

DIAMOND CRATERS, OREGON

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

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 of 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.

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 examining 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.

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.

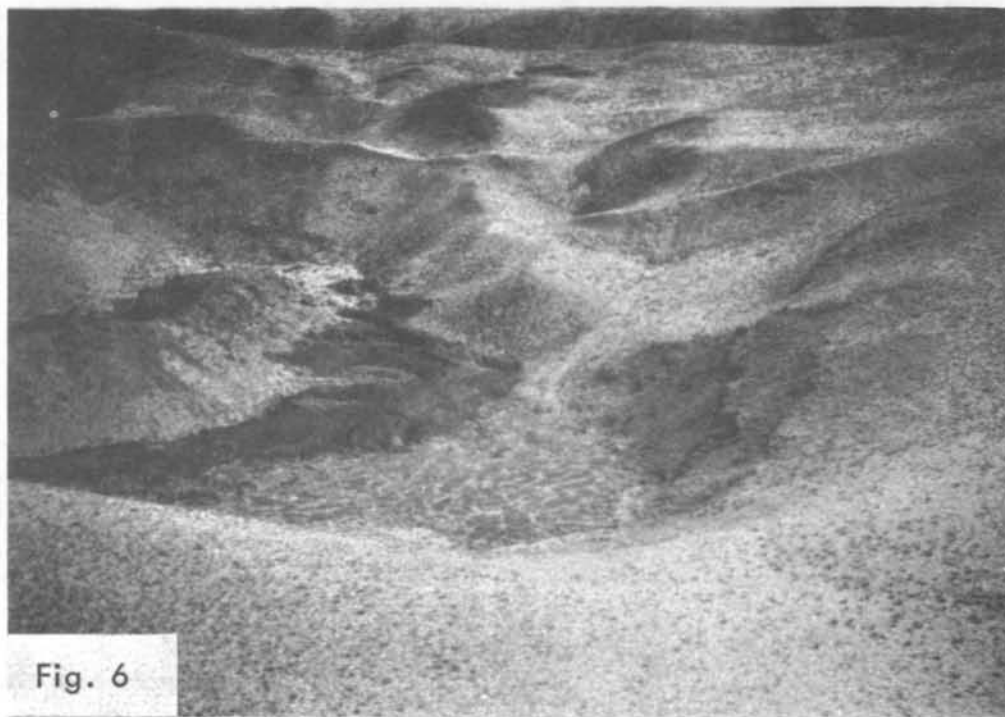
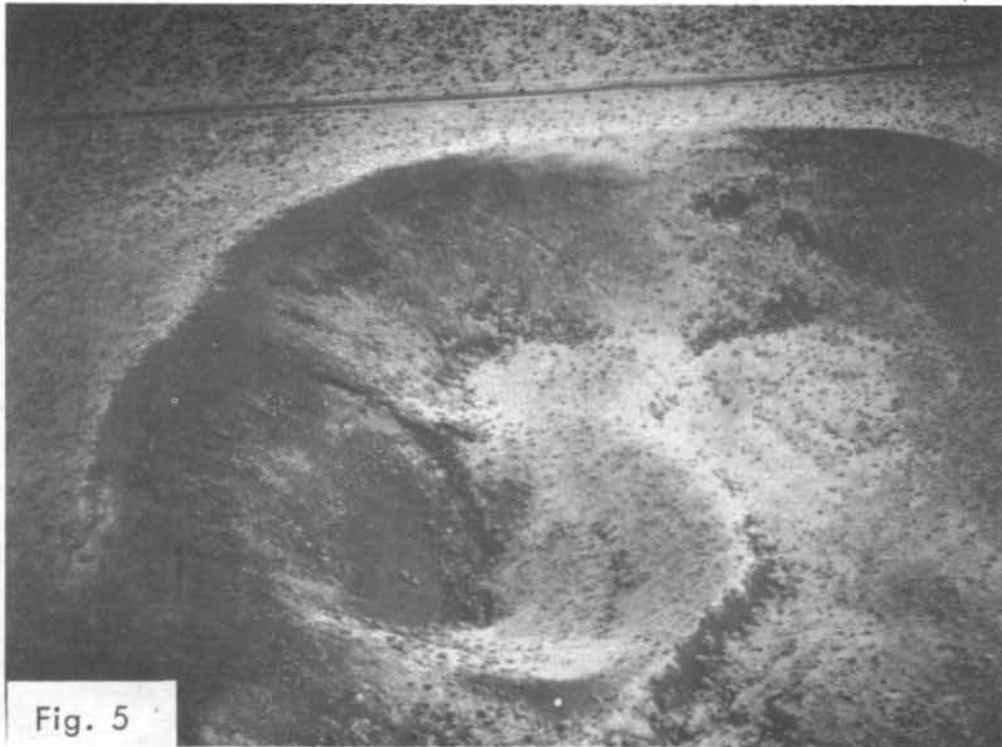
Figure 6. A small part of Central Crater Complex. Rather than being round or oval like most craters, it is rectangular with rounded corners. The feature is 1 mile long and 3,500 feet wide. The crater floor is as much as 200 feet below the rims near the outside edges, but the center is choked with piles 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 stoned upward to fill depressions near the edges of the crater.

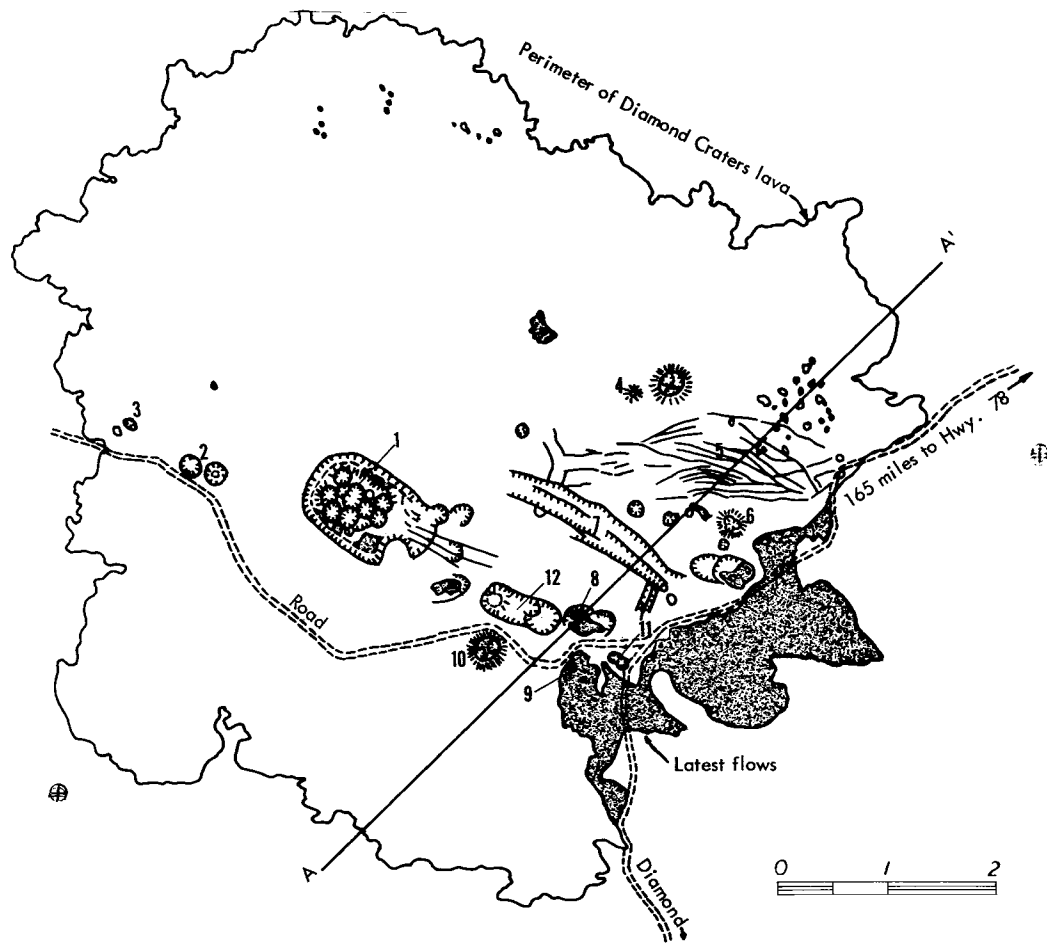
funnel-shaped bottoms of the inner craters and the loose debris still lying at steep angles on the walls attest to a very recent origin, probably within the last 1,000 years.

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





GEOLOGIC CROSS SECTION

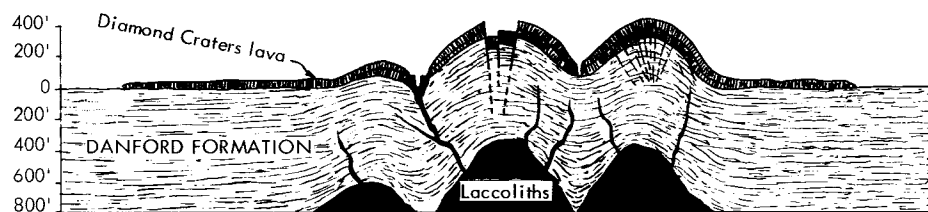


Plate 1. Index map and aerial



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

Photograph 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.

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 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 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

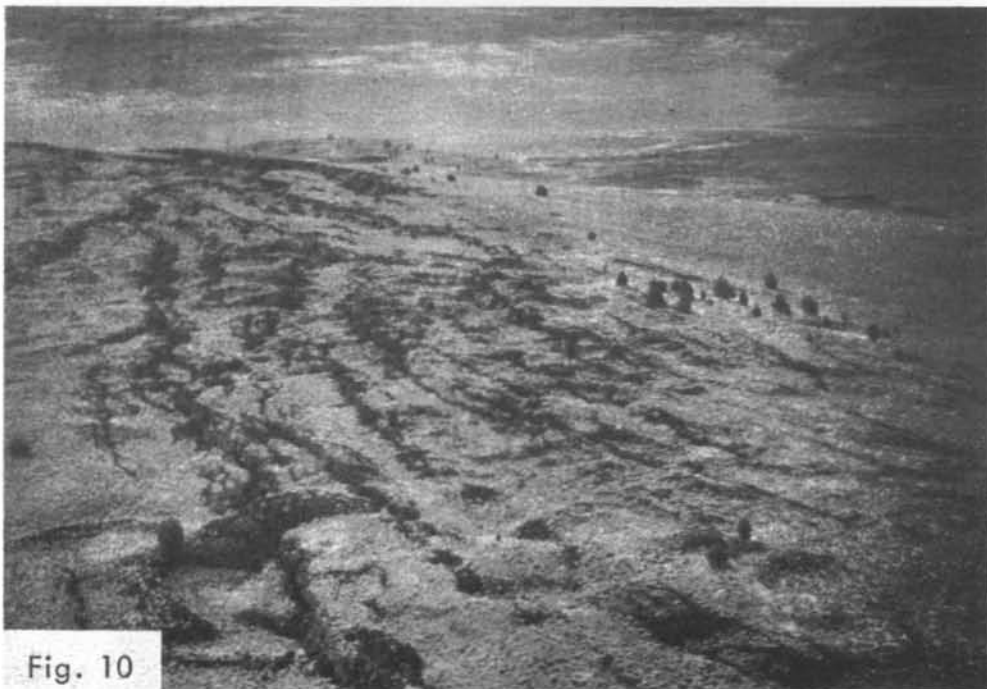


Fig. 10

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.

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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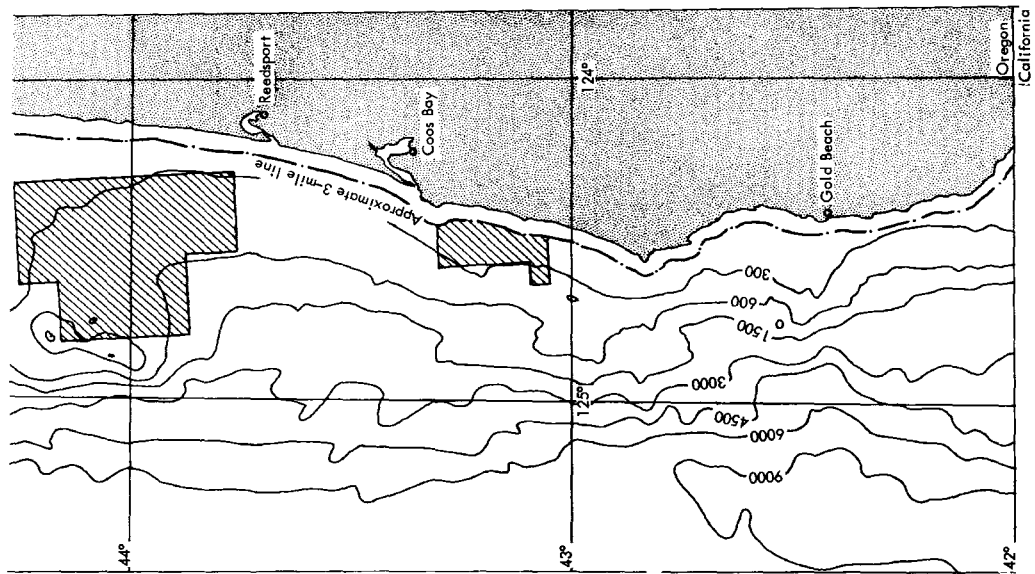
DEEP-WATER OIL DRILLING ASSURED IN THE NORTHWEST

The U.S. Department of the Interior announced February 18, 1964 that 1,090,000 acres of shelf lands were opened to oil leasing along the coasts of Oregon and Washington. The offered lease blocks (see map for Oregon blocks) represent areas of major interest which were selected from 3,000,000 acres suggested by the various oil firms. Deep-water leases offered adjacent to the northern California coast in May, 1963, received bids that netted \$13 million. Comments by industry spokesmen indicate that more money will be bid on the Oregon-Washington lands.

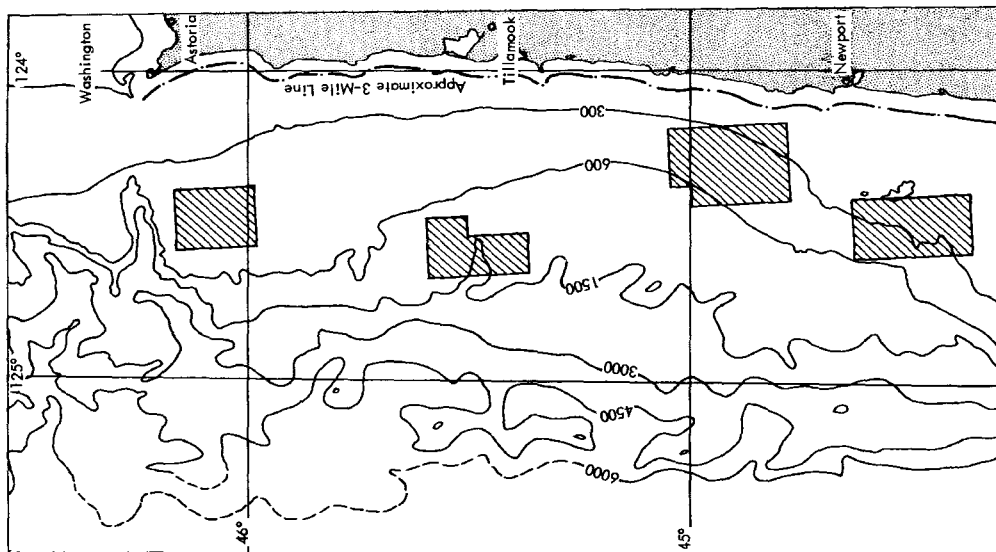
A total of 836,000 acres (1,300 square miles) offshore from Oregon and 254,000 acres (396 square miles) offshore from Washington is available for leasing. Rental has been established at \$3 per acre per year, plus a minimum bid of \$5 per acre. Thus, the federal government has set a minimum value of the lands offered at \$8,720,000.

Oil companies began exploration along the northwest coast in 1961 and have been making extensive geophysical and geological studies for the past 3 years. In order to obtain areas for drilling, the companies must submit sealed bids to the U.S. Bureau of Land Management by October 1, 1964, at which time the leases will be awarded to the highest bidders. The federal government issues its leases in 3-by-3-mile parcels (5,760 acres). Data on federal lease blocks is given in the table on page 36.

The State Land Board, preliminary to conducting a lease sale of state-owned submerged lands, approved an offshore lease form on February 25, 1964, and announced the availability of state submerged lands for oil and gas leasing. The board also continued preparing bidding procedure and hearing schedules as provided for in the Oregon Tide and Submerged Lands Act of 1961. Oil companies will probably be asked to make their selections by the end of May; opening of sealed bids will be in October of this year.



Offered lease areas



MAP OF OFF-SHORE FEDERAL LEASE AREAS, OREGON

Federal Lease Blocks			
Area	Acreage	No. of Parcels	Average Water Depth
Skipanon-Seaside	69,120	12	300 feet
Rockaway-Netarts	69,120	12	1,500
Cascade Head-			
Cape Foulweather	132,480	18	300
Newport-Waldport	103,680	26	360
Yachats-Florence	401,360	41	360
Coos Bay-Bandon	47,360	11	240

Oregon, because of its irregular shoreline and east-west boundaries, has divided its parcels by extending the east-west federal lease grid lines to the shore. A total of 102 parcels has been designated within the state boundary. The largest parcel is 11,800 acres and the smallest is 6,100; the parcels average 8,000 acres.

Governmental policies as well as the interest expressed in federal shelf lands will determine the success of the leasing on state lands. The state-controlled area is a very minor portion of accessible shelf land. However, 811,500 acres of submerged land are contained in the three-and-a-half mile strip bordering the coastline and an additional 42,200 acres are contained in the Columbia River estuary west of the 124th West Meridian.

Federal outer continental shelf land offered for lease abuts state lands only along the Coos Bay-Bandon block. The state land adjacent to this area will very likely be placed for bid in October. State land in the Coos Bay-Bandon block totals 36,000 acres and will be presented in 5 parcels of approximately 8,000 acres each. Other areas of state leases along the coast may be offered if companies nominate them.

Exploration activity has progressed to the point where deep drilling is necessary for further evaluation of the oil potential. A variety of deep-water drilling techniques may be tried in the next two years. Perhaps a vital new industry is being established in Oregon.

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AMERICAN MINING CONGRESS NATIONAL MEETING

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