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K-Ar THERMOCHRONOLOGY OF A MESOZOIC PLUTONIC COMPLEX, AVAWATZ MOUNTAINS, SOUTHEASTERN CALIFORNIA

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The Avawatz Mountains are located at the southern end of Death Valley in the northeastern Mojave Desert region of southeastern California. The eighteen conventional K-Ar dates reported here reveals long and complex cooling history.

GEOLOGY. The crystalline rocks forming most of the arcuate Avawatz Mountains are exposed within an elongate, northwest-trending fault block bounded to the northeast by the active Mule Spring and Mormon Spring reverse faults and to the southwest by the Miocene Arrastre Spring fault (fig. 1). Diachronous vertical Tertiary movement on both faults has resulted in uplift and exposure of a plutonic complex that form most of the range (Spencer, 1981).

Five plutonic rock types are exposed within the Avawatz Mountains. The Avawatz quartz monzodiorite, by far the most areally extensive rock type, is generally medium grained, equigranular, and contains up to 40% biotite and hornblende. It has been dated at 175 ± 5 m.y. by the U/Pb method (DeWitt and others, 1984). The older granite of Avawatz Peak forms pendants and inclusions within the Avawatz quartz monzodiorite along the crest of the range and is exposed on the southwest side of the Arrastre Springs fault where it intrudes Mesozoic metavolcanic and metasedimentary rocks. Pendants of pre-Mesozoic metasedimentary rocks are also exposed at higher elevations in the range. The Avawatz quartz monzodiorite is intruded by the granodiorite of Mormon Canyon in the central part of the range. The quartz monzonite of Cave Spring Wash in the northwestern Avawatz Mountains is faulted against the Avawatz quartz monzodiorite; the relative ages of the two are unknown.

The Cordilleran fold and thrust belt is well represented to the east of the Avawatz Mountains where imbricate stacked thrust sheets are exposed in the Spring and Clark Mountains (Burchfiel and Davis, 1981). The Avawatz Mountains presumably is within the hangingwall of these thrusts. The Avawatz Mountains also lies within the eastern edge of the Mesozoic batholith belt of western North America. Thus, regional relationships suggest that cooling of rocks in the Avawatz Mountains was a consequence of regional heat loss following batholith emplacement plus erosional denudation and isostatic uplift following thrusting and associated crustal thickening.

DISCUSSION. The sample (AV-1269) yielding the oldest hornblende date obtained (174.7 ± 1.1 m.y.) was collected from an area that is considered to be the structurally highest part of the plutonic complex, from just below a middle Miocene depositional contact at the base of part of the Avawatz Formation, and within the belt of pre-Mesozoic pendants and older Mesozoic granites that forms most of the range crest. This age is essentially identical to the U/Pb age of the Avawatz quartz monzodiorite reported by DeWitt and others (1984), and the sample is interpreted to have remained below the closure temperature for argon in hornblende since crystallization. Biotite from the same sample yielded the oldest biotite age (138.8 ± 0.8 m.y.).

The second-oldest hornblende age (154.1 m.y.), from a sample (AV-961) of the quartz monzonite of Cave Spring Wash, is considered suspect because, unlike the other rock types dated, the quartz monzonite of Cave Spring Wash contains one to several percent pyroxene which could not be completely separated from the hornblende, raising the possibility that excess argon trapped in pyroxene resulted in an anomalously old age.

Younger ages were obtained from all other samples. Excluding the 174.7 m.y. hornblende age (AV-1269), the 154.1 m.y. hornblende age (AV-961), and the young ages from samples in the far northwestern Avawatz Mountains and the west edge of the map area, the 5 other hornblende ages fall in the range of 141.6 to 91.1 m.y. Excluding the young biotite age from the far northwestern Avawatz Mountains, all biotite ages (7 ages) fall in the range of 138.8 to 66.6 m.y. These ages span a time period during which most of the exposed crystalline rocks cooled from greater than approximately 500°C to less than approximately 300°C (argon closure temperatures from Harrison, 1981, and Harrison and others, 1985). This long, gradual cooling history is interpreted to have resulted during erosional denudation and uplift, perhaps punctuated by heat pulses associated with plutonism and more rapid cooling due to tectonic uplift. The small discordance between biotite and hornblende ages in two samples (AV-132 and AV-133) indicates rapid cooling probably related to local magmatism or uplift due to tectonism. Emplacement of fine-grained mafic dikes in the vicinity of sample AV-132 could have caused heating and argon loss. The wide scatter of the K-Ar ages conceal any regional heat pulses related to magmatism or widespread rapid cooling related to tectonism.

The Avawatz quartz monzodiorite yielded relatively young ages in the far northwestern Avawatz Mountains. The biotite age of 45.7 m.y. is surprisingly young considering that early Tertiary igneous rocks are virtually nonexistent in the Mohave region (Snyder and others, 1976; Coney and Reynolds, 1977). The quartz monzodiorite has a strong, south-dipping crystalloblastic foliation in this area which dies out eastward over a distance of 4 kilometers. Pegmatite dikes, both discordant and concordant to foliation, are abundant in the strongly foliated rock, and are interpreted as broadly synchronous with the foliation-producing deformation (Spencer, 1981). The 62.4 m.y. age on coarse muscovite from a post-deformation pegmatite places a younger limit on the age of deformation. The 45.7 m.y. biotite age is interpreted as either: (1) recording early Tertiary cooling during gradual, regional, early Cenozoic denudation and uplift, following regional Mesozoic magmatism; or (2) recording rapid cooling during tectonic uplift of a fault sliver along an early Tertiary ancestral Garlock fault. The presence of lower Tertiary sedimentary rocks along the western Garlock fault and their virtual absence elsewhere in the Mohave region is evidence supporting the existence of an ancestral Garlock fault (Dibblee, 1967; Nilsen and Clarke, 1975; Cox, 1982) unrelated to Miocene and younger extensional tectonism (Davis and Burchfiel, 1973).

The 77.6 m.y. hornblende age from a dioritic pluton, that is thrust over Mesozoic volcanic and sedimentary rocks west of the Avawatz Mountains, possibly represents either: (1) the crystallization age of the pluton; or (2) uplift

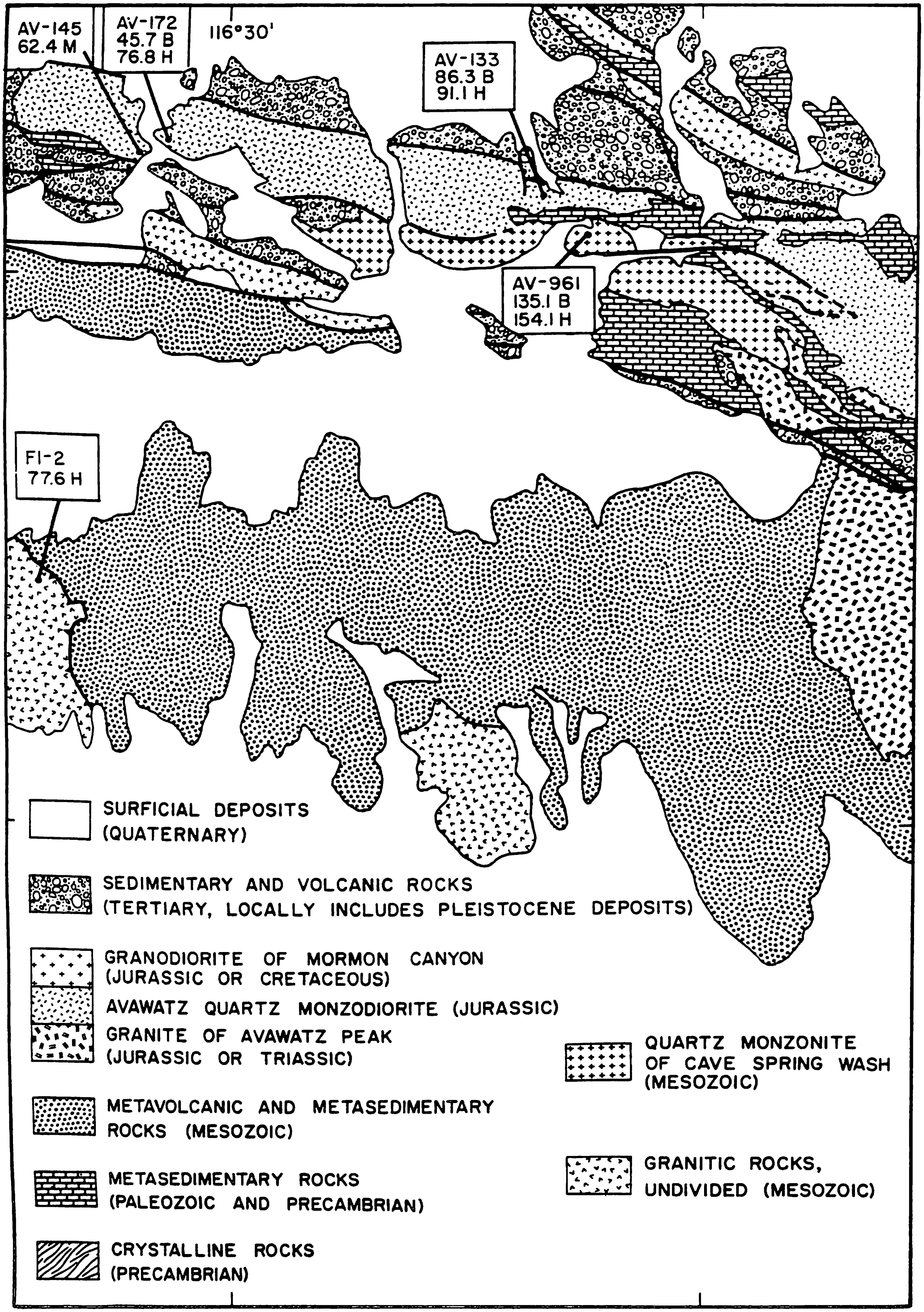
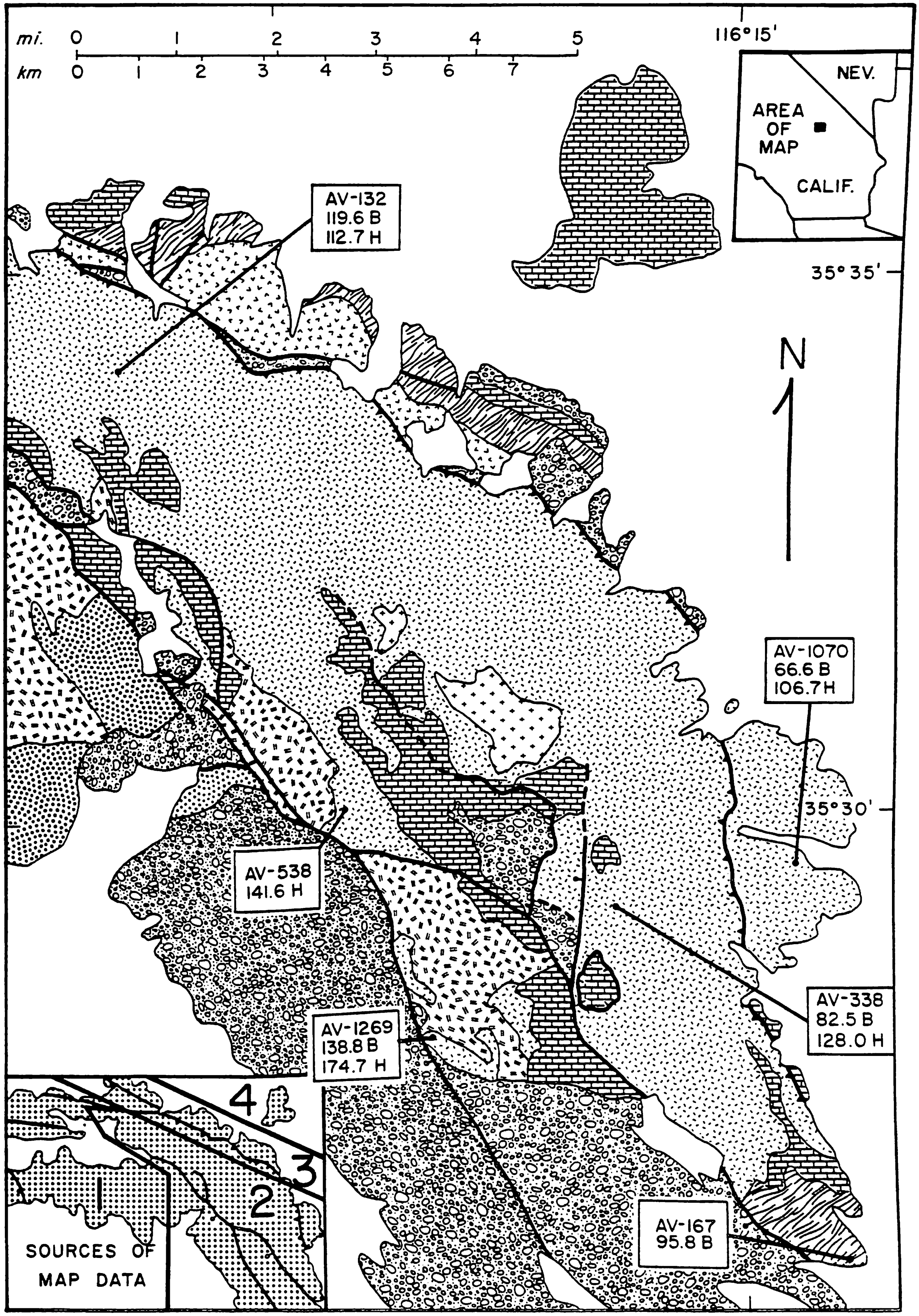


FIGURE 1. Simplified geologic map of the Avawatz Mountains and adjacent areas to the west. K-Ar sample locations and ages are also shown. Geologic map data from (1) Brady (1986), (2) Spencer (1981), (3) Troxel and Butler (1979), and (4) Troxel, (1979).


mi. 0 1 2 3 4 5
km 0 1 2 3 4 5 6 7
116°15'
NEV.
AREA OF MAP
CALIF.
35°35'
N
AV-132
119.6 B
112.7 H
AV-1070
66.6 B
106.7 H
35°30'
AV-538
141.6 H
AV-338
82.5 B
128.0 H
AV-1269
138.8 B
174.7 H
AV-167
95.8 B
1
2
3
4
SOURCES OF MAP DATA

and cooling during and immediately after latest-Cretaceous thrusting.

CONCLUSIONS. Conventional K-Ar thermochronology of the Mesozoic plutonic complex reveals a complex cooling history. Most of the K-Ar ages were set during Cretaceous time. The wide scatter in K-Ar ages is suggestive of gradual regional uplift and erosional denudation as the cause of cooling through argon-closure-temperature isotherms, although magmatism and tectonism probably played an important role, at least locally.

ACKNOWLEDGMENTS

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ANALYTICAL PROCEDURES

All samples were collected and mineral separates prepared by the author. Potassium was measured by flame photometry using a lithium internal standard, and was done at the U.S.G.S. by B. Lai, D. Vivit, and M. Taylor. Two analyses were done for each sample. Error in potassium analyses used in age calculation is either sample standard deviation of potassium analyses or 0.5%, whichever is greater. Argon measurements were made using standard techniques of isotope dilution. Argon extractions and analyses were done by J. Spencer and E. Sims. Age calculation based on decay and abundance constants recommended by Steiger and Jager (1977). Error in calculated age for single argon extraction determined by method of Cox and Dalrymple (1967). Error in calculated age for multiple extractions is average analytical precision of individual analyses determined by method of Cox and Dalrymple (1967) or is sample standard deviation of ages determined for each extraction, whichever is larger.

SAMPLE DESCRIPTIONS

1. *AV-132* K-Ar
Avawatz quartz monzonite (116°21'26"W, 35°34'01"; CA). *Analytical data:* (biotite) $\%K_2O$ = 8.80, 8.77; $^{40}Ar^*$ = 15.6211 × 10^{-10} mol/g, 15.6384 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 87.7%, 88.3%; (hornblende) $\%K_2O$ = 1.462, 1.466; $^{40}Ar^*$ = 2.41351 × 10^{-10} mol/g, 2.48675 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 88.1%, 83.6%.
(biotite) 119.6 ± 0.7 m.y.
(hornblende) 112.7 ± 2.3 m.y.

2. *AV-133* K-Ar
Avawatz quartz-monzodiorite (116°26'34"W, 35°35'54"N; CA). *Analytical data:* (biotite) $\%K_2O$ = 9.12, 9.12; $^{40}Ar^*$ = 11.6063 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 91.3%; (hornblende) $\%K_2O$ = 1.456, 1.459; $^{40}Ar^*$ = 1.96038 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 53.8%.
(biotite) 86.3 ± 0.5 m.y.
(hornblende) 91.1 ± 0.6 m.y.

3. *AV-145* K-Ar
Pegmatite dike (116°30'53"W,35°36'10"N; CA) in strongly foliated Avawatz quartz-monzodiorite. *Analytical data:* $\%K_2O$ = 10.75, 10.77; $^{40}Ar^*$ = 9.83358 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 91.5%. *Comment:* pegmatite dike is unfoliated and cuts across foliation at a high angle.
(muscovite) 62.4 ± 0.4 m.y.

4. *AV-167* K-Ar
Precambrian gneiss (116°13'48"W,35°25'49"N; CA). *Analytical data:* $\%K_2O$ = 9.44, 9.47; $^{40}Ar^*$ = 13.3903 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 87.4%.
(biotite) 95.8 ± 0.6 m.y.

5. *AV-172* K-Ar
Avawatz quartz-monzodiorite (116°30'44"W, 35°36'15"N; CA). *Analytical data:* $\%K_2O$ = 9.24, 9.24; $^{40}Ar^*$ = 6.13402 × 10^{-10} mol/g, 6.17652 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 76.7%, 80.8%.
(biotite) 45.7 ± 0.3 m.y.

6. *AV-172* K-Ar
Avawatz quartz-monzodiorite (116°30'44"W, 35°36'15"N; CA). *Analytical data:* $\%K_2O$ = 1.572, 1.573; $^{40}Ar^*$ = 1.77696 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 80.2%.
(hornblende) 76.8 ± 0.5 m.y.

7. *AV-338* K-Ar
Avawatz quartz-monzodiorite (116°16'16"W, 35°29'06"N; CA). *Analytical data:* (biotite) $\%K_2O$ = 8.76, 8.66; $^{40}Ar^*$ = 10.5821 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 88.2%; (hornblende) $\%K_2O$ = 1.196, 1.206; $^{40}Ar^*$ = 2.33190 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 90.3%.
(biotite) 82.5 ± 0.5 m.y.
(hornblende) 128.0 ± 0.8 m.y.

8. *AV-538* K-Ar
Avawatz quartz-monzodiorite (116°19'31"W, 35°30'05"N; CA). *Analytical data:* $\%K_2O$ = 0.801, 0.803; $^{40}Ar^*$ = 1.70125 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 81.8%.
(hornblende) 141.6 ± 0.9 m.y.

9. *AV-961* K-Ar
Quartz monzonite of Cave Spring Wash (116°26'07"W, 35°35'28"N; CA). *Analytical data:* (biotite) $\%K_2O$ = 8.995 (average of two analyses); $^{40}Ar^*$ = 18.1695 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 91.9%; (hornblende) $\%K_2O$ = 1.013, 1.021; $^{40}Ar^*$ = 2.35513 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 72.8%.
(biotite) 135.1 ± 0.8 m.y.
(hornblende) 154.1 ± 1.2 m.y.

10. *AV-1070* K-Ar
Avawatz quartz-monzodiorite (116°14'41"W, 35°29'22"N; CA). *Analytical data:* (biotite) $\%K_2O$ = 9.36 (average of two analyses); $^{40}Ar^*$ = 9.14203 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 77.0%; (hornblende)

%K_2O = 0.732, 0.724; $^{40}Ar^*$ = 1.15175 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 81.5%.

(biotite) 66.6 ± 0.4 m.y.
(hornblende) 106.7 ± 0.7 m.y.

11. *AV-1269* K-Ar

Avawatz quartz-monzodiorite (116°18′14″W, 35°27′58″N; CA). *Analytical data:* (biotite) %K_2O = 8.635 (average of two analyses); $^{40}Ar^*$ = 17.9391 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 92.0%; (hornblende) %K_2O = 0.716, 0.708; $^{40}Ar^*$ = 1.90184 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 82.3%.

(biotite) 138.8 ± 0.8 m.y.
(hornblende) 174.7 ± 1.1 m.y.

12. *FI-2* K-Ar

Dioritic granitoid (116°32′03″W,35°32′09″N; CA). *Analytical data:* %K_2O = 1.95, 1.97; $^{40}Ar^*$ = 2.23832 × 10^{-10} mol/g; $^{40}Ar^*/^{40}Ar$ = 81.7%.

(hornblende) 77.6 ± 0.5 m.y.

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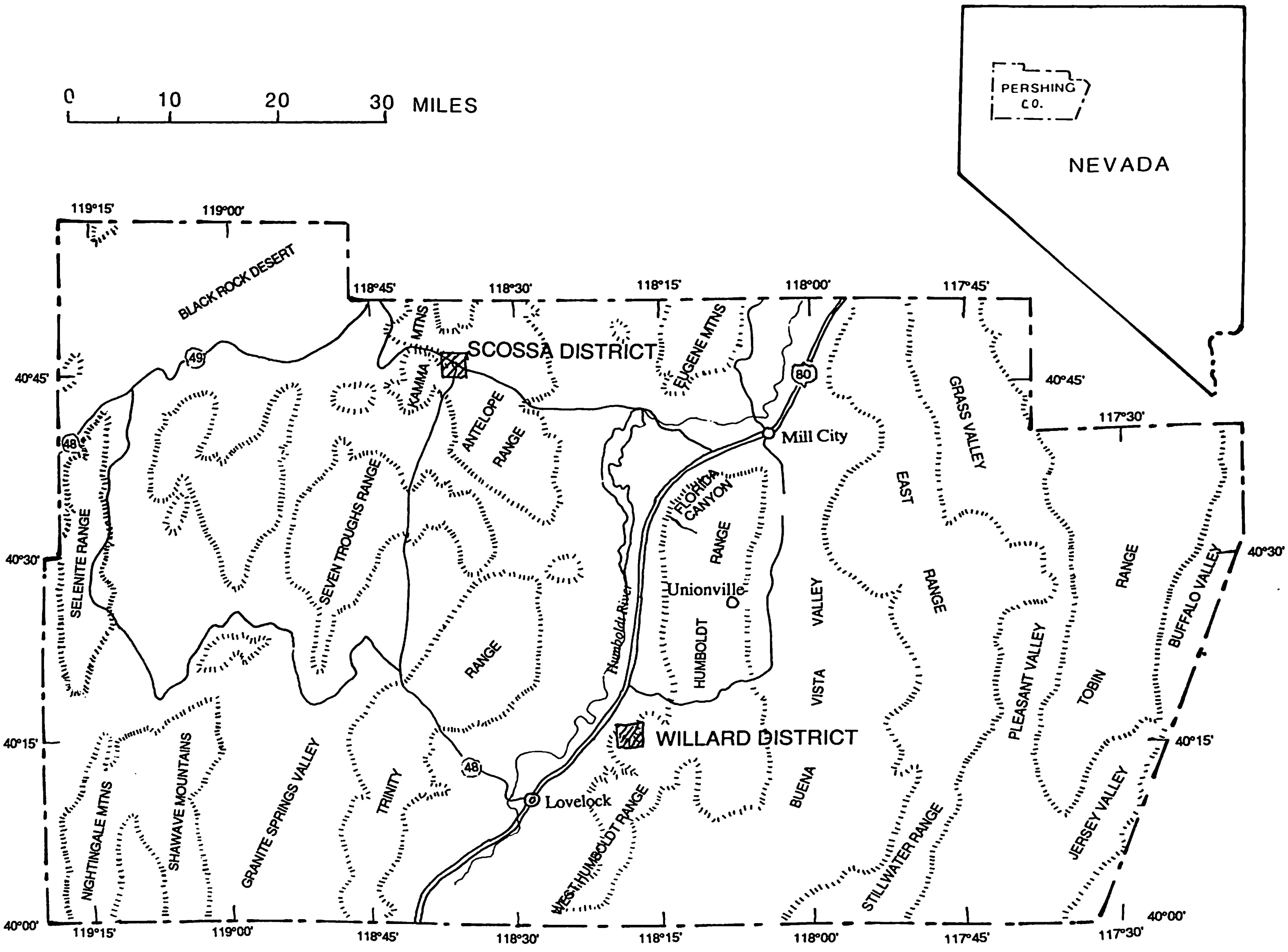

FIGURE 1. Map of Pershing County showing location of Scossa and Willard districts.