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Isochron/West, Bulletin of Isotopic Geochronology, v. 39, pp. 3-8

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K-Ar AGES RELATING TO METAMORPHISM, PLUTONISM, AND GOLD-QUARTZ VEIN MINERALIZATION NEAR ALLEGHANY, SIERRA COUNTY, CALIFORNIA

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DISCUSSION

The Alleghany gold district (Sierra County, CA) is located on the west flank of the northern Sierra Nevada, approximately 60 km north of the Mother Lode gold belt as defined by Knopf (1929), but structural and mineralogical features of gold mineralization are similar in both areas. The Alleghany district, as outlined by Ferguson and Gannett (1932), straddles the Melones fault zone (Clark, 1960) and includes rocks of diverse origins (fig. 1). From east to west, roughly, they are: (1) metamorphosed sandstone, siltstone, and shale of early Paleozoic age (Shoo Fly Formation of Clark [1976]); (2) tuffaceous, siliceous, and argillaceous metasedimentary and metavolcanic(?) rocks of the Paleozoic Tightner and Kanaka Formations, locally with blueschist assemblages; (3) garnet-bearing quartzites, amphibolites, and hornblendites of uncertain origin; and (4) foliated metatuff and argillite (Cape Horn Slate of former usage). Separating these diverse rock groups are shear zones marked by planar to podiform serpentinite bodies, which are crudely concordant with the dominantly north-northwest-trending, nearly vertical foliations in the metamorphic rocks. Granitic intrusions are scarce within the district, but major plutons are present to the east and west (fig. 1).

Gold-quartz veins, which have produced well over 1,000,000 oz of gold throughout the district, occur in all of the above-mentioned rocks. The veins occupy minor faults, usually with some reverse offset. Most veins trend north to northwest, parallel or slightly oblique to the dominant north-northwest foliation. Veins dip both east and west, cutting foliation and lithologic boundaries.

Potassium-argon age determinations were made on mineral separates from one granodiorite pluton, two amphibolites, one micaceous quartzite, and two gold-quartz veins. These data were obtained to impose constraints on the age relations among metamorphism, plutonism, and gold mineralization within the district. More work is currently underway to refine and extend these results both at Alleghany and in other parts of the Sierra Nevada metamorphic belt.

ANALYTICAL PROCEDURES

K-Ar dating was done in the laboratories of the U.S. Geological Survey, Menlo Park, California, using standard isotope-dilution procedures as described by Dalrymple and Lanphere (1969). The age determinations were performed on pure mineral concentrates prepared by heavy liquid, magnetic, electrostatic, and hand-picking procedures. Potassium analyses were performed by lithium metaborate flux fusion-flame photometry techniques, with the lithium serving as an internal standard (Ingamells, 1970). Argon analyses were performed using a 60° sector, 15.2 cm-radius, Nier type mass spectrometer operated in the static mode for mass measurement. The precision of the data, shown as the ± value, is the estimated analytical uncertainty at one standard deviation. It represents uncertainty in the measurement of radiogenic ^{40}Ar and K in the sample and is based on experience with replicated analyses in the Menlo Park laboratories. The decay constants used for ^{40}K are those adopted by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jager, 1977): $\lambda_\epsilon + \lambda_\epsilon' = .581 \times 10^{-10} yr^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10} yr^{-1}$; $^{40}K/K_{Total} = 1.167 \times 10^{-4}$. Precision (±) is at σ.

AGES OF METAMORPHIC AND PLUTONIC ROCKS

The amphibolite-grade rocks just west of Alleghany are host for the veins of the Oriental Mine, one of the major producers of the district (Coveney, 1981). The hornblende amphibolite and quartzite samples were collected from a fault-bounded complex of recrystallized and folded hornblendites, hornblende-plagioclase amphibolites, schists, and quartzites of amphibolite grade. Almandine-rich garnet is abundant in some of the quartzites and quartz-bearing amphibolites of the complex. Ferguson and Gannett (1932) tentatively correlated the quartzose rocks with the Carboniferous Relief Quartzite and interpreted the hornblende-rich rocks as various facies of recrystallized gabbro which intruded the Relief.

Recent mapping (Coveney, 1981; Bohlke, unpub. data, 1981) suggests that the amphibolite-quartzite complex was recrystallized and deformed as a unit and subsequently faulted into place near lower grade rocks. Two K-Ar hornblende ages from amphibolites in the complex (322 ± 27, 345 ± 9 m.y.) therefore indicate that the volcanic-sedimentary-plutonic(?) protolith was Early Mississippian or older. One biotite sample from a micaceous quartzite unit (273 ± 5 m.y.) is partially altered and probably lost argon during lower grade late Paleozoic or Mesozoic metamorphism. The three K-Ar ages from the amphibolite complex should be regarded as minimum ages for amphibolite-grade metamorphism.

The amphibolites of the Alleghany district lie near the middle of a discontinuous belt of Paleozoic ophiolitic rocks that extends from the Klamath Mountains to the southern Sierra Nevada (Irwin, 1977). Amphibolite-grade metamorphism, possibly related to emplacement of the rocks along the continental margin, ranges from Devonian in the central metamorphic belt in the Klamaths to Early Jurassic in the Kings-Kaweah area in the southern Sierra Nevada (Lanphere and others, 1968; Irwin, 1977; Saleeby and Sharp, 1980). Just north of Alleghany, mafic schists, amphibolites, and metagabbros adjacent to the Feather River and other ultramafic bodies, also along the Melones fault zone, yield K-Ar and ^{39}Ar-^{40}Ar ages of 236–285 m.y. (Weisenberg and Avé Lallemant, 1977; Standlee, 1978; Hietanen, 1981). The dates reported in the Sample Descriptions are the oldest yet obtained for amphibolites in the western Sierra Nevada foothills belt and approach the ages obtained for similar rocks in the central metamorphic belt of the Klamaths (Lanphere and Irwin, 1965).

Evidence for later (though undated) retrograde events in the amphibolite complex includes pervasive saussuritization of plagioclase; stilpnomelane overgrowths on hornblende; chloritization of biotite, garnet, and hornblende; and rotation of foliated blocks along joints. Blueschist assemblage rocks from the Tightner Formation near Alleghany (Ferguson and Gannett, 1932; fig. 1) yield whole-rock and white mica K-Ar ages of 157–190 m.y.

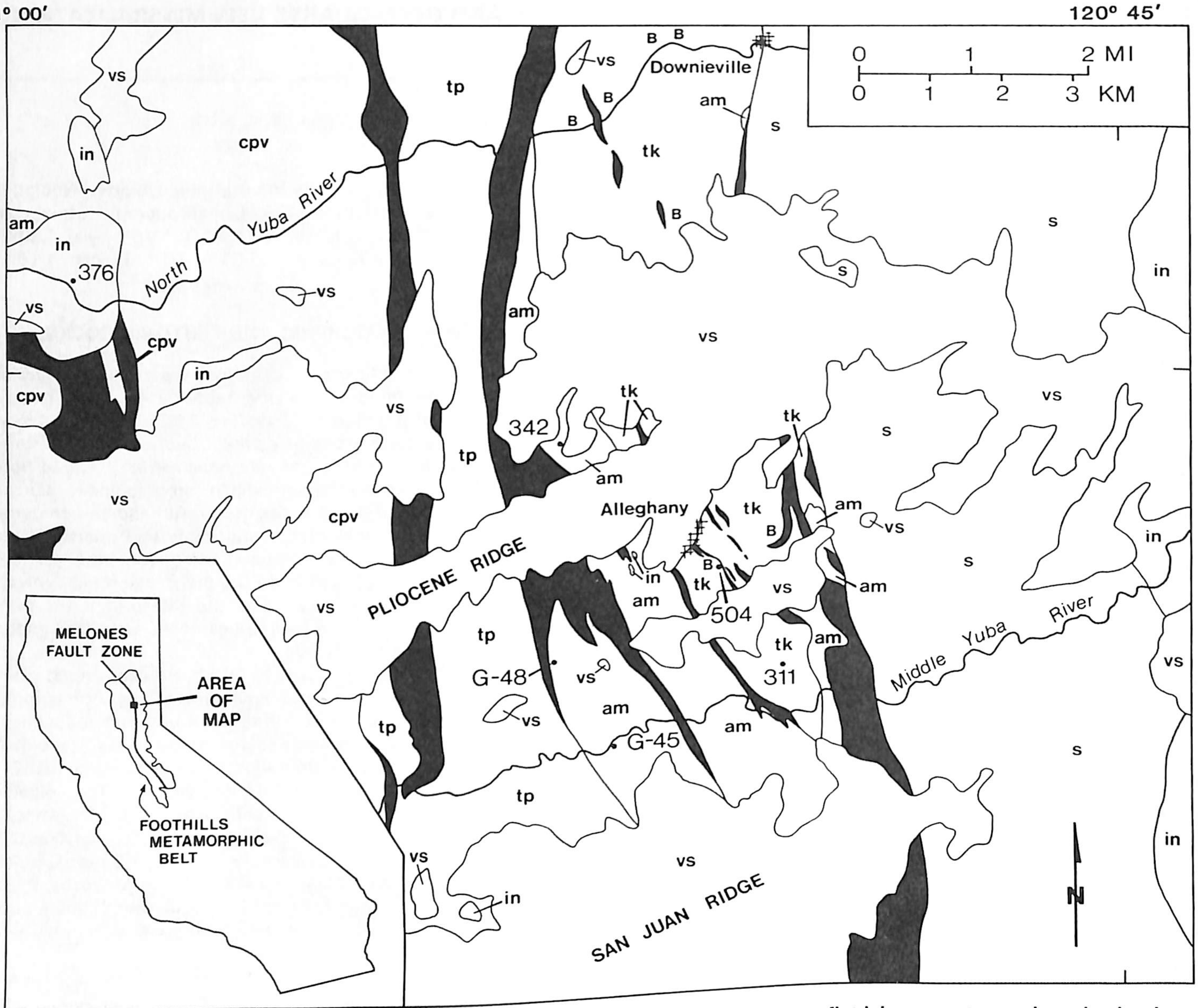

FIGURE 1. Generalized geologic sketch map showing K-Ar sample localities near Alleghany. vs, flat-lying unmetamorphosed volcanic and sedimentary rocks of Tertiary age; in, felsic to intermediate intrusive rocks; cpv, metachert and phyllite with intermediate metavolcanic rocks (Delhi Formation of Ferguson and Gannet [1932]); tp, foliated metatuff and argillite (Cape Horn Slate of Ferguson and Gennett [1932]), equivalent in part to Calaveras Formation of Hietanen (1981); tk, Tightner and Kanaka Formations (Paleozoic?); B, known outcrops of blueschist assemblage rocks; s, metamorphosed sandstone, siltstone, and shale (early Paleozoic Shoo Fly Formation of Clark [1976]); am, amphibolite complex (including lithologically similar outliers); solid areas, ultramafic and associated rocks (mainly serpentinite); also tectonic inclusions of adjacent metamorphic rocks, including metagabbro and metadiorite. Geology modified from Ferguson and Gannett (1932), Hietanen (1981), Yeend (1974), and Burnett and Jennings (1962).

(Schweickert and others, 1980). These ages were thought to reflect partial Late Jurassic Nevadan(?) argon loss from rocks that were metamorphosed during pre-Late Jurassic subduction. Thus, the older, higher grade rocks (amphibolites) could have been either incorporated within a Paleozoic to early Mesozoic subduction complex or otherwise tectonically juxtaposed against lower grade greenschists and blueschists within the Melones fault zone.

Undeformed plutonic rocks from the northwestern Sierra Nevada have yielded hornblende K-Ar ages of 131–146 m.y. and biotite K-Ar ages of 126–143 m.y. (Evernden and Kistler, 1970). These plutons cut the regional north-northwest foliation of the metamorphic rocks, which apparently formed during the Late Jurassic Nevadan orogeny (Schweickert, 1981) or earlier (Saleeby, 1981). Our date for the previously undated Indian Valley pluton (143 ± 5 m.y.) is within this range. Another undated, undeformed (post-Nevadan) intrusive outcrops just south of Alleghany on San Juan Ridge in the Cape Horn Slate (fig. 1). The undated Oriental granite (Coveney, 1981) is confined to the amphibolite complex and has apparently undergone at least one of the pre-Cretaceous low-grade metamorphic events along with its enclosing rocks; it is therefore probably older than most dated plutonic rocks in the area.

AGE OF GOLD-QUARTZ MINERALIZATION

The gold-quartz veins of Alleghany and the Mother Lode occupy minor reverse faults that cut and offset wallrock lithologic units and Nevadan(?) and older metamorphic foliations. These faults were apparently active during and after quartz deposition (Knopf, 1929; Ferguson and Gannett, 1932). Mariposite (green Cr-bearing phengitic mica) occurs within and adjacent to gold-quartz veins wherever they intersect serpentinite wallrocks. K-Ar ages ranging from 108 to 127 m.y. have been obtained from mariposite concentrates from the southern Mother Lode (Evans and Bowen, 1977; Dodge and others, 1983). A Rb/Sr isochron on associated carbonate and mariposite yielded an age of approximately 115 m.y., roughly concordant with the K-Ar age from the same locality (Dodge and others, 1983).

The two mariposite dates reported here from Alleghany (112 ± 3, 113 ± 3 m.y.) are indistinguishable from the concordant age from the southern Mother Lode. These ages suggest that hydrothermal gold-quartz vein mineralization and minor reverse faulting occurred concurrently at various points along the full length of the Melones fault zone during Cretaceous time. Furthermore, it appears that gold mineralization occurred considerably later than the last regional penetrative deformation of the metamorphic host rocks and also long after crystallization of the intrusive rocks surrounding the district.

IMPLICATIONS FOR PROCESSES OF MINERALIZATION

K-Ar and Rb-Sr ages indicate that widespread blueschist-type metamorphism of Franciscan rocks under the Coast Range thrust in northern California occurred about 110–130 m.y. ago (Lanphere and others, 1978). U-Pb zircon ages of plutonic rocks south of the Mother Lode point to a major surge of magmatism in part of the Sierran arc around 110–130 m.y. ago (Saleeby and Sharp, 1980; Stern and others, 1982). Though neither of these events can be directly correlated genetically with mineralization, it appears that the gold-quartz veins along the Melones fault zone are temporally related to a significant Cretaceous tectonic-magmatic event that occurred later than the last major penetrative deformation of their metamorphic host rocks (Late Jurassic Nevadan orogeny) (Albers, 1981). Gold-quartz veins were formed in rocks of widely contrasting previous metamorphic histories at the same time. The mineralized veins therefore cannot be genetically related to prograde metamorphism of their immediate host rocks, are not clearly related to any pervasive heating caused by regional retrograde metamorphism, and are apparently not related to local plutonism that has been dated thus far. Alternative genetic explanations would seem to require either upward escape of volatiles driven off by deep-seated prograde metamorphism, partial melting, or magma consolidation; or large-scale convection of fluids in response to a deep or somewhat distant heat source.

RELATION TO TERTIARY PLACERS

Undeformed fluvial deposits and volcanic rocks occupy east-west trending ridge crests of the Alleghany district (fig. 1). Gold-bearing gravels and conglomerates of the ancestral Yuba River and its tributaries were laid down in the vicinity of Alleghany during Eocene, and perhaps Paleocene, time (Yeend, 1974). Andesitic to rhyolitic volcanic rocks overlying the gold-producing gravels have K-Ar ages as old as 32–38 m.y. (Dalrymple, 1964; Yeend, 1974). Thus, the major fossil placer deposits of the foothills appear to have been laid down roughly 50–70 m.y. after the formation of the gold-quartz veins from which the placers were presumably derived (Lindgren, 1911).

RESULTS

The K-Ar age of the Indian Valley pluton (North Fork Yuba River) is within the range given by Evernden and Kistler (1970) for undeformed plutons in the northwest Sierra Nevada. Amphibolite-grade mafic and siliceous rocks from the west side of the Alleghany district were apparently metamorphosed prior to Pennsylvanian time and may represent evidence of the mid-Paleozoic Antler orogeny in the western part of the Sierra Nevada metamorphic belt.

On the basis of radiometric age determinations and generalized models of Cordilleran evolution, we offer the following tentative conclusions regarding gold mineralization:

Gold-quartz vein formation at Alleghany postdated the Nevadan compressional event by approximately 35 m.y., and postdated cooling of nearby dated granodiorite plutons by at least 15 m.y.

The time elapsed between gold-quartz vein mineralization and subsequent coarse placer gold accumulation in the Tertiary Yuba River may have been on the order of 50–70 m.y.

The vein mineralization event is not well recorded in the K-Ar systematics of prograde minerals in metamorphic host rocks in the Alleghany district; thus, the gold-quartz veins do not appear to be coeval with prograde metamorphism or major regional heating of the host rock environment.

Mineralization at Alleghany is nearly contemporaneous with that in the southern Mother Lode. Gold-quartz veins were formed in close proximity to the Melones fault zone over a distance of more than 200 km within a fairly restricted interval of time (possibly peaking around 110–120 m.y. ago).

The age of gold-quartz vein formation corresponds approximately to ages of blueschist metamorphism of Franciscan rocks (now > 100–130 km west of the Mother Lode) and onset of voluminous Cretaceous (post-Nevadan) plutonism in the Sierra Nevada (mainly south and east of the Mother Lode).

Minor Early Cretaceous compression (mainly east-west) is indicated by reverse faulting (contemporaneous and postmineralization) of veins throughout the Mother Lode, including the Alleghany district.

ACKNOWLEDGMENTS

We wish to thank Don Dickey (Dickey Exploration Company) for helping to support our work in Alleghany, and Dan Mason and Tim Sapp for allowing access to samples. Jerry Infeld and Paul Ostendorf assisted with the mineral separations. XRF analyses were performed by J. S. Wahlberg, A. Bartell, J. Taggart, and J. Baker of the U.S. Geological Survey analytical labs.

SAMPLE DESCRIPTIONS

1. *G-45* K-Ar
Hornblende diopside amphibolite (39°29.95′N, 120°51.68′W; from S bank of Middle Yuba River E of Foote's crossing; Alleghany 7½′ quad, CA). Foliated to gneissic textured, massive; consists mainly of brownish hornblende, sausseritized plagioclase, pale clinopyroxene. Minor apatite, pyrite, and chalcopyrite. From the middle of a large (> 100 m across) outcrop of streaky gneissic amphibolite. XRF analysis of whole rock: SiO_2 = 48.1, TiO_2 = 0.94, Al_2O_3 = 14.8, Fe_2O_3* = 11.1, MnO = 0.18, MgO = 8.40, CaO = 11.8, Na_2O = 2.32, K_2O = 0.69, P_2O_5 = 0.07,

L.O.I. = 1.49, Σ = 99.89%. *Analytical data:* K_2O = 0.268%, $^{40}Ar^*$ = 1.3596 x 10^{-10} mole/gm, $^{40}Ar^*/^{40}Ar$ = 15.6%. *Comment:* Impurities are a few percent pale-green clinopyroxene.

(hornblende) 322 ± 27 m.y.

2. *G-48* K-Ar
Feldspathic biotite quartzite (39°26.85'N, 120°52.47'W; from S bank of Kanaka Creek W of Kenton Mine; Alleghany 7½' quad, CA). Hard, massive, moderately foliated quartzite with sausseritized plagioclase, reddish biotite, and lesser muscovite, apatite, pyrrhotite, and graphite. Interbedded (cm–m scale) with micaceous metasediments; intruded by and (or) interbedded with amphibolite. XRF analysis of whole rock: SiO_2 = 73.6, TiO_2 = 0.51, Al_2O_3 = 11.4, $Fe_2O_3^*$ = 3.92, MnO = 0.06, MgO = 2.10, CaO = 1.73, Na_2O = 2.97, K_2O = 1.87, P_2O_5 = 0.08, L.O.I. = 1.21, Σ = 99.45%. *Analytical data:* K_2O = 7.38%, $^{40}Ar^*$ = 3.1361 x 10^{-9} mole/gm, $^{40}Ar^*/^{40}Ar$ = 91.6%. *Comments:* Dated material is pink to red mica, grading to black; may be partially altered. Impurities are < 1% quartz.

(biotite) 273 ± 5 m.y.

3. *311* K-Ar
Gold-quartz-carbonate vein with "mariposite" (39°26.70'N, 120°49.40'W; from no. 1 ore zone, lower level of Irelan Mine; coordinates are for adit portal; Alleghany 7½' quad, CA). Segment of sheeted vein with milky to translucent quartz, arsenopyrite, and native gold; bordered by white dolomite crystals on walls and inclusions of carbonatized wallrock. Mariposite occurs as massive green films (up to a few hundred microns thick) included in the quartz or along the vein walls. *Analytical data:* K_2O = 10.1%, $^{40}Ar^*$ = 1.6944 x 10^{-9} mole/gm, $^{40}Ar^*/^{40}Ar$ = 89.7. *Comments:* Dated material is nearly pure, massive green mica. Typical microprobe analysis of mica: SiO_2 = 52.0, Al_2O_3 = 26.9, FeO* = .81, MgO = 3.8, CaO = <.1, Na_2O = <.1, K_2O = 10.6, Cr_2O_3 = .63.

(mica) 113 ± 3 m.y.

4. *342* K-Ar
Hornblende biotite amphibolite (39°29.20'N, 120°52.35'W; from roadcut on Forest–Mountain House Rd just S of Sandusky Creek crossing; Alleghany 7½' quad, CA). Folitated, folded, massive with dark and light streaks; consists mainly of brownish hornblende and sassuritized plagioclase, respectively. Lesser altered reddish biotite, clinopyroxene, apatite, and Fe-Ti oxides. May be interbedded with quartzose metasediments. XRF analysis of whole rock: SiO_2 = 46.5, TiO_2 = 2.91, Al_2O_3 = 14.0, $Fe_2O_3^*$ = 13.6, MnO = 0.18, MgO = 7.3, CaO = 10.2, Na_2O = 2.97, K_2O = 0.82, P_2O_5 = 0.37, L.O.I. = 1.09, Σ = 99.94%. *Analytical data:* K_2O = 0.869%, $^{40}Ar^*$ = 4.7514 x 10^{-10} mole/gm, $^{40}Ar^*/^{40}Ar$ = 64.7%. *Comment:* Impurities are < 5%, mainly partially altered plagioclase.

(hornblende) 345 ± 9 m.y.

5. *376* K-Ar
Biotite quartz diorite (39°31.00'N, 120°59.10'W; from roadcut on Highway 49 at Indian Valley, 0.7 mi E of Fiddle Creek crossing; Goodyears Bar 7½' quad, CA). Massive, gray, unfoliated intrusive rock consists of zoned plagioclase (with partially altered cores), quartz, biotite (partially altered to chlorite ± epidote), and hornblende; lesser potassium feldspar, apatite, sphene, magnetite partially oxidized to hematite(?), and zircon(?). XRF analysis of whole rock: SiO_2 = 64.8, TiO_2 = 0.35, Al_2O_3 = 17.3, $Fe_2O_3^*$ = 3.84, MnO = 0.08, MgO = 1.85, CaO = 5.17, Na_2O = 4.19, K_2O = 1.45, P_2O_5 = 0.15, L.O.I. = 0.46, Σ = 99.64. *Analytical data:* K_2O = 0.491%, $^{40}Ar^*$ = 1.0488 x 10^{-10} mole/gm, $^{40}Ar^*/^{40}Ar$ = 38.1%. *Comment:* Impurities < 5%, mainly epidote.

(hornblende) 143 ± 5 m.y.

6. *504* K-Ar
Quartz vein with "mariposite" inclusions (39°27.78'N, 120°50.28'W; from an E-dipping vein, creek level, S of Kanaka Creek in the Rainbow Extension Mine; coordinates are for adit portal; Alleghany 7½' quad, CA). Massive, white quartz vein; large inclusions (to almost 1 cm across) of pale-green mica and minute disseminated sulfide grains. *Analytical data:* K_2O = 9.21%, $^{40}Ar^*$ = 1.5265 x 10^{-9} mole/gm, $^{40}Ar^*/^{40}Ar$ = 97.7%. *Comments:* Dated material is pale-green mica with < 1% disseminated sulfide. Typical microprobe analysis of mica: SiO_2 = 48.0, Al_2O_3 = 34.6, FeO* = .5, MgO = .94, CaO = <.1, Na_2O = .2, K_2O = 10.0, Cr_2O_3 = <.1.

(mica) 112 ± 3 m.y.

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