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Geochronology of Tertiary Igneous Rocks in Central Nevada

ABSTRACT

Potassium-argon dating of Tertiary igneous rocks in Lander County, central Nevada, indicates that igneous activity was episodic and can be separated into three periods. Igneous activity started abruptly about 37 m.y. ago with local extrusion of andesitic to quartz-latitic lava flows and intrusion of hypabyssal rocks of similar composition. This activity ceased about 33 m.y. ago and was followed by extrusion of rhyolite ash-flow sheets that blanketed large parts of the region. These ash-flow sheets range from about 34 to 22 m.y. in age. The final phase, represented by basalt and basaltic-andesite flows and intrusive rhyolite flow-dome complexes, took place about 16 to 10 m.y. ago.

Andesitic to dacitic lava and hypabyssal rocks about 35 m.y. old are widespread east of Lander County and rhyolitic ash-flow tuffs 34 to 20 m.y. old are found south and east of Lander County. The younger (16 to 10 m.y.) basalt and basaltic-andesite flows are related to volcanism of the Snake River plain province to the north.

The precision of the ages was evaluated by means of: (1) repeat analyses of the same mineral separate, (2) age determination of mineral pairs from the same hand specimen, and (3) age determinations on widely spaced samples from the same geologic body or formation. The last method seems most meaningful from a geologic point of view.

INTRODUCTION

Thirty-six potassium-argon age determinations were made on 14 extrusive and 5 intrusive rock units carefully selected to ascertain the geochronology of Tertiary igneous activity in Lander County, Nevada. These units are considered representative of the Tertiary igneous rocks of Lander County and of a much larger region including most of east-central and north central Nevada.

Previous to this study only a scattering of radiometric ages of Tertiary units from this region of more than 12,000 sq mi had been reported, and no time pattern of igneous activity was indicated. The potassium-argon dates reported here, determined in conjunction with regional mapping under the Nevada Bureau of Mines county map program in cooperation with the U.S. Geological Survey, show a pronounced picture of episodic igneous activity in central Nevada. In addition, the periodicity of these igneous events can be related to the distribution and petrochemistry of all the Tertiary rocks in the central part of the Great Basin.

GEOLOGIC SETTING

Tertiary igneous rocks lie unconformably on, or intrude, Paleozoic and Mesozoic rocks in most areas of central Nevada. The oldest Tertiary rocks in this region are latest Eocene or earliest Oligocene, as suggested by potassium-argon ages, and the youngest of the basement rocks are Jurassic or Cretaceous. The hiatus between Tertiary and older rocks amounts to at least 50 m.y. and at many places is more than two to three times this long. The bulk of the igneous rocks in the area are welded tuffs and lava flows. Intrusive rocks are less widespread and probably make up less than 10 percent of the total volume of Tertiary igneous rocks and are most common in the northern part of the county.

Distribution of Tertiary Rocks

Tertiary rocks comprise almost all of the Simpson Park Range, a large part of the northern Toiyabe Range, and the central part of the Shoshone Range (Fig. 1). Because the extrusive rocks are limited in extent, no single section contains more than a few units in stratigraphic sequence. Also, the units are lenticular because they flowed over a surface of moderate relief (Mesozoic to Eocene or Oligocene unconform-

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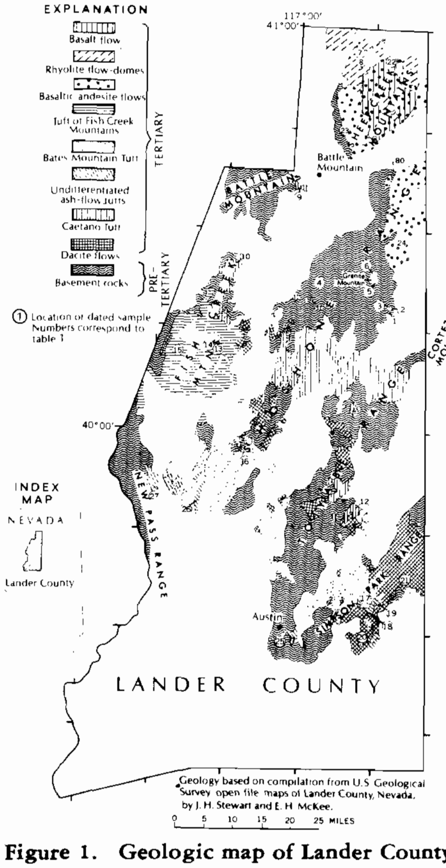
ity) and because they are separated from each other by small erosional unconformities.

The Simpson Park Range contains a series of andesite to dacite lava flows in some places more than 1000 ft thick (McKee, 1968a, 1968b). These lava flows are unconformably overlain, in the southern part of the range, by welded tuffs with minor amounts of intercalated tuffaceous sedimentary rock. At least three different ash-flow sheets can be distinguished. The upper sheet (Bates Mountain Tuff) can be traced northwestward almost continuously across the north-central part of the Toiyabe Range and the central part of the Shoshone Range. A few isolated outcrops of this tuff sheet are recognized in the northern part of the Fish Creek Mountains. The other ash-flow sheets of the southern Simpson Park Range occur a short distance west of the range; they are found to the south and southeast of the Simpson Park Range in southern Lander and Eureka Counties.

North of the area described above, in north-central Lander County, two distinctive welded tuffs make up the Tertiary igneous section. The older of these tuffs, the Caetano Tuff, crops out almost exclusively in a west-trending belt from the northernmost Toiyabe Range to the west edge of the central part of the Shoshone Range. This tuff also crops out at the northern end of the Fish Creek Mountains and at a number of places on Battle Mountain. The younger welded tuff informally called the tuff of Fish Creek Mountains makes up almost all of the Fish Creek Mountains and is found only in these mountains or within a few miles of them. Numerous local dacite lava flows and small intrusive bodies are exposed in the same region.



Geology based on compilation from U.S. Geological Survey open file maps of Lander County, Nevada, by J. H. Stewart and E. H. McKee.

Figure 1. Geologic map of Lander County.

Basalt and basaltic andesite flows blanket most of northern Lander County north of Interstate 80 and crop out to the south across a large area of the northern Shoshone Range. In the Sheep Creek Mountains north of the town of Battle Mountain, at least 18 flows can be distinguished in the basalt and basaltic andesite section; their aggregate thickness is about 1000 ft. To the south the number of flows and the thickness of individual units decreases, and the section thins to about 200 ft in the Shoshone Range (Gilluly and Gates, 1965, p. 83). Similar rocks, considered to be a southeast extension of this lava field, have been mapped in the Cortez Mountains by Gilluly and Masursky (1965). Here, as in the northern Shoshone Range and Sheep Creek Mountains, the flows form a cuesta capping most other rocks. In the Cortez Mountains the total thickness of the basaltic andesite ranges from 120 to 350 ft (Gilluly and Masursky, 1965, p. 83).

North of Battle Mountain several rhyolite flow-domes intrude all but the top basalt flow (J. H. Stewart, 1969, oral commun.). Small rhyolite lava flows associated with the intrusive domes clearly lap onto basalt locally, and a lenticular section of tuffaceous sedimentary rocks, capped by a basalt flow, seems to overlie the rhyolite (J. H. Stewart, 1969, oral commun.). In the Cortez Mountains, rhyolite plugs intrude the basaltic andesite, and no younger basalt flow is recognized (Gilluly and Masursky, 1965, p. 84).

Most of the intrusive rocks in the region consist of fine-grained porphyritic quartz diorite to quartz monzonite; they usually occur in bodies less than 1 sq mi in area. However, a granodiorite stock at Granite Mountain in the northern part of the Shoshone Range covers an area of 5 to 10 sq mi. Dikes of rhyolite porphyry and of diorite to quartz monzonite occur in the northern part of the Shoshone Range (Gilluly and Gates, 1965) and in the Cortez Mountains (Gilluly and Masursky, 1965). The intrusive rocks cut Paleozoic strata; near the intrusive contact, the rocks are locally bleached or converted to hornfels.

The Granite Mountain stock is the largest Tertiary intrusive body in the region—more than twice the size of any of the other nearby intrusives. It is a medium- to coarse-grained hypidiomorphic granular rock which is more like the large Mesozoic plutons of central Nevada than most Tertiary intrusive bodies in this region.

POTASSIUM-ARGON DATES

Analytical Techniques

Specimens for this study were collected from the major Tertiary igneous units in the region. Analysis was made on biotite, sanidine, or hornblende mineral separates and on three whole-rock samples of basalt. Mineral pairs were dated from each of five samples. Sixteen of the samples were from the same rock units as determined by geologic criteria and may have been collected from localities as much as 50 mi apart.

The argon analyses were carried out using standard isotope-dilution techniques on a Nier-type 6-in.-radius 60°-sector mass spectrometer or with a Reynolds-type 4.5-in.-radius mass spectrometer (Sample nos. 5, 6, 22, 23, 24). The potassium analyses were obtained by flame photometer using a lithium internal standard. The decay constants used for K^{40} are $\lambda e = 0.585 \times 10^{-10}\ yr^{-1}$ and $\lambda\beta = 4.72 \times 10^{-10}\ yr^{-1}$, and the atomic abundance of K^{40} is 1.19×10^{-4}. Ages are reported in Table 1.

Precision and Significance

The precision of the dates reported in this paper is evaluated in three ways. The first is to determine the precision of each date, considering the analytical uncertainties in the measurement of radiogenic argon 40 and potassium in the mineral that is used for dating. The second is to compare the calculated ages of a mineral pair from the same specimen. This approach gives an estimate of the precision achieved in dating a particular specimen. The third method, and probably the most meaningful one from a geological point of view, is a comparison of ages determined on geographically separated samples of the same unit. Because it depends on some type of geologic interpretation, this method is clearly subject to errors of a geologic as well as an instrumental nature. The estimates of precision discussed in this paper are similar to those discussed by Kistler (1968) in an analysis of the potassium-argon ages of tuffs in Nye and Esmeralda Counties, Nevada, and Armstrong (1970) for igneous rocks of eastern Nevada and western Utah. The statistical parameters used in the tables are those described by McIntyre (1963). For our argon analyses, the pooled standard deviation is 1.1 percent (Table 2), and the 95 percent confidence limits for σ are 0.7 to 2.4 percent. The pooled standard deviation of all potassium analyses made for this study is 1.3 percent, and the population standard deviation is approximately 1.0 to 1.7 percent at the 95-percent level of confidence. For the Tertiary rocks of this study, the analytical uncertainty in the calculated age is approximately equal to the uncertainty in the ratio Ar^{40}/K^{40}. The estimated analytical precision of a single potassium-argon age based on these data is 1.7 percent. The 95-percent confidence intervals for σ are 1.1 to 3.8 percent.

The pooled standard deviation (Table 3) for ages calculated for six samples for which potassium and argon were determined on a mineral pair is 2.4 percent, and the population standard deviation lies between 1.6 and 5.4 percent with 95 percent confidence.

The pooled standard deviation of determination of the age of a unit from potassium-argon analyses on geographically separated samples was calculated from analyses on two stocks, a rhyolite flow dome and two ash-flow sheets (Table 4). The pooled standard deviation of the age is 2.5 percent and the 95-percent confidence intervals are 1.7 and 4.8 percent.

Table 5 summarizes the results of analytical and observed precision of the age data. The data show that the analytical precision of a single age determination seems to be slightly better than that for an age based on a mineral pair, although statistical analysis (F test) for pooled standard deviations indicates that they do not differ at the 95-percent confidence level. More samples in each group would be necessary to test the difference in standard deviations adequately. It is possible to conclude from the data that the precision of an individual potassium-argon age based on evaluation of analytical uncertainties is better than the precision determined by statistical analyses of a series of dates on the same rock unit (Table 5). When potassium-argon age determinations are used for correlation, this difference in precision must be taken into account, especially where only a single age is

TABLE 1. POTASSIUM-ARGON ANALYTICAL DATA FOR TERTIARY IGNEOUS ROCKS FROM LANDER COUNTY, NEVADA

Sample designation		Location no. fig. 2	Longitude	Latitude	Name	Mineral	K_2O percent	Ar^{40} rad mole/gm X10^{-10}	$\frac{Ar^{40}\text{ rad}}{Ar^{40}\text{ total}}$	Apparent age
	Mineral pair same hand specimen	1	116°41'08"	40°18'12"	Rhyolite porphyry dike	Biotite	8.19 8.28	4.22	80.34	34.4
						Repeat Ar analysis from same biotite separate.		4,33	80.73	35.3
		Do.	do.	do.	do.	Sanidine	11.55 11.64	6.00	97.47	34.7
Replicate analysis of same body or formation		2	116°41'54"	40°18'31"	Porphyritic grano-diorite	Biotite	8.75 8.77 8.84	4.89	78.29	37.3
						Repeat Ar analysis from same biotite separate.		4.87	55.30	37.2
	Mineral pair same hand specimen	3	116°41'41"	40°18'29"	Porphyritic grano-diorite	Biotite	7.95 8.02	4.43	81.42	37.2
						Repeat Ar analysis from same biotite separate.		4.47	83.04	37.5
		Do.	do.	do.	do.	Hornblende	1.077 Average of 8	0.61	71.31	38.2
		4	116°55'30"	40°21'35"	Porphyritic grano-diorite	Biotite	7.64 7.58	3,98	70.90	35.1
Replicate analysis of same body or formation	Mineral pair same hand specimen	5	116°45'22"	40°22'41"	Granodiorite of Granite Mountain	Biotite	7.60 Average of 4	4.34	62.64	38.0
		Do.	do.	do.	do.	Hornblende	0.953 Average of 4	0.52	55.20	36.7
	Mineral pair same hand specimen	6	116°44'48"	40°24'12"	Granodiorite of Granite Mountain	Biotite	7.25 7.25	4.00	37.64	37.0
		Do	do.	do.	do.	Hornblende	.892 Average of 4	0.48	62.64	36.0
Replicate analysis of same body or formation		7	110°48'28"	40°55'50"	Rhyolite flow dome	Sanidine	9.76 9.77	2.00	76.26	13.8
		8	116°48'37"	40°56'15"	Rhyolite flow dome	Sanidine	10.07 10.12	2.08	73.81	13.9

TABLE 1. *(Continued)*

Sample designation		Location no. fig. 2	Longitude	Latitude	Name	Mineral	K_2O percent	$Ar^{40}{}_{rad}$ mole/gm $X10^{-10}$	$\frac{Ar^{40}{}_{rad}}{Ar^{40}{}_{total}}$	Apparent age
Replicate analysis of same body or formation	Mineral pair same hand specimen	9	116°59'20"	40°36'31"	**Caetano Tuff** (Elephant Head)	Biotite	8.41 8.38	2.59	78.65	33.6
		10	11 °12'19"	40°24'28"	**Caetano Tuff**	Biotite	8.62 8.68	4.31	63.63	33.4
		Do.	do.	do.	do.	Sanidine	12.10 12.15	5.63	89.78	31.2
	Mineral pair same hand specimen	11	117°00'48"	40°0 '00"	**Caetano Tuff**	Biotite	8.34 8.35	3.89	73.53	31.3
		Do.	do.	do.	do.	Sanidine	11.78 11.78	5.42	71.63	31.0
		12	116°47'51"	39°48'30"	**Caetano Tuff**	Biotite	8.47 8.28	4.18	85.92	33.5
Replicate analysis of same body or formation		13	117°15'15"	40°11'54"	Tuff of Fish Creek Mountains	Sanidine	8.91 8.98	3.26	77.31	24.5
		14	117°15'45"	40°12'48"	Tuff of Fish Creek Mountains	Sanidine	9.44 9.48	3.31	73.84	23.6
		15	117°24'45"	40°12'48"	Tuff of Fish Creek Mountains	Sanidine	9.14 9.24	3.33	93.56	24.4
		16	117°09'30"	39°56'15"	Bates Mountain Tuff	Sanidine	10.04 10.05	3.70	95.7	24.7
		17	116°45'15"	39°33'43"	Bates Mountain Tuff	Sanidine	8.18 8.18	2.94	93.87	24.1
		18	116°43'45"	39°33'05"	Welded tuff	Biotite	8.25 8.30	3.83	91.0	31.1
		19	116°43'15"	39°33'12"	Welded tuff (lowest tuff)	Biotite	8.12 8.10	4.11	90.76	34.0
		20	116°48'06"	39°28'12"	Dacite flow	Hornblende	0.926 0.927	0.49	70.50	35.4
		21	116°39'48"	39°34'54"	Dacite flow	Biotite	6.50	3.34	75.71	34.5
		22	116°42'50"	40°55'00"	Basalt flow	Whole rock	0.306	$4.5X10^{-12}$	7.15	10.0
		23	116°51'08"	40°44'55"	Basalt flow	Whole rock	0.733	.016	36.29	14.8
		24	116°38'27"	40°28'03"	Basaltic andesite flow	Whole rock	1.575	.038	43.26	16.3
		25	117°26'45"	39°30'48"	Rhyolite welded tuff	Biotite	7.88 7.92	3.46	67.7	29.4
		26	117°19'00"	39°49'30"	Welded tuff	Biotite	4.66 4.67	1.83	67.2	26.3
		27	117°28'00"	39°51'30"	Welded tuff	Biotite	8.41 8.47	3.52	38.5	28.0

TABLE 2. DUPLICATE ARGON DETERMINATIONS ON SAME MINERAL

Sample	Mineral	Ar^{40} rad/gm $\times 10^{-10}$ (moles)	Average	S (percent)
Rhyolite porphyry dike	Biotite	4.218 4.332	4.275	1.89
Granodiorite	Biotite	4.888 4.877	4.883	0.16
Granodiorite	Biotite	4.436 4.472	4.454	0.57
Pegmatite (Northern Nye Co., Nev.)	Muscovite	12.06 12.00	12.03	0.35
[*][†] Granodiorite (Northern Nye Co., Nev.)	Biotite	19.50 19.80	19.65	1.08
Basalt (Seward Peninsula, Alaska)	Whole Rock	0.0959 0.0977	0.0968	1.38

$S_p = 1.09$ percent.

$2\sigma = 0.70$ to 2.40 percent with 95 percent confidence.

[*] Samples from outside the region covered by this report.

[†] The confidence limits for σ are calculated from S_p using tables prepared by Crow and others (1960, p. 242).

$$S_p = \frac{\sum_{i=1}^{N} (n_i^{-1}) S_i^2}{\sum_{i=1}^{N} (n_i^{-1})}$$

S_p = pooled standard deviation;
S = sample standard deviation;
σ = population standard deviation.

obtained. These data suggest that an estimate of precision of approximately 3 percent, may be used as the uncertainty of a particular age that is based upon a single potassium-argon determination. The observed analytical uncertainty suggests an analytical resolution that is greater than an understanding of the geologic framework will permit.

Rocks Dated and Their Ages

Potassium-argon dates were secured for several units from the sequence of flow rocks in the Simpson Park Range. Two samples from dacite flows from the bottom part of the section were dated, and three from overlying welded ash-flow tuffs. The dacite flows yield ages of 35.4 and 34.5 m.y. (Table 1, nos. 20, 21; Fig. 1, locs. 20, 21). The oldest welded tuff—a unit which crops out only locally in the Simpson Park Range and at a few localities south of this range—has an age of 34.0 m.y. (Table 1, no. 19; Fig. 1, loc. 19). On top of this tuff locally is a second welded tuff which has an age of 31.1 m.y. (Table 1, no. 18; Fig. 1, loc. 18). The uppermost unit in these mountains is the Bates Mountain Tuff within its type area, with a potassium-argon age of 24.1 m.y. (Table 1, no. 17; Fig. 1, loc. 17). A second sample of the Bates Mountain Tuff from the Shoshone Range was dated as 24.7 m.y. (Table 1, no. 16; Fig. 1, loc. 16). Three welded tuffs which underlie and appear from stratigraphic evidence to be older than the Bates Mountain Tuff were dated at three localities. One from the Toiyabe Range east of Austin is 29.4 m.y. old (Table 1, no. 25; Fig. 1, loc. 25), the other two are from the Shoshone and New Pass Ranges; they are 26.3 and 28.0 m.y. old, respectively (Table 1, nos. 26, 27; Fig. 1, locs. 26, 27).

Three samples of the tuff of Fish Creek Mountains collected on the east and west side of these mountains have ages of 24.4, 24.5, and 23.6 m.y. (Table 1, nos. 15, 13, 14; Fig. 1, locs. 15, 13, 14).

The Caetano Tuff was dated at four localities. Two western localities, one at the north end of the Fish Creek Mountains, the other at the east edge of Battle Mountain, gave ages of 33.4 (biotite) and 31.2 (sanidine)—a mineral pair—and 33.6 m.y., respectively (Table 1, nos. 10, 9; Fig. 1, locs. 10, 9). A pair of minerals, sanidine and biotite, from a specimen collected in the Shoshone Range about 30 mi southeast of the Fish Creek and Battle Mountain localities, yielded potassium-argon ages of 31.0 (sanidine) and 31.3 (biotite) m.y. (Table 1, no. 11; Fig. 1, loc. 11). A sample from the eastern edge of the Toiyabe Range about 50 mi from the western localities or about 30 mi from the Shoshone site,

Table 3. Mineral Pair Ages on Same Hand Specimen

Location Number Figure 1	Sample	Mineral	Age	Mean age	S (percent)
1	Rhyolite porphyry dike	Biotite Sanidine	34.9* 34.7	34.8	0.41
3	Porphyritic granodiorite	Biotite Hornblende	37.4* 38.2	37.8	1.50
5	Porphyritic granodiorite	Biotite Hornblende	38.0 36.7	37.4	2.47
6	Porphyritic granodiorite	Biotite Hornblende	37.0 36.0	36.5	1.95
10	Caetano Tuff	Biotite Sanidine	33.4 31.2	32.3	4.82
11	Caetano Tuff	Biotite Sanidine	31.3 31.0	31.2	0.41

S_p = 2.44 percent;
σ = 1.57 to 5.37 with 95 percent confidence.
* Mean of two determinations

is 33.5 m.y. old (Table 1, no. 12; Fig. 1, loc. 12).

The basalt flows from the northern part of Lander County were dated at three places. Two dates were obtained on whole rock samples from the Sheep Creek Mountains north of the town of Battle Mountain. One of these is from the lowest flow in a sequence of at least 18 flows. The other is from the top flow; this flow is separated from the lower 18 or so flows by a lenticular sequence of sedimentary rocks. The ages of these units are 14.8 and 10.0 m.y., respectively (Table 1, nos. 23, 22; Fig. 1, locs. 23, 22). The third whole-rock sample to be dated is from the southern edge of this basalt lava field in the northern part of the Shoshone Range, and it is 16.3 m.y. old (Table 1, no. 24; Fig. 1, loc. 24).

Rhyolite domes and flows which intrude or overlie the lower basalt flows, but which are overlain by the top basalt, yielded two ages of 13.8 and 13.9 m.y. on sanidine (Table 1, nos. 7, 8; Fig. 1, locs. 7, 8).

Samples from the large coarse-grained stock at Granite Mountain in the northern Shoshone Range were dated at two localities, and mineral pairs were used from both samples. Potassium-argon ages of 38.0 and 36.7 (Table 1, no. 5; Fig. 1, loc. 5) were obtained at one place and 37.0 and 36.0 (Table 1, no. 6; Fig. 1, loc. 6) were obtained at the other. Two smaller intrusive bodies, approximately 5 mi southeast of the southern edge of the Granite Mountain stock, yield dates that are slightly younger than those at Granite Mountain. One body is a rhyolite porphyry dike (Fig. 1, loc. 1) from which a biotite sample, analyzed twice, gives ages of 34.4 and 35.3 m.y. (Table 1, no. 1) and sanidine from the same sample an age of 34.7 m.y. (Table 1, no. 1). The second body is a small porphyritic granodiorite stock (Fig. 1, loc. 2) that has an age of 37.3, 37.2 (repeat analysis of biotite, Table 1, no. 2), 37.2, 37.5 (repeat analysis of biotite from a second locality, Table 1, no. 3; Fig. 1, loc. 3) and 38.2 m.y. (Table 1, no. 3) on hornblende from the second specimen. The average of these ages is 37.6 m.y. A small granodiorite stock in the western part of the northern Shoshone Range yielded an age of 35.1 m.y. on biotite (Table 1, no. 4; Fig. 1, loc. 4).

Age Distribution

Samples considered representative of the major Tertiary units were used to establish the chronology of Tertiary igneous events in the region. The ages range from about 38 to 10 m.y. and are summarized in Figure 2. There are three groups of rocks that can be distinguished by age, and four groups that can be distinguished

TABLE 4. REPLICATE DETERMINATIONS ON MINERALS FROM DIFFERENT LOCATIONS IN THE SAME STRATIGRAPHIC OR INTRUSIVE UNIT

Location Nos. Figure 1	Sample	Age	Age (mean)	S (percent)
9, 10, 11, 12	Caetano Tuff	33.6 32.3 31.2 33.5	32.7	3.49
13, 14, 15	Tuff of Fish Creek Mountains	24.5 23.6 24.4	24.2	2.05
2, 3	Porphyritic granodiorite stock	37.8* 37.3	37.6	0.96
5, 6	Porphyritic granodiorite stock	36.5 37.4	37.0	1.73
7, 8	Rhyolite flow-dome	13.8 13.9	13.9	0.71

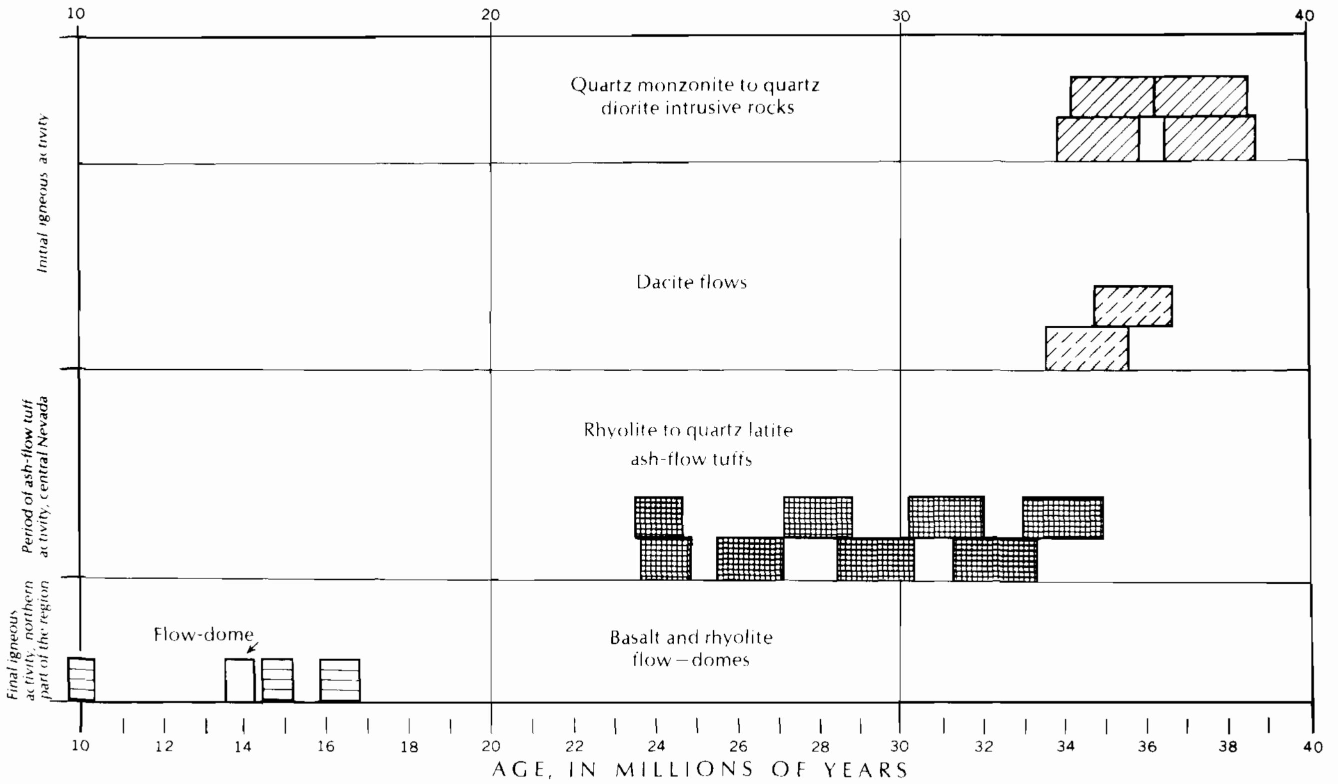
S_p = 2.48 percent;
σ = 1.68 to 4.76 percent with 95 percent confidence.
* Average age of three analyses

by composition and mode of emplacement. The oldest are quartz monzonite to quartz diorite intrusions and dacite lava flows that are from 38.2 to 34.4 m.y. old. There are no known rocks of this composition or with this mode of emplacement younger than about 34 m.y. old in the region.

The second group of ages includes rocks from about 34 to 23 m.y. old. These ages are all on rhyolite to quartz-latite welded ash-flow tuffs. There are a number of additional welded tuffs in the southwestern part of the region which can be bracketed in age, by stratigraphic relations, between tuffs dated at about 23 and 30 m.y. These units, described by McKee and Stewart (1970), only tend to emphasize the age group of the welded tuffs. There are no known welded tuffs in the region older than 34 or younger than about 23 m.y. The third age group contains rocks from about 16 to 10 m.y. in age. These rocks include basalt and basaltic-andesite flows and rhyolite flow-domes and are restricted to the northern part of the region. The distribution both in time and space as well as the different chemical composition of these rocks suggest that they are unrelated to the older Tertiary

TABLE 5. SUMMARY OF ANALYTICAL AND OBSERVED PRECISION OF POTASSIUM-ARGON AGES OF CENTRAL NEVADA TERTIARY IGNEOUS ROCKS

1. Estimated analytical precision of a single potassium-argon age determination:		
		95 percent confidence limits for population standard deviation
S_p Ar	= 1.09 percent	0.70 to 2.40 percent
S_p K	= 1.34 percent	1.12 to 1.66 percent
S_p Ar/K	= 1.72 percent	1.11 to 3.79 percent
2. Observed precision of age calculated from a mineral pair or suite:		
S_p	= 2.44 percent	1.57 to 5.37 percent
3. Observed precision of age of rock unit calculated from several age determinations from geographically separate samples:		
S_p	= 2.48 percent	1.68 to 4.76 percent



Each box represents the age of one unit. An average is used for units for which more than one age was determined. A precision of 3 percent, rounded off, is used on the ages and is represented by the width of the box. This precision is based on replicate analyses of the same rock unit and probably represents a realistic evaluation of the age in a geologic framework.

Figure 2. Age distribution of some Tertiary igneous rocks, Lander County, Nevada.

igneous rocks (welded tuffs and dacite flows and hypabyssal rocks).

REGIONAL SIGNIFICANCE

Potassium-argon dating of Tertiary rocks in east- and north-central Nevada, in conjunction with geologic mapping, indicates that the general threefold subdivision of Tertiary igneous rocks reported here in Lander County may be more widely applicable. East of Lander County in Eureka and White Pine Counties (Fig. 3), widespread locally derived andesite and dacite flows (chemically similar to the rocks called dacite in this paper), with an average age of about 35 m.y., are the oldest Tertiary igneous rocks (Blake and others, 1969). In the southern part of Eureka County and the southwestern part of White Pine County, these rocks are overlain by, or locally interfinger with, the oldest ash-flow tuffs from the east-central Nevada ignimbrite province (Fig. 3) described by Cook (1965). Dacite lava flows become less extensive in this southern region and are rare farther south. Most of the ash-flow tuffs from the ignimbrite province range from about 33 to 23 m.y. in age. In southern Lander and north-central Nye Counties many of the same welded tuffs lie on dacite lava flows. The stratigraphic relations and existing potassium-argon dates strongly suggest that the age relationship between these lava flows and ash-flow tuffs is the same as that recorded in central Lander or in southwestern White Pine Counties.

Hence, in a large region of central and east-central Nevada, the oldest Tertiary igneous rocks are dacitic types with an average age of about 35 m.y. Extrusion and some intrusion of this type of rock from many local sources started abruptly across this entire region within a time span of, at most, 5 m.y. (39 to 34 m.y. ago) and ceased abruptly about 34 m.y. ago. Only a few small flows of this type of rock that are younger than 34 m.y. have been found.

Deposition of welded rhyolitic ash-flow tuffs, mostly from sources south of the dacite lava fields, started after the dacitic igneous activity and is the next event in the Tertiary history. The oldest ash-flow tuffs are about 34 m.y., but most of them are from 33 to 23 m.y. old in central Nevada. Similar ash-flow tuffs with progressively younger ages are found more or less concentrically outward from east-central Nevada (Armstrong and others, 1969).

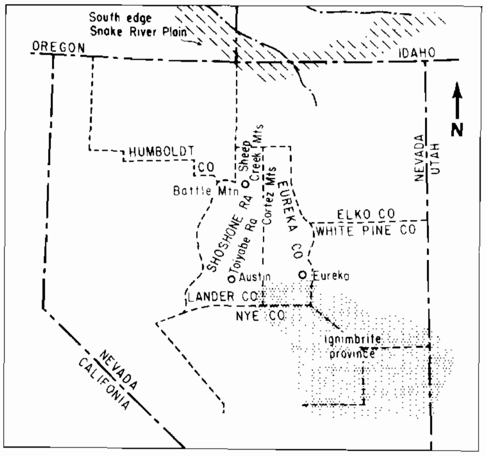


Figure 3. Map of central and northern Nevada and southern Idaho and Oregon showing location of the Snake River Plain and the east-central Nevada Ignimbrite province with relationship to Lander County.

The basalt flows and rhyolite flow-domes, which constitute the third and youngest group of Tertiary igneous rocks in Lander County, are part of an igneous province which extends into the Snake River Plain and which is less than 16 m.y. old. These rocks are unrelated in time and space to the widespread rhyolite ash-flow tuffs (23 to 34 m.y. old) in central Nevada or to the extensive older (34 to 38 m.y. old) dacite flows or intrusive rocks from the same region.

The age of the lowest flow in the Sheep Creek Mountains (14.8 m.y.) and of the basaltic andesite from the northern Shoshone Range (16.3 m.y.) is approximately the same as two K-Ar ages (14.7 ± 1 m.y. and 14.5 ± 1.5 m.y.) described by Armstrong (1970) on basaltic andesites from the Cortez and Simpson Park Mountains. The Cortez and Simpson Park localities are from the southernmost edge of the north-central Nevada basalt province. The age of the rhyolite flow-dome (13.9 m.y.) in the Sheep Creek Mountains is about the same as the lowest basalt flow, but the difference of 0.9 m.y. (13.9 flow-dome and 14.8 basalt flow) may be real, because the rhyolite overlies the basalt at this locality. Other rhyolite flow-domes in north-central Nevada associated with the widespread basalt flows, are probably about the same age as the Sheep Creek Mountain dome.

The youngest basalt (10 m.y.), which represents the most recent basalt activity in northern Lander County, possibly represents the youngest of the flows over a much larger region.

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REFERENCES CITED

Armstrong, R. L., 1970, Geochronology of Tertiary igneous rocks, eastern Basin and Range province, western Utah, eastern Nevada, and vicinity, U.S.A.: Geochim. et Cosmochim. Acta (in press).

Armstrong, R. L., Ekren, E. B., McKee, E. H., and Noble, D. C., 1969, Space-time relations of Cenozoic silicic volcanism in the Great Basin of the western United States: Am. Jour. Sci., v. 267, p. 478–490.

Blake, M. C., Jr., Hose, R. K., and McKee, E. H., 1969, Tertiary volcanic stratigraphy of White Pine County, Nevada (abs.): Geol. Soc. America Abstracts with Program for 1969, Pt. 5, p. 8.

Cook, E. F., 1965, Stratigraphy of Tertiary volcanic rocks in eastern Nevada: Nevada Bur. Mines Rept. 11, 61 p.

Crow, E. L., Davis, F. A., and Maxfield, M. W., 1960, Statistics manual, with examples taken from ordnance development: New York, Dover Publications, Inc., 288 p.

Gilluly, James, and Gates, Olcott, 1965, Tectonic and igneous geology of the northern Shoshone Range, Nevada, *with sections on* Gravity in Crescent Valley, *by* Donald Plouff, *and* Economic geology *by* K. B. Ketner: U.S. Geol. Survey Prof. Paper 465, 153 p.

Gilluly, James, and Masursky, Harold, 1965, Geology of the Cortez quadrangle, Nevada, *with a section on* Gravity and aeromagnetic surveys *by* D. R. Mabey: U.S. Geol. Survey Bull. 1175, 117 p.

Kistler, R. W., 1968, Potassium-argon ages of volcanic rocks in Nye and Esmeralda Counties, Nevada, p. 251–262 *in* Eckel E. B., *Editor*, Nevada Test Site: Studies of Geology and Hydrology: Geol. Soc. America Mem. 110, 290 p.

McIntyre, D. B., 1963, Precision and resolution in geochronometry, p. 112–134 *in* Albritton, C.C., Jr., *Editor*, The Fabric of Geology: Reading, Massachusetts, Addison-Wesley, 374 p.

McKee, E. H., 1968a, Geologic map of the Spencer Hot Springs quadrangle, Lander County, Nevada: U.S. Geol. Survey GQ-770.

——1968b, Geologic map of the Ackerman Canyon quadrangle, Lander and Eureka Counties, Nevada: U.S. Geol. Survey GQ-761.

McKee, E. H., and Stewart, J. H., 1970, Stratigraphy and potassium-argon ages of some Tertiary tuffs from Lander and Churchill Counties, central Nevada: U.S. Geol. Survey Bull. 1311-B (in press).

Stewart, J. H., and McKee, E. H., 1968, Geologic map of the Mount Callaghan quadrangle, Lander County, Nevada: U.S. Geol. Survey GQ-730.

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