UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGIC MAP OF NEWBERRY VOLCANO, DESCHUTES, KLAMATH, AND LAKE COUNTIES, OREGON

By

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This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

Howel Williams (1935) provided the first comprehensive study of the geology of Newberry Volcano. It was based on fieldwork done in a brief period of time when roads and transportation were limited and before some volcanologic phenomena were well understood. Nevertheless it was a remarkable study. Subsequent investigations by Higgins (1969, 1973), Higgins and Waters (1968, 1970), Peterson and Groh (1969), Beyer (1973), Friedman (1977) and others have provided substantial new data and interpretations, but have concentrated on the summit caldera and young flank flows. Most of the flank rocks have a surface veneer of Mazama ash derived from Mt. Mazama (Crater Lake), lack significant erosion in many areas, and are locally buried by widespread tephra deposits from eruptions in the summit caldera. No prior geologic mapping of the entire volcano has been undertaken since the brief reconnaissance by Williams (1935, 1957).

The geologic map presented here is a product of an evaluation of the geothermal potential of Newberry Volcano conducted under the Geothermal Research Program of the U.S. Geological Survey. Fieldwork was done in the summers of 1976, 1977, and 1978, during which time we also mapped adjacent areas. The results of geothermal exploration drilling, which identified a shallow, high-temperature (265°C) zone beneath the caldera, are presented elsewhere (Sammel, 1981; MacLeod and Sammel, 1982). A guidebook to Newberry Volcano by MacLeod and others (1981) lists distinctive outcrop localities and summarizes the geologic evolution of the volcano and its summit caldera.

The base for the geologic map is a mosaic of sixteen 1:24,000-scale topographic maps (fig. 1) which has been reduced to 1:62,500. Owing to the scale reduction, letters and numbers on the base map are difficult to read; for clarification of names and elevations the reader is referred to the original 1:24,000-scale topographic maps. In addition, the four 1:24,000-scale maps of the southeast sector of the volcano are preliminary unpublished maps that have neither lettering nor numbers on them; the reader is referred to other maps for names of topographic features there. We refer to names of volcanic features in the summit caldera and of young flows on the flanks following the usage of other authors (Williams, 1935, 1957; Peterson and Groh, 1969; Higgins, 1973; Friedman, 1977).

In compiling this geologic map, we attempted to determine the distribution of rock units that lay buried beneath surficial fragmental rocks (largely tephra deposits). Many rock units have very limited exposure and the locations of some contacts shown on the map are based on topographic expression. In rare cases, rock units shown on the map do not crop out, but their location was suggested by geomorphic expression and they were identified by digging deep holes through the surface veneer

121°30' | 121°15' | 121° — 44° / 43°45' / 43°30'

Benham Falls 1963 (20)	Lava Butte 1963 (20)	Kelsey Butte 1967 (10)	Horse Ridge 1967 (20)
Anns Butte 1963 (20)	Lava Cast Forest 1963 (40)	Fuzztail Butte 1967 (40)	Evans Well 1967 (10)
Finley Butte 1963 (20)	Paulina Peak 1963 (40)	Newberry Crater 4NW (unpub.) (20)	Newberry Crater 4NE (unpub.) (20)
Moffit Butte 1963 (20)	Spring Butte 1963 (20)	Newberry Crater 4SW (unpub.) (20)	Newberry Crater 4SE (unpub.) (20)

Figure 1. Index map showing names and dates of publication of 7-1/2', 1:24,000 scale topographic maps utilized to make base map. Contour intervals, in feet, are shown in brackets.

of fragmental rocks. The surficial tephra deposits in and near the caldera have a complicated stratigraphy, show little erosion, and were studied mostly in holes dug into them. We were unsuccessful in delineating most of the individual tephra units and were forced to show them as undifferentiated deposits derived from several vents of different ages; they warrant further work because they can provide data needed to decipher some of the later stages of volcanism and magma evolution.

Ages of Holocene rock units determined by ^{14}C methods are reported in ^{14}C years. Carbon that is 3,000 to 7,000 years old yields ^{14}C ages that are 100 to 700 years younger than the real age. Thus, rocks which have a ^{14}C age of 6,100 years have a real age of about 6,800 years (see Faure, 1977, Fig. 17.3). For rocks younger than 3000 years the deviation in age is less than 100 years. In contrast, the reported hydration-rind ages of obsidian flows should represent absolute ages. We divide Holocene rocks into two parts based on their age relations to Mazama ash. Bacon (1982) estimates Mazama ash to have a ^{14}C age of about $6{,}845 \pm 50$ years based on numerous new and published isotopic determinations. Rocks referred to the upper Holocene are younger than Mazama and those of the lower Holocene are older.

E. H. McKee has determined the K-Ar age of many of the rock units on and adjacent to Newberry Volcano. A complete list of these K-Ar ages and the locations of the samples is given in Fiebelkorn and others (1982). Some K-Ar ages, determined on whole rocks and on plagioclase, do not correspond to known geologic relations and some replicate age determinations on individual rock bodies are discordant. This apparently is caused by the combination of relatively youthful age, low potassium content, and large degree of contamination by atmospheric argon; also some anomalously old ages probably result from incorporation of radiogenic argon in the rocks when they formed. We refer in the rock descriptions below only to those K-Ar ages which we consider to be reliable or for which we have insufficient data to constrain the age.

A large number of Newberry rocks have been analyzed (see particularly Higgins, 1973, and Beyer, 1973) and we augmented these with numerous new analyses. In the rock descriptions below we refer principally to the SiO_2 content rounded to the nearest weight percent and based on analyses that have been recalculated water-free to 100 percent.

The volcanic rock names used in this report are based largely on chemical composition; rocks for which analyses are not available were compared petrographically to analyzed rocks. We classify the rocks in 5 percent increments of SiO_2 content as follows: basalt, less than 52; basaltic-andesite, 52-57; andesite, 57-62; dacite, 62-67; rhyodacite, 67-72; and rhyolite, 72 or more. Although rocks which crop out at Newberry Volcano form a bimodal assemblage in which basaltic-andesite with about 54 percent SiO_2 and rhyodacite and rhyolite with 72 percent dominate, analyzed rocks include every SiO_2 percent from 47 to 75.

CONTACT--Approximately located or inferred. Dotted where concealed (caldera only; concealed unit shown in bracket, surficial unit without bracket)

MARGIN OF INDIVIDUAL Qb FLOW--Based partly on interpretation of aerial photographs

INFERRED POSITION OF SUBSURFACE FISSURE

FAULT--Dotted where concealed; ball on apparent downthrown side

INFERRED CALDERA RING FAULT--Ring faults are entirely concealed and lie near or inward from indicated position

2 — ISOPACH OF QHt--Contour interval is 0.25 m.

× 172 — THICKNESS OF QHt--numbers are in centimeters.

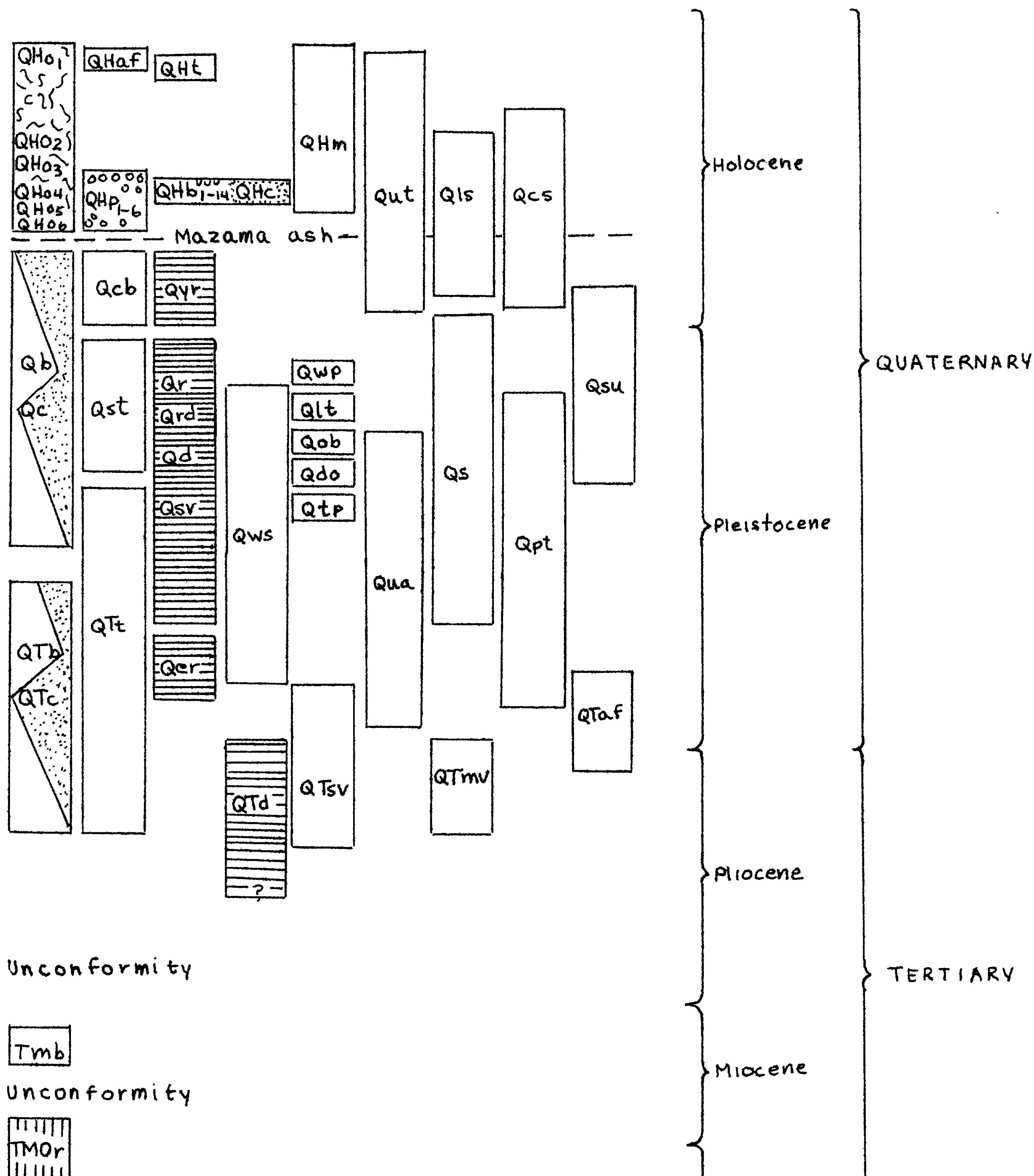
ISOPACH OF QHc CINDER FALL DEPOSITS--Contours are in centimeters; t = trace

X — LOCATION OF VENT FOR QHo, QHp and Qyr

U.S.G.S. GEOTHERMAL WELLS IN CALDERA AND ON NORTHEAST FLANK

× H.S. × F. — HOT SPRINGS (H.S.) AND FUMAROLE (F.) IN CALDERA

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

QHo_{1-6} RHYOLITIC OBSIDIAN FLOWS IN CALDERA (upper Holocene)--Flows consist of banded, massive to vesicular or pumiceous, nearly aphyric obsidian. Most obsidian is dark gray or black; brown colored obsidian locally results from collapse of originally vesicular or pumiceous slightly oxidized obsidian. Surfaces of flows have concentric ridges and valleys formed of blocky dense to pumiceous obsidian and contain scattered small craters, possibly of phreatic origin. Flow fronts are generally steep and as high as 25 m. Vents for flows are shown by "X". Includes:

QHo_1 Big Obsidian flow--Age about 1,300 years based on ^{14}C age of underlying QHaf and hydration-rind age of obsidian. Flow is youngest volcanic unit on Newberry Volcano. 73 percent SiO_2.

QHo_2 East Lake obsidian flows--Hydration-rind age is 3,500 years. Probably fourth oldest unit; older than QHo_1, QHaf, and QHt. 73 percent SiO_2.

QHo_3 Central Pumice Cone obsidian flow--Hydration-rind age is 4,500 years. Reported age is younger than that of Central Pumice Cone (6,700 years); ages may both be 6,700 years if, as seems likely, the flow represents the remains of a ponded lava lake (see Qhp_1). 73 percent SiO_2

QHo_4 Game Hut obsidian flow--Hydration-rind age is 6,700 years. May be derived by draining of former lava lake interpreted to have partly filled Central Pumice Cone. 73 percent SiO_2.

QHo_5 interlake obsidian flow. Hydration-rind age is 6700 years. Younger than Central Pumice Cone. 73 percent SiO_2.

QHo_6 unnamed small pumiceous obsidian flow in pumice ring east of Big Obsidian flow. Undated: does not have obvious Mazama ash on its surface, but is covered by pumice fall deposit (QHT) and conceivably may be older than Mazama.

Hydration-rind ages reported above are by Friedman (1977). Numerous chemical analyses of flows by Williams (1935), Laidley and McKay (1971), Higgins (1973), Beyer (1973), and MacLeod (unpublished data) show that the obsidian flows differ only slightly in chemical composition. Laidley and McKay (1971) show that the Big Obsidian flow is homogeneous in chemical composition, based on 91 analyses. The flows and related tephra deposits (QHt, QHaf, QHp, Qut), as well as some slightly older rhyolites (Qyr), differ from most other rhyolitic rocks on Newberry Volcano in their much higher Rb/Sr ratio and to a lesser extent in their content of other trace elements. Chemical similarities suggest all the young relatively evolved rhyolites are derived from the same magma, even though erupted over an interval exceeding 6,000 years. Chemical differences, though slight, suggest the SiO_2 and K_2O content is systematically lower for progressively younger rocks and that systematic changes also occur for other major oxides and trace elements (Laidley and McKay, 1971; MacLeod, unpublished data). Also, even though most of the rocks are nearly aphyric, the younger ones have progressively fewer phenocrysts.

QHaf ASH-FLOW TUFF OF PAULINA LAKE (upper Holocene)--Extends west and north of Big Obsidian flow to Paulina Lake. Typically consists of a massive poorly sorted pinkish-brown deposit of ash shards and pumiceous ash, lapilli, and blocks and less common ash- and lapilli-size accidental lithic fragments. Pumice blocks are most abundant near top of unit. Lapilli and blocks are rounded. Deposits on slopes southwest of Big Obsidian flow are complex. Holes dug in these deposits expose many thin ash-rich units which may be ash-flow cloud deposits or parts of a pumice ring associated with the vent. Deposits at the northeast end of unit consist of pinkish ash with only rare pumice lapilli, are massive to well bedded, and are ash-flow cloud deposits and secondary flowage deposits derived from them. They extend as deposits less than 20 cm thick east beyond mapped contact beneath a thin cover of reworked pumice deposits and also also occur locally (included in Qut) farther south along east side of Big Obsidian flow. Deposits of pumiceous ash, lapilli, and blocks that occur at the north margin of the unit along the shoreline of Paulina Lake are well bedded and may be of phreatic origin due to interaction of hot tuffs and cool lake water. Age about 1,300 ^{14}C years based on ^{14}C ages of 1,270$\pm$60 (Pierson and others, 1966), 1,340$\pm$60 (S. W. Robinson, written commun., 1979), and 1,390$\pm$200 years (Meyer Reubin, _in_ Friedman, 1977); older age (2,054$\pm$230 years) reported by Libby (1952). Except for Big Obsidian flow (QHo_1), which overlies southern part of deposit, this is youngest volcanic unit on Newberry Volcano. Pumice in deposit is nearly aphyric, has 73 percent SiO_2, and is chemically indistinguishable from Big Obsidian flow (QHo_1) and pumice fall deposit (QHt) that extends across east flank of volcano.

QHt RHYOLITIC PUMICE FALL DEPOSIT (upper Holocene)--Derived from the same vent as the Big Obsidian flow (QHo_1) and covers southern part of caldera and east flank of volcano (Sherrod and MacLeod, 1979). Outcrop area and thickness shown by isopachs; numbers on map show thickness of fall at individual localities. Consists of well sorted angular light-gray pumice lapilli and lesser lithic fragments (red cinders, basalt, obsidian, rhyolite, etc.) and ash. Contains breadcrusted obsidian blocks and accidental blocks to more than 1 m in diameter in area extending 2 km east from vent. Deposits within 2 km of vent consist of many thin units in upper part and lower part was not penetrated even in deep holes dug in deposit. Between 2 and 9 km east of vent, upper part of deposit contains 1 to 5 pumice lapilli beds separated by centimeter-thick ash beds and overlies a thick lower massive part which forms most of the deposit. Farther from vent deposit consists of single unit which is coarsest-grained in lower one-third. Median grain size decreases regularly eastward from a diameter of 1.1 cm at 3 km, 0.75 cm at 15 km, to 0.3 cm at 45 km. 25-cm-isopach extends beyond east edge of map to a distance of 60 km from vent with its axis oriented N 82° E. Age about 1,600 ^{14}C years based on reported ^{14}C ages of 1,720±250 (Higgins, 1969) and 1,550±120 years (S. W. Robinson, written commun. 1979). Although related to QHaf, and probably essentially the same age, ^{14}C ages suggest QHt may have been erupted about 300 years before QHaf. Pumice is essentially aphyric and is uniform in composition in vertical section. It has the same major- and trace-element composition as QHaf and the Big Obsidian flow.

QHm PUMICEOUS MUDFLOWS (upper Holocene)--Poorly sorted pumiceous ash, lapilli, and blocks with rare accidental lithic fragments in deposits which fill floors of ravines. Pumiceous mudflow deposits on upper south flank overlie and are typically much coarser grained and more poorly sorted than QHt and may have been produced during eruptions that formed QHaf. Deposit in small ravine northeast of Paulina Lake probably formed immediately after adjacent pumice cones (QHp_3) which are only slightly younger than Mazama ash.

QHp_{1-6} PUMICE CONE AND PUMICE RING DEPOSITS OF THE CALDERA (upper Holocene)--Consists of poorly to well bedded and sorted deposits of pumiceous ash, lapilli, and blocks that dip away from central craters. Flanks of cones are as steep as 20 to 30 degrees, and crater walls are also steep-sided. Rings have lesser topographic expression and lower slopes. Contacts of cones and rings with adjacent tephra deposits are arbitrary and largely based on geomorphic expression. Includes:

- QHp_1 Central Pumice Cone, between Paulina and East Lakes. Hydration-rind age is 6,700 years (Friedman, 1977). Contains massive and agglutinated obsidian plastered onto the innerwall midway from the top that may represent a "bathtub-ring" remnant of a former lava lake. The Game Hut obsidian flow (QHo_4) may have been produced by draining of this lava lake and the obsidian flow in the crater of the cone (QHo_3) may represent the remnants of the lake.
- QHp_2 pumice deposits that surround the vent at north end of interlake obsidian flow. Probable age is about 6,700 years.
- QHp_3 pumice cone complex west of interlake obsidian flow. Younger than Mazama ash and older than interlake obsidian flow.
- QHp_4 large pumice ring partly filled by Big Obsidian flow. Contains small satellitic crater on southeast side. No Mazama ash was noted on this ring deposit, but it is locally covered by other tephra deposits, is weathered, and may be older than Mazama.
- QHp_5 elongate small pumice ring along inner south wall. Overlain by QHt and probably younger than Mazama ash.
- QHp_6 poorly developed pumice ring near inner caldera wall south of East Lake. Overlain by QHt and probably younger than Mazama ash.

Game Hut obsidian flow (QHo_4) may fill the broad crater of an unmapped poorly preserved pumice ring. Probable pumice ring deposits around the vent for the Big Obsidian flow are included in Qut. The pumice blowout vent of Higgins (1973), at the top of the inner south caldera wall south of East Lake, may be part of a pumice ring, but it is completely buried by QHt. Air-fall pumice lapilli and ash deposits related to QHp are included in Qut. SiO_2 content about 73 percent; nearly aphyric.

QHb_{1-14} BASALTIC-ANDESITE FLOWS (upper Holocene)--Flows occur mostly on the northwest flank of volcano in a zone popularly referred to as the northwest rift system. Most flows are of aa or block type and have very fresh, young-appearing surfaces with only sparse vegetation, except where covered by cinders from related vents (QHc). Tree molds occur in many of the flows and are abundant in some areas, especially along flow margins. Flows on upper north flank (QHb_{9-11}) contain rhyolite and pumice inclusions. Includes:

QHb_1 Lava Butte flow, northwest flank. ^{14}C age 6,160±65 years. 55-57 percent SiO_2

QHb_2 Gas Line flow, northwest flank. ^{14}C age 5,800±150, 6,050±65, & 6,150±65 years

QHb_3 Mokst Butte flows, northwest flank. Younger than Mazama ash, probably same age as other flows in unit. 56-58 percent SiO_2

QHb_4 unnamed flow on middle north flank. Younger than Mazama ash, probably same age as other flows in unit

QHb_5 north Sugarpine Butte flow, northwest flank. ^{14}C age 5,870±100 years. 51 percent SiO_2

QHb_6 south Sugarpine Butte flow, northwest flank. Younger than Mazama ash, probably same age as other flows in unit. 53 percent SiO_2

QHb_7 Forest Road flow, northwest flank. ^{14}C age 5,960±100 years. 54 percent SiO_2

QHb_8 Lava Cast Forest flow, northwest flank. ^{14}C age 6,380±130 & 6,150±210 years. 54 percent SiO_2

QHb_9 Lava Cascade flow, northwest flank. ^{14}C age 5,800±100 years. 54-56 percent SiO_2

QHb_{10} unnamed flow on upper north flank. Younger than Mazama ash, probably same age as other flows in unit.

QHb_{11} north summit flows. ^{14}C age 6,090±65 years. Overlies pumice fall deposits related to $QHp_{1,2}$ or 3. 55-56 percent SiO_2

QHb_{12} Surveyor flow, south flank. ^{14}C age 6,080±100 years. 54-56 percent SiO_2

QHb_{13} unnamed flow on upper south flank. Overlain by pumice-fall deposit (QHt), but no Mazama ash observed on flow. 54 percent SiO_2

QHb_{14} The Dome flow, upper southeast flank. Overlain by pumice fall deposit (QHt), but no Mazama ash observed on flow.

Ages referred to above are by Peterson and Groh (1969), Chitwood and others (1977), and S. W. Robinson (written commun., 1978). These flows are all about the same age and no mafic flows are known to be younger. Chemical analyses indicate most flows are basaltic-andesite; the analyzed rocks, however, include basalt and andesite (see SiO_2 contents listed above). The rocks are fresh, dark gray, sparsely porphyritic, and vesicular. Phenocrysts consist of plagioclase with microphenocrysts of augite and olivine.

QHc CINDER CONE AND FISSURE VENT DEPOSITS (upper Holocene)--Rudely bedded bombs, blocks, lapilli, and ash which form cones, and agglutinated spatter with interbedded blocks, bombs, lapilli, and ash adjacent to fissures. Fissure vent deposits on the upper north flank locally contain small steep-walled pit craters as deep as 10 m. Flows adjacent to fissures are commonly fountain-fed and contact with agglutinated spatter of vent deposits is arbitrary. Thin cinder fall deposits extend leeward from most cones and fissures. Isopachs of cinder fall deposits associated with Lava Butte, south Sugarpine Butte, and Mokst Butte on the northwest flank are shown on map; note that Mokst Butte is a vent complex and has a cinder fall older than some of its flows and another younger than them. Cones and fissure vent deposits on middle and upper flank commonly contain scattered inclusions of rhyolite and fused vesicular rhyolitic glass. East Lake fissure on the caldera wall north of East Lake contains abundant inclusions of rhyolite, fused rhyolite, obsidian, etc. (Williams, 1935; Higgins and Waters, 1970). Age of the cinder cones and fissure vent deposits is about 6,100 ^{14}C years. East Lake fissure, the only post-Mazama basaltic vent in the caldera, has not yielded carbon for dating, but it is along an extension of fissure that fed north summit flows (QHb_{11}) about 3 km to the north which yielded a ^{14}C age of $6,090 \pm 65$ years, and they are almost certainly the same age. The East Lake fissure overlies pumice-fall deposits, probably from vents (QHp_{1-3}) on the north side of the caldera, and Mazama ash.

Qut UNDIFFERENTIATED YOUNG RHYOLITIC TEPHRA DEPOSITS (Holocene)--Consists of several units of different ages, most of which are younger than Mazama ash. Recognized subunits include: (1)Widespread and thick pumice deposit, informally called the East Lake tephra deposit for excellent exposures in roadcuts near the southwest side of East Lake. It extends eastward from approximately the longitude of Central Pumice Cone (QHp_1) and covers most of the east side of caldera and the upper east flank of volcano. Deposit is typically 4 to 5 m thick and consists of several subunits. Lower 3 m formed of massive to vaguely bedded poorly sorted pumiceous ash, lapilli, and blocks; upper 1 to 2 m consists of thin interbeds of mud-armored pumice lapilli, accretionary lapilli, and pumiceous ash and lapilli. Pumice is sparsely porphyritic. Some large pumice lapilli have breadcrusted obsidian rinds; the pumice cores of these lapilli have unusually low density. Contains scattered accidental fragments, especially of palagonite tuff. Character of unit does not change substantially even where exposed in holes dug through it on very steep slopes. Unit probably is largely of phreatomagmatic origin. Location of vent(s) is not known, but is in eastern part of caldera, and may lie beneath East Lake. It is younger than Mazama ash, older than East Lake obsidian flows (QHo_2), and apparently older than Game Hut and Interlake obsidian flows ($QHo_{4,5}$), but has not yielded carbon for dating. Chemically it is similar to all post-Mazama rhyolitic rocks in caldera and has a SiO_2 content of 74 percent. (2)Thin deposits of fine ash locally overlie East Lake tephra deposit near the southwest corner of East Lake. This ash, which is similar to ash that overlies Game Hut obsidian flow (QHo_4), is younger but its vent(s) is not known. (3)Post-Mazama age pumice-fall deposits derived from post-Mazama vents (QHp) in the caldera, especially on the upper north and east flanks of the volcano. (4)Pumice-ring and pumice-fall deposits around and east of the vent for the Big Obsidian flow (see QHt). (5)Pumice and lithic deposits related to and surrounding the vent for the East Lake obsidian flows (QHo_2). (6)Pre-Mazama-age pumice deposits were found in holes dug in Qut on the upper north and east flanks and locally in the east side of the caldera. Pre-Mazama pumiceous tephra deposits also occur at several localities along the west rim of the caldera and on Paulina Peak dome (Qrd), but their distribution is too poorly known to show on map. As a consequence of poor exposure owing to lack of significant erosion, Qut could not be subdivided. It was studied in holes, as much as 5 m deep, dug in it at scattered localities. However, significant data relevant to location, composition, and age of the products of relatively recent volcanism in the caldera could be generated by a more thorough study of these deposits. It would require digging many deep holes.

MAZAMA ASH (Holocene)--Pumiceous ash and lapilli fall deposit derived from the climactic eruption of Mount Mazama (Crater Lake) in the Cascade Range 100 km southwest of Newberry. Not shown on map. Forms a surficial deposit of variable thickness that covers most of Newberry Volcano, except where buried by younger units. Ranges from about 1.2 m thick in southwest part of map to a few centimeters thick in northeast part where it is largely reworked; deposit in caldera is typically 50 to 55 cm thick. Forms a very useful time horizon with which to distinguish relative ages of young rocks. However, it locally has been removed from surfaces of older deposits by wind and to a minor degree is wind-blown onto younger deposits. Grain-size decreases northward and eastward. Near southwest corner of map deposit consists mostly of small angular pumice lapilli and crystals; in caldera the deposit is formed mostly of coarse ash and crystals. Mazama ash on Newberry is a multiple fall unit which is coarsest at the top and contains a characteristic very fine brownish-colored ash layer near its base. Charcoal commonly occurs beneath deposit, probably the result of large lightning-caused forest fires associated with the eruption. Crystals of plagioclase, orthopyroxene, clinopyroxene, and hornblende are abundant. Easily distinguished from pumice- and ash-fall deposits derived from Newberry Volcano, especially by abundance of crystals and presence of hornblende which is rare in Newberry rocks. Numerous ^{14}C ages range mostly from 6,600 to 7,000 years; probable age about $6,845 \pm 50$ ^{14}C years (Bacon, 1982).

Qls LANDSLIDE DEPOSITS (Holocene)--Mostly older than Mazama ash, but includes talus aprons younger than Mazama. Mapped only near Paulina Peak; smaller unmapped deposits also occur locally at the base of the caldera walls in other areas, especially on the east side of East Lake.

Qcs ALLUVIAL AND LACUSTRINE DEPOSITS OF THE CALDERA (Holocene)--Consists of silt, sand, and gravel marginal to Paulina and East Lakes. Unconsolidated to well cemented pumiceous gravel and sand on the east shore of Paulina Lake, which are younger than adjacent mafic rocks (Qb and Qpt), contain abundant wood and *Equisetum*, are locally silicified, and were deposited when the water level was several meters higher than at present. ^{14}C age of wood from the deposit is $4,300 \pm 100$ years (S. W. Robinson, written. commun., 1977); Mazama ash occurs on the wave-cut terrace at the top of this deposit, however, indicating the deposit is older than Mazama. Holes dug through a surface veneer of Mazama ash southwest of Paulina Lake penetrated pumiceous sand and gravel, probably also deposited along a former higher stand of the lake. Subsequent downcutting by Paulina Creek at the outlet of Paulina Lake has lowered the lake to its present level. Unmapped gravel deposits southeast of Paulina Lake beneath QHaf and Mazama ash are higher in elevation than Qs along the shoreline; they may have been deposited along a former drainage connecting East Lake and Paulina Lake. Pumiceous gravels around East Lake are of both post- and pre-Mazama age. A post-Mazama lake level about 4 m above the present level is recorded by rounded pumice on rude terraces developed on the interlake obsidian flow (QHo_5).

Qyr YOUNG RHYOLITIC DOMES AND FLOWS OF THE CALDERA AND UPPER SOUTHEAST FLANK (lower Holocene?)--Includes: (1)Dome exposed near inner caldera wall south of East Lake and an associated obsidian flow that extends northward to East Lake. Flow is buried beneath Mazama ash and 4 to 5 m of pumiceous tephra deposits (Qut and, on south part, QHt), but was identified in deep holes dug through them; large blocks of obsidian along the south shoreline of East Lake are derived from it. (2)Small domes and pumice-ring(?) deposits on the upper southeast flank. No Mazama ash was observed on them, but they are thickly covered by pumice-fall deposit (QHt) and likely are somewhat older than Mazama ash. Rocks in this unit are chemically similar to rhyolitic rocks that are younger than Mazama ash (QHo, QHt, QHaf, QHp, and parts of Qut), but different than older silicic rocks (Qr and Qrd). SiO_2 content is 73-74 wt. percent; very sparsely porphyritic (plagioclase).

Qcb BASALTIC-ANDESITE FLOWS IN CALDERA (lower Holocene and Pleistocene?)--Includes three flows, all of which are overlain by thick pumice lapilli and ash deposits (Qut) and by Mazama ash. (1)Interlake basaltic-andesite flow of Higgins and Waters (1967) occurs along east shore of Paulina Lake and is older than adjacent strand line sediments (Qcs). Vent is presumably buried by Central Pumice Cone (QHp_1). SiO_2 content 53-54% percent. (2)Sheeps Rump basaltic-andesite flow extends to near the northeast shore of East Lake; only its steep leveed margin protrudes through Qut and Mazama ash, resulting in dike-like outcrops. SiO_2 content is 53 percent. (3)Resort flow (Higgins, 1973) occurs southeast of East Lake. It extends beneath a veneer of Qut, Mazama ash, and, locally, QHt, to the east rim fissure near the top of the caldera wall. Flow has highly variable phenocryst content and it and the east rim fissure (included in Qc) range from basaltic-andesite to rhyodacite (SiO_2 ranges from 56 to 68 percent); they may be products of mixed magmas. Small fountain-fed flows, locally associated with other pre-Mazama basaltic vents on the north caldera walls, are included in Qc.

Qb BASALTIC-ANDESITE, BASALT, AND MINOR ANDESITE FLOWS OF THE FLANKS (lower Holocene and Pleistocene)--Typical flows are 0.5 to 3 km wide and 4 to 8 km long. Many flows on the lower and middle flanks are buried progressively upslope by successively younger flows. Levees, pressure ridges, and tumuli are common, and lava tubes are developed in some flows (Greeley, 1971). Older flows on the lower northern and southern flanks cover much larger areas than flows higher on the flanks, and extend many kilometers beyond map area (see Peterson and others, 1976). Flows showing inverted topography occur locally on lower northeast flank. Well preserved flow margins shown by dashed lines are mapped on the basis of field observation and on interpretation of aerial photographs; however, numerous other unmapped flow boundaries with lesser topographic expression are locally obvious. Older than Mazama ash. All flows whose magnetic polarity was checked with a field fluxgate magnetometer are normally polarized, thus likely formed during the Brunhes Normal Epoch (younger than about 0.7 m.y.). Flows with very well preserved surface features that suggest a relatively young age, perhaps 8000 to 15000 years, are particularly abundant on the southeast, middle southwest, and northwest flanks. The bulk of the flows, however, are probably much older than 15,000 years and many have pumiceous tephra deposits, gravel, cinders, and loess, as well as Mazama ash, on their surfaces. Some of these older flows are interbedded between Qlt, Qsu, Qdo, and Qtp. Of 88 chemical analyses (Williams, 1935; Higgins, 1973; Beyer, 1973; MacLeod, unpublished data) of mafic to intermediate rocks (mostly Qb, but also including analyses of other units), 12 have 47 to 52 percent SiO_2, 64 have 52 to 57 percent, and 22 have 57 to 62 percent. Thus, the dominant analyzed mafic rock is basaltic-andesite. These analyses tend to be biased toward younger flows, and many voluminous older flows, especially those low on the flanks of the volcano, probably have less than 52 percent SiO_2. On the other hand, silicic andesite flows with 60-62 percent SiO_2 were found at only a few localities. Higgins (1973) and Beyer (1973) recognize two chemical types of the mafic and intermediate rocks, one calc-alkaline, the other high-iron tholeiite. The calc-alkaline flows greatly dominate. They contain 16 to 19 wt. percent Al_2O_3, 7 to 9.5 wt. percent total iron oxide, and are similar in their major and trace element composition to mafic flows that form the dominant part of the adjacent Cascade Range (see, for instance, analyses in Taylor, 1978). Some of these flows have diktytaxitic texture, especially the more mafic ones low on the flanks. The tholeiitic flows contain 15 to 16 wt. percent Al_2O_3, 10 to 13 wt. percent total iron oxides, and are characterized by much higher content of TiO_2 and P_2O_5 than the calc-alkaline flows. The tholeiitic flows have been identified by Higgins (1973) in the caldera walls (included in Qws), but also occur locally on the flanks (Beyer, 1973). Flows of both types commonly are plagioclase- and olivine-phyric and some also contain clinopyroxene phenocrysts; opaque oxides and apatite microphenocrysts are more common and abundant in tholeiitic flows. Vents for Qb are marked by cinder cones and fissure vent deposits (Qc).

Qc CINDER CONE AND FISSURE VENT DEPOSITS (lower Holocene and Pleistocene)--Related to Qb and Qcb flows. Cones are formed of mafic ash, lapilli, blocks, bombs, and agglutinated spatter which, where exposed in artificial cuts, are well bedded. Fissure vents are mostly formed of agglutinated spatter. The color of the deposits is variable, but is commonly red, dark gray, or black; cinders in some cones are brilliant metallic blue, green, and red. Cinder cones range from a few tens of meters to 140 m high and from 100 m to about 1 km across. Craters are common at the tops of cones. Crater rims are commonly asymmetric, being higher on leeward and lower on windward sides; rims are locally absent on sides where flows emerge (flows transported vent deposits "piggy-back" on their surfaces away from vent). Many older cones have no preserved craters. Cinder air-fall deposits extend several kilometers leeward of some younger cones, such as Pilpil Butte on the upper north flank. Cones commonly occur in linear arrays (shown by barred lines on map) that are interpreted to be fed by fissures at depth. Depressions locally occur on opposite rims of individual cones over inferred fissures. Fissure vents generally parallel inferred fissures. Several fissures on the northwest flank labled Qc? are inferred based on morphology of the flows and lineaments on them, but do not have obvious associated pyroclastic material. Most cone arrays on the south flank trend NNE and those on the north flank trend NW; faults low on the flanks have the same orientations. Cone arrays near the caldera commonly are concentric to it; possible cone arrays on the middle north and northeast flank (not shown, but note cone distribution) may also be concentric to the caldera rim. Many cones and fissure vents, especially those on the upper flanks, contain inclusions of pumice and fused rhyolite as well as inclusions of more mafic rocks. A well known example is "Mixture Butte" on the west flank (Williams, 1935); rhyolitic rocks crop out near it and likely occur below it. A fissure on the southeast flank that cuts a rhyolite dome (Qer) contains inclusions of rhyolite similar to the dome and also contains pumice that appears to be derived from fusing and frothing the rhyolitic rocks. Some pumice inclusions at other vents, however, may be derived from buried pumice deposits such as in pumice rings associated with domes, or from mixed magmas. The young (but pre-Mazama ash) fissure deposits along the east rim of the caldera and the associated flow (Qcb) in the caldera are highly variable in composition, both chemically and petrographically, and may be the product of magma mixing.

Qsu UNDIFFERENTIATED SEDIMENTS AND INTERBEDDED PYROCLASTIC ROCKS OF THE FLANKS (Pleistocene)--Occurs mainly on the northeastern flank, but also present on the other flanks where it commonly occurs as windows surrounded by younger mafic flows (Qb). Formed mostly of unconsolidated alluvial sand and gravel which is rarely well exposed owing to cover of Mazama ash and of pumiceous tephra deposits from the caldera. Judging largely by float derived from Qsu, it commonly contains cobbles and boulders high on the flanks, gravel with interbedded cobble beds on the middle flanks, and sand and gravel on the lower flanks. Boulders and cobbles occur as float on steep slopes in areas covered by thick deposits of Qut on the upper southern, eastern and northeastern flanks and at the top of the caldera walls above Qws, suggesting that Qsu locally extends buried to the caldera rim. A few holes dug through the tephra penetrated these sediments. Angular rhyolitic to dacitic pumice lapilli occur as float derived from probable air-fall deposits in Qsu in many areas. Thick pumice lapilli deposits are particularly obvious near and as far as 7 km southwest of China Hat on the lower east and southeast flanks. Unit represents deposits of several different ages and may be intercalated with other units, but its contacts are difficult to establish. In many areas on the middle and upper flanks Qsu contains very abundant dark colored lapilli identical to those in Qlt. Some areas mapped as Qsu likely are primary deposits of Qlt rather than being reworked from it. Qsu on the flanks is largely the result of one or more periods of substantial erosion of the volcano with intermittant periods of explosive volcanism during the late Pleistocene.

Qs FLUVIAL AND LACUSTRINE SEDIMENT (Pleistocene)--Occurs in the La Pine Basin west of Newberry and near Horse Ridge northeast of Newberry. Deposits nearest the flanks are mostly alluvial fans and they grade outward to interbedded fluvial and lacustrine deposits which locally contain thick diatomite beds. Partly correlative with Qsu. Commonly contains abundant detritus derived from Qlt. Also includes alluvial deposits in the eastern part of the Cascade Range in the northwest corner of the map; some of these may be fluvio-glacial deposits.

Qst NEAR VENT RHYODACITE TEPHRA DEPOSITS OF THE FLANKS AND CALDERA (Pleistocene)--Consists of three unrelated deposits: (1)Deposit on the southwest flank consists of thick units of rhyodacitic ash-flow tuff and pumice-fall deposits; the large size of the lapilli and blocks in the pumice-fall deposit suggests a near vent location. SiO_2 content is about 70 percent; unit differs in composition from nearby Paulina Peak dome (Qrd) and adjacent obsidian flow (Qr) at caldera wall. (2)Deposit on the upper northeast flank, which yielded a K-Ar age of $.07 \pm .12$ m.y., consists of unconsolidated to agglutinated pumiceous rhyodacitic air-fall deposits, welded tuffs that may also be of air-fall origin, and obsidian; the latter may be densely welded tuff. Locally occurs as well bedded steeply dipping deposits that may be remnant of pumice ring. Similar weakly agglutinated pumice deposits of probable air-fall origin were found in holes on pumice-littered small hill 2-1/2 km to northeast. SiO_2 content also about 70 percent, but differs in other oxides from southwest flank deposits. Porphyritic with plagioclase, hypersthene, and opaque phenocrysts. Welded tuffs at the top of the caldera wall sequence in the east wall (see Qws) have chemical compositions (Higgins, 1973, table 4, cols. 17 and 18) similar to these upper northeast flank deposits, also appear to be largely of air-fall origin even though mostly densely welded, and may represent part of the same deposit. (3)Qst deposit in caldera consists of massive to bedded pumice lapilli and ash that occur adjacent to rhyodacite dome (Qrd) along Paulina Lake; may be remnant of pumice ring related to dome.

Qr RHYOLITIC OBSIDIAN FLOWS (Pleistocene)--Includes flow at top of south caldera wall east of Paulina Peak and flow at northeast side of East Lake which extends to vent near top of north caldera wall. Both flows are mostly buried by tephra deposits (Qut; south wall flow also by QHt) and are bounded by probable caldera ring faults (outer south caldera fault, and inner north caldera fault). Flows are indistinguishable in major oxide and trace element composition, and phenocryst (plagioclase, trace hypersthene) proportion and characteristics, suggesting they are comagmatic and coeval. SiO_2 content 72.4 percent. Similar to Qrd and Qd in trace element composition but different than Qer and all Holocene rhyolitic rocks.

Qrd RHYODACITE DOMES AND FLOWS (Pleistocene)--Some domes are mapped based on very sparse outcrops combined with geomorphic expression. Large flow on upper south flank 5 km due south of East Lake does not crop out and was identified by digging deep holes through overlying veneer of pumice lapilli tuff (QHt) and gravel deposits (Qsu). Two probable domes on upper east flank (east and northeast of QHb_{14}) are almost entirely buried by QHt and Qut. Includes Paulina Peak dome (K-Ar age .24$\pm$.07 and .58$\pm$.4 m.y.), two domes in caldera along shore of Paulina Lake (K-Ar age .56$\pm$.4 and .58$\pm$.4, but likely younger than Paulina Peak dome), dome on upper east flank (K-Ar age .20$\pm$.03 m.y.), dome on west flank (K-Ar age .40$\pm$.15 m.y.), and numerous other domes which have not been dated or which yielded ages considered to be unreliable. Locations of dated samples are listed in Fiebelkorn and others (1982). SiO_2 content 68-72 percent; phenocrysts are plagioclase, $\pm$ hypersthene, $\pm$ augite, $\pm$ opaques. Several domes in widely scattered localities have the same chemical composition and phenocryst assemblage suggesting some are comagmatic and coeval.

Qd DACITE DOMES AND FLOWS (Pleistocene)--Occurs on southwest and northeast flanks. SiO_2 content 64-66 percent; phenocrysts include plagioclase, hypersthene, augite, and opaques.

Qer OLDER RHYOLITE DOMES AND FLOWS (Pleistocene)--Known or inferred to be older than Qr, Qrd, and Qd. Includes domes and associated flows at China Hat (K-Ar age .80±.2 m.y.; reversely magnetized) and East Butte (K-Ar age .87 ±.04 m.y.; reversely magnetized) at the base of the east flank, three domes at and adjacent to McKay Butte (K-Ar age .60±.10; magnetization not known) on west flank, and four small domes on southeast flank (ages probably comparable to McKay Butte domes). SiO_2 content 72 to 75 percent; characterized by high Rb/Sr. Somewhat similar in chemical composition to Holocene rhyolitic rocks (QHo, QHaf, QHt, QHp, Qut, and Qyr). Aphyric to porphyritic with plagioclase, hypersthene, ± augite, ± Fe-olivine phenocrysts in glassy to felsophyric matrix. China Hat and East Butte domes lie on west end of age-transgressive belt of rhyolitic rocks which extends across eastern Oregon (Walker, 1974; MacLeod and others, 1975). The other rhyolitic rocks in this group may also relate to this age progression inasmuch as they appear to occur in groups alined northeast approximately parallel to the isochrons of the age-transgressive rhyolites.

Qsv RHYOLITE, RHYODACITE, AND DACITE DOMES AND FLOWS, UNDIFFERENTIATED (Pleistocene)--Similar to other silicic rock units on flanks, but have not been chemically analyzed.

Qwp ANDESITIC TEPHRA DEPOSITS OF UPPER WEST FLANK (Pleistocene)--Forms the surface of the upper west flank extending to the caldera wall. Unit changes characteristics toward caldera. Westerly exposures consist of numerous interbedded lapilli air-fall deposits and ash-flow tuffs. Fall deposits occur as beds that are mostly less than 1 m thick, are commonly slightly agglutinated to densely welded, and are formed mostly of lapilli. Ash-flow tuffs are as much as 3 m thick, poorly sorted, and weakly consolidated to slightly welded (in basal parts). Near caldera rim, as at Paulina Falls, consists mostly of dense agglutinated deposits of probable near vent air-fall origin. Along caldera rim north of Paulina Creek unit consists of dense flow-like deposits which have a streaky appearance and contain scattered accidental fragments suggesting a pyroclastic origin. Lapilli, bombs, and blocks in unit are pumiceous to scoriaceous, commonly contain accidental felsophyric inclusions, and are very porphyritic with plagioclase, orthopyroxene, and opaque phenocrysts. Ashy matrix contains abundant accidental lithic fragments. Juvenile fragments in deposit are mostly andesitic to dacitic (SiO_2 ranges from 61 to 66 percent). The deposits at the caldera rim north of Paulina Creek are basaltic-andesite with SiO_2 content of 52-53 percent (Higgins, 1973, Table 4, cols. 22-23). Unit has not yielded meaningful K-Ar ages. Overlies Qlt, which is locally exposed beneath it in the bed of Paulina Creek, and is banked against and locally overlies cinder cones (Qc) and related flows on its west side. Mafic flows (Qb) on north side are younger than Qwp; talus obscures contact with Paulina Peak dome (Qrd), but Qwp is probably younger. Normally polarized. Qwp is youngest major pyroclastic-flow unit on flanks of volcano. Unit is as much as 50 m thick.

Qlt BASALTIC-ANDESITE LAPILLI TUFF (Pleistocene)--Occurs on west flank, and locally on northeast flank. Poorly to moderately consolidated massive poorly sorted dark-gray lapilli tuff. Lapilli and less abundant bombs are dark-gray, finely vesicular to pumiceous, have cauliflowerlike surfaces, and contain ubiquitous angular rhyolitic to basaltic inclusions; some silicic inclusions are fused and frothed. The abundant inclusions, found in virtually all lapilli, and the characteristic shape and color allow lapilli from this unit to be readily recognized. Matrix consists of dark colored ash with abundant accidental lithic fragments. Lapilli and matrix have the same normal magnetic polarity as measured by field fluxgate magnetometer which suggests emplacement temperatures above the Curie point. Lapilli tuff was probably deposited dominantly as ash flows. In largest of three isolated outcrop areas north of McKay Butte on middle WNW flank, however, unit is well consolidated due to palagonitization and has characteristics suggesting mudflow origin. Unit is deeply eroded and everywhere poorly exposed except where it occurs as possible mudflows. Parts of unit on west flank are formed of alluvium derived from lapilli tuff, but exposures are too poor to delineate juvenile and reworked deposits. Areas on north and northeast flank mapped as Qsu locally contain abundant detritus from Qlt; some areas mapped as Qsu likely are juvenile deposits of Qlt, but exposures are available only in holes dug in deposits. Unit has not yielded meaningful K-Ar ages. On west flank overlies basaltic flows derived from vents midway on flank and some silicic domes and flows which have K-Ar ages of about .4 m.y. Underlies Qwp in bed of Paulina Creek on upper flank at scattered localities too small to show on map. Older than basaltic flows (Qb) which border it on north and south sides. On northeast flank younger than Qdo and overlain by or interbedded in Qsu. Chemical analyses of lapilli indicate a basaltic-andesite composition with a SiO_2 content of 54 - 55 percent; slightly porphyritic with plagioclase phenocrysts and microphenocryts. Maximum thickness is about 35 m; original thickness probably significantly greater. Alluvial sediments on all sides of volcano contain abundant detritus derived from Qlt indicating original volume of Qlt before erosion was substantial, probably several tens of cubic kilometers.

Qob ASH-FLOW TUFF OF ORPHAN BUTTE (Pleistocene)--Dark-gray to brown very pumiceous ash-flow tuff adjacent to and near cinder cone which forms Orphan Butte on middle northeast flank. Also crops out intermittantly farther to the south. Apparently interbedded in Qsu, and younger than Qdo. Normally polarized. Contains abundant small plagioclase and hypersthene phenocrysts. SiO_2 content 66%; chemically similar to but slightly more mafic than Qdo.

Qdo DACITIC PUMICEOUS ASH-FLOW TUFF (Pleistocene)--Occurs in walls of ravines on middle northeast flank where it is overlain by or is interbedded in Qsu; base is not exposed. Dark-gray or brown poorly sorted pumice blocks, lapilli, and ash with minor accidental lithic fragments; obsidian fragments which are probably cognate are a ubiquitous minor constituent. Pumice blocks and lapilli are locally collapsed. Pumice has SiO_2 content of 66.5 percent and is moderately porphyritic with plagioclase, augite, hypersthene and opaque phenocrysts and microphenocrysts; obsidian fragments in matrix have same phenocrysts in same relative proportion. Normally polarized. Older than Qlt and younger than Qtp. Base of unit is not exposed and top is eroded. Maximum exposed thickness is 20 m, but probably originally much thicker.

Qtp ASH-FLOW TUFF OF TEEPEE DRAW (Pleistocene)--Crops out on lower east and northeast flanks. Consists of poorly sorted pumiceous ash, lapilli, and blocks which range from weakly consolidated in most northeasterly exposures to moderately welded higher on flanks. In individual outcrops degree of welding increases upward with most densely welded part at eroded top. Fossil fumaroles are locally common. Angular pumice float at one locality is derived from between overlying and underlying exposures of ash-flow tuff suggesting unit may be formed of more than one flow unit with an interbed of pumice lapilli air-fall tuff. Bordered by younger mafic flows (Qb) and buried upslope by progressively thicker gravel and sand deposits (Qsu). Contact with Qsu is arbitrary and largely based on most westerly occurrence of abundant Qtp float. In largest area of exposure overlies and surrounds kipukas of older basalt. Base not exposed (except adjacent to kipukas) and upper surface eroded; maximum preserved thickness is about 20 m, but originally much thicker. Pumice in ash-flow tuff contains 70-71 percent SiO_2 and has much higher P_2O_5 content (.33 - .36 percent) than any other analyzed Newberry rock of similar SiO_2 content. Pumice is porphyritic with relatively abundant plagioclase, lesser augite and Fe-rich olivine, and rare hypersthene phenocrysts. Differences in color and phenocryst abundance suggest that pumices have varied composition. K-Ar ages are $.51 \pm .25$ and $.7 \pm .7$ m.y.; most likely age is about .5 m.y. Normally polarized. Probably oldest major tephra unit on flanks of volcano and most likely associated with first period of caldera collapse. May be present in subsurface on other flanks, in which case volume is likely several tens of cubic kilometers.

Qua UNDIFFERENTIATED ASH-FLOW TUFFS (Pleistocene?)--Includes several unrelated ash-flow tuffs: (1)Very poorly exposed tuff on west side of China Hat rhyolite dome (Qer) on easternmost flank that was identified by abundant float of large rounded pumice blocks and by digging holes into deposit. Appears to be plastered on west side of China Hat dome (K-Ar age 0.8$\pm$.2 m.y.) and thus is likely younger. SiO_2 content 72 percent. Chemically similar to Qtp, but pumice is much darker colored; petrographically and chemically different than QTt. (2)Lithic-rich pumiceous ash-flow tuff on upper south flank about 3 km south of Big Obsidian flow. Well exposed basal vitrophyre of tuff has an anomalously steep dip (45 to 70° northeast). Contacts of tuff with surrounding rocks are not exposed; may be isolated kipuka of pre-Newberry rock. (3)Scattered ash-flow tuffs interbedded in Qsu

Qpt PALAGONITE TUFF CONES AND RINGS (Pleistocene)--Includes the following: (1)Tuff cones and rings in caldera on the southwest side of Paulina Lake and on the south side of East Lake (Higgins, 1973). Both are complexes representing more than one vent. The palagonite tuff along the south shore of East Lake contains abundant mud-armored lapilli and accretionary lapilli and also includes accidental blocks of more altered palagonite tuff similar to that found in East Lake tephra deposits (included in Qut). (2)Palagonite tuff plastered on the north caldera wall above interlake obsidian flow (QHo_5). Vent for tuff is in the caldera, probably buried on the north side. (3)Palagonite tuff cones at Moffitt Butte on the southwesternmost flank. Qb flows mapped on it are related to it, flows adjacent to it are younger and derived from vents higher on the flanks. Probably relates to a series of palagonite tuff cones, rings and maars which extend east-southeast beyond the map area to Fort Rock Valley.

Qws CALDERA WALL ROCKS (Pleistocene)--Several caldera walls are present, locally occurring one inside the other. These probably are result of several periods of collapse of caldera. Detailed descriptions of rocks in wall sequence are given in Higgins and Waters (1968) and Higgins (1973). Rocks which extend from the walls onto the flanks, such as Paulina Peak rhyodacite dome, are shown as separate units (Qwp, Qrd, Qr). (1) South wall: Rocks in the south outer wall are exposed at three localities south and southwest of Big Obsidian Flow (QHo_1). The westernmost locality is a small ledge of basalt (Williams, 1935) surrounded by landslide and talus deposits. The second and largest exposure occurs below Qr near Big Obsidian flow. From base to top it consists of: platy rhyolite; unconformably overlain by basaltic-andesite flows, cinders, and agglutinate deposits with rhyolitic pumice fall interbed and cut by basaltic-andesite dike; overlain by massive to bedded mafic lapilli tuff with abundant silicic inclusions (similar to those in Qlt); overlain by rhyolitic pumice lapilli tuffs, probably part of pumice ring and locally densely collapsed and welded by overlying flow; and upper obsidian flow (mapped separately as Qr). The third exposure lies a short distance east and consists of dacitic(?) pumiceous ash-flow tuff and overlying basaltic-andesite flows and agglutinate deposits; the contact between the two units is not exposed. The remainder of the outer south wall has no exposures. The inner south wall has exposures only due south of East Lake where rhyodacite crops out. The rhyodacite is locally highly sheared and may be part of a dome cut by faults subsidiary to the caldera ring fault. (2)East wall: Rocks in the east caldera wall form bold outcrops at Cougar Point above the central east side of East Lake and are discontinuously exposed farther north. At Cougar Point the section consists of basaltic-andesite, an overlying unexposed area which contains float of lapilli tuff similar in appearance to Qwp, and at the top a sequence of welded rhyodacitic pumice lapilli tuffs. The latter tuffs extend a short distance southward where they are locally unwelded and the lapilli not collapsed, and they have characteristics suggesting very near vent air-fall rather than ash-flow origin. North of Cougar Point the tuffs are discontinuously exposed and densely welded. Contacts of the basal basaltic-andesite at Cougar Point with other wall rocks are not exposed. The basaltic-andesite is steeply flow-banded, crops out as a narrow and steep east-west-trending ridge, and has cinders and agglutinate at its top. It most likely is an exhumed shallow dike, but conceivably could be a flow that was originally in a narrow ravine (topography now inverted). Immediately north of the bold outcrops are discontinuous outcrops of palagonite tuff below the rhyodacite welded tuff. Antidune orientations in the palagonite tuff indicate the vent is to the northeast. (3)North wall: The north side of the caldera has two apparent walls. The outer wall extends north of East Lake and has no exposures in it, but has mafic cinder vents on it. Wall sequence rocks are exposed on the inner wall from East Lake westward to Paulina Lake. North of East Lake an obsidian flow (mapped separately as Qr), whose vent is near the outer caldera wall, extends to the shore of East Lake where it probably is cut by the inner caldera ring fault. Farther west discontinuous exposures of the wall sequence consist of platy rhyolite, overlain by basaltic-andesite flows, cinder deposits, agglutinated cinders and bombs, and palagonite tuff. The principal palagonite tuff unit occurs at the top of the sequence, but a second palagonite tuff is interbedded in the basaltic-andesite unit below. The upper half of the caldera wall is tephra covered, but locally has pumice float at some horizons, and rounded boulders at others suggesting a correlation with Qsu. (4) West wall: Wall sequence is Qwp which is mapped separately. Age of the caldera wall rocks is not well known. Rhyolite at base of caldera wall southeast of Paulina Peak has K-Ar age of .81±.23 m.y., but is normally polarized and thus likely less than .7 m.y. Rhyolite in lower part of north wall at "The Spire" (for location see Higgins and Waters, 1968, fig. 7) has K-Ar age of .12±.01; this rhyolite may intrude wall sequence rather than being in sequence. Paulina Peak dome, cut by south caldera ring fault, but included in Qrd, has K-Ar ages of .24±.07 and .58±.4 m.y.

QTt ASH-FLOW TUFF OF THE CHINA HAT AREA (Pleistocene?)--Poorly consolidated to welded very pumiceous lithic-rich ash-flow tuff. Color varies from dark-gray to tan, pink, and black. Locally contains concentrations of large dark-gray to black pumice blocks at top which are as much as 1 m in diameter. Overlain by Qsu and Qb; contacts with adjacent QTv not exposed. Northern part of mapped extent based partly on exposures in holes dug through thin deposits of Qsu. K-Ar age 2.75±.49 m.y. Most likely derived from Newberry Volcano in which case the K/Ar age is not correct, but a source other than Newberry cannot be discounted. Similar in appearance to some ash-flow tuffs in the Pliocene Peyerl Tuff (K-Ar age about 4.6 m.y.) which crop out south of Newberry, but also similar to some ash-flow tuffs (Qtp, Qdo, and Qob) derived from Newberry. SiO_2 content 70 percent; slightly porphyritic with small plagioclase and rare Fe-rich olivine(?) phenocrysts.

QTaf ASH-FLOW TUFFS AND PUMICE LAPILLI AIR-FALL DEPOSITS NEAR THE DESCHUTES RIVER AREA (Pleistocene and(or) Pliocene)--In map area consists of two units which have different sources and compositions. The lower unit is rhyolitic in composition and consists of a pumice lapilli fall deposit as much as 6 m thick and an overlying weakly consolidated to welded pumiceous ash-flow tuff locally more than 6 m thick. Crops out in northwest corner of map north of Benham Falls and east and west of the Deschutes River; crops out more extensively north of map and west of the Deschutes River (Mimura, 1977, unpublished geologic map; Taylor, 1981). Isopachs of the pumice fall and orientation of imbricated pumice in the ash-flow tuff indicate they were derived from a vent west of Newberry along the eastern side of the Cascade Range (Mimura and MacLeod, 1978). SiO_2 content is 73 to 75 wt. percent; chemically zoned in vertical sections. Sparsely porphyritic (plagioclase, rare hypersthene and augite). K-Ar ages of this unit are 2.1±2.1, 2.50±2.0, and 4.0±2.0 m.y.; both the pumice fall and ash-flow tuff overlie rhyodacite at Benham Falls (QTsv) which has a K-Ar age of 1.75±.8 m.y. This relationship suggests that the age of the fall, flow, and rhyodacite are probably about 2 to 2.5 m.y. Normally polarized. The upper unit, an andesitic to dacitic ash-flow tuff, crops out in northeast corner of map; readily accessible exposures occur along U.S. 97. The tuff has a pinkish-tan to black color, contains pumice lapilli of varied color and chemical composition (SiO_2 ranges from 59 to 65 wt. percent), and is crystal-rich (plagioclase, hypersthene, augite). Unit crops out in large areas west and north of the northwest part of the map (Taylor, 1981; MacLeod, unpublished geologic map; Mimura, unpublished geologic map). Distribution of unit and orientation of imbricated pumice within it indicate that it was derived from a vent in the highland area near Broken Top volcano (Mimura and MacLeod, 1978; Taylor, 1981). K/Ar age is 2.58±2.2; overlies the lower unit, but is probably also about 2 - 2.5 m.y. old. Normally polarized. Poorly exposed ash-flow tuff on lower WNW flank surrounded by basalt flows (Qb) may correlate with QTaf or may be derived from Newberry Volcano.

QTb BASALT AND BASALTIC-ANDESITE FLOWS OF THE EASTERN PART OF THE CASCADE RANGE (Pleistocene and Pliocene?)--Occurs west of the Deschutes River. Widespread very plagioclase-phyric basalt or basaltic-andesite flows west and north of Benham Falls are derived from a large vent complex (QTmv) near Kiwa Springs, only part of which is in the mapped area. Other flows are derived from scattered vents (QTc) within and west of the mapped area. Includes flows of a variety of ages; some flows are older than QTaf, others are younger.

QTc CINDER CONES OF THE EASTERN PART OF THE CASCADE RANGE (Pleistocene and Pliocene?)--Also includes cinder cones related to QTmv on northwest, south, and southeast flank of Newberry. Generally more eroded than cinder cones related to Newberry Volcano.

QTsv RHYOLITIC TO DACITIC DOMES AND FLOWS OF THE DESCHUTES RIVER AREA (Pleistocene or Pliocene)--Largest body is a rhyolite or rhyodacite dome at Benham Falls which has yielded a K-Ar age of 1.75±.8 m.y. and which is overlain locally by QTaf. Smaller poorly exposed domes or flows southwest of Benham Falls are dacitic.

QTmv MAFIC VENT COMPLEXES (Pleistocene or Pliocene)--Occurs on lower northwest, southwest, and southeast flanks. Shield-like polygenetic accumulations of basaltic flows, tuff, and breccia. Green Mountain and small unnamed hill northeast of Lava Butte, both on the northwest flank, are locally overlain by QTaf suggesting that they are pre-Pleistocene in age. Green and Spring Buttes on the southwest flank may be kipukas of older rocks or may relate to early stages of growth of Newberry Volcano. Vent complexes on the lower southeast flank were mapped as Quaternary or Tertiary in the adjacent area to the east (Walker and others, 1967).

QTd DACITE OF THE SOUTHEAST FLANK (Pleistocene or older)--Occurs on Indian and adjacent Amota Buttes and consists of massive to flow banded dacite; probably a dome or dome complex. Very porphyritic with plagioclase, hypersthene, and augite phenocrysts and microphenocrysts set in glassy to finely crystalline matrix. SiO_2 content 64 to 66 percent (Beyer, 1973). Reversely polarized; older than surrounding basaltic flows (Qb). Northeast-trending fault has a much higher scarp where it cuts QTd than where it offsets adjacent Newberry basaltic flows (Qb), suggesting that QTd is much older than the flows and that the fault has had recurrent movement.

TMb BASALT FLOWS OF THE HORSE RIDGE AREA (upper Miocene)--Occurs in northeast part of map area and is well exposed along U.S. 20 and along Dry River. Consists of thin basalt flows, flow breccias, and interbedded near vent deposits of basaltic cinders, blocks, and bombs. Probably derived from scattered eroded vents within mapped area and to northeast. Cut by faults which are part of the Brothers fault zone (see Walker and Nolf, 1981). K-Ar age $7.6\pm.1$ m.y.

TMOr RHYOLITE OR RHYODACITE (lower Miocene or upper Oligocene)--Crops out only in very small area along eastern border of map near latitude 43° 49' N, midway between China Hat and Horse Ridge. Crops out much more extensively to east (Walker and others, 1967) on and near Pine Mountain where it consists of rhyolite, rhyodacite, dacite, and andesite flows, domes, and near vent tephra deposits. K-Ar age $22.0\pm.4$ m.y. from rocks in unit east of map area. Probably correlates with upper part of the John Day Formation.

REFERENCES CITED

Bacon, C. R., 1982, Eruption history of Mount Mazama, Cascade Range, U.S.A., Journal of Volcanology and Geothermal Research [in press].

Beyer, R. L., 1973, Magma differentiation at Newberry crater in central Oregon: Eugene, University of Oregon, Ph. D. thesis, 84 p.

Chitwood, L. A., Jensen, R. A., and Groh, E. A., 1977, The age of Lava Butte: The Ore Bin, v. 39, no. 10, p. 157-164.

Faure, Gunter, 1977, Principles of isotope geology: New York, John Wiley and Sons, 464 p.

Fiebelkorn, R. B., Walker, G. W., MacLeod, N. S., McKee, E. H., and Smith, J. G., 1982, Index to K-Ar age determinations for the State of Oregon: U. S. Geological Survey Open File Report 82-596, 40 p.

Friedman, Irving, 1977, Hydration dating of volcanism at Newberry Crater, Oregon: U.S. Geological Survey Journal of Research, v. 5, no. 3, p. 337-342.

Greeley, Ronald, 1971, Geology of selected lava tubes in the Bend area, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 71, 47 p.

Higgins, M. W., 1969, Airfall ash and pumice lapilli deposits from Central Pumice cone, Newberry caldera, Oregon, in Geological Survey research 1969: U.S. Geological Survey Professional Paper 650-D, p. D26-D321.

____1973, Petrology of Newberry volcano, central Oregon: Geological Society of America Bulletin, v. 84, p. 455-488.

Higgins, M. W., and Waters, A. C., 1968, Newberry caldera field trip, in Andesite conference guidebook: Oregon Department of Geology and Mineral Industries Bulletin 62, p. 59-77.

____1970, A re-evaluation of basalt-obsidian relations at East Lake Fissure, Newberry Caldera, Oregon: Geological Society of America Bulletin, v. 81, no. 9, p. 2835-2842.

Laidley, R. A., and McKay, D. S., 1971, Geochemical examination of obsidians from Newberry caldera, Oregon: Contributions to Mineralogy and Petrology, v. 30, p. 336-342.

Libby, W. F., 1952, Chicago radiocarbon dates III: Science, v. 161, p. 673-681.

MacLeod, N. S., Walker, G. W., and McKee, E. H., 1975, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeast Oregon: Second United Nations Symposium on the Development and Use of Geothermal Resources, Proceedings, v. 1, p. 465-474.

MacLeod, N. S., Sherrod, D. R., and Chitwood, L. A., 1981, Newberry Volcano, Oregon, in Johnston, D. A. and Donnelly-Nolan, Julie, eds., Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U.S. Geological Survey Circular 838, p. 85-103.

MacLeod, N. S., and Sammel, E. A., 1982, Newberry Volcano, Oregon - a Cascade Range Geothermal Prospect: Oregon Geology, [in press].

Mimura, Koji, and MacLeod, N. S., 1978, Source directions of pumice and ash deposits near Bend, Oregon: Geological Society of America Abstracts with Programs, v. 10, no. 3, p. 137.

Peterson, N. V., and Groh, E. A., 1969, The ages of some Holocene volcanic eruptions in the Newberry volcano area, Oregon: The Ore Bin, v. 31, p. 73-87.

Peterson, N. V., Groh, E. A., Taylor, E. M., and Stensland, D. E., 1976, Geology and mineral resources of Deschutes County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 89, 66 p.

Pierson, F. J., Jr., Davis, E. M., and Tamers, M. A., 1966, University of Texas radiocarbon dates IV: Radiocarbon, v. 8, p. 453-466.

Sammel, E. A., 1981, Results of test drilling at Newberry Volcano, Oregon, and some implications for geothermal prospects in the Cascades: Geothermal Resources Council Bulletin, v. 10, no. 11, p. 3-8.

Sherrod, D. R., and MacLeod, N. S., 1979, The last eruptions at Newberry volcano, central Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 3, p. 127.

Taylor, E. M., 1978, Field Geology of S.W. Broken Top quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 2, 50 p.

____1981, Central High Cascade roadside geology, in, Johnston, D. A., and Donnelly-Nolan, Julie, eds., Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U. S. Geological Survey Circular 838, p. 55-83.

Walker, G. W., 1974, Some implications of Late Cenozoic volcanism to geothermal potential in the High Lava Plains of south-central Oregon: The Ore Bin. v. 36, no. 7, p. 109-119.

Walker, G. W., Peterson, N. V., and Greene, R. C., 1967, Reconnaissance geologic map of the east half of the Crescent quadrangle, Lake, Deschutes, and Crook Counties, Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-493, scale 1:250,000.

Walker, G. W., and Nolf, Bruce, 1981, High Lava Plains, Brothers Fault Zone to Harney Basin, Oregon, in Johnston, D. A., and Donnelly-Nolan, Julie, eds., Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U. S. Geological Survey Circular 838, p. 105-118.

Williams, Howel, 1935, Newberry volcano of central Oregon: Geological Society of America Bulletin, v. 46, p. 253-304

____1957, A geologic map of the Bend quadrangle, Oregon, and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Department of Geology and Mineral Industries Map, scales 1:125,000 and 1:250,000.