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C.T. Higgins and S.H. Evans

Isochron/West, Bulletin of Isotopic Geochronology, v. 36, pp. 3-6

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K-Ar DATES OF VOLCANIC ROCKS IN THE WESTERN BODIE HILLS, CALIFORNIA

CHRIS T. HIGGINS *California Division of Mines and Geology, Sacramento, CA 95814*
STANLEY H. EVANS, JR. *Department of Physics, University of Utah, Salt Lake City, UT 84112*

The Bodie Hills in eastern California (fig. 1) are part of a constructional volcanic highland comprised predominantly of Miocene volcanic rocks of intermediate chemical composition. This volcanic complex extends northeastward to Aurora, Nevada, where rocks at Aurora Crater have been dated as young as about 250,000 years (Silberman and McKee, 1972). Previous dating of rocks in the complex has been confined mainly to the mining districts at Bodie and Aurora with some from the southwestern Bodie Hills. This previous work is summarized in Kleinhampl and others (1975) and in Gilbert and others (1968).

We dated four samples of volcanic rocks from the western Bodie Hills by the K-Ar method as part of a study of geothermal resources in that area (Higgins and others, 1982). The dates aided study of the volcanic stratigraphy of the area, especially the age of the youngest volcanism. Funds for the dates were provided by the Division of Geothermal Energy, U.S. Department of Energy, under contract DE-AC07-80ID12079. All laboratory work was performed at the University of Utah Research Institute.

DISCUSSION

Three distinctive groups of Miocene volcanic rocks are recognized in the western Bodie Hills. From oldest to youngest, the groups are calc-alkalic andesite, alkali-calcic andesite and dacite, and bimodal basalt-rhyolite.

The oldest group is exposed over much of the northwestern Bodie Hills, mainly north of Aurora Canyon (fig. 2). Its calc-alkalic character was determined by Al-Rawi (1969), who reported that the rocks are mostly pyroxene andesite. Both Al-Rawi (1969) and Kleinhampl and others (1975) mapped them as Miocene in age. The locations of the vents from which these rocks erupted are unknown, although they were probably to the north; intrusive bodies in the Masonic area may represent the locations of some of them.

Our date of 10.8 ± 1.1 m.y. on a representative sample from Aurora Canyon is the first known published age on these rocks. The date is consistent with field relations that indicate this group is the oldest of the three. The group is probably part of a regional assemblage of calc-alkalic volcanic rocks, discussed by Silberman and others (1976), that was erupted along a northwest-trending zone that extended from the northern Sierra Nevada in California into western Nevada along the Walker Lane. They interpreted this volcanism to be the result of subduction along the west coast of North America between 22–6 m.y. ago with the major activity 17–12 m.y. ago.

The second group, the alkali-calcic andesite and dacite, forms the main mass of the Bodie Hills. These rocks were erupted from several local centers, the most important of which were at Bodie Mountain, Potato Peak, Mount Biedeman, and Big Alkali caldera (Chesterman, 1968; Al-Rawi, 1969). Hornblende and biotite are characteristic of the rocks, which are more silicic and potassic than the older calc-alkalic group. Lesser amounts of basalt and rhyolite are also present.

The range of previously reported ages for the rocks of the second group is about 7.8–9.5 m.y., based on the work of Silberman and Chesterman (1972) and Al-Rawi (1969). The two new ages reported here for this group are consistent with this range. The older, at 9.20 ± 0.68 m.y., is from a flow of biotite-hornblende andesite near the town of Bridgeport. Rocks of this age may be more extensive in the western Bodie Hills than previously recognized; Al-Rawi (1969) mapped the rocks near Bridgeport as part of an older unit of Miocene andesite that corresponds to the calc-alkalic andesite discussed above. He inferred that this unit is at least 12.5 m.y. old, based on stratigraphic position. Chesterman and Gray (1975) mapped the same rocks as part of the alkali-calcic andesite and dacite of the second group described here. The age reported here suggests that some of the rocks near Bridgeport represent one of the earliest pulses of the alkali-calcic volcanism that constructed the main mass of the Bodie Hills. Farther southeast of Bridgeport, these rocks are overlain by extensive flows of biotite-hornblende andesite, which were dated at 7.8 ± 0.2 m.y. (Al-Rawi, 1969) and 8.0 ± 0.2 m.y. (Silberman and Chesterman, 1972). Our date of 7.73 ± .44 m.y. on a flow considered to be a part of this unit is consistent with these data. The flows were possibly erupted from Big Alkali caldera (Chesterman, 1968) and may represent the final major eruptions of the alkali-calcic volcanism in the Bodie Hills.

The last known episode of volcanism in the western Bodie Hills is represented by a bimodal association of basalt and rhyolite. Small plugs of rhyolite and rhyodacite within and south of Big Alkali caldera were dated at 5.2–5.7 m.y. by Silberman and Chesterman (1972); the plugs indicate the presence of a silicic magma chamber under this area at that time. Farther north, along the north rim of Aurora Canyon and beyond, are remnants of flows of olivine basalt. Al-Rawi (1969) recognized a nearby vent for these flows (fig. 2). We selected the basalt for dating because its youthful morphology and stratigraphic position suggested that it might be the youngest volcanic unit in the western Bodie Hills, including the rhyolitic plugs to the south. The whole-rock date of 5.55 ± 0.69 m.y. on the basalt indicates that these flows are coeval with and perhaps genetically related to the rhyolitic plugs.

The bimodal volcanism in the western Bodie Hills was characteristic of a more widespread pattern of waning volcanism in the Great Basin, as described by Silberman and others (1976). According to these workers, the end of subduction about 6 m.y. ago brought about an end to the predominantly calc-alkalic volcanism discussed above and initiated a period of crustal extension along the western margin of the Great Basin. This extension allowed the rapid ascent of basaltic and rhyolitic magmas, particularly in the region of California and Nevada where the Great Basin borders the Sierra Nevada.

It is not yet proven that the bimodal volcanism of 5.5 m.y. ago was the last igneous activity in the western Bodie Hills. The presence of Holocene volcanic domes in nearby Mono Basin, some as close as 15 km south of Mount Biedeman, suggests the possibility of local activity much younger than the bimodal episode of 5.5 m.y. ago. Such activity, especially if silicic in composition, could significantly upgrade current estimates of the geothermal resources of the Bodie Hills.

Field relations and morphologies of surface exposures of volcanic rocks in the western Bodie Hills do not indicate rocks significantly younger than the bimodal suite discussed above. An exception might be a complex of rhyolite

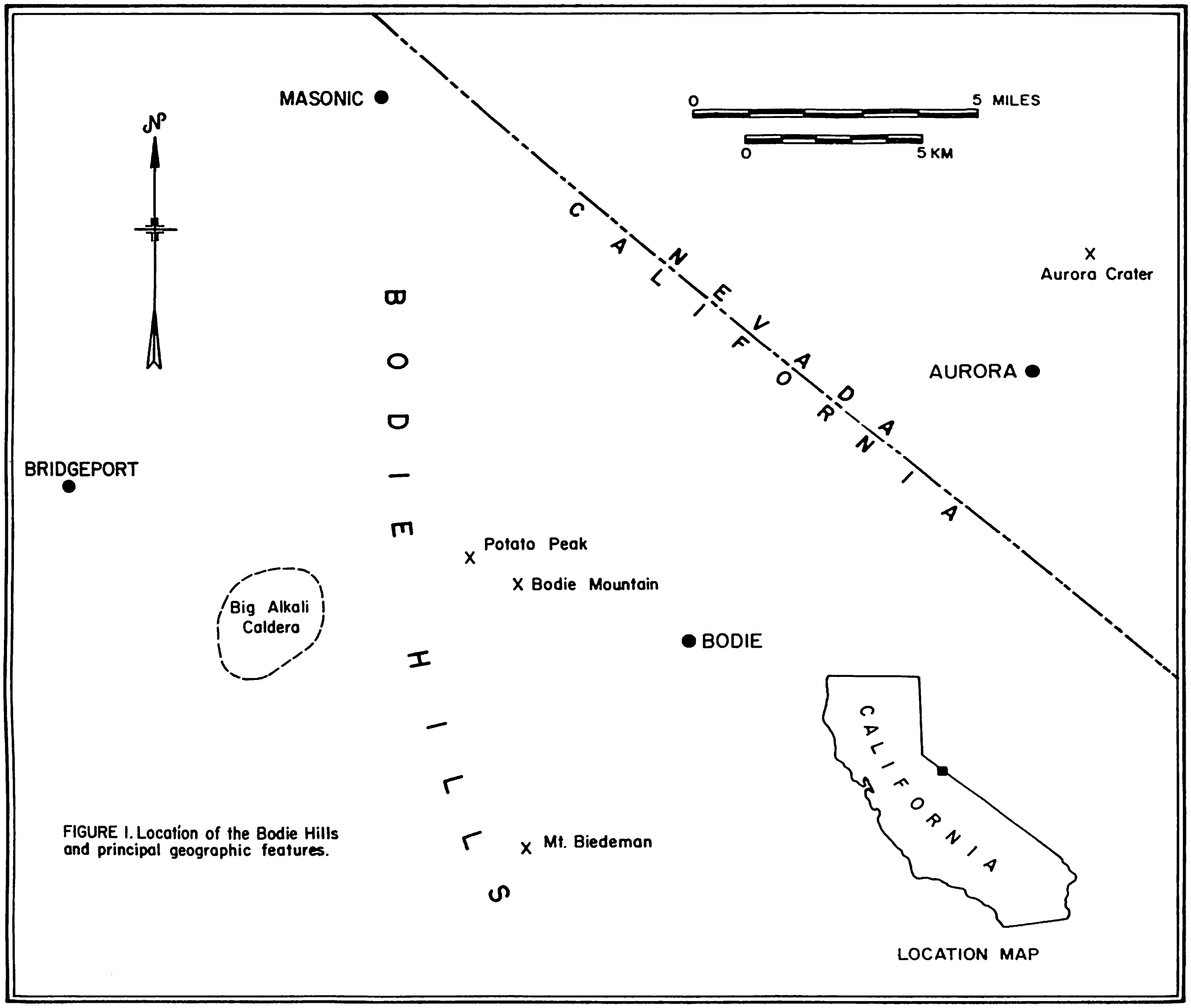


FIGURE I. Location of the Bodie Hills and principal geographic features.

domes just east of the basalt in Aurora Canyon (fig. 2). We attempted to date one of the domes but were unsuccessful because of the lack of suitable minerals.

At depth, younger solidified intrusions may be present. These intrusions could be the source of heat for an active hydrothermal convection system that currently feeds two groups of thermal springs along the west edge of the Bodie Hills near Bridgeport (fig. 2). Alternatively, the system may be unrelated to remnant magmatic heat and is driven instead by heat obtained from the geothermal gradient when meteoric water circulates to great depths. If the bimodal volcanism of 5.5 m.y. ago is truly the last igneous episode in the western Bodie Hills, the latter explanation of the convection system is likely, as any igneous body associated with that episode has long since solidified and cooled to ambient temperatures.

ANALYTICAL PROCEDURES

Locations where the four samples were collected are shown in figure 2. Dates on the samples were determined by standard techniques described below.

Plagioclase separates from three of the four samples were prepared with a magnetic separator and hand-picked to achieve greater than 98% purity. Final separates were successively leached in hydrochloric acid to remove iron stains and then in a 10% hydrofluoric acid to complete cleaning. The whole-rock sample was initially crushed to −20, +30 mesh, then leached in dilute nitric acid and 10% hydrofluoric acid. This treatment effectively reduces both carbonate contamination and atmospheric argon in whole-rock specimens without any appreciable effect on age results.

Potassium was analyzed by flame photometry. The samples and in-house standards were fused with lithium metaborate and run against one another to determine concentrations of potassium (Ingamells, 1964). Argon was determined by mass-spectrometry. Samples were prepared by fusion with an R.F. induction heater and by clean-up in a gas-handling line similar to that described by Dalrymple and Lanphere (1969). Argon determinations were then completed utilizing a 60° sector Nier-type glass spectrometer. Uncertainties in the ages reported represent one standard deviation. The following constants were used: $\lambda_\beta = 4.962 \times 10^{-10} yr^{-1}$; $\lambda_\epsilon = 0.581 \times 10^{-10} yr^{-1}$; $\lambda = 5.543 \times 10^{-10} yr^{-1}$; $^{40}K/K_{tot} = 1.167 \times 10^{-4}$ atom/atom.

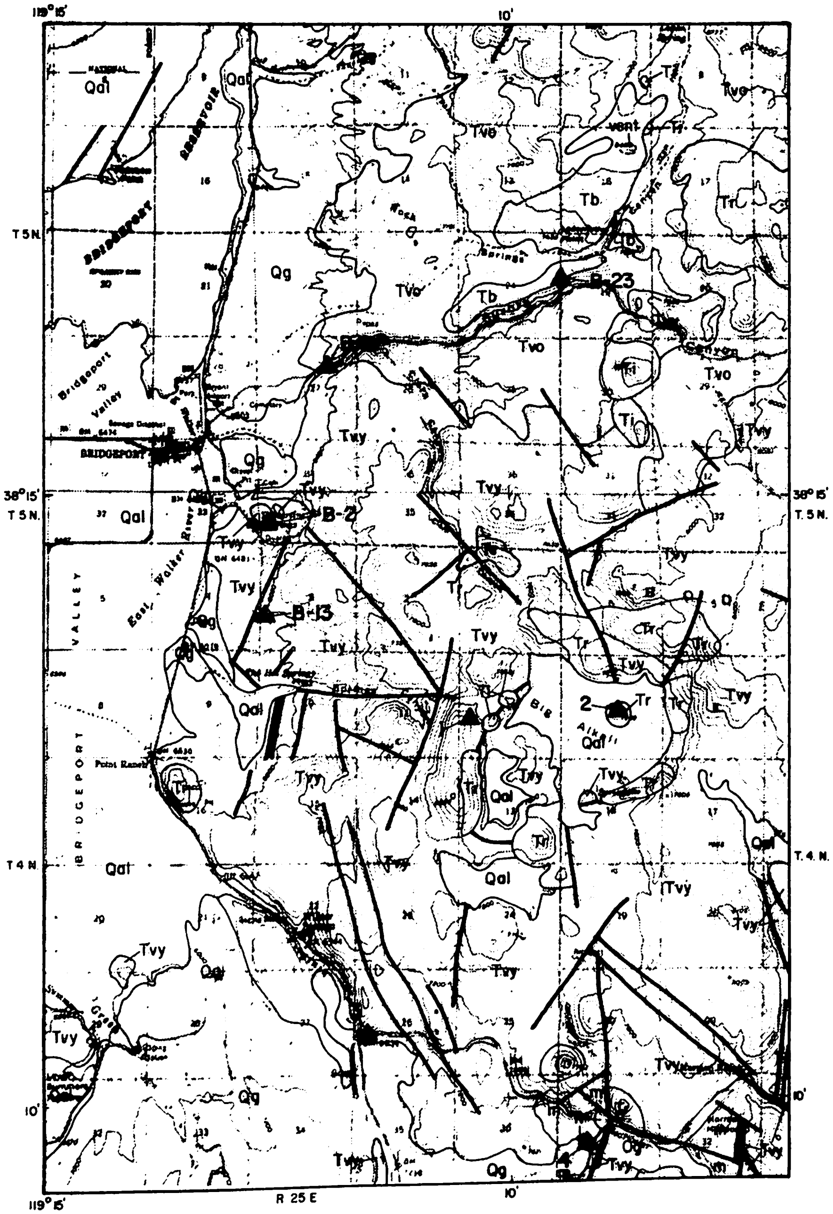


FIGURE 2. Generalized geologic map of a portion of the western Bodie Hills, with locations of radiometric dates.

LEGEND

Qal	Quaternary alluvium and fan deposits
Qg	Quaternary glacial outwash and terrace deposits
Tb	Olivine basalt
Tvy	Younger alkalic-calcic andesite and dacite of main Bodie Hills
Tvo	Older calc-alkalic andesite
m	Pre-Cenozoic metamorphic rocks

Intrusive Bodies

Tr	Rhyolite and rhyodacite
Ti	Andesite and dacite

Symbols

—— Contact

━━ Fault

B-22 ▲ Location of K-Ar date

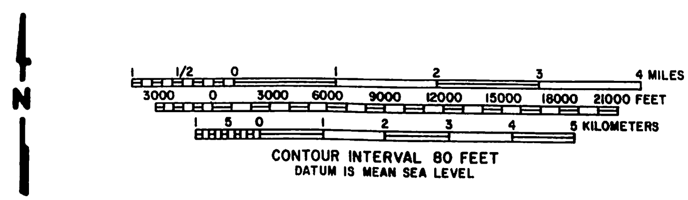
1 = 8.0±0.2 m.y. (Silberman and Chesterman, 1972)

2 = 5.2±0.3 m.y., 5.4±0.6 m.y. (Silberman and Chesterman, 1972)

3 = 7.8±0.2 m.y. (Al-Rawi, 1969)

4 = 5.7±0.2 m.y. (Silberman and Chesterman, 1972)

Geology modified from Chesterman and Gray (1977) and from Kleinhampl and others (1975). Base map reduced from U.S.G.S. Bridgeport 15' and Bodie 15' Quadrangles.



SAMPLE DESCRIPTIONS

1. *B-2/UT-283* K-Ar
Biotite-hornblende andesite (SW¼ SW¼ S34,T5N,R25E; 38°14.75'N, 119°12.60'W; summit of small hill SE of CALTRANS maintenance station; Mono Co., CA). *Analytical data:* K_2O = 1.06%; rad^{40}Ar = 1.696 × 10^{-11}m/gm; atm^{40}Ar = 81%.
(plagioclase) 9.20 ± 0.68 m.y.

2. *B-13/AH-108* K-Ar
Biotite-hornblende andesite (NW¼ SW¼ S3,T4N,R25E; 38°13.95'N, 119°12.70'W; flow N of dirt road; Mono Co., CA). *Analytical data:* K_2O = 1.30%; rad^{40}Ar = 1.748 × 10^{-11}m/gm; atm^{40}Ar = 74%.
(plagioclase) 7.73 ± 0.44 m.y.

3. *B-22/AH-109* K-Ar
Pyroxene andesite (SW¼ NE¼ S27,T5N,R25E; 38°16.05'N, 119°11.90'W; prominent outcrop of platy-jointed flows on N side of Aurora Canyon Road; Mono Co., CA). *Analytical data:* K_2O = 0.69%; rad^{40}Ar = 1.292 × 10^{-11}m/gm; atm^{40}Ar = 86%.
(plagioclase) 10.8 ± 1.1 m.y.

4. *B-23/UT-284* K-Ar
Olivine basalt (SW¼ NW¼ S19,T5N,R26E; 38°16.80'N, 119°09.45'W; prominent flow that caps ridge N of Aurora Canyon Road; Mono Co., CA). *Analytical data:* K_2O = 1.30%; rad^{40}Ar = 1.252 × 10^{-11}m/gm; atm^{40}Ar = 89%.
(whole-rock) 5.55 ± 0.69 m.y.

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