K-Ar ages for igneous rocks and vein minerals from the Christmas Mine area, Arizona

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K-Ar AGES FOR IGNEOUS ROCKS AND VEIN MINERALS FROM THE CHRISTMAS MINE AREA, ARIZONA

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We present K-Ar age determinations for five igneous hornblende samples, one hydrothermal biotite sample, one hydrothermal sericite sample, and one whole-rock basalt sample from the Christmas Mine area, Gila County, Arizona (Table 1). Table 1 also shows a K-Ar date for the Christmas stock taken from the literature (Creasey and Kistler, 1962). This study is part of a decade-long investigation of the geology and ore deposits at Ray, Arizona and the surrounding region conducted by the U.S. Geological Survey (for example, see Cornwall and others, 1971; Banks and others, 1972; Banks and Stuckless, 1973; Banks and Krieger, 1977; Banks, 1981; Cornwall, 1981; Koski and Cook, 1981). The Christmas deposit is located at the southeast end of the Dripping Spring Mountains, 27 km southeast of Ray.

The porphyry copper mineralization at Christmas is centered on a composite granodioritic stock and associated dikes that intrude a sequence of Paleozoic carbonate rocks and mafic volcanic breccia and flows of the Cretaceous Williamson Canyon Volcanics (Eastlick, 1968; Perry, 1969; Koski, 1978; and Koski and Cook, 1981). The sedimentary and volcanic strata are also intruded by unmineralized dikes, sills, and stocks of hornblende andesite porphyry and hornblende rhyodacite porphyry (Fig. 1). These and other calc-alkaline intrusions in the Dripping Spring Mountains were emplaced, in part, along a series of east- to northeast-trending fractures, extensional features developed during a Laramide tectonic event involving east- to northeast-directed lateral compression (Banks and Krieger, 1977; Rehrig and Heidrick, 1976). The K-Ar ages presented here were obtained in order to determine the age, duration, and sequence of the Laramide magmatic episode and the temporal relations of spatially associated hydrothermal veins at Christmas.

Supporting analytical data and sample locations are given in the SAMPLE DESCRIPTIONS section below. Sample locations are shown in Figure 1. Mineral separates and the whole-rock sample were prepared by R. A. Koski. Potassium analyses by lithium metaborate fusion and flame photometry were conducted by S. Neil and J. Christie. E. H. McKee performed the argon analyses using standard isotope-dilution and mass-spectrometry techniques (Dalrymple and Lanphere, 1969). The constants used for the age calculations are $\lambda_\epsilon = 0.581 \times 10^{-10}yr^{-1}$, $\lambda\beta = 4.962 \times 10^{-10}yr^{-1}$, and $K^{40}/K_{total} = 1.167 \times 10^{-4}$ mole/mole.

GEOLOGICAL DISCUSSION

Eight of the nine K-Ar ages given in Table 1 are presented graphically in Figure 2, including a biotite K-Ar age from the biotite granodiorite phase of the Christmas stock obtained from Creasey and Kistler (1962). In addition to data from Christmas, Figure 2 shows the period of intrusive activity in the nearby Ray district taken from K-Ar and fission-track studies by Banks and others (1972) and Banks and Stuckless (1973), respectively. The combined data show that Laramide magmatism in the Dripping Spring Mountains evolved over an extended period from within the Late Cretaceous (∿85–75 m.y. ago) into the early Tertiary (∿62 m.y. ago). Ore deposits were formed at Christmas (∿63–61 m.y. ago) and at Ray (∿61–60 m.y. ago) as magmatic activity waned in early Paleocene time.

The single K-Ar age for hornblende from volcanic breccia of the Williamson Canyon Volcanics (sample 74AB75) conflicts with ages for hornblende andesite porphyry dikes cutting the volcanic pile. The volcanic hornblende age may be too young (possibly reset by loss of radiogenic argon during a thermal event or alteration) and/or the porphyry dike hornblende ages may be too old because of excess argon, leaching of potassium, or contamination,

Although evidence is sufficient for an unequivocal explanation, the first option is preferred. Hornblende (sample 74AB75) separated from lapilli tuff appears minimally altered, but rounded and embayed crystal margins indicate significant resorption effects. The sample also contains uralitized clinopyroxene, which probably formed during widespread propylitic alteration of the volcanic pile. Furthermore, the sample was collected less than 150 m from the west tip of the Christmas stock, a heat source, and rock fragments and matrix (although not the hornblende) are locally peppered with fine-grained secondary biotite owing to the passage of a hydrothermal fluid phase. Despite evidence indicating that hornblende retains more argon than other K-silicates during thermal events (Hart, 1964; Dalrymple and Lanphere, 1969), the cumulative effects of partial recrystallization and hydrothermal alteration may have released enough argon to reset the potassium-argon "clock".

S. B. Keith (personal communication, 1976) reports that K-Ar age determinations on hornblendes from three andesite porphyry dikes from the Saddle Mountain mining district, immediately southeast of the Christmas area, yielded an average age of 81 m.y. Thus, from Keith's results and ours, five hornblende ages from andesite porphyry intruding the Williamson Canyon Volcanics exceed 76 m.y. and four exceed 80 m.y.

If the age of hornblende from volcanic breccia is anomalous, the eruption of the Williamson Canyon Volcanics and emplacement of some hornblende andesite dikes occurred about, or prior to, 80 m.y. before present. This estimate is temporally consistent with the Late Cretaceous (approximately 80 m.y. ago) tectonic transition from "thin-skinned" Sevier orogeny to classic Laramide orogeny in the North American Cordillera (Coney, 1972, 1976).

The K-Ar ages (69.8 m.y., 72.3 m.y.) of hornblende samples from barren hornblende rhyodacite porphyry intrusive rocks near Christmas are similar to ages for preore Upper Cretaceous Tortilla Quartz Diorite and Rattler Granodiorite (70 ± 1 m.y.) belonging to Intrusive Period I in the Ray district (Banks and Stuckless, 1973). Consanguinity of the Granite Basin laccolith 8 km northeast of Christmas (Willden, 1964) and the petrographically similar McDonald stock (Fig. 1) is also indicated. The presence of east-trending hornblende rhyodacite porphyry dikes north of the Christmas Mine and similar dikes with trends N65°–70°E in the Hayden quadrangle (Banks and Krieger, 1977) suggests that extension fractures generated by northeast-directed compression (Banks and Krieger, 1977; Rehrig and Heidrick, 1976) may have developed in the

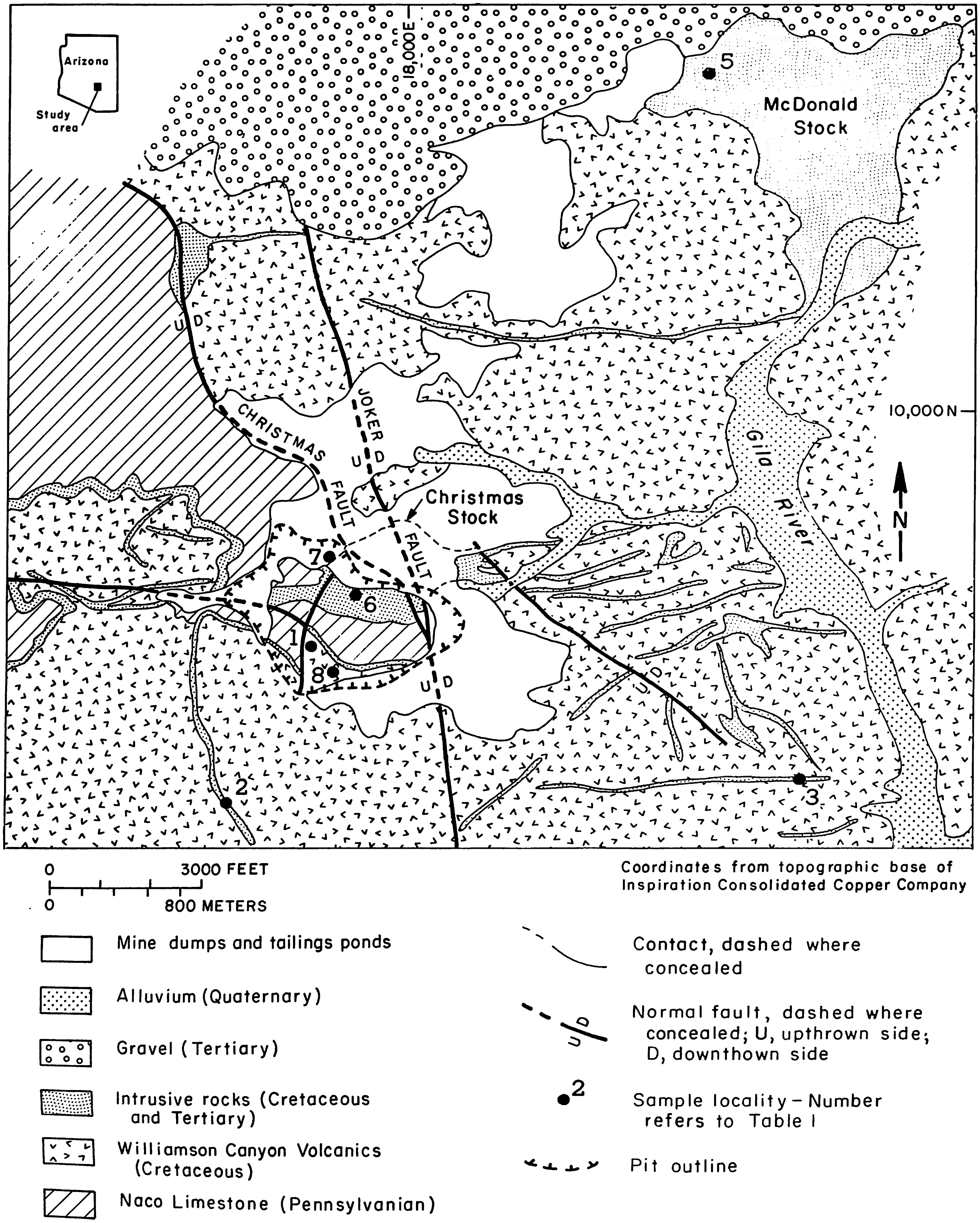

FIGURE 1. **General geology of the Christmas Mine area, Arizona, generalized from Koski (1978).**

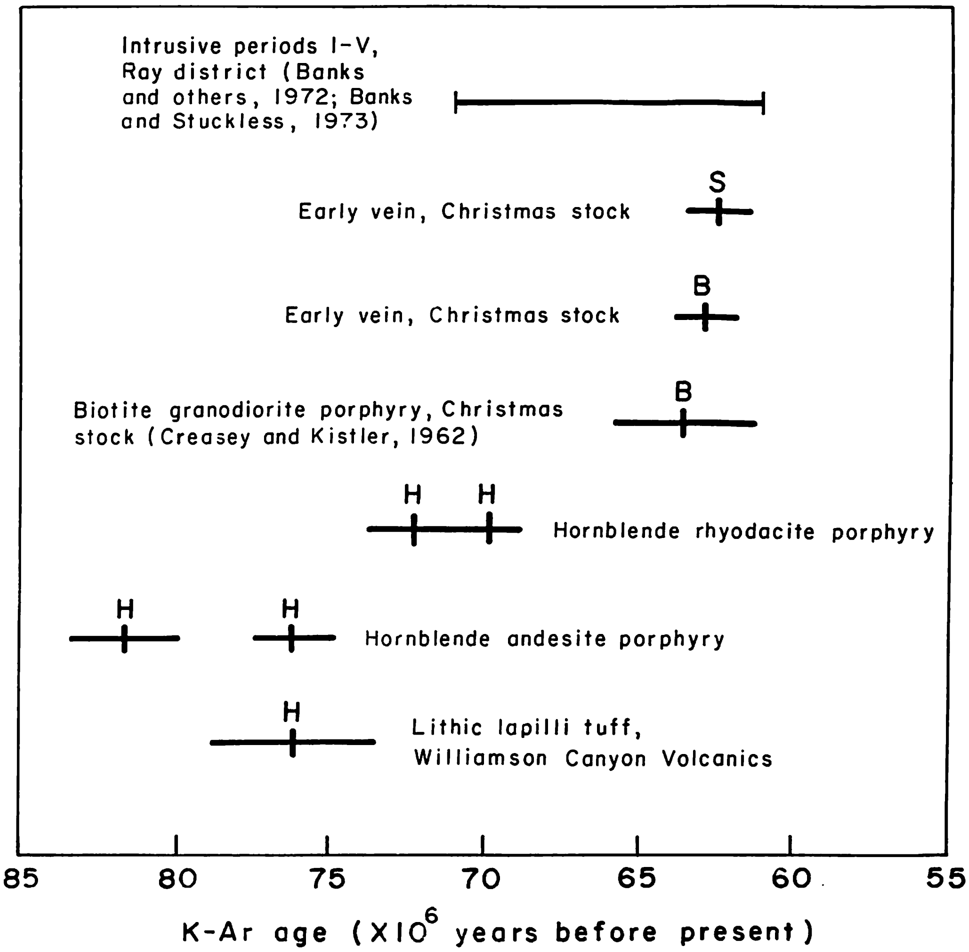

FIGURE 2. K-Ar ages of hornblende, biotite, and sericite from igneous rocks and hydrothermal veins at Christmas Mine area. Also shown is the period of intrusive activity for the Ray district. Horizontal bars represent the analytical uncertainty in each determination. S = sericite; B = biotite; H = hornblende.

Dripping Spring Mountains by approximately 70 m.y. ago.

K-Ar ages for hydrothermal biotite (62.8 m.y.) and sericite (62.5 m.y.) in veins and the biotite age (64 m.y.) for their biotite granodiorite porphyry host in the Christmas stock (from Creasey and Kistler, 1962) support the viewpoint derived from field and petrographic observations (Koski, 1978) that emplacement of biotite granodiorite porphyry and early hydrothermal alteration-mineralization are essentially synchronous events. However, the minerals dated, a chloritic biotite and coarse sericite, are less common constituents of early K-silicate veins. No time-limiting brackets can yet be placed on the total episode of intrusion and ore deposition at Christmas, nor on specific events during the evolution of the deposit. These Late Cretaceous and/or early Paleocene ages at Christmas are roughly concordant with the age of Granite Mountain Porphyry (Intrusive Period III) and the apparent age of the Ray deposit (61–60 m.y.) reported by Banks and others (1972) and Banks and Stuckless (1973).

In the Dripping Spring Mountains, igneous rocks with Laramide ages younger than approximately 60 m.y. are not known. One of several narrow basalt dikes emplaced along northeast- to northwest-trending faults that offset the mineralized Christmas stock yielded a whole-rock K-Ar age (Table 1) of 25.5 m.y., which places it near the Oligocene–Miocene boundary. The trend of these post-mineralization structures is diagnostic of basin and range tectonism, and the 25.5-m.y. date is characteristic of the middle Tertiary magmatic pulse in Arizona (Damon and Mauger, 1966).

SUMMARY

K-Ar ages for igneous rocks from the Christmas Mine area, Arizona, indicate that Late Cretaceous and early Tertiary Laramide magmatism in the Dripping Spring Mountains began with the eruption of the Williamson Canyon Volcanics and emplacement of hornblende andesite porphyry dikes about, or prior to, 80 m.y. before present. Hornblende rhyodacite porphyry intrusions, including the barren McDonald stock, were emplaced approximately 72–70 m.y. ago. Concordant K-Ar ages for the biotite granodiorite porphyry phase of the Christmas stock and biotite and sericite from crosscutting veins suggest that emplacement of the porphyry and early hydrothermal alteration-mineralization were essentially concurrent events in early Paleocene time (∿62 m.y. ago). Post-mineralization basalt dikes cutting the Christmas stock were emplaced during late Oligocene or early Miocene time, part of the middle Tertiary magmatic pulse.

SAMPLE DESCRIPTIONS

1. *74AB75* K-Ar
   Lithic lapilli tuff from Williamson Canyon Volcanics

Table 1. K-Ar age dates from the Christmas Mine area.

Sample	Material dated/Rock type	Apparent age (m.y.)	Sample location in Figure 1
74AB75	hornblende/lapilli tuff, Williamson Canyon Volcanics	76.2 ± 2.3	1
54AB75	hornblende/hornblende andesite porphyry	81.7 ± 2.4	2
72AB74	hornblende/hornblende andesite porphyry	76.2 ± 1.9	3
GB-1	hornblende/hornblende rhyodacite porphyry	72.3 ± 2.2	(not on Fig. 1)
83AB75	hornblende/hornblende rhyodacite porphyry	69.8 ± 2.1	5
CS-1-75	biotite/vein in biotite granodiorite porphyry	62.8 ± 1.6	6
D148-337	sericite/vein in biotite granodiorite porphyry	62.5 ±1.6	7
AB49-73	whole rock/basalt porphyry	25.5 ± 0.6	8
KA9*	biotite/biotite granodiorite porphyry	64	(not on Fig. 1)

The ± value is the estimated cumulative analytical uncertainty at 1 standard deviation. Differences with values presented elsewhere (Koski, 1978; Koski and Cook, 1981) are due to re-evaluation of analytical reproducibility.

*Age from Creasey and Kistler (1962) has been recalculated with new decay and abundance constants recommended by 1976 IUGS Subcommission on Geochronology. Error estimated at ± 4 percent.

(33°03'28"N, 110°45'04"W; T4S,R16E; Gila Co., AZ). *Analytical data:* K_2O = 0.495%, Ar^{40} = 5.521 x 10^{-11}mole/gm, $^*Ar^{40}/\Sigma Ar^{40}$ = 28.9%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U.S. Geological Survey. *Comment:* Hornblende occurs as rounded crystal fragments and as grains in larger lithic fragments. Dark matrix of breccia contains finely disseminated secondary biotite.

(brown hornblende) 76.2 ± 2.3 m.y.

2. *54AB75* K-Ar
Hornblende andesite porphyry dike, fine-grained variety (33°02'59"N, 110°45'08"W; T4S,R16E; Gila Co., AZ). This type of dike has the following modal proportions: plagioclase (23.8%), hornblende (10.2%), augite (0.3%), opaque (2.5%), quartz (1.1%), apatite (0.1%), calcite + chlorite + epidote (1.6%), and groundmass (60.4%). *Analytical data:* K_2O = 0.494%, Ar^{40} = 5.931 x 10^{-11}mole/gm, $^*Ar^{40}/Ar^{40}$ = 33.03%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U. S. Geological Survey.

(dark-brown hornblende) 81.7 ± 2.4 m.y.

3. *72AB74* K-Ar
Hornblende andesite porphyry dike, coarse-grained variety (33°03'02"N, 110°43'15"W, T4S,R16E; Gila Co., AZ). This type of dike has the following modal composition: plagioclase (17.7%), hornblende (6.6%), augite (0.6%), opaque (3.6%), apatite (0.1%), quartz (0.1%), epidote + calcite chlorite (0.2%), groundmass (71.1%). *Analytical data:* K_2O = 0.548%, $^*Ar^{40}$ = 6.125 x 10^{-11}mole/gm, $^*Ar^{40}/Ar^{40}$ = 40.7%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U.S. Geological Survey.

(dark-brown hornblende) 76.2 ± 1.9 m.y.

4. *GB-1* K-Ar
Hornblende rhyodacite porphyry intrusion (Granite Basin 8 km NE of Christmas; 33°07'08"N, 110°40'56"W, T4S,R16E; Gila Co., AZ). The modal composition is: hornblende (9.2%), biotite (3.0%), plagioclase (28.5%), quartz (1.0%), opaque (0.9%), apatite (0.3%), calcite (0.3%), chlorite (0.1%), groundmass (56.7%). *Analytical data:* K_2O = 0.528%, $^*Ar^{40}$ = 5.595 x 10^{-11}mole/gm, $^*Ar^{40}/Ar^{40}$ = 29.2%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U.S. Geological Survey. *Comment:* This pluton is a 600-m-thick laccolith that intrudes Paleozoic carbonate rocks. Porphyry-type mineralization is absent.

(green hornblende) 72.3 ± 2.2 m.y.

5. *83AB75* K-Ar
Hornblende rhyodacite porphyry intrusion known as the McDonald stock (33°05'01"N, 110°43'38"W; T4S,R16E; Gila Co., AZ). The modal composition is: hornblende (10.3%), biotite (2.9%), plagioclase (33.1%), quartz (0.8%), opaque (1.3%), apatite (0.1%), chlorite + epidote (0.3%), groundmass (51.2%). *Analytical data:* K_2O = 0.516, $^*Ar^{40}$ = 5.2726 x 10^{-10}mole/gm, $^*Ar^{40}/Ar^{40}$ = 22.1%. *Collected by:* R. A. Koski. *Dated by: E. H. McKee, U.S. Geological Survey.*

(green hornblende) 69.8 ± 2.1 m.y.

6. *CS-1-75* K-Ar
Vein cutting biotite granodiorite porphyry in the Christmas stock (33°03'34"N, 110°44'41"W; T4S,R16E; Gila Co., AZ). *Analytical data:* K_2O = 3.74%, $^*Ar^{40}$ = 3.4441 mole/gm, $^*Ar^{40}/Ar^{40}$ = 64.1%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U.S. Geological Survey. *Comment:* Biotite

in veins is a less common feature of early (Stage I) K-silicate alteration at Christmas.

(pegmatitic, greenish-black, chloritic biotite) 62.8 ± 1.6 m.y.

7. *D148-337* K-Ar

Quartz-K-feldspar-sericite-chlorite vein cutting biotite granodiorite porphyry in the Christmas stock (from drill core; 33°03′40″N, 110°44′49″W; T4S,R16E; Gila Co., AZ). *Analytical data:* K_2O = 10.45%, $^*Ar^{40}$ = 9.5676 x 10^{-10}mole/gm $^*Ar^{40}/Ar^{40}$ = 86.32%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U.S. Geological Survey. *Comment:* Vein type may be transitional between early (Stage I) K-silicate veins in late (Stage II) quartz-sericite veins at Christmas.

(coarse-grained sericite) 62.5 ± 1.6 m.y.

8. *AB49-73* K-Ar

Olive-gray basalt porphyry dike (33°03′22″N, 110°44′44″W; T4S,R16E; Gila Co., AZ) with phenocrysts of plagioclase, augite, and olivine (replaced by pale-green clay) in groundmass of plagioclase, clinopyroxene, and brown glass. *Analytical data:* K_2O = 1.78%, $^*Ar^{40}$ = 6.587 x 10^{-11}mole/gm, $^*Ar^{40}/Ar^{40}$ = 77.11%. *Collected by:* R. A. Koski. *Dated by:* E. H. McKee, U.S. Geological Survey. *Comment:* Dike also cuts mineralized portions of Christmas stock and metasomatically altered carbonate rocks.

(basalt) 25.5 ± 0.6 m.y.

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