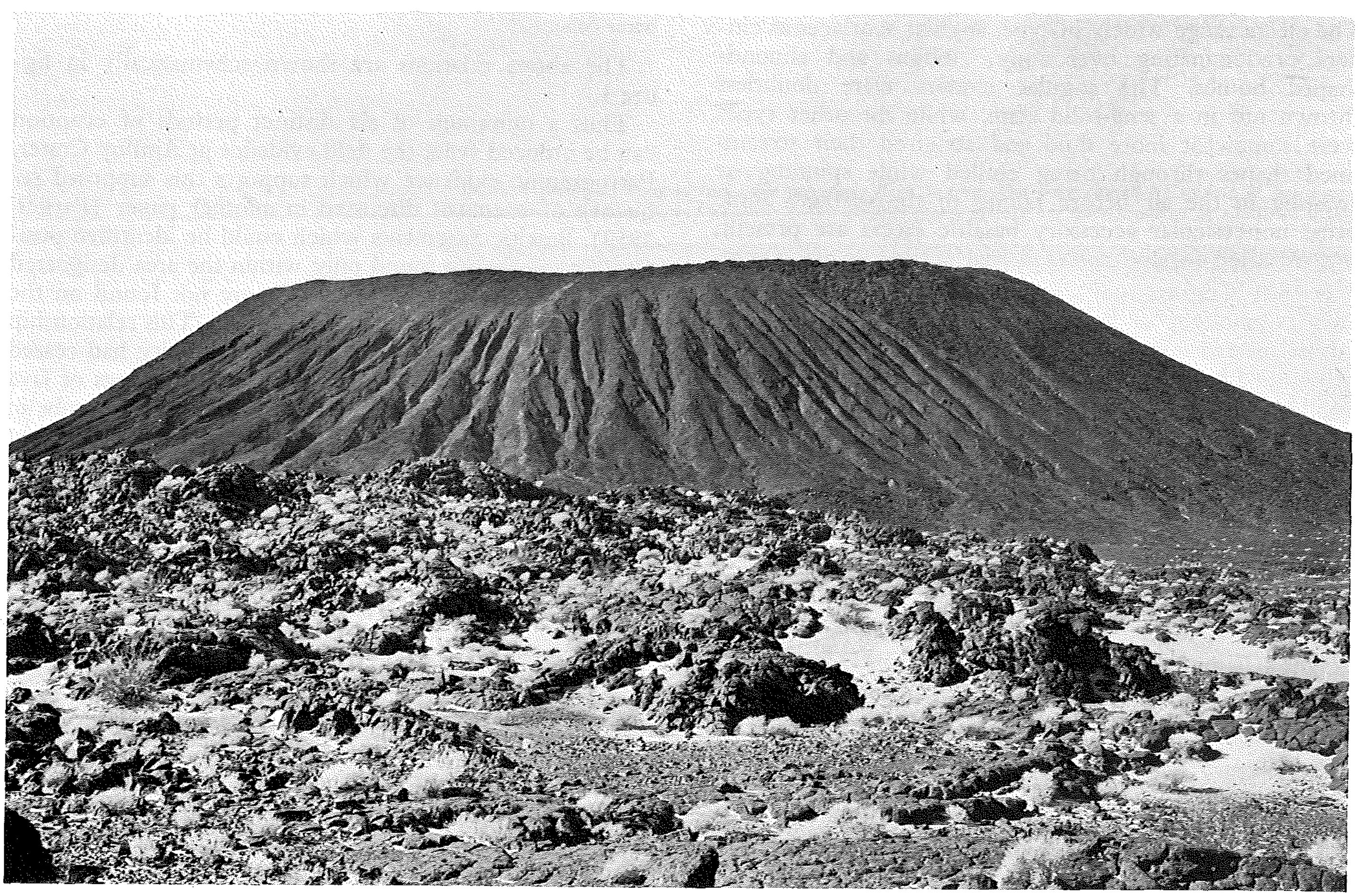


Photo 1 (left). Typical almond-shaped bombs and ribbon bombs from the area northeast of the cone. The smooth shapes are indicative of ejection in a fluid state. Cooling and hardening of the bombs took place in the air, prior to their falling to the ground.

Photo 2 (below). Eastern side of Amboy Crater, showing gullies in the old cone surface. The gullies are filled with later basaltic material near the rim of the crater and on either side of the photograph. The irregular flow surface in the foreground is typical.



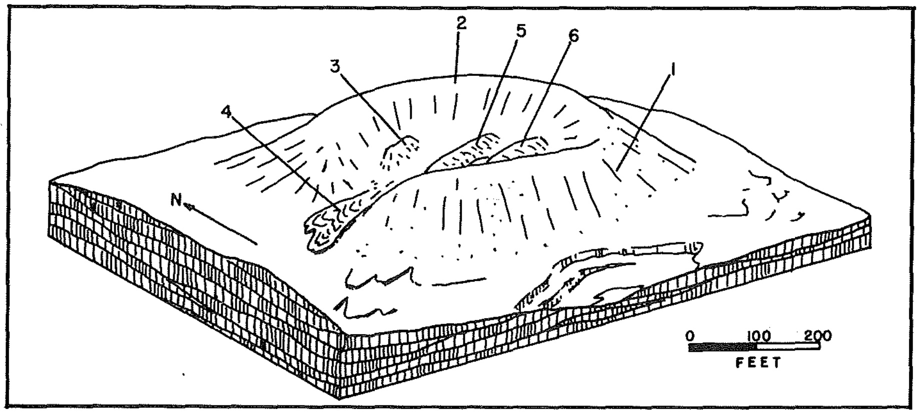


FIGURE 3. Block diagram of Amboy Crater. Stages in the development of the complex cone are numbered from oldest to youngest.

tocene river system which drained from Death Valley to the Colorado River. In any case the Bristol Lake basin has been in existence in much its present form for a long enough time for the salines to accumulate.

AMBOY CRATER

Amboy Crater rises approximately 250 feet above the surrounding lava flows, and is about 1,500 feet in basal diameter. It is composed of a loose accumulation of volcanic ejecta (material thrown out by volcanic explosions) with secondary amounts of agglutinated ejecta and flows. The ejecta range widely in type, angular scoriaceous cinders predominating over ropy, ribbon- and almond-shaped bombs. The angular cinders were doubtless thrown out in a semi-solid state, while the other types were somewhat more fluid and acquired their streamlined shapes through being chilled while spinning or twisting in the air before falling to the surface. Some lithic nonvesicular accessory basaltic ejecta are present, but included foreign or accidental fragments are absent.

Amboy Crater is not a single cone, but is complex; it may be thought of as a group of at least four nearly coaxial nested cones. The outer slopes of the main cone are gullied by erosion and avalanches of loose debris except near the crater rim and on the western flank; there the gullies have been obliterated by an agglutinated mass of basaltic blocks erupted after the gullies formed. Within the main outer cone there is a remnant of a second cone on the west side. Both of these cones are breached on the west side. The breach is now occupied by a short lava tongue. In addition to the two cones, there are two relatively undisturbed cone walls within the main crater. These innermost conelets are composed almost entirely of angular scoriaceous cinders; ropy bombs are absent.

From the above data the following sequence of events at the main vent of Amboy Crater has been synthesized.

1. Early eruptions were explosive, and many fluid bombs were erupted. The main cone was formed at this time. A period of inactivity followed, during which the outer slopes of the cone were gullied by erosion or by avalanching volcanic material.

2. A second phase of eruptive activity resulted in the deposition of an agglutinated aggregate of basaltic blocks on the rim and western flank of the cone. This was probably accomplished by the eruption of pasty bombs.

3. The outermost inner conelet was formed by a mild explosive phase.

4. The two cone walls were then breached on the western side by a sideways-directed explosion or by the flow which now occupies this breach.

5. Activity was renewed with the formation of another inner conelet.

6. Formation of the innermost conelet terminated the explosive eruptions at the volcanic center now occupied by Amboy Crater.

7. Subsequent eruptions, if any, from this central vent took the form of quiet outpourings of fluid lava from the base of the main outer cone.

The above relations are shown schematically in figure 3.

Thus a minimum of six distinct periods of eruption can be induced from the field evidence at Amboy Crater. Petrographic evidence which supports this supposed sequence of events is discussed in another paper (Parker, 1959). Basaltic fragments which could be identified positively as ejecta are found only within the area designated *limit of bombs* on plate 1. Bombs are not found on the flows to the south and west of the cone. This relationship leads to the conclusion that explosive activity had ceased or greatly diminished before the last outpourings of lava as flows, since one would expect to find some bombs in these areas if they had not been buried by subsequent flows. This is in accord with observations at the Mexican cinder cone Parícutin where early explosive eruptions gave way to quiet effusive outpourings of lava (Howel Williams, personal communication).

THE FLOWS

The flows are hummocky and irregular and contain numerous arched portions, collapse depressions, blisters, irregular tongues, and blocky slopes. The irregularity of the surface and a discontinuous cover of sand make an evaluation of the location of the vent or vents from which this lava poured uncertain. Flows total a greater thickness in the area of the cone and of the plateau 2 miles southeast of the cone. Individual flows range from a foot to 12 feet in thickness. There are many individual

Photo 3 (above). Hummocky flows east of the cone area. The irregularity here is due to closely spaced wrinkles caused by collapse of portions of the lava surface. In the foreground is a desert pavement of small basalt fragments which lie upon windblown sand.

Photo 4 (below). Ropy surface of a pahoehoe flow. The wrinkles were caused by folding of the viscous skin as more liquid lava flowed beneath it. The original glassy surface has been removed by sandblast action.

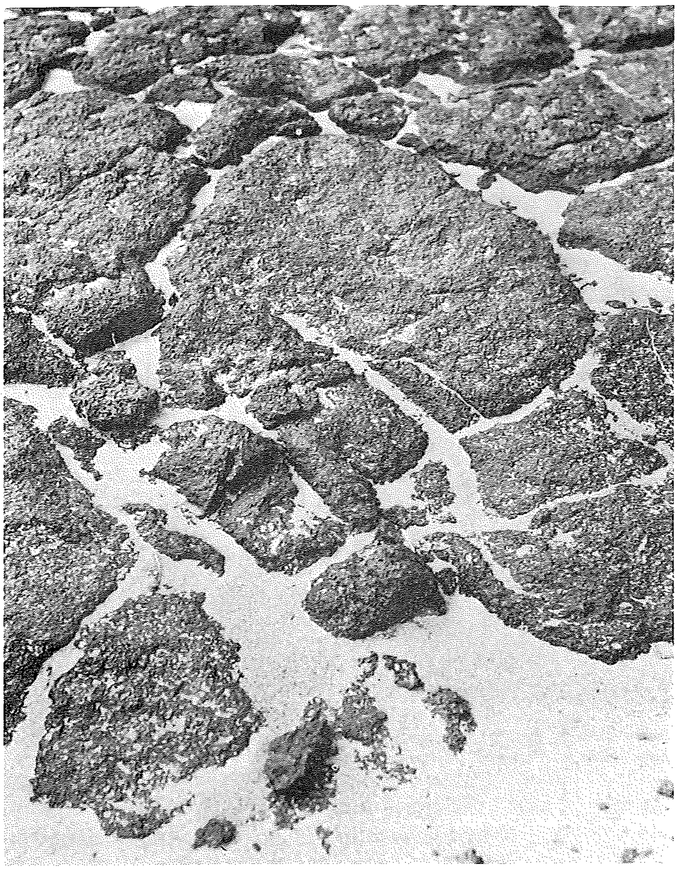


Photo 5. Jointed surface of a flat-lying flow, showing the scoriaceous or vesicular character. Drifted sand fills joint cracks. Width of the area covered by the photo is above 4 feet.

Photo 6. Blocky snout of a thick flow west of the cone. Earlier flows, to the left of the blocky portion, are partially covered by sand.

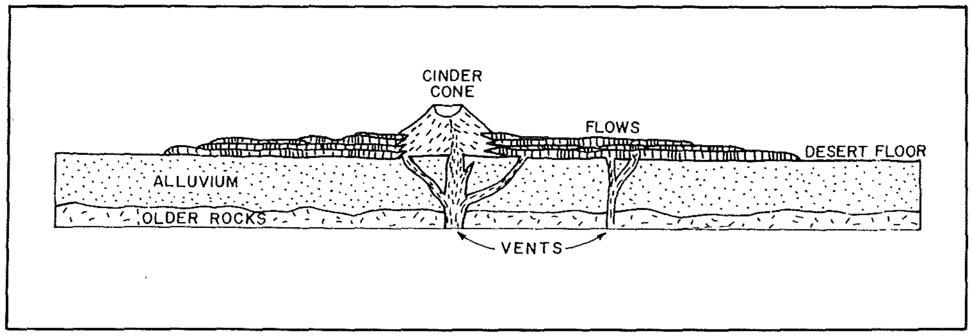


FIGURE 4. Cross-section of Amboy Crater and vicinity. The cross-section is schematic, with a greatly exaggerated vertical scale.

flows which must have issued from several vents in this area. Two locations which are particularly likely vent sites are the area of the cone and of the plateau. A schematic cross-section of Amboy Crater area is shown in figure 4.

Many of the flows are of the pahoehoe type, and exhibit typical ropy, twisted, and wrinkled surfaces. Blocky material is not uncommon, however, especially at the snouts of some of the flows. It was not possible to trace the areal extent of individual flows because of exposure problems and lack of obvious lithological distinctions.

Collapse Depressions and Flow Units

Horizontal flows in the area are scarred by numerous oval or circular depressions. These depressions are from a few feet to 150 feet in mean diameter, and are of uncertain depth, as most of them are partially filled with sand; but depths of one-quarter the diameter are not uncommon. The depressions, which are commonly bounded by collapse fractures, are inferred to be the result of gravitative collapse of a cooled crust subsequent to withdrawal of molten lava from beneath. The lava which was withdrawn formed smaller secondary flows or flow units (Nichols, 1936, pp. 617-624) in front of the parent flow. This sequence may recur several times in the course of the advance of a single flow, giving a gross stepped appearance to some flows (fig. 5). Undisturbed lava tunnels were not found, but collapsed remnants are widespread.

FIGURE 5. Sketch of flow units emergent from parent flow. Parent flow on left is pock-marked with collapse depressions. Flow units on right side have themselves been parent flows to additional flow units. Area covered by sketch is approximately 600 feet in width. *(From an aerial photograph.)*

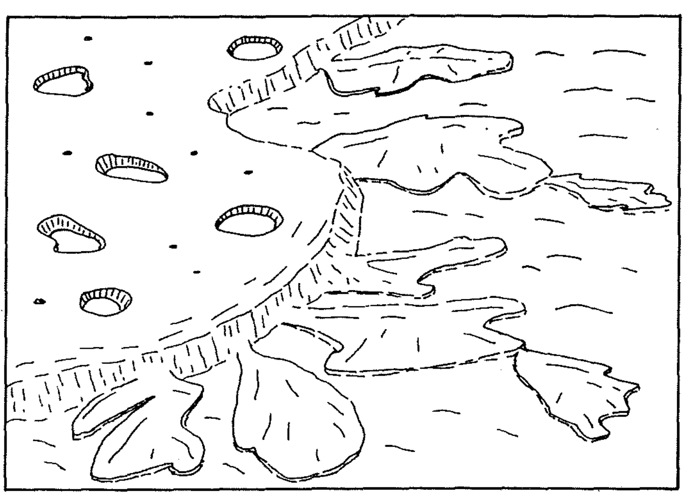
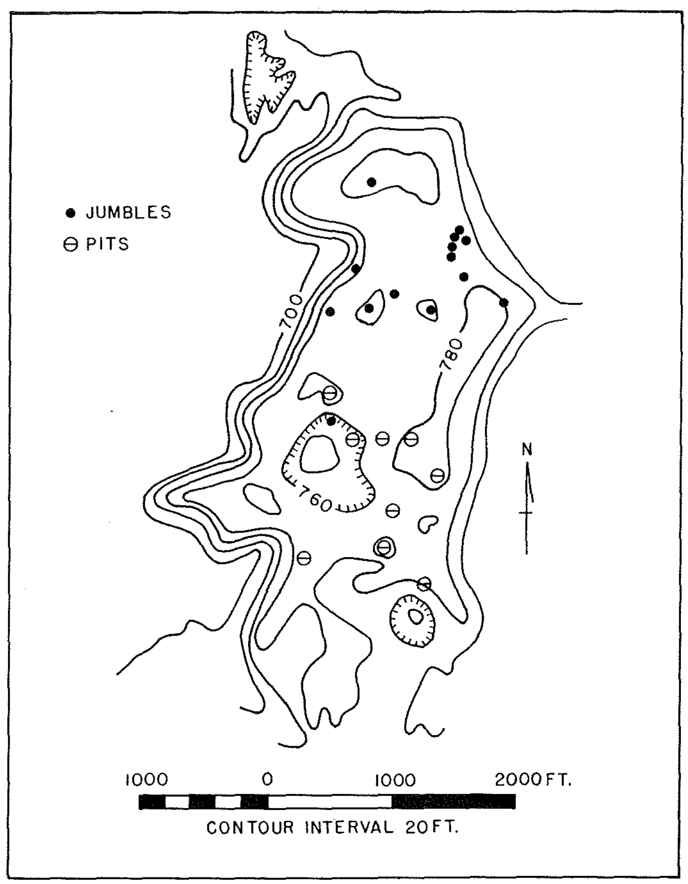


FIGURE 6. Map of the plateau area, enlarged from a portion of plate 1. Pits and jumbles lie along nearly straight lines. This area may have been underlain by volcanic vents.



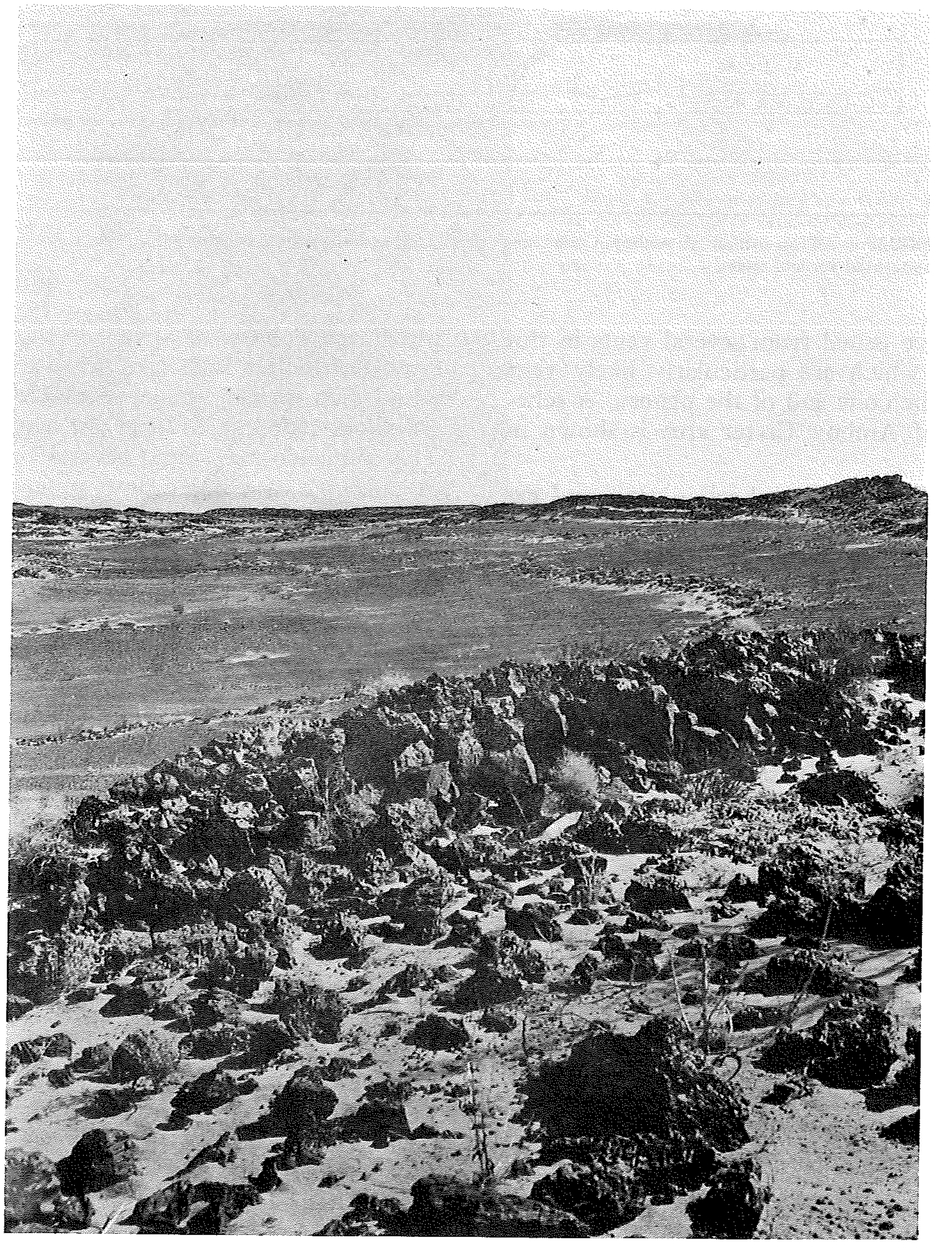


Photo 7. Edges of a number of thin flows near the western margin of the lava field. The thin flows have a large horizontal extent.

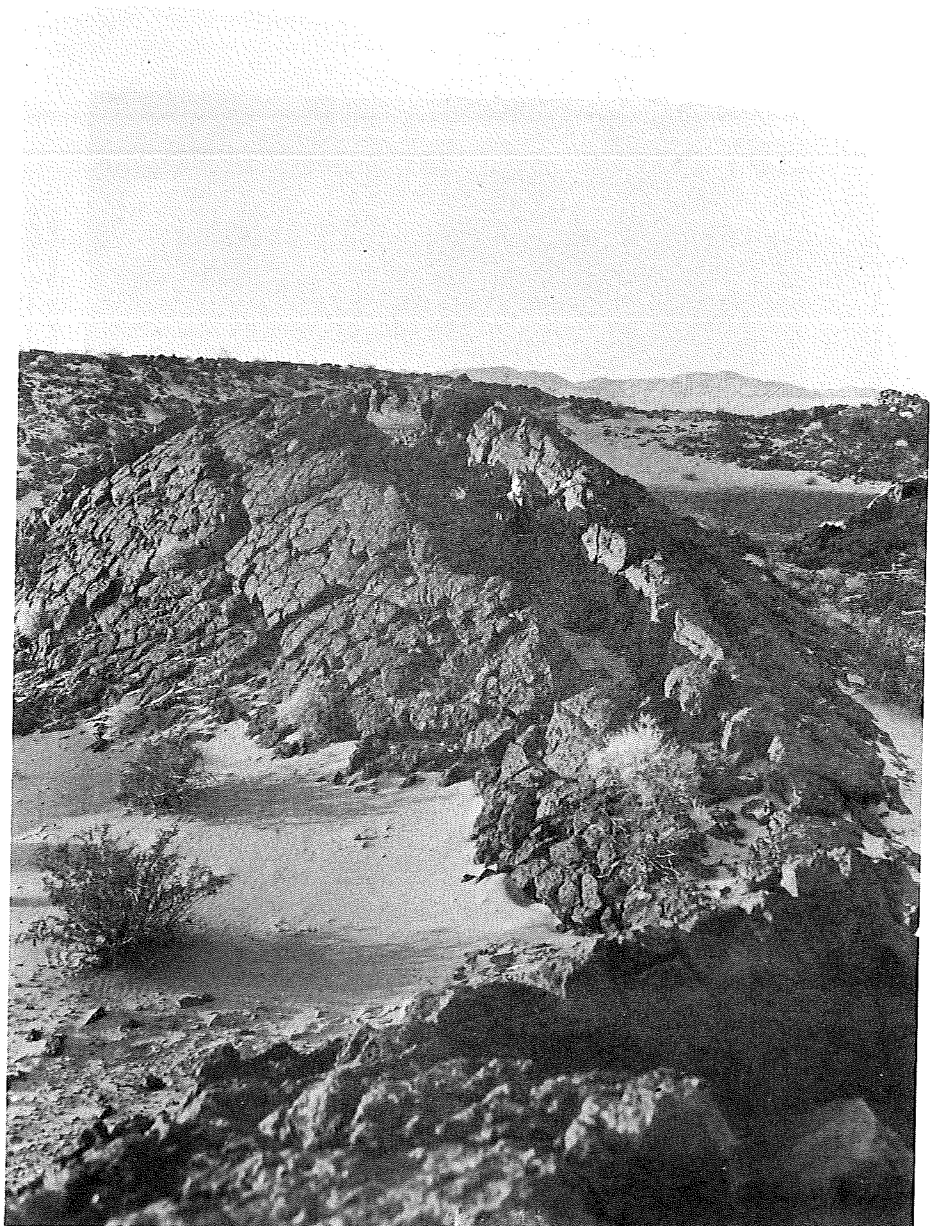


Photo 8. A breached pressure ridge. This arch was formed by the collapse of flows to either side. The figure of the man indicates the size of the ridge.

Photo 9. A collapse depression east of the cone, showing slumped lava slabs about its rim. The surface lava here solidified prior to the withdrawal of liquid lava from beneath it. The bottom of the depression is filled with drifted sand. The depression is approximately 100 feet in mean diameter.

Photo 10. A large basalt blister (approximately 75 feet in basal diameter). The uplift and disruption of flows was caused by the intrusion beneath the surface of a lens-shaped laccolith of later basalt.

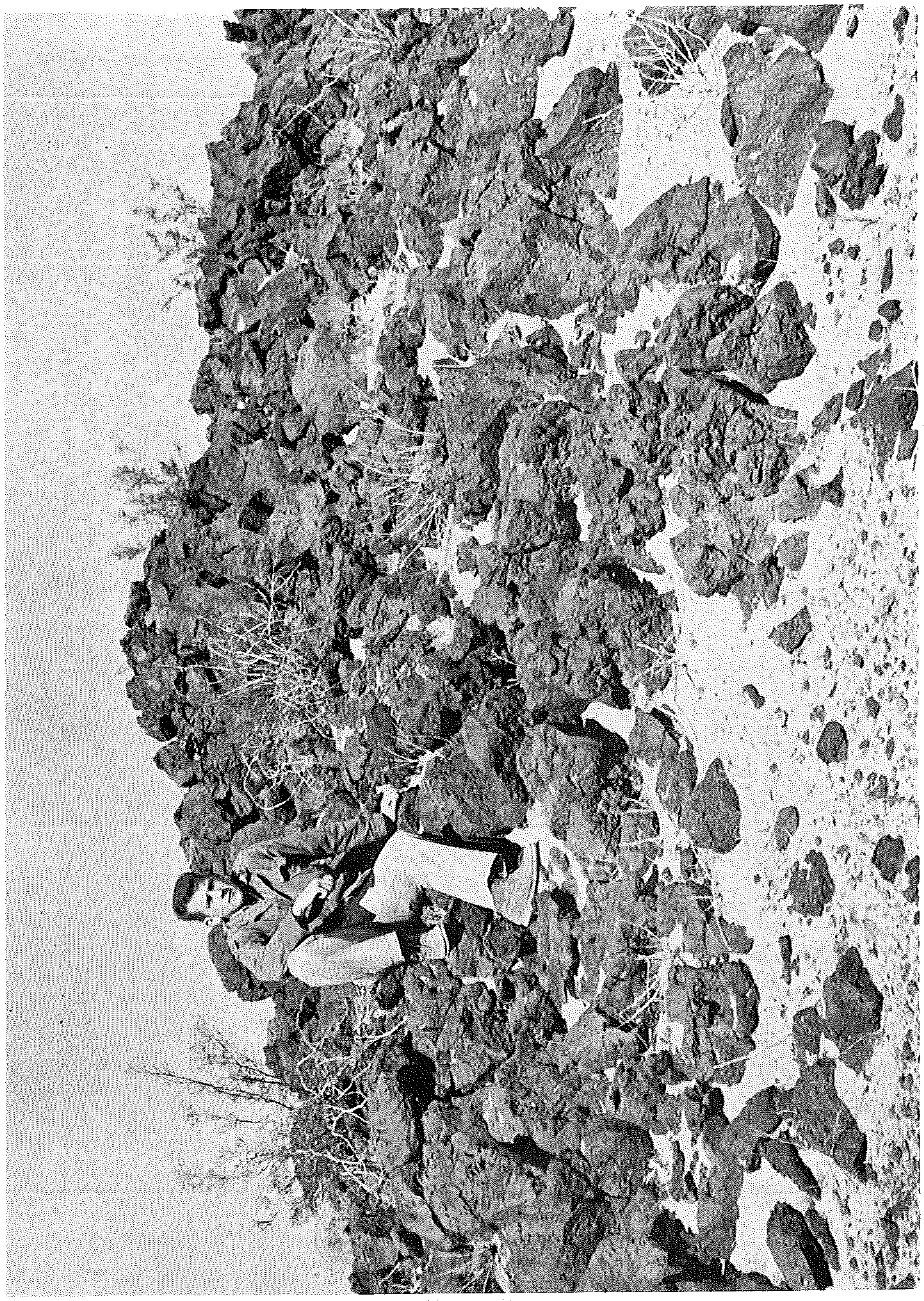


Photo 11. A typical jumble. The origin is ascribed to subsurface explosions that disrupted hardened lava flows.

Pressure Ridges

Pressure ridges (Nichols, 1946, pp. 1049-1086) or breached basaltic barriers (Skeats and James, 1937, pp. 245-291) are common in the Amboy Crater flows. They are elongate domical folds in the flows which range from low wrinkles to large folds 150 feet long and 50 feet high. They are oval in plan, and nearly symmetrical along a vertical axial plane; most of them are breached by a lengthwise trough from 4 to 20 feet in depth and from 2 to 10 feet in width. The walls of these breaches are strongly grooved, suggesting that adjacent blocks scraped together during folding.

The areal distribution of the ridges is random. As may be seen by an inspection of plate 1, the axes of the pressure ridges bear little or no relationship to the direction of flow of the lava. They appear to have formed primarily as a result of the collapse of nearby portions of the lava crusts. Had the pressure ridges formed during the advance of a moving flow, one would expect that they would be asymmetrical with the steep side facing the direction of flow. A discussion of the origin of comparable features in New Mexico is presented by Nichols (1946, pp. 1049-1086).

Basaltic Blisters

Several dome-shaped folds of lava, circular in plan, are present in addition to the pressure ridges (photo 10). They are about 100 feet in diameter and as much as 30 feet in height. They are characterized by a summit depression 3 to 4 feet across, and one or more radial fractures leading outward from this depression. The doming seems to be a result of internal pressure, inasmuch as the surface fractures are tensional. Some of the domes are disrupted as if by weak explosions. Jagger (1931, pp. 1-3) has attributed the formation of similar features in Hawaii to the intrusion of a laccolithic (lens-shaped) mass of lava between layers of already cooled flows. The final stage of the process is the squeezing out of fluid lava or the building of a summit spatter cone on the blister. These secondary features were not observed at Amboy Crater, but the general principles of the mechanism seem applicable.

THE PLATEAU

The area designated on the map (plate 1) as the plateau, and shown enlarged on figure 6, is of interest because of several features which are peculiar to the plateau area. These features are of two types.

First, there are 14 piles of chaotically arranged blocks of basalt (photo 11). The surfaces of many of these blocks are red, presumably indicating the presence of ferric iron in some form, a feature not observed elsewhere in the area except on the surfaces of a small number of bombs. Olivine crystals in some of the basalt from the *jumbles* are partly replaced by red-brown alternation products. The jumbles range in size from 8 to 40 feet in diameter and from 3 to 12 feet in height.

Second, there are 12 bowl-shaped depressions, some with raised rims of basalt blocks. These depressions are confined to the southern half of the plateau while the jumbles are confined to the northern half. The depressions are from 25 to 300 feet in diameter, and from 4 to 40 feet in depth. At two places the central depression is surrounded by a roughly concentric polygonal fracture along which the central area has subsided, forming basins within basins. The larger of the two is now a depression of 900 feet overall diameter (see photo 12).

It seems likely that both the jumbles and the depressions were produced by explosions. It is difficult to ascertain the source of the explosive force. An examination of figure 6 will show the tendency for the jumbles and depressions to lie along nearly straight lines. It could be concluded from this relationship that these features are concentrated along and above steep planes of weakness or topographic highs in the subsurface rocks. The reddening of the outer surfaces of the blocks and the formation of alteration products were probably due to the action of steam on heated rocks. The reddening probably resulted from the formation of ferric oxides and hydroxides from iron-rich basaltic glass and magnetite.

There are two possible explanations which satisfy the above evidence. First, the area could represent outpourings of lavas from a secondary vent from which the eruptions were primarily effusive—except for minor explosive activity. A second possibility is that lava from another source flowed onto wet sediments on the floor of the playa, and that the resulting steam was trapped beneath the advancing flow, causing phreatomagmatic (Stearns, 1953, pp. 599-600) explosions similar to those in Iceland described by Thorarinsson (1953, pp. 30-41).

Abundant steam would be present in either case. A feature favoring the phreatomagmatic hypothesis is the complete absence of recognizable ejecta, which would be expected had there been vents in the area. On the other hand, the fact that the flows total a greater thickness under the plateau suggests the presence of one or more secondary vents.

AGE OF THE VOLCANISM

Rocks at Amboy Crater as well as those of the flows have been but slightly attacked by weathering. Cinders of the cone itself are not visibly affected; those on the surface appear the same as those one finds by digging a few feet below the surface. The only effects of erosion present are the gullies on the outer wall of the cone, and these are so slight as not to appear on the topographic map at a scale of 1:24,000.

Fluting and polishing by wind-driven sand is common on the flows, but is confined to a few inches above the surface and to those places where the amount and velocity of wind is intensified by circumstances of topography. In most places angular details of the flows are very perfectly preserved, and tachylitic (glassy) selvages are common.

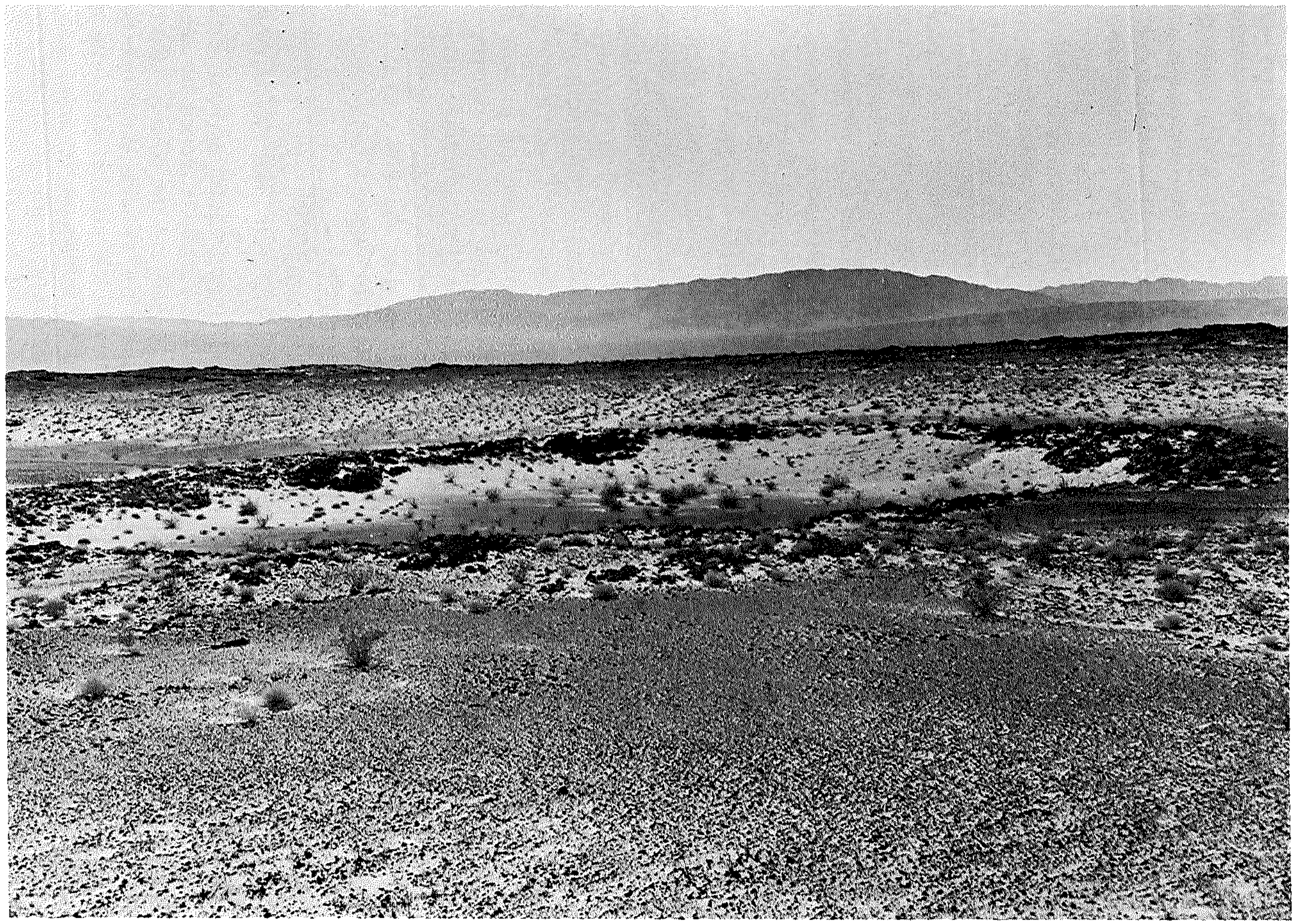


Photo 12. The largest depression on the plateau, approximately 300 feet in diameter from left to right. It is rimmed by basaltic blocks. The view is south, from a secondary fracture along which subsidence of an area concentric with the depression took place.

Sediments of Bristol Lake have—to a very limited extent—lapped onto the eastern and southern margins of the flows. Borings near the contact between the lava and the lake beds disclosed no buried flows. On the northwestern lava-sediment contact, flows are partially covered by sandy alluvium of the outwash plain from the Bristol Mountains; but deposits of this sort accumulate rapidly.

The volcanic features in general imply very recent activity; Amboy Crater appears to be younger than many cinder cones and flows along the eastern front of the Sierra Nevada in Mono County which are described by Blackwelder (1931, p. 891) as interglacial. Probably the activity at Amboy Crater was post-glacial, for one would expect to find flows more extensively buried by lake beds and alluvium if they had been present during a moist glacial cycle.

While no definite age may be assigned from this limited and uncertain evidence, it does seem likely that the volcanism was post-Tioga (the latest glacial stage in California). The end of Tioga glaciation has been estimated by Mumford (1954, p. 18), on the basis of C^{14} dates, as approximately 6,000 years ago.

PETROGRAPHY

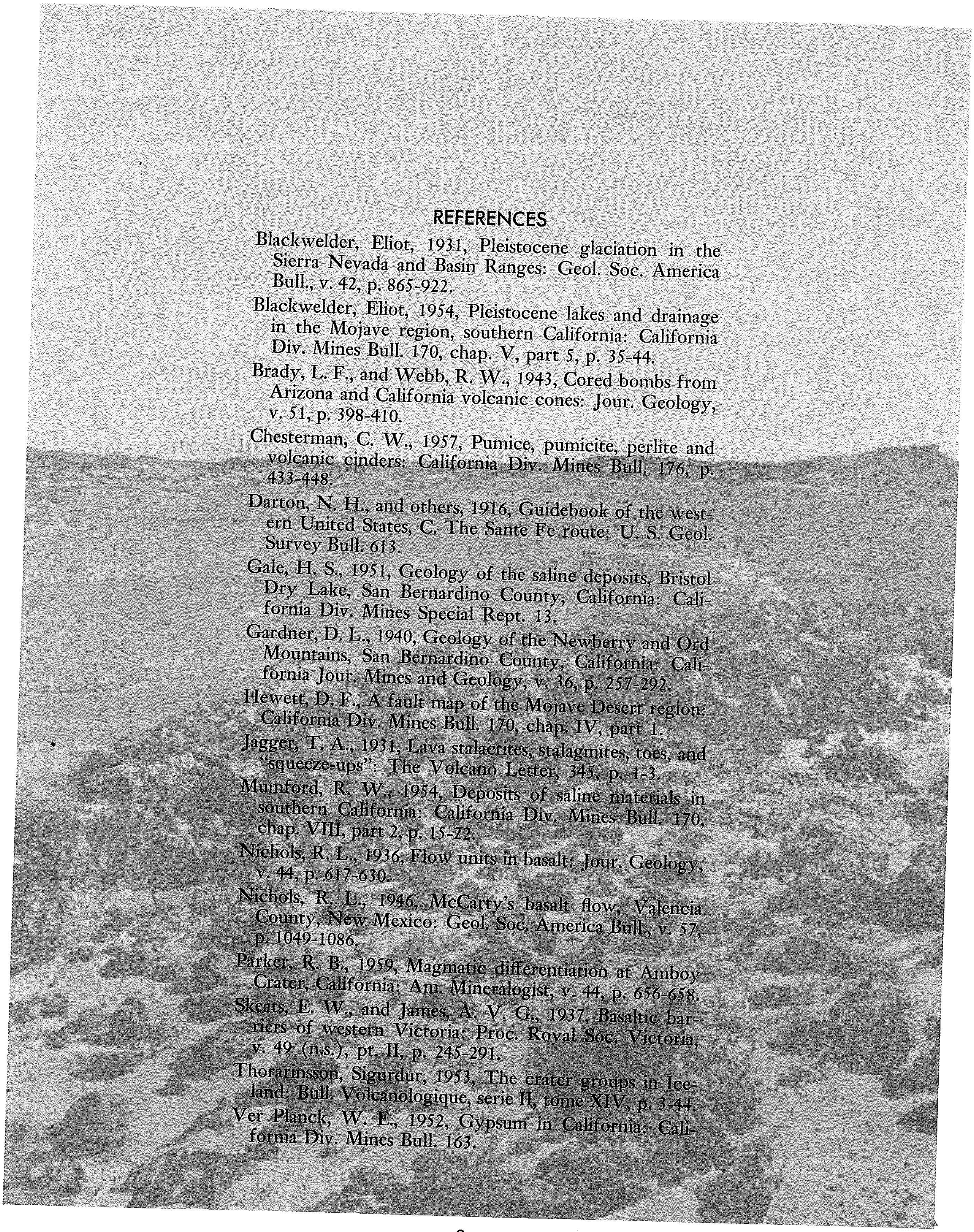
All of the rocks of volcanic origin at Amboy Crater are fine-grained, porphyritic olivine basalt, for the most part vesicular. Olivine (Fa_5 to Fa_{23}) and a minor amount of plagioclase (An_{45-60}) form the phenocrysts. The groundmass is composed of brown basaltic glass (refractive index = 1.58-1.60), plagioclase microlites (An_{47-55}), clinopyroxene (pigeonite ?), and magnetite. Calcite and zeolites (?) are present as amygdules in a few specimens. The chemical analysis given below is an average of three analyses of rocks from Amboy Crater.

A suite of rocks from the crater itself was examined with a view to determining chemical and mineralogical variations, if any, with decreasing age of eruption as established from field evidence. Regular changes in mineralogy and chemical composition verify the proposed sequence of eruptions. The details of petrography of these rocks are discussed elsewhere (Parker, 1959).

*Average * chemical analysis of basalt from Amboy Crater.*

	Weight percent
SiO_2	46.97
TiO_2	2.32
Al_2O_3	16.71
Fe_2O_3	4.94
FeO	5.35
MnO	.19
MgO	7.24
CaO	9.10
Na_2O	3.14
K_2O	1.66
H_2O+	.65
H_2O-	.39
P_2O_5	.28
CO_2	1.06
	100.00

* Average of three specimens from Amboy Crater. W. H. Herdsman, analyst.



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