New Radiometric Ages Related to Alteration and Mineralization in the Vicinity of Yucca Mountain, Nye County, Nevada

by

E.H. McKee J.R. Bergquist

U.S GEOLOGICAL SURVEY
Open-File Report 93-538

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

NEW RADIOMETRIC AGES RELATED TO ALTERATION AND MINERALIZATION IN THE VICINITY OF YUCCA MOUNTAIN, NYE COUNTY, NEVADA

By

EDWIN H. McKEE[1] and JOEL R. BERGQUIST[1]

Open-File Report 93-538

[1]Menlo Park, CA 94025

1993

CONTENTS

ACKNOWLEDGMENTS

The authors wish to express their thanks to the following people who helped in the production of this report. Steven I. Weiss of the University of Nevada-Reno carefully reviewed the manuscript and offered many technical suggestions. Robert J. Miller produced the digital map and gave us valuable advice on preparing the plate. Diana Mangan drafted additional work on the plate, and produced the cover and report. Ana Barrales worked on the manuscript and helped with production. John Stuckless, Rick Spengler, Zell Peterman, and Larry Hayes of the Yucca Mountain Project Branch provided much appreciated administrative support and guidance through the paperwork maze.

GEOLOGIC SETTING

Yucca Mountain is in the western part of the southwest Nevada volcanic field. This volcanic province is comprised of widespread middle and late Miocene ash-flow sheets and lavas deposited on complexly deformed and locally metamorphosed Precambrian and Paleozoic sedimentary rocks. The Precambrian and Paleozoic strata are mostly carbonate and quartzose marine sedimentary rocks deposited on the ancient North American continental shelf. Nearby, southwest of Yucca Mountain, are several geologically young (ca. 140 thousand years old) cinder cones and associated basalt lava flows (Turrin and others, 1991). Exposures on Yucca Mountain are entirely Miocene ash-flow tuffs—no Precambrian or Paleozoic rocks crop out and no younger basaltic rocks occur.

Igneous activity of the SW Nevada volcanic field can be divided into four magmatic stages. The first and most voluminous stage began about 15.2 Ma (million years ago) with emplacement of the Redrock Valley Tuff and ended about 12.8 Ma with eruption of the Paintbrush Tuff (Noble and others, 1991). This stage is characterized by eruption of many (at least 9) large rhyolitic ash-flow tuff sheets of subalkaline character and some dacitic lava flows. The first of the large collapse calderas, which characterize the SW Nevada volcanic field, formed after eruption of the large-volume ash-flow tuff sheets. After a lull of more than 1 million years the second magmatic stage began with eruption of the Timber Mountain Tuff at about 11.4 Ma, which is comprised of two very widespread ash-flow tuffs, the Rainier Mesa Member and overlying Ammonia Tanks Member. The Timber Mountain caldera formed at this time. Much less voluminous rhyolite tuffs and lavas and associated mafic and intermediate lavas about 10 million years old mark the end of this stage. The third stage is represented by alkaline, peralkaline, and subalkaline rocks of the Black Mountain and Stonewall Mountain volcanic centers (both collapse calderas) erupted between about 9 to 7 Ma (Noble and others, 1991). These centers are north of Yucca Mountain and tuffs from them do not crop out on Yucca Mountain. The fourth and last igneous stage is represented by the very small volume basaltic eruptions typified by the Lathrop Wells cinder cone, Red cinder cone and associated small cones and lava flows. Rocks from this last stage are all less than 0.5 Ma.

This report presents information on the ages of mineralization (primarily hydrothermal) and its relation to volcanism in the vicinity of Yucca Mountain. Samples of alteration minerals taken from mines, prospects, and mineralized areas in the vicinity of Yucca Mountain have been analyzed for radiometric age. This compilation of unpublished information allows better understanding of the relationship between volcanic events and mineralization in the vicinity of Yucca Mountain, and will be valuable in assessing the mineral resource potential of the volcanic and underlying sedimentary rocks at the proposed repository site.

GEOCHRONOLOGY

General

Samples of alunite and adularia from altered, and locally mineralized, rocks at or near mines or prospects, in the vicinity of Yucca Mountain, were dated to establish time of alteration (and locally mineralization) at the mine or in the region in general. Both minerals form by hydrothermal alteration associated with silicic volcanic or subvolcanic magma systems. Epithermal metal deposits commonly contain these two minerals: (1) deposits termed kaolinite-*alunite*, acid sulfate, or high sulfidation are characterized by high sulfidation and oxidation state mineral assemblages, a high degree of host rock alteration and metasomatism, and massive and vuggy chert, (2) deposits termed quartz-*adularia*-sericite, or low sulfidation, are characterized by mineral assemblages indicative of lower sulfidation and oxidation states from fluids dominantly of meteoric origin and fairly neutral pH. This alteration typically develop open-space mineral growth.

Extensive study of the volcanic rocks in the vicinity of Yucca Mountain has established that widespread volcanic activity took place in the region in middle and late Miocene time, especially from about 15 to 7 Ma (Noble and others, 1991). These voluminous silicic igneous systems produced the expected eruptive rocks types including air-fall ash, ash-flows, lava flows, dikes, sills, and domes of many sizes. Like other silicic igneous systems, hydrothermal activity was a major part of the magmatic event especially in the waning stages of the system as a whole. Local and widespread alteration and some mineralization took place as a consequence of hydrothermal activity. Most of the alunite in the Yucca Mountain region probably formed from acid alteration associated with the oxidation and condensation of H_2S vapor and steam above the watertable and it may or may not be above areas of adularia-sericite alteration. Some alunite formed locally where high sulfidation and oxidation conditions prevailed, whereas adularia formed in lower sulfidation environments. Both types of alteration followed the main igneous events by one to two million years or less. Radiometric dating of adularia and alunite in the vicinity of Yucca Mountain clearly bears out this age relationship - epithermal alteration is coeval with, to one to two million years younger than, the main eruptive or intrusive rocks. A summary of the nature and geologic setting of selected areas of mineralization in the vicinity of Yucca Mountain is given by Castor and Weiss (1992).

K-Ar and $^{40}Ar/^{39}Ar$ age determinations

K-Ar and $^{40}Ar/^{39}Ar$ ages were determined on samples collected in 1986-1989, by D. Finn, M.R. Jackson, D.C. Noble, and S.I. Weiss of the University of Nevada-Reno. Preparation of purified mineral concentrates was done in the mineral preparation laboratory in the Geology Department at the University of Nevada-Reno. All analyses for age determination were by E.H. McKee of the U.S. Geological Survey at the Menlo Park geochronology laboratory. Many of the ages were included in the M.S. thesis of M.R. Jackson (1988).

Seventeen samples (6 adularia, 10 alunite) were dated by the K-Ar technique using purified adularia or alunite concentrates. The argon analyses were done using standard isotope-dilution techniques similar to those described by Dalrymple and Lanphere (1969). A multi-collector mass spectrometer was used for argon analysis. Potassium analyses were performed by a lithium metaborate flux fusion-flame photometer technique, using lithium as an internal standard (Ingamells, 1970). The precision of the experiment, shown as the± value, is the estimated analytical reproducibility at one standard deviation. It represents uncertainty in the measurement of

the argon isotopes and K_2O based on replicate analyses in the U.S. Geological Survey Menlo Park laboratories.

Four adularia samples were dated by $^{40}Ar/^{39}Ar$ total fusion. The samples were irradiated in the U.S. Geological Survey TRIGA reactor in Denver, Colorado for a period of 24 hours at 1 megawatt. Irradiation flux was monitored by use of the SB-3 biotite standard, which has an age of 162.9 Ma. Correction used in the Menlo Park laboratory for Ca-and K-derived isotopes are described by Dalrymple and Lanphere (1971; 1974).

As expected from the known age of igneous activity in the region, which ranged between about 7 and 15 Ma, hydrothermal alteration took place during this interval, specifically between 8.9 and 13.4 Ma. The general age fits well with the regional magmatic history, and individual ages are consistent with the age of the local host rock or with the age of the volcanic center from which it seems related.

SAMPLE DESCRIPTIONS, ANALYTICAL DATA AND AGE

No. 1[1] K-Ar

Location: Oasis Mountain; 37° 2.6' N, 116° 44.9' W; NW/4 NW/4 Section 29, T 10S, R 47E. Thirsty Canyon SW 7.5' quadrangle, Nye Co., Nevada.

Collection and analyses: collected by M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: adularized welded tuff from the Ammonia Tanks Member of the Timber Mountain Tuff.

Comment:: sample collected from a north-trending fault in Oasis Mountain (Byers and others, 1976a). Argillization and silification extend into the overlying tuffs of Fleur-de-Lis Ranch and tuff of Buttonhook Wash to the east side (Jackson, 1988).

Sample mineralogy: quartz, 67%; adularia, 26%; muscovite, 5%; Fe oxides, 2%.

Analytical data: K_2O = 5.32%; $^{40}Ar_{rad}$ = 8.1468 x 10^{-11} mole/g; $^{40}Ar_{rad}/^{40}Ar$ = 43.4%.

Age: 10.6 ± 0.3 Ma (adularia)

[1]Numbers correspond to locations on Plate 1.

No. 2 $^{40}Ar/^{39}Ar$

Location: Northern part of the Bullfrog Hills, Yellow jacket mine; 37° 1.92' N; 116° 47.64 W; SE/4 unsurveyed Section 26, T 10S, R 46E; Springdale, 7.5' quadrangle, Nye Co., Nevada.

Collection and analyses: collected by S.I. Weiss, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif. in 1990.

Sample: quartz-calcite-pyrite vein and adularized welded tuff.

Comment:: vein along steeply dipping N-trending fault cutting units of the Crater Flat and Paintbrush Tuffs (S.I. Weiss and K.A. Conners, unpublished map, 1991).

Sample mineralogy: quartz, 75%; adularia, 20% illite, 5%, trace pyrite

Analytical data: $^{40}Ar/^{39}Ar$ = 3.157, $^{37}Ar/^{39}Ar$ = 2.3505 X 10^{-3}, $^{36}Ar/^{39}Ar$ = 6.7613 x 10^{-3}, $^{40}Ar_{rad}$ = 34.7%, $^{39}Ar_{Ca}$ = 1.582 x 10^{-4}%, $^{36}Ar_{Ca}$ = 9.178 x 10^{-3}%, J = 0.00574.

Age: 11.3 ± 0.3 Ma (adularia)

No. 3 K-Ar

Location: Northern part of the Bullfrog Hills, 37° 0.80'N, 116° 45.53' W, W/2 NE/4 Section 6, T 11 S, R 47 E; Springdale Nev., 7.5' quadrangle, Nye Co., Nevada.

Collection and analyses: collected by D. Finn, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif. in 1987.

Sample: adularized welded tuff.

Comment:: sample collected from a mine dump at the north end of a N 20° E trending, 75° W dipping fault in a unit of the Crater Flat Tuff (S.I. Weiss and K.A. Conners, unpublished map, 1991). Alteration along the fault is zoned from a quartz-adularia-sericite-bearing assemblage near the fault to kaolinite-bearing rock 200 ft from the fault (Jackson 1988).

Sample mineralogy: quartz, 75%; adularia, 21%; illite/muscovite, 4%.

Analytical data: K_2O = 11.19%, $^{40}Ar_{rad}$ = 1.7741 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 65.7%.

Age: 11.0 ± 0.3 Ma (adularia)

No. 4a K-Ar

Location: Northern part of the Bullfrog Hills, Mayflower Mine; 36° 59.73 N, 116° 47.3' W; SE/4 NE/4 Section 11, T 11 S, R 46 E. Bullfrog Hills 15' quadrangle.

Collection and analyses: collected by D. Finn, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif. in 1990.

Sample: adularized welded tuff. Same as 4b.

Comment: sample collected from a mine dump at the shaft of the Mayflower Mine. This shaft is collared in silicified and adularized tuff of the post-Timber Mountain rhyolite of Rainbow Mountain (Maldonado and Hausback, 1990).

Sample mineralogy: quartz, 81%; adularia, 18%; iron oxide, 1%.

Analytical data: K_2O = 13.71%, $^{40}Ar_{rad}$ = 1.9745 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 78.7%.

Age: 10.0 ± 0.3 Ma (adularia)

No. 4b $^{40}Ar/^{39}Ar$

Location: Northern part of the Bullfrog Hills, Mayflower Mine; 36° 59.73 N, 116° 47.3' W; SE/4 N/E4 Section 11, T 11 S, R 46 E. Bullfrog Hills 15' quadrangle.

Collection and analyses: collected by D. Finn, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif. in 1990.

Sample: adularized welded tuff. Same as 4a.

Comment:: sample collected from a mine dump at the shaft of the Mayflower Mine. This shaft is collared in silicified and adularized tuff of the post-Timber Mountain rhyolite of Rainbow Mountain (Maldonado and Hausback, 1990).

Sample mineralogy: quartz, 81%; adularia, 18%; iron oxide, 1%.

Analytical data: $^{40}Ar/^{39}Ar = 1.9522$, $^{37}Ar/^{39}Ar = 1.9447 \times 10^{-3}$, $^{36}Ar/^{39}Ar = 3.0617 \times 10^{-3}$, $^{40}Ar_{rad} = 50.3\%$, $^{39}Ar_{Ca} = 1.309 \times 10^{-4}\%$, $^{36}Ar_{Ca} = 1.677 \times 10^{-2}$, J = 0.0056.

Age: 9.9 ± 0.3 Ma (adularia)

No. 5 K-Ar

Location: Bailey's Hot Spring, about 5.5 mi. NE of Beatty on highway 95; 36° 58.6' N, 116° 43.1' W; SE/4 Section 16, T 11 S, R 47 E; Bare Mtn., 15' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by D.C. Noble, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1989.

Sample: alunite-altered ash-flow tuff of the Timber Mountain Tuff.

Comment: active hot spring within area of high-level alunitic alteration.

Sample mineralogy: quartz, 40%; cristobalite, 10%; alunite, 40%; kaolinite, 10%.

Analytical data: K_2O = 7.89%, $^{40}Ar_{rad}$ = 1.1572 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 60.2%.

Age: 10.2 ± 0.3 Ma (alunite)

No. 6a $^{40}Ar/^{39}Ar$

Location: Bullfrog Mtn., Original Bullfrog Mine, 36° 51.1' N, 116° 53.1' W; SW/4 SE/4 Section 12, T 12 S, R 45 E. Bullfrog Mountain 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by M.R. Jackson, University of Nevada-Reno, dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1990.

Sample: adularized Lithic Ridge Tuff containing veinlets of quartz and adularia.

Comment: sample is from wallrock of the quartz-calcite vein along the low-angle Original Bullfrog fault.

Sample mineralogy: quartz, 80%; adularia, 18%; illite-montmorillonite, 1%; FeOx 1%.

Analytical data: $^{40}Ar/^{39}Ar = 27.4667$, $^{37}Ar/^{39}Ar = 1.4295 \times 10^{-3}$, $^{36}Ar/^{39}Ar = 5.0852 \times 10^{-2}$, $^{40}Ar_{rad} = 45.3\%$, $^{39}Ar/_{Ca} = 1.0421 \times 10^{-4}\%$, Ar $^{36}Ar_{Ca} = 7.7302 \times 10^{-4}\%$, J = 0.0004.

Age: 9.2 ± 0.3 Ma (adularia)

No. 6b K-Ar

Location: Bullfrog Mtn., Original Bullfrog Mine, 36° 51.1' N, 116° 53.1' W; SW/4 SE/4 Section 12, T 12 S, R 45 E. Bullfrog Mountain 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by M.R. Jackson, University of Nevada-Reno, dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1990.

Sample: same as No. 6a

Comment: same as No. 6a

Sample mineralogy: quartz, 80%; adularia, 18%; illite-montmorillonite, 1%; FeOx 1%.

Analytical data: K_2O = 12.4%, $^{40}Ar_{rad}$ = 1.5497 x 10^{-10} mole/g

Age: 8.7 ± 0.3 Ma (adularia).

No. 7 $^{40}Ar/^{39}Ar$

Location: Open pit of the Lac Gold Bullfrog mine, east side of Ladd Mtn.; 36° 53.7' N, 116° 48.8' W; SE/4 NW/4 Section 15, T 12 S, R 46 E. Beatty 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss, University of Nevada-Reno, dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1990.

Sample: adularia-quartz-pyrite altered ash-flow tuff of the Rainier Mesa Member of the Timber Mountain Tuff.

Comment: sample is thoroughly recrystallized wallrock fragment within the main quartz-carbonate vein of the mine.

Sample mineralogy: quartz, 80%; adularia, 19%; illite-montmorillonite, 1%.

Analytical data: $^{40}Ar/^{39}Ar = 1.7893$, $^{37}Ar/^{39}Ar = 3.3729 \times 10^{-3}$, $^{36}Ar/^{39}Ar = 2.6974 \times 10^{-3}$, $^{40}Ar_{rad} = 51.8\%$, $^{39}Ar_{Ca} = 2.270 \times 10^{-4}\%$, $^{36}Ar_{Ca} = 3.301 \times 10^{-2}\%$, J = 0.0059.

Age: 9.8 ± 0.3 Ma (adularia)

No. 8a K-Ar

Location: Transvaal Hills; 37° 1' N, 116° 34.5' W; SW/4 SE/4 Section 35, T 10S, R 48E, Thirsty Canyon SE 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss, and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: vein containing alunite cutting the Rainier Mesa Member of the Timber Mountain Tuff.

Comment: coarsely crystalline (1 mm diameter), clear alunite fracture fillings in bleached vitrophyre of the 11.6 Ma Rainier Mesa Member of the Timber Mountain Tuff (Byers and others, 1976b).

Sample mineralogy: quartz, 60%; alunite, 35%; kaolinite, 5%.

Analytical data: K_2O = 9.05%, $^{40}Ar_{rad}$ = 1.2940 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 37%.

Age: 9.9 ± 0.4 Ma (alunite)

No. 8b K-Ar

Location: Transvaal Hills; 37° 1' N, 116° 35' W; NE/4 NW/4 Section 2, T 11S, R 48E, Thirsty Canyon SE 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by D.C. Noble, S.I. Weiss and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: adularized debris flow in the Rainier Mesa Member of the Timber Mountain Tuff.

Comment : quartz-adularia alteration along fault cutting a debris flow. The debris flow intertongues with and overlies the 11.6 Ma Rainier Mesa Member of the Timber Mountain Tuff.

Sample mineralogy: quartz, 75%; adularia, 18%; biotite, 4%; illite and muscovite, 3%.

Analytical data: K_2O = 6.27%, $^{40}Ar_{rad}$ = 1.1049 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 67.3%.

Age: 12.2 ± 0.3 Ma adularia

No. 9 K-Ar

Location: Tram Ridge, Silicon Mine, about 5 mi NE of Beatty; 36° 57.5' N, 116° 39.6' W; NW/4 NW/4 Section 30, T 11S, R 48E, Bare Mtn., 15' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by D.C. Noble, M.R. Jackson, and D. Finn, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: alunitized Rainier Mesa Member of the Timber Mountain Tuff.

Comment: the Silicon Mine is hosted by the 11.6 Ma Rainier Mesa Member of the Timber Mountain Tuff (Carr and others, 1986).

Sample mineralogy: quartz, 65%; alunite, 35%.

Analytical data: K_2O = 6.89%, $^{40}Ar_{rad}$ = 1.1560 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 52.3%.

Age: 11.6 ± 0.4 Ma (alunite)

No. 10 K-Ar

Location: Thompson Mine, about 5 mi NE of Beatty; 36° 56.9' N, 116° 38' W; NW/4 SE/4 Section 29, T 11S, R 48E, Bare Mtn., 15' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by D.C. Noble, M.R. Jackson, and D. Finn, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: from a vein containing fine grained alunite and halloysite.

Comment: the Thompson Mine is in the Yucca Mountain Member of the Paintbrush Tuff. The Yucca Mountain Member is beneath the 12.8 Ma Tiva Canyon Member of the Paintbrush Tuff which is altered west of the Thompson Mine.

Sample mineralogy: alunite, 85%; halloysite, 15%.

Analytical data: K_2O = 6.48%, $^{40}Ar_{rad}$ = 1.2080 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 19.6%.

Age: 12.9 ± 0.5 Ma (alunite)

No. 11a K-Ar

Location: about 1 mi. north of Meiklejohn Peak, Bare Mtn., in the Telluride Mine area; 36° 53.9' N, 116° 39.5' W; NW/4 NW/4 Section 18, T 12S, R 48E, Bare Mtn., 15' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: silicified and alunized gravel.

Comment: sample from the hanging wall of the northern, range-bounding fault at Bare Mountain as mapped by Cornwall and Kleinhampl (1961). The fault is mineralized at depth. Altered hanging wall gravel is intercalated with ash-flow and air-fall tuffs, correlated with a tuff beneath the 11.6 Ma Rainier Mesa Member of the Timber Mountain Tuff

Sample mineralogy: quartz, 60%; alunite, 30%; halloysite, 10%.

Analytical data: K_2O = 2.25%, $^{40}Ar_{rad}$ = 3.9508 x 10^{-11} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 26.6%.

Age: 12.2 ± 0.4 Ma (alunite)

No. 11b K-Ar

Location: about 1 mi. north of Meiklejohn Peak, Bare Mtn., in the Telluride Mine area; 36° 53.7' N, 116° 39.5' W; NW/4 NW/4 Section 18, T 12S, R 48E, Bare Mtn., 15' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: alunite clasts in a matrix supported breccia.

Comment: clasts of nearly pure alunite in a pipe-like breccia in the Silurian Roberts Mountain Formation (limestone).

Sample mineralogy: pure alunite.

Analytical data: K_2O = 10.65%, $^{40}Ar_{rad}$ = 1.7212 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 71.3%.

Age: 11.2 ± 0.3 Ma (alunite)

No. 12 K-Ar

Location: eastern edge of Bare Mtn., Goldspar Mine (Diamond Queen Mine); 36° 50.4' N, 116° 38.3' W; NE/4 NW/4 Section 5, T 13S, R 48E, Bare Mtn., 15' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1987.

Sample: adularized quartz latite dike.

Comment: dike cropping out in the north part of the Goldspar Mine. Here it cuts dolomite of the Cambrian Nopah Formation (Cornwall and Kleinhampl, 1961; Papke, 1979). Other quartz bearing dikes in Bare Mtn., have yielded K-Ar ages of about 13.9 Ma (Carr and others, 1986; Monsen and others, 1992). Veinlets of fluorspar invade the dike in the north pit and some gold is associated with fluorite mineralization here.

Sample mineralogy: quartz, 65%; adularia, 16%; kaolinite, 12%; biotite, 5%; and calcite, 2%.

Analytical data: K_2O = 7.68%, $^{40}Ar_{rad}$ = 1.4345 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 58.9%.

Age: 12.9 ± 0.4 Ma (adularia)

No. 13 K-Ar

Location: western part of the Calico Hills; 36° 52.8' N, 116° 21.5' W; SE/4 NE/4 Section 23, T 12S, R 50E, Topopah Spring 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1988.

Sample: alunitized rhyolite tuff.

Comment: alunite in altered tuff of the 12.9 Ma (Sawyer and others, 1990) rhyolite of Calico Hills (Orkild and O'Connor, 1970).

Sample mineralogy: alunite, 50%; cristobalite, 50%.

Analytical data: K_2O = 11.2%, $^{40}Ar_{rad}$ = 1.67856 x 10^{-10} mole/g $^{40}Ar_{rad}/^{40}Ar$ = 73.9%.

Age: 10.4 ± 0.3 Ma (alunite)

No. 14 K-Ar

Location: eastern part of the Calico Hills; 36° 54.2' N, 116° 14.3' W; SE/4 SW/4 Section 12, T 12S, R 51E, Mine Mountain 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1988.

Sample: vein containing fine grained alunite and quartz.

Comment: from a vein cutting the 11.6 Ma Rainier Mesa Member of the Timber Mountain Tuff.

Sample mineralogy: alunite, 95%; quartz, 5%.

Analytical data: K_2O = 11.02%, $^{40}Ar_{rad}$ = 1.6491 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 87.3%.

Age: 10.4 ± 0.3 Ma (alunite)

No. 15 K-Ar

Location: Mine Mountain; 36° 58.5' N, 116° 9.8' W; SW/4 SE/4 unsurveyed Section 15, T 11 S, R 52 E, quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1989.

Sample: alunized ash-flow tuff of the Ammonia Tanks Member of the Timber Mountain Tuff.

Comment:: high-level alunitic alteration is association with a NW-trending normal fault.

Sample mineralogy: alunite, 40%; cristobalite, 40%; kaolinite, 20%.

Analytical data: K_2O = 9.04%, $^{40}Ar_{rad}$ = 1.4483 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 55.6%.

Age: 11.1 ± 0.3 Ma (alunite)

No. 16a K-Ar

Location: Hornsilver Mine, NW of Wahmonie Flat; 36° 49.2' N, 116° 10.1' W, NE/4 SE/4 Section 18, T 13 S, R 52E, Skull Mountain 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1989.

Sample: quartz veined adularized lava of the Wahmonie Formation; wallrock adjacent to NE-trending quartz-calcite veins.

Comment: the Wahmonie Formation has yielded K-Ar ages of 13.2 Ma (Ekren and Sargent, 1965) and 12.8 Ma (Kistler, 1968).

Sample mineralogy: quartz, 70%; adularia, 26%; illite, 2%; oxidized pyrite, 1%; calcite, 1%.

Analytical data: K_2O = 14.0%, $^{40}Ar_{rad}$ = 2.6018 x 10^{-10} mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 66.5%.

Age: 12.6 ± 0.4 Ma (adularia)

No. 16b K-Ar

Location: Hornsilver Mine, NW of Wahmonie Flat; 36° 49.3' N, 116° 10' W; NE/4 SE/4 Section 18, T 13 S, R 52 E Skull Mountain 7.5' quadrangle, Nye Co., Nevada.

Collection and analysis: collected by S.I. Weiss and M.R. Jackson, University of Nevada-Reno; dated by E.H. McKee, U.S. Geological Survey, Menlo Park, Calif., in 1989.

Sample: adularized lava of the Wahmonie Formation cut by veins of quartz and adularia.

Comment: the Wahmonie Formation has yielded K-Ar ages of 13.2 Ma (Ekren and Sargent, 1965) and 12.8 Ma (Kistler, 1968).

Sample mineralogy: quartz, 47%; adularia, 46%; illite, 5%; pyrite, 0.5%; oxidized pyrite, 1.5%.

Analytical data: K_20 = 12.96%, $^{40}Ar = 2.3657 \times 10^{-10}$ mole/g, $^{40}Ar_{rad}/^{40}Ar$ = 59.5%.

Age: 12.6 ± 0.4 Ma (adularia)

REFERENCES

Byers, F.M., Jr., Carr, W.J., Orkild, P.P., Quinlivan, W.D., and Sargent, K.A., 1976a, Volcanic suites and related cauldrons of Timber Mountain-Oasis Valley caldera complex: U.S. Geological Survey Professional Paper 919, 70 p.

Byers, F.M., Jr., Carr, W.J., Christiansen, R.L., Lipman, P.W., Orkeld, P.P., and Quinlivan, W.D., 1976b, Geologic map of the Timber Mountain caldera area, Nye County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series, I-891, 1:48,000.

Carr, W.J., Byers, F.M., Jr., and Orkild, P.P., 1986, Stratigraphic and volcano-tectonic relation of Crater Flat Tuff and some older volcanic units, Nye County, Nevada: U.S. Geological Survey Open-File Report 84-114, 97 p.

Castor, S.B., and Weiss, S.I., 1992, Contrasting styles of epithermal precious metal mineralization in the Southwestern Nevada Volcanic Field, U.S.A.: Ore Geology Review; v. 7, p. 193-223.

Cornwall, H.R., and Kleinhampl, F.J., 1961, Geology of the Bare Mountain quadrangle, Nevada: U.S. Geological Survey Quadrangle Map GQ-157, 1:62,500.

Dalrymple, G.B., and Lanphere, M.A., 1969, Potassium-argon dating—principles, techniques, and applications to geochronology: San Francisco, W.H. Freeman Co., 258 p.

Dalrymple, G.B., and Lanphere, M.A., 1971, $^{40}Ar/^{39}Ar$ technique of K-Ar dating: A comparison with the conventional technique, Earth and Planetary Science Letters, v. 12, p. 300-308.

Dalrymple, G.B., and Lanphere, M.A., 1974, $^{40}Ar/^{39}Ar$ age spectra of some undisturbed terrestrial samples: Geochimica et Cosmochimica Acta, v. 38, p. 715-738.

Ekren, B.B., and Sargent, K.A., 1965, Geologic map of Skull Mountain quadrangle at the Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-387.

Ingamells, C.O., 1970, Lithium metaborate flux in silicate analysis: Analytica Chemica Acta, v. 52, no. 2, p. 323-334.

Jackson, M.R., Jr., 1988, The Timber Mountain magmato-thermal event: an intense widespread culmination of magmatic and hydrothermal activity at the Southwestern Nevada Volcanic Field: Reno, Nevada, University of Nevada-Reno, M.S. thesis 45 p.

Kistler, R.W., 1968, Potassium-argon ages of volcanic rocks in Nye and Esmeralda Counties, Nevada in Eckel, E.B., ed., Nevada Test Site: Geological Society of America Memior, v. 110, p. 251-263.

Maldonado, Florian, and Hausback, B.P., 1990, Geologic map of the northeast quarter of the Bullfrog 15-minute quadrangle, Nye County, Nevada: U.S. Geological Survey Map I-2049, 1:24,000.

Monsen, S.A., Carr, W.J., Reheis, M.C., and Orkild, P.P., 1992, Geologic map of Bare Mountain, Nye County, Nevada: U.S. Geological Survey, Map I-2201, 1:24,000.

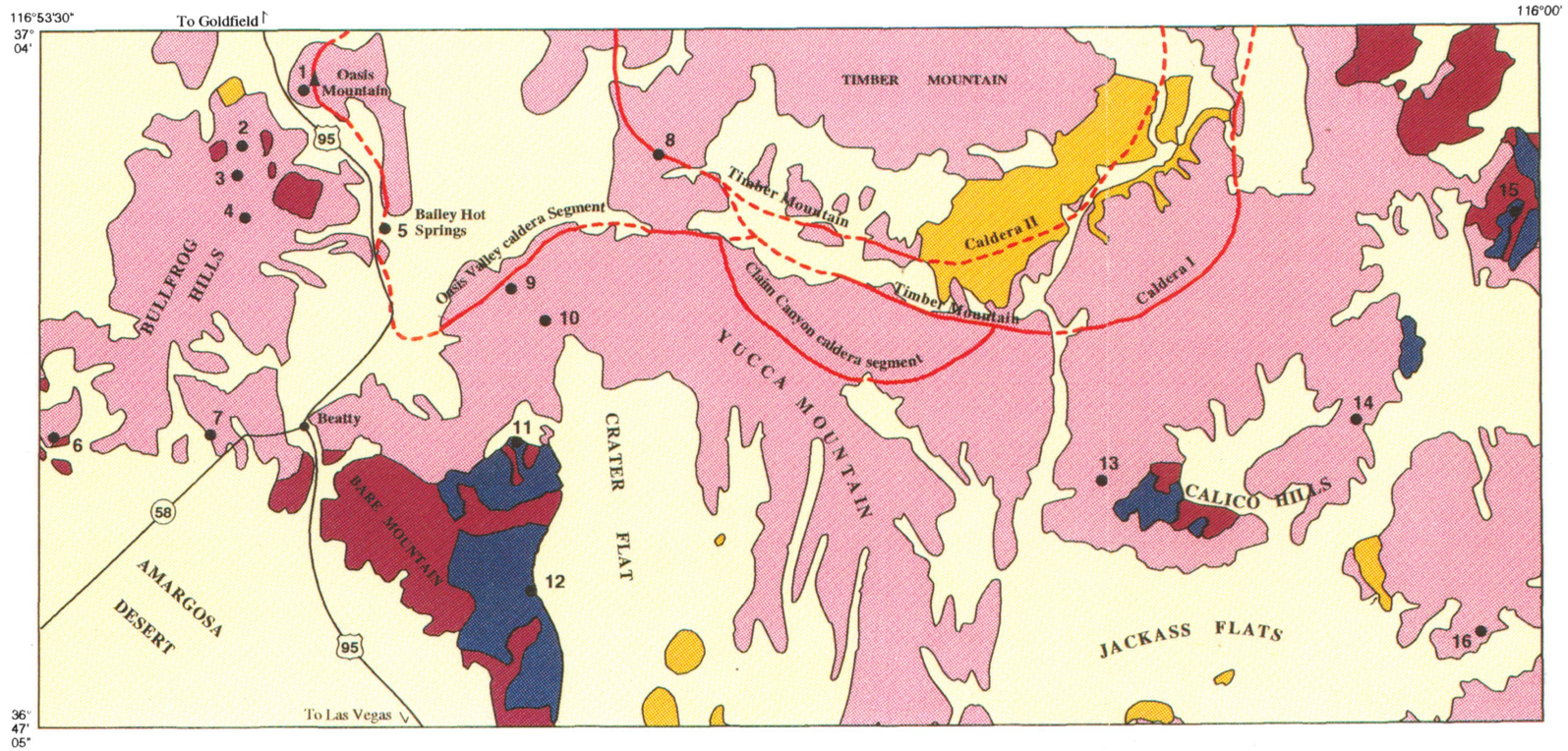
Noble, D.C., Weiss, S.I., and McKee, E.H., 1991, Magmatic and hydrothermal activity, caldera geology, and regional extension in the western part of the Southwestern Nevada Volcanic Field: [in] Geology and ore deposits of the Great Basin, Symposium Proceedings published by the Geological Society of Nevada, Reno, Nevada, v. II, p. 913-939.

Orkild, P.P., and O'Connor, J.T., 1970, Geologic map of the Topopah Spring quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-849.

Papke, K.G., 1979, Fluorspar in Nevada: Nevada Bureau of Mines and Geology Bulletin 93, 77 p.

Sawyer, D.A., Fleck, R.J., Lamphere, M.A., Warren, R.G., and Brexton, D.E., 1990, Episodic volcanism in the Southwest Nevada volcanic field — new $^{40}Ar/^{39}Ar$ geochronologic results; EOS, Transactions of the American Geophysical Union; v, 71, p. 1296.

Turrin, B.D., Champion, D.E., and Fleck, R.J., 1991, $^{40}Ar/^{39}Ar$ age of the Lathrop Wells volcanic center, Yucca Mountain, Nevada; Science, v. 253, p. 654-657.



EXPLANATION

- Alluvial deposits — Quaternary and Tertiary; Cenozoic
- Basaltic rocks — Quaternary and Tertiary; Cenozoic
- Silicic volcanic rocks — Miocene and Oligocene; Tertiary; Cenozoic
- Granitic rocks — Mesozoic; Cenozoic
- Carbonate rocks — Paleozoic and Precambrian; Mesozoic; Cenozoic
- Quartzose rocks — Paleozoic and Precambrian; Mesozoic; Cenozoic
- Approximate boundary of Miocene caldera
- ●4 K-Ar or $^{40}Ar/^{39}Ar$ sample locality (see sample descriptions in text)

N

AREA OF MAP

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

0 1 2 3 4 5 MILES

GEOLOGIC MAP OF THE YUCCA MOUNTAIN REGION, NEVADA WITH LOCALITIES OF RADIOMETRICALLY DATED ALTERATION MINERAL SAMPLES

By
Edwin H. McKee and Joel R. Bergquist
1993

McKee E.H., and Bergquist J.R., 1993, New radiometric ages related to alteration and mineralization in the vicinity of Yucca Mountain, Nye County, Nevada, U.S. Geological Survey Open-File Report 93-538.