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MAARS OF SOUTH-CENTRAL OREGON

By

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Introduction

If we could go back in time some 5 to 10 million years to the Pliocene Epoch and recreate the landscape of south-central Oregon, here are some of the things we would probably see:

From a plain originally of slight relief, faulting has already delineated broad basins containing large, shallow lakes. To the west, the High Cascade volcanoes are beginning to erupt on a grand scale. In and around the basins, volcanic vents, aligned along northwest-trending fissures, spew out fire fountains to form reddish-black scoria cones. These break through, spreading thin sheets of basaltic lava to fill depressions and further disrupt the existing drainage. When the basaltic magma rises beneath the lakes or near their borders, tremendous steam pressures are generated that trigger catastrophic initial explosions. Ash, lapilli, and large blocks of all the rocks involved are thrown high into the air in successive explosive eruptions to settle and to build raised rims of ejecta around the funnel-shaped craters. In some, the explosive phase dies quickly and fluid magma rises to fill the craters with a lava lake. In others the magma solidifies at depth, or withdraws, and water enters to form crater lakes. In still others, the same vents or ones nearby again explode violently to modify the original simple features.

Returning to the present, we see only the eroded and buried remnants of these peculiar volcanic features; our colorful reconstruction of the past had to be based on imagination and the little geologic evidence that remains.

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Distribution of Basaltic Tuff Landforms

During the summer of 1962, we made a broad reconnaissance of northern Klamath County and north-central Lake County to determine the distribution of the landforms described above to see if they form a pattern that would help to explain the special conditions necessary for their formation; we also looked for criteria that would make them easy to recognize.

The index map (pages 82 and 83) shows the distribution of basaltic tuff landforms that have been definitely recognized in the field during this study and also during other assignments in Klamath and Lake Counties in 1959, 1960, and 1961.

There are concentrations in two broad northwest-trending zones, one in the Fort Rock-Christmas Lake valleys in northern Lake County and the other in the Yonna and Sprague River valleys of central Klamath County. Individual occurrences and small groups of occurrences have also been identified adjacent to the Klamath River west of Keno and in the southern Fremont Mountains north and west of Lakeview, Oregon.

Future study will be extended to the south and east to cover the area bounded by Summer, Abert, and Alkali Lakes, and more detailed studies will be made of the individual landforms already recognized, to determine their original structures and origins.

Definition of terms

Maar, dry maar, ubehebe, tuff cone, tuff ring, and diatreme have all been used by various authors to describe relatively large, shallow, flat-floored craters that resulted from short-lived volcanic explosions.

Maar: As defined in the American Geological Institute glossary, a maar is "a relatively shallow flat-floored explosion crater, the walls of which consist largely or entirely of loose fragments of the country rock and only partly of essential, magmatic ejecta. Maars are apparently the result of a single violent volcanic explosion, probably of phreatic origin. Where they intersect the water table, they are usually filled with water and form natural lakes. The term was originally applied to craters of this nature in the Eifel district of Germany."

Dry maar or ubehebe: These terms have been used by Cotton (1941) to describe two small craters in Death Valley, California. These craters have raised rims built of layers of rock fragments derived from the immediately underlying terrain.

Tuff cone or tuff ring: These are synonymous terms for volcanic cones built primarily of consolidated ash and generally shaped something like a saucer, with a rim in the form of a wide circle and a broad central depression often nearly at the same elevation as the surrounding country. They usually show maximum growth on the leeward side. Individual tuff beds forming the cone dip both inward and outward, those in the high part of the rim approaching the angle of repose. Tuff cones are believed to be the result of hydroexplosions caused when lava erupts under water or water-saturated rocks close to the surface. In form tuff cones, or tuff rings, bear a general resemblance to maars.

Diatreme: A general term given to funnel-shaped or pipelike volcanic vents that are filled with angular fragments of many sizes of the rock types through which the pipe passes. In some there is no trace of magmatic material, but in others basaltic tuffs are present. An explosion crater is the surface expression of a diatreme. The term should probably be restricted to eroded features where only the pipe or the pipe-filling breccia remains.

The term maar is becoming more popular and is being used increasingly to describe these explosion craters with rims built of volcanic tuffs and breccias, even though no lakes were present. The term is also utilized for the volcanic processes that form this type of crater.

Tuff cone (or tuff ring) seems to be a more descriptive term, however, and is probably more nearly correct for describing the south-central Oregon structures where high rims of layered tuffs and breccias are present. These two terms, then, maar and tuff ring will be used interchangeably for the features in south-central Oregon.

Maar or Tuff Ring Field Identification

General types

Most of the central Oregon maar/tuff-ring features are similar and probably resulted from almost identical volcanic explosive processes. On the basis of the ones examined so far, there are enough differences in individual occurrences so they can be classified into three general types:

1. Simple maars: Circular or roughly circular craters surrounded by rims made up of steeply dipping, thin to thick layers of pyroclastic rocks. Excellent examples of this type are Hole-in-the-Ground and Big Hole,

shown in figure 1. As this type becomes more dissected and its original crater obliterated, the layers of tuff are usually exposed as low, curving hogback ridges that show their original ring shape, or as bold cliffs with a roughly circular shape, such as Fort Rock, shown in figure 2.

2. Simple maars modified by later lava: In this type, the conditions necessary for violent explosive activity ceased after a time, and the craters were filled by quiet extrusion with basaltic lava, which in some cases overflowed the rims and poured down the sides. Erosion of this type results in a lava-capped hill or butte surrounded by inward-dipping layers of explosion tuffs. Typical of maars of this type in the Fort Rock valley are Flat Top, shown in figure 3, and Table Mountain, in figure 4.

3. Complex maars: Where individual explosive vents were closely aligned or spaced, the tuff layers from separate explosions are superimposed on one another. Erosion of these complexes results in oval to elongate ridges of the layered tuffs with anomalous attitudes. A good example of this type can be seen in the large mass which makes up Table Rock near Silver Lake. This massive ridge is about 5 miles long and 3½ miles wide and covers about 15 square miles with bold erosional outcrops of layered basaltic explosion tuffs.

Surface expression

The landforms that still retain crater depressions are the easiest to recognize, and so far two have been found in the Fort Rock-Christmas Lake valley. Hole-in-the-Ground has a crater almost a mile in diameter and Big Hole, 1½ miles in diameter. Williams (1935) has reported three tuff rings within the Newberry caldera, one of which still has a saucer-shaped crater. The surface expression of eroded outcrops of the others examined indicates that this size is probably about the minimum, and where they occur in clusters they formed much larger masses.

Thickness of the layered tuffs

The layered tuffs and breccias at the rim crest of Hole-in-the-Ground are only about 150 feet thick, and they thin rapidly in all directions away from the crater. At Fort Rock (figure 2) the eroded cliffs show at least 300 feet of the thinly layered tuffs, indicating that either it was originally much larger than Hole-in-the-Ground, or that it had higher rims. At Table Rock near Silver Lake, the explosion tuffs make up most of the highest point, which is more than 1,000 feet above the surrounding plain.

(a)

(b)

Figure 1. Examples of typical simple maars. (a) Aerial view of Hole-in-the-Ground, showing truncated edges of the older rocks through which the vent was drilled. A small lake probably once filled the crater. (b) Aerial view of Big Hole. Walls and rim are composed entirely of thin layers of basaltic lapilli tuffs and breccias. Crater depression is broad and shallow.

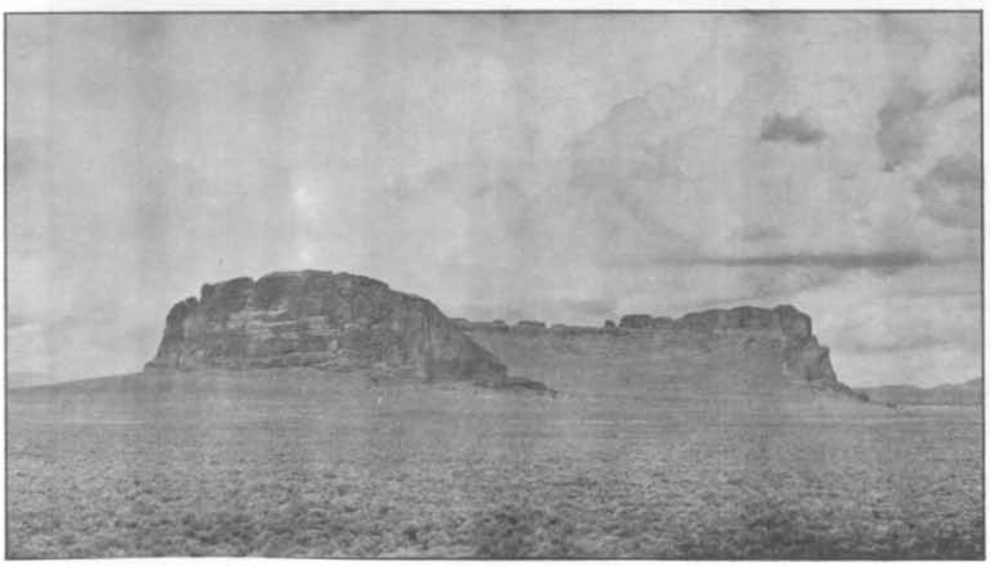


Figure 2. Fort Rock, an eroded remnant of a once much larger maar. The steep cliffs expose hundreds of thin layers of typical basaltic explosion tuffs. Well developed wave-cut terraces were formed by Pleistocene lake.

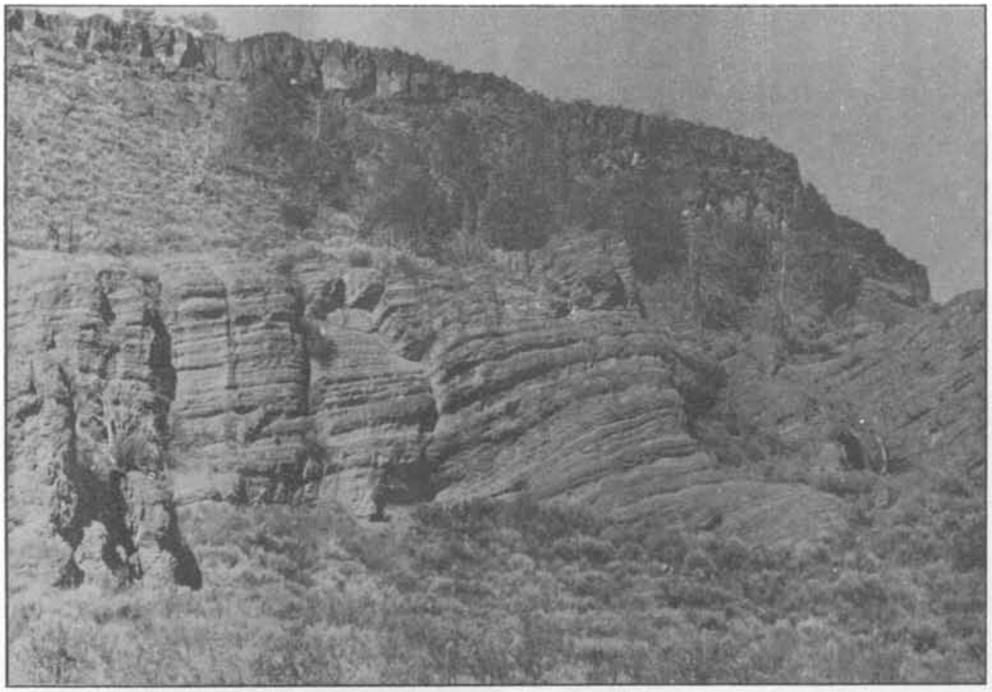


Figure 3. Flat Top, a remnant of a modified, simple maar. Layers of tawny basaltic tuffs dip beneath a basalt capping that originally filled the crater.

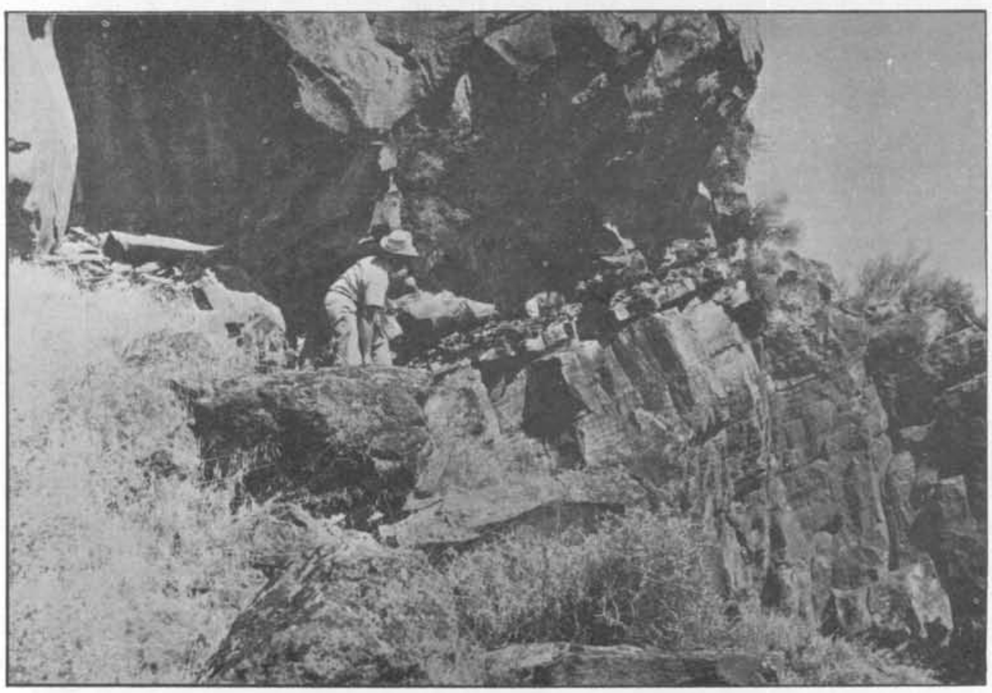


Figure 4. Table Mountain, illustrating a closer view of the contact of crater-filling lava with slightly baked, undisturbed tuffs which dip inward toward the crater.

Composition and structure of the tuffs

Thin layers of vitric lithic tuffs are present in all the maar/tuff-ring features and are perhaps the best criteria for their identification. Colors range from gray to drab yellows and browns, but are usually tawny. Tuffs of this type are composed of a variety of angular volcanic rock fragments in a matrix of fine, frothy basaltic glass. The fragments vary in size from microscopic shards to large blocks as much as 10 feet in diameter (figures 5 and 6), with lapilli sizes most abundant. The glassy nature of the groundmass in most of the explosion tuffs is easily recognized with a hand lens.

The tuffs and breccias almost always show a thin layering even though the rock fragments are large. This layering results from powerful sporadic showers of ejected material that drop directly into place. Cross bedding, channeling, and other sedimentary features resembling those of waterlaid deposits are locally present. Some layers are deformed by the larger fragments and blocks that have fallen directly on them.

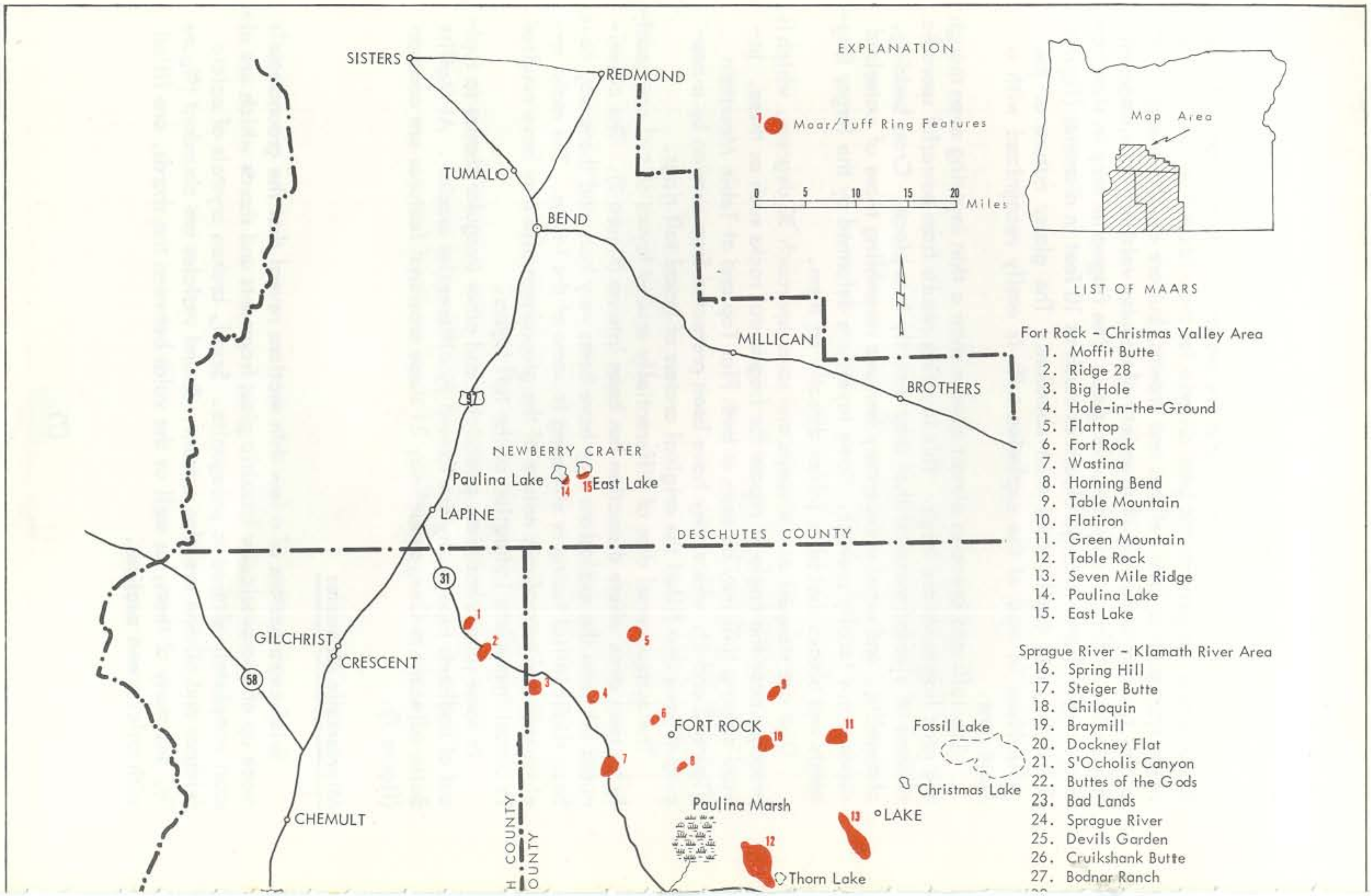
Dips are steepest at rim crests and some approach 30 degrees, which is probably near the angle of repose for fragmental rocks such as these. Inward dipping tuffs may be seen at both Flat Top and at Table Mountain (figures 3 and 4), where they have been protected from erosion by a capping of lava that filled the original craters of broad tuff rings.

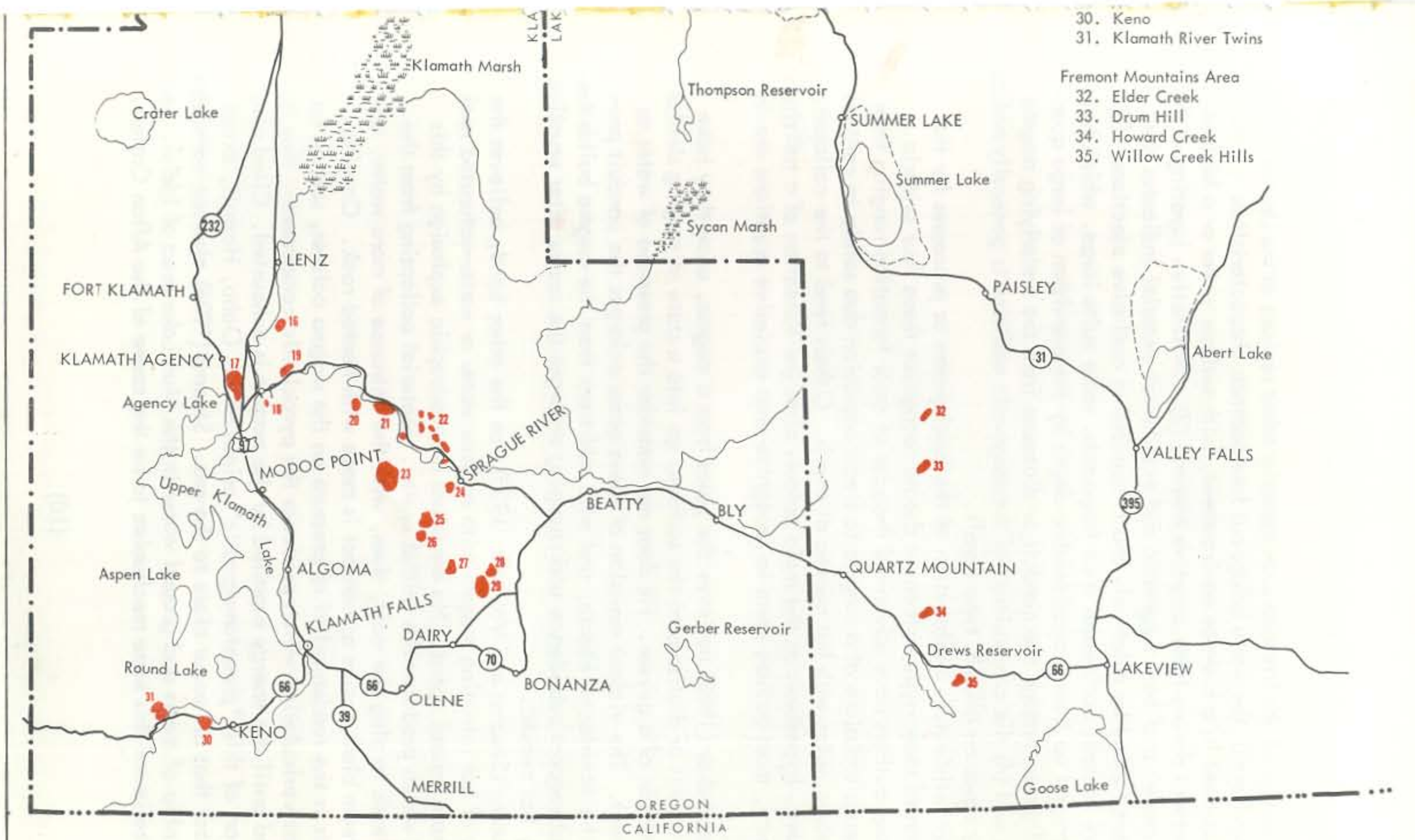
The quaquaversal dips of differentially eroded layers of tuff can usually be seen even where dissection has been intense (figure 2). The comminuted ash from the explosions may have been very hot, and there may have been slight initial fusing or sintering in some of the layers. The moist environment and pozzolanic nature of the groundmass also may have resulted in almost immediate induration of the tuff layers.

In some places hoodoos, pedestals, and other irregular shapes so typical of badlands topography are formed by differential erosion. At Moffitt Butte adjacent to Oregon highway 31 these erosional features are common (figure 7).

Microscopic character

Brief examinations of a few thin sections reveal that the groundmass is made up of microvesicular basaltic glass fragments and shards which are almost completely altered to palagonite. Small, broken crystals of calcic feldspar and olivine are also present. Round vesicles are abundant (figure 8), and many of them, as well as the voids between the shards, are filled with calcite and zeolites.


EXPLANATION
Maar/Tuff Ring Features
0 5 10 15 20 Miles
Map Area
LIST OF MAARS
Fort Rock - Christmas Valley Area
1. Moffit Butte
2. Ridge 28
3. Big Hole
4. Hole-in-the-Ground
5. Flattop
6. Fort Rock
7. Wastina
8. Horning Bend
9. Table Mountain
10. Flatiron
11. Green Mountain
12. Table Rock
13. Seven Mile Ridge
14. Paulina Lake
15. East Lake
Sprague River - Klamath River Area
16. Spring Hill
17. Steiger Butte
18. Chiloquin
19. Braymill
20. Dockney Flat
21. S'Ocholis Canyon
22. Buttes of the Gods
23. Bad Lands
24. Sprague River
25. Devils Garden
26. Cruikshank Butte
27. Bodnar Ranch
SISTERS
REDMOND
TUMALO
BEND
MILLICAN
BROTHERS
NEWBERRY CRATER
Paulina Lake
East Lake
LAPINE
DESCHUTES COUNTY
31
97
58
GILCHRIST
CRESCENT
CHEMULT
FORT ROCK
Fossil Lake
Christmas Lake
Paulina Marsh
LAKE
Thorn Lake



DISTRIBUTION OF MAARS IN SOUTH-CENTRAL OREGON

Volcanic Processes in Maar Formation

A review of the literature on maars in other regions of the United States and elsewhere in the world brings out four common characteristics: (1) maars have occurred in a hydrous environment, with surface water or a high water table present during their eruptive history; (2) a distinctive layering of the ejecta made up of both magmatic and accidental material indicates that they were formed by relatively short, successive explosive ejections; (3) there are present accidental rock fragments, some quite large, which have been brought up from a considerable depth by the expulsion of large quantities of gases through the conduit or diatreme from the underlying magma source; and (4) the composition of the magmatic addition is generally mafic, in many cases an alkalic type basalt.

Any satisfactory explanation of the mechanisms or processes for the formation of maar-type volcanoes should recognize these four criteria. Numerous authors have advanced theories of maar formation ranging from the gaseous emissions of a magma to steam explosion due solely to contact of meteoric water with hot magma at depth. Others tend to the collapse, or caldera, hypothesis as the main process after the formation of a tuff ring. In general, most authors seem to recognize that explosive eruptions are involved.

Shoemaker (1962) believes the gases from a magma, once they have drilled a vent or diatreme to the surface, go into a state of surging similar to the action of a geyser. He does not consider the presence of water as significant. The violent emission of these gases enlarges the conduit providing the accidental ejecta, and with additions from the magma builds the maar; subsequent subsidence and slumping enlarges the crater after eruptive activity has ceased.

Stearns (Stearns and Vaksvik, 1935), on the other hand, believes the contact of hot intruding magma with surface water or water-saturated rock is the main causal agent. He envisions a catastrophic explosion by this method which produces the initial crater. Material collapsing from the crater tends to plug the vent, then, with the entrance of more water, another steam blast occurs as contact is made with heated rock. Coupled with this is the sudden relief of pressure on the magma column, setting up a violent vesiculation which produces the pyroclastic component. This is repeated until the energy supplied by the magma is exhausted. Cited also in support of this "phreatomagmatic" origin of the Oahu, Hawaii, maars is the fact that all occur close to the sea. Stearns (1926) also has noted the relationship of maars and ground water in the Mud Lake area of Idaho. Lee (1907) believed this same mechanism to be the cause of the Afton Craters,

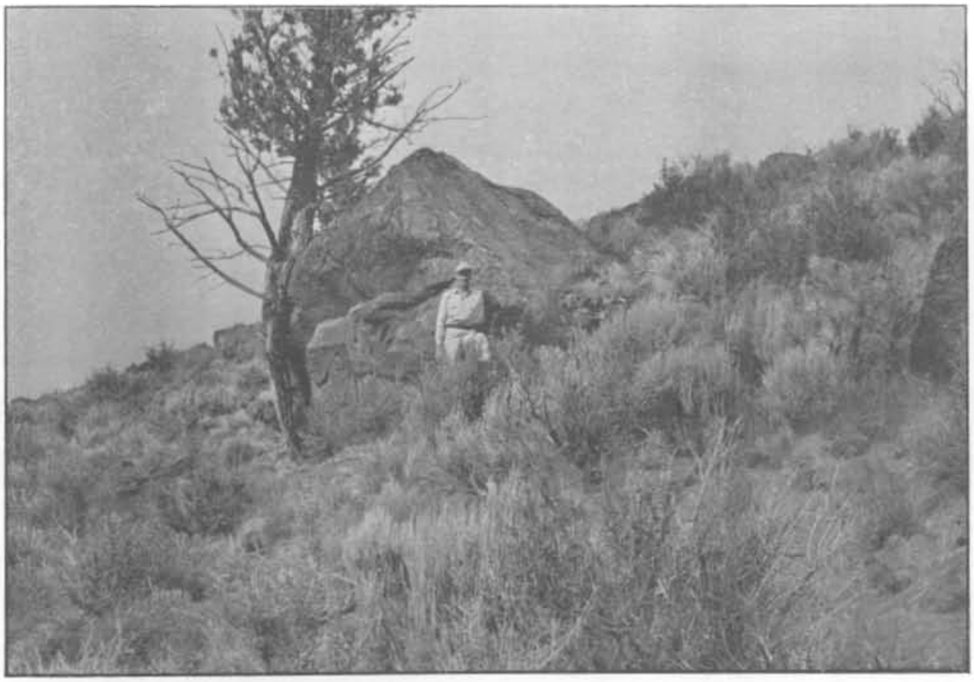


Figure 5. Enormous accidental block of porphyritic basalt lying near the crest of the east rim of Hole-in-the-Ground.

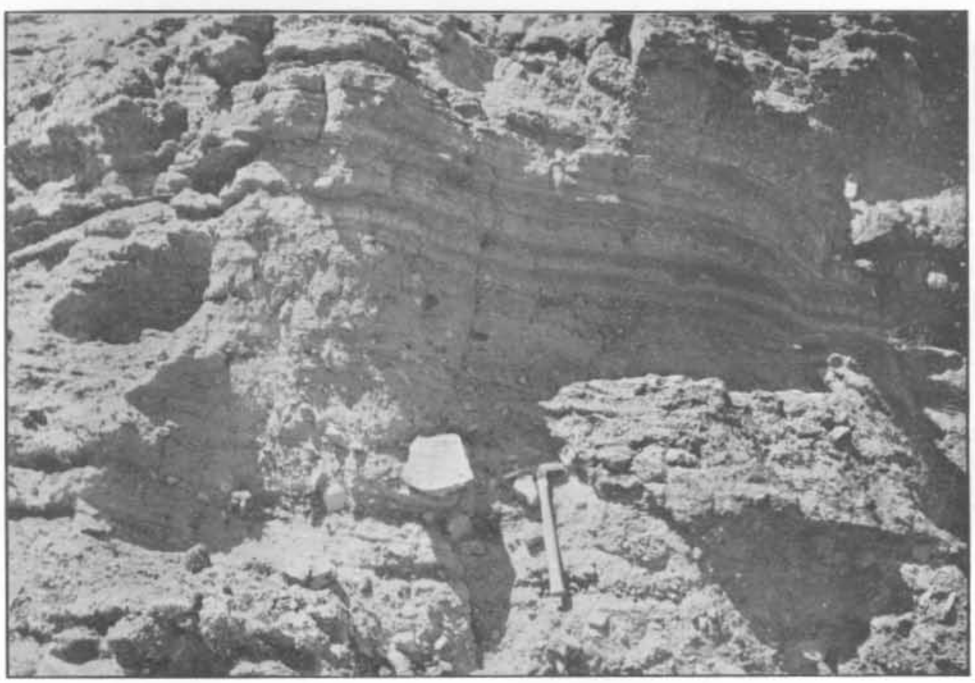


Figure 6. Closeup of Horning Bend showing thin layers and intimate mixing of angular rock fragments. The tuffs at this location contain a high percentage of accidental glassy rhyolite.

Figure 7. Hoodoo and badlands type of erosional landforms at Moffitt Butte. These and other differential weathering features are characteristic.

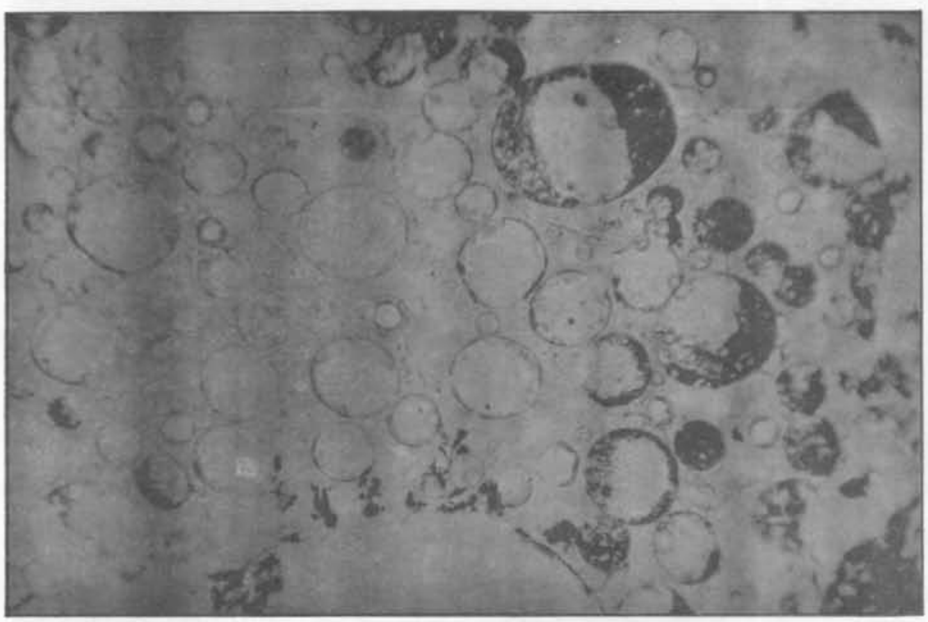


Figure 8. Micro-photograph of basaltic (palagonite) tuff showing the microvesicular nature of the groundmass, which is composed of fragments and shards of yellow-brown basaltic glass.

New Mexico. In his study of the Hopi Buttes area diatremes, and remnant maars, Hack (1942) has postulated the "phreatomagmatic" origin of these features which are closely associated with the Pliocene sedimentation of that region.

Jahns (1959), in his study of the Pinacate Craters in Sonora, Mexico, postulates the formation of a large tuff breccia cone by explosive action of a vesiculating magma on a catastrophic scale. When this magmatic energy is expended, collapse and foundering into the partially evacuated magma chamber results in the formation of a caldera. Since the Pinacate Craters belt is confined to only a part of a large volcanic field containing hundreds of cinder cones. Jahns also cites Stearns' (Stearns and Vaksvik, 1935) theory as a possible alternate explanation.

A different view of the formation of a maar is offered by Mueller and Veyl (1957) by their observations of the eruption of a new maar called Nilahue Maar, in Chile. It is their contention that the pyroclastics making up the maar cone were formed from fusion of the rock originally contained in the crater by the enormous quantity of hot gases expelled and that no addition of magmatic material took place. Added to this was also unfused accidental ejecta of the rocks penetrated by the vent. Theorizing on the origin of the maar, they believe gases which accumulate at the top of an intruding magma erupt through the overlying rock and continue their spasmodic expulsions until exhausted. Surface water, and presumably ground water (although they do not specifically mention ground water), breaching the weak ash barrier and flowing into the vent help to keep it open by secondary steam blasts. Otherwise, in the absence of water, they believe a regular pyroclastic cone would be built which would place a damping effect on the gases escaping, this in turn allowing the cone to grow by keeping the ejecta close to the vent.

All of these hypotheses attempt to explain the causes for the characteristic features of maars, but there are still many questions which are not completely answered. The one point that most authors do agree on is that violent expulsion of gases is an important requirement in maar volcanism.

The writers' studies and field work on the maars discovered to date in south-central Oregon strongly point to a hydrous environment existing at the time of their formation. Many probably erupted into the shallow lakes present throughout this region during the Pliocene and Pleistocene epochs. Others were formed in the areas where the water table was near the surface around the lakes and in the drainage system of the region. In such an environment it can well be expected that magma and/or the volatiles heating fractured and porous water-bearing rock would produce a phreatic or steam explosion, throwing out this rock and forming a funnel-shaped crater, as advocated by Stearns (Stearns and Vaksvik, 1935). Corwin and Foster (1959) describe an explosive eruption on Iwo Jima which occurred in such a manner.

The numerous beds of crudely sorted ejecta which make up a maar or tuff ring indicate a similar number of ejecta falls, each expelled essentially as a unit. Each bed apparently was explosively ejected in a short interval of time with a relatively quiescent period between successive eruptions. The observations of Mueller and Veyl (1957) confirm this evidence. Yet these short, violent eruptions, of perhaps 20 or 30 minutes duration, do not seem to be satisfactorily explained solely by ground or surface water contacting heated rock, the magma, or its volatiles. After the initial phreatic explosion, the major share of energy must be derived from the magma, mainly its hot gases. Some mechanism that causes a plugging or stoppage between successive eruptions seems to be a necessary requirement. A point that has not been previously emphasized in the maar volcanic process is possibly the influence of the wide crater, a feature common to all maars. After phreatic eruption forms the initial crater, part of the fallback would tend to plug the vent until increased gas pressure could blow this material out again. As the crater widens with repeated new eruptions, a greater portion of the fallback is collected and funneled into the vent. Thus a temporary plugging by a load of loose material falling back into a wide crater may be of major importance in maar volcanism. Stearns (Stearns and Vaksvik, 1935) advocates a similar process of plugging by fallback, but does not consider the importance of a wide crater in relation to this action. The infiltration of surface and ground water into the lower and hotter portion of the vent may help to produce steam blasts causing further fragmentation of the rock and adding some energy during eruptions. Crater diameter enlarges to a size which is related to the maximum energy expended in the eruptive process.

With each eruption, tremendous volumes of gases must be generated by an explosive frothing of the magma. A fluid, mafic magma carrying volatiles would permit this action more readily than a viscous one. This would account for the glassy, vesicular ash of basaltic composition typically present as the magmatic addition in the maars of south-central Oregon. Expulsion of a large volume of gases also can be expected to provide a high velocity streaming through the conduit. This streaming of gases carries rock broken from the walls up the conduit. Some quite large blocks are brought from considerable depths in this manner. Fragments of rock transported from depths of several thousand feet have been reported in studies of maars and diatremes of other localities (Hack, 1942, and Shoemaker, 1956). The fragments are probably brought to the surface during one single eruption, although some may fall back and require two or more eruptive episodes. As previously mentioned, the writers' study of Hole-in-the-Ground has pointed out that some enormous blocks have been carried up from depths of at least several hundred feet (fig. 5).

After all volcanism ceases, the diameter of the crater is further increased by subsidence and compaction of the material in the vent, slump of the crater walls, and normal erosion.

Conclusions

A wide distribution of maars/tuff rings occurs throughout south-central Oregon, and the evidence shows an association with a hydrous setting at the time of their formation. Studies of the Pliocene-Pleistocene rocks of areas not as yet examined in this region will no doubt expose many more of these features. At present, these peculiar volcanic structures show a pattern along two rather broad, northwest-trending zones which is also, as expected, the major direction for the faults of this region. As additional maars are discovered, some modification of this pattern may be noted.

Since accidental fragments in the tuff-breccia beds of these maars have been expelled from a conduit or diatreme, they provide a rough sample of a section of the underlying rocks. Petrographic study of these fragments, some of which may have been brought up from depths of several thousand feet, can confirm whether a certain known rock formation exists below. This may aid the geologist, for instance, in solving a structural problem when mapping a particular area in the vicinity of a maar.

Many hypotheses for the volcanic processes of maar formation have been offered by various writers from their observations of these features. Generally, all who have studied maars or tuff rings agree that explosive eruptions are necessary to their production. The almost universal association of maars with a water-bearing environment seems also to be an essential factor. Relating this factor to the explosive volcanic process which forms a maar leaves many questions unsatisfactorily answered. The maars of south-central Oregon, ranging from those little eroded to those completely dissected, present an unusual opportunity for study.

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