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DIAMOND CRATERS, OREGON

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Introduction

Diamond Craters is the name given to an isolated area of recent volcanism near the center of Harney County in southeastern Oregon. The area lies about 60 miles south of Burns in Tps. 28 and 29 S., R. 32 E.

The whole of this volcanic feature is not easily described, but it probably fits most correctly the definition of a small shield volcano. The first volcanic activity produced a field of lava that was shaped much like a huge pancake about 6 miles across (see plate 1). This lava welled up and flowed out in radial directions from a now-hidden vent near the center. Slight irregularities in the topography over which the coalescing tongues of lava flowed created a design at the perimeter resembling the scalloped edges of a lace tablecloth. Later on, sporadic volcanism, both explosive and quiet, domed, split, and pockmarked the original relatively smooth surface producing a concentrated variety of stark, fresh volcanic landforms.

Diamond Craters were known to the early settlers of eastern Oregon and were named about 1875 for their proximity to the Diamond Ranch. This ranch took its name from the diamond-shaped cattle brand used by Mace McCoy, an early settler. The name Diamond was also given to a small community and post office nearby. Even though the craters are remote from population centers, access is not difficult. The easiest route is southeast from Burns on Oregon State Highway 78 to the junction at New Princeton, then south and west by well-marked, all-weather roads that skirt the east and south parts of the Diamond Craters. A well maintained dirt road crosses the broad, cratered and domed area from east to west on its southern flank. This road passes between or near many of the most interesting landforms, as shown on the index map in plate 1.

The names given to the numbered features on the index map and referred to in the text are only for the purpose of the report.

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Previous investigations

I. C. Russell (1903), one of the first geologists to make a reconnaissance of eastern Oregon, visited Diamond Craters in 1902. He gives a rather comprehensive description of many of the craters and other features. From his observations he described lapilli cones and lava cones as the principal features of the area. He mistakenly interpreted the low dome on the northeast side, feature No. 5, to be a cone built up of layers of lava flows. If he had been able to view this feature from above or to see aerial photographs of it, he would most certainly have realized that this is a structural dome, bowed up by the pressure of intruding magma. Russell gives an interesting description of the large crater complex (feature No.1) at the center of the Diamond Craters field and also details of the small graben (feature No. 7) which he calls a gulf. He also mentions the peculiar spherical lava balls or bombs found in the low rims of most of the craters of explosive origin but does not postulate as to their origin.

Rocks of the Diamond Craters have been mapped as "late basalt and ejectamenta" of latest Pleistocene to Recent age (Piper and others, 1939). The lack of any appreciable erosion was believed to indicate that some of the volcanic activity may have taken place only a few hundred to a few thousand years ago. Piper and others (1939) refer to the Diamond Craters as "a basaltic lava field whose predominant feature is a lava dome whose crest is broken by a linear pit."

Field work

This study of Diamond Craters is part of a project of the State of Oregon Department of Geology and Mineral Industries to evaluate the recent volcanic landforms of Oregon. The field work was done on the ground on August 6, 7, and 8, 1963. On August 21 the area was viewed and photographed from various elevations in a small airplane. Available aerial photographs from government sources were also used to help determine the sequence of volcanic activity.

Geologic Setting

The Diamond Craters area is at the very southern edge of the broad alluvial plain of the Harney Basin. Just to the south are the dissected uplands of the long westward slope at the northern end of Steens Mountain. From this dissected upland the Donner und Blitzen River, Kiger Creek, and McCoy Creek enter the Harney Basin to meander to Malheur and Harney Lakes, shallow playa lakes that form the sumps for the large undrained basin. Riddle Creek, a little farther to the east, once joined the Donner und Blitzen just west of the Diamond Craters, but its course was dammed by the first flows of the Diamond Craters lava and it now turns northward and empties into shallow Barton Lake. Kiger Creek was also forced to the south and west by the encroaching Diamond Craters lava.

The rocks immediately beneath and surrounding the Diamond Craters are geologically young. Piper and others (1939) have separated them into three mappable units. The oldest rocks are the Danforth Formation of Pliocene age, made up of stratified siltstones, sandstones, and tuffs with at least one prominent layer of welded tuff. This is the most widespread rock unit directly beneath and surrounding the Diamond Craters on the south and west. A younger Pliocene formation, the Harney Formation, contains massive basaltic tuffs and breccia layers, sandstone, and siltstone, with a prominent capping layer of basalt. The Harney Formation is present to the north and east of the Diamond Craters as isolated mesas and other erosional remnants perched on the Danforth Formation. The youngest of the three units is a lava field that Piper and others (1939) have called the "Voltage Lavas." This lava flowed out on an erosional surface and surrounded the isolated remnants of the Harney Formation. Its surface shows some weathering and a thin layer of soil is present. From this evidence it is estimated (Piper and others, 1939) that the lava was probably erupted during Pleistocene time, much earlier than the Diamond Craters lava.

Volcanic History of the Diamond Craters

The original land surface, before the first eruptions of the Diamond Craters lava, was very nearly as it is now. Erosion had removed all but a few patches of the Harney Formation from the basin. Alluviation of the central part had already begun, because drainage to the Malheur River and ultimately to the Snake River to the east had effectively been dammed by the flows of Voltage Lavas. The streams draining the western slopes of Steens Mountain were bringing in more sediment as they meandered across the flat valley floor to Malheur Lake.

The first event in the formation of the Diamond Craters was the eruption of a very fluid olivine basalt from a single, or a few closely spaced, vents along a zone of weakness that trends northwest through the area. The eruptions were probably preceded by earth tremors as a fissure opened at depth and the magma began its upward rise from a small independent reservoir. The lava flowed out from a source the type and location of which cannot now be determined because of obliteration by later volcanic activity. It probably existed in the vicinity of what is now the Central Crater Complex, indicated by the radial pattern of the lava flows. The lava spread out

Figure 1. Aerial view ot the pahoehoe lava surface in the northeast part of the Diamond Craters lava field. As the flood of fluid lava spread farther from its source, a thin, rubbery, undulating crust was formed. The waning supply of lava drained beneath the cooling crust through a system of lava tubes and channelways. The lava roofs, already weakened by shrinkage joints and cracks, collapsed into the voids to form sinks of many sizes and shapes. In this view some of the depressions resemble giant foot tracks 100 to 200 feet long; others are small and nearly circular. These collapse depressions are characteristic of pahoehoe lava fields.

Figure 2. Oval Crater. The west end of a long, oval crater which formed as the vent shifted from east to west over an extended period of sporadic explosivity. The low, rounded rims are made up of lapilli and bombs. The truncated edges of pahoehoe lava flows can be seen in the crater walls. At this west end it is 900 feet from rim to rim; the long oval crater extends for 2,000 feet to the east.

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rapidly as pahoehoe flows to cover roughly a 6-mile-diameter circular area. In the final stages much of the pahoehoe crust foundered into drained lava tubes producing abundant, well developed collapse depressions (figure 1). Thickness of these lava flows is estimated to be 75 to 100 feet in the center of the field, thinning to a foot or so at the margins.

Following this initial relatively quiet eruption of lava, the sequence and time duration of volcanic events becomes slightly more obscured, but from viewing the aerial photographs and examing the features in the field, it is judged that their general sequence is probably thus:

A. A renewed upward surge and lateral intrusion of basaltic magma into the sediments of the Danforth Formation bowed up parts of the newly formed circular lava field into three low, rounded domes, aligned generally northwest-southeast above the fissures through which the magma rose. The most westerly of these is just north of the Twin Craters on the index map. The second and highest elongate dome is now modified by the Central Crater Complex, and the third has been somewhat modified by Oval Crater.

B. Accompanying and closely following this doming, gas from the vesiculating magma plus steam, which was generated as the magma heated water-saturated rocks, furnished energy for explosions of varying violence to form craters of different sizes and types. Many of these craters were subsequently enlarged by engulfment or collapse after the explosive eruptive stage, leaving little or no rims of ejecta. Twin Craters, and Oval Crater (figure 2) are two examples. Others such as Malheur Maar (figure 3) and Cloverleaf Crater (figure 4) have rims of ejecta containing a considerable number of accidental fragments and show evidence of little or no collapse. Red Bomb Crater (figure 5) and Big Bomb Crater, on the other hand, have built shallow cones made up of lapilli, scoria, and a multitude of red and black spherical and ellipsoidal cored bombs (described in more detail on page 29). These craters are more like cinder or scoria cones,

Fig. 1

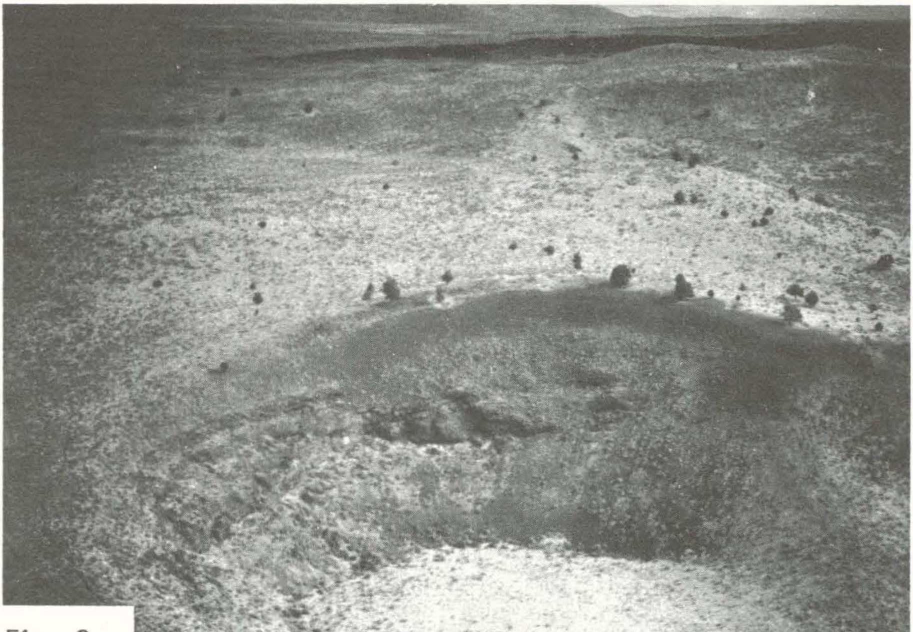

Fig. 2

Figure 3. Malheur Maar. This lake-filled explosion crater and an adjoining one fit the original definition of a maar. The feature is 250 feet in diameter and 100 feet deep. It was probably formed by one or more gas eruptions or steam blasts. Very little or no magmatic material was erupted and only low rims of broken rock fragments are present. On the pahoehoe surfaces in the background are low, rounded to oval bulges called "tumuli." These are believed to form when the partly congealed lava crust is raised by a local build-up of lava immediately beneath it. The tops of many of the tumuli are cracked open, and molten lava from below has squeezed up into some of the cracks.

Figure 4. Cloverleaf Crater. Brief sporadic explosions from separate, closely spaced vents formed this multiple-lobed crater rim that surrounds individual shallow craters. The several small craters occupy an area about 600 feet in diameter.

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since there is a larger addition of magmatic material in their composition.

C. At the close of the above eruptive phase, new activity was concentrated at the Central Crater Complex (figure 6). Additional doming by intrusion of the magma was followed by violent explosive eruptions that perforated the roof and showered broken rock and ash high into the air. To a contemporary observer, a mushrooming cloud of vapors and ash would have been seen billowing to a great height. Pulverized rock and comminuted ash fell back from this cloud to form a thin masking layer about 5 miles in diameter surrounding the erupting vent. This mantle of debris can be seen in the aerial photo (plate 1) as a halo encircling the Central Crater Complex. Eruptions continued less frequently and less violently from vents that shifted within the eruptive center until at least 17 funnel-shaped crater pits, of which not all are represented on the index map, were formed amid the hummocky debris. These inner crater rims, like the rims of the smaller explosive features to the south and east, contain basaltic lapilli, scoria, and similar cored bombs mixed with rock fragments of many sizes and varieties. Fragments and blocks of gray welded tuff characteristic of the Danforth Formation are common to abundant, and a large outcropping of this same tuff is present high in the wall of one of the smaller inner craters. This is strong evidence for the conclusion that considerable doming had taken place prior to the eruptions. After all the explosive activity had ceased, fluid basaltic lava again welled up and formed several small flows which filled in slight depressions at the outer edges of the crater complex.

This volcanic feature is certainly an unusual one, and a detailed study would probably show that many individual volcanic episodes are responsible for its present configuration. The explosive eruptions must have fractured the whole mass, causing subsidence or collapse, which action has also been a factor in producing the shape of this crater complex. The

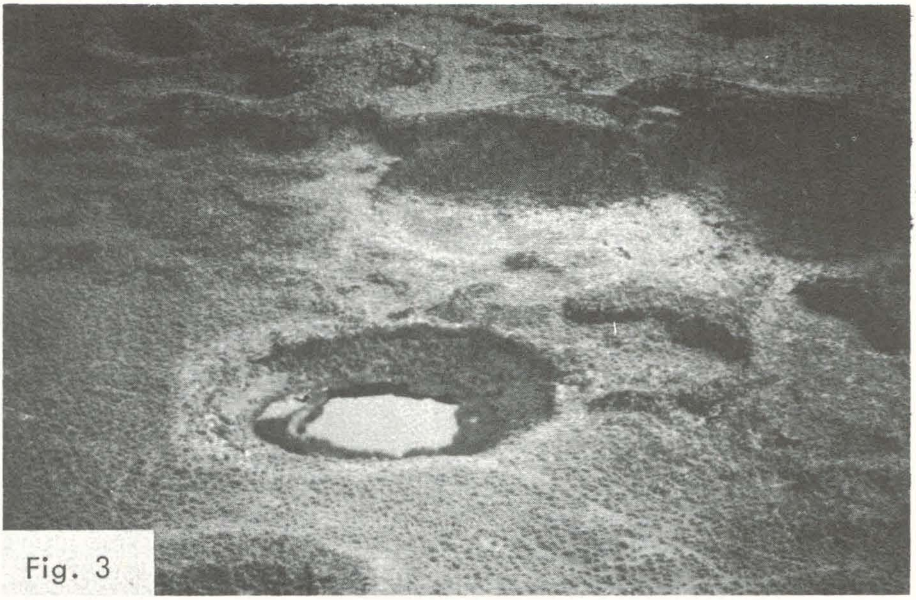

Fig. 3

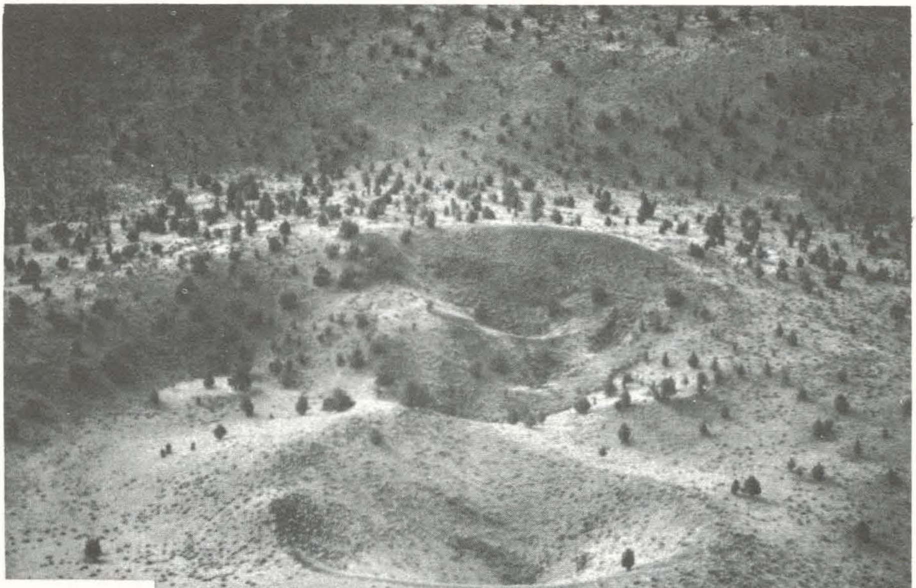

Fig. 4

Figure 5. Red Bomb Crater. A portion of Red Bomb Crater showing a scalloped rim and multiple funnel-shaped crater pits within a larger one that is more than 900 feet in diameter. The latest explosive eruption came from the crater in the lower left. The rims consist of accretionary lapilli and numerous bombs.

Figure 6. A small part of Central Crater Complex. Rather than being round or oval like most craters, it is rectangular with rounded corners. The feature is 1 mile long and 3,500 feet wide. The crater floor is as much as 200 feet below the rims near the outside edges, but the center is choked with piles of debris that are as high as the encircling rims. Within the hummocky debris there are at least 17 individual funnel-shaped craters with steep slopes and narrow bottoms. Part of this debris is accidental and part is magmatic in the form of cinders, scoria, and bombs. Fresh black lava in small amounts has stoped upward to fill depressions near the edges of the crater.

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funnel-shaped bottoms of the inner craters and the loose debris still lying at steep angles on the walls attest to a very recent origin, probably within the last 1,000 years.

D. Another surge of magma, this on the eastern edge of the area, intruded to form another bulge, Graben Dome, now marked by an almost textbook example of a graben (figure 7). The graben appears to have been formed by subsidence when lava broke out at lower elevations and drained away, thereby withdrawing support. The outflow of fluid black lava occurred at many places low on the south and east flanks of the rising dome. Lava rose within some of the older explosion craters and formed small pools of lava in the crater bottoms. Before the lava pools had cooled, drainage occurred within the conduit, leaving round, steep-walled pit craters with floors of jumbled, thin black lava crusts such as Keyhole Crater (figure 8) and Lava Pit Crater (figure 9). Over other vents small spatter cones were built. Fluid lava from half a dozen sources joined to fill depressions and cover another $1\frac{1}{2}$ square miles (stippled area on index map). The exposed surfaces are glassy and show the ropy texture and collapsed crustal features so common on thin pahoehoe flows.

E. Intruding magma next manifested itself to the northeast of Graben Dome and formed Northeast Dome, the western end of which joins Graben Dome. As the brittle lava overlying the Northeast Dome was bowed upward, tension caused fractures to form the pattern that can be so easily seen from the air (figure 10). On the ground these open fissures are as much as 15 feet wide and 50 feet deep. It appears that the magma which raised up this dome did not break out at the surface to form lava flows, but instead, it is probably now cooling at some depth as a laccolithic mass.

The nature of the underlying Danforth Formation has probably made it possible for these domes to form in the Diamond Craters. Magma rising from a fissure could move laterally between the incompetent claystone and

Fig. 5

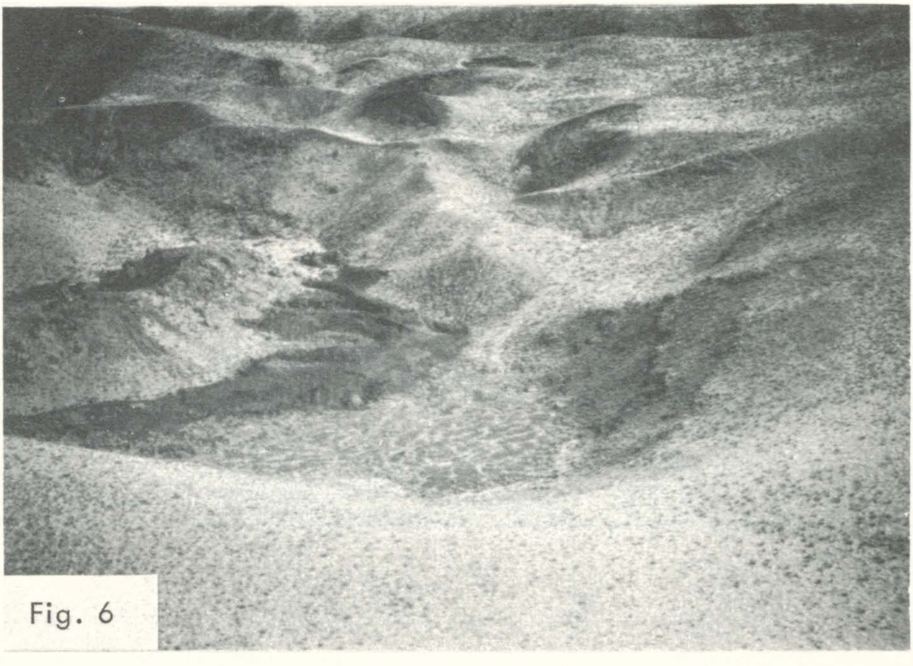
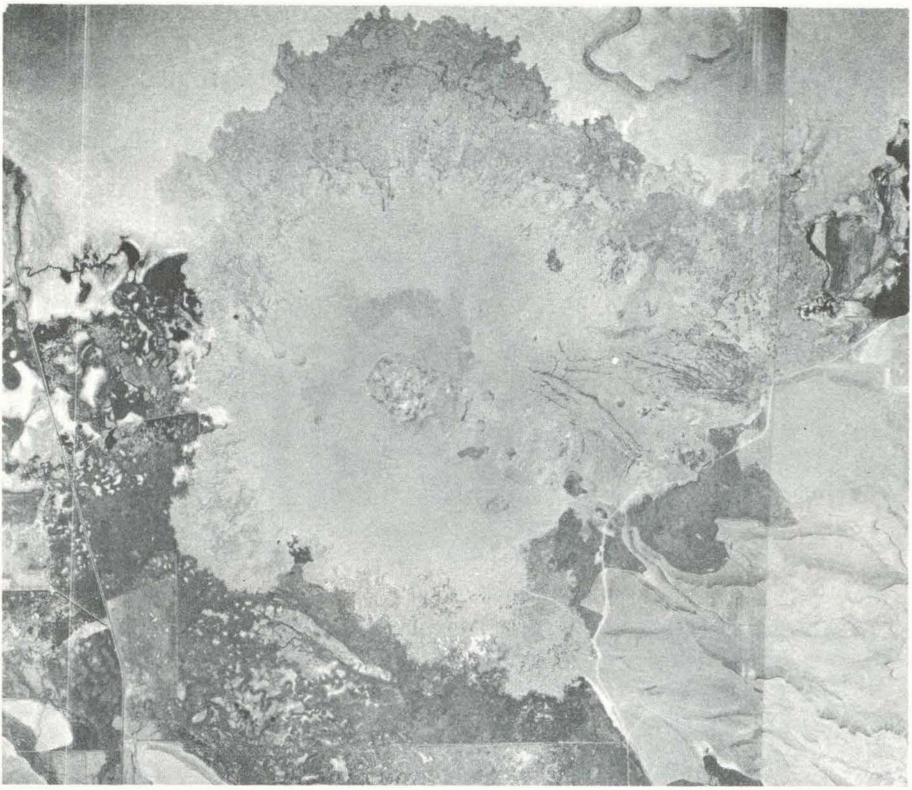


Fig. 6



Feature	Name		
1.	Central Crater Complex	7.	Graben Dome
2.	Twin Craters	8.	Keyhole Crater
3.	Malheur Maar	9.	Lava Pit Crater
4.	Little Red Cone	10.	Red Bomb Crater
5.	Northeast Dome	11.	Big Bomb Crater
6.	Cloverleaf Crater	12.	Oval Crater

tograph of Diamond Craters, Oregon.

Fig. 7

Fig. 8

Figure 7. Looking west along the crest of Graben Dome. Shown is the graben that developed as a collapse feature when the magma which domed up the lava surface broke out at lower elevations to the south and west, withdrawing support. The graben is well developed for 7,000 feet and averages about 1,250 feet in width. Displacement of the down-dropped block is as much as 100 feet. Two accessory grabens cross the main graben at nearly right angles.

Figure 8. Keyhole Crater. The inner, steep-walled pit in stark, black lava is about 400 feet in diameter and 100 feet deep. Fluid basalt welled up to form a lava lake that filled the floor of an existing broad explosion crater. Then the magma column above the vent drained through some subterranean channelway and the thin crust collapsed to form the steep-walled pit. Part of the west wall of hardened basalt was carried back down the vent. Lava benches show that drainage of the lava was intermittent.

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sandstone layers and remain confined at depth except for that portion extruded to the surface by various conduits. The geologic cross-section (plate 1) shows the general relationship of the laccolithic masses believed to underlie the domes.

F. Still later sporadic volcanic eruptions produced features such as Little Red Cone (figure 11), which looks almost as though it were formed yesterday. Volcanism and magmatic intrusion in the Diamond Craters are now presumed to be dormant. No fumarolic activity or hot springs are known to exist.

Cored bombs

The crater rims, floors, and even the debris-covered flat areas near the explosion craters commonly contain unusual spherical to ellipsoidal cored volcanic bombs. They range from the size of a pea to as much as 2 feet in diameter. Most of them are made up of accretionary layers of black or reddish lava surrounding an angular accidental rock fragment. Siltstone, diatomite (?), sandstone, welded tuff, and a variety of other volcanic fragments are all present as cores. These xenoliths have been thermally metamorphosed. In some of the bombs, the lake-bed stiltstone fragments have been burned to a reddish color, the sandstone has been sintered, and welded tuff fragments have been partially to completely melted to a frothy glass. The more basic lava fragments show a lesser degree of alteration.

The origin of these interesting bombs is not completely known, but they probably began as rock fragments which were broken from the walls of the conduit, coated with lava, and carried through the vent into the air by the exploding gases and steam, only to fall or roll back into the vent from which

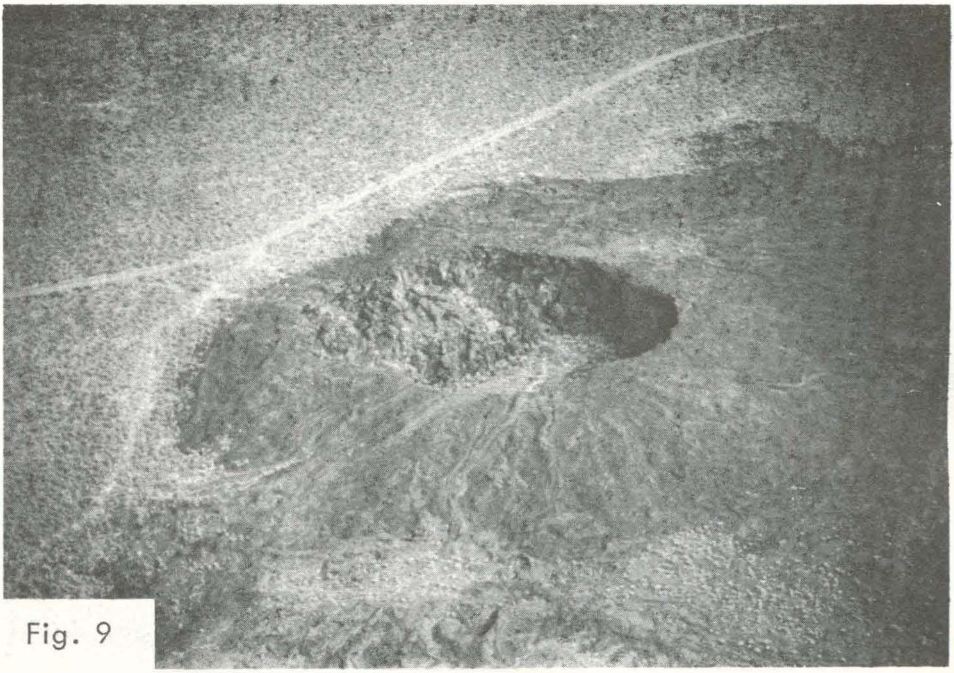

Fig. 9

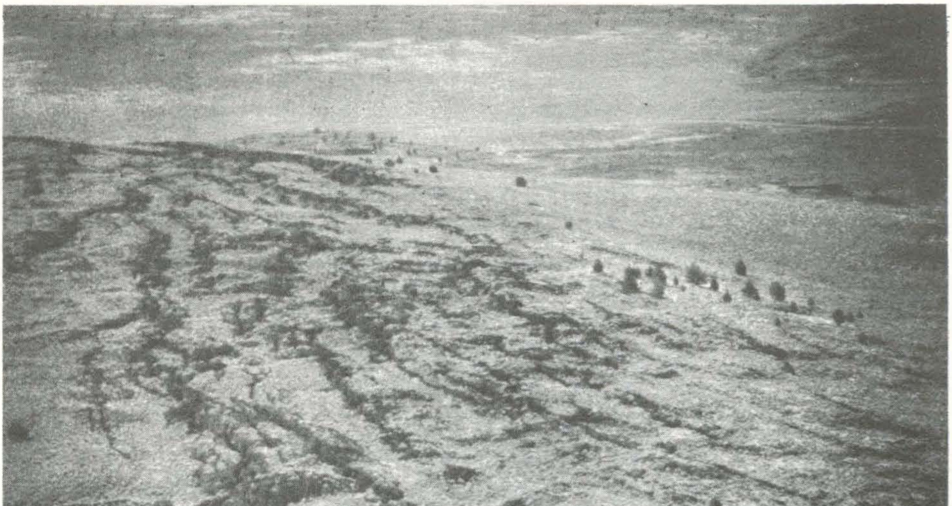

Fig. 10

Figure 9. Lava Pit Crater. This feature is so similar to the small basaltic shield volcanoes with summit pits of Iceland that it could probably be called a miniature shield volcano. Lava welled up slowly on a gently sloping surface. As it overflowed, small lava-tube distributaries carried off the lava in all directions to build up the low, broad dome that is typical of the larger shield volcanoes. Then, just as at Keyhole Crater, drainage of the lava resulted in collapse over the vent to form this steep-walled pit.

Figure 10. Looking eastward along the crest of Northeast Dome, showing the jagged fractures opened by tension as a rising magma domed an area more than a mile long and 3/4 mile wide. Like glacier crevasses, these open cracks are hazards to travel. Some of the largest cracks are 15 feet wide, 40 to 50 feet deep, and extend for long distances. There is no apparent displacement of the basalt walls on either side of the cracks, indicating that little or no subsidence has taken place at the dome crest.

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they came. With further churning in the vent, these fragments received another coating of lava, were thrown out again when a more violent blast occurred, and finally, after repeated activity, came to rest on the rim of the crater. Such a combination of processes is probably responsible for the smooth, rounded shape of most of these unusual bombs.

A further, more detailed study of the composition and texture of the accretionary coatings and cores is being made in order to determine more details about their origin. Figures 12a and 12b show a group of typical, cored bombs from various crater rims in the Diamond Craters area.

Conclusion

Diamond Craters lie in an isolated recent volcanic field at the southern edge of Harney Basin. The nearest recent volcanic areas are the Four Craters Lava Field about 100 miles to the west and the Jordan Craters about 60 miles to the east. Diamond Craters present many unusual features that exist at no other recent volcanic areas in Oregon. Three of these features stand out above the rest for special interest. One is the Central Crater Complex, for which one can neither give a simple explanation of its origin nor provide a simple description of its physical characteristics. A second unique feature is the graben at Graben Dome, which can be examined as though it were a model for classroom study, since almost no detail has been destroyed by weathering and erosion. Lastly, the system of fissures on Northeast Dome, a multitude of gaping cracks, provides an outstanding example of what happens to a brittle sheet of lava when it is rapidly warped upward. These structures, along with the many other recent volcanic forms, provide variety to anyone interested in delving into the processes of volcanism.

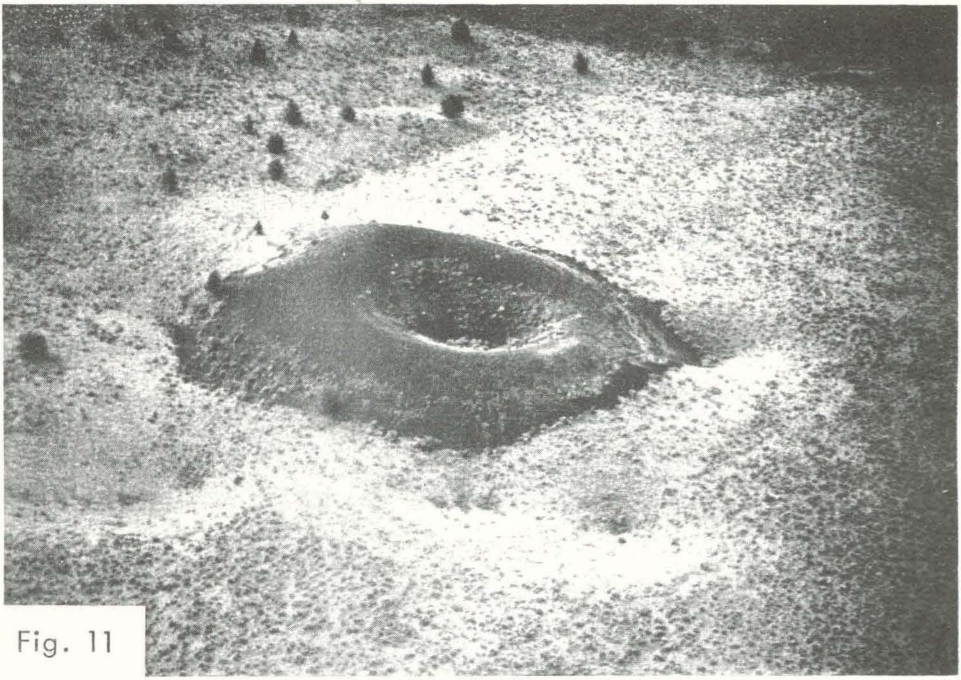

Fig. 11

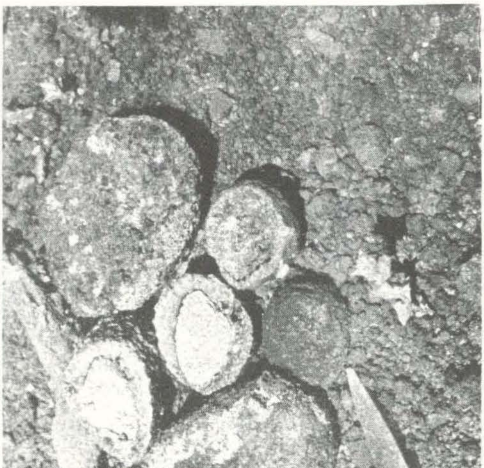

Fig. 12a

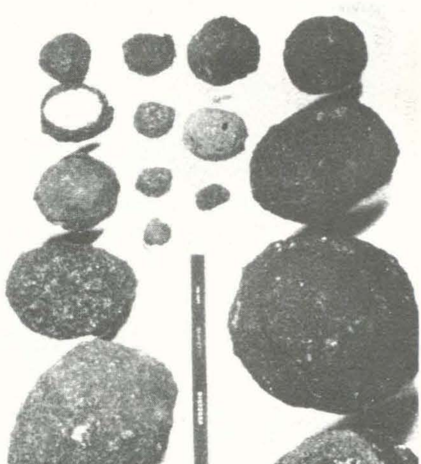

Fig. 12b

Figure 11. Little Red Cone. This small cinder cone, only 250 feet in diameter and less than 75 feet high, has smoothly rounded rims of reddish cinders and scoria. It was born of one of the most recent explosive eruptions at Diamond Craters and is one of the least eroded features in the area. Partly obliterated older craters show that Little Red Cone is built over a vent that has a history of explosive eruption.

Figure 12. Cored bombs. a) A variety of the peculiar and interesting cored bombs from a crater rim within the large Central Crater Complex. Fragments of shale, mud, welded tuff, and basalt are the most common cores that have been encased in concentric layers of black and red lava. b) An assortment of sizes and shapes of cored bombs. These objects can range from the size of a pea to 3 feet in diameter. Most are round or oval, but some are merely lava-coated angular fragments.

Another aspect of the Diamond Craters which deserves further investigation is their possible potential for the development of geothermal energy. Since the most probable cause for the domes is the formation of small laccoliths, these may be at a moderate depth, perhaps no more than a few hundred feet below the surface. The recency of the latest volcanism leads one to believe that considerable heat may still exist in these intrusive bodies and surrounding rock, even though no fumarolic activity or hot springs are known in the area. Geophysical exploration might confirm the presence of these intrusives and determine their approximate depth. If conditions were found to be favorable, the drilling of a test hole could prove the existence of steam or superheated water at depth. Engineering studies on the amounts of steam and/or superheated water which could be produced, its temperature and pressure, corrosiveness, and other properties would then determine the commercial feasibility of generating power.

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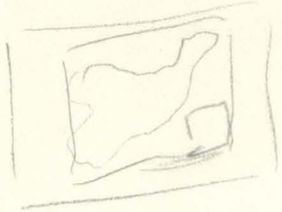
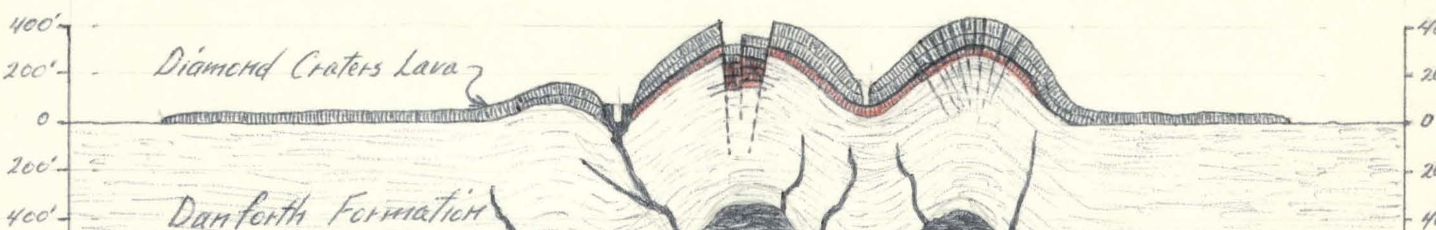
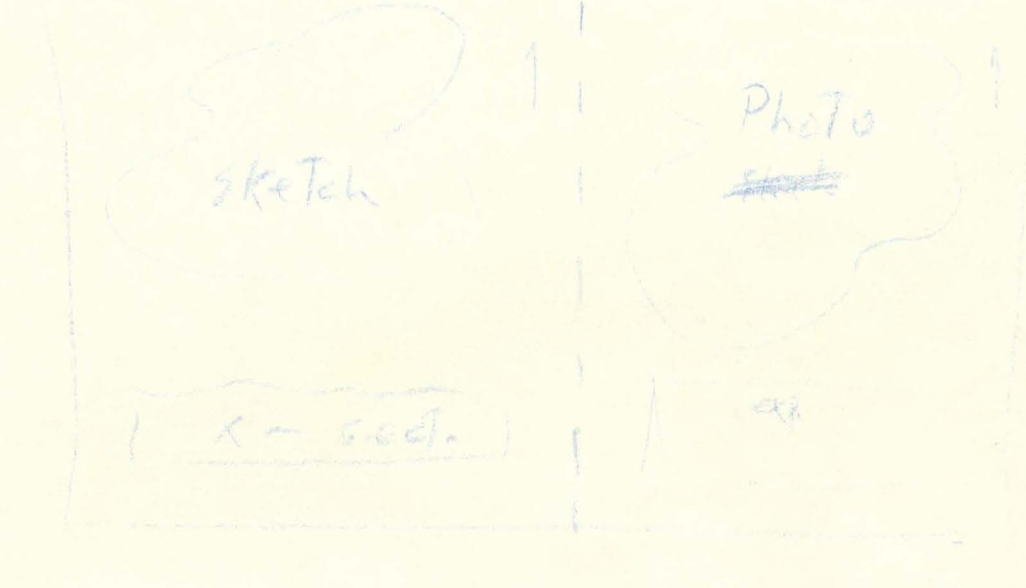


Omit areas in red.

~~Generalized~~ Geologic Cross Section A-A' - Diamond Craters





1 1/3 mile

Volcanic Landforms

1. Complex Crater – Collapse plus explosion – this feature responsible for the blanket of ash + tuff that covers much of the Diamond Crater area.

2+3 Maar type craters flat floored crater – 900 to 1000' in diameter – 150' deep – low rims of ejecta including large blocks of flow basalt.

3a ~~3~~ smaller true maar contains lake and probably resulted from a single phreatic explosion

3b smaller yet but has a low rim of ejecta and is maar type crater

3c. Collapse and/or explosion features – most likely collapse.

3d. Small pit crater

4. Complex explosion feature – partially eroded or destroyed by later explosive activity – most recent activity at west end of the elongate composite crater

5. Partially destroyed twin explosion craters that are modified by later basalt lake filling – then collapse because of draining of lava back down the vent to form pit crater #23 (Keyhole crater) Here we have crater within crater.

~~6 pit crater atop small lava dome is south of road~~

6. Multiple explosion crater with low rims of lapilli bombs and other ejecta. Maar type craters – Cored bombs and accretionary lapilli abundant in the rims

7. Small pit crater at top of dome of freshest lava. – lava welled up and flowed out in all direction – then drained back down the vent and collapse followed. This appears to be the source for 2 separate flows of lava – the first flowed slightly west of south and the latest just east of south. Both post explosive events

8. Graben – length 1 1/3 miles – 1000' width 1100.

smaller grabens at either end – 1500' long 500' wide One of latest event to happen probably associated with later adjustment of magma after doming up and outflow of lava on flanks.

(9) ~~Northeast~~ Elongate Northeast lava dome - 7000' long 3500' wide about 400' high - originally was flat underlain by pahoehoe lava showing typical primary features - ropy surfaces, collapse depression, etc. Then a rising magma raised the surface resulting in the present fracture pattern and dome. Magma still present or ~~not~~ no adjustment to cause collapse like at the graben.

(10) Superimposed explosion craters and pits.

(11) Cloverleaf crater - 3 or 4 overlapping craters to form this odd explosion feature.

(12) 2 smaller explosion features again partially destroyed by later explosive activity.

(13) 13A & 14 Partially obliterated explosion craters in part filled with debris from large complex - 13A cut in half by subsidence ~~of the~~ of the larger feature. 14 split by fractures that extend from complex to graben.

(15) similar to 13 & 14 but in this one lava has welled up to form a small lake feature (16) that has on it surface a small spatter cone probably just above the lava source.

(17) Explosion crater with rims of accretionary lapilli and bombs - abundant accidental fragments mainly lake beds and welded tuff - cored bombs are abundant here. The material has been quarried as cinders for road surfacing.

#18 (18) small rounded cinder cone - shallow crater - shows almost no erosion and must be one of the most recent formed explosive features of the diamond craters.

(19) collapsed source areas of the ~~most~~ latest lava flows, contain spatter features.

(20) small spatter feature in latest lava.

(21) area where sporadic explosive activity occurred and vents shifted, also shows collapse near sources of ~~[illegible]~~ latest flow lava, spatter and scoria ~~features~~ common

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Conclusion: Ed's

Diamond Craters lies as an isolated Recent volcanic field in the lower part of the Harney Basin. The nearest Recent volcanics, the Four Craters Lava Field, is about 65 miles due west on the southeastern edge of the tremendous area of Recent lavas of Central Oregon. Another isolated but larger field of Recent lavas, the Jordan Craters, is about the same distance to the east. Diamond Craters is also alone in the respect that it presents many unusual features that exist at no other Recent volcanic areas or land forms in Oregon.

Three of the features stand out above the rest for special interest. One of course, is the central crater complex for its odd form and unique origin. Another is the graben which offers a classic setting for its study. Last is the tension caused fissure system with its multitude of open fractures.

Another aspect of the Diamond Craters which demands further study is its possible potential for the development of geothermal energy. Since the most probable cause for the domes is the formation of small laccoliths, which may be at a moderate depth, perhaps 1000 to 2000 feet below the surface. The recency of the last volcanism leads one to believe that considerable heat may still exist in these intrusive bodies. An aeromagnetic or gravity survey might confirm the presence of these intrusive bodies, and show their approximate depth. Then if conditions are found to be favorable, the drilling of a test hole should follow. While no fumarolic activity or hot springs are known in the Diamond Craters area this does not preclude the existence of heat at depth.

Preliminary Geology of the Diamond Craters, Oregon

Introduction

Diamond Craters, is a name given to an isolated area of recent volcanic activity near the center of vast Harney County in southeastern Oregon. The whole of it is not easily described but it probably most correctly fits the definition of a miniature shield volcano. From ~~25,000 feet above~~ high altitude, the Diamond Craters appears roughly circular. The 25 square mile area is shaped much like an inverted saucer and made up of thin pahoehoe lava flows that welled up and flowed out in all directions from a now hidden vent near the center. The perimeter resembles the scalloped edges of a lace tablecloth, the design created by slight irregularities in the topography over which the overlapping tongues of lava flowed. Later sporadic volcanism, both explosive and quiet, has pockmarked, split, and domed up the original relatively smooth surface of the broad ~~pancake~~ shield like dome. The result is a concentration of and variety of stark, fresh volcanic landforms.

Their isolation and small aereal size are probably reasons that the Diamond Craters are less well known than other areas where similar volcanic landforms are found (Craters of the Moon). They were known to the early settlers of eastern Oregon and they were named about 1875 for their proximity to the Diamond Ranch. This ranch took its name from the Diamond shaped cattle brand used by Mace McCoy, an early settler. The name Diamond was also given to a small community and postoffice near the ranch. Even though the craters are remote from population centers, access is not difficult. The area is within T. 28 S., and T. 29 S., R. 32 E., slightly to the east of the center of Harney, County, about 60 miles south of Burns, the County seat. The easiest access is southeast from

Burns on Oregon State Highway ~~58~~ 78 to ~~Princeton~~ the Jct. at New Princeton, then south and west by well marked all weather roads that skirt the east and south parts of the Diamond Craters. A well maintained dirt road crossed the broad cratered dome from east to west on its souther flank. This road passes between or near many of the interesting craters.

Previous Investigations:

I. C. Russell, one of the first geologists to study the geology of Eastern Oregon visited the Diamond Craters in 1902. In USGS Bulletin 217, Geology of SW Idaho and SE Oregon, 1903, he gives a rather comprehensive description of many of the craters and other features. From his observations he described lapilli cones and lava cones as the principle features of the area. He mistakenly observed the low dome on the northeast side to be a lava cone built up of layers of lava flows. If he had been able to view this feature from above or to see aerial photographs of it, he would most certainly have realized that this is a structural dome, bowed up by a rising magma. Russell gives an interesting description of the large complex explosion crater at the center of the Diamond Craters and also gives details of the small graben which he called a gulf. He also mentioned the peculiar spherical lava balls or bombs found in the low rims of most of the craterss of explosive origin, but does not postulate as to their origin.

~~C. F. Park, Jr.~~ Piper et al., in USGS WSP 841, Geology and ground-water resources of the Harney Basin, Oregon, 1939, mapped the rocks of the Diamond Craters as "late basalt and ejectementa", and estimates their age as latest Pleistocene to Recent. He states that the lack of any appreciable erosion indicates that some of the volcanic activity may have taken place only a few hundred or thousand years ago.

Park refers to the Diamond Craters as a basaltic lava field whose predominant feature is a lava dome whose crest is broken by a linear pit.

Field Work:

This study of the Diamond Craters is part of a project of the State of Oregon Department of Geology and Mineral Industries to evaluate the recent volcanic landforms of Oregon. The field work was done in 3 days, Aug. 6, 7, and 8, 1963, and 2 hours on August 21 when the area was viewed from various elevations ina small airplane. Aerial photographs, both high altitude (from 29,000 feet) and medium altitude(from 10,000 feet) were used to determine the sequence of volcanic activity.

Geologic Setting:

The Diamond Craters area is at the very southern edge of the broad alluvial plain of the Harney Basin. Just to the south are the dissected uplands of the long westward slope at the northern end of the Steens Mountains. From this dissected upland the Donner und BlitzenRiver, Kiger Creek, and MCCoy Creek enter the Harney Basin to meander to Malheur and Harney Lakes, shallow playa lakes that form the sumps for the large undrained basin. Riddle Creek a little farther to the east once joined the Donner und Blitzen just west of the Diamond Craters but its course was dammed by the first flows of the Diamond Craters lava and it now turns northward and empties into shallow Barton Lake. Kiger Creek was also forced to the south and west by the encroaching Diamond Craters lava.

The rocks immediately beneath and surrounding the Diamond Craters are geologically young and Park on his geologic map in WSP 841, has separated them into 3 mappable units. The oldest rocks are of Pliocene age and Park has formally named and described 2 formations from them. The Danforth formation made up of stratified siltstones, sandstones, and tuffs, with at least one prominent layer of welded tuff is the most widespread rock type directly beneath and surrounding the Diamond Craters on the south and west. The younger Pliocene formation, the Harney formation contains massive basaltic tuffs and breccia layers, sandstone, and siltstone, with a prominent capping layer of basalt. The Harney formation is present to the norht and east of the Diamond Craters as isolated mesas and other erosional remnants perched on the Danforth formation. The northern edge of the Diamond Craters lava covers a portion of a much larger and slightly older lava field that Park has called the "Voltage lavas". This lava flowed out on the erosional surface mentioned above and surrounds the isolated remnants of the Harney formation. Its surface shows some weathering and a thin layer of soil is present. From this evidence Park estimates that this lava was probably erupted during Pleistocene time, much earlier than the Diamond Craters Lava.

Volcanic History:

The original land surface, before the first eruptions of the Diamond Craters lava, was very nearly as it is now. Erosion had removed all but a few patches of the Harney formation from the basin and alluviation of the central part had already begun as its outlet to the Malheur River and ultimately to the Snake River to the east had effectively been dammed by the Voltage lava flows. The streams draining the western slopes of the Steens Mountains were bringing in more sediment as the meandered across the flat valley floor to Malheur Lakes.

The first event in the formation of the Diamond Craters was the eruption of a very fluid olivine basalt from a single or a few closely spaced vents from a zone of weakness that trends Northwest through the area. The eruptions were probably preceded by earth tremors as a fissure opened at depth and the magma began its upward rise from a small independent magma reservoir. The first lava reached the surface amid mild explosions and fire fountains. (The lava was fluid and welled upward over the flat valley floor to form a molten lava lake that overflowed in all directions until an area of 25 square miles was covered with thin pahoehoe lava flows.) fig.). ~~Slight doming probably accompanied these first eruptions so the center was raised a few hundred feet higher than the edges.~~ The eruptions ceased as abruptly as they began and much of the molten lava lake above the central conduit drained away through subtereanean cracks and passageways. Immediate collapse of the roof and walls plugged the vent and left a smoking steep-walled oval pit at the summit of the broad low lava dome.

Following this initial relatively quiet eruption of lava, the sequence and time duration of volcanic events becomes slightly more obscured, but from viewing the aerial photographs and examining the features in the field, they happened generall like this:

1. A renewed upward surge and lateral movement of basaltic magma bowed up parts of the newly formed circular lava field into 3 low rounded domes, aligned generally NW/SE above the fissures through which the magma rose. The most westerly of these is just north of the Twin Craters, #2 on the index map. The second and highest elongate dome is now modified by central crater complex, #1, and the third has been somewhat modified by #12 Oval Crater.

2. Accompanying and closely following this doming, vesiculation of the rising magma plus steam, generated as the molten lava contacted water saturated rocks, furnished energy for explosions of varying violence to form explosion craters of many sizes and types. Of the more than 20 explosion craters that are roughly aligned adjacent to the NW/SE eruptive zone there is a general pattern. On the western part the craters are typical maar type craters, circular steep-walled, with low rims built mainly of accidental rock fragments and ash. Very little new magma was

erupted from these vents and steam explosions were the principal events. In the eastern part the most common craters are broad and shallow with low rounded rims made up of lapilli, scoria, and the unusual spherical black and red cored bombs. This type crater is ~~usually referred to as a~~ not easily defined cinder or scoria cone. Figures ** ______, show variations in this type crater.

3. At the close of the above explosive phase there was concentrated activity at the Central Crater Complex (fig. feature #1). Additional doming preceded violent explosive eruptions that cleared the vent and showered broken rock and ash high into the air. As a mushrooming black cloud billowed higher and higher the pulverized rock and comminuted ash fell back to form a thin masking layer over 5 miles in diameter. Much of the coarser debris fell back into the ever widening pit, only to be thrown up again and again. Eruptions continued less frequently and less violently from a vent or vents that shifted within the large rectangular shaped crater, until ~~15 to 20~~ at least 17 funnel shaped crater pits are now present amid the hummocky debris. Just as in the rims of the smaller explosion features to the south and east, these inner crater rims contain basaltic lapilli, scoria, and the same rounded accretionary bombs mixed with rock fragments of many sizes and varieties. Fragments and blocks of gray welded tuff are common to abundant and a large outcropping of this same tuff is present high in the wall of one of the smaller inner craters. This certainly shows that considerable doming has taken place and also indicates the thinness of the flows at the crest of the dome. After all the explosive activity had ceased , fluid lava again welled up,and as though it barely reached the level of a porous floor oozed out to fill in slight depressions at the outer edges.

This volcanic feature is certainly an interesting one and a detailed study would probably show that many individual volcanic episodes are responsible for its present configuration. The sharpness of the funnel shaped crater bottoms, with loose debris lying at steep angles attest to a very recent origin, probably within the last 1000 years.

4. Another surge of magma, this time on the eastern edge of the area, welled up to form a local bulge now marked by the almost textbook example of a graben, #7on the index map. This graben formed by collapse as lava broke out at lower elevations and drained away to leaving a void. The breakout of fluid black lava occurred at many places low on the south and east flanks of the rising dome. Lava rose within explosion craters and small pools of lava filled the crater bottoms. Before the entire pool had cooled drainage occurred within the conduit leaving round steep walled pit craters with floors of jumbled thin black lava crusts. Over other vents small spatter cones were formed and flows from half a dozen sources joined to fill depressions and cover another 1½ square miles (stippled area on index map). This lava was fluid and the upper surfaces are glassy and show the ropy texture, and collapse pits so common on pahoehoe flows.

5. A shift of magma to the northeast shows the forces present as a magma rises. As the brittle lava flows atop the Northeast Dome, #5 were bowed upward, tensions caused fractures form the pattern that is so easily seen from above. On the ground these fractures are open as much as 15 feet wide and 30 feet deep. It appears that the magma that rose up to form this dome did not break out to form lava flows and is probably now cooling as a laccolithic mas. The nature of the underlying Danforth formation has probably made it possible for domes such as this to form in the Diamond Craters. Magma rising from a fissure can move laterally between the incompetent claystone and sandstone layers

but was confined beneath the relatively unbroken layer of welded tuff.

6. There may have been later brief sporadic events to form features like Little Red Crater (#4) that appears almost as fresh as the day it was formed; These were minor and the forces that started the magma to the surface were spent and are at rest.

Cored Bombs:

The sperical bombs mentioned briefly are unusual enough to be described more fully. ~~Thexcraterx~~

The crater rims, floors, and even the debris covered flat areas near the explosion craters commonly contain spherical to oval, cored volcanic bombs. They range from those the size of a pea to large ones as much as 2 feet in diameter. Most of them are made up of accretionary layers of black or reddish lava surrounding an angular accidental rock fragment. Siltstone, diatomite(?), sandstone, welded tuff and a variety of other volcanic fragments are all present as cores. These xenoliths in some of the bombs have been thermally metamorphosed. The lake bed siltstone fragments have been burned to a reddish color, the sandstone has been sintered, and welded tuff fragments have been partially to completely melted to a frothy glass. The more basic lava fragments show a lesser degree of alteration.

The origin of these interesting bombs is not completely known but they probably formed as fragments broken from the walls of the conduit were coated with lava and carried up in the vent to be thrown into the air by the exploding gases and steam, only to fall back or roll back into the vent from which they came. Additional coatings of lava built up, a further churning in the vent, thrown out again and again only to roll back in, then lodging on the rim as a slightly more violent blast came along. A combination of these processes is probably responsible for the smooth rounded shape of most of these unusual bombs.

A further more detailed study of the composition and texture of the accretionary coatings and cores is being made in order to determine more details about their origin. Fig. _____ shows a group of typical cored bombs from various crater rims in the Diamond Craters area.

Conclusion:

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RECENT VOLCANIC HISTORY OF THE DIAMOND CRATERS AREA

By Norman V. Peterson* and Edward A. Groh**

The condition of the oldest lava surfaces in the Diamond Craters area indicates that volcanism began in Recent time with the latest extrusions occurring perhaps only a few hundred years ago. The original land surface, before the first eruptions, was very nearly as now presented, a flat alluvial valley floor. At that time, Riddle Creek drained to the Donner und Blitzen River which is just to the west of the Diamond Craters. With the formation of the Diamond Craters, Riddle Creek was dammed and now flows into Barton Lake. The course of Kiger Creek appears also to have been affected and it now flows in a channel somewhat to the south of the original before entering the Donner und Blitzen River.

Underlying the major part of the Diamond Craters are rocks of the Pliocene Danforth Formation. These consist of an upper prominent welded tuff member, stratified siltstones, sandstones, breccias, and tuffs. Accidental fragments of the welded tuff are found throughout the pyroclastics of the Diamond Craters. The thickness of the Danforth Formation in this area is

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unknown but may be as much as 800 feet or more. Little deformation of these rocks has taken place, and where shallow dips exist the cause is more probably due to tilting of fault blocks than warping. Lying unconformably below the Danforth Formation is a thick sequence of basalt flows called the Steens Basalts. A mesa to the northeast of the Diamond Craters and some tableland to the southeast are made up of a capping basalt flow and breccias and sediments of the late Pliocene Harney Formation which overlies the Danforth rocks. At most, a few thin remnants of the Harney Formation may be present on the Danforth beneath the Recent volcanic flows of the Diamond Craters. However, it appears that the Harney rocks had been completely removed by stream planation before volcanism started, although a thin veneer of alluvium probably existed.

The northernmost part of the Diamond Craters lava field laps older basalt flows which cover a large area to the north. These flows have been weathered to a degree and soil, probably eolian in origin, is present. It represents a very large field of lava similar in several respects to the Diamond Craters but extruded sometime in the late Pleistocene. It has been named the Voltage lava field by Piper and others (1939).

With the advent of Recent volcanism, a very fluid olivine basalt lava flowed from probably several vents, located in the neighborhood of the central crater complex (Feature 1, as shown on sketch map, Fig. ___). Numerous flows occurred throughout the field building a total thickness of an estimated 50 to 100 feet in the central part of the lava field. An area of about 25 square miles was covered by the time the extrusions ceased. Well developed typical pahoehoe crusts formed on these flows as is characteristic of hot fluid lavas little charged with gases. Also great numbers of collapse features are present throughout the field which were caused by lava draining from beneath and thereby removing support of the cooled crust, another characteristic of this type of lava.

The sequence of volcanic events becomes somewhat hidden from this point onward. A mantle of pyroclastics thrown out from the central crater complex (Feature 1) tends to obscure the relationship of various features. Doming by laccolithic intrusion at moderate depth is believed to be the next phase in order of occurrence. Intrusion probably took place at the contact between the incompetent Danforth rocks and the resistant underlying Steens Basalts. The domes first to form appear to be three aligned along a northwest trend.

This trend is related to the dominant fault trend in this region of block faulting. One dome lies just north of Features 2 and 3. The second now comprises the central crater complex (Feature 1), and the third has been cratered somewhat by Feature 4. The dome whose crest contains the graben (Feature 8) and the dome having the fissure system (Feature 9) are apparently younger, at least doming seems to have progressed to a later time. The axis of the dome having the graben also trends northwesterly, but the axis of the fissured dome is nearly east-west.

Craters, such as Features 2, 3, 4, 5, 13, 14, 15, and 16, were formed after doming and exhibit the properties of both collapse or subsidence and explosion. Evidently, foundering of the dome roof at weak points is the major cause of these features. Rims of ejecta are lacking in many cases, although Features 2 and 5 show development of rims containing material explosively erupted, some being very large blocks of accessory or accidental ejecta. Many may have developed as large pit craters whose lava pools did not overflow, and subsequent withdrawal of the lava leaves these features exhibiting only the properties of collapse or subsidence. Several of these craters do have flat floors which are probably lava filled rather than due to slump and wash. Features 6, 17, 11, 12, and the pair 24 exhibit explosive eruptions as being the cause of their formation. In these craters, lapilli, accidental fragments, and a profusion of cored bombs make up the rims. These maar-type craters show that great violence did not occur in the eruptions producing them. Most of the ejected material fell back into the craters and was erupted over and over many times in relatively mild convulsions. This action provides an explanation for the generation of the rather unique cored bombs which are described later in this article. Steam formed in porous water-bearing sedimentary strata of the underlying Danforth Formation and/or water circulating in faults may have been a principal factor in the eruptions of these maar-type cones.

Next in the sequence of volcanism is the development of the central crater complex. Here, as previously mentioned, a dome was formed. An accumulation of gases in the underlying laccolithic intrusion, aided in probably a great degree by steam generated in porous water-bearing rocks and faults, perforated the roof of the dome and formed a group of craters. These phreatomagmatic eruptions were the most violent of any occurring in the Diamond Craters volcanic area. Pyroclastics were ejected and covered the previous flows and craters for a radius of about 2 miles encircling the central crater complex. A large exposure of the Danforth welded tuff member in place on the rim of one of the northern craters provides the strongest evidence that a dome existed prior to the eruptions since the position of the welded tuff is not satisfactorily explained in any other way. A multitude of cored bombs are found in and about the craters, and many of the cores consist of rock fragments characteristic of the Danforth Formation. Subsidence of the whole crater complex has proceeded to form a graben. When subsidence occurred is not clear, but that it may have been contemporaneous with the period of eruption seems most probable. The final volcanic event in this crater complex was the extrusion of several small basalt flows about the perimeter of the graben walls, although small flows also occur in the bottoms of two craters. Two generations of these lavas are indicated, some presenting much fresher surfaces which are typical pahoehoe. Evidence is strong that the volcanism of this feature happened within the last 1000 years or less, since the crater walls are step, much of the material is lying at the angle of repose, and the crater bottoms are sharp. Observation of the craters also shows that they were apparently erupting simultaneously and activity ceased in a similar manner. None of the craters appear to have received ejecta from a neighboring crater, which would be indicated by at least a partial filling of some of the craters.

At the time eruption of the central crater complex was taking place, it is thought that the graben (Feature 8) started to form. After eruptions stopped in the crater complex, the latest flows of basalt were extruded. These flows (stippled areas on sketch map, Fig. ___) cover an area of about $1\frac{1}{2}$ square miles on the southeastern edge of the Diamond Craters lava field. They were extruded from several pit craters and spatter cones (Features 7, 19, and 20), and this action proceeded as the graben continued to sink. These lavas were very fluid and developed well defined pahoehoe surfaces. Miniature lava tubes and ropy surfaces show how the lava flowed as the molten pools spilled over the edges of the pit craters. Several other small flows of lava (Features 10, 16, 21, 22, and 23) are present at various isolated locations but are believed to be roughly contemporaneous with the larger field of youngest lavas. A small cone (Feature 18), more a maar-type crater rather than a cinder cone, is also apparently contemporaneous by its young appearance. The small spatter cone (Feature 10) has such fresh surfaces that it may only be a few hundred years old at most and could represent the last sputter of volcanic activity in the Diamond Craters.

The system of open fissures present on the easternmost dome (Feature 9) provides further confirmation that doming by forces from below has taken place, such as the intrusion of a small laccolith into the underlying incompetent sediments of the Danforth Formation. Considering the estimated age of the most recent volcanism in this area, intrusion at depth and doming may have just finished progressing on this particular dome.

CONCLUSION

Diamond Craters lies as an isolated Recent volcanic field in the lower part of the Harney Basin. The nearest Recent volcanics, the Four Craters Lava Field, is about 65 miles due west on the southeastern edge of the tremendous area of Recent lavas of central Oregon. Another isolated but larger field of Recent lavas, the Jordan Craters, is about the same distance to the east. Diamond Craters is also alone in the respect that it presents many unusual features that exist at no other Recent volcanic areas or land forms in Oregon.

Three of these features stand out above the rest for special interest. One, of course, is the central crater complex for its odd form and unique origin. Another is the graben which offers a classic setting for its study. Last is the fissure system with its multitude of gaping cracks caused by tension produced in the doming process.

Another aspect of the Diamond Craters which demands further study is its potential for the development of geothermal energy. Since the most probable cause for the domes is the formation of small laccoliths, these may be at a moderate depth, perhaps no more than 1000 feet below the surface. The fact that some of the last volcanism has been quite recent leads one to believe that considerable heat may still exist in these intrusive bodies. An aero-magnetic or gravity survey would be the first step in such an exploration to help confirm the presence of these intrusives and their approximate depth. Then if conditions are found to be favorable, the drilling of a test hole to a depth of perhaps 300 or 400 feet could be made. Temperature measurements along this drill hole would show if, and how much of, an abnormal geothermal gradient is present. Again, if conditions are satisfactory, the next stage would be the drilling of a development well as deep as temperatures would permit. Engineering studies on the amounts of steam and/or superheated water which could be produced, its temperature and pressure, corrosiveness, and other properties would determine the commercial feasibility of generating power.

While no fumarolic activity or hot springs are known in the Diamond Craters area, this does not preclude the existence of heat at shallow depth.

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Numerous flows occurred throughout the field building a total thickness of an estimated 50 to 100 feet in the central part of the lava field. An area of about 27 square miles was covered by the time the extrusions ceased. Well developed typical pahoehoe crusts formed on these flows as is characteristic of hot fluid lavas little charged with gases. Also great numbers of collapse features caused by lava draining from beneath and thereby removing support of the cooled crust, are produced in this type of lava.

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Craters, such as Features 2, 3, 4, 5, 13, 14, 15, and 16, were formed after doming and exhibit the properties of both collapse or subsidence and explosion. Evidently foundering of the dome roof at weak points is the major cause of these features. Rims of ejecta are lacking in many cases, although Features 2 and 5 show development of rims containing material explosively erupted, some being very large blocks of accessory or accidental ejecta. Several of these craters have flat floors which are probably lava filled rather than due to slump and wash. Features 6, 17, 11, 12 and its satellite 18, exhibit explosive eruptions as the cause of their formation. In these craters, lapilli, accidental fragments, and a profusion of cored bombs make up the rims. These maar-type craters do not show that any great violence occurred in the eruptions producing them. Most of the ejected material fell back into the craters and was erupted over and over many times in relatively mild convulsions. This action provides an explanation for the generation of the rather unique cored bombs which are described later in this article. Steam formed in porous water bearing sedimentary strata of the underlying Danforth Formation and/or water circulating in faults may have been a principal factor in the eruptions of these maar-type cones.

Next in the sequence of volcanism is the development of the central crater complex. Here, as previously mentioned a dome was formed. An accumulation of gases in the laccolithic intrusion aided in a great degree by steam generated in porous rocks and faults perforated the roof of the dome and formed a group of craters. These phreatomagmatic eruptions were the most violent of any occurring in the Diamond Craters volcanic area. Pyroclastics were ejected and cover the previous flows and craters for a radius of about 2 miles encircling the central crater complex. A large exposure of the Danforth weld tuff member in place on the rim of one of the northern craters provides the strongest evidence that a dome existed prior to the eruptions. A multitude of cored bombs exist in the craters and many of the cores are rock fragments ~~characteristic to the~~ Danforth Formation. ~~Subsidence of the whole crater complex has proceeded to form a graben.~~ When subsidence occurred is not clear, but that it may have been contemporaneous with the period of eruption seems most probable. The final volcanic event in this crater complex was the extrusion of several small basalt flows about the perimeter of the graben walls, although one does occur in the bottom of a crater. The lava surfaces are characteristic pahoehoe. It is strongly indicated that the volcanism of this feature happened within the last 1000 years or less, since the crater walls are steep, much of the material lies at the angle of repose, and the crater bottoms are sharp.

At the time eruption of the central crater complex was taking place, it is thought that the graben, Feature 8, started to form. After eruptions stopped in the crater complex, the latest flows of basalt were extruded. These flows (stippled areas on the sketch map, Fig. ( ) cover an area of about one and a half square miles on the southeastern edge of the

Diamond Craters lava field. They were extruded from several pit craters, Features 7, 19, and 20, and this action proceeded as the graben Feature 8, continued to sink. These lavas were very fluid and developed well defined pahoehoe surfaces. Miniature lava tubes and ropy surfaces show how the lava flowed as the lava pools spilled over the edges of the pit craters. Several other small flows of lava, Features 10, 16, 21, 22, and 23, are present at various isolated locations, but are believed to be contemporaneous with the larger field of youngest lavas. The small spatter cone, Feature 10, has such fresh surfaces that it may only be a few hundred years old at most and represent the last sputter of volcanic activity in the Diamond Craters.

The system of open fissures present on the easternmost dome, Feature 9, provides strong evidence that doming by forces from below has taken place, such as the intrusion of a small laccolith into the underlying incompetent sediments of the Danforth Formation. Considering the estimated age of the most recent volcanism in this area, intrusion at depth and doming may still be progressing on this particular dome.

Field Notes -- 1963 Summer Season

Tuesday- August 6: ax 7:30 am from Burns enroute to Diamond Craters, 1:00 hour travel time -- made a brief stop just before the fresh lava area to check the Danforth welded tuff that outcrops along the road and caps the low hills to the southeast of Diamond Craters lava field --

Our first entry into the fresh lava is on the northeast edge where thin tongues of pahoehoe lava fill the low are on the northeast-- (this is probably part of the original drainage of Riddle Creek) just as the road enters the lava area there are 5 or 6 small cinder or lapilli cones amid the flows.

The prominent dome on the northeast edge is very interesting, shows steep rounded smooth surfaces of pahoehoe lava with typical collapse features -- also there are individual sinuous narrow flows that meander on the later domed surface. The small flows come out under the surface in excellent exposures.

On to the south on top of broad dome -- all or most of the primary flow features on pahoe hoe surface are exposed - the most prominent features are the large round collapse pits and the linear cracks that trend north 70 degrees west and parallel the long dimension of the dome - pictures 6 and 7 of these features. The cracks are spectacular up to 10 feet wide and 50 feet deep.

One very prominent circular depression was looked at and is about 100' in diameter and 40 feet deep - the bottom filled with bk blocks of flow lava - can only assume this is a collapse feature. The walls expose thin to thick flows with one thick flow that is a light gray olivine (diktytaxitic basalt and weathers rather easily and differentially. Why so round and deep? On a fairly steep rounded slope of the broad dome!

On to the south crossing the fractures that trend N 70 degrees West, noting that some parallel flows and some cut across narrow tongues of lava. the aerial photos show this pattern very well. Note that some of the fractures at the SW tend to be arcuate.

On to the south and east toward the cloverleaf shaped depression. This one is explosive and an occassional fragment of welded tuff can be found in the low rounded rims of this one.

Before checking the Cloverleaf there is an interesting small spatter cone that is the source of quite a volume of liquid lava that extends out from it to the east in narrow sinuous bulbous snouted flows. Truly pahoehoe lava flows.

On the way back to the car checked the row of spatter cones that trend N 25 E -- these are low and broad from weak aporadic firefountain activity.

Mac Arthur, ~~1944~~ 1944, Oregon Geographic Names page 165

Diamond, Harney County

Diamond post office and Diamond Craters both get their names from the Diamond Ranch, which was established in pioneer days by Mace McCoy. This ranch used a diamond shaped brand. Mrs. Dolly Kiger applied the name of the ranch to the community about 1874, according to information given the writer by C. H. Smyth, postmaster at Diamond in 1925. Diamond Craters are about six miles northwest of Diamond post office. There are about 20 of them occupying an area of some five square miles, surrounded by about 30 square miles of rough lava. They are well described in USGS Bulletin 217. In 1927 Mrs. Minerva J Kiger, of Corvallis, wrote the compiler that she was the Dolly Kiger referred to above. She confirmed the history of the name Diamond as given herein.

Israel C. Russell, 1903, Geology of SW Idaho and SE Oregon, USGS Bulletin 217.

p. 54 Diamond Craters

A group of recently extinct volcanoes which it is convenient to term the "Diamond Craters" is situated in the east-central part of Harney County, Oregon., about 6 miles west of Diamond post-office. The craters, about 20 in number, occupy an area of about 5 square miles, and are surrounded by at least 30 square miles of rough lava which flowed from them.

The Diamond Craters are situated near the base of the long west slope of Stein Mountain, and came into existence after the land over which they discharged their lava had been deeply dissected by erosion. The lava entered the valleys and canyons and obstructed the drainage so as to cause swamps to form. A significant fact in this connection is that the basins above some of the lava dams are still unfilled and have never been occupied by water bodies except ephemeral or playa lakes. This evidence seems to show that the climate of the region has been as arid as at present ever since the lava streams obstructed the drainage.

The Diamond Craters are of two types, namely, lapilli cones and lava cones, the lapilli cones situated in the southwest and the lava cones in the northeast portion of the group. The lapilli craters are mostly low, and range in size from one measuring about 2500 feet across to small conical piles of brownish debris. "Within the largest crater there are hills and mounds of lapilli of the same character as the material forming its encircling rim, but rising to a height of from 50 to 75 feet above it. This great accumulation of fragmental material presents an uneven surface consisting of hillocks and crater like hollows and bears evidence of the occurrence of weak explosions in a crater so abundantly charged with debris that it could not clear itself. From analogy with streams, the volcano may be said to have been overloaded with debris. The fragmental material was blown up into hills, and crater-like pits opened in it, but the escaping lava did not have sufficient force to eject it from the crater."

The hills and rings of lapilli among the Diamond Craters present many variations. Some are simple conical piles of the normal type, with depressions in their summits; in others lava rose and, breaching the inclosing wall, overflowed. In one instance the lava, after rising in a crater and outflowing, was drawn off beneath the crust formed on its surface and within the bowl of lapilli, about 600 feet across, causing the crust to fall in and leaving a black, irregular gulf 30 feet deep, and one lapilli ring or crater has another, composed of the same kind of material, within it, thus recording two stages of activity. In one instance a small crater is composed of compact, spherical lava balls or bombs, ranging in size from about 2 inches to the size of small shot. these bombs are rough, of a dull-red color, not cellular and exhibit no evidence of rotation excepting their well-rounded shapes. bordering the lapilli craters on all sided are the broad, rough surfaces of recent lava fields, which in most instances are covered to some extent with sagebrush and other vegetation.

Russell, I. C. 1903, USGS Bulletin 217

p. 55 . . . . . . To the north of the lapilli craters and merging with them as topographic forms are rounded hills composed of lava sheets, which furnish examples of lava cones. The highest of these hills rises about 400 feet above the adjacent plains and is the highest and most conspicuous summit in the group of which it is a member. This central dome is about 1 ½ miles in diameter, and so far as is indicated by the exposures is composed throughout of lava sheets, which occupy its summit and descend its sides in all directions to the surrounding plain. There is no true crater to be seen, but at the summit of the hill there is a gulf, due to the falling in of a large block of lava of which the surface of the hill is composed. This gulf has a nearly vertical wall from 40 to 70 feet high, runs about east and west, is from 500 to 800 feet across and fully 2000 feet long. Within it are several irregular ridges formed by the edges of large tilted blocks of the fallen crust. The lava exposed in the walls of the break is irregularly columnar, and the topmost layer, which arches over the summit of the hill is about 40 feet thick. This sheet is continuous from one side of the hill to the other, passing over the summit, but in the central part of the dome thus formed the rock is highly scoriaceous and the bedding less distinct than at the sides. From the gulf in the summit of the hill branching fractures extend down its sides to the east and southeast, and in part these radiating breaks are gulfs produced by the subsidence and tilting of large blocks of the surface layer. To the north of the hill just described there are other elevations of a similar nature, but lower and less broken, and about the group there are rough lava flows, which came from it and spread over the previously eroded land. On one of these lava sheets there are small driblet cones, two of whcich are represented on Pl XI, B.

The interpretation of the facts in reference to the domes of lava briefly described above seems to be that from certain of the Diamond Craters, which were probably lapilli cones like those of that nature still remaining, great quantities of lava were extruded in a liquid or plastic condition, which buried or carried away the preceding craters of lapilli and, thickening about the opening from which it came, built up rounded hills. The outwelling lava flowed down the sides of the hill and a thick crust was formed on its surface. After this, the outflow continued beneath the stiffened surface, and finally, when no more lava rose from the conduit beneath, a considerable portion of the surface crust fell in, leaving the black gulf now forming such a conspicuous feature of the summit and eastern side of the largest dome. The smaller lava cones or domes to the north of the principal cone were less fractured than the main one of the series, and retain nearly all of their constructional features unmodified by either fracture, subsidence, or erosion. In fact but slight changes by erosion are anywhere visible throughout the entire group of craters.

The rounded hills of lava among the Diamond Craters are, as may be judged from the description just given, examples of lava cones, and are similar to may other elevations in Idaho and Oregon, which were produced in each case by the escape of lava in large volume from a volcanic conduit. The chief differences between the lava cones here

p. 56,57 . . . .

The chief difference s between the lava cones here considered and those of the normal type are the prominence of the rounded central hills and the comparatively small extent of the surrounding lava fields with which they merge. The usually characteristic profile presented by lava cones, consisting of long, gentle slopes leading up to a low central flat topped butte, is mot present. In this connection it may be suggested that the lava poured out to form the hills referred to was less liquid and did not flow away so readily, as in many other similar instances, but thickened in a more conspicuous manner than normally about the openings from which it came.

In the formation of lava cones, as is the case with the flow of lava streams generally, an inportant condition , and the one which makes it possible for a small hill to form with a sheet of lava extending completely over its summit, is the subsurface flow of liquid or plastic lava beneath a stiff crust. The degree to which lava escapes in this manner from a deep accumulation determines the extent to which its surface will be fractured and the amount of surface change which will result from the subsidence of fragments of the crust.

Piper, Robinson, and Park, 1939, Geology and ground water resources of the Harney Basin, Oregon:

P. 15 . . . . Landforms . . . . ." Surfaces of colcanic origin that are virtually unweathered and but little eroded are extensive in the Harney Basin, especially in its southeastern part. These are relatively permeable and probably allow an appreciable part of the rainfall to penetrate to the ground-water table. The youngest is a basaltic lava field, the Diamond Craters, which covers about 25 square miles in Tps. 28 and w9 S., R. 32 E. This field dams the basin of Riddle Creek and in all probability has diverted the lower part of Kiger Creek toward the west. Its dominant feature is a lava dome about 400 feet high whose crest is broken by a linear pit about 1200 feet long, 600 to 700 feet wide, and about 50 feet deep. Small spatter cones are numerous along the eastern edge of the field. Satellitic cinder cones flank the central lava dome on the south and west, and from them a barren cinder plain extends southwestward. At some places the marginal lava field is hummocky with collapse pits and a few pressure ridges; at other places it is relatively smooth and composed of ropy(pahoehoe) lava; still elsewhere it is built from blocky (aa) lava with a jagged surface that is all but impass able. All these recent volcanic features stand unscarred by erosion. Very little soil has formed, but sagebrush and other desert plants grow here and there.

p. 36 . . . Late Basalt and Basaltic Ejectamenta . . .

The youngest volcanic rocks in the Harney Basin form the Diamond Craters, in Tpl. 28 and 29 S., R. 32 E. (p. 15). These include compact olivine basalt and relatively large bodies of highly inflated scoria, lapilli, cinders, and bombs. Ordinarily the coarsest pyroclastic fragments are less than a foot in diameter. Most of the basalt has some diconnected gas holes or vesicles, the number and size being greatest near the tops of the respective layers. In some hand specimens olivine is visible to the unaidedeye; in general the olivine is fresh. The tops of some of the layers are blocky and fragmental whereas others are relatively smooth but ropy. . . . .

The age of the late basalt is known approximately. Because the rocks show little evidence of disintegration and decay, and because the lava domes and cinder cones have been little scarred by erosion it is believed that none of the extrusions occurred before late Pleistocene time. On the other hand, at the Diamond Craters even the tenuous lips of minor spatter cones and small mounds of fine cinders have not disintegrated appreciably. Hence some of the volcanic activity may have taken place only a few hundreds or thousands of years ago; if so, it may have been in the Recent epoch. In each of the three areas the first extrusions of late basalt occurred ~~after the~~ after the upper members of the Harney formation had been stripped from the western part of the basin and after the central valley had been eroded. . . . . . .

p. 37 "The late basalt near Diamond is clearly somewhat younger; in large part it was extruded after most of the valley filling had taken place. Accordingly, its age is taken to be latest Pleistocene or Recent.

Structure . . . . . .

p. 56 - - - - -In the southeast quadrant of the area another small structural basin and complementary anticline deform the Danforth formation and span the Kiger Creek Valley about 4 miles northwest of Diamond. These structural features adjoin the Diamond Craters; they are thought to be simple puckers formed by sagging of the roof above the magma chamber that supplied the late basalt.

p. 57 . . . . . . The writers concur in the belief that the conspicuous faults in the Harney Basin and elsewhere in south-central and southeastern Oregon are of the normal or gravity type-- that is, they have resulted from tensional stress. On the other hand, Smith, following the hypothesis of Wayland, has advocated the idea that the fault along the eastern face of the Steens Mountain is a thr ust fault-- that is, it was caused by compressive stress. This theory of compression has been vigoriusly opposed by Fuller and Waters. In his discussion, Smith cites a small anticline east of the Diamond Craters as competent evidence of compression. The anticline is a relatively small and gentle flexure which the writers have inferred was produced by sagging or slumping in the volcanics. Commonly the oldest Tertiary rocks of the basin (older siliceous extrusives)are loosely crumpled as if by compression, but even in those rocks no thrust faults have been observed.

1.1/12.

1. Doming by laccolithic intrusion with accompanying rising magma moving laterally into water saturated rocks

2. phreatic explosions – maar explosive activity
give a good description of this again

– Formation of Crater Complex –

3. Magma again rising into the central main vent water saturated one great explosion that hurled pulverized pyroclastics ~~into~~ high into the air to form a mantle of fine debris extending outward for 2 miles in all directions. enlarging the summit pit and ~~collapse of crater walls back~~ by explosion and collapse.

particularly powerful – relatively ~~with~~ sheet of lava under a layer of debris – gas explosions to form the complex of crater funnels – the waning fluid lava welled up around the edges to fill in depressions.

rythmic ejection of ash and of scoriae especially when the vent becomes blocked with material falling in from the crater walls.

"Use Russels description here. –

4. Doming as magma rose in the eastern part
Fluid lavas flowed out from numerous vents on the eastern part adjacent to the weakened zone to ~~form~~ cover an area of about 1½ square miles. ~~The with~~

5. Withdrawal and outflow of magma removed support and the ~~graben, feature no~~ – central block of feature no 8 began to sag and adjust to fill in the void as the magma chamber emptied.

interesting features formed by this fresh lava – pit crater very fluid lavas.

1. Upward + lateral movement of magma ~~bowed up~~, ~~famili~~ forming 3 small domes aligned NW/SE.

2. Explosive phase formed 20 or more explosion pits and craters, maar types to the west, scoria mounds + cinder cones near the center and eastern edge. Abundant unusual round cored bombs in and around the rims of most of these craters.

3. ~~Contemporaneous~~ During late stage ~~the~~ of or immediately following the above explosive phase ~~fo~~ + rhythmic violent explosions in the large central crater, slump and fallback of debris with as the expl waning explosion — pockmarking this pit full of debris with rim surrounded funnels. Cored bombs abundant here too.

4. Another surge of lava ~~to~~ form graben dome and northeast dome. Breakout of fluid lava from vents low on dome flanks, explosion crater vents and ~~at the perimeter~~ other isolated points. As magma drained — the roof of graben dome gave way to form this textbook feature! Small lava pools filled crater bottoms — these too were drained to leave round steep walled pit-craters where a lava lake once stood and overflowed. This rise of lava was barely high enough to reach the porous floor of the central crater and oozed up to fill depressions within it. ~~This last flow of lava was of the most fluid variety and~~

5. ~~At the northeast dome the rising magma~~ The northeast dome is smaller but shows the forces present as a magma rises. As the brittle lava surface was bowed upward tension caused the fracture pattern that is so starkly seen from above or in the aerial photographs. These fractures on the flanks and summit of this dome are open as much as 10 feet wide and 20 to 30 feet deep.

(Red Bomb Crater)
Photo # 12 - Maar type crater in which the explosive vent was not always in the same place resulting in a multiple cratered feature. There are 4 crater funnels within this larger crater. Layers of lapilli and accretionary bombs drape over the rim.

Photo # 3 - (Cloverleaf Crater) Brief sporadic explosions from closely spaced vents result in multiple craters superimposed on one another to give a scalloped edge like this.

Photo # 13,13A,14 - (Pit Crater) Formed by collapse as lava that had welled up to form a lake was drained back down the vent through which it rose. This is similar to pit craters on the flanks of Hawaiian volcanoes and some of the small broad shield volcanoes of Iceland. This pit crater is 220' in diameter and 75' deep.

Photo # 24,25,25A - (Northeast Dome) Crest of the elongate Northeast Dome showing intricate fracture pattern developed by tension as the lava flow surface was bowed upward by a rising magma. Dome height is about 400' and it is 1¼ miles long and 3/4 mile wide.

Photo # 22 - Pahoehoe lava surface in the northeast part of the Diamond Craters lava field, showing detail of collapse as lava drained from beneath an almost cooled crust. Some depressions resemble irregular giant tracks, while others are almost circular.

Photo # 4 - (Little Red Cone) Small cinder cone, perhaps one of the latest explosive events at the Diamond Craters. Less violent explosive activity, mild fire-fountaining formed this rounded pile of lappilli and bombs.

Photo # 29 (Twin Craters) One of the Twin Craters, a maar type crater, with low rims of lapilli and accidental fragments. Note the flows of basalt outcropping in the crater walls. Cored bombs are abundant in the low rims. Graben escarpment visible in the background.

Photo # 15 (Graben Dome) Looking west along the crest of Graben Dome. Partially obliterated explosion crater in foreground.

Photo # 26 (Unnamed) Typical maar type crater on north flank of the Graben Dome, basalt flows visible in the walls of the crater, low rims of ejecta attest to a rather violent single explosion for its formation.

Photo # 29 (Oval Crater) North end of a long oval crater which formed as the vent shifted slightly from xxxxx south to north over a rather long period of explosivity. The low rims are made up of lapilli, and bombs. Note the truncated flow basalt outcropping in the crater walls.

Photo (Keyhole Crater) Crater within a crater. Fluid basalt has welled up in the same xxxx explosive vent that formed the broad shallow lapilli crater. Ax The crater floor filled to form a lava lake. Asxthexlaxa Breakout of the lava at a lower elevation to the south or east, drained the vent below the lake, andxxxxxxxxx the thin crust collapses to form the steep walled crater pits. Foundering of the west wall has given this one its unusual keyhole shape.

Photo # 8 (Malheur Maar) A small explosive gas eruption or steam blasted out this and an ajoining crater. Very little or no magmatic material was erupted and only thin rims of broken rock fragments are present. Lake-filled, this fits the definitionof a maar. Tumuli and collapse features well exposed on the pahoehoe surface all around.

Photo # 11 (Central Crater Complex) Looking into the crater from the east, Irregular piles of lapilli, blocks, and bombs jumbled with rock fragments, of welded tuff with funnel shaped craters in between. As though the floor was porous, later fluid lava oozed up to fill in the lowest depressions.

Slide (Cored Bombs) A variety of cored bombs amid black barren lapilli, from within the Central Crater Complex.

Slide # 20 Assortment of cored bombs from Diamond Craters

These are the slides of the features from the aerial photos -- I'm not sure whether they are useable or not -- someone up there will probably know -- If we can I think we should use one of the High altitude shots of the Diamond Craters and also one of the Central Crater Complex -- Do you xxxxx remember the one Herb Schlicker had? Maybe we could use it if this other one won't print satisfactorily.

Sent to Ed