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RADIOMETRIC AGES OF VOLCANIC AND PLUTONIC ROCKS AND HYDROTHERMAL ALTERATION-MINERALIZATION IN THE TONOPAH MINING DISTRICT AND VICINITY, NYE AND ESMERALDA COUNTIES, NEVADA 1/

By

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Radiometric Ages of Volcanic and Plutonic Rocks and Hydrothermal Alteration-Mineralization in the Tonopah Mining District and Vicinity, Nye and Esmeralda Counties, Nevada

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Introduction

The radiometric ages reported here are the product of a detailed program of geochronological investigation of the volcanic and plutonic rocks and hydrothermal alteration and mineralization in the Tonopah mining district and vicinity carried out by members of the Nevada Bureau of Mines and Geology and the U.S. Geological Survey.

Samples were collected by the writers or by collaborators. Sample preparation, including purified mineral separates was done at laboratories of the Nevada Bureau of Mines and Geology, Reno, or the U.S. Geological Survey, Menlo Park, using procedures described in Silberman and McKee (1971). Whole-rock samples were ground to approximately 60-100 mesh before analysis. This procedure reduces atmospheric argon content (Keeling and Naughton, 1974). Samples were prepared by J. B. Murphy, Louis Scalise, R. D. Dockter, J. A. Peterson, R. C. Evarts, and M. L. Silberman.

Potassium was analyzed from aliquots of the purified mineral separates or ground whole rocks by flame photometry, using a lithium metaborate fusion technique, the lithium serving as an internal standard

(Ingamells, 1970). Analysts were L. B. Schlocker, Gil Ambats, J. H. Christie, and M. Cremer. Some samples in addition were analyzed by X-ray fluorescence using techniques described in Dodge and others (1971). Analysts were L. F. Espos and B. P. Fabbi.

Argon analysis was done by standard isotope dilution, mass spectrometry techniques using procedures described in Silberman and McKee (1971). Analysts were M. L. Silberman, E. H. McKee and J. L. Morton.

The constants used in K-Ar age calculation were:

$\lambda_e = 0.585 \times 10^{-10}$ yr^{-1}

$\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}

^{40}K/K(total) = 1.22×10^{-4} g/g

New decay constants for λ_β and λ_e and for ^{40}K/K(total) are now (1978) in use (Morton and others, 1977) but the data for the Tonopah samples were completed before these constants became generally established. The difference in calculated age using the new constants is small, being on the order of 1 to 2 percent of the reported age. We report the Tonopah ages using the old constants in order to simplify comparisons with ages reported from nearby areas, for example Goldfield (Ashley and Silberman, 1976) and other areas of western Nevada (Silberman and others, 1975) which were published using the old constants.

Plus-minus values for K-Ar ages represent estimated analytical uncertainty of the combined K and Ar analyses at one standard deviation. They vary from 2 to 3 percent to approximately 10 percent depending on the atmospheric argon correction (Dalrymple and Lanphere, 1969).

Fission track ages were determined at the U.S. Geological Survey, Menlo Park, by R. P. Ashley and R. C. Evarts using techniques described in Ashley (1973), and Ashley and Silberman (1976). The fission track decay constant for U^{238} is $(\lambda_F) = 6.85 \times 10^{-17}$ yr^{-1} (Fleischer and Price, 1964). Error estimates are made at two standard deviations by methods currently employed by C. W. Naeser (oral commun., 1973, in Ashley, 1973).

Locations of dated samples are shown on figure 1.

A brief geologic description follows this section. Sample descriptions and brief comments where appropriate follow in the section on sample descriptions.

Geologic Discussion

A detailed description of the geology and mineral deposits of the Tonopah mining district and vicinity can be found in Bonham and Garside (1978, in press). A generalized geologic sketch map of the central part of the area, the Tonopah mining district (fig. 2) was constructed from the detailed mapping of the region (Bonham and Garside, 1978, in press).

Volcanic activity within the mining district and surrounding areas in Nye and Esmeralda Counties was essentially continuous from approximately 26 to 10 m.y. ago and may have extended back in time perhaps intermittently until about 34 to 35 m.y. ago. The igneous activity, both intrusive and extrusive, produced a wide variety of rocks, ranging from basalt to rhyolite in composition and from ignimbrites (ash-flow tuffs) and tuffs to lavas and breccias, flow-dome complexes, dikes, sills, and irregular intrusions in mode of emplacement. Based on the geologic mapping and radiometric age determinations, the geologic history of the Tonopah region has been divided into five stages (figs. 3 ,4). K-Ar and fission track ages of the volcanic units used to construct this division are presented and discussed briefly in the following section on sample descriptions. Many other volcanic and sedimentary units defined by the mapping, but not dated radiometrically, are not shown on the figures (see discussion by Bonham and Garside, 1974; 1978, in press).

The complexity of the relations between the volcanic units in the region is shown on figures 3 and 4 . During stages 3, 4 and 5 (about which the most information is available) volcanic rocks of a variety of types were erupted from many volcanic centers at Tonopah and to the north and south of Tonopah. Thus, many petrologically and areally distinct volcanic units have the same age or similar ranges of age.

At least two major episodes and several minor episodes of hydrothermal alteration and mineralization occurred that appear to be related to specific volcanic events. The first major episode occurred 18 to 19 m.y. ago at Tonopah, during the period of time of emplacement of the upper unit of the King Tonopah Member of the Fraction Tuff (a major ash flow sequence in the region). The ore bodies at Tonopah are replacement veins that follow faults and fractures and frequently exhibit gradational boundaries with enclosing wall rock (Nolan, 1935). The principal host rock is the Mizpah Formation which underlies the

Fraction Tuff and consists of flows and mud-flow breccias of dacite composition. The silver-rich veins of the main stage of mineralization are composed of quartz-adularia-sericite with sulfide and sulfosalt minerals and are enclosed by alteration halos of the same gangue minerals, that grade outward to argillic and propylitic mineral assemblages (Bonham and Garside, 1974; 1978, in press). In the central part of the district overlapping halos of intense quartz-adularia-sericite alteration have produced a zone of altered rock that is composed entirely of this mineral assemblage. Tonopah produced approximately $150,000,000 from about 1.8 million oz gold, and 174 million oz silver (Bonham and Garside, 1974).

Less intense alteration and gold mineralization at Tonopah is related to emplacement of small intrusions of the Oddie Rhyolite (average age 16.7 m.y.). The veins associated with the Oddie Rhyolite are rich in gold, whereas the main stage mineralization which occurred earlier is silver-rich.

The oldest clearly post-main stage mineralization volcanic unit at Tonopah is the Heller Tuff (17.0 $\pm$ 0.1 m.y.). Although the Mizpah Formation is the main host rock, minor mineralization is present in the Fraction Tuff. The major portion of the ore deposits may be localized in the Mizpah Formation due to its greater suitability as a host rock than the rhyolite ash flows. This preferred occurrence of precious metal-vein deposits in rocks of intermediate composition is very common in the western Great Basin (Silberman and others, 1976). It appears that the hydrothermal system responsible for the mineralization was an effect of development and evolution of the magma system that produced the Fraction Tuff, or at least some of its members (see later discussion and also Bonham and Garside, 1978, in press).

A second major period of hydrothermal activity occurred between 16 and 15 m.y. ago in the Divide mining district 8 km south of Tonopah, from which production of approximately $3.5 million from 3.2 million oz silver, and 33,000 oz gold is recorded (Bonham and Garside, 1974). Ore bodies at Divide consist of silicified and pyritized country rock localized along faults and fractures. The Fraction Tuff is the principal host rock for the Divide veins but the overlying Siebert Formation and the Oddie Rhyolite are also mineralized. The veins associated with the Oddie Rhyolite are gold-rich, whereas the mineralization in the Siebert and Fraction are silver-rich.

A very widespread hydrothermal system was active at Divide. Veins crop out over 5 mi^2 (13 km^2), and hydrothermal alteration is widespread. Surface thermal spring activity occurred, as indicated by widespread silicification and the presence of fossil sinter terraces at Hasbrouck Peak on the western edge of the Divide mining district (J. Livermore, A. G. Wallace, and M. L. Silberman, unpubl. data). The timing of hydrothermal activity as indicated by K-Ar ages of altered rocks (15.3 to 16.4 m.y.) may be related to intrusions of the Oddie Rhyolite (16.7 m.y.) but the timing also overlaps volcanic activity which generated the Brougher Rhyolite, the Divide Andesite and the volcanics of Donovan Peak (16.8 to 14.8 m.y.) in the Divide area. The later two units are local, and restricted to the Divide area.

Minor episodes of gold and silver mineralization or hydrothermal alteration also occurred to the north and south of Tonopah until about 10 m.y. ago when volcanic activity essentially ceased in the area (fig. 4).

Sample Descriptions

Pre-Tertiary Rocks, San Antonio Range

1. SAgd-1 FT

Granodiorite of Frazier's Well. (SW¼SW¼ S36, unsurveyed T4N, R42E; 30°09'13"(09.22')N, 117°13'09"(13.15')W; Nye Co., NV).
Analytical data: (sphene) Ps = 4.565×10^6 tracks/cm^2, ½Pi = 2.795×10^6 tracks/cm^2, $\phi = 1.19 \times 10^{15}$ N/cm^2, no. of grains counted = 8; (zircon) Ps = 1.786×10^7 tracks/cm^2, ½Pi = 9.548×10^6 tracks/cm^2, $\phi = 1.19 \times 10^{15}$ N/cm^2, no. of grains counted = 6.
Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology and R. P. Ashley and M. L. Silberman, U.S. Geological Survey.
Dated by: R. P. Ashley, U.S. Geological Survey. Comment: Epidote present as a deuteric (?) alteration mineral. Rhyolite porphyry and dacite dikes of similar lithology to Mizpah Formation intrude the granodiorite. We consider the mineral ages to be minimum figures.

(sphene) 59.3 $\pm$ 7.4 m.y.

(zircon) 67.9 $\pm$ 8.4 m.y.

2. Mzwt-1 K-Ar

Mesozoic(?) welded tuff. (NW¼NE¼ S12, T4N, R43E; 38°13'18" (13.30')N, 117°06'00"(06.00")W; Nye Co., NV). Analytical data: K_2O = 1.57%, $^{40}Ar^*$ = 4.031 x 10^{-11} mole/g, $^{40}Ar^*/^{40}Ar$ = 0.32. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Chlorite, actinolite, calcite and epidote are present in sample as alteration minerals. The age should be considered a minimum.

(plagioclase) 17.3 ± 0.8 m.y.

Older Tertiary Rocks

3. TF-2 FT

Ash-flow tuff, Tonopah Formation. (NW¼ S31, T4N, R43 E; 38°09'46" (09.77')N, 117°11'50"(11.83')W; Nye Co., NV). Analytical data: λ_F = 6.85 x 10^{17} yr^{-1}, Ps = 2.420 x 10^6 tracks/cm^2, ½Pi = 2.527 x 10^6 tracks/cm^2, ϕ = 1.19 x 10^{15} N/cm^2, no. of grains counted = 7. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: R. P. Ashley, U.S. Geological Survey. Comment: The Tonopah Formation consists of ash-flow and air-fall tuffs and sedimentary rocks and rhyolite flow-dome complexes. The intrusive rhyolites in places cut the tuffs.

(zircon) 34.8 ± 4.2 m.y.

4. OWT-1 K-Ar, FT

Altered welded tuff, with phenocrysts of cloudy feldspar with many inclusions, large amounts of iron oxide and some epidote; tuff of Ralston Valley. (SE¼NE¼NE¼ S21, T4N, R44E; 38°11'27"(11.45')N, 117°02'27"(02.45')W; Nye Co., NV). Analytical data: (alkali feldspar) K_2O = 6.63%, $^{40}Ar^*$ = 1.780 x 10^{-10} moles/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.82; (zircon) Ps = 1.342 x 10^7 tracks/cm^2, ½Pi = 1.555 x 10^7 tracks/cm^2, ϕ = 1.19 x 10^{15} N/cm^2, no. of grains counted = 6. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology. Dated by: (alkali feldspar) M. L. Silberman, U.S. Geological Survey; (zircon) R. P. Ashley, U.S. Geological Survey. Comment: Alkali feldspar age is alteration age. The fission track zircon age is believed to be closer to the age of emplacement of this unit, as zircon appears to resist annealing during post-crystallization hydrothermal alteration (Ashley and Silberman, 1976). Alteration has affected this rock and is probably the cause of the anomalously young alkali feldspar age.

(alkali feldspar) 18.1 ± 0.5 m.y. (K-Ar)

(zircon) 31.4 ± 3.8 m.y. (FT)

5. Mc-1 K-Ar

Tuff of Murphy's Camp. (SW¼ S3, unsurveyed T4N, R46E; 38°18'30" (18.5')N, 116°49'00"(49.0')W; Nye Co., NV). Analytical data: (biotite) K_2O = 8.24%, $^{40}Ar^*$ = 3.084 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.66; (plagioclase) K_2O = 2.51%, $^{40}Ar^*$ = 8.978 x 10^{-11} mole/g,

$^{40}Ar^*/\Sigma^{40}Ar$ = 0.84. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Overlies the tuffs of Rye Patch, in the Big Ten Peak caldera, and thus provides a minimum age limit for them.

(biotite) 25.2 $\pm$ 0.8 m.y.

(plagioclase) 24.0 $\pm$ 0.7 m.y.

6. Taf_2 (1) K-Ar

Tuffs of Antelope Springs (?). (NW¼SW¼SE¼ S5, T1S, R43E; 37°52'36"(52.60')N, 117°10'33"(10.55')N; Esmeralda Co., NV). Analytical data: K_2O = 8.81%, $^{40}Ar^*$ = 3.381 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.69. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: E. H. McKee, U.S. Geological Survey. Comment: Minimum age; plagioclase in sample is altered to calcite and sericite and hornblende is altered to Fe-Ti oxides, sericite, quartz and chlorite. Ekren and others (1971) report ages of 25.4 $\pm$ 0.8 m.y., 27.7 $\pm$ 0.8 m.y., and 26.2 $\pm$ 0.8 m.y. on tuffs from this unit.

(biotite) 25.8 $\pm$ 0.8 m.y.

7. TF-1 FT

Flow-banded rhyolite, Tonopah Formation. (SE¼SE¼SE¼ S1, T3N, R42E; 38°08'19"(08.32')N, 117°12'14"(12.23')W; Nye Co., NV). Analytical data: λ_F = 6.85 x 10^{-17} yr^{-1}, Ps = 1.002 x 10^7 tracks/cm^2,

½Pi = 1.437 x 10^7 tracks/cm^2, ϕ = 1.14 x 10^{15} N/cm^2, no. of grains counted = 6. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and M. L. Silberman, U.S. Geological Survey. Dated by: R. P. Ashley, U.S. Geological Survey. Comment: Most likely age for the intrusive phase of the Tonopah Formation, which in places cuts the ash-flow and air-fall tuffs. The time span between the extrusive and intrusive phases seems long (11 m.y.). Considerable intrusive rhyolitic activity occurred at about this time (24-22 m.y.); see discussion sample 50 (GRP-1, Lone Mountain).

(zircon) 24.3 $\pm$ 2.8 m.y.

Mizpah Formation

8. GC-135 K-Ar

Porphyritic biotite-hornblende dacite, Mizpah Formation. (NW¼SW¼SE¼SE¼ S26, T3N, R42E; 38°04'49"(04.82')N, 117°13'28" (13.47')W; Nye Co., NV). Analytical data: K_2O = 8.71%, $^{40}Ar^*$ = 2.656 x 10^{-10} mole/g, $\Sigma^{40}Ar^*/^{40}Ar$ = 0.66. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Main host rock for ore deposits of the Tonopah mining district.

(biotite) 20.5 $\pm$ 0.8 m.y.

9. T 219 (Bonham and others, 1972) K-Ar

Porphyritic biotite-hornblende dacite, Mizpah Formation. (SE¼SE¼ S15, T3N, R42E; 38°06'39"(06.65')N, 117°14'44"(14.72')W;

location slightly changed from that reported in Bonham, Garside, and Silberman (1972)). Comment: Concordant with age of sample GC135. The Mizpah Formation is the main host rock for mineralization at Tonopah and places a lower limit on the age of the Tonopah ore deposits.

(biotite) 20.4 ± 0.6 m.y.

Fraction Tuff

10. 74 MLS-1 K-Ar

Tonopah Summit Member, Fraction Tuff. (NW¼SW¼ S17, T2N, R43E; 38°01'37"(01.62')N, 117°10'57"(10.95')W; Nye Co., NV). Analytical data: K_2O = 8.25%, $^{40}Ar^*$ = 2.064 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.43. Collected by: M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: See comment next sample (11, TFR_2-1).

(biotite) 16.9 ± 0.5 m.y.

11. TFR_2-1 K-Ar

Tonopah Summit Member, Fraction Tuff. (SW¼NW¼NE¼ S10, T1N, R42E; 37°57'34"(57.57')N, 117°14'50"(14.83')W; Esmeralda Co., NV). Analytical data: (sanidine) K_2O = 11.03%, $^{40}Ar^*$ = 2.636 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.77; (biotite) K_2O = 8.38%, $^{40}Ar^*$ = 2.094 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.62. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman and E. H. McKee, U.S. Geological Survey. Comment: Two members of the Fraction Tuff are exposed at Tonopah, the Tonopah Summit Member and the upper and lower units of the King Tonopah Member. The K-Ar ages of these members are in reverse order to their stratigraphic position (see ages samples 15, 13, 12 and 14--TV-1, TV-2, SS-25 and TFR-1). Both of the Tonopah Summit samples were affected by hydrothermal alteration--produced probably by the proximity of younger rhyolite intrusions (Oddie and Brougher Rhyolites of 16-17 m.y. age). The K-Ar ages of these rocks have probably been reset by this thermal activity. A minimum age for the Tonopah Summit Member is given by the average age of the lower unit of the King Tonopah Member (19.7 $\pm$ 0.1 m.y.; see discussion for sample 14 (TFR-1)) which overlies it.

(sanidine) 16.1 $\pm$ 0.5 m.y.

(biotite) 16.8 $\pm$ 0.7 m.y.

12. SS-25 K-Ar

Hydrated glass from vitrophyre with the lower unit, King Tonopah Member of Fraction Tuff. (SE¼SW¼SW¼ S22, T3N, R42E; 38°05'39" (05.65')N, 117°15'17"(15.28')W; Nye Co., NV). Analytical data: K_2O = 5.66%, $^{40}Ar^*$ = 1.647 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.55. Collected by: L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: This sample had too many lithic fragments to attempt mineral separation. The age of the glass appears to agree within analytical uncertainty with mineral ages from other samples of the lower unit, King Tonopah Member of the Fraction Tuff.

(glass) 19.6 $\pm$ 0.4 m.y.

13. TV-2 K-Ar

Lower unit, King Tonopah Member of Fraction Tuff. (SW¼SE¼ S15, T3N, R42E; 38°06'40"(06.67')N, 117°14'39"(15.65')W; Nye Co., NV). Analytical data: K_2O = 6.26%, $^{40}Ar^*$ = 1.850 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.66. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: See comment sample 11 (TFR_2-1).

(alkali feldspar) 19.9 $\pm$ 0.6 m.y.

14. TFR-1 K-Ar

Lower unit, King Tonopah Member of Fraction Tuff. (NE¼SW¼SW¼ S24, T3N, R42E; 38°05'50"(05.83')N, 117°13'06"(13.10')W; Nye Co., NV). Analytical data: (alkali feldspar) K_2O = 5.71%, $^{40}Ar^*$ = 1.668 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.49; (biotite) K_2O = 8.58%, $^{40}Ar^*$ = 2.740 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.65. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman and E. H. McKee, U.S. Geological Survey. Comment: The three samples of the lower unit of the King Tonopah Member yield an average age of 20.2 $\pm$ 0.4 m.y. The biotite age from this sample is slightly greater than the other mineral ages, due perhaps to crystal contamination during the eruption process--a common occurrence in ash-flow tuffs. The average age of the unit calculated without this biotite date is 19.7 $\pm$ 0.1 m.y.

(alkali feldspar) 19.7 $\pm$ 0.6 m.y.

(biotite) 21.5 $\pm$ 0.6 m.y.

15. TV-1 K-Ar

Upper unit, King Tonopah Member of Fraction Tuff. (SW¼NW¼ S24, T3N, R42E; 38°06'04"(06.07')N, 117°13'06"(13.10')W; Nye Co., NV). Analytical data: K_2O = 4.81%, $^{40}Ar^*$ = 1.299 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.65. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: The upper unit of the King Tonopah Member of the Fraction Tuff yields an age approximately 1.5 m.y. younger than that of the lower. Its age and that of rhyolite of the Cleft (erupted to the north of the Tonopah mining district) appears to overlap in time the hydrothermal mineralization and alteration in the district. See discussion of hydrothermal alteration and mineralization in the text.

(alkali feldspar) 18.2 $\pm$ 0.6 m.y.

Heller Tuff

16. USGS-(M)-11549-1 (Bonham and others, 1972) K-Ar

Rhyolite welded tuff from Heller Tuff (originally called the Heller Dacite); some workers have included this unit in the Fraction Breccia in the past. (NE¼ S2, T2N, R42E; $38^{\circ}03'38''(03.63')$N, $117^{\circ}13'37''(13.62')$W; at Heller Butte, Nye Co., NV). Comment: This rock is the oldest post-ore unit at Tonopah and is not affected by alteration and mineralization. It is younger than the Fraction Tuff (see other ages and discussion) and represents the lower (younger) age limit of hydrothermal mineralization within the main part of the Tonopah district.

(biotite) 17.1 $\pm$ 0.3 m.y.

(sanidine) 16.9 $\pm$ 0.3 m.y.

Rhyolite of the Cleft

17. R-1 K-Ar

Rhyolite of the Cleft. (NW¼ S2, unsurveyed T4N, R42E; $38^{\circ}14'22''(14.37')$N, $117^{\circ}15'16''(15.27')$W; Nye Co., NV). Analytical data: K_2O = 9.58%, $^{40}Ar^* = 2.697 \times 10^{-10}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.81$. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Part of rhyolite flow dome complexes and associated pyroclastic rocks that are overlain by the trachyandesite of Lime Mountain. Ages from rhyolite of the Cleft and the upper unit of the King Tonopah Member of the

Fraction Tuff overlaps in time the hydrothermal mineralization-alteration ages in the Tonopah mining district. See later discussions. Relations between rhyolite of the Cleft and Fraction Tuff are unknown, but this unit overlaps in time the King Tonopah Member of the Fraction. Its age is between that of the upper and lower units of that member.

(sanidine) 19.2 ± 0.6 m.y.

Alteration and Mineralization, Tonopah

18. T-291 K-Ar

Fine-grained intergrowth of quartz-adularia-sericite replacing prophyritic dacite of the Mizpah Formation. (center, SE¼ S 35, T3N, R42E; 38°04'07"(04.12')N, 117°13'35"(13.58')W; Nye Co., NV). Analytical data: K_2O = 7.36%, $^{40}Ar^*$ = 1.979 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.53. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Represents sample of wall-rock alteration. The age is younger than, but nearly within analytical uncertainty, of that reported by Bonham and others (1972) on a purified adularia from a vein in the Belmont Mine (sample 19, USGS-M-TV-1). K-silicate wall-rock ages appear to give the same ages of mineralization as separated vein minerals in Tertiary epithermal deposits (Morton and others, 1977).

(adularized whole rock) 18.1 ± 0.7 m.y.

19. USGS-M-TV-1 (Bonham and others, 1972) K-Ar

Vein material consisting of adularia, with intergrowths of sericite, sulfides, and quartz. (Belmont Mine, center, W½ S36, T3N, R42E; $38^{0}04'17''(04.28')N$, $117^{0}12'58''(12.97')W$; location slightly changed from that reported in Bonham, Garside, and Silberman, 1972). Comment: Represents age of emplacement of Belmont vein system. Overlaps age of emplacement of upper unit of King Tonopah Member of the Fraction Tuff and rhyolite of the Cleft (to the north of the mining district).

(adularia) 19.1 $\pm$ 0.4 m.y.

20. T-229 K-Ar

Fine-grained quartz-adularia-sericite replacing porphyritic dacite of the Mizpah Formation. (Center, W½ S35, unsurveyed T4N, R42E; $38^{0}09'34''(09.57')N$, $117^{0}14'05''(14.08')W$; Nye Co., NV). Frazier's Well area, 10 km north of Tonopah. Analytical data: $K_2O = 9.21\%$, $^{40}Ar^* = 2.328 \times 10^{-10}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.46$. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Relationship of this alteration-mineralization to that at Tonopah is unknown, but it appears to be slightly younger, although overlapping the younger mineralization date (T-291) within analytical uncertainty (see fig. 4).

(adularized whole rock) 17.0 $\pm$ 0.7 m.y.

Siebert Formation

21. SIE-1 K-Ar

Air-fall tuff in the Siebert Formation. (SW¼SW¼NE¼ S3, T2N, R42E; 38°03'29"(03.48')N, 117°14'56"(14.93')W; Esmeralda Co., NV). Analytical data: (sanidine) K_2O = 9.50%, $^{40}Ar^*$ = 2.768 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.71; (biotite) K_2O = 7.85%, $^{40}Ar^*$ = 1.872 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.20. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: K-Ar age for sanidine too old, probably due to contamination of sample by older feldspars picked up during eruption. The biotite age, although low in atmospheric argon content appears to have a more reasonable age from regional stratigraphic considerations. See samples 22, 23, and 24 (SIE-2, SIE-3A, and AD-34).

(sanidine) 19.5 ± 0.4 m.y.

(biotite) 16.1 ± 1.0 m.y.

22. SIE-2 K-Ar

Fine-grained porphyritic basalt from Siebert Formation. (SW¼ S3, T2N, R42E; 38°03'09"(03.15')N, 117°15'15"(15.25')W; Esmeralda Co., NV). Analytical data: K_2O = 2.54%, $^{40}Ar^*$ = 6.101 x 10^{-11} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.66. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological

Survey. Comment: Sample is from a basalt flow interbedded in the Siebert Formation. Its age agrees well with several other mineral ages from air-fall and reworked tuffs in the formation from other localities.

(whole rock) 16.2 ± 0.6 m.y.

23. SIE-3A K-Ar

Air-fall tuff containing biotite and alkali feldspar crystals in pumiceous matrix from Siebert Formation. (NE¼SW¼NE¼ S3, T2N, R42E; $38^{0}03'32''(03.52')N$, $117^{0}14'51''(14.85')W$; Esmeralda Co., NV). Analytical data: K_2O = 2.15%, $^{40}Ar^{*} = 6.371 \times 10^{-11}$ mole/g, $^{40}Ar^{*}/\Sigma^{40}Ar = 0.20$. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Age believed to be too old for stratigraphic position of the Siebert Formation, which overlies the Heller Tuff. Some crystal contamination during eruption or emplacement may have occurred, a common problem in tuffaceous rocks.

(alkali feldspar) 20.0 ± 1.2 m.y.

24. AD-34 (Silberman and McKee, 1972) K-Ar

Air-fall tuff from Siebert Formation. (Center, W½NE¼ S20, T2N, R42E; $38^{0}01'02''(0.95')N$, $117^{0}17'01''(17.02')W$; Esmeralda Co., NV; location slightly changed from that reported in Silberman and McKee, 1972). Comment: Age has large uncertainty due to high atmospheric argon content; however, it appears to be within the correct range indicated by stratigraphic considerations.

(biotite) 15.5 ± 1.6 m.y.

Oddie Rhyolite, and Brougher Rhyolite

25. 11550-1 K-Ar

Columnar-joined biotite-bearing porphyritic rhyolite with phenocrysts of biotite and alkali feldspar, Oddie Rhyolite. (NE¼NE¼NE¼ S35, T3N, R42E; 38°04'38"(04.63')N, 117°13'21"(13.35')W; Nye Co., NV). Analytical data: K_2O = 8.49%, $^{40}Ar^*$ = 2.12 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.42. Collected by: M. L. Silberman and F. J. Kleinhampl, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Sample comes from between Mt. Oddie and Ararat Mountain in the main part of the mining district. It is unaltered. See comment sample 26 (Od-1-Bo).

(biotite) 16.9 ± 0.5 m.y.

26. Od-1-Bo K-Ar

Oddie Rhyolite. (SE¼NE¼ S35, T3N, R42E; 38°04'26"(04.43')N, 117°13'26"(13.43')W; Nye Co., NV). Analytical data: K_2O = 8.91%, $^{40}Ar^*$ = 2.176 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.64. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: E. H. McKee, U.S. Geological Survey. Comment: Sample taken 0.5 km south of sample 11550-1, from the slopes of Mt. Oddie. The Oddie Rhyolite is associated with gold mineralization at Divide and minor gold mineralization at Tonopah. It is believed to be slightly older than the Brougher Rhyolite, which is not altered or mineralized or associated with mineralization. The ages of the Oddie Rhyolite and Brougher Rhyolite overlap within analytical uncertainty, but the average age of the Oddie Rhyolite (16.7 $\pm$ 0.3) is slightly older than that of the Brougher Rhyolite (16.1 $\pm$ 0.1); see samples 27 and 28 (659-66, BQL-1).

(biotite) 16.5 $\pm$ 0.5 m.y.

27. 659-66 (Albers and Stewart, 1972) K-Ar

Porphyritic rhyolite, phenocrysts of sanidine and biotite, Brougher Rhyolite. (Center S10, T1N, R42E; 37°57'N, 117°15'W; Esmeralda Co., NV). Comment: See comment sample 28 (BQL-1).

(sanidine) 16.2 $\pm$ 0.4 m.y.

(biotite) 16.2 $\pm$ 0.4 m.y.

28. BQL-1 K-Ar

Brougher Rhyolite. (SE¼NW¼SE¼ S2, T2N, R42E; 38°03'18"(03.82')N, 117°13'42"(13.70')W; Nye Co., NV). Analytical data: (sanidine) K_2O = 10.95%, $^{40}Ar^*$ = 2.617 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.95; (biotite) K_2O = 8.67%, $^{40}Ar^*$ = 2.055 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.60. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman and E. H. McKee, U.S. Geological Survey. Comment: From Mt. Butler, along road to radio tower.

See comment sample 29 (BQL-2). Brougher Rhyolite intrudes the Siebert Formation and the Fraction Tuff and is slightly younger than the similar Oddie Rhyolite. See discussion of samples 25 and 26 (Od-1-Bo and 11550-1) for relations between the chemically and petrographically similar Oddie and Brougher Rhyolites.

(sanidine) 16.1 ± 0.5 m.y.

(biotite) 16.0 ± 0.5 m.y.

29. BQL-2 K-Ar

Brougher Rhyolite (?), probably a younger unit--rhyolite of Rhyolite Peak. (Center, S½ S27, unsurveyed T4N, R42E; $38^{o}10'12''$ (10.20')N, $117^{o}14'56''$(14.93')W; Nye Co., NV). Analytical data: (alkali feldspar) K_2O = 6.41%, $^{40}Ar^{*}$ = 1.348 x 10^{-10} mole/g, $^{40}Ar^{*}/\Sigma^{40}Ar$ = 0.48; (biotite) K_2O = 8.98%, $^{40}Ar^{*}$ = 1.761 x 10^{-10} mole/g, $^{40}Ar^{*}/\Sigma^{40}Ar$ = 0.48. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: BQL-2 is younger than Brougher intrusions near Tonopah, but the ages are strongly discordant. The data suggest that there has been post-crystallization argon loss--perhaps due to a later thermal event in this immediate area.

(alkali feldspar) 14.5 ± 0.4 m.y.

(biotite) 13.2 ± 0.4 m.y.

Divide Andesite

30. D-1 K-Ar

Divide Andesite, porphyritic biotite-hornblende dacite or andesite. (NW¼SW¼NW¼ S33, T2N, R43E; $37^{0}59'14''(59.23')N$, $117^{0}10'00''(10.00')W$; Esmeralda Co., NV). Analytical data: (biotite) $K_2O = 6.54\%$, $^{40}Ar^* = 1.632 \times 10^{-10}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.64$; (hornblende) $K_2O = 0.86\%$ (X-ray fluorescence), $^{40}Ar^* = 2.113 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.58$; (plagioclase) $K_2O = 0.495\%$, $^{40}Ar^* = 1.093 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.60$. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Plagioclase is vermicular; see sample 31 (D-3).

(biotite) 16.8 $\pm$ 0.5 m.y.

(hornblende) 16.6 $\pm$ 0.8 m.y.

(plagioclase) 14.9 $\pm$ 0.4 m.y.

31. D-3 K-Ar

Divide Andesite, porphyritic biotite-hornblende dacite or andesite. (NW¼NW¼ S33, T2N, R43E; $37^{0}59'20''(59.33')N$, $117^{0}09'39''(09.65')W$; Nye Co., NV). Analytical data: $K_2O = 0.934\%$, $^{40}Ar^* = 2.338 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.33$. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: The Divide Andesite is stratigraphically slightly older than the Brougher Rhyolite in the vicinity of the Divide mining district. It is altered and mineralized in the district, whereas the Brougher is not. The Divide Andesite is cut by Brougher Rhyolite, by rhyolite dikes and by latites of volcanics of Donovan Peak. The reported ages, with the exception of plagioclase of sample D-1, are concordant, and are slightly older than ages reported on samples of the Brougher Rhyolite at Tonopah (sample 28, BQL-1, Mt. Butler) and 5 km south of Divide (sample 27, 659-66).

(hornblende) 16.9 ± 0.7 m.y.

Volcanics of Donovan Peak

32. L-1 K-Ar

Fine-grained, grey quartz latite, volcanics of Donovan Peak. (SW¼SW¼SW¼ S20, T1N, R43E; 37°55'08"(55.13')N, 117°11'03"(11.05')W; Esmeralda Co., NV). Analytical data: K_2O = 3.94%, $^{40}Ar^*$ = 9.297×10^{-11} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.75. Collected by: M. L. Silberman and R. P. Ashley, U.S. Geological Survey, and H. F. Bonham, Nevada Bureau of Mines. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: See samples 33 and 34 (HL-1 and FBR-2).

(whole rock) 15.9 ± 0.5 m.y.

33. FBR-2 K-Ar

Rhyolite, volcanics of Donovan Peak. (SW¼NW¼ S32, T2N, R43E; 37°59'06"(59.10')N, 117°11'02"(11.03')W; Esmeralda Co., NV). Analytical data: K_2O = 8.46%, $^{40}Ar^*$ = 2.048×10^{-10} mole/g,

$^{40}Ar^*/\Sigma^{40}Ar = 0.42$. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey.

(biotite) 16.3 ± 0.7 m.y.

34. HL-1 K-Ar

Rhyodacite, volcanics of Donovan Peak. (SW¼NW¼ S32, T2N, R43E; 37°59'00"(59.00')N, 117°11'02"(11.03')W; Esmeralda Co., NV). Analytical data: $K_2O = 0.862\%$, $^{40}Ar^* = 1.889 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.26$. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Volcanics of Donovan Peak are a complex volcanic unit consisting of a variety of lithologies including rhyolite, quartz latite and rhyodacite. K-Ar age data suggest the unit was emplaced over a period of approximately 1.5 m.y. coincident in part with the time of emplacement of the Divide Andesite.

(hornblende) 14.8 ± 0.6 m.y.

Alteration and Mineralization, Divide Mining District

35. TD-2 K-Ar

Altered Fraction Tuff, Tonopah Summit Member, alteration is transitional between propylitic and sericitic with original biotite now consisting of mixed layer chlorite and sericite. (Center, SW¼ S26, T2N, R42E; 37°59'44"(59.73')N, 117°14'11"(14.18')W; Esmeralda Co., NV; mine dump sample, from Gold Zone shaft). Analytical data: K_2O = 2.322%, $^{40}Ar^*$ = 5.392 x 10^{-11}, 5.400 x 10^{-11} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.59, 0.52. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Mineralization at Divide consists largely of replacement veins in faults and fractures. The veins consist of silicified and pyritized country rock ranging in thickness from 2 cm or less to more than 30 m. The chief host rock is the Fraction Tuff, but the Siebert Tuff and Oddie Rhyolite is also mineralized. Gold mineralization is characteristic of veins in the Oddie Rhyolite, whereas the veins in the Fraction and Siebert are silver-rich, with considerable base metal sulfides. The alteration age here suggests that hydrothermal activity took place for some period of time after Oddie Rhyolite emplacement had ended. See samples 36, 37, 38, and 39.

(sericite/chlorite) 15.7 $\pm$ 0.2 m.y.

36. TD-3 K-Ar

Quartz-sericite alteration of Fraction Tuff, Divide district. (NW¼SW¼NW¼ S27, T2N, R42E; $38^{o}00'08''(00.13')$N, $117^{o}15'25''(15.42')$W; Esmeralda Co., NV; outcrop sample). Analytical data: K_2O = 5.86%, $^{40}Ar^*$ = 1.325 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.37. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological

Survey. Comment: From the Belcher vein system, at Tonopah Divide Shaft, 1 km north of Hasbrouck Peak. Age is concordant with sample 35 (TD-2), and with sample 37 (THA 6) and overlaps within analytical uncertainty the ages of samples 38 and 39 (THA 25 and THA 25C).

(sericite) 15.3 ± 0.6 m.y.

37. THA 6 K-Ar

Lapilli tuff in the Siebert Formation; interbedded in epiclastic sedimentary rocks; sericitic alteration; sample taken in adit of Tonopah Hasbrouck Mine. (SE¼SW¼SE¼ S28, T2N, R42E; 37°59'32" (59.53')N, 117°15'59"(0.9')W; Esmeralda Co., NV). Analytical data: K_2O = 8.02%, $^{40}Ar^*$ = 1.879 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.56. Collected by: M. L. Silberman, U.S. Geological Survey, and John Livermore, A. B. Wallace, and P. E. Dircksen, Cordex Exploration Co. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Sample is from a sericitic alteration zone. Most of the rock on the surface is silicified. The age of alteration of this sample overlaps those of the two dates on a silicified (K-silicate) altered sample from the surface of Hasbrouck Peak. See samples 38 and 39 (THA 25 and THA 25C).

(muscovite) 15.8 ± 0.5 m.y.

38. THA 25R K-Ar

Dark grey silicified rock, probably originally a pumice breccia, largely replaced by silica. Adularia replaces parts of many of the pumice fragments. The adularia is fine grained (0.05-0.07 mm). Vugs are also filled with adularia some (5-6 percent) phenocrysts of sanidine are present. Siebert Formation, Divide mining district, Hasbrouck Peak. (NW¼NE¼ S33, T2N, R42E; 37°59'27"(59.45')N, 117°16'00"(16.00')W; Esmeralda Co., NV). Analytical data: K_2O = 5.61%, $^{40}Ar^*$ = 1.369 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.48. Collected by: M. L. Silberman, U.S. Geological Survey, and John Livermore, A. B. Wallace, and P. E. Dircksen, Cordex Exploration Co. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Silicification and accompanying K-metasomatism in this area appears to have resulted from hot spring activity. Banded siliceous sinter is present in the immediate area where this sample was collected (J. Livermore, A. B. Wallace, and M. L. Silberman, unpubl. data, 1976). The presence of detrital sanidine in the sample has evidently not affected the age. The sanidine probably lost any pre-alteration argon during the silicification, as indicated by concordance of the age of the whole rock with an adularia separate from the same sample (THA 25C). The sample contains 2 ppm silver, 5 ppm mercury, 800 ppm arsenic, and 10 ppm antimony--typical hot spring trace metal assemblage. X-ray analysis and petrographic examination indicate the sample contains quartz, adularia, and pyrite.

(adularized whole rock) 16.4 ± 0.5 m.y.

39. THA 25C K-Ar

Hydrothermal alteration, Siebert Formation, Divide district, Hasbrouck Peak. (NW¼NE¼ S33, T2N, R42E; 37°59'27"(59.45')N, 117°16'00"(16.00')W; Esmeralda Co., NV). Analytical data: K_2O = 9.51%, $^{40}Ar^*$ = 2.300 x 10^{-10} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.56. Collected by: M. L. Silberman, U.S. Geological Survey, and John Livermore, A. B. Wallace, and P. E. Dircksen, Cordex Exploration Co. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Purified K-feldspar concentrate, separated from sample THA 25R. Concordance of age indicates detrital K-feldspar is not affecting the result. The ages on samples from the Divide district suggest a hydrothermal system--including a thermal spring system existed in this age from 16.4 to about 15.3 m.y. or for a period of time of about 1 m.y. Mineralization at Divide appears to be related to intrusions of Oddie Rhyolite (average age 16.7 m.y.) but volcanic activity in this region--represented by the Brougher Rhyolite (16.1 m.y.), Divide Andesite (16.8 m.y.), and volcanics of Donovan Peak (14.8 to 16.3 m.y.)--occurred over an approximately 2 m.y. interval. Hydrothermal alteration probably coincided with, and perhaps continued after, much of this volcanic activity.

(adularia) 16.3 ± 0.5 m.y.

Porphyritic Dacite of San Antonio Mountains

40. USGS(M)-12789-75 (Silberman and McKee, 1972) K-Ar

Porphyritic biotite-hornblende dacite flow. (Center S34, T6N, R42E; 38°20'09"(20.15')N, 117°15'00"(15.00')W; Nye Co., NV). Comment: Part of extensive unit of dacite as much as 1500 ft (460 m) thick which overlies Tertiary ash flows in the northern San Antonio Mountains.

(biotite) 16.7 ± 0.5 m.y.

(hornblende) 16.8 ± 0.5 m.y.

Trachyandesites of Lime Mountain, Thunder Mountain, and Red Mountain

41. LM-2 K-Ar

Trachyandesite of Lime Mountain. (SE¼NE¼ S4, unsurveyed T4N, R42E; 38°13'59"(13.98')N, 117°15'42"(15.70')W; Nye Co., NV). Analytical data: (hornblende) K_2O = 0.802%, $^{40}Ar^*$ = 1.865 x 10^{-11} mole/g, $^{40}Ar^*/^{40}Ar$ = 0.31; (plagioclase) K_2O = 0.375%, $^{40}Ar^*$ = 9.261 x 10^{-12} mole/g, $^{40}Ar^*/\Sigma^{40}Ar$ = 0.34. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Plagioclase phenocrysts are vermicular. See note, sample 42 (LM-3).

(hornblende) 15.7 ± 0.6 m.y.

(plagioclase) 16.6 ± 0.8 m.y.

42. LM-3 K-Ar

Trachyandesite of Lime Mountain. (SW¼ S4, unsurveyed T4N, R42E; $38^{\circ}13'45''(13.75')N$, $117^{\circ}16'20''(16.33')W$; Nye Co., NV). Analytical data: $K_2O = 0.726\%$, $^{40}Ar^* = 1.699 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.40$. Collected by: L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Trachyandesite of Lime Mountain is part of a thick sequence of rhyodacite to trachyandesite lavas erupted in the northern part of the San Antonio Mountains, north of Tonopah. The sequence includes porphyritic dacite of Davis and others (1971) of slightly older age, which crops out to the north of Lime Mountain (sample 40).

(hornblende) 15.8 ± 0.5 m.y.

43. TM-1 K-Ar

Trachyandesite of Thunder Mountain. (Center, NW¼NW¼NE¼ S22, T4N, R44E; $38^{\circ}11'33''(11.55')N$, $117^{\circ}01'39''(01.65')W$; Nye Co., NV). Analytical data: $K_2O = 1.91\%$, $^{40}Ar^* = 4.473 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.54$. Collected by: H. F. Bonham and L. J. Garside, Nevada Bureau of Mines and Geology. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Armstrong and others (1972) report an age of 18.9 ± 1.5 m.y. from this unit. Their sample was analyzed for argon using the method of fusing a single, sawed chunk of basalt. The present sample was analyzed using approximately 2 g of basalt ground to approximately 60-100 mesh (0.25-0.15 mm). This technique usually results in reducing the atmospheric argon content of the sample, most of which is evidently held physically in vesicles, and along grain boundaries (Keeling and Naughton, 1974). The present sample has 55 percent radiogenic argon, as opposed to 8 percent from the sample reported in Armstrong and others (1972). We consider the age reported here to be both more precise and more accurate than the earlier result.

(whole rock) 15.8 ± 0.5 m.y.

44. RMB 2 K-Ar

Trachyandesite of Red Mountain. (NE¼SW¼NW¼ S29, T3N, R43E; $38^{0}05'21''(05.35')N$, $117^{0}10'52''(10.87')W$; Nye Co., NV). Analytical data: $K_2O = 0.891\%$, $^{40}Ar^* = 2.000 \times 10^{-11}$ mole/g, $^{40}Ar^*/\Sigma^{40}Ar = 0.45$. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and R. P. Ashley and M. L. Silberman, U.S. Geological Survey. Dated by: M. L. Silberman, U.S. Geological Survey. Comment: Armstrong and others (1972) report two additional whole-rock ages from this unit of 15.8 ± 2 and 17.9 ± 3 m.y. Their results lack precision due to high atmospheric argon levels (94-97 percent). The mineral age reported above is considerably more precise, and fits well with the stratigraphic sequence. Trachyandesite of Red Mountain is part of a sequence of intermediate to mafic lavas which include the trachyandesites of Thunder Mountain (sample 43, TM-1) which erupted north of Tonopah during Stage IV of the volcanic history (fig. 3).

(hornblende) 15.1 ± 0.5 m.y.

Rhyolite and Muscovite-Granite of the Klondike Mining District

45. K-1 (Silberman and others, 1975) K-Ar

Crystal-poor columnar-jointed intrusive rhyolite with sparse phenocrysts of quartz and sanidine with rare iron oxides in a fine-grained groundmass of feldspars and quartz; rhyolite of Klondike. (NW¼NW¼ S31, T1N, R43E; $37^{o}54.1'N$, $117^{o}12.2'W$; Esmeralda Co., NV). Comment: Rhyolite represents the end phase of volcanic activity in the Tonopah area and is approximately the same age as the rhyolite of Cactus Peak (11.2 $\pm$ 0.2) which crops out south of Klondike in the northern part of the Goldfield Hills (Ashley and Silberman, 1976). The rhyolite intrudes limestones of the Middle and Late Cambrian Emigrant Formation. Gold-bearing quartz veins occur along contacts with the sedimentary rocks and rhyolite dikes (Albers and Stewart, 1972).

(sanidine) 10.5 $\pm$ 0.3 m.y.

46. Mg-1 (Silberman and others, 1975) K-Ar

Medium- to coarse-grained intergrowth of quartz, K-feldspar, and muscovite. Muscovite is primary, apparently not an alteration product. (SW¼NW¼NE¼ S25, T1N, R42E; $37^{o}54.92'N$, $117^{o}12.93'W$; Esmeralda Co., NV). Comment: The small granitic body is emplaced along a thrust fault zone offsetting the carbonate rocks of the Emigrant Formation of Late and Middle Cambrian age. Quartz veins carrying argentiferous galena and cerussite occur in the granite in joint fractures parallel to bedding in the surrounding sedimentary rocks (Silberman and others, 1975).

(muscovite) 104 ± 2 m.y.

Felsic and Mafic Igneous Rocks of the Lone Mountain Area

47. SPR-1 (Silberman and others, 1975) K-Ar

Coarse-grained intergrowth of K-feldspar, plagioclase, quartz, and muscovite, adjacent to a 1 to 2 in. quartz vein. The pegmatite occurs as a segregation within biotite granite, with quartz filling the central part. (SE¼NW¼ S15, unsurveyed T2N, R40E; 38°01.88'N, 117°28.23'W; Esmeralda Co., NV). Comment: See samples 48 and 49 (SPR-1A and GB-1).

(muscovite) 71.1 ± 1.4 m.y.

48. SPR-1A (Silberman and others, 1975) K-Ar

Medium-grained granite consisting of microcline, quartz, plagioclase, and green pleochroic biotite. (SE¼NW¼ S15, unsurveyed T2N, R40E; 38°01.88'N, 117°28.23'W; Esmeralda Co., NV; approximately 300 ft southwest of).

(biotite) 69.2 ± 1.4 m.y.

49. GB-1 (Silberman and others, 1975) K-Ar

Medium-grained intergrowth of plagioclase, pyroxene, green pleochroic hornblende, and minor chloritized biotite. (NE¼SE¼SE¼ S35, T3N, R40E; 38°04.08'N, 117°26.55'W; Esmeralda Co., NV).

Comment: Lone Mountain consists of a mass of granite, cropping out over 28 mi^2, intruded into Precambrian and Cambrian sedimentary rocks (Albers and Stewart, 1972). At least two other petrographic types of granitic plutonic rocks are present on the northeast flank of Lone Mountain, as well as dikes and an irregular mass of altered felsic porphyritic intrusive rock. Roof pendants of Cambrian sedimentary rocks and masses of an older gabbro occur in these granitic rocks. Thin diabase dikes cut the main pluton and sedimentary rocks near their mutual contact.

Two K-Ar ages were obtained from separate samples taken close together in the main mass of the pluton. Biotite from coarse-grained biotite granite yielded an age of 69.2 m.y. (sample 48) and muscovite from a late-stage pegmatite segregation in the biotite granite yielded an age of 71.1 m.y. (sample 47). The ages overlap within analytical uncertainty. Edwards and McLaughlin (1972) report a 63 ± 7 m.y. age on biotite from this pluton.
No samples of the felsic porphyritic rocks suitable for K-Ar dating were found, and the other granitic units were not dated. Hornblende separated from a gabbro mass yielded an age of 113 m.y.

Albers and Stewart (1972) report three K-Ar ages from the Lone Mountain pluton, 367 ± 18 m.y. on hornblende from one of a series of hornblende-bearing dikes cutting the pluton, and 67 ± 3 and 20 ± 1 m.y., respectively, from biotite separated from different samples of the pluton. Their sample localities were not specified. The 67 m.y. age agrees within analytical uncertainty with those reported here. Concordance between the biotite and muscovite ages (this report) suggests that they have recorded reasonably accurately the crystallization age of the main granitic part of the pluton. It is not possible to evaluate the other ages reported previously without accurate information or sample locations. Further work is necessary to define adequately the age of all phases of the igneous rocks in the pluton (Silberman and others, 1975). See sample 50 (GRP-1).

(hornblende) 113 ± 3 m.y.

50. GRP-1 FT

Silicic porphyry dike, Lone Mountain. (SE¼SW¼SW¼ S2, unsurveyed T2N, R40E; 38°03'05"(03.08')N, 117°27'25"(27.42')W; Esmeralda Co., NV). Analytical data: $\lambda = 6.85 \times 10^{-17}$ yr^{-1}, Ps = 2.182×10^{6} tracks/cm^2, ½Pi = 3.598×10^{6} tracks/cm^2, $\phi = 1.19 \times 10^{15}$ N/cm^2, no. of grains counted = 7. Collected by: H. F. Bonham, Nevada Bureau of Mines and Geology, and M. L. Silberman, U.S. Geological Survey. Dated by: R. P. Ashley, U.S. Geological Survey. Comment: May be related to younger rocks of the Tonopah Formation, and the above age is within the analytical uncertainty of sample 7 (TF-1, zircon). The dikes intrude carbonate rocks of the Deep Springs and Reed Formations and are associated with Ag-Pb-Zn mineralization in the area of occurrence.

(zircon) 22.1 ± 3.2 m.y.

51. Miller-1 K-Ar

Quartz and sanidine phenocrysts in a fine-grained groundmass of similar composition. Phenocrysts are banded and partially embayed. Some feldspars have been partially or wholly replaced by quartz as aggregate crystals. Secondary quartz as aggregate crystals similar to those replacing feldspars has also crystallized as irregular stringers and blebs in the groundmass, which contains some carbonate. FeOX present probably after altered mafics. (SE¼SW¼ S13, T3N, R40E; 38°06.58'N, 117°26.12'W; Esmeralda Co., NV). Comment: The rock has been hydrothermally altered, and the age should be considered a minimum. It intrudes Cambrian sedimentary rocks, Mesozoic (?) granitic rocks, and rhyolite ash-flow tuffs at the northernmost outcrops of Lone Mountain.

(sanidine) 14.7 ± 0.3 m.y.

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Illustrations

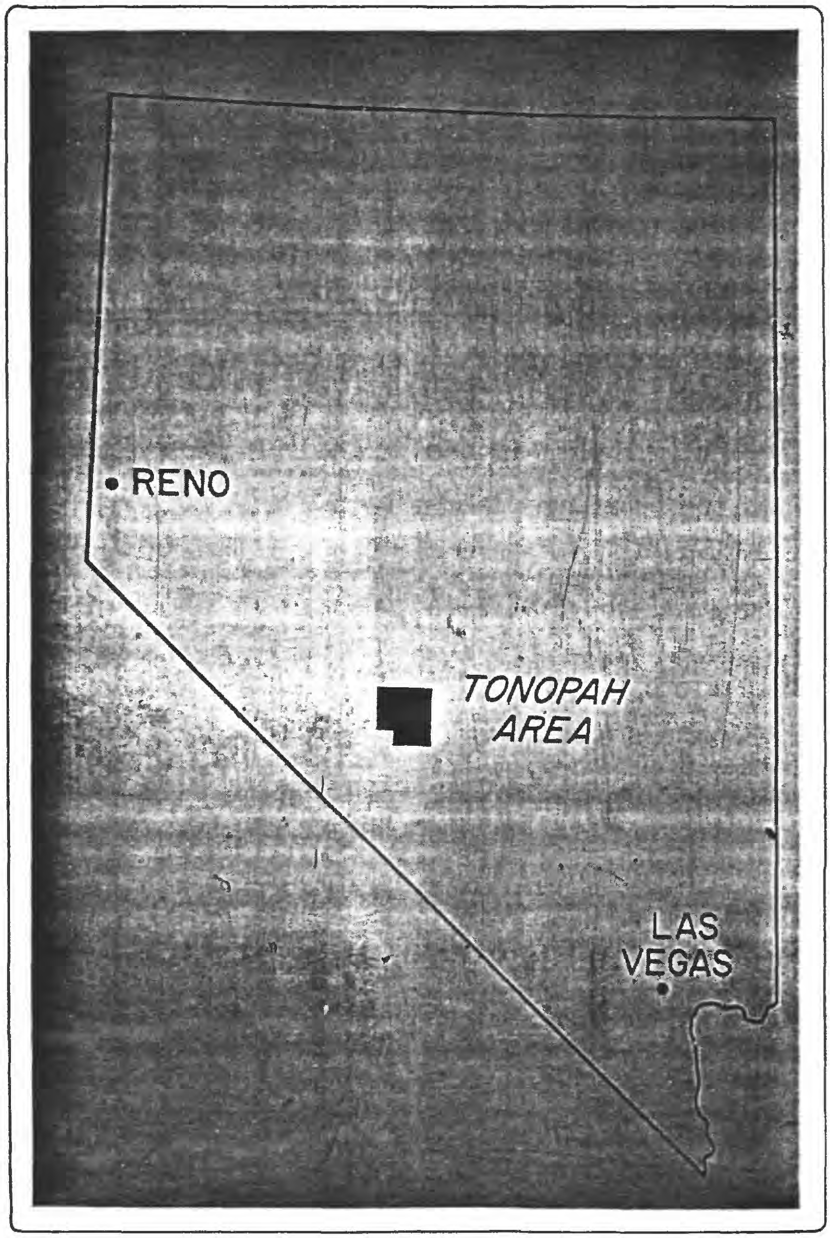
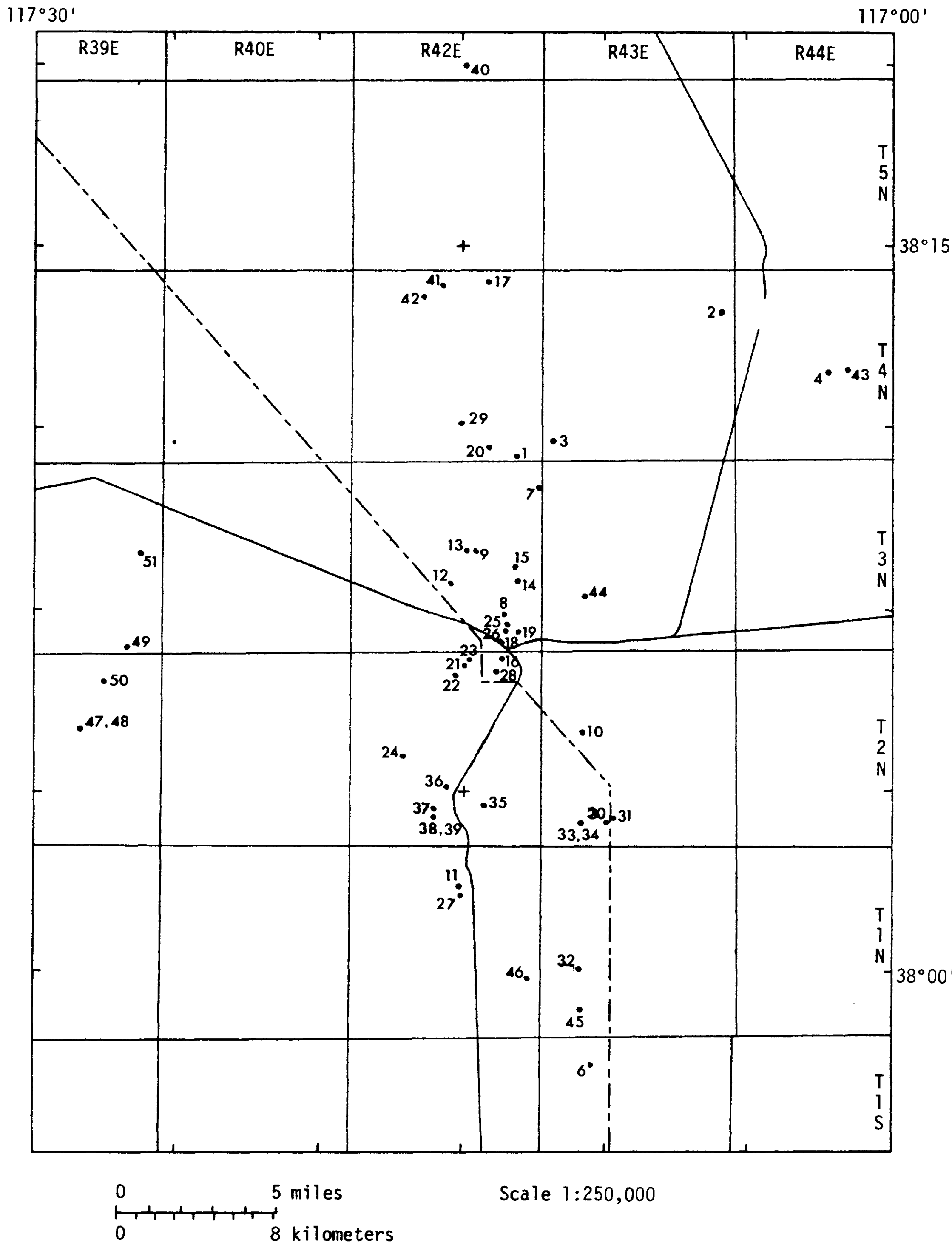


FIGURE 1A


117°30'
117°00'
R39E
R40E
R42E
R43E
R44E
T 5 N
T 4 N
T 3 N
T 2 N
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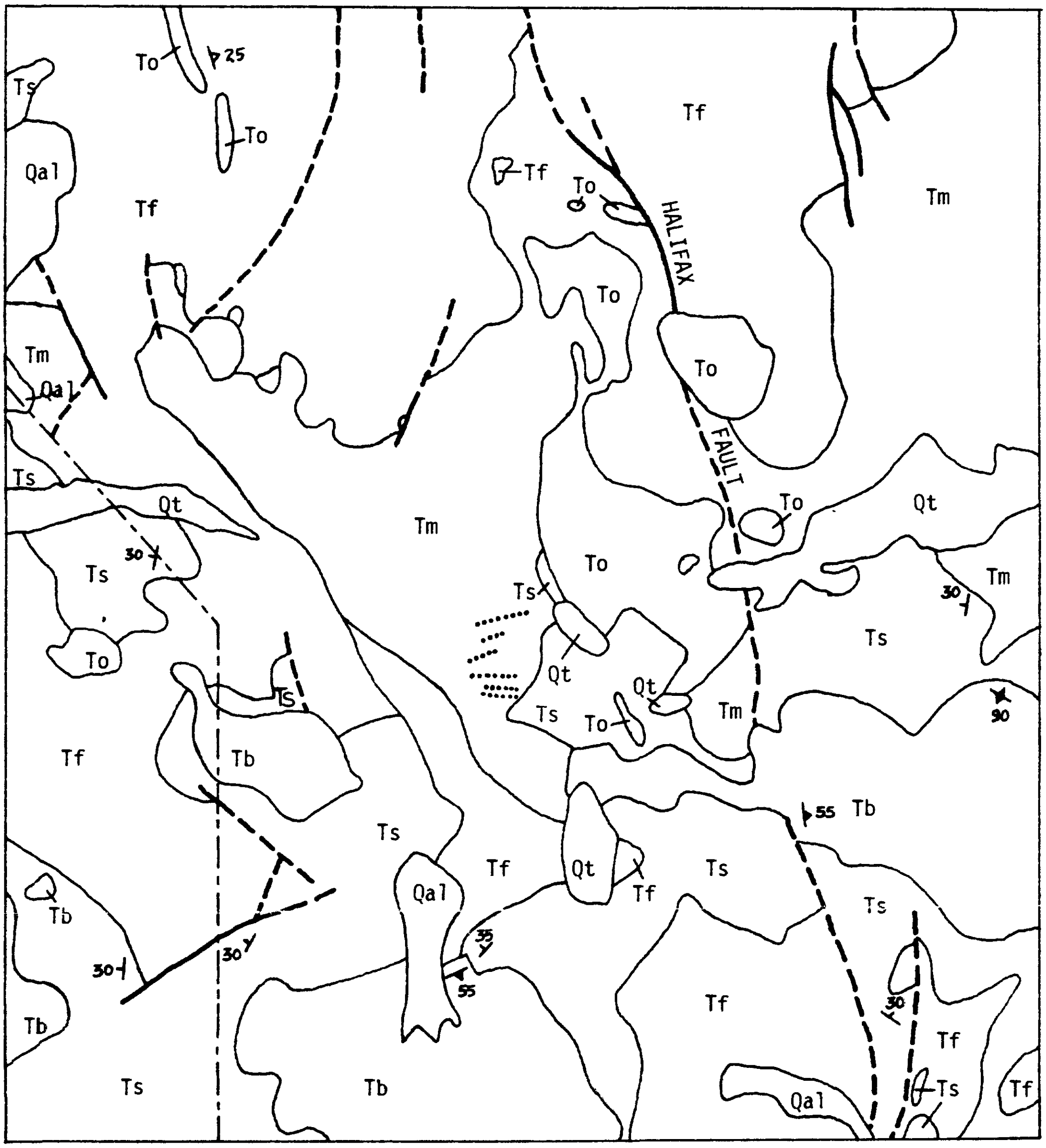
38°15'
38°00'
40
41
17
42
2
4
43
29
3
20
1
7
13
9
15
12
14
44
51
8
25
26
19
18
49
23
21
16
28
22
50
47,48
10
24
36
35
37
30
31
38,39
33,34
11
27
46
32
45
6
0
5 miles
0
8 kilometers
Scale 1:250,000

FIGURE 1B

GEOLOGIC MAP OF THE TONOPAH DISTRICT



Quaternary	Qt	Tailings, dumps, and fill
	Qal	Alluvium
Tertiary	Tb	Brougher Rhyolite
	To	Oddie Rhyolite
	Ts	Siebert Formation
	Tf	Fraction Tuff
		Veins
	Tm	Mizpah Formation

0 1 kilometer

strike and dip of beds

strike and dip of flow banding

strike and dip of compaction foliation

INTERPRETIVE HISTORY OF VOLCANIC ACTIVITY AND HYDROTHERMAL ALTERATION-MINERALIZATION IN THE SAN ANTONIO MOUNTAINS, NYE AND ESMERALDA COUNTIES, NEVADA

(See figure 4 for explanation of symbols.)

MILLION YEARS B.P.

END OF VOLCANIC ACTIVITY

10 -

STAGE V CRUSTAL EXTENSION, AND RHYOLITE-TRACHYANDESITE VOLCANISM SOUTH OF TONOPAH (KLONDIKE AND MUD LAKE) AND NORTH AND WEST OF TONOPAH (RHYOLITE PEAK AND LONE MOUNTAIN). ALTERATION-MINERALIZATION AT MILLERS (LONE MTN.) AND KLONDIKE.

12 -

14 -

STAGE IV RENEWED EMPLACEMENT OF GRANITIC MAGMA, MAINLY NORTH AND SOUTH OF TONOPAH. ERUPTION AND EMPLACEMENT OF A VARIETY OF VOLCANIC ROCKS. BEGINNING OF BASIN AND RANGE FAULTING TOWARDS END OF THIS STAGE. BROUGHER AND ODDIE RHYOLITE AND SIEBERT FORMATION AT TONOPAH. VOLCANISM AT DIVIDE AND NORTH OF TONOPAH, MINERALIZATION AT DIVIDE.

16 -

18 -

STAGE III EMPLACEMENT OF REGIONAL GRANODIORITE TO QUARTZ MONZONITE MAGMA IN AREA. MAJOR VOLCANIC CENTERS (TONOPAH, GOLDFIELD, ETC.) DEVELOP OVER CUPOLAS. INTERMEDIATE VOLCANIC UNITS ERUPT FROM STRATOVOLCANOES--MIZPAH FM. COOLING AND DIFFERENTIATION OF BATHOLITH LEAD TO DEVELOPMENT OF SILICIC MAGMAS. ERUPTION AND EMPLACEMENT OF FRACTION TUFF AND HELLER TUFF AT TONOPAH, RHYOLITE OF THE CLEFT, NORTH OF TONOPAH. HYDROTHERMAL ALTERATION AND MINERALIZATION AT TONOPAH (SILVER GOLD VEINS), AND TO THE NORTH AT FRAZER'S WELL. (For details of timing, see fig. 4 .)

20 -

22 -

Z Rhyolite dike, Lone Mtn.

STAGE II EMPLACEMENT OF RHYOLITE FLOW DOMES OF TONOPAH FORMATION, RHYOLITE INTRUSIONS AT LONE MTN., ERUPTION OF TUFFS OF RYE PATCH, ANTELOPE SPRINGS AND MURPHY'S CAMP, AND ASSOCIATED CALDERA COLLAPSE.

24 -

P

Z Rhyolite intrusion, Tonopah Fm.

Ash flow, Tuff of Murphy's Camp

B

B Ash flow, Tuff of Antelope Springs

26 - ? ? ? ?

STAGE I ERUPTION OF ASH FLOWS AND AIR FALL TUFFS OF TONOPAH FM., TUFF OF RALSTON VALLEY FROM CALDERA SOURCES IN OR NEAR SAN ANTONIO MTNS.

28 -

30 -

Z Ash flow, Tuff of Ralston Valley

32 -

34 -

Z Ash flow tuff, Tonopah Fm.

FIGURE 4--INTERPRETIVE HISTORY OF VOLCANIC ACTIVITY AND HYDROTHERMAL ACTIVITY IN AND NEAR TONOPAH, STAGES III, IV AND V