State of Oregon
Department of Geology
and Mineral Industries
1069 State Office Bldg.
Portland Oregon 97201

The ORE BIN
Volume 36, No. 7
July 1974

SOME IMPLICATIONS OF LATE CENOZOIC VOLCANISM TO GEOTHERMAL POTENTIAL IN THE HIGH LAVA PLAINS OF SOUTH-CENTRAL OREGON

George W. Walker
U.S. Geological Survey, Menlo Park, California 94025

Introduction

Stratigraphic and volcanologic data obtained during reconnaissance mapping along the Brothers fault zone in the High Lava Plains of south-central Oregon (Walker and others, 1967; Greene and others, 1972) suggest a progressive decrease in age of eruption of silicic magmas from the Harney Basin westward to Newberry Volcano and possibly beyond into the Cascade Range. South of the Brothers fault zone, a separate less well defined, parallel zone of silicic domes and flows extends westward from Beatys Butte; this zone also appears to show a decrease in age westward, although the time span apparently is shorter and the age decrease not as well documented. The apparent age progression and the obviously very young age and character of some of the silicic volcanic rocks at the western end of the zone are important in geologic evaluations of the geothermal potential of eastern Oregon. They suggest that igneous heat sources sufficiently young to have retained significant magmatic heat are most likely to occur at the western end of the zone.

Geothermal energy associated with silicic volcanism is being explored or developed in several parts of the world (White, 1965; Muffler and White, 1972; Grose, 1972). In areas of known geothermal potential, such as New Zealand, Italy, Japan, and in North America at Yellowstone, the Jemez Mountains (New Mexico), and probably The Geysers area of California, the age of silicic volcanism is very young, mostly less than a million years and commonly only a few tens or hundreds of thousands of years old, and the volume of silicic volcanism generally is large, in many places measured in terms of many cubic kilometers of magma. Because some domal masses at the west end of the Brothers fault zone are very young and some of the silicic volcanism along the zone was volumetrically large, the potential for magmatic heat sources seems promising.

To test the concept of an age progression in and along the Brothers fault zone, as determined from field geologic evidence, and to establish the absolute ages of some of the silicic volcanic rocks in and near this zone, several potassium-argon ages have been determined on crystalline phases from rhyolitic, rhyodacitic, and dacitic domes and associated flows, on rhyolitic obsidian from chilled selvages on several domes and flows, and on crystals and glass from basal vitrophyre of small- and large-volume ash-flow tuffs erupted from centers spatially and probably genetically related to the Brothers fault zone.

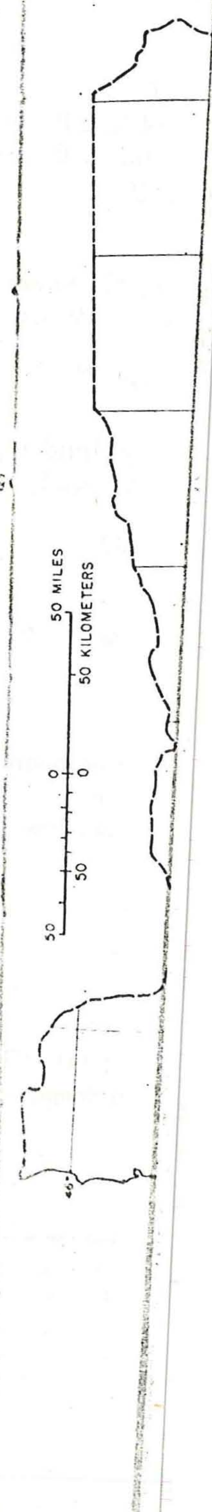
General Geology

The area from Harney Basin westward to Newberry Volcano, entirely within the High Lava Plains province of Dicken (1950), consists of a middle and upper Cenozoic volcanic upland nearly 260 km long and several tens of kilometers wide. The principal structural feature is a west-northwest-trending zone of en echelon normal faults (Figure 1), informally called the Brothers fault zone. Eruptive centers for both basaltic and rhyolitic volcanic rocks are concentrated in this zone of faults and in nearby subsidiary fault and fracture zones.

Except for small areas of older Cenozoic volcanic and tuffaceous sedimentary rocks locally exposed along the northern margin of the High Lava Plains that represent parts of the Columbia River Group and the John Day and Clarno Formations (Walker and others, 1967), the oldest rocks are small silicic domal masses of either late Miocene or early Pliocene age near the eastern margin of the province and nonporphyritic olivine basalt and andesite flows of late Miocene, or more likely early Pliocene age, exposed along the southern and southeastern margin of the province.

Both the domes and flows are partly buried by widespread sheets of ash-flow tuffs of early and middle Pliocene age; in a few places the ash-flow tuffs and olivine basalt flows appear to be interbedded. Several isotopic ages of the earliest ash-flow tuff in this sequence indicate that it was erupted about 9 m.y. ago. It spread laterally over thousands of square kilometers of the ancestral Harney Basin and adjacent parts of the High Lava Plains, the Blue Mountains, and the Basin and Range provinces. Somewhat younger (≈6-7 m.y.) large-volume ash-flow tuffs also are present in this region (Walker, 1970; Greene and others, 1972). Eruption of tremendous volumes of rhyolitic ash and ash flows apparently permitted some crustal collapse into the evacuated magma chambers. This collapse was partly responsible for the development of the large structural depression of Harney Basin, the probable source area of the ash-flow tuffs. Lower parts of the depression were subsequently filled with younger ash-flow tuffs, tuffaceous sedimentary rocks, and local basalt flows and basaltic vent complexes, all of late Cenozoic age (Piper and others, 1939; Greene and others, 1972).

In the western part of the High Lava Plains province, middle and upper Cenozoic basalt flows, ash-flow tuffs, silicic domal masses and sedimentary



on in and along the Brothers
evidence, and to establish the
rocks in and near this zone,
rmined on crystalline phases
es and associated flows, on
veral domes and flows, and
small- and large-volume ash-
probably genetically related

gy

Newberry Volcano, entirely
en (1950), consists of a middle
60 km long and several tens of
ure is a west-northwest-trending
nformally called the Brothers
and rhyolitic volcanic rocks
nearby subsidiary fault and

volcanic and tuffaceous sedi-
rn margin of the High Lava
r Group and the John Day
7), the oldest rocks are small
early Pliocene age near the
litic olivine basalt and ande-
ly Pliocene age, exposed along
rovince.
ed by widespread sheets of ash-
a few places the ash-flow tuffs
led. Several isotopic ages of
cate that it was erupted about
s of square kilometers of the
e High Lava Plains, the Blue
. Somewhat younger (≈6-7
sent in this region (Walker,
remendous volumes of rhyolitic
ustal collapse into the evacu-
responsible for the develop-
ey Basin, the probable source
depression were subsequently
sedimentary rocks, and local
f late Cenozoic age (Piper

ins province, middle and upper
domal masses and sedimentary

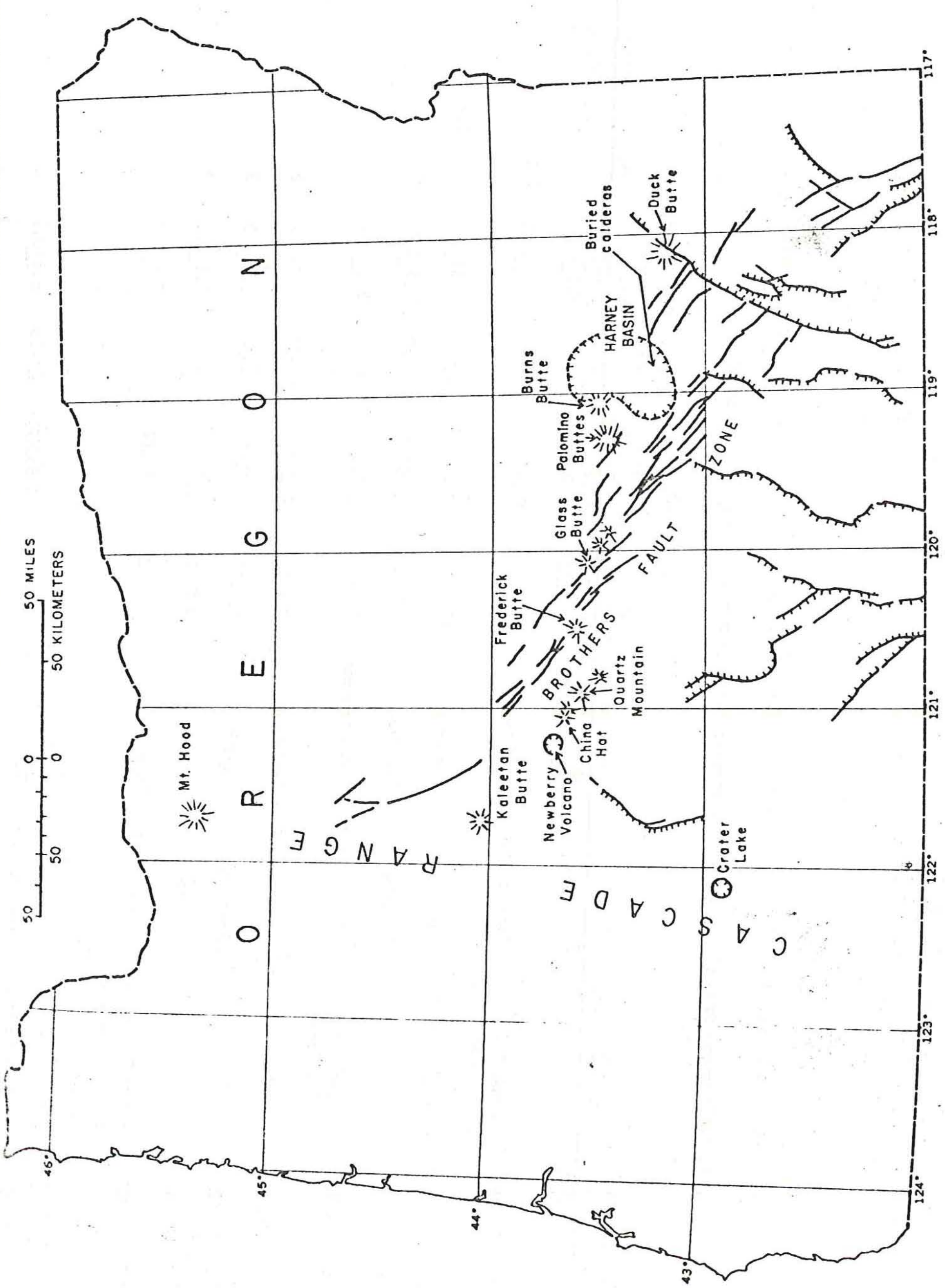


Figure 1. Index map showing some major structural elements and location of some silicic domes and vents.

Table 1. Potassium-argon dates of silicic volcanic rocks from vents in or near the Brothers fault zone*

Map No.	Sample No.	Latitude (north)	Longitude (west)	Geologic unit	Rock type	Material dated	K_2O Wt. %	^{40}Ar rad (10^{-11} mol/gm)	% ^{40}Ar rad	Calculated age (10^6 years)	Ref.	Remarks
1	RCG 281-1-67	43°12.2'	118°07.5'		Rhyodacite	Biotite Plagioclase	7.68 7.82 0.754 0.754	11.52 1.066	51 32	10.0±0.4 9.6±0.6	1	} Duck Butte
2	RCG 248-66	43°45.5'	118°59.9'	Welded tuff of Devine Canyon	Ash-flow tuff	Sanidine	7.10 7.14	9.710	15	9.2±0.50	1,2	
3	RCG 54-5-66	43°30.8'	119°08.3'		Rhyodacite	Plagioclase	1.147 1.163	1.338	59	7.82±0.26	1,2	Burns Butte
4	YU-DP-119	43°14.3'	119°13.5'		Rhyolite	Rhyolite	4.55(2)	5.555(2)	47-59	8.2±0.12	3	
5	GWW-176-62	43°00.6'	118°38.1'	Welded tuff of Devine Canyon	Ash-flow tuff	Alkali feldspar	7.15	8.976	61	8.5±0.3		
6	YU-DP-243	43°04.9'	119°03.8'		Ash-flow tuff	Sanidine	7.86(2)	8.214(2)	55-59	7.1±1.0	3	
7	YU-DP-146	43°13.5'	119°21.2'		Rhyolite	Rhyolite	5.13(2)	6.38(2)	4-5	8.4±1.3	3	
8	YU-DP-316-D	43°17.0'	119°18.8'		Rhyolite	Rhyolite	4.92(2)	5.713	16	7.8±0.5	3	
9	YU-DP-311-B	43°09.0'	119°22.4'	Prater Creek Member of Parker and Armstrong (1972, p.7) of Danforth Fm.	Welded tuff	Tuff	4.51(2)	5.912(2)	8-4	8.6±0.2	3	
10	YU-DP-311-G	43°09.0'	119°22.4'	Rattlesnake Fm.	Welded tuff	Tuff	4.93(2)	4.852(2)	21-26	6.6±0.2	3	
11	YU-DP-330	43°09.0'	119°22.4'	Rattlesnake Fm.	Welded tuff	Tuff	4.87(2)	4.797(2)	10-11	6.7±0.4	3	
12	RCG 257-3-66	43°37.7'	119°04.2'	Welded tuff of Double O Ranch	Ash-flow tuff	Anorthoclase	4.93 4.93	4.978	31	6.82±0.33	1,2	
13	RCG 121-66	43°47.2'	119°18.9'	Welded tuff of Double O Ranch	Ash-flow tuff	Anorthoclase	4.64 4.66	3.713	60	5.40±0.20	1,2	
14	YU-DP-214	43°30.3'	119°18.0'		Rhyolite	(Rhyolite (Biotite	4.89(2) 8.31(2)	4.047 7.831	16 35	5.6±0.4 6.4±0.2	3	) About same unit) as PB-2-70
15	PB-2-70	43°28.8'	119°18.0'		Rhyolite or rhyodacite	(Biotite (Plagioclase	8.26 8.28 1.27 1.27	7.434 1.227	53 31	6.1±0.2 6.5±0.3	1 1	Dome, Palamino Buttes
16	GWW-16-65	43°41.7'	119°54.1'	Welded tuff of Devine Canyon	Ash-flow tuff	Alkali feldspar	6.65 6.65	9.306	75	9.45±0.21	1,2	

				Armstrong (1972, p.7) of Danforth Fm.									
10	YU-DP-311-G	43°09.0'	119°22.4'	Rattlesnake Fm.	Welded tuff	Tuff	4.93(2)		4.852(2)	21-26	6.6±0.2	3	
11	YU-DP-330	43°09.0'	119°22.4'	Rattlesnake Fm.	Welded tuff	Tuff	4.87(2)		4.797(2)	10-11	6.7±0.4	3	
12	RCG 257-3-66	43°37.7'	119°04.2'	Welded tuff of Double O Ranch	Ash-flow tuff	Anorthoclase	4.93	4.93	4.978	31	6.82±0.33	1,2	
13	RCG 121-66	43°47.2'	119°18.9'	Welded tuff of Double O Ranch	Ash-flow tuff	Anorthoclase	4.64	4.66	3.713	60	5.40±0.20	1,2	
14	YU-DP-214	43°30.3'	119°18.0'		Rhyolite	(Rhyolite (Biotite	4.89(2) 8.31(2)		4.047 7.831	16 35	5.6±0.4 6.4±0.2	3	) About same unit) as PB-2-70
15	PB-2-70	43°28.8'	119°18.0'		Rhyolite or rhyodacite	(Biotite (Plagioclase	8.26 1.27	8.28 1.27	7.434 1.227	53 31	6.1±0.2 6.5±0.3	1 1	Dome, Palamino Buttes
16	GWW-16-65	43°41.7'	119°54.1'	Welded tuff of Devine Canyon	Ash-flow tuff	Alkali feldspar	6.65	6.65	9.306	75	9.45±0.21	1,2	
17	RCG 61-1-65	43°48.1'	120°01.2'		Ash-flow tuff	Alkali feldspar	6.75	6.77	9.298	92	9.29±0.23	1,2	
18	RCG 106-1-65	43°48'	120°00.6'		Ash-flow tuff	Alkali feldspar	6.70	6.91	9.252	88	9.05±0.28	1,2	
19	GWW-140-61	42°35.6'	119°16.5'	Welded tuff of Devine Canyon	Ash-flow tuff Ash-flow tuff	Alkali feldspar Glass	6.67 5.32		9.872 7.160	56 36	10.0±0.3 9.1±0.3	1,2 1,2	
20	MO-73-33	43°32.2'	110°01.3'		Selvage on flow?	Obsidian	4.15	4.21	3.038	17	4.9±0.3	1	
21	FB-1-70	43°37.5'	120°27.6'		Rhyodacite	Plagioclase	0.377(2)		0.219	13	3.9±0.4	1	Dome, Frederick Butte
22	GWW-121-64	43°47.8'	120°22.8'		Ash-flow tuff	(Plagioclase (	0.62	0.63	0.335	59	3.6±0.6)	1,4	
23	M3-33	43°31.8'	120°46.8'			(Glass	3.63	3.67	1.93	71	) 3.6±0.2)		
					Selvage on flow	Obsidian	3.98		2.116	54	3.6±0.1	1	Squaw Ridge
24	MO-73-31	43°37.2'	120°53.1'		Selvage on flow	Obsidian	3.83	3.84	0.627	36	1.1±0.05	1	Quartz Mtn.
25	MO-73-29	43°40.1'	120°59.5'			Obsidian	3.84		0.482	23	0.85±0.04	1	East Butte
26	M3-53	43°41.3'	121°02.0'			Obsidian	3.80		0.428	7	0.76±0.1	1	China Hat

* For additional dates on these and related units also see:
Dalrymple, G. B., Cox, Allan, Doell, R. R., and Grommé, C. S., 1967
Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964

References:
1. U.S. Geological Survey, unpub. data
2. Greene, R. C., and others, 1972
3. Parker, Donald and Armstrong, R. L., 1972
4. Walker, G. W., 1970

rocks are mostly buried beneath basalt flows of late Pliocene, Pleistocene, and Holocene age (Williams, 1957; Oregon Dept. Geology and Mineral Industries, 1965; Walker and others, 1967) that erupted nonexplosively from widely scattered cones, shield volcanoes, and fissures.

Progressive Age of Volcanism

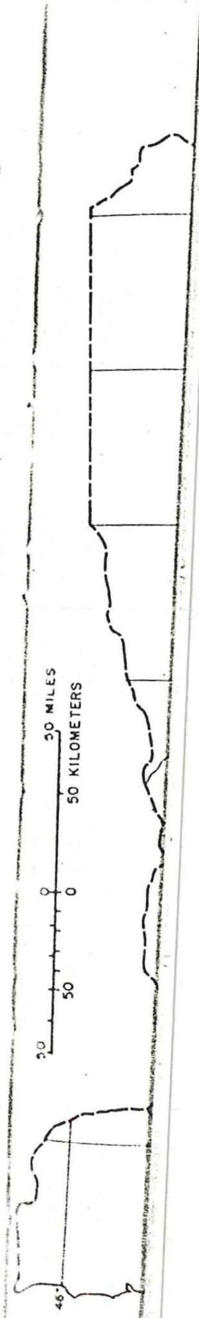
Several lines of evidence indicate a progressive, somewhat sporadic, decrease in the age of both basaltic and rhyolitic volcanism from Harney Basin westward to Newberry Volcano and beyond into the Cascade Range; although this progression is broadly defined by the geographic distribution of volcanic units of different ages, it is more precisely manifested by silicic volcanic activity and the isotopic ages of the resultant domes, flows, and ash-flow tuffs.

In the eastern part of Harney Basin, at Duck Butte, and elsewhere, large domal masses of rhyodacite are closely related structurally and stratigraphically to the Steens Basalt. In places the domes appear to be lapped by these middle(?) and late Miocene basalt flows, and in other places they penetrate the flows. Potassium argon-dates (sample 1*) on plagioclase and biotite from Duck Butte rhyodacite indicate an age of about 10 m.y., or, in the time scale of Evernden and others (1964), an earliest Pliocene (Clarendonian) age.

No rhyolitic rocks are exposed in the broad, sedimented expanse of central Harney Basin, but domal masses and flows of rhyodacite that yielded a date of 7.8 ± 0.26 m.y. (sample 3) form part of Burns Butte on the northwest edge of the central lower basin, and silicic domes and flows west of Harney Lake near Double O Ranch were dated at about 8 m.y. (sample 8) by Parker and Armstrong (1972). Also, very large volume ash-flow tuffs, ranging in age from about 10 m.y. (samples 2, 4, 16, 19) to less than 6 m.y. (samples 6, 10, 11, 12, 13) were erupted from vents buried beneath the sedimentary veneer of the central part of the basin.

One of the oldest of these ash-flow tuffs, informally called welded tuff of Devine Canyon (Greene and others, 1972) and equivalent to the crystal-rich basal member of the Drewsey Formation of Bowen and others (1963), covers thousands of square kilometers mostly north, south, and east of Harney Basin. It erupted from a buried caldera apparently located in the north-central to northwest part of the basin. The domal masses at Burns Butte and those west of Harney Lake are lapped by a pumiceous ash-flow tuff, informally called welded tuff of Double O Ranch by Greene and others (1972) and mapped as part of the Danforth Formation by Piper and others (1939); it also is equivalent to a welded tuff in the Rattlesnake Formation (Brown and Thayer, 1966; Enlows and others, 1973). This large-volume pumiceous tuff (Walker, 1970) is traceable over thousands of square kilometers of southeast and south-central Oregon mostly north, south, and west

*All sample numbers refer to those listed in Table 1 and shown on Figure 2.



of late Pliocene, Pleistocene, Dept. Geology and Mineral nat erupted nonexplosively from d fissures.

olcanism

rogressive, somewhat sporadic, litic volcanism from Harney ond into the Cascade Range; y the geographic distribution precisely manifested by silicic resultant domes, flows, and

Duck Butte, and elsewhere, related structurally and strati- ne domes appear to be lapped flows, and in other places they sample 1*) on plagioclase and an age of about 10 m.y., or, 4), an earliest Pliocene

broad, sedimented expanse of flows of rhyodacite that yielded of Burns Butte on the northwest domes and flows west of Harney out 8 m.y. (sample 8) by Parker me ash-flow tuffs, ranging in 9) to less than 6 m.y. (samples buried beneath the sedimentary

ffs, informally called welded 1972) and equivalent to the rmation of Bowen and others s mostly north, south, and east aldera apparently located in sin. The domal masses at Burns sed by a pumiceous ash-flow O Ranch by Greene and others ormation by Piper and others in the Rattlesnake Formation 1973). This large-volume ver thousands of square kilo- mostly north, south, and west

able 1 and shown on Figure 2.

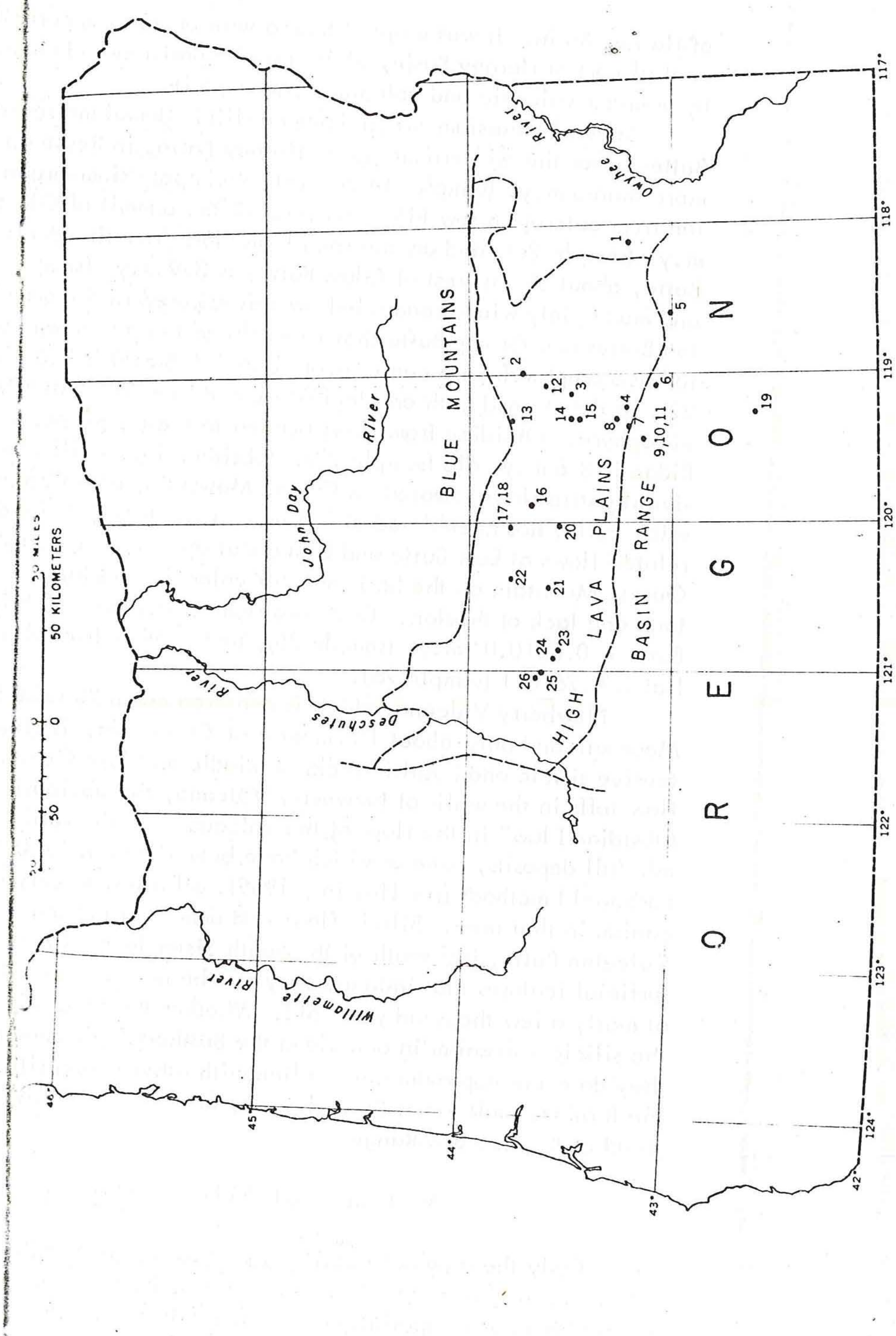


Figure 2. Index to sample localities.

of Harney Basin. It was erupted from a vent or vents apparently in the south-central part of Harney Basin, whose precise position and character is obscured by younger volcanic and volcaniclastic deposits.

Several potassium-argon dates on silicic domal masses at Palomino Buttes, near the western margin of Harney Basin, indicate an age of slightly more than 6 m.y. (samples 14 and 15). One potassium-argon age on obsidian from outcrops a few kilometers east of the summit of Glass Butte is 4.9 m.y. (sample 20), and another on plagioclase from rhyodacite at Frederick Butte, about 32 km west of Glass Butte, is 3.9 m.y. (sample 21). A thin and moderately widespread ash-flow tuff exposed in the area between Hampton Buttes and Grassy Butte that is unrelated to any known vent (but appears to have erupted from a center near Frederick Butte) is 3.6 m.y. old (sample 22), as determined both on plagioclase and glass separates from the basal vitrophyre. Obsidian from flows related to the exogenous domes at Squaw Ridge is 3.6 m.y. old (sample 23). Obsidian from chilled selvages of massive rhyolite flows exposed on Quartz Mountain, about 35 km west of Frederick Butte, has been dated at 1.1 m.y. (sample 24). The glassy domes and related flows at East Butte and China Hat appear even younger than those at Quartz Mountain on the basis of their volcanic constructional physiographic form and lack of erosion. One potassium-argon age on obsidian from East Butte is 0.85 ± 0.04 m.y. (sample 25), and another from obsidian on China Hat is 0.76 ± 0.1 (sample 26).

Newberry Volcano, which is centered about 20 to 30 km west of Quartz Mountain and only about 15 km west of China Hat, is characterized by extensive silicic and basaltic rocks of middle and late Quaternary age. Ash-flow tuffs in the walls of Newberry Volcano, the obviously very young "Big Obsidian Flow" in the floor of the volcano, and the surficial pumice and ash-fall deposits, some of which have been dated at 1720 ± 250 years by carbon-14 methods (see Higgins, 1969), all attest to very recent silicic volcanism in that area. Silicic flows and domes on the southeast flanks of Kaleetan Butte, just south of the South Sister in the Cascade Range, exhibit surficial features that indicate they can be no more than a few hundred or, at most, a few thousand years old. Whether they are related in any way to the silicic volcanism in and along the Brothers fault zone is unknown, but they do occur approximately in line with other young silicic masses along the Brothers fault zone; they also are, of course, generally in line with the trend of the Cascade Range.

Volumes of Silicic Magma

Only the roughest qualitative estimates are possible on the volumes of silicic magmas involved in the Pliocene and younger ash-flow tuffs and domes erupted from vents spatially associated with the Brothers fault zone. Several of the ash-flow tuffs of early and middle Pliocene age, generally referred formally to either the Danforth or Drewsey Formations or informally to welded

or vents apparently in the south-
position and character is obscured
posits.
ic domal masses at Palomino
basin, indicate an age of slightly
e potassium-argon age on obsid-
he summit of Glass Butte is 4.9
se from rhyodacite at Frederick
3.9 m.y. (sample 21). A thin
posed in the area between Hamp-
d to any known vent (but appears
k Butte) is 3.6 m.y. old (sample
glass separates from the basal
the exogenous domes at Squaw
an from chilled selvages of mas-
ntain, about 35 km west of Fred-
ample 24). The glassy domes and
ppear even younger than those at
anic constructional physiographic
argon age on obsidian from East
another from obsidian on China

d about 20 to 30 km west of Quartz
hina Hat, is characterized by ex-
and late Quaternary age. Ash-
o, the obviously very young "Big
, and the surficial pumice and
n dated at 1720±250 years by
l attest to very recent silicic vol-
nes on the southeast flanks of
ter in the Cascade Range, exhibit
no more than a few hundred or,
er they are related in any way to
hers fault zone is unknown, but
ther young silicic masses along
ourse, generally in line with the

c Magma

tes are possible on the volumes of
d younger ash-flow tuffs and dome
h the Brothers fault zone. Severa
liocene age, generally referred
Formations or informally to welde

tuffs of Devine Canyon or Double O Ranch, represent volumes of hundreds of cubic kilometers of magma (Walker, 1970; Greene, 1972). Collectively, the early and middle Pliocene domes must represent an additional several tens of cubic kilometers of magma, mostly in exogenous bodies peripheral to the low central part of Harney Basin. The Quaternary silicic volcanic rocks near the western end of the Brothers fault zone are of much smaller volume, the ash-flow tuffs and domes combined probably totaling less than 100 km^3. The volume of Quaternary silicic rocks is particularly difficult to evaluate because the widespread young basalt flows inundated all but the most prominent domal or erosional masses.

Summary

The implications of this extensive silicic volcanism and the apparent age progression from early Pliocene to very recent activity near Newberry Volcano are only now being evaluated. The age of silicic volcanism, as well as associated basaltic activity, at the western end of this zone is comparable to that found in several areas presently yielding or capable of yielding geothermal energy. However, the volume of silicic magma involved apparently is smaller at the western end of the zone than that found in favorable areas elsewhere. At the eastern end of this zone, where the volumes of silicic magma erupted to the surface were very large, the early and middle Pliocene age may be so old for the volume of magma originally involved that cooling to near ambient temperatures may have occurred; such temperatures would be lower than those that characterize commercial geothermal fields. Furthermore, although the age progression seems reasonably well established, there is presently no obvious way to predict where the next eruption of silicic magma will occur or where, along this zone, unvented silicic magma might be located relatively high in the crust. Certainly the Brothers fault zone and adjacent areas deserve further study as an area with some as yet poorly defined potential for geothermal energy.

Geologically, this apparent age progression may relate to sporadic differential movement along some deeply buried northwest-trending structural element related to movement of crustal plates that is also the underlying cause of the Brothers fault zone. Although it is tempting to relate the progressive age change to plate movement over a "hot spot" such as postulated by Dalrymple and others (1973) for Hawaiian volcanoes, the direction of age decrease appears incorrect.

Acknowledgments

I am indebted to U.S. Geological Survey colleagues who provided several kinds of data or support in obtaining potassium-argon ages. L. B. Schlocker provided potassium analyses and R. W. Kistler, Marvin Lanphere, J. C. Von Essen, and E. H. McKee made age determinations on both whole-rock samples and mineral separates, part of which they prepared.

References

Bowen, R. G., Gray, W. L., and Gregory, D. C., 1963, General geology of the northern Juntura Basin, in The Juntura Basin--studies in earth history and paleoecology: Am. Philos. Soc. Trans., v. 53, pt. 1, p. 22-34.

Brown, C. E., and Thayer, T. P., 1966, Geologic map of the Canyon City quadrangle, northeastern Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-447, scale 1:250,000.

Dalrymple, G. B., Cox, Allan, Doell, R. R., and Grommé, C. S., 1967, Pliocene geomagnetic polarity epochs: Earth and Planetary Sci. Letters, v. 2, no. 3, p. 163-173.

Dalrymple, G. B., Silver, E. A., and Jackson, E. D., 1973, Origin of the Hawaiian Islands: Am. Scientist, v. 61, p. 294-308.

Dicken, S. N., 1950, Oregon geography, 1st ed.: Ann Arbor, Mich., Edward Bros., Inc., 104 p.

Enlows, H. E., Parker, Donald, and Davenport, R. E., 1973, The Rattlesnake ignimbrite tongue [abs.]: Geol. Soc. America, Cordilleran Sec., Abstracts, v. 5, no. 1, p. 38-39.

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.

Greene, R. C., 1972, Petrology of the welded tuff of Devine Canyon, southeast Oregon: U.S. Geol. Survey Prof. Paper 797, 26 p.

Greene, R. C., Walker, G. W., and Corcoran, R. E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-680, scale 1:250,000.

Grose, L. T., 1972, Geothermal energy--geology, exploration, and developments: Colorado School Mines Research Inst. Mineral Indus. Bull., v. 15, no. 1, pt. 2, p. 1-16.

Higgins, M. W., 1969, Airfall ash and pumice lapilli deposits from central pumice cone, Newberry Caldera, in Geological Survey Research 1969: U.S. Geol. Survey Prof. Paper 650-D, p. D26-D32.

Muffler, L. J. P., and White, D. E., 1972, Geothermal energy: The Sci. Teacher, v. 39, no. 3.

Oregon Department of Geology and Mineral Industries, 1965, State of Oregon lunar geological field guidebook: Oregon Dept. Geol. and Mineral Indus. Bull. 57, 51 p.

Parker, Donald, and Armstrong, R. L., 1972, K-Ar dates and Sr isotope ratios for volcanic rocks in the Harney Basin, Oregon: Isochron/West no. 5, p. 7-12.

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.

Walker, G. W., 1970, Cenozoic ash-flow tuffs of Oregon: Ore Bin, v. 32, no. 6, p. 97-115.

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. Geol. Survey Misc. Geol. Inv. Map I-493, scale 1:250,000.

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

Williams, Howel, 1957, A geologic map of the Bend quadrangle, Oregon, and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Dept. Geol. and Mineral Indus., in coop. with U.S. Geol. Survey, scales 1:125,000 and 1:250,000.

* * * * *

RECENT GEOTHERMAL DEVELOPMENTS

Gulf Mineral Resources Company has delayed plans to drill a 6,000-foot geothermal test well near Meadow Lake, about 5 miles northeast of Klamath Falls, in sec. 19, T. 38 S., R. 10 E. A permit to drill the well was granted Gulf last year by the Department of Geology and Mineral Industries and Gulf negotiated a contract for Hunnicutt and Camp of Rio Vista, California to drill the well. But because the Oregon State Engineer requires that all geothermal wells be drilled by Oregon-licensed water-well drilling contractors, the drilling of this test has been postponed. The drilling contractor, Hunnicutt and Camp, has long experience in the drilling of geothermal wells, having drilled many in The Geysers field.

Magma Energy Corporation has filed applications with the Department of Geology and Mineral Industries to drill four 6,000-foot geothermal test wells, two southeast of Vale in sec. 28, T. 18 S., R. 45 E., and two southeast of LaGrande in sec. 9, T. 4 S., R. 39 E. Magma hopes to drill these wells within the next 30 to 60 days.

Republic Geothermal, Inc., Whittier, California, was declared high bidder on June 27 to lease 1,347 acres of national resource lands in the Vale KGRA (known geothermal resource area). Republic's bonus bid was $10.26 per acre or a total of $13,813.00. Three other bidders were Union Oil Co., offering $5.60 per acre; Magma Energy Corp., $5.55 per acre; and LVO Corp., $3.05 per acre. This land is adjacent to the block where Magma Energy plans to drill the two 6,000-foot test wells.

American Metals Climax Corp. (AMAX) announced the establishment of a regional geothermal exploration office in Portland. AMAX, an integrated metals mining, processing, and fabricating firm has recently taken steps to enter the energy field and has purchased geothermal leases in Oregon and other western States. The office in Portland will be headed by Dean Pilkington.

* * * * *