The Ore Bin

Vol. 36, No. 7
July 1974

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

The Ore Bin

Published Monthly By

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
Head Office: 1069 State Office Bldg., Portland, Oregon - 97201
Telephone: 229 - 5580

FIELD OFFICES

2033 First Street
Baker 97814

521 N. E. "E" Street
Grants Pass 97526

Subscription rate - $2.00 per calendar year
Available back issues $.25 each

Second class postage paid
at Portland, Oregon

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

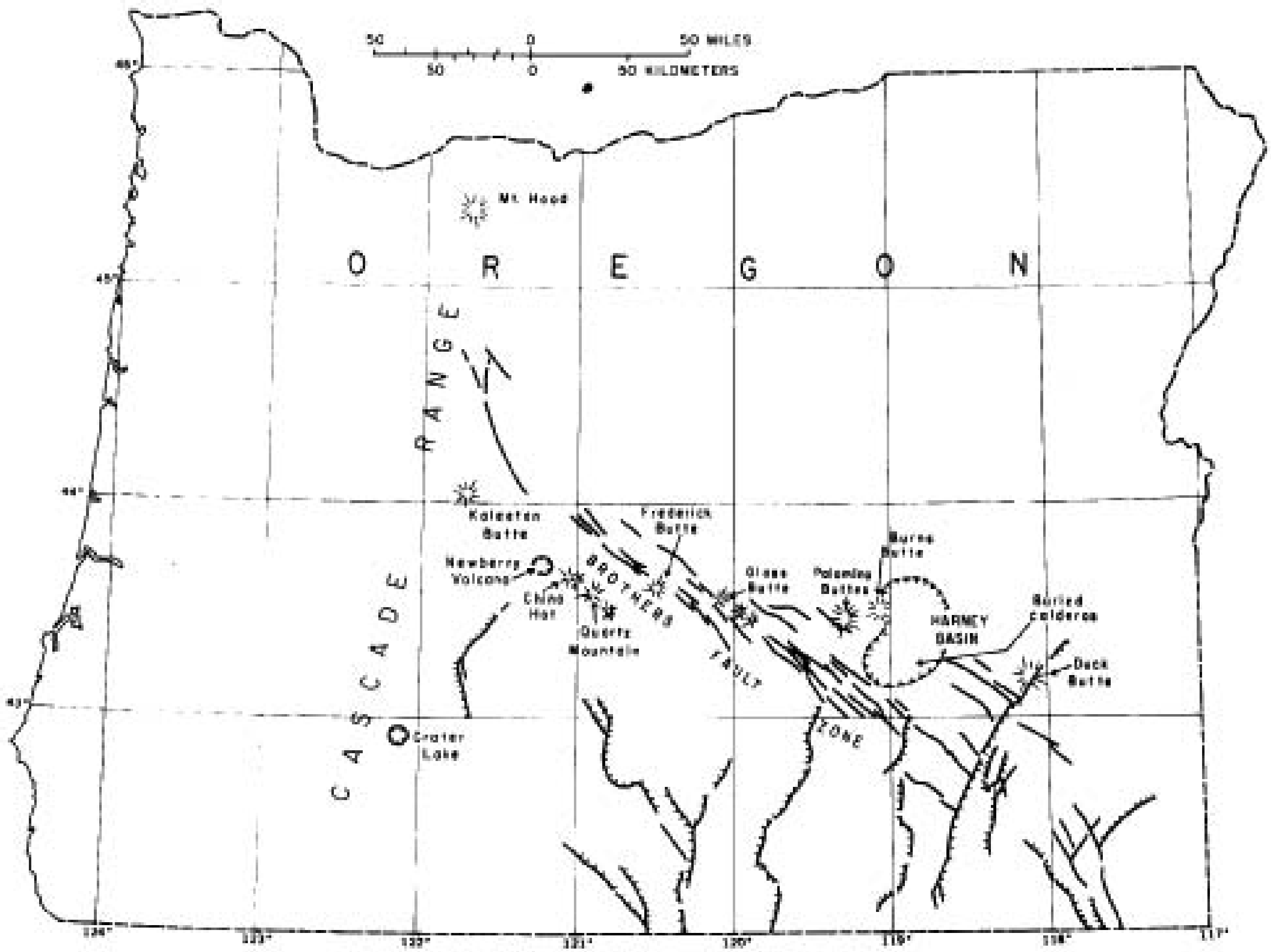


Figure 1. Index map showing some major structural elements and location of some silicic domes and vents.

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	31 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 1.27	8.28 1.27	7.434 1.227	53 31	6.1±0.2 6.5±0.3	1 1	Dome, Palomino 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.

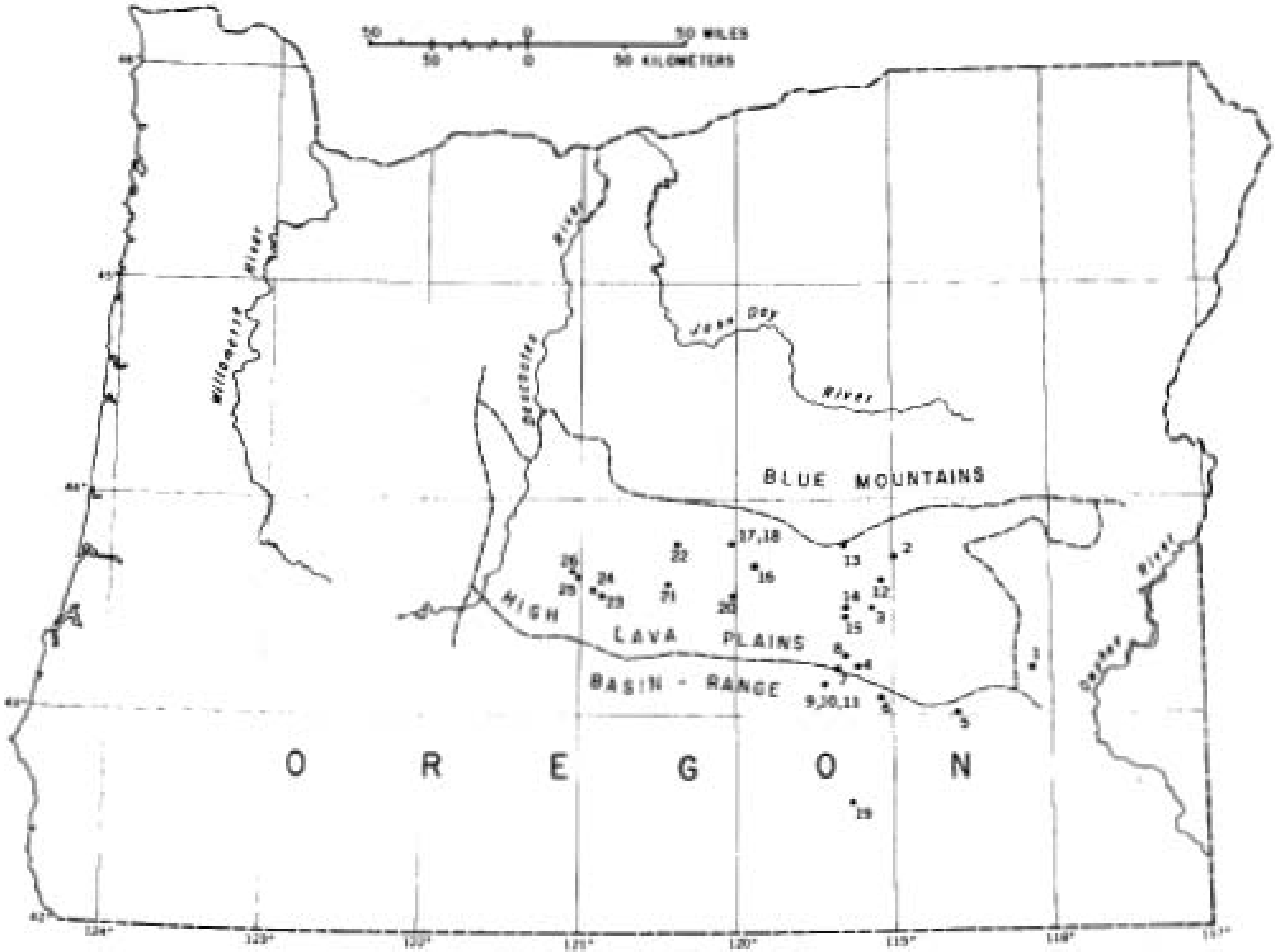


Figure 2. Index to sample localities.

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 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.

* * * * *

THE TYEE-YAMHILL RELATIONSHIPS: A DISCUSSION

It is widely accepted that in the Oregon Coast Range the middle Eocene Tyee Formation (5,000 feet of turbidite sandstone derived largely from the Klamaths) grades northward into the Yamhill Formation (a predominately siltstone unit). In November 1973 Dr. Robert McWilliams of Miami University published an alternative interpretation in The ORE BIN, maintaining that the Yamhill Formation postdates the Tyee Formation. Controversy since that time has culminated in a rebuttal by Dr. Weldon Rau in this month's issue of The ORE BIN. It is in the precise exchange of ideas such as Rau's rebuttal and the accompanying reply by McWilliams that geologic knowledge undergoes the refinement needed to resolve conflicts.

Stratigraphic and Biostratigraphic Relationships of the Tyee and Yamhill Formations: Comments

Weldon W. Rau
Olympic, Washington

A correlation of the lower part of the Yamhill Formation and the Tyee Formation has been generally accepted by Pacific Northwest geologists. McWilliams (1973) presents a contrary conclusion - that these two formations are definitely separated in time, that no part of one correlates with any part of the other. Although it is not my intent to present evidence to prove a correlation between the lower part of the Yamhill Formation and the Tyee Formation, I believe there is considerable reason to question the conclusion of McWilliams.

First, McWilliams pointed out that the fossil mollusks from the Yamhill Formation are regarded as late Eocene in age (Vokes in Baldwin and others, 1955), but failed to mention that Vokes clearly stated that the fauna probably indicated an early late Eocene age - in other words, a position in the lower part of the upper Eocene sequence. Furthermore, the fossils were from well above the base of the formation and so do not provide evidence on the age of the lower part. Baldwin and others (1955) pointed out further that middle Eocene mollusks known to occur in the Tyee Formation and upper Eocene mollusks known to occur in the Nestucca Formation are found together in the Yamhill Formation. Thus, the molluscan fauna of the Yamhill Formation appears to contain elements of both the middle and upper Eocene. I see no reason, therefore, on the basis of mollusks, to reject the possibility of partial correlation of the Yamhill and Tyee Formations, particularly since no molluscan faunas are reported from the lowermost part of the Yamhill Formation.

Second, foraminifera of the Yamhill Formation, specifically those occurring in the Mill Creek section, do not support McWilliams' conclusions. Contrary to the views of McWilliams, I agree with Stewart (1957) that many of the foraminiferal assemblages from that section are comparable to those of the Sacchi Beach beds, a lower part of the McIntosh Formation of Washington, and that they are reasonably close to the fauna of the Llajas Formation of California, which Laiming (1940) assigned to his B-1A zone. Furthermore, I interpret assemblages from the lower part of this section as representing an uppermost part of the Ulatisian Stage or lowermost part of the Narizian Stage of Mallory (1959), a conclusion supported by a number of other workers (for example, J. E. Eke, K. A. McDougall, R. E. Thoms, and Ann Tipton, written communications, 1974). This position within our Pacific Coast biostratigraphic framework is not greatly different from that usually assigned to the faunas of at least part of the Tyee Formation. In addition, even though I do not consider the fauna of the lower part of the Mill Creek section to be diagnostic specifically of either one or the other stage, I disagree with the conclusion of McWilliams that it definitely represents the Narizian Stage. That the upper part of the Yamhill Formation is younger than the Tyee Formation is not in dispute as it has been mapped this way by virtually all workers (for example, Snavely and others, 1972). However, biochronologic evidence certainly does not point to a "black or white" middle Eocene (Ulatisian)-upper Eocene (Narizian) difference in the age of the lower part of the Yamhill Formation and the upper part of the Tyee Formation.

Third, McWilliams places undue emphasis on the chronologic significance of individual species. For example, because both *Amphimorphina californica* and *Nodosaria latejugata* are now known to extend in places up into the Narizian Stage, he rules out a Ulatisian age in favor of Narizian for the entire fauna of the Yamhill Formation. Paleontology is far from an exact science. Its application to biostratigraphy makes use of many subtleties. The interpretation of biochronologic position is not a "cut and dried" procedure based on the presence or absence of individual species. The hope that a particular species will be found to be restricted to a consistent "biochronologic niche" is sooner or later shattered when it is found somewhere above or below its expected range. Chronologically dependable species are rare indeed. Therefore, to interpret the relative age of given assemblages, the paleontologist must not only evaluate the significance of each form, but must consider the *combination of diagnostic species* contained in each assemblage. McWilliams has overemphasized the significance of individual species without giving due attention to the total congregation. His paleontological evidence is thus presented as more definitive than it actually is.

Fourth, McWilliams has arbitrarily mapped other strata together with Yamhill strata so that the stratigraphic meaning of Yamhill is lost. His mapping ignores much of what others have mapped and defined as either the Tyee Formation, Yamhill Formation, Nestucca Formation, or Siletz River Volcanics. For example, on his map the contacts of the Yamhill Formation in its type locality differ markedly from the defined limits of this unit. A large part of his Yamhill Formation was mapped as the uppermost Eocene Nestucca Formation by Baldwin and others (1955), who defined the Yamhill Formation. It is no wonder then that McWilliams lists uppermost Eocene (upper Narizian) assemblages as occurring in his Yamhill Formation.

In summary, because McWilliams has overlooked certain important concepts of biochronology, overemphasized the importance of other paleontological data, and not followed certain principles of geologic mapping, his arguments are insufficient to warrant his outright rejection of earlier interpretations. In my opinion, a truly objective evaluation of all available data does not justify his conclusions "...that correlation or interfingering of the two formations...is not possible."

References

Baldwin, E. M., Brown, R. D., Jr., Gair, J. E., and Pease, M. H., Jr., 1955, Geology of the Sheridan and McMinnville quadrangles, Oregon: Oil and Gas Inv. Map OM-155.

Laiming, Boris, 1940, Some foraminiferal correlations in the Eocene of San Joaquin Valley, California: Pacific Sci. Cong. Proc. 6th session, v. 2, p. 538-568.

Mallory, V. S., 1959, Lower Tertiary biostratigraphy of the California Coast Ranges: Am. Assoc. Petroleum Geologists, Tulsa, Okla., 415 p., 42 pl.

McWilliams, R. G., 1973, Stratigraphic and biostratigraphic relationships of the Tyee and Yamhill Formations in central-western Oregon: Ore Bin, v. 35, no. 11, p. 169-186.

Snavely, P. D., MacLeod, N. S., and Wagner, H. C., 1972, Bedrock geologic map of the Cape Foulweather and Eucher Mountain quadrangles, Oregon: U.S. Geol. Survey open-file map.

Stewart, R. E., 1957, Stratigraphic implications of some Cenozoic foraminifera from western Oregon: Ore Bin, v. 19, no. 2, p. 11-15.

* * * * *

Reply to Comments

Robert G. McWilliams
Miami University, Hamilton, Ohio

Dr. Rau's first point correctly notes that Vokes interpreted the fossil mollusks of the lower Yamhill to be "of late Eocene age, probably early late Eocene."

However, Vokes reported only two positively identified species, Acila (Truncacila) decisa Conrad and Turritella uvasana Conrad stewarti Merriam. The first species ranges through the Eocene and the second is restricted to the upper Eocene. This limited data provides no clear basis for a refined determination of age within the upper Eocene. Baldwin and others (1955) noted that Venericardia hornii subsp. calafia Stewart and Cardiomya comstockensis Turner have been recorded previously only from the middle Eocene Tyee Formation. However, these species have not been recorded from the Yamhill Formation. Schenck identified Venericardia hornii cf. var. calafia Stewart and Vokes identified Cardiomya sp. aff. C. comstockensis Turner from the Yamhill. The locality of these fossils ("two-tenths of a mile south of the Sheridan quadrangle") is clearly upper Eocene because it was so interpreted by Vokes and also because my locality 20 (three-tenths of a mile south of the Sheridan quadrangle), which is stratigraphically lower, contains a definite Narizian assemblage. Locality 20 contains Amphimorphina becki Mallory, Cibicides natlandi var. olequahensis Beck and Plectofrondicularia sacatensis Hornaday which have been previously recorded only from the Narizian. This locality also contains Bulimina sculptilis var. lacinata Cushman and Parker and Robulus chiranus Cushman and Stone, which have not been reported previously below the Narizian. It also contains Amphimorphina ignota Cushman and Siefgus, Cibicides warreni Cushman, Stewart and Stewart, and Valvulineria jacksonensis var. welcomensis Mallory, which have not been reported from above the Narizian. These eight species have a time of joint occurrence restricted to the Narizian. The fossils of this locality, together with Narizian fossils of localities 22 through 33, indicate that all of the type Yamhill Formation which I sampled is Narizian, or upper Eocene.

Dr. Rau's second point is that the fauna of the lower Yamhill Formation is not diagnostic of either the Ulatisian or the Narizian Stages. He recognizes that the upper Yamhill is younger than Tyee Formation but sees no biochronologic evidence that points to a "black or white" distinction in age between the lower Yamhill and the upper Tyee Formation. My interpretation that the Yamhill is definitely Narizian is based on the age of the uppermost Siletz River Volcanics beneath the type Yamhill Formation. Samples from localities 18 and 19 (collected below a 6-inch thick basalt bed within the Siletz River Volcanics) contain Cibicides hodgei Cushman and Schenck, and Vaginulinopsis saundersi (Hanna and Hanna) which are not known from below the Narizian. The samples also contain Vaginulinopsis mexicana var. nudicosta Cushman and Hanna which is unknown above the Ulatisian. The joint occurrence of these and other species listed on Table 2 (McWilliams, 1973) indicates to me that localities 18 and 19 are located on the Ulatisian-Narizian boundary and therefore the overlying lower Yamhill Formation can be no older than Narizian. There is no exposure between locality 19 in the uppermost Siletz River and locality 20 in the lower Yamhill Formation. The thickness of this disputed portion of the lowermost Yamhill Formation is between 80 and 100 feet. My interpretation that the Yamhill is younger than the Tyee Formation is based on the fact that Tyee is not known to be younger than Ulatisian, and the fact that my map shows that Yamhill overlies Tyee Formation and that it does not interfinger with the Tyee. I believe Dr. Rau and I are in agreement about the upper Yamhill, and our differences are centered on the age and relationship of the lower 80 to 100 feet of Yamhill Formation.

Dr. Rau's third point is that paleontology is far from an exact science and that determination of biochronologic age is not based on only the presence or absence of individual species. However, as I have pointed out (McWilliams, 1973, p. 172) Stewart's (1957) designation of the Yamhill as B-1A was based on precisely the type of data to which Dr. Rau objects. Stewart based his conclusion on the occurrence of Amphimorphina californica Cushman and McMasters and Nodosaria latejugata Gümbel. Dr. Rau agrees that these species are now known to occur in the Narizian. Therefore, I conclude there is no longer any basis for designating the lower Yamhill Formation B-1A or Ulatisian. As I pointed out above, my designation of the lower Yamhill as Narizian was based on the recognition of the Ulatisian-Narizian boundary in the uppermost Siletz River Formation. I agree that paleontology is not an exact science. I believe, however, that it can become more exact by strict use of the Oppelian method of age determination which uses the time of joint occurrence of several species as outlined above in the discussion of point one.

Dr. Rau's fourth point is that my map arbitrarily groups portions of what others have called Tyee, Siletz River, and Nestucca Formations with the Yamhill so that the stratigraphic meaning of Yamhill Formation is lost. In particular, he notes that I have grouped what Baldwin and others (1955) defined as Yamhill with what they mapped as Nestucca Formation. All of my mapping was based on purely lithic criteria. I have explained the basis for distinguishing Yamhill and Tyee Formations (McWilliams, 1973, p. 170). The primary lithic distinction I used to differentiate the underlying Siletz River from the Yamhill Formation is the presence of basalt volcanics in the former and its absence in the Yamhill Formation. The contact between the Yamhill and the overlying Nestucca Formation was drawn at the base of the basalt flows. There is no lithic change where the contact was drawn by Baldwin and others (1955). The case cited by Dr. Rau involves the uppermost Yamhill, which he agrees is younger than Tyee. In general, I believe that my map refines the stratigraphic meaning of the Yamhill since it shows what I consider to be Yamhill over a wider and more continuous area than has ever been mapped before.

In conclusion, I would like to add that my work has been an attempt to build on previous work. I regard the work of other geologists who have studied this area to be of high quality. It is primarily because more is now known than was then about the stratigraphic range of certain fossils that I have questioned the conclusions of earlier workers. Dr. Rau has done a service in examining my conclusions objectively. I will be pleased to communicate directly with others who disagree with or have questions about my conclusions.

References

Baldwin, E. M., Brown, R. D., Jr., Gair, J. E., and Pease, M. H., Jr., 1955, Geology of the Sheridan and McMinnville quadrangles, Oregon: U.S. Geol. Survey Oil and Gas Inv. Map OM-155.

McWilliams, R. G., 1973, Stratigraphic and biostratigraphic relationships of the Tyee and Yamhill Formations in central-western Oregon: Ore Bin, v. 35, no. 11, p. 169-186.

Stewart, R. E., 1957, Stratigraphic implications of some Cenozoic foraminifera from western Oregon: Ore Bin, v. 19, no. 2, p. 11-15.

* * * * *

LLOYD STAPLES RETIRES FROM U. OF O.

Lloyd W. Staples, new professor emeritus, retired from the Department of Geology at the University of Oregon on June 30. In 1939 he became an instructor of geology at the University and served as head of the Department from 1958 until 1968, when he took leave to do consulting work in Europe and Iraq. Over the years, he has made news by his discoveries of new, undescribed minerals, two of which he found in Oregon. He has written extensively on rocks and minerals in Oregon and elsewhere and is widely known for his definitive study of thundereggs, Oregon's State Rock, that was published in the October 1965 The ORE BIN and reprinted many times by popular request. Staples plans to travel, look for more interesting minerals, and do research on many unsolved geological problems.

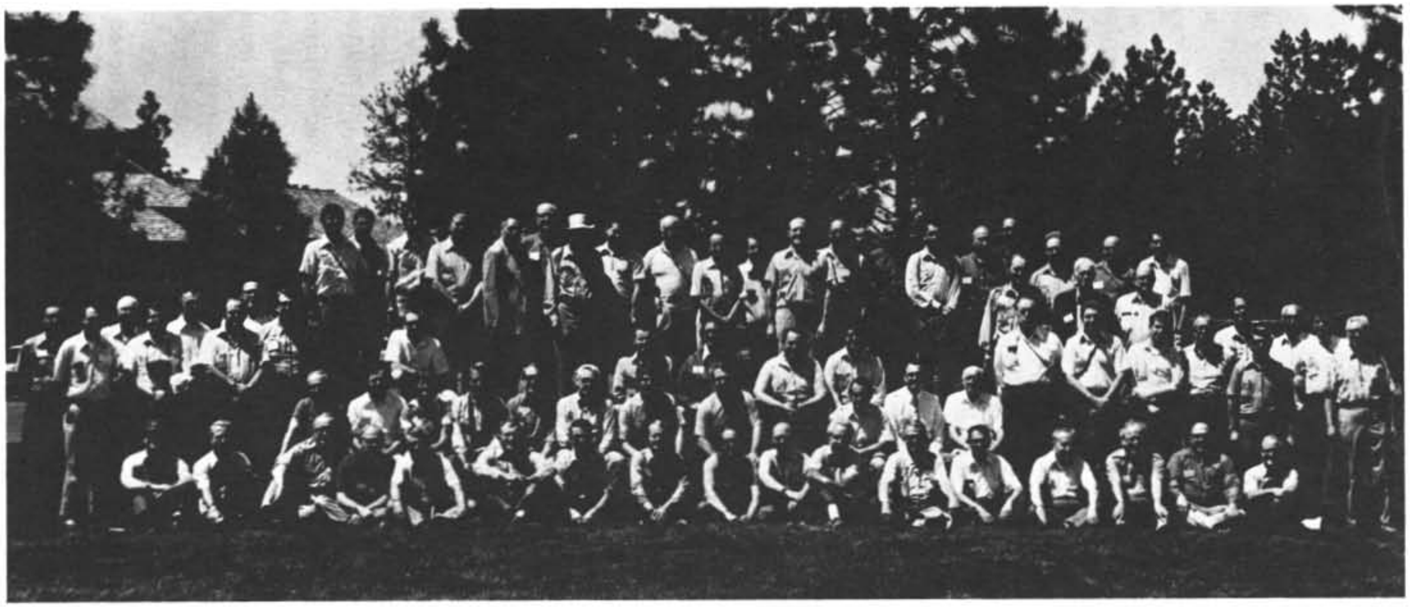
Sam Boggs, Jr., Associate Professor in the Department of Geology at U. of O., will be that Department's new Chairman beginning August 1. He will replace William T. Holser, who has served as Department Chairman for the past three years.

* * * * *

LAND USE PLANNING BILL SIDETRACKED

The House of Representatives, by a vote of 204-211 on June 11, rejected a resolution that would have cleared for floor consideration H.R. 10294, the "Land Use Planning Act." It appears that no attempt will be made to revive this legislation during the 93rd Congress.

* * * * *



The Association of American State Geologists held its annual conference this year at Bend, Oregon, June 9 through 13, with more than 80 participating. Heads of State Geological Surveys came from nearly every state in the Union. Members of the U.S. Geological Survey, U.S. Bureau of Mines, A.E.C., and a number of other Federal agencies and professional geological organizations also attended the meetings. The 3-day conference was devoted to business and the exchange of ideas, during which time energy research, environmental problems, Federal ownership of lands, outer continental shelf exploration were some of the topics discussed. Conference sessions were broken by two field trips to see volcanic features of the area - Lava Butte and Lava River Cave. The conference ended with a banquet, at which time each visitor received a thunderegg, Oregon's State Rock, to take home.

RECENT DEVELOPMENTS IN ENERGY FIELD

The U.S. Department of Commerce has established a panel of experts in the energy field. It is a subgroup of the Commerce Technical Advisory Board (CTAB). Although its membership is not complete, the panel held its first meeting July 10.

Briefly, the objectives and duties of this new panel will be to "...provide an independent assessment of the feasibility of the actions and policies resulting from the Project Independence Blueprint. The panel will represent a central input of private sector views concerning governmental policy decisions designed to expand the domestic supply of energy sources of the United States." Further, the panel will provide advice and information with respect to the following questions:

What is the realistic capacity for expansion of domestic energy resources within a given time frame?
What are the constraints which must be overcome to achieve this expansion?
What are the costs of expanding domestic energy resources, in terms of capital, materials, and manpower?
What are the social and environmental implications of such an expansion?

On July 10, the newly appointed head of the Federal Energy Administration, John Sawhill, following his swearing-in ceremonies at the White House, held a briefing session for high-level Administration officials on the existing and projected energy picture. Later that day Sawhill and other FEA officials held a briefing session on Project Independence for the Project Independence Advisory Committee. Mr. Sawhill declared: "The need for Project Independence at this time cannot be stressed strongly enough. Our demand has been growing rapidly while energy production for many fuels has leveled off or declined. The Middle East oil embargo alerted the nation to the risks of extensive foreign energy dependence. Although the embargo was imposed at a time when we were able to manage the shortage, a future supply disruption could have much more serious economic and social impacts. The Project Independence Blueprint will evaluate the growing dependence of the United States on foreign sources of energy, future supply and demand alternatives, and will develop positive programs to reduce our vulnerability to future oil cut-offs and price increases."

For a copy of Sawhill's briefing paper, write to the American Mining Congress, Ring Building, Washington, D.C. 20036.

(American Mining Congress News Bulletin No. 74-14)

* * * * *

GEOTHERMAL RESEARCH ON INCREASE

Growing interest in utilization of natural geothermal resources to help meet the nation's energy needs is stimulating geothermal research and increasing the demand for this kind of information. In last month's The ORE BIN (June), the Department published "Telluric Current Exploration for Geothermal Anomalies in Oregon" by workers at Oregon State University. In this month's issue is a report on the relation of geothermal potential in south-central Oregon to progressive ages of late Cenozoic volcanism. The following recently completed theses were received by this Department's library:

Res Wai-Yuen Tang: Geothermal exploration by telluric currents in the Klamath Falls area, Oregon: OSU Dept. of Oceanography master's thesis, 86 p., 29 figs., 6 tables, June 1974.

Talal Hussein Hassoun: Optimization of single- and double-flash cycles and space heating systems in geothermal engineering: PSU Dept. of Geology master's thesis, 1974.

* * * * *

MINED LAND RECLAMATION STATISTICS RELEASED

A newly released information circular of the Bureau of Mines shows that between 1930 and 1971, the mining industry only used .16 of 1% of the surface area of the United States, and of that amount about 40% has been reclaimed.

The 61-page circular, entitled "Land Utilization and Reclamation in the Mining Industry, 1930-71," contains numerous tables and charts depicting, by State and commodity group (i.e., "metals," and "fossil fuels") the amount of land used by each and the amount of land reclaimed. The report states that growing public interest in the reclamation of surface-mined land has led to proposals for "legislation and regulation, sometimes based on seriously inadequate information" and says that the report grew out of the need for adequate data.

The report is available from the Superintendent of Documents at the Government Printing Office for $1.05 per copy.

* * * * *

SCENIC PLACES IN CASCADE RANGE

A few copies of "Some little-known scenic pleasure places in the Cascade Range in Oregon" by Ira A. Williams, published in 1916 by Oregon Bureau of Mines and Geology, are available. The 114-page booklet contains 60 photos, several in color. For sale in Portland office only for $2.00.

* * * * *

AVAILABLE PUBLICATIONS

(Please include remittance with order; postage free. All sales are final - no returns. Upon request, a complete list of Department publications, including out-of-print, will be mailed)

BULLETINS

8.	Feasibility of steel plant in lower Columbia River area, rev. 1940: Miller . . .	$0.40
26.	Soil: Its origin, destruction, preservation, 1944: Twenhofel	0.45
33.	Bibliography (1st suppl.) geology and mineral resources of Oregon, 1947: Allen. .	1.00
35.	Geology of Dallas and Valsetz quadrangles, Oregon, rev. 1963: Baldwin. . . .	3.00
36.	Papers on Tertiary foraminifera: Cushman, Stewart & Stewart. vol. 1 $1.00; vol. 2	1.25
39.	Geology and mineralization of Morning mine region, 1948: Allen and Thayer . .	1.00
46.	Ferruginous bauxite deposits, Salem Hills, 1956: Corcoran and Libbey	1.25
49.	Lode mines, Granite mining district, Grant County, Oregon, 1959: Koch . . .	1.00
52.	Chromite in southwestern Oregon, 1961: Ramp	3.50
57.	Lunar Geological Field Conf. guidebook, 1965: Peterson and Groh, editors . . .	3.50
58.	Geology of the Suplee-Izee area, Oregon, 1965: Dickinson and Vigrass	5.00
60.	Engineering geology of Tualatin Valley region, 1967: Schlicker and Deacon . . .	5.00
61.	Gold and silver in Oregon, 1968: Brooks and Ramp	5.00
62.	Andesite Conference Guidebook, 1968: Dole	3.50
64.	Geology, mineral, and water resources of Oregon, 1969	1.50
66.	Geology, mineral resources of Klamath & Lake counties, 1970: Peterson & McIntyre	3.75
67.	Bibliography (4th suppl.) geology and mineral industries, 1970: Roberts	2.00
68.	The Seventeenth Biennial Report of the State Geologist, 1968-1970	1.00
69.	Geology of the Southwestern Oregon Coast, 1971: Dott	3.75
70.	Geologic formations of Western Oregon, 1971: Beaulieu	2.00
71.	Geology of selected lava tubes in the Bend area, 1971: Greeley.	2.50
72.	Geology of Mitchell Quadrangle, Wheeler County, 1972: Oles and Enlows . . .	3.00
73.	Geologic formations of Eastern Oregon, 1972: Beaulieu	2.00
74.	Geology of coastal region, Tillamook Clatsop Counties, 1972: Schlicker & others	7.50
75.	Geology, mineral resources of Douglas County, 1972: Ramp	3.00
76.	Eighteenth Biennial Report of the Department, 1970-1972	1.00
77.	Geologic field trips in northern Oregon and southern Washington, 1973	5.00
78.	Bibliography (5th suppl.) geology and mineral industries, 1973: Roberts and others	3.00
79.	Environmental geology inland Tillamook Clatsop Counties, 1973: Beaulieu . . .	6.00
80.	Geology and mineral resources of Coos County, 1973: Baldwin and others . . .	5.00
81.	Environmental geology of Lincoln County, 1973: Schlicker and others	7.50
82.	Geol. hazards of Bull Run Watershed, Mult. Clackamas Cos., 1974: Beaulieu . .	5.00
83.	Eocene stratigraphy of southwestern Oregon, 1974: Baldwin	in prep.
84.	Environmental geology of western Linn Co., 1974: Beaulieu and others	in press.
85.	Environmental geology of coastal Lane Co., 1974: Schlicker and others	in prep.

GEOLOGIC MAPS

Geologic map of Oregon west of 121st meridian, 1961: Wells and Peck	2.15
Geologic map of Oregon (12" x 9"), 1969: Walker and King	0.25
Geologic map of Albany quadrangle, Oregon, 1953: Allison (also in Bulletin 37) . .	0.50
Geologic map of Galice quadrangle, Oregon, 1953: Wells and Walker	1.00
Geologic map of Lebanon quadrangle, Oregon, 1956: Allison and Felts	0.75
Geologic map of Bend quadrangle, and portion of High Cascade Mtns., 1957: Williams	1.00
GMS-1: Geologic map of the Sparta quadrangle, Oregon, 1962: Prostka	1.50
GMS-2: Geologic map, Mitchell Butte quad., Oregon: 1962, Corcoran and others . .	1.50
GMS-3: Preliminary geologic map, Durkee quadrangle, Oregon, 1967: Prostka . . .	1.50
GMS-4: Gravity maps of Oregon, onshore & offshore, 1967: Berg and others [sold only in set] flat $2.00; folded in envelope	2.25
GMS-5: Geology of the Powers quadrangle, 1971: Baldwin and Hess	1.50
GMS-6: Prelim. report, geology of part of Snake River Canyon, 1974: Vallier . . .	in prep.

[Continued on back cover]

The ORE BIN
1069 State Office Bldg., Portland, Oregon 97201

The Ore Bin

POSTMASTER: Return postage guaranteed.

Available Publications, Continued:

SHORT PAPERS

18. Radioactive minerals prospectors should know, 1955: White and Schafer . . . $0.30
19. Brick and tile industry in Oregon, 1949: Allen and Mason 0.20
21. Lightweight aggregate industry in Oregon, 1951: Mason 0.25
24. The Almeda mine, Josephine County, Oregon, 1967: Libbey 2.00

MISCELLANEOUS PAPERS

1. Description of some Oregon rocks and minerals, 1950: Dole 0.40
2. Oregon mineral deposits map (22 x 34 inches) and key (reprinted 1973): Mason . . 0.75
4. Rules and regulations for conservation of oil and natural gas (rev. 1962) 1.00
5. Oregon's gold placers (reprints), 1954 . . . . 0.25
6. Oil and gas exploration in Oregon, rev. 1965: Stewart and Newton 1.50
7. Bibliography of theses on Oregon geology, 1959: Schlicker 0.50
7. (Supplement) Bibliography of theses, 1959 to Dec. 31, 1965: Roberts 0.50
8. Available well records of oil and gas exploration in Oregon, rev. 1963: Newton 0.50
11. A collection of articles on meteorites, 1968 (reprints from The ORE BIN) 1.00
12. Index to published geologic mapping in Oregon, 1968: Corcoran 0.25
13. Index to The ORE BIN, 1950-1969, 1970: Lewis 0.30
14. Thermal springs and wells, 1970: Bowen and Peterson 1.00
15. Quicksilver deposits in Oregon, 1971: Brooks 1.00
16. Mosaic of Oregon from ERTS-1 imagery, 1973: 2.00

OIL AND GAS INVESTIGATIONS SERIES

1. Petroleum geology, western Snake River basin, 1963: Newton and Corcoran . . 2.50
2. Subsurface geology, lower Columbia and Willamette basins, 1969: Newton . . 2.50
3. Prelim. identifications of foraminifera, General Petroleum Long Bell no. 1 well 1.00
4. Prelim. identifications of foraminifera, E. M. Warren Coos Co. 1-7 well: Rau . 1.00

MISCELLANEOUS PUBLICATIONS

Landforms of Oregon: a physiographic sketch (17" x 22"), 1941 . . . . 0.25
Geologic time chart for Oregon, 1961 . . . . free
Postcard - geology of Oregon, in color . . . . . 10¢ each; 3 - 25¢; 7 - 50¢; 15 - 1.00
Oregon base map (22 x 30 inches) 0.50
Mining claims (State laws governing quartz and placer claims) 0.50
The ORE BIN - Annual subscription . . . . ($5.00 for 3 yrs.) 2.00
Available back issues, each 0.25
Accumulated index - see Misc. Paper 13