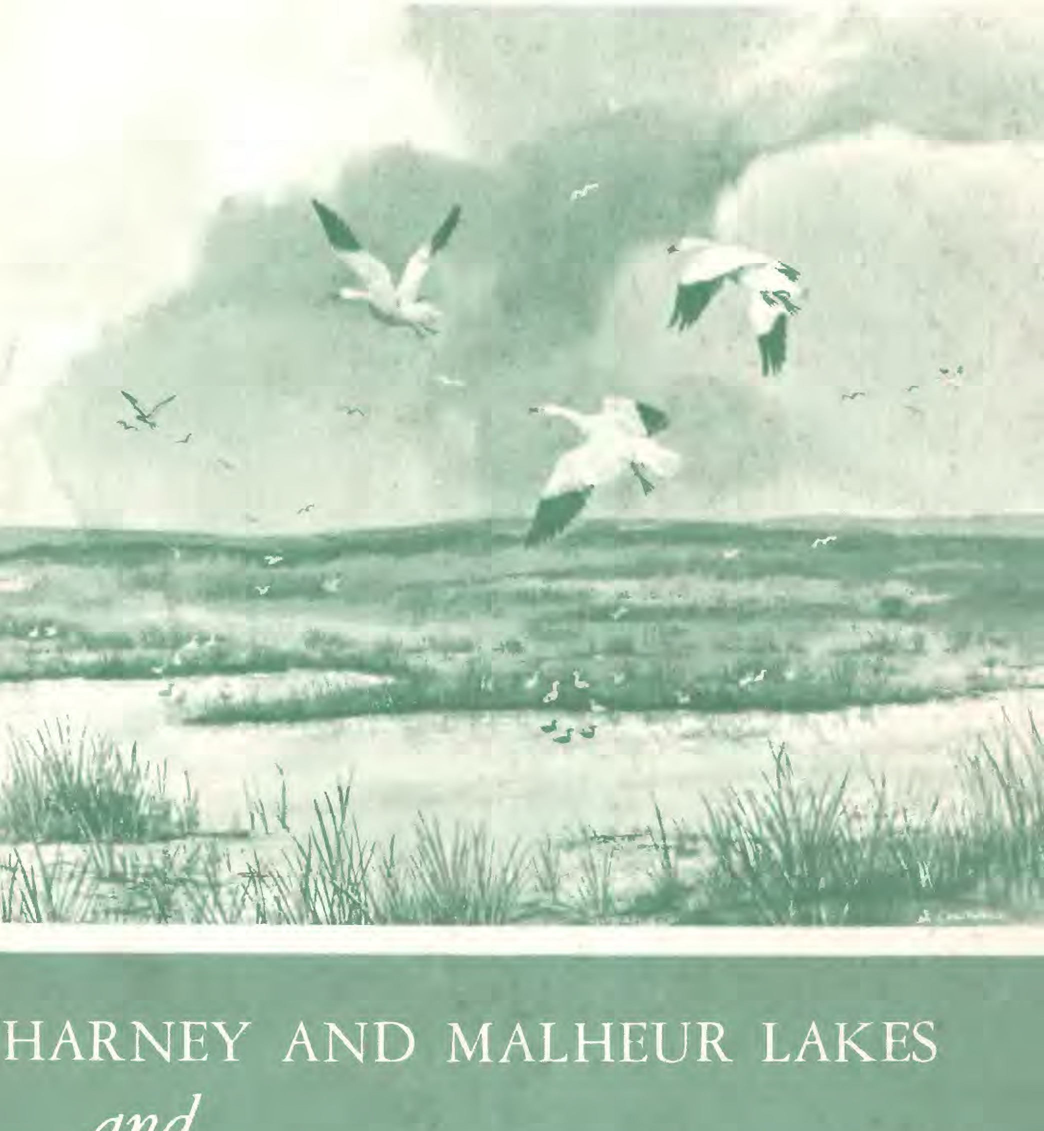
STUDIES RELATED TO WILDERNESS
WILDLIFE REFUGES



HARNEY AND MALHEUR LAKES *and* POKER JIM RIDGE AND FORT WARNER, OREGON

GEOLOGICAL SURVEY BULLETIN 1260-L,M

Summary Report on the Geology and Mineral Resources of the—

Harney Lake and Malheur Lake Areas of the Malheur National Wildlife Refuge North-Central Harney County, Oregon

Poker Jim Ridge and Fort Warner Areas of the Hart Mountain National Antelope Refuge, Lake County, Oregon

By GEORGE W. WALKER *and* DONALD A. SWANSON

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A compilation of available geologic information

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UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

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STUDIES RELATED TO WILDERNESS

WILDLIFE REFUGES

The Wilderness Act (Public Law 88-577, Sept. 3, 1964) directs the Secretary of the Interior to review roadless areas of 5,000 contiguous acres or more, and every roadless island, within the national wildlife refuges and game ranges under his jurisdiction and to report on the suitability or nonsuitability of each such area or island for preservation as wilderness. As one aspect of the suitability studies, existing published and unpublished data on the geology and the occurrence of minerals subject to leasing under the mineral leasing laws are assembled in brief reports on each area. This bulletin is one such report and is one of a series by the U.S. Geological Survey and the U.S. Bureau of Mines on lands under the jurisdiction of the U.S. Department of the Interior.

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SUMMARY REPORT ON THE GEOLOGY AND MINERAL RESOURCES OF THE HARNEY LAKE AND MALHEUR LAKE AREAS OF THE MALHEUR NATIONAL WILDLIFE REFUGE, NORTH-CENTRAL HARNEY COUNTY, OREGON

By George W. Walker and Donald A. Swanson

SUMMARY

The Harney Lake and Malheur Lake candidate areas are in the Malheur National Wildlife Refuge, north-central Harney County, Oreg. The two areas occupy the shallow center of the Harney Basin, a broad structural and physiographic depression filled by several varieties of silicic to mafic volcanic rocks, sedimentary rocks, and unconsolidated surficial deposits. Although some of the rocks in the Harney Basin are of Miocene age, all the rock in the two candidate areas are of Pliocene or younger age. Northwest-trending normal faults form prominent scarps in and near the two areas.

No minerals have been produced from either of the two areas, and no mineral commodities that are exposed in the two areas can be mined economically at present (1966). However, many of the Pliocene tuffs and tuffaceous sedimentary rocks that crop out in nearby bluffs are altered to zeolites and to potassium feldspar. Some of the zeolitized rocks now consist of 90 percent clinoptilolite, and the feldspathized rocks contain as much as 60 percent feldspar. The altered beds dip into the candidate areas, and large volumes of zeolitized and feldspathized rocks may be present at depth beneath the surficial sediments that blanket most of the two areas. Determination of the subsurface distribution of these minerals would require drilling or other underground exploration. Moreover, zeolites and bedded potassium feldspar are only now (1966) entering the industrial mineral market, and their future value is therefore uncertain.

The complexly faulted volcanic region that includes the two candidate areas is highly unfavorable for the accumulation of petroleum; commercial deposits of coal or peat, sulfur, and oil shale also are not likely to be present. Thin surficial saltpans containing halite and trona cover Harney Lake playa during periods of low Lake level, but they are too limited in extent to be of commercial interest. Subsurface commercial saline deposits are not likely to exist. Several hot springs occur in and near Harney Lake, but they are much cooler than hot springs developed elsewhere for geothermal power; however, physical exploration at depth would be necessary to evaluate fully their geothermal power potential.

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INTRODUCTION

PURPOSE AND SCOPE

This report describes briefly the geology and mineral resources of two areas in the Malheur National Wildlife Refuge of southeast Oregon that are being considered for inclusion in the wilderness system. The two candidate areas—Harney Lake and Malheur Lake—center around shallow, transient desert lakes in the central part of the Harney Basin, a large physiographic and structural basin.

This review of the area is directed mainly toward the potential for those mineral commodities subject to leasing under Federal mineral leasing laws, including gas, oil and oil shale, coal and peat, uranium, potassium and sodium saline minerals, and sulfur. Because hot springs occur in the region, the potential for the development of geothermal power is also considered.

The area was examined by the U.S. Geological Survey in the course of a regional geologic study being conducted in southeastern Oregon.

Reconnaissance geologic maps of marginal parts of the refuge and some adjacent lands outside the refuge are included in this report. Knowledge of these marginal areas is necessary to make meaningful inferences regarding the subsurface geology of the Harney Lake and Malheur Lake areas, which are largely covered, either by lakes or by a veneer of young unconsolidated sedimentary deposits, on which hay and tule grasses grow. Additional subsurface geologic information was obtained from logs of water wells located principally south of Harney and Malheur Lakes. During the course of regional work, samples of bedrock, saltpan crusts, hot-spring sinters, and surficial clastic sediments were collected and examined in thin section and by X-ray-diffraction techniques.

In the absence of mineral production or commercial deposits, the U.S. Bureau of Mines has not examined the candidate areas, but the Bureau has been informed of the findings and recommendations of the Geological Survey and concurs in them.

Prior to the present study, the geology of the Harney Lake and Malheur candidate areas was mapped by Piper, Robinson, and Park (1939) as part of a water-resource study of the Harney Basin. Most of the lithologic units shown in figures 2 and 3 are readily equated with those shown on the geologic map of those authors. Minor modifications were made, however, including separation of the rocks of the mafic vent areas from widespread tuffaceous sedimentary units and revision of the terminology of silicic volcanic rocks. The Bonneville Power Administration, U.S. Department of the Interior, has also made studies of the resources of the region (unpub. data, 1944).

Cooperation of several staff members of the U.S. Bureau of Sports Fisheries and Wildlife and the U.S. Bureau of Land Management is greatly appreciated. We particularly thank John C. Scharff, Manager of the Malheur National Wildlife Refuge, who supplied valuable information and base-map material, and Reginald A. Ross, U.S. Bureau of Land Management, who helped in obtaining well-log data. E. C. Pattee made available information from the files of the U.S. Bureau of Mines.

LOCATION AND GEOGRAPHY

The Harney Lake and Malheur Lake candidate areas are in the northern part of the Malheur Wildlife Refuge, north-central Harney County, Oreg. The relative positions of the two areas are shown in figure 1 and more detailed outlines of the individual areas are shown in figures 2 and 3. The Harney Lake candidate area, which contains 30,117 acres, is centered on Harney Lake, about 25 miles south of Burns, Oreg., and includes all of the present lakebed, marginal saltpans, and adjacent shore areas. The Malheur Lake candidate area, containing about 48,000 acres, is several miles east of Harney Lake and about 25 miles southeast of Burns; it includes all of Malheur Lake and peripheral shore areas. Paved State Highway 205 provides easy access from Burns to the Narrows, which is about halfway between Harney and Malheur Lakes. Dirt and gravel roads leading from the highway at the Narrows encircle both candidate areas. Moderate- to poor-quality secondary roads afford access to the areas from several other directions. State Highway 205 continues southward from the Narrows to the hamlet of Frenchglen at the southern end of Malheur National Wildlife Refuge, where it connects with graded gravel roads leading to ranches and small communities in southeast Oregon and northern Nevada.

The shallow desert lakes that characterize both of the candidate areas occupy low parts of the broad, flat Harney Basin, which under present climatic conditions has no external drainage. The lakes receive runoff mostly from the Silvies and Donner and Blitzen Rivers and from Silver and Warm Springs Creeks and show evidence of a cyclic water-level fluctuation over a period of years (Piper and others, 1939, p. 20–23). During periods of heavier than normal rainfall, Malheur Lake overflow into Harney Lake through the low, almost imperceptible divide at the Narrows. The configurations of Harney and Malheur Lakes in figures 1–3 were obtained from base maps prepared during the 1950's, when the lakes were much larger than at present (1966). Most of the areas shown on the maps as water covered were dry in October 1966, and in places consist of playas, saltpans, hayfields, and extensive patches of tule grasses.

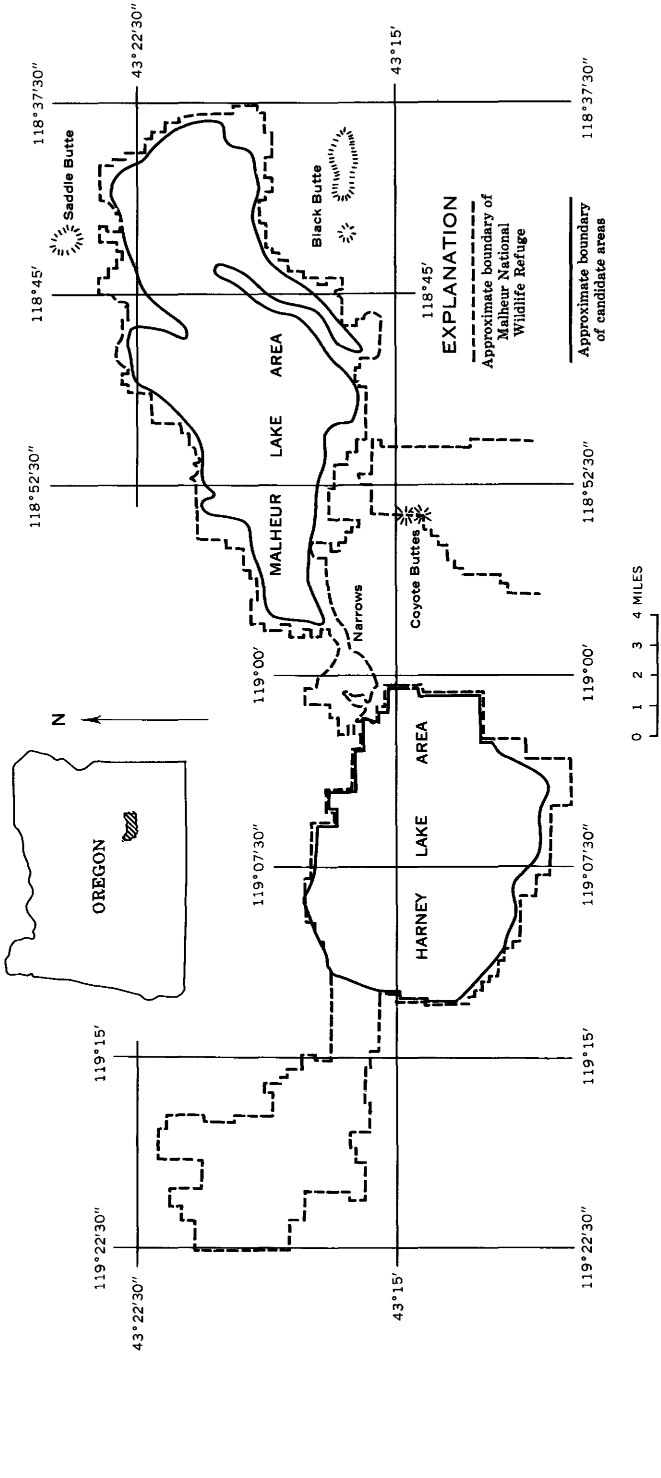


FIGURE 1.—Index map showing northern part of Malheur National Wildlife Refuge and location of Harney Lake and Malheur Lake candidate areas.

The candidate areas have a total relief of less than 100 feet, although some of the bluffs just outside the areas are several hundred feet high. Vegetation consists of meadow and marsh grasses, bulrushes, cattails, sagebrush, rabbitbrush, and other small desert plants. The extensive playa and associated saltpan that occupies most of the bed of Harney Lake is bare except for local patches of saltgrass.

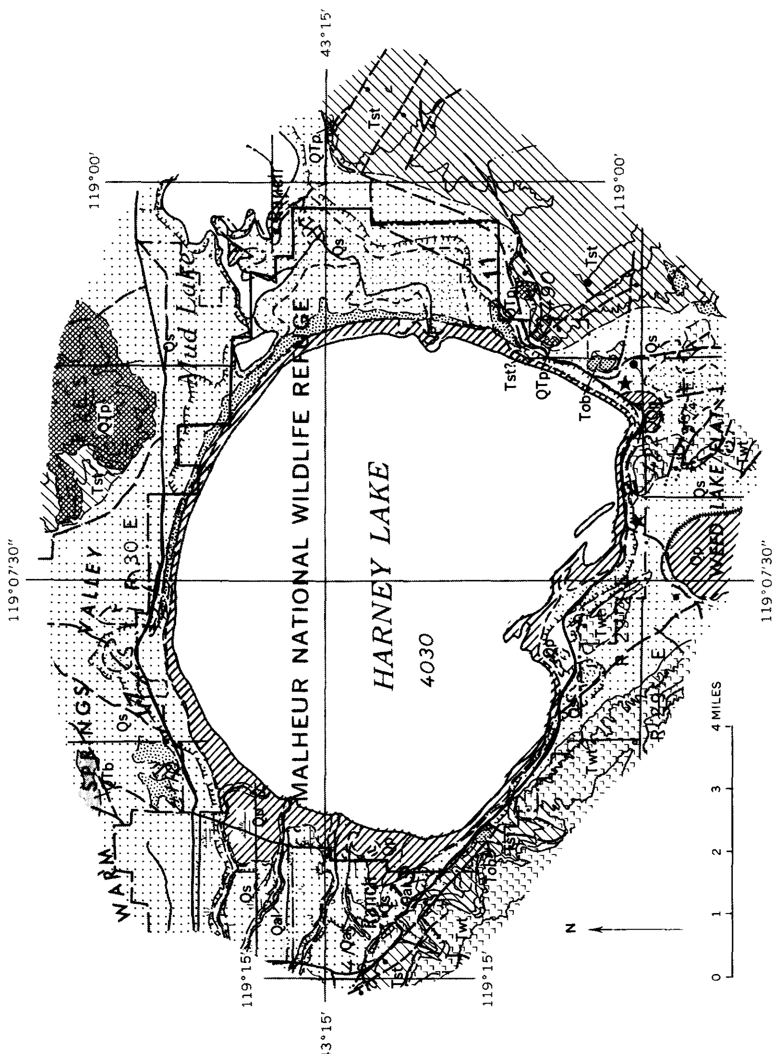
GEOLOGY

All the rocks in and near the Harney Lake and Malheur Lake candidate areas are of Pliocene or younger age and include airfall and ash-flow tuffs and tuffaceous sedimentary rocks, interstratified basalt flows, local accumulations of basaltic eruptive material, and broad expanses of several different kinds of Pleistocene and Recent surficial sediments (figs. 2, 3). All these rocks were deposited in the shallow physiographic and structural basin that evolved in late Miocene or early Pliocene time. Faults, mostly with small displacement, traverse parts of the basin, and both silicic and mafic volcanic vents are present locally.

Piper, Robinson, and Park (1939) separated the rocks of the Harney Basin into several formations, principally the Danforth Formation of Pliocene age and the overlying Harney Formation of questionable Pliocene age. Emphasis is placed in this report on descriptions of the various lithologies that occur in and near the candidate areas rather than on the formations to which they belong, because the lithologies bear directly on the mineral potential; hence the formal formation names are not used. Most of the rocks which Piper, Robinson, and Park (1939) called rhyolite of the Danforth Formation are now recognized as rhyolitic or rhyodacitic welded ash-flow tuff, although some extensive outcrops of rhyolite are present west of Harney Lake near the "00" (Double-0) Ranch.

STRATIGRAPHY

Tuffaceous sedimentary rocks, interstratified ash-flow tuffs, and thin basalt flows of middle(?) Pliocene age, representing mostly the Danforth Formation and possibly some older parts of the Harney Formation, are extensively exposed peripherally to the areas and occur in one place within the Harney Lake candidate area. These Pliocene rocks are the oldest rocks exposed in the northern part of the Malheur National Wildlife Refuge; however, several miles to the south and east, along the margins of the Harney Basin, Miocene volcanic rocks have been described by Fuller (1931) and partly delineated by Walker and Repenning (1965). South and southwest of Harney Lake, the Pliocene rocks consist primarily of a thick widespread welded ash-flow tuff of rhyolitic composition (unit Twt in fig. 2) characterized by


HARNEY LAKE
4030
MALHEUR NATIONAL WILDLIFE REFUGE
Mud Lake
WARM SPRINGS VALLEY
R. 30 E.
R. 29 E.
119°00′
119°07′30″
119°15′
43°15′
N
0
1
2
3
4 MILES

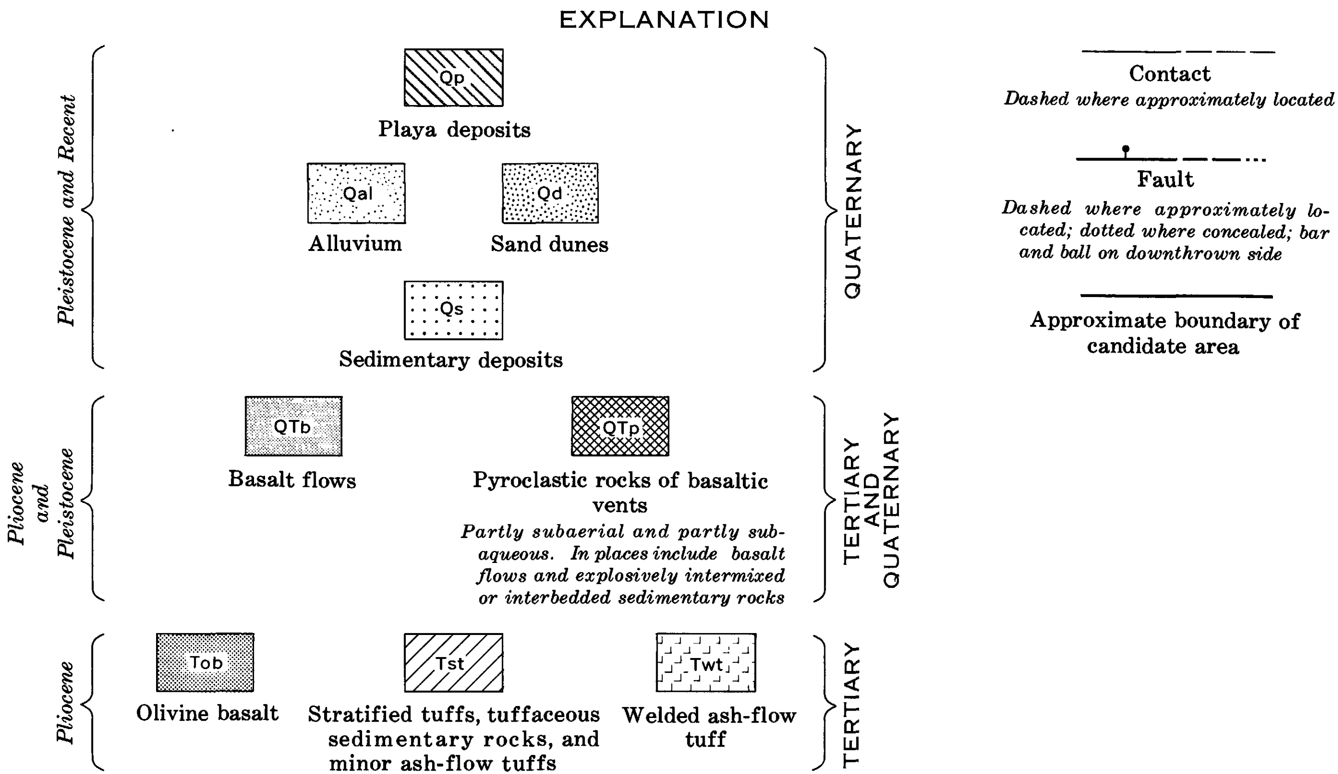
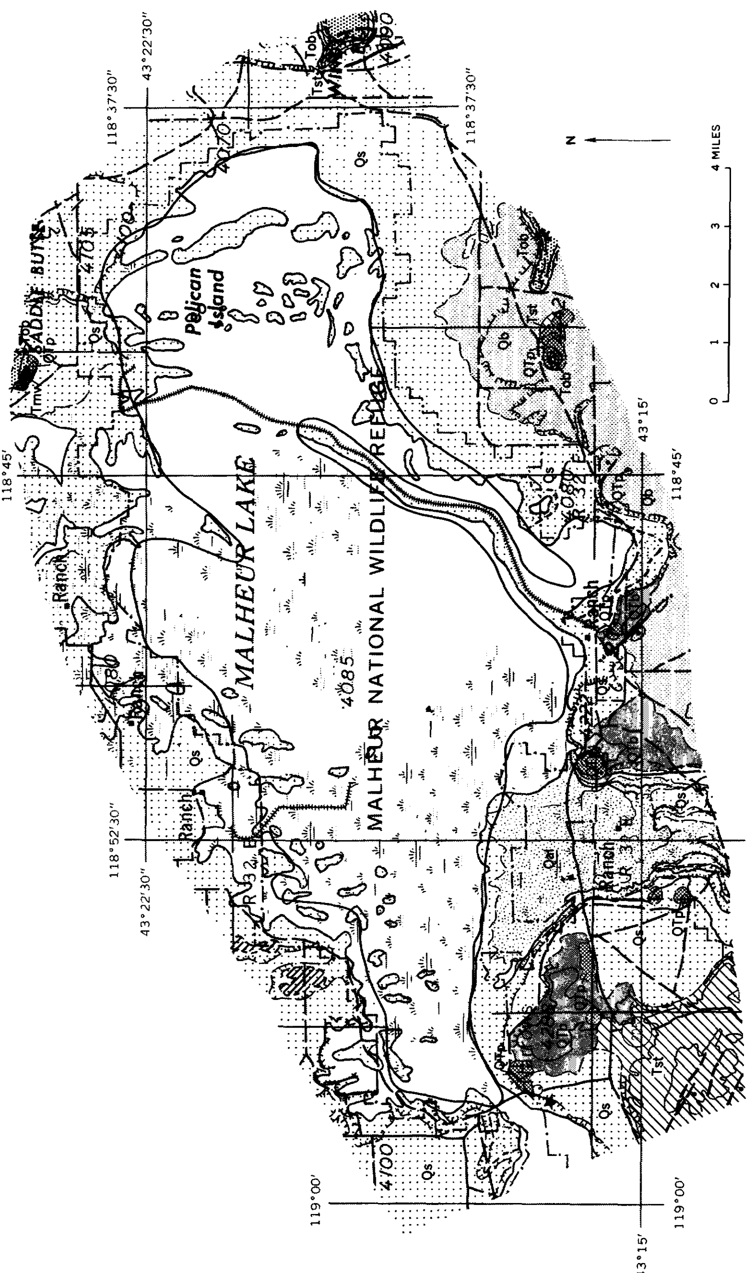


FIGURE 2.—Reconnaissance geologic map of the Harney Lake candidate area, Malheur National Wildlife Refuge.


MALHEUR LAKE
MALHEUR NATIONAL WILDLIFE REFUGE
Pelican Island
SADDLE BUTTE
118°37'30"
43°22'30"
118°45'
118°52'30"
119°00'
43°15'
N
0
1
2
3
4 MILES
Qs
Qb
QTp
Tst
Tob
Tmw
Qal
Ranch
4085
4100

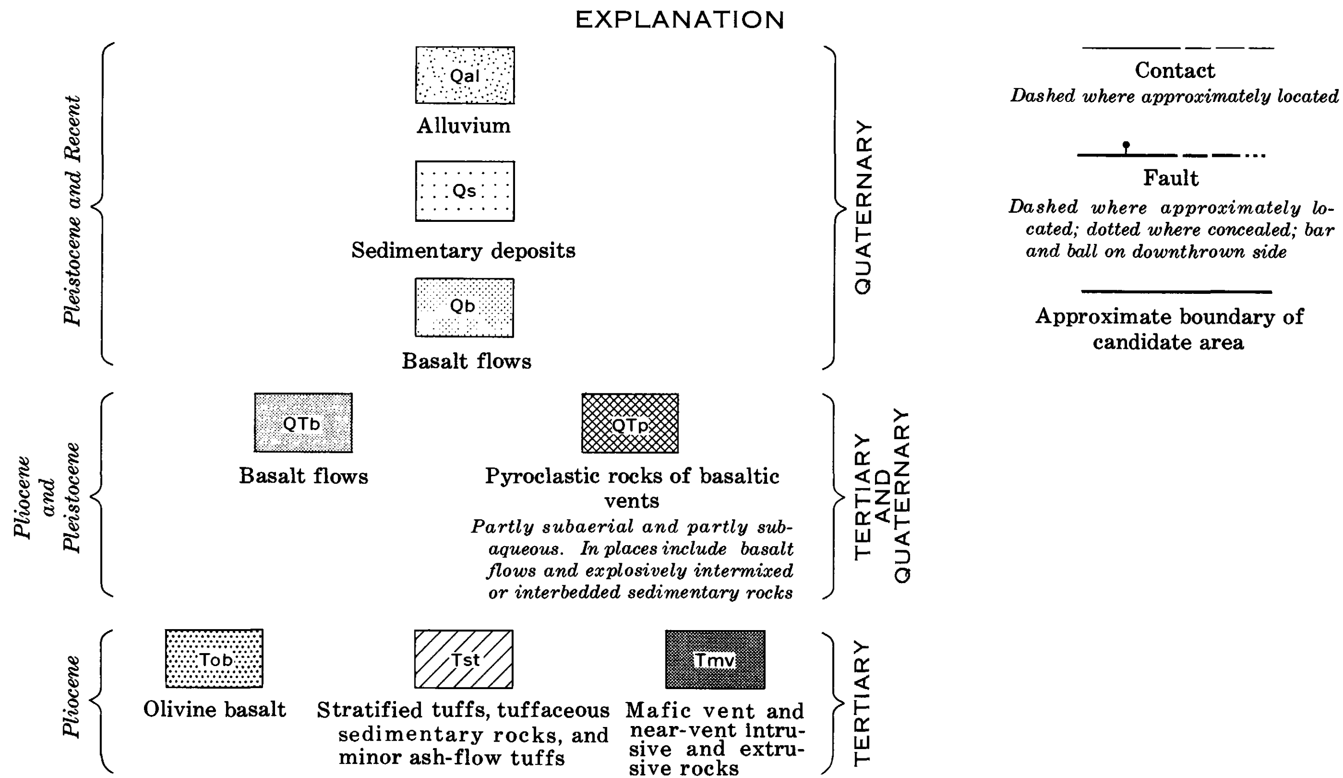


FIGURE 3.—Reconnaissance geologic map of the Malheur Lake candidate area, Malheur National Wildlife Refuge.

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abundant flattened pumice lapilli and internal zones of gas-phase alteration. Tuffaceous sedimentary rocks (unit Tst in fig. 2) underlie or are interstratified with several ash-flow tuffs in places south and southwest of Harney Lake. Fine-grained tuffs and tuffaceous sedimentary rocks and a few interstratified and altered ash-flow tuffs predominate in the bluffs on the east margin of Harney Lake and in the low hills south of Mud Lake and the Narrows. Some of these rocks seem to represent a lateral lacustrine facies of the rocks south of Harney Lake, which are mostly subaerial. These lake deposits are described in somewhat greater detail than the other rocks, because they have been altered to minerals of potential economic value.

Piper, Robinson, and Park (1939, p. 46) measured 265 feet of tuffs, tuffaceous sedimentary rocks, and an overlying ash-flow tuff—called rhyolite by them—in the cliff east of Harney Lake, and a similar thickness is exposed on the west side of the broad valley of the Donner und Blitzen River. The rocks are cut by northwest-trending faults but are little brecciated or deformed. Despite intense alteration, their primary structures and textures are well preserved.

The tuffs and tuffaceous sedimentary rocks are chiefly light tan, buff, and gray, and most are of well-sorted clay-to-silt grain size. They occur in beds that are as much as 3 feet thick but commonly only a few inches thick. In most places, the beds have features such as planar upper and lower surfaces, laminated structure, and sharply angular shards that indicate that they were deposited in lakes below wave base, but locally they display crossbedding, channels, and lenses of thin sandstone and intraformational conglomerate that indicate reworking by moderate currents. Calcareous shells of microscopic size, questionably either ostracodes or pelecypods, and opaline diatoms occur in some of the finer grained rocks. Interbedded lake silt and reworked and channeled sandstone and grit, such as those halfway up the cliff east of Harney Lake, record periodic fluctuations in water levels like those of present-day Harney Lake playa. The section of bedded rocks near Harney Lake contains more coarse detritus than the section farther east along State Highway 205, perhaps because of proximity of the Harney Lake section to a major inlet.

The tuffs and tuffaceous siltstone and claystone vary widely in their proportions of fine ash, glass shards, phenocrysts, lithic volcanic fragments, and rounded detrital quartz and feldspar. Some rocks were nearly pure vitric tuffs before alteration, whereas others are dominantly composed of epiclastic detritus with but little ash-sized material. The phenocrysts in the tuffs are largely alkali feldspars and quartz.

Rocks other than tuffs and tuffaceous siltstone and claystone are uncommon but conspicuous in outcrop. Beds of oolites and pisolites are interbedded with tuffs in roadcuts along State Highway 205 south of the Narrows and in hills southwest of the Narrows. The oolites and pisolites are silicified, but were once calcareous, as shown by relict carbonate layers in thin section. Formation of oolites requires a high-energy environment, which suggests that the lake was shallow and that wave activity affected sedimentation. Their primary calcareous composition shows that carbonate, probably calcite, was chemically precipitated from the lake water during oolite formation.

Ash-flow tuffs were found associated with the sedimentary rocks at two localities, one atop the cliff east of Harney Lake and the other along State Highway 205, where it descends the bluffs into Donner and Blitzen valley just south of the map area (fig. 3). The ash-flow tuffs are poorly welded to nonwelded, are highly altered, and show evidence of having poured into the shallow lake in which the interbedded ash and sedimentary detritus were being deposited.

Some of the rocks contain scattered diatoms, but no pure diatomite was found. Deposits of saline minerals are also lacking, though rare veinlets of gypsum, which have been prospected, cut the sedimentary rocks adjacent to basaltic vents east of Harney Lake.

The tuffs and tuffaceous sedimentary rocks are altered, and probably none retains its original mineralogy or chemical composition. Diagenetic minerals make up a significant amount of all specimens examined under the microscope and by X-ray techniques, and many of the vitric tuff specimens contain 90 percent or more zeolites or 60 percent or more diagenetic potassium feldspar. The zeolites are principally clinoptilolite (a Na-K-Ca zeolite), with lesser amounts of erionite, stilbite(?), phillipsite, and heulandite. In several of the samples tested, clinoptilolite, erionite, and phillipsite occur together. Clinoptilolite, diagenetic potassium feldspar, and secondary quartz make up most of some rock samples examined in the laboratory, and monoclinic potassium feldspar, 98 percent orthoclase molecule by X-ray analysis, is the dominant mineral (as much as 60 percent or more) in a few rocks from the cliff east of Harney Lake. The zeolites fill pore spaces and replace glass shards, so relict textures are well preserved. Some of the zeolitized rocks can be recognized in the field by their fairly tough and splintery nature. In contrast, the rocks altered principally to potassium feldspar lack relict vitroclastic texture; some beds have a white, powdery appearance and thus resemble diatomite. The diagenetic feldspar in the most highly feldspathized rocks is exceedingly fine grained and is associated with clay and delicate calcareous shells that are not chemically corroded but are somewhat deformed owing to compaction. Neither the distribution of the zeolitic and potassium feldspar alteration throughout the area nor the extent of individual altered beds is known.

Flows of olivine basalt (unit Tob in fig. 3), of middle(?) Pliocene age, cap Windy Point and Black and Saddle Buttes north and east of Malheur Lake. Most of these flows are less than 20 feet thick. Photogeologic mapping suggests that the flows are interstratified with tuffs and tuffaceous sedimentary rocks in the upper part of the stratified tuff unit shown in figures 2 and 3. At one time these flows probably covered extensive areas in the eastern part of Harney Basin, but in the area of Malheur National Wildlife Refuge, only erosional remnants forming flat-topped hills remain. On Saddle Butte, north of Malheur Lake, a mafic vent area characterized by a thick pile of massive basalt and small amounts of eruptive fragmental material is associated with the capping basalt flows. It may occupy a vent area, and is shown separately in figure 3.

Pyroclastic rocks from numerous basaltic vents, probably of late Pliocene and Pleistocene age, occur around the margins of the Harney and Malheur Lake areas as delineated in figures 2 and 3. Eruptions from some of the vents were subaerial and gave rise to accumulations of red and black cinders, bombs, and restricted flows. At most vents, however, basalt lava apparently invaded and broke through water-soaked stratified tuffs and tuffaceous sedimentary rocks, or possibly even shallow playa lakes. This invasion resulted in numerous phreatic explosions interspersed with less violent outpourings of basalt. The deposits of these vents consist of partly altered basalt cinders and granulated and fragmented bombs which are intermixed with chunks and lenses of partly sintered and altered sedimentary and tuffaceous rocks; thin basalt flows and small basaltic tuff rings are present locally. Spherical to ellipsoidal bombs with cores of sedimentary rocks, tuffs, and older basalt are typical products of the basaltic eruptions through wet sediments. They are comparable to the cored bombs described by Peterson and Groh (1965) from Diamond Craters about 14 miles south of Malheur Lake. Dikes and sills of basalt protrude in places through the accumulations of fragmental material.

Subaerial basalt flows were erupted from many of these late Pliocene and Pleistocene vents. Only the more extensive flows are distinguished in the Harney and Malheur Lake areas.

Poorly consolidated surficial lake and alluvial deposits of Pleistocene and Recent age cover the greater part of the two candidate areas. Most of these deposits are clastic sediments consisting of debris eroded from adjoining bluffs and highlands and of volcanic ash erupted in neighboring regions. Small amounts of evaporites, hot-spring sinter, and peaty soils are present locally.

The sedimentary deposits are mostly pluvial lake sediments and older alluvium of Pleistocene age, but include, at or near the surface, Recent lake sediments, caliche zones, and a few layers in which clastic debris is intermixed with small to moderate amounts of organic plant material to form low-grade peat or peaty soils. Most of the lake sediments are fine-grained sand, silt, and clay, but spits, bars, and beaches along old shorelines are covered with pebbles and cobbles, mostly of welded tuff, rhyolite, and basalt. Some thin near-shore lake sediments are composed of sand and pebbles derived from the zeolitized Pliocene tuffs exposed in the adjacent bluffs; locally these beds of reworked material are composed mostly of zeolites and potassium feldspar.

The younger surficial deposits are sand dunes, mostly marginal to Harney Lake, alluvium along stream drainages, and playa deposits restricted to Weed Lake and marginal parts of Harney Lake. The playa deposits are mostly clay and fine clastic sedimentary debris, but a saltpan composed chiefly of halite (NaCl) and trona ($NaCO_3 \cdot HNaCO_3 \cdot 2H_2O$) occurs at the surface. Halite, trona, and opal are dispersed throughout some of the clay in minor amounts, and thin interlayers of pure saline minerals may be present beneath the surface. In October 1966, Harney Lake was nearly dry, and most of the area shown as lake in figure 2 was a salt-pan crust.

Thin Pleistocene basalt flows cover much of the flat to gently sloping terrane south and southeast of Malheur Lake. The flows came from several lava cones and small craters about 6–8 miles east and southeast of the refuge headquarters. They conform to older topography, lapping around erosional highs such as Black Butte, and retain many of their primary surface-flow features. The flows are part of the so-called late basalt of Piper, Robinson, and Park (1939) and are overlain in several places by surficial deposits.

Small deposits of sinter occur around hot springs southeast and west of Harney Lake. The sinter appears to consist mostly of slightly altered saltpan minerals, for halite and trona, in addition to sulfohalite, are the predominant minerals in the one sample examined by X-ray methods.

STRUCTURE

The Harney Basin, which contains the two areas, is a broad, downwarped region (Russell, 1903; Waring, 1909; Piper and others, 1939) that is cut by numerous partly contemporaneous normal faults and silicic and mafic volcanic vents. Both candidate areas are centrally located in this downwarp, so most of the Tertiary rocks exposed adjacent to Harney and Malheur Lakes dip lakeward at a few degrees; the surficial deposits marginal to the lakes are undeformed.

Normal faults, most of which trend northwest, are abundant south and southwest of Harney Lake, where broken and displaced layers of welded tuff cap conspicuous fault blocks and fault slivers. Displacement on most of these faults is small, commonly only a few tens of feet in Pliocene rocks and even less in Pleistocene rocks. Many normal faults that belong to the same fault system have hundreds, and locally, thousands of feet of displacement in adjoining regions where they displace Miocene and older rocks.

In areas adjoining the candidate areas, both the mafic and silicic volcanic vents apparently are localized by normal faults.

MINERAL RESOURCES OF THE REGION

The Harney Basin contains few economic deposits of metallic or nonmetallic minerals, although small deposits of mercury, uranium, borax, diatomite, and bentonite have been found in adjacent areas. Mercury has been produced in small amounts from the Glass Buttes mine (Brooks, 1963, p. 173), 45 miles northwest of Harney Lake; from the Gray Prospect in the Coyote Hills (Brooks, 1963, p. 177), located many miles southwest of the refuge; and from several properties in the Steens Mountain and Pueblo Mountains area (Williams and Compton, 1953) south of the refuge. Production of uranium ores has been limited to several mines northwest of Lakeview, Oreg.; none has been reported from the prospects at the east base of Steens Mountain. Most of the mercury and uranium deposits are associated with Tertiary intrusive and near-vent extrusive silicic rocks of Tertiary age (Williams and Compton, 1953; Brooks, 1963; Peterson, 1958). A small quantity of borax was produced during a brief period about 1900 from surficial deposits in extensive saltpans in Alvord Valley (Struthers, 1904; Libbey, 1960), about 65 miles south-southeast of the Malheur National Wildlife Refuge.

Deposits of diatomite have been reported in the Otis Basin in northeastern Harney County (Moore, 1937, p. 95–107), in the Trout Creek Formation of Smith (1926) in the southeastern corner of Harney County, and in Christmas Lake Valley in north-central Lake County (Mason, 1963, p. 7). Bentonite has been quarried from deposits in the Camp Creek area of Crook County (Mason, 1963, p. 7).

Evidence of petroleum products in the region is limited to gas seepages and traces of oil reported in some shallow water wells and in several deeper wells drilled as oil or gas tests (Newton, 1965, p. 20–21). Most of these wells are either in the Burns or Lawen areas, several tens of miles north of the refuges, or in areas about a mile north of Harney Lake and 2 or 3 miles northwest of Malheur Lake.

Wells drilled along the northern edge of Malheur Lake, in an area known locally as Sunset Valley, were reported to have penetrated strata rich in magnesium-bearing brines (Burns [Oregon] Herald, May 1, 1942). Chemical analyses of these brines indicate high sulfate and bicarbonate contents, but other dissolved constituents are not unusually abundant and most occur in quantities less than in sea water. The brines probably have no potential commercial value.

Small prospect pits and a few claim monuments are scattered south and east of Harney Lake outside the boundaries of the refuge. Some of the pits have been dug in altered and silicified tuffaceous sedimentary rocks, probably by mineral collectors looking for agate, and others explore small fracture zones that contain discontinuous veinlike masses of gypsum. Except for silicification and the introduced vein gypsum, no evidence of mineralization was noted in the pits.

MINERAL POTENTIAL OF CANDIDATE AREAS

No mineral production is recorded from either the Harney Lake or Malheur Lake candidate areas, nor is there any indication of undiscovered minerals or mineral products of present commercial interest in the surficial deposits covering these areas. Any mineral potential of the candidate areas is in subsurface rocks which, in the light of present geologic and mineralogic data, may contain concentrations of some potentially valuable minerals.

A thin conglomerate composed of pebbles of older zeolitized tuff, eroded from bluffs outside the candidate areas, is exposed in shallow pits in the surficial deposits at the southeast base of Coyote Buttes; similar sedimentary accumulations probably are present in surficial deposits within the candidate areas, but are unlikely to be of commercial importance. Some of the soils contain small amounts of organic matter, but they are low grade and unsuited as a source of peat. The saltpan crust of Harney Lake is not suitable for economic exploitation because of the small volume of saline minerals, and because the halite and trona identified in these evaporites are both abundantly available at low cost in high-grade deposits in other areas. The dune sands are composed of a variety of rock-forming minerals, mostly alkali feldspar and some quartz, and contain sizeable amounts of altered glass and clay; they have no value as a source of quartz sand.

Inferences regarding the mineral potential of rocks buried beneath the surficial deposits are based on projections of bedrock geology and mineral occurrences exposed in adjoining areas. The zeolitized and feldspathized tuff beds that are exposed in the hills south of the Narrows and east of Harney Lake dip toward the candidate areas and probably are present beneath the veneer of surficial deposits. The depth of these buried beds and the distribution of the zeolites and potassium feldspar within them cannot be predicted, however, and the precise figures on grade and extent cannot be established without systematic subsurface exploration. Presumably the buried beds contain amounts of clinoptilolite and potassium feldspar comparable to the beds east of Harney Lake, which by Xray analysis of selected samples, locally contain as much as 95 percent clinoptilolite (a Na-K-

Ca zeolite) and 60 percent or more of nearly pure monoclinic potassium feldspar.

The value of these minerals is not known, inasmuch as uses for natural zeolites and bedded authigenic feldspar are only now being investigated. Some aspects of the potential uses of clinoptilolite as an absorber of waste products in the atomic energy field are briefly summarized by Brown (1962). Possible uses of bedded potassium feldspar are discussed by Sheppard and Gude (1965), who describe deposits in the Mojave Desert, Calif., similar to those of the Harney Basin but of higher grade.

Lack of bedded deposits of saline minerals in the exposed Pliocene and younger sediments of the region and the general low salinity of most nearby well and spring waters indicate that subsurface deposits of evaporites of commercial size are unlikely to exist, although beds of evaporite minerals an inch or less thick, comparable to the surficial saltpan crust in Harney Lake, probably are present locally.

Neither the structure nor the volcanic lithologies of Tertiary rocks in the region is that normally found in areas with an established potential for accumulations of gas, oil and oil shale, or sulfur. Numerous and widely distributed basaltic and silicic volcanic vents are also indicative of an environment unfavorable for these commodities, as is the presence of thermal springs and hot water in some wells.

POTENTIAL FOR GEOTHERMAL POWER

Several hot springs in and near the Harney Lake area (Piper and others, 1939) and hot well water in adjacant parts of Harney Basin (Newton, 1965) indicate that the region may have a small but untested potential for thermal power. Some aspects of this potential have been briefly described by Groh (1966). However, the maximum temperatures of the thermal springs and well waters do not exceed 68°C, which is far below those normally found in areas developed for geothermal power (White, 1965; Bodvarsson, 1966). Physical exploration at depth is necessary, however, to evaluate fully their geothermal power potential.

CONCLUSIONS

The present evaluation indicates there are no potentially valuable deposits of either leasable or locatable minerals exposed at the surface in the Harney Lake and Malheur Lake candidate areas. Deposits of diagenetic clinoptilolite and potassium feldspar are probably present beneath the transient lakes and surficial veneer of young sediments, but the mineral economics of naturally occurring zeolites and bedded deposits of diagenetic feldspar need further clarification before values can be established for these commodities. Evaluation of the distribution, quality, and quantity of these potentially valuable minerals would require subsurface exploration. There is no evidence indicating the presence of other minerals in economic quantities in the candidate areas. The geothermal power potential probably is small.

REFERENCES CITED

Bodvarsson, Gunnar, 1966, Energy and power of geothermal resources: Ore Bin, v. 28, no. 7, p. 117–124.

Brooks, H. C., 1963, Quicksilver in Oregon: Oregon Dept. Geology and Mineral Industries Bull. 55, 223 p.

Brown, R. E., 1962, The use of clinoptilolite: Ore Bin, v. 24, no. 12, p. 193–197.

Fuller, R. E., 1931, The geomorphology and volcanic sequence of Steens Mountain in southeastern Oregon: Washington Univ. Geology Pub., v. 3, no. 1, p. 1–130.

Groh, E. A., 1966, Geothermal energy potential in Oregon: Ore Bin, v. 28, no. 7, p. 125–135.

Libbey, F. W., 1960, Boron in Alvord Valley, Harney County, Oregon: Ore Bin, v. 22, no. 10, p. 97–105.

Mason, R. S., 1963, Oregon's mineral industry in 1962: Ore Bin, v. 25, no. 1, p. 1–7.

Moore, B. N., 1937, Nonmetallic mineral resources of eastern Oregon: U.S. Geol. Survey Bull. 875, 180 p.

Newton, V. C., Jr., 1965, Oil and gas exploration in Oregon (revised): Oregon Dept. Geology and Mineral Indus. Misc. Paper 6, 41 p. Originally compiled in 1954 by R. E. Stewart.

Peterson, N. V., 1958, Oregon's uranium picture: Ore Bin, v. 20, no. 12, p. 111–117.

Peterson, N. V., and Groh, E. A., 1965, Diamond Craters, Oregon: Ore Bin, v. 26, no. 2, p. 17–34.

Piper, A. M., Robinson, T. W., Jr., and Park, C. F., Jr., 1939, Geology and ground-water resources of the Harney Basin, Oregon: U.S. Geol. Survey Water-Supply Paper 841, 189 p.

Russell, I. C., 1903, Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: U.S. Geol. Survey Water-Supply Paper 78, 53 p.

Sheppard, R. A., and Gude, A. J., 3d, 1965, Potash feldspar of possible economic value in the Barstow Formation, San Bernardino County, California: U.S. Geol. Survey Circ. 500, 7 p.

Smith, W. D., 1926, Physical and economic geology of Oregon; the southeastern lake province: Oregon Univ., Commonwealth Review, v. 8, nos. 2–3, p. 199–253.

Struthers, Joseph, 1904, Borax: U.S. Mineral Resources of the United States, calendar year 1902, p. 891–898.

Walker, G. W., and Repenning, C. A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake, Harney, and Malheur Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I–446.

Waring, G. A., 1909, Geology and water resources of the Harney Basin region, Oregon: U.S. Geol. Survey Water-Supply Paper 231, 93 p.

White, D. E., 1965, Geothermal energy: U.S. Geol. Survey Circ. 519, 17 p.

Williams, Howel and Compton, R. R., 1953, Quicksilver deposits of Steens Mountain and Pueblo Mountains, southeast Oregon: U.S. Geol. Survey Bull. 995–B, p. 19–77.

Summary Report on the Geology and Mineral Resources of the Poker Jim Ridge and Fort Warner Areas of the Hart Mountain National Antelope Refuge, Lake County, Oregon

By GEORGE W. WALKER *and* DONALD A. SWANSON

STUDIES RELATED TO WILDERNESS—WILDLIFE REFUGES

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A compilation of available geologic information

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By George W. Walker and Donald A. Swanson

SUMMARY

The Poker Jim Ridge and Fort Warner areas, which are candidate areas for inclusion in the National Wilderness Preservation System, are in the Hart Mountain National Antelope Refuge in east-central Lake County, south-central Oregon. The two areas form part of an upraised and tilted fault block—a structural element that is typical of the northern part of the Great Basin province. Rocks in the two areas are principally volcanic in origin. They have been faulted, uplifted, and tilted eastward, the older rocks having been more strongly deformed than the younger ones.

No mineral raw materials that are in the category of leaseable minerals have been produced from either of the two candidate areas, and no mineral commodities known to occur within the two areas can be mined economically at present (1966). Many of the older tuffs and tuffaceous sedimentary rocks of the Fort Warner candidate area are altered to zeolites (principally clinoptilolite) which make up 90–95 percent of some beds. The mineral economics of natural zeolites is not yet clearly established, and large, more accessible deposits of clinoptilolite occur elsewhere in Oregon; hence the future value of the Fort Warner deposits cannot at present be determined.

Small deposits of precious opal (of interest mainly to mineral collectors) and low-grade bentonite occur locally, but are not of commercial importance. The complexly faulted volcanic area is not favorable for the accumulation of petroleum or for commercial deposits of coal, sulfur, saline minerals, or oil shale.

INTRODUCTION

PURPOSE AND SCOPE

The Poker Jim Ridge and Fort Warner areas of the Hart Mountain Antelope Refuge, Lake County, Oreg. (fig. 1), have been proposed for inclusion in the National Wilderness Preservation System. The geology and mineral resources of the two areas are summarized

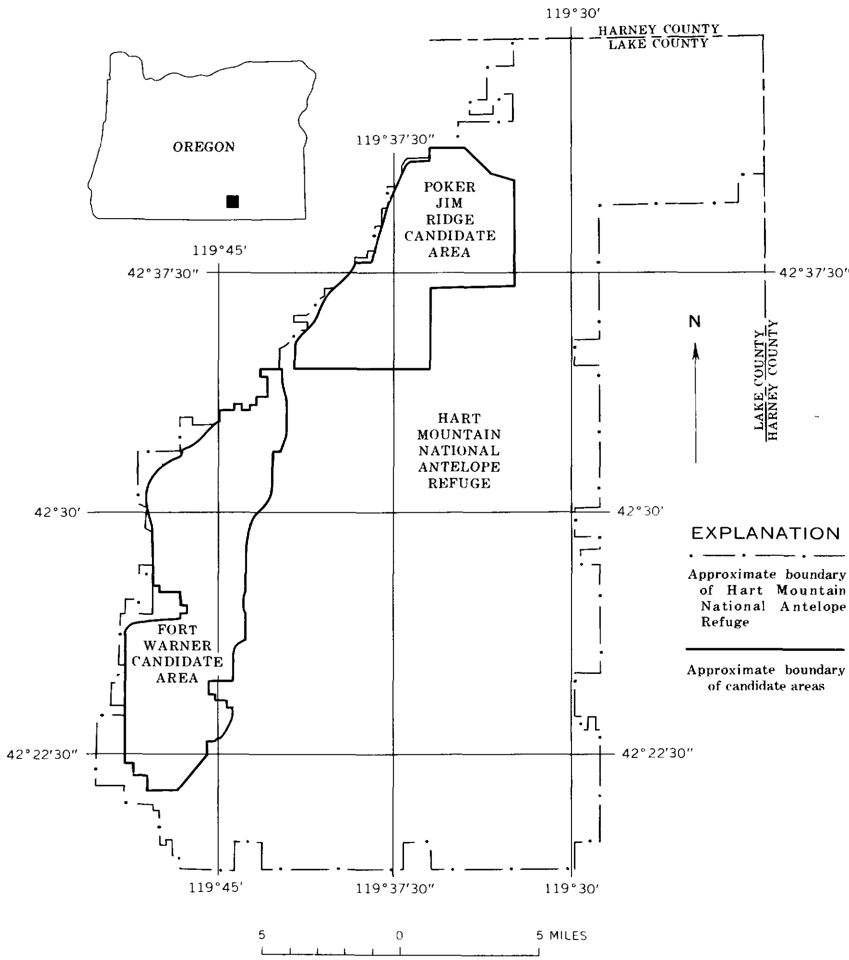

FIGURE 1.—Location of the Poker Jim Ridge and the Fort Warner candidate areas of the Hart Mountain National Antelope Refuge, Oreg.

here with special attention to the potential for leasable minerals, including gas, oil and oil shale, coal, potassium and sodium minerals, and sulfur.

Reconnaissance geologic maps accompanying this report (figs. 2, 3) are based on reconnaissance and photogeologic mapping done in 1961 by G. W. Walker, C. A. Repenning, and D. H. Lindsley (Walker and Repenning, 1965) as part of a project to prepare a geologic map of Oregon. Some of the earlier reconnaissance geologic work in the region, by Russell (1884) and subsequent workers, is summarized in a report by Fuller and Waters (1929) on the structure of southeast Oregon. The most recent and detailed study of the area that contains both Hart Mountain and Poker Jim Ridge is an unpublished Ph. D. thesis by E. E. Larson, submitted in 1965 to Colorado University, Department of Geology.

Many rocks and mineral samples collected in 1961 were later examined in the laboratories of the Geological Survey and were found to contain zeolites and possibly also bentonite and diatomite. Samples of tuff and tuffaceous sedimentary rocks were analyzed by means of X-ray diffraction techniques to determine their mineral content.

Because of the absence of mineral production, the U.S. Bureau of Mines has not had occasion to examine the candidate areas, but the Bureau has been informed of the findings and recommendations of the Geological Survey and concurs in them.

LOCATION AND GEOGRAPHY

Both the Poker Jim Ridge and Fort Warner candidate areas are in the Hart Mountain National Antelope Refuge in east-central Lake County, Oreg., about 40 miles by air and 65 miles by road northeast of Lakeview. Access to the refuge is by graded gravel roads either from the hamlet of Plush, about 10–15 miles southwest of the candidate areas, or from the road intersection on U.S. Highway 395 several miles northeast of Lake Abert and about 30 miles northwest of the areas. The refuge can also be reached over a poorly maintained desert road from Frenchglen, a small community about 60 miles south of Burns, Oreg., via State Highway 205.

The outlines and relative positions of the Poker Jim Ridge and Fort Warner candidate areas are shown in figure 1 and the outlines of the individual areas also are shown on the geologic maps (figs. 2, 3). Several small tracts of privately owned land within the candidate areas are not shown in the figures.

The Poker Jim Ridge candidate area (fig. 2) is about 8 miles long and 3–6 miles wide; it covers 18,500 acres. Included within the area is a major part of the prominent physiographic feature known as Poker Jim Ridge or, to some local inhabitants, as Blue-joint Rim. The ridge is asymmetric, with an 1,800-foot precipitous scarp on the west and northwest and a gentler east-facing back slope; the western boundary of the candidate area closely follows the base of the precipitous scarp.

The Fort Warner candidate area, a short distance southwest of Poker Jim Ridge, covers about 22,500 acres; it is about 15 miles long and ranges in width from less than a mile at its northern end to a maximum of about 4 miles to the south (fig. 3). The Fort Warner area includes most of Hart Mountain—one of the best defined fault-block mountains in the world and a prominent physiographic feature of of the region rising to a maximum elevation of 8,065 feet at Mount

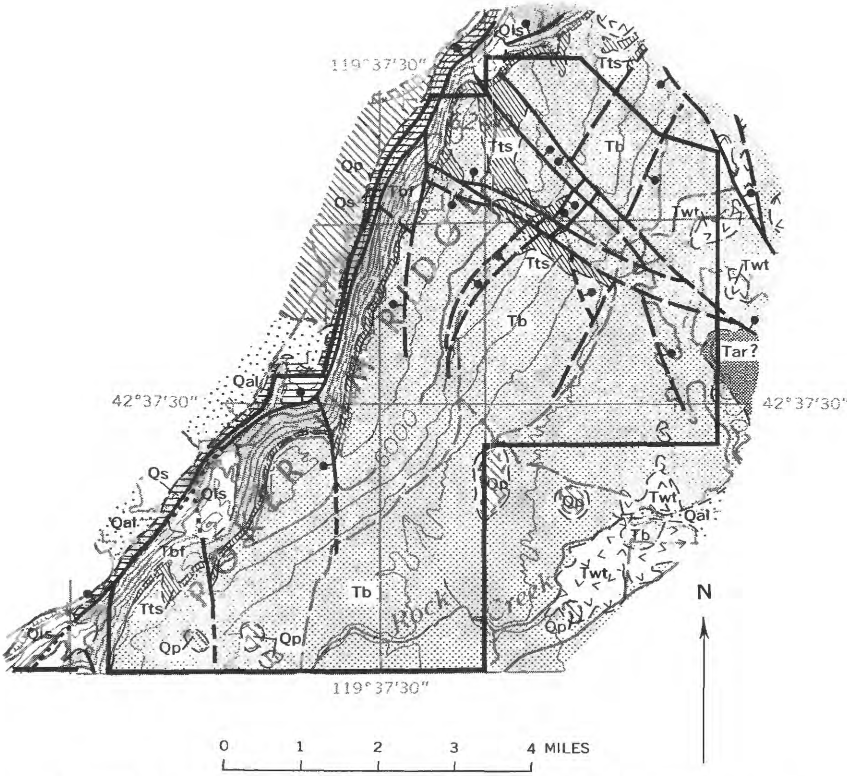

Figure 2.—Reconnaissance geologic map of the Poker Jim Ridge area.

Warner. Warner Valley, west of Poker Jim Ridge and Hart Mountain, is a flat desert valley dotted with ephemeral lakes and having an average elevation of about 4,400 feet. Parts of the steep west-facing fault scarp of Hart Mountain are more than 3,000 feet above Warner Valley and locally consist of unassailable crags and sheer cliffs. The eastern scarp is neither as precipitous nor as high. In several places, jeep roads lead to the elevated tableland on the south and north ends of the mountain.

Upper parts of De Garmo Canyon and adjacent Mount Warner show erosional features indicative of minor valley glaciation during the Pleistocene Epoch.

The vegetation of both candidate areas is typical of the high desert regions of southeast Oregon and includes a few groves of aspen and yellow pine, widely distributed western juniper, sage and rabbitbrush, and several varieties of grasses and flowering plants.

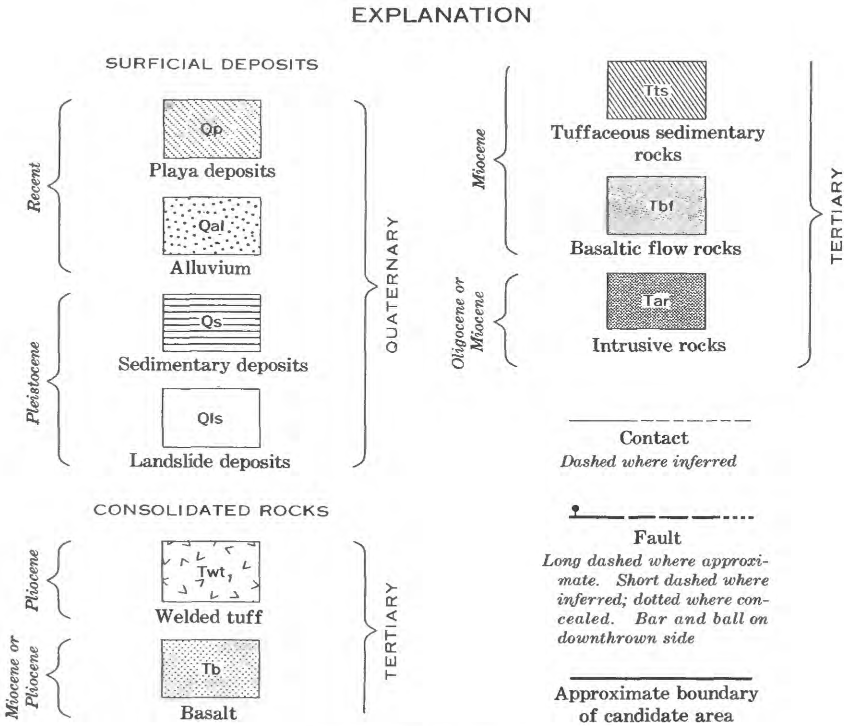

FIGURE 2.—Continued

GEOLOGY

Hart Mountain and Poker Jim Ridge form part of a large complex uplifted fault block—a structure typical of the northern Great Basin. All the rocks in the refuge are of Cenozoic age; they include many flows of basalt and andesite, some rhyolite flows, flow breccias, tuffaceous sedimentary rocks, a few partly welded ash-flow tuffs, and some comparatively young surficial deposits. In addition, several areas of silicic vent rocks are present, chiefly in or near the major faults that bound the large fault block or horst.

CONSOLIDATED ROCKS

STRATIGRAPHIC SEQUENCE

The oldest rocks in the Fort Warner and Poker Jim Ridge areas include gently dipping moderately to well-lithified commonly altered tuffs, tuffaceous sedimentary rocks, and andesite flows and flow breccias. These are exposed along the west side of Hart Mountain, par-

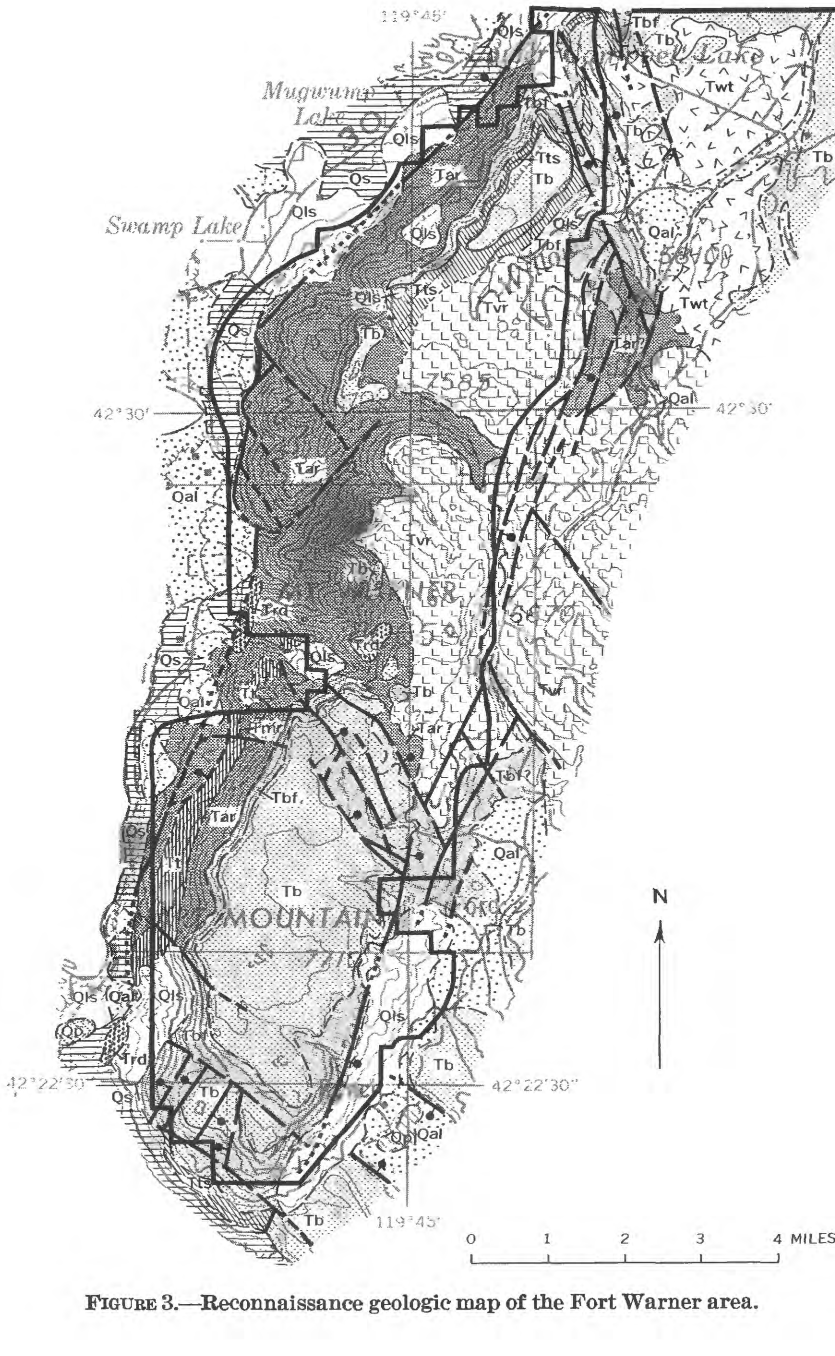

FIGURE 3.—Reconnaissance geologic map of the Fort Warner area.

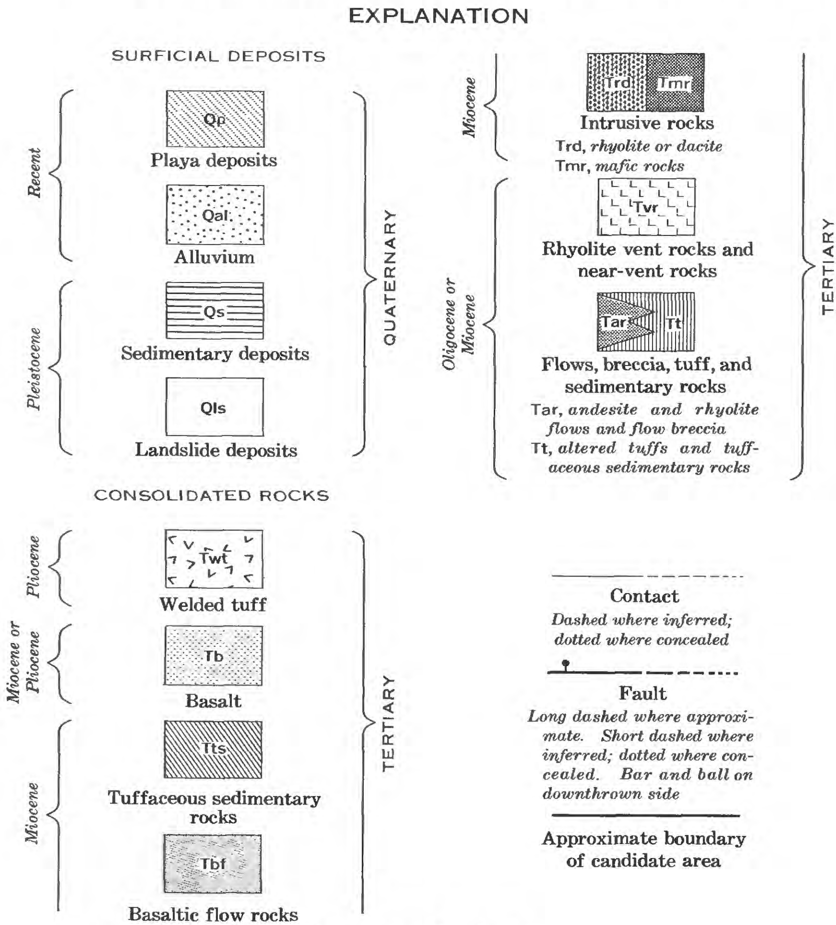

FIGURE 3.—Continued

ticularly south of De Garmo Canyon. The precise age of the rocks is not known, but their stratigraphic position beneath rocks dated as middle and late Miocene and the degree and type of their alteration suggest that they may in part be correlative in age with the John Day Formation of central Oregon (late Oligocene and early Miocene). However, the upper part of the sequence is thought to be somewhat younger than the typical John Day Formation and perhaps as young as middle Miocene.

Southwest of Mount Warner, the oldest rocks consist of a thick continuous unit of altered tuffs and tuffaceous sedimentary rocks (fig. 3). The rocks are composed chiefly of pumice lapilli and glass shards or their alteration products. They are localized on the flanks of a large silicic volcanic pile, most of which was erupted from vents a few miles northeast of Mount Warner. These clastic rocks contain zeolites of possible commercial importance, and are of three types: well-sorted tuffs, many of which formed directly from falls of ash on land; poorly sorted volcanic sandstone and siltstone of probable slurry-flood origin; and pumice lapilli tuffs and tuff breccias, which were deposited by nuées ardentes or by mudflows.

The well-sorted tuffs occur in beds less than a foot thick. They are laminated in places, are fine to medium grained, and consist mainly of ash and small pumice lapilli. The well-sorted tuffs form only a small part of the section in the area west-southwest of Mount Warner. In these tuffs the glass is completely altered to clinoptilolite and mixed-layer montmorillonitic (bentonitic) clay with some mordenite, phillipsite, calcite, and celadonite. A few pure vitric tuffs are now 90–95 percent clinoptilolite. Rocks having small amounts of clay but abundant zeolites are yellow brown, whereas those rich in clay but poorer in zeolites are shades of green.

Farther south the well-sorted tuffs are more abundant and tend to be finer grained and less altered than those to the north. All the glass shards are finely devitrified to alkali feldspar and silica minerals, and contain minor amounts of clay minerals, sodic plagioclase, clinoptilolite, and mordenite.

Poorly sorted volcaniclastic sedimentary rocks are interbedded with the well-sorted tuffs, commonly along erosional contacts. These rocks form a large part of the section west-southwest of Mount Warner, but a very much smaller part farther south. They consist largely of coarse-ash- to fine-lapilli-size volcanic rock fragments in a matrix of fine- to medium-size vitric ash and detrital clay—the matrix making up more than half of some rocks. The volcaniclastic sedimentary deposits occur in beds several inches to a few feet thick that are lenticular and commonly channeled.

The greater proportion of well-sorted tuffs to the south and their generally finer grain size suggest a greater distance from the source vents than the tuffs farther north. The poor sorting, channeling, and erosional lenticularity suggest that the rocks are products of slurry floods or overloaded streams that periodically scoured loose debris from hill slopes and carried it in a muddy suspension far out into adjacent lowlands.

Alteration of the poorly sorted volcanic sandstone and siltstone is similar to that affecting the well-sorted tuffs. Zeolites are less abundant, however, inasmuch as vitric ash, the material most susceptible to zeolitization, is less plentiful than in the air-fall tuffs.

Nuées ardentes and mudflow deposits about 10–50 feet thick make up most of the upper half of the stratigraphic section west-southwest of Mount Warner, but they form less than a quarter of the unit farther south. These chaotic lapilli tuffs and tuff breccias are interlayered with slurry flood deposits and air-fall tuffs. Commonly, the underlying rocks show evidence of having been gouged and scoured along the contact, and ripped-up fragments of tuff and volcaniclastic sediments are dispersed throughout the lower parts of some of the lapilli tuffs and tuff breccias. The lithology and relationships to interbedded rocks suggest that the unsorted lapilli tuffs and tuff breccias are products of near-vent nuées ardentes or, possibly, thick mudflows carrying newly erupted ash, pumice, and lithic fragments away from the vent areas.

The lapilli tuffs and tuff breccias are altered to zeolites and clay similar to those in the interlayered rocks.

Silicic flow and intrusive rocks, principally rhyolite or dacite but including some soda rhyolite (Walker, 1961), occur near the top of the sequence of tuffs and tuffaceous sedimentary rocks. Some of these silicic rocks are delineated in figure 3 as intrusive rocks (map unit Trd); most of them, however, are included either in the rhyolitic vent rocks (unit Tvr) near Mount Warner, or in the upper part of the older flows, breccias, and tuffs (unit Tar) that are essentially conformable with other layered rocks outside the vent area.

A regional unconformity, with hundreds and perhaps several thousand feet of relief, separates this older sequence of clastic and silicic rocks from the overlying basaltic flow rocks that are partly correlative with the Steens Basalt (Steens Mountain Basalt of Fuller, 1931, p. 101–113) of middle(?) and late Miocene age (Walker and Repenning, 1965; Evernden and others, 1964). These flows and associated scoria and breccia more than 1,800 feet thick form most of the scarp on Poker Jim Ridge, but they thin southward and lap out on Hart Mountain several miles north of De Garmo Canyon. The basalt flow rocks reappear a few miles south of Mount Warner and thicken to several hundred feet at the south end of Hart Mountain.

The basaltic flow rocks are overlain by a discontinuous but widespread unit of poorly bedded moderately well sorted tuffaceous sedimentary rocks composed largely of vitric ash and detrital clay. Sparse vertebrate fossils, found in several places in the northern part of the Fort Warner candidate area (Walker, 1960), indicate approximate age equivalence with the Beatty Butte (Wallace, 1946), Mascall (Downs, 1956), and Virgin Valley (Merriam, 1910) faunas of late middle or late Miocene age. In contrast to the older tuffaceous sedimentary rocks of Oligocene or early Miocene age, most of the vitric ash is fresh or only slightly altered, and no zeolites were recognized in any samples tested.

A thin unit of basalt overlies the tuffaceous sedimentary rocks. It is not precisely dated, but is either of late Miocene or early Pliocene age. In places the flows rest directly on the Miocene basaltic flow rocks and elsewhere on the intervening fossiliferous Miocene tuffaceous sedimentary rocks. In adjoining parts of the region the tuffaceous sedimentary rocks may interfinger with both the overlying and underlying basalt flows.

A thin discontinuous sheet of pumice lapilli welded tuff crops out in some of the flatter parts of the refuge—mostly north and east of the two candidate areas. Several small patches of the tuff occur along the eastern boundary of the Poker Jim Ridge candidate area, and more extensive outcrops are present near the headquarters of the refuge between the two candidate areas. The tuff is about 15 feet thick in the northern part of the refuge but thin southwestward. The ashflow tuff in areas several miles to the east and north has been determined to be of early or middle Pliocene age, both by potassium-argon isotopic methods and from vertebrate fossils collected from adjacent sedimentary beds. The tuff, moderately to poorly welded, is light gray and pale yellowish to pinkish brown. It is composed dominantly of pumice fragments and glass shards that locally are converted to secondary alkali feldspar and cristobalite or quartz through vapor-phase alteration.

VENT ROCKS

Intrusive vent rocks and extrusive near-vent rocks of several different kinds have been recognized near Mount Warner and in several places along the major faults at the west base of Hart Mountain. Only the larger masses of these rocks are shown in figure 3.

Minor amounts of red cindery near-vent scoriaceous andesite and several small dikes and sills are associated with the older andesite flows and flow breccias of map unit Tar. The scoria and intrusive rocks probably represent in part the source of the flows and breccias. Most of the vent rocks in the refuge, however, are flow-banded locally brecciated porphyritic rhyolite or dacite, in the form of intrusive or exogenous domes and closely associated flows. Several of the intrusive masses and related near-vent flows are soda rhyolite characterized by phenocrysts of anorthoclase and microlites of anorthoclase, riebeckite(?), acmite, and aenigmatite-rhonite(?) (Walker, 1961). The largest accumulation of silicic vent rocks lies east of Hart Mountain and parts extend into the Fort Warner candidate area near Mount Warner.

All of the vent rocks are Oligocene or Miocene in age and none exhibits evidence of associated metallic mineralization or strong alteration.

SURFICIAL DEPOSITS

Unconsolidated surficial deposits within the Hart Mountain National Antelope Refuge include landslide debris, pluvial lake sediments, alluvium, and playa deposits, most of which are of late Pleistocene or Recent age, although some may be latest Pliocene.

Several of the large landslides that originated on the precipitous west side of Hart Mountain slid laterally into the large pluvial lake that occupied Warner Valley during the Pleistocene. Apparently, the mobility of these landslides was greatly increased as they mixed with the lake waters. This mobility permitted completely unsorted material, including blocks of basalt as much as 4–5 feet in diameter, to advance far across the nearly flat lake floor. In places these landslide lobes extend for more than a mile from the base of Hart Mountain.

The alluvium consists mostly of sedimentary deposits that are fine grained and well sorted along gentler stream channels but are very coarse and poorly sorted in the large alluvial fans at the west base of Hart Mountain and Poker Jim Ridge. Some talus and fluvio-glacial deposits are also included in the alluvium, and in Warner Valley the near-surface alluvium locally contains minor amounts of peat mixed with clastic debris.

During periods of drought, small amounts of saline minerals form surface crusts in playas and in the shallow basins of the transient lakes of Warner Valley.

STRUCTURE

The two candidate areas are parts of a major structural feature consisting of a great complex horst on the south that forms Hart Mountain and a large faulted monoclinical warp on the north that forms Poker Jim Ridge. Structural elements transitional from the monoclinal warp to the horst are present in and between the candidate areas.

Both of the candidate areas are separated from Warner Valley—a very large and complex graben on the west and southwest—by an arcuate zone of north-trending normal faults whose aggregate displacement is more than 2,000 feet. The east side of Poker Jim Ridge is principally a dip slope of basalt and is only locally broken and faulted. The east side and north end of Hart Mountain, however, are bounded by low and less preciptious scarps in a zone of normal faults having an aggregate displacement of about 1,000 feet.Tilted fault blocks on the east side of Hart Mountain in places represent the broken parts of the original monoclinal structural feature that now characterizes Poker Jim Ridge and that once extended to Hart Mountain. The Hart Mountain fault block, which is nearly flat topped and about 14 miles long and 2 miles wide, is cut by several normal faults that have displacements of several tens of feet and, in places, is intruded by masses of rhyolite, dacite, and andesite or basalt. The largest pile of rhyolite and dacite, in the east central part of Hart Mountain, must have been a volcanic mountain in middle to late Miocene time, because the middle(?) and late Miocene basalt flows lap out against these rocks.

Some aspects of the origin of the huge fault-block structural features in southeast Oregon, including Hart Mountain and Poker Jim Ridge, have been described by Fuller and Waters (1929).

MINERAL RESOURCES

REGIONAL FEATURES

Some metallic and nonmetallic mineral deposits have been exploited on a small scale in the region that includes the Hart Mountain National Antelope Refuge. Within the refuge, however, there is no past record of mining or quarrying and only a few minor occurrences of potentially valuable minerals have been reported.

Brooks (1963, p. 171–179) notes the presence of several commercial quicksilver deposits, including one with small production in the Coyote Hills about 10 miles west of Hart Mountain, and he lists one minor occurrence on Hart Mountain with no recorded production. Deposits of uranium, locally associated with some molybdenum and a minor amount of antimony, quicksilver, and lead have been discovered several tens of miles east and west of the refuge (Matthews, 1955; Peterson, 1959a), although recorded production of uranium ores from south-central Oregon has come only from the deposits northwest of Lakeview. Nearly all of these metallic mineral deposits are either in silicic intrusive rocks or in the adjacent wallrocks and are probably of hydrothermal origin closely related genetically to the intrusive rocks.

Deposits of low-grade diatomite and bentonite and several perlite deposits have been located in parts of the region (Moore, 1937; Peterson, 1961). Although some of these deposits have been explored in a limited way, mostly by bulldozer trenching, none have been of sufficiently high grade or close enough to potential markets to warrant commercial exploitation.

Several of the large desert basins of the general region have been explored for saline minerals, notably potash salts and borates (Phalen, 1917; Libbey, 1960; Ore Bin, 1960). Some borax was produced from Alvord Valley, in southern Harney County, about 1900 (Struthers, 1904, p. 894). A minor and noncommercial occurrence of ulexite was discovered on the shore of Flagstaff Lake (R. S. Mason, written commun., 1952), a few miles northwest of Hart Mountain. Precious fire opal has been collected in the Virgin Valley area of northern Nevada and also in minor amounts from several areas on the west face of Hart Mountain, where it occurs as detrital fragments and as vesicle and fracture fillings in basalt flows (Dake, 1954).

Sporadic interest in the petroleum and gas potential of the region has centered either in the Lakeview area, 40–50 miles to the west, or in areas at even greater distances from Hart Mountain to the northeast. The most recent petroleum activity in the region, during the late 1950's and early 1960's, culminated in the drilling of two deep test wells, one 20–25 miles northwest of Lakeview and the other several miles south of Lakeview, in a volcanic terrane geologically similar to that on the refuge. The tests were negative, and interest in the area subsequently waned.

MINERAL POTENTIAL OF CANDIDATE AREAS

The Fort Warner and Poker Jim Ridge candidate areas contain few, if any, resources of metallic minerals and no apparent potential for the commercial production of saline minerals, petroleum, sulfur, coal, oil shale, or peat. Small amounts of precious opal occur on Hart Mountain and are of interest to mineral collectors. Both areas contain noncommercial bentonitic (montmorillonitic) tuffaceous sedimentary rocks. The Fort Warner area contains the potentially valuable mineral commodity clinoptilolite, a potassium-sodium-calcium zeolite.

Thin-section and X-ray analyses of many samples collected throughout both candidate areas indicate that several different zeolites are present—principally clinoptilolite, mordenite, and phillipsite, with minor heulandite (?). These zeolites are concentrated in the older upper Oligocene or lower Miocene tuffs and tuffaceous sedimentary rocks on the west face of Hart Mountain in the Fort Warner candidate area. Most of these rocks contain only minor amounts of zeolites, but some of the thin-bedded fine-grained tuffs in the sequence, originally nearly pure vitric ash, are now composed of 90–95 percent clinoptilolite. Mordenite, phillipsite, and heulandite (?) are much less abundant, constituting less than 10 percent of any of the rocks tested. The precise distribution, volume, and grade of zeolitized tuffs is not established.

The value and mineral economics of naturally occurring zeolites, including clinoptilolite, are not yet clearly established, although some aspects of their use as absorbants of radioactive or other waste products are briefly described by Brown (1962). The interest in natural zeolites is increasing, however, and certain deposits in the Western United States, including some in central and southern Malheur County in southeast Oregon, are being explored at present (1966) by private industry.

Natural zeolites have been found in large amounts in areas more accessible than the Fort Warner candidate area, including some extensive deposits of clinoptilolite in the John Day Formation of central Oregon (Hay, 1962; Fisher, 1962). Under conditions existing in 1966, the potential value of the deposits of clinoptilolite within the Fort Warner candidate area is difficult, if not impossible, to estimate.

POTENTIAL FOR GEOTHERMAL POWER

Several thermal springs in the Hart Mountain National Antelope Refuge (Stearns and others, 1937, p. 175) and along the eastern edge of Warner Valley, about 10 miles southwest of Hart Mountain (Peterson, 1959b), suggest that an as yet undetermined potential for thermal power may exist in the area (Groh, 1966). All the thermal springs are small, however, and the few recorded surface temperatures of the hot water are about 94°C or less—temperatures well below those currently used for the generation of power (White, 1965, table 1; Bodvarsson, 1966). Nevertheless, the presence of these springs in an area characterized by relatively young (middle to late Cenozoic) volcanism and intense faulting suggests that higher temperatures probably occur at depth, particularly adjacent to major faults and in large intrusive bodies. However, there is no way to determine, without physical exploration, whether temperatures adequate for thermal power exist at depth in the candidate areas.

CONCLUSIONS AND RECOMMENDATIONS

Neither the Fort Warner nor the Poker Jim Ridge candidate area in the Hart Mountain National Antelope Refuge contains deposits of mineral fuels, metallic minerals, or, with one exception, nonmetallic minerals that may be considered as potential mineral resources. The Fort Warner candidate area contains some high-grade deposits of the zeolite clinoptilolite. A growing demand for zeolites is evident, but readily accessible deposits are widely available in central Oregon, as well as in many other States.

Insofar as mineral content is a determining factor, the Poker Jim Ridge area is well suited for inclusion in the wilderness system. However, in weighing the values of wilderness as against other values of the Fort Warner area, it is recommended that consideration be given to the zeolite potential of this area.

REFERENCES CITED

Bodvarsson, Gunnar, 1966, Energy and power of geothermal resources: Ore Bin, v. 28, no. 7, p. 117–124.

Brown, R. E., 1962, The use of clinoptilolite: Ore Bin, v. 24, no. 12, p. 193–197.

Brooks, H. C., 1963, Quicksilver in Oregon: Oregon Dept. Geology and Mineral Industries Bull. 55, 223 p.

Dake, H. C., 1954, Opal in Oregon: Mineralogist, v. 22, no. 2, p. 68, 70.

Downs, Theodore, 1956, The Mascall fauna from the Miocene of Oregon: California Univ. Pubs. Geol. Sci. v. 31, no. 5, p. 199–354.

Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: Am. Jour. Sci., v. 262, no. 2, p. 145–198.

Fisher, R. V., 1962, Clinoptilolite tuff from the John Day Formation, eastern Oregon: Ore Bin, v 24, no. 12, p. 197–203.

Fuller, R. E., 1931, The geomorphology and volcanic sequence of Steens Mountain in southeastern Oregon: Washington Univ. Geology Pub., v. 3, no. 1, p. 1–130.

Fuller, R. E., and Waters, A. C, 1929, The nature and origin of the horst and graben structure of southern Oregon: Jour Geology, v. 37, no. 3, p. 204–238.

Groh, E. A., 1966, Geothermal energy potential in Oregon: Ore Bin, v. 28, no. 7, p. 125–135.

Hay, R. L., 1962, Origin and diagenetic alteration of the lower part of the John Day Formation near Mitchell, Oregon, *in* Geol. Soc. America, Petrologic studies; a volume in honor of A. F. Buddington: New York, p. 191–216.

Larson, E. E., 1965, The Structure, stratigraphy, and paleomagnetics of the Plush area, southeastern Lake County, Oregon: Colorado Univ., Ph. D. thesis.

Libbey, F. W., 1960, Boron in Alvord Valley, Harney County, Oregon: Ore Bin, v. 22, no. 10, p. 97–105.

Matthews, T. C., 1955, Oregon radioactive discoveries in 1954 and 1955: Ore Bin, v. 17, no. 12, p. 87–91.

Merriam, J. C., 1910, Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada. Pt. 1, Geologic history: California Univ. Dept. Geology Bull., v. 6, no. 2, p. 21–53.

Moore, B N., 1937, Nonmetallic mineral resources of eastern Oregon: U.S. Geol. Survey Bull. 875, 180 p.

Ore Bin, 1960, Active mines and mills in Oregon in 1960: Ore Bin, v. 22, no. 9, p. 85–88.

Peterson, N. V., 1959a, Preliminary geology of the Lakeview Uranium Area, Oregon: Ore Bin, v. 21, no. 2, p. 11–16.

——— 1959b, Lake County's new continuous geyser [Oregon]: Ore Bin, v. 21, no. 9, p. 83–88.

——— 1961, Perlite occurrences in southeastern Klamath and southwestern Lake Counties, Oregon: Ore Bin, v. 23, no. 7, p. 65–70.

Phalen, W. C., 1917, Potash salts, including simple tests for potash, by W. B. Hicks: U.S. Geol. Survey, Mineral Resources United States, 1915, pt. 2–1., Nonmetals, p. 95–133.

Russell, I. C., 1884, A geological reconnaissance in southern Oregon: U.S. Geol. Survey Ann. Rept. 4, p. 431–464.

Stearns, N. D., Stearns, H. T., and Waring, G. A., 1937, Thermal springs in the United States: U.S. Geol. Survey Water-Supply Paper 679–B, 59–206 p.

Struthers, Joseph, 1904, Borax: U.S. Geol. Survey Mineral Resources United States, Calendar Year 1902, aa, p. 891–896.

Walker, G. W., 1960, Age and correlation of some unnamed volcanic rocks in south-central Oregon: U.S. Geol. Survey Prof. Paper 400-B, p. B298-B300.

——— 1961, Soda rhyolite (pantellerite?) from Lake County, Oregon; U.S. Geol. Survey Prof. Paper 424-C, p. C142-C145.

Walker, G. W., and Repenning, C. A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake, Harney, and Malheur Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-446, scale 1:250,000.

Wallace, R. E., 1946, A Miocene mammalian fauna from Beatty Buttes, Oregon: Carnegie Inst. Washington Pub. 551, p. 113-134.

White, D. E., 1965, Geothermal Energy: U.S. Geol. Survey Circ. 519, 17 p.

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