K-Ar and fission-track ages (dates) of volcanic intrusive, altered, and metamorphic rocks in the Mohave Mountains area, west- central Arizona

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K-Ar AND FISSION-TRACK AGES (DATES) OF VOLCANIC INTRUSIVE, ALTERED, AND METAMORPHIC ROCKS IN THE MOHAVE MOUNTAINS AREA, WEST-CENTRAL ARIZONA

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The Mohave Mountains and adjacent ranges of west-central Arizona (fig. 1) occupy a key area for unraveling the evolution of Tertiary tectonics in the Colorado River extensional corridor. The area lies in the east part of the north-trending, 100-km-wide corridor, and flanks a belt of metamorphic core complexes that define the center of the corridor (Davis and others, 1980; Howard and John, 1987). Field studies in the Mohave Mountains area indicate a record of extension-related Tertiary intrusion, volcanism, sedimentation, detachment faulting, tectonic fragmentation, and tilting (Howard and others, 1982a, in press; Pike and Hansen, 1982; Nakata, 1982; Light and others, 1983; Nielson, 1986; Nielson and Glazner, 1986; Howard and John, 1987; Nielson and Beratan, in press). The dating was carried out partly to support an appraisal of mineral-resource potential (Light and others, 1983). Preliminary K-Ar dates reported earlier (Light and others, 1983; Nielson, 1986; Glazner and others, 1986) are here fully documented, and in some cases have been corrected. Corrections follows discovery by Nakata of a spike calibration error.

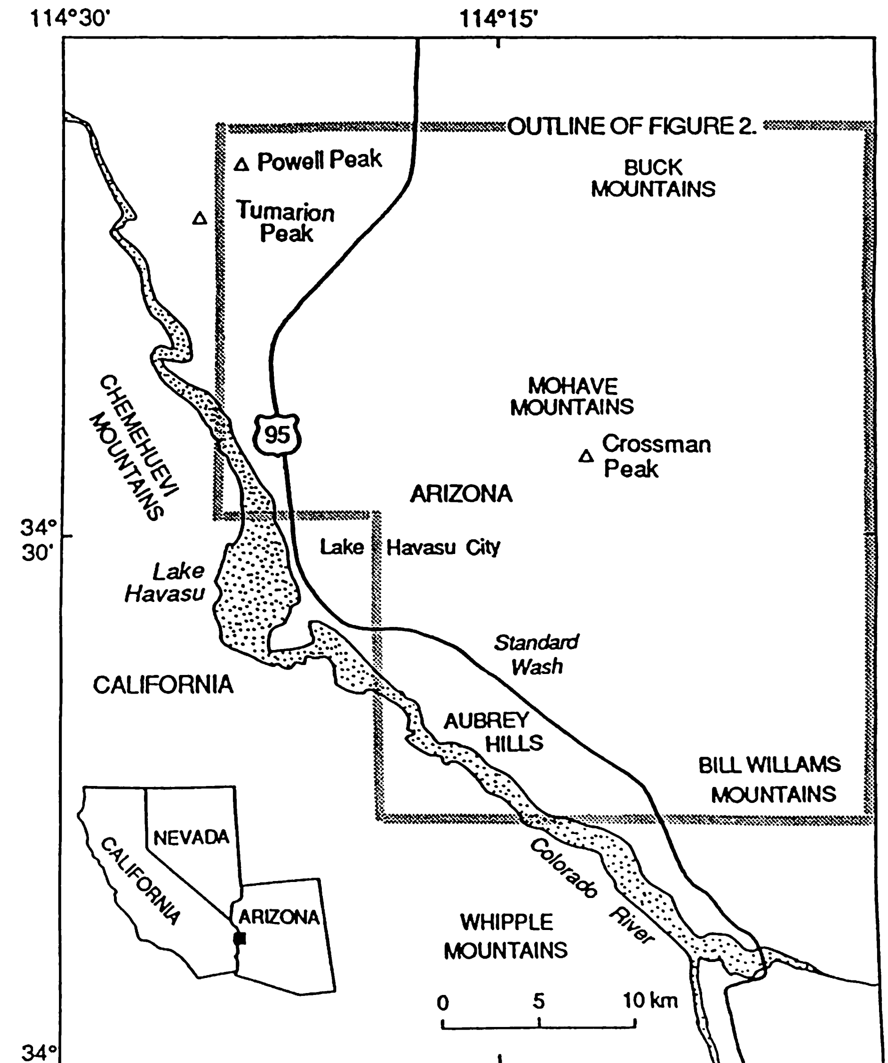

FIGURE 1. Location map of the Mohave Mountains area, AZ.

In this paper we report 57 conventional K-Ar and 7 fission-track ages (dates) on 52 rock samples located in figure 2. We term those with mixed cooling histories dates, following Armstrong (1966), to emphasize that they do not necessarily correspond to emplacement ages. Dated rocks include 13 volcanic, 14 dike, 6 granitoid, and 9 gneissic rocks and 6 rocks that experienced alteration related to mineralizing processes. Materials dated by K-Ar were: biotite, sanidine, plagioclase, muscovite, sericite, hornblende, and whole rocks. Zircon was dated by fission tracks. Figure 3 divides the dated rocks into four sample groups and presents histograms of the ages, identified by the material dated.

These ages help to calibrate the time of Tertiary deposition and deformation, constrain the timing of different styles of Tertiary magmatism, and provide age information helpful for interpreting Tertiary uplift, Mesozoic alteration and intrusion, and cooling of Proterozoic rocks. We interpret ages of events from these dates within the framework of our working model established by field studies from 1979 to 1987.

The ages on volcanic rocks (figs. 3a, 4) in most cases are consistent with or close to the crystallization age inferred from regional geologic relations, although dates on some hornblende and sanidine separates seem too young. Tertiary and Mesozoic dikes and stocks (fig. 3b) yielded biotite ages that in many cases are geologically consistent as emplacement ages but, whole-rock, plagioclase, and hornblende dates are nearly all variant. Secondary muscovite from altered gneiss yielded dates that can be interpreted as near the age of alteration, but finer grained low-K_2O sericite and zircon yielded younger dates. Dates determined from biotite and zircon (fission-track) on

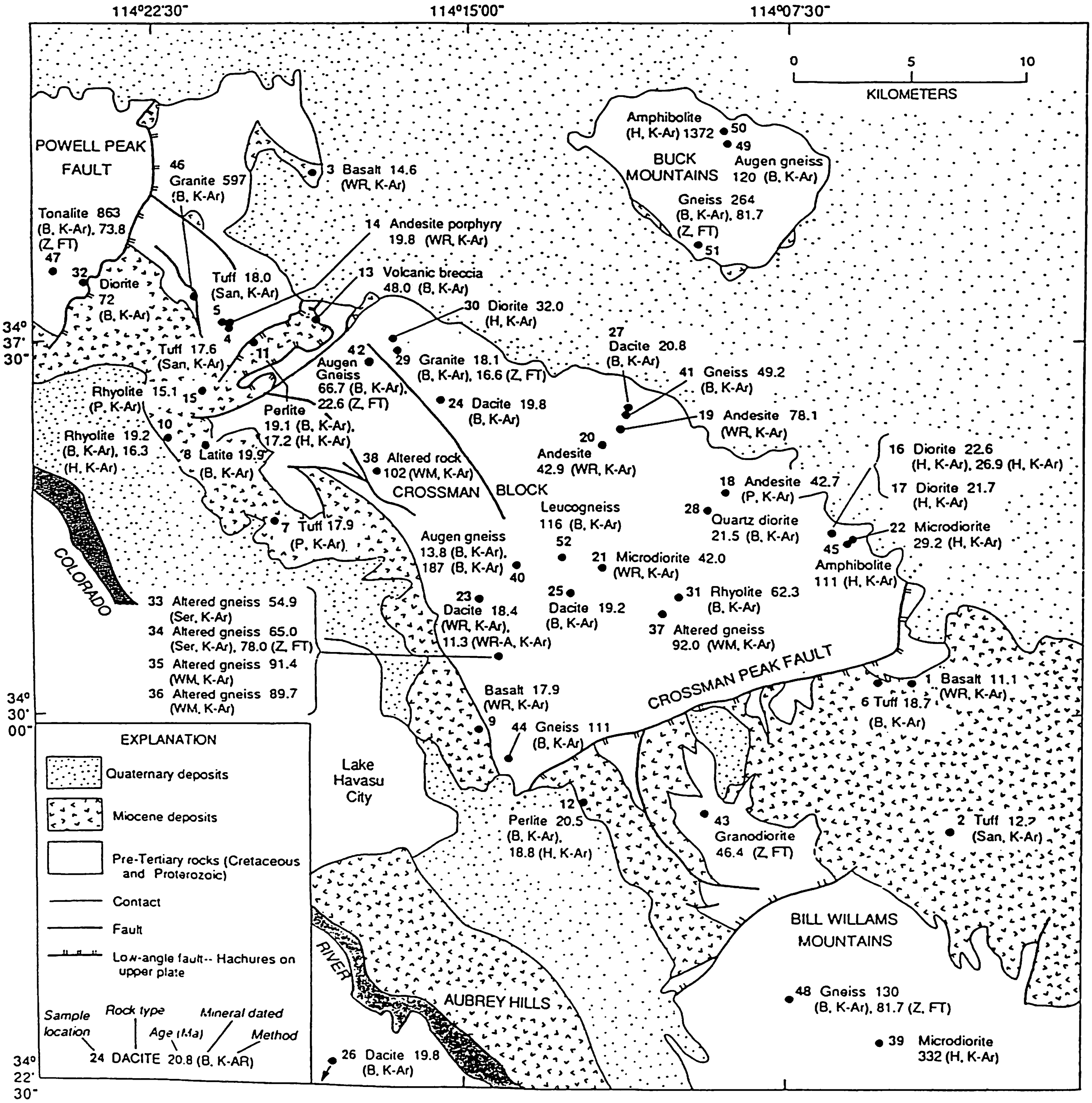

FIGURE 2. Simplified geologic index map of the Mohave Mountains area showing sample localities and dates except for sample number 26, which was collected from the Whipple Mountains west of the map area. The northwest-southeast trending Mohave Mountains dike swarm is not portrayed for graphic simplicity. The mineral and rock abbreviations are as follows: B = biotite, H = hornblende, P = plagioclase, San = sanidine, Ser = sericite, WR = whole rock, WM = white mica, Z = zircon.

Proterozoic rocks are all younger than the original crystallization age.

If cooling is relatively slow and excess radiogenic products are not incorporated by the minerals, those species with lower blocking temperatures will give younger ages than those with higher blocking temperatures. A common order of progressively decreasing closure or annealing temperatures is: hornblende (K-Ar), muscovite (K-Ar), biotite (K-Ar) and zircon (fission-track) (Armstrong 1966; Turner and Forbes 1976; Harrison and others 1979; and Hurford 1986). This order varies depending upon the extraction technique used to determine the blocking temperature (Harrison and Fitzgerald 1986; Gaber and others 1988). Other factors that complicate interpretation of the numerical age include rate of cooling, mineral structure, and availability of excess radiogenic argon from external sources.

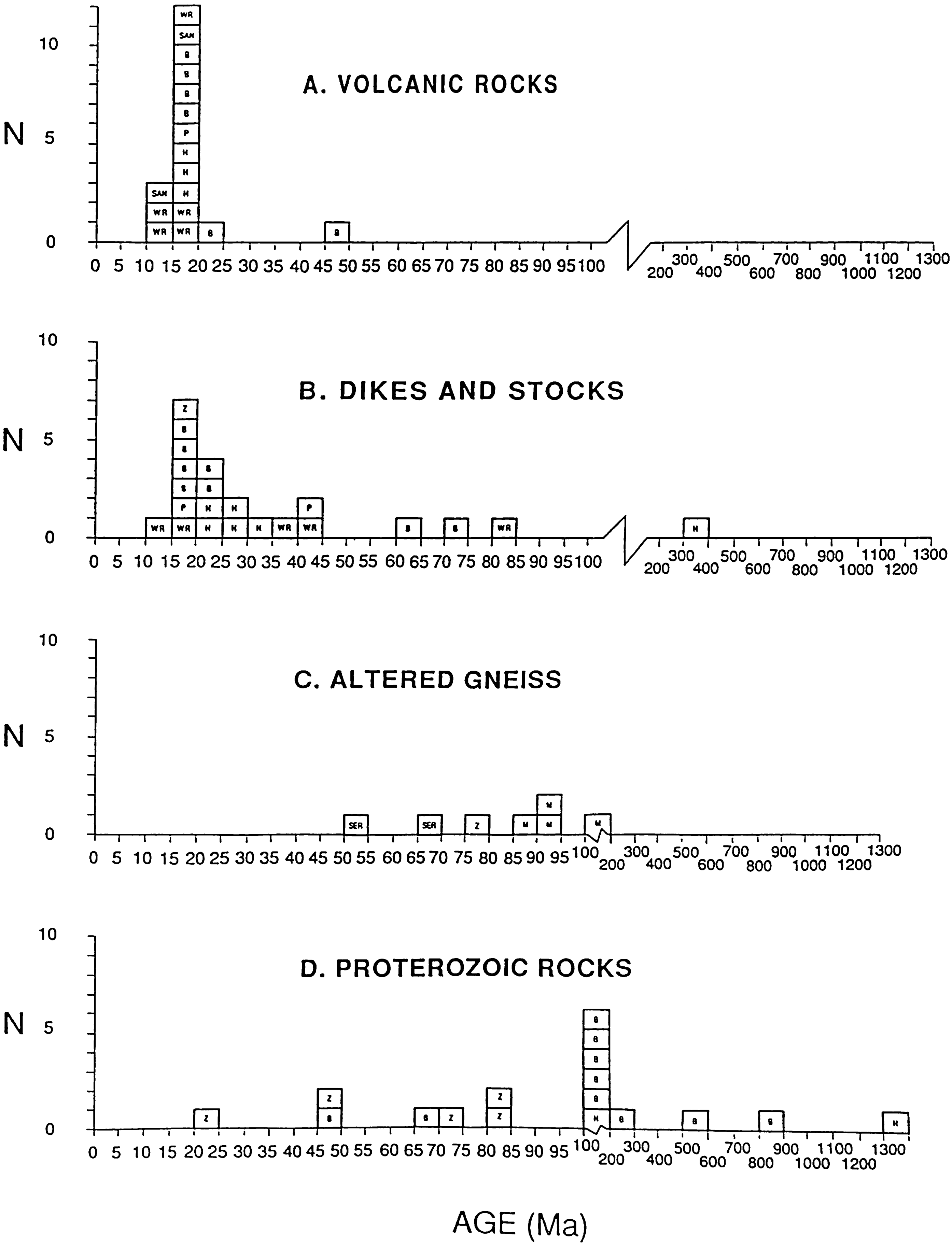

FIGURE 3. Histograms of dates, divided into four groups of samples. Abbreviations: (K-Ar) WR = whole rock, H = hornblende, P = plagioclase, San = sanidine, B = biotite, M = muscovite, Ser = sericite; (fission-track) Z = zircon.

GEOLOGIC FRAMEWORK

The Mohave, Buck, and Bill Williams Mountains expose Proterozoic gneisses and intrusive rocks, Mesozoic intrusive rocks, Tertiary dikes, and Neogene volcanic and sedimentary rocks (fig. 2). Paleozoic and Mesozoic strata that are present elsewhere in the region were stripped prior to the middle Tertiary, so that the pre-Tertiary rocks are overlain nonconformably by volcanic and clastic rocks of Miocene and Oligocene(?) age. In the Mohave Mountains a swarm of northwest-trending dikes intrudes the pre-Tertiary rocks and lower parts of the Tertiary section. The dikes occupy about 16 percent of the central Mohave Mountains east of Lake Havasu City, where their total thickness is about 2 km (Nakata, 1982).

Angular unconformities in the lower Miocene section document progressive westward tilting due to extensional growth faults. The younger strata are little tilted or faulted, in contrast to the older units, which commonly dip at steep angles and are locally overturned. Tilting of fault blocks was unidirectional to the southwest. The Crossman Peak fault and the probably equivalent Powell Peak fault are both normal faults with moderate dips. They juxtapose numerous fault-bounded blocks 1 to 2 km thick in their hanging walls against large rotated crustal blocks as much as 15 km across. These large blocks form the central Mohave Mountains (Crossman block), Bill Williams Mountains, and Powell Peak/Tumarion Peak area. The structurally equivalent Whipple Mountains and Chemehuevi faults, in exposures near the Colorado River, project beneath these large rotated blocks (Howard and others, 1982a, 1987, in press; Howard and John, 1987).

VOLCANIC ROCKS

Conventional K-Ar ages of volcanic rocks (figs. 3a and 4) help to constrain the time of tilting and faulting as well as to calibrate the magmatism. Nielson (1986) divided the pre-Pliocene Tertiary section into four sequences numbered: I, II, III and IV, from oldest to youngest.

The Peach Springs Tuff of Young and Brennan (1974) is the only unit of regional extent found in the Mohave Mountains area. It is a single cooling unit of welded tuff that outcrops in an area of at least 280 by 170 km (Glazner and others, 1986; Wells and Hillhouse, 1989). The Peach Springs has yielded a spread of K-Ar ages (Young and Brennan, 1974, Glazner and others, 1986), but studies using the $^{40}Ar/^{39}Ar$ technique indicate its emplacement age is 18.5 ± 0.2 Ma (Nielson and others, 1990).

The youngest rocks dated are olivine basalt (sample no. 1) at 11.1 ± 0.3 Ma (whole rock), and an underlying silicic tuff (no. 2) dated at 12.7 ± 0.6 Ma (sanidine); both are included in sequence IV. These rocks have southwest dips of 5° to 15° and contain normal faults with down-to-the northeast displacements in contrast with much steeper to overturned beds in the underlying Miocene strata. The change in dip marks the waning stages of deformation following extreme extensional faulting and tilting that affected the older rocks. Suneson and Lucchitta (1979, 1983) reported similar ages for basalt and rhyolite that occur a few kilometers to the southeast of samples no. 1 and 2, in the Castaneda Hills; they reported a age of 8.6 Ma for an undeformed basalt flow 8 km southwest of sample no. 1 (fig. 2).

A 14.6 ± 0.4 Ma whole-rock age was determined on a steeply dipping olivine basalt lava flow in a fault block in the

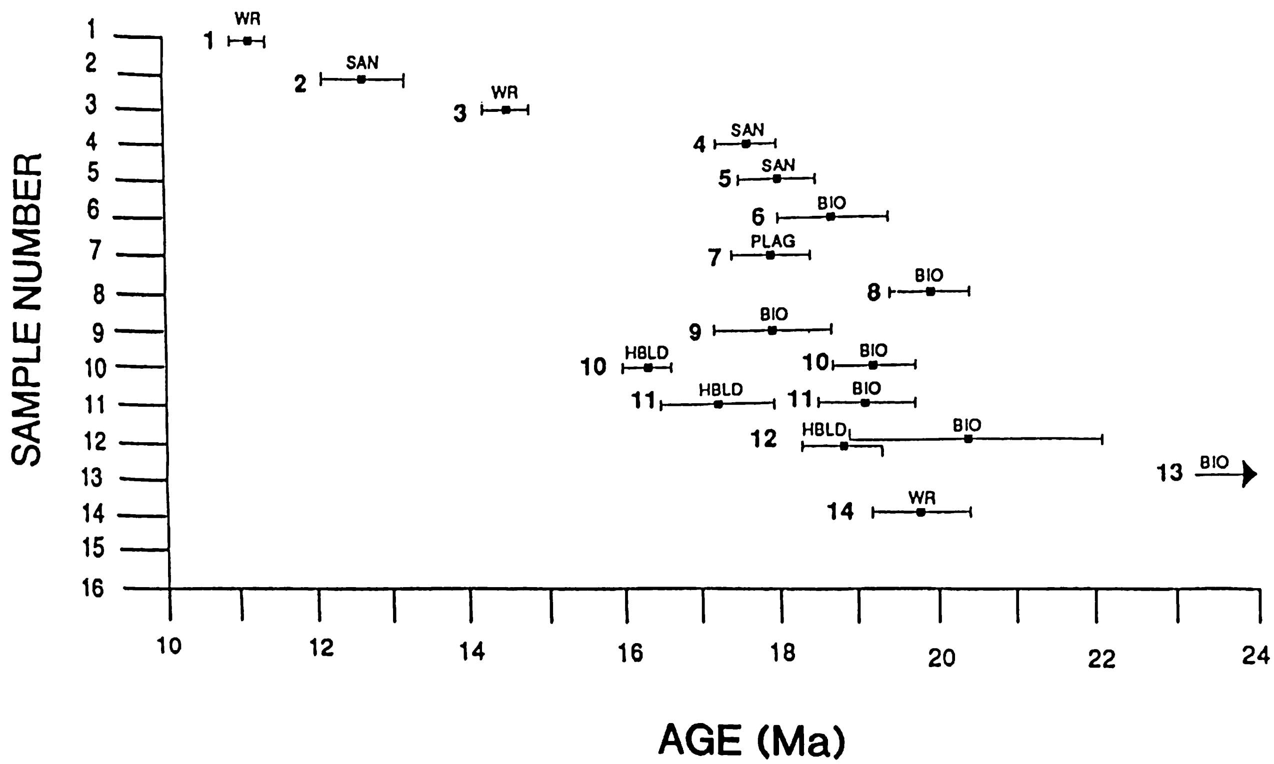

FIGURE 4. K-Ar ages (error bars) for volcanic rocks, arranged by sample number along the ordinate in approximate order of increasing stratigraphic age. A geologically anomalous date of 48.0 ± 1.2 Ma (no. 13) is not shown.

northern Mohave Mountains (no. 3). The basalt overlies and dips the same direction as volcanic rocks of sequence I and is overlain by moderately dipping arkosic sandstone of sequence III. Similar olivine basalt flows both underlie and overlie the Peach Springs Tuff nearby in the same fault block. This association suggests that the dated basalt may be close in age to the Peach Springs age of 18.5 Ma reported by Nielson and others (1990). If the 14.6-Ma K-Ar age correctly dates the basalt, alternatively then its steep dip implies that this fault block tilted since 14.6 Ma. This age of tilting is not inconsistent with the time of tilting of laterally equivalent units in adjacent areas; for example, 55 km to the northnorthwest in the Sacramento Mountains 14.6 Ma, and the Dead Mountains later than 12.2 Ma (Spencer, 1985). Major tilting ceased by 13 Ma 20 km to the south in the Whipple Mountains region (Davis and others, 1980; Dickey and others, 1980).

Major tilting of some large fault blocks, including the Crossman block of the central Mohave Mountains (fig. 2), occurred earlier. Gently dipping (100) rocks dated at 17.9 ± 0.7 Ma (plagioclase, no. 7) and 19.9 ± 0.5 Ma (biotite, no. 8) unconformably overlie vertical to moderately tilted older Miocene strata (sequence I) that are part of that upended block. Within the estimated precision (± 0.5 Ma) the age on no. 8 overlaps a biotite age on the underlying sequence (19.2 ± 0.5 Ma, no. 10), which suggests that the unconformity age is within the overlap, about 19.5 Ma. The section containing samples 7 and 8 lacks the Peach Springs Tuff, which elsewhere is an important regional marker (Glazner and others, 1986).

The Peach Springs Tuff in other fault blocks of the study area commonly dips at moderate angles, and overlies sequence I with slight angular discordance. Within the map area the Peach Springs Tuff yielded K-Ar sanidine dates of 17.6 ± 0.4 and 18.0 ± 0.5 Ma (nos. 4 and 5), and a rock tentatively identified as belonging to the Peach Springs Tuff yielded a biotite age of 18.7 ± 0.7 Ma (no. 6). The young K-Ar dates on the sanidine may reflect incomplete recovery of argon during extraction because of high sample viscosities, as suggested by McDowell (1983) and G. B. Dalrymple (written communication, 1986).

Volcanic rocks that are or thought to be stratigraphically below the Peach Springs Tuff yielded K-Ar dates ranging from 16.3 ± 0.4 to 48 ± 1.2 Ma (nos. 9-14), but the most reliable lie between 18 and 21 Ma. A basalt (no. 9) dated at 17.9 ± 0.7 Ma occurs in sequence I where the Peach Springs Tuff is absent. It may be a sill that post-dates eruption of the Peach Springs. A "turkey-track"-textured porphyry with altered composition (no. 14) yielded a geologically reasonable whole-rock age of 19.8 ± 0.6 Ma. Three rhyolitic rocks (nos. 10, 11, 12) yielded biotite ages of 19.2 ± 0.5, 19.1 ± 0.6 and 20.5 ± 1.6 Ma, but consistently younger hornblende dates of 16.3 ± 0.4, 17.2 ± 0.7 and 18.8 ± 0.5 Ma; repeated extractions showed similar results. Miller and Morton (1980) found that 35 percent of their 45 biotite-hornblende pairs from the southern Mojave Desert, California, yielded younger hornblende dates because at standard extraction temperature (1,200° to 1,400° C) the refractory hornblende was not completely fused. Like theirs, our samples were run before the availability of water-cooled extraction bottles which allow higher fusing temperatures. All our samples appeared fused, but dates are systematically younger than biotite by as much as 15 percent, suggesting incomplete recovery of argon. A whole-rock K-Ar age of 21.5 Ma was reported by W. Rehrig for a mafic lava flow low in sequence I (Pike and Hansen, 1982; Nielson, 1986; Nielson and Beratan, 1990). One silicic breccia (no. 13) yielded an anomalously old date on biotite of 48 ± 1.2 Ma, from which contamination by xenocrystic biotite is suspected. Based on ages that we consider the most reliable, the age of the part of the volcanic section lower than the Peach Springs Tuff (sequence I of Nielson, 1986) is concluded to be about 19 to 22 Ma. This age span matches that for fresh rocks of similar stratigraphic position dated from the Turtle and Stepladder Mountains, 50 km west of the study area (Howard and others 1982b; Nielson and Glazner, 1986).

We conclude, based on these data and on biotite ages from dies and stocks (see below), that a suite of basaltic, andesitic, dacitic, latitic, and rhyolitic rocks were intruded and erupted in the early part of the extensional event between about 19 and 22 Ma. After the rhyolitic Peach Springs Tuff was deposited across the area at 18.5 Ma, magmatism in the area produced mainly olivine basalt and rhyolite through the late stages of deformation from 15 to 12 Ma and the cessation of deformation between 8 and 12 Ma.

DIKES AND STOCKS

Dike rocks yielded a wide variety of dates, only a few of which seem consistent with geological evidence for the age of emplacement. Most of the dates appear to be too old, and may reflect excess argon derived from the Proterozoic host rocks and incorporated in the younger intrusive rocks. For nonvolcanic rocks we regard the K-Ar ages on potash-rich mica as minimum ages and relatively insensitive to excess argon.

A 15.1-Ma plagioclase age is taken as the emplacement age of a distinctive thick rhyolitic dike (no. 15) that cuts Miocene volcanic and sedimentary rocks. Its trend, outcrop style, and subvolcanic character are different from dikes in the Mohave Mountain dike swarm.

The Mohave Mountains dike swarm is interpreted as having intruded at about 20 Ma on the basis of (a) similar biotite ages (19.8 ± 0.5, 19.8 ± 0.2, 20.8 ± 0.5 Ma, nos. 24, 25, 27) on dacitic dikes, (b) a biotite age of (19.8 ± 0.5 Ma, no. 26) on a similar dike from the possibly correlative Chambers Well dike swarm in the Whipple Mountains, California, and (c) intrusion of the swarm into the lower part of the volcanic section of sequence I. A diorite dike in Proterozoic rocks, which cuts other dikes of the Mohave Mountains swarm, yielded hornblende dates of 22.6 ± 0.7 (no. 16), 26.9 ± 0.7 (flux added to no. 16), and 21.7 ± 0.7 (no. 17). These dates (no. 16 and no. 16 w/flux) are older than seem likely for the emplacement age because the dike swarm is intrusive into part of sequence I. Other intermediate-composition dikes from the Mohave Mountains dike swarm yielded discordant hornblende, plagioclase, and whole-rock dates ranging from 11.3 ± 0.3 to 78.1 ± 2.0 Ma (nos. 18-23). We do not interpret these as emplacement ages. A small body of quartz diorite (no. 28) that grades into a mafic dike of the dike swarm yielded a biotite age of 21.5 ± 0.5 Ma, in agreement with most other biotite ages from dikes and with the geologically interpreted emplacement age.

Evidence of Laramide-age (Cretaceous to earliest Tertiary) magmatism is provided by ages on a rhyolite dike and a granitoid porphyry apophysis. Except for its northeast-trend, the rhyolite dike (no. 31), resembles rocks of the middle Tertiary dike swarm. It yielded an age of 62.3 ± 1.6 Ma on biotite. The porphyry (no. 32), which yielded a biotite age of 72.0 ± 1.8 Ma, is satellitic to a granodiorite pluton at Powell Peak, which is tentatively correlated to biotite granodiorite of Late Cretaceous age in the Chemehuevi Mountains (Howard and others, 1982a; John, 1988; John and Mukasa, 1990). Further independent support for an age of about 72.0 Ma (no. 32) for the Powell Peak pluton is a

73.8 ± 7.7-Ma zircon fission-track date on a nearby Proterozoic rock which yielded a biotite date of 863 ± 21.6-Ma (no. 47). We infer that the ambient temperature in the local Proterozoic rocks was colder than the blocking temperature for biotite, but was thermally perturbed by emplacement of the pluton and its satellites at about 72-74 Ma.

Ages on a small diorite stock and associated younger granite, which resembles Late Cretaceous granites in the region, are harder to interpret (nos. 30 and 29). The diorite yielded a hornblende date of 32.0 ± 1.0 Ma and the granite yielded a biotite (K-Ar) date of 18.1 ± 0.5 Ma and zircon fission-track date of 16.6 ± 1.7 Ma. The dates are younger than mica and zircon cooling ages in most of the rest of the Crossman Peak fault block, and suggest the possibility of Tertiary emplacement.

A microdiorite dike which cuts an augen gneiss in the Bill Williams Mountains yielded a hornblende date of 332 ± 16 Ma (no. 39), which is not a crystallization age because Paleozoic sections in nearby regions exhibit no evidence of magmatism (Stone and others, 1983). The dike could be Tertiary, Mesozoic, or most likely Precambrian in age.

ALTERED ROCKS

Ages were measured on white mica from six intensely altered and sericitized Proterozoic rocks associated with metalliferous mineralization, (Light and others, 1983) in order to investigate the age of mineralization (fig. 3c). The white mica replaced feldspars during the alteration event. Four of the white mica samples were muscovite coarser than 0.1 mm. These micas have normal K_2O contents of 10.5 to 11.2 percent (nos. 35, 36, 37, and 38) and yielded dates of 91.4 ± 2.3, 89.7 ± 2.2, 92.0 ± 2.3, and 102 ± 2.6 Ma. The other two samples were sericitic mica finer than 0.1 mm, which yielded younger K-Ar dates of 65 and 55 Ma (nos. 34 and 33). The two younger dates correlate approximately linearly with lower K_2O contents when compared with the muscovite dates. The sericite that yielded the youngest date (55 Ma) has a K_2O content of only 6.7 percent, whereas the next older (65 Ma) one has an intermediate K_2O content of 8.9 percent. McDougall and Harrison 1988 suggest that low-K_2O sericites may in fact be illite or hydromuscovite. The sericite may record cooling through lower blocking temperatures than does the muscovite. If so, a measure of the sericite blocking temperature for argon retention may be a zircon fission-track date for the sericite sample (no. 34) of intermediate-K_2O content. Zircons in the sample seem to represent 2 populations. The fission-track age of 78 ± 9 Ma although crude nevertheless slightly exceeds the sericite K-Ar age and suggests that this sericite retained argon only at or below the annealing temperature for fission tracks in zircon, on the order of 200° (Harrison and others, 1979; Hurford, 1986). The lower-K_2O sericite (no. 33) from the same locality, with the youngest apparent age, may record a lower cooling temperature yet.

The muscovite dates between 90 and 102 Ma are crudely concordant. Because they occur at different pre-tilting structural depths, we suspect that they may approximate the age of the alteration event rather than younger cooling, which would be expected to vary systematically with structural depth. An age of alteration of about 100 Ma would be consistent with dates obtained from plutons in the Turtle Mountains and from an upper plate adamellite in the Whipple Mountains (Davis and others, 1980; Howard and others, 1982b): both localities are near restored pre-extension positions of the Mohave Mountains fault blocks (Howard and others 1982a).

PROTEROZOIC ROCKS

Dates determined on altered Proterozoic rocks (fig. 3d) can be interpreted as mixed cooling ages. The regional Proterozoic rock suite is known to comprise Early Proterozoic gneisses and granitoids and Middle Proterozoic granitoids and diabase (Lanphere 1964; Howard and others, 1982b; Anderson, 1983; in press; Wooden and others, 1988). Granodiorite, tentatively correlated with the Middle Proterozoic granodiorite of Bowmans Wash of Anderson (1983), yielded a fission track date on zircon of 46.4 ± 5.4 Ma (no. 43). Rocks assigned to the Early Proterozoic by Howard and others (1982a; in prep.) (samples 40 to 42 and 44 to 52) yielded hornblende K-Ar dates ranging from 104 ± 2.6 to 1372 ± 34 Ma, biotite K-Ar dates ranging from 49.2 ± 10.5 to 863 ± 21.6 Ma, and zircon fission-track dates ranging from 22.6 ± 1.9 to 81.7 ± 8.7 Ma. These dates are taken to imply cooling of some rocks as recently as the Miocene. An analysis of cooling and uplift patterns is in progress.

ANALYTICAL METHODS

K-Ar

The K-Ar age determinations were made in the isotope laboratories of the U.S. Geological Survey at Menlo Park, California, using the methods described by Dalrymple and Lanphere (1969). Argon was extracted on an ultrahigh vacuum system by fusion; the reactive gases were then scrubbed by an artificial molecular sieve, Cu-CuO and Ti metals.

The spectrometry was performed on a Nier-type, 15-cm radius, 60° sector and a multichannel, 23-cm radius, 90° sector mass spectrometers, both operated in the static mode. Argon was analyzed by comparing the liberated gas to a "pure" ^{38}Ar spike of known volume and composition added during fusion. The decay constants used are those published by Steiger and Jager (1977):

$^{40}K/K$	1.67×10^{-4} mol/mol
$\lambda\ (^{40}K_{b}-)$	$4.962 \times 10^{-10}\ yr^{-1}$
$\lambda\ (^{40}Ke) + \lambda'\ (^{40}Ke)$	$0.581 \times 10^{-10}\ yr^{-1}$

Flame photometry with a lithium internal standard was used to analyze potassium using the procedure described by Cremer and others (1984). All samples were run in duplicate to check precision.

Radiogenic argon ($^{40}Ar^*$) as a percent of total argon ($\Sigma^{40}Ar$) may differ by as much as 17 percent from replicate analysis of the same sample on different extraction lines, with different bakeout times, spike sets and the total amount of sample used. These factors contribute varying atmospheric components and thereby lead to an apparent discrepancy in the radiogenic argon percentages from one extraction to the next. However, the total atmospheric components are subtracted and the final age calculations are based on radiogenic Ar concentration measured in moles/gram, which differ by no more than 3 percent.

The 2.5-3.0 percent (±)error represents a conservative estimate of the overall analytical precision for samples with greater than 10 percent radiogenic argon. This is based on empirical tests over a period of 14 years at the U.S. Geological Survey Isotope laboratory in Menlo Park, California, (Tabor and others 1985). All samples run prior to 1980 have an error of 3.0 percent; at this time a change to digital readouts decreased the error to 2.5 percent. For results averaged from determinations on two splits of the same sample, the error reflects the same conservative 2.5–3.0 percent estimates at ± 1 standard deviation and 68-percent confidence level. However, agreement between replicate analysis were usually less then 2 percent. For those samples with greater than 3 percent error between replicate analysis the dates were averaged and a standard deviation was calculated and reported to ± 1 standard deviation.

Fission Track

The external detector method was used to date the zircons (Naeser, 1976, 1979), which were mounted in Teflon and etched in a eutectic melt of KOH-NaOH (Gleadow and others, 1976) at 215°C for 30–50 hours. The Teflon mounts were covered with a muscovite detector and irradiated along with neutron dose monitors (U-doped glasses SRM 962 also covered with muscovite detectors) in the U.S. Geological Survey TRIGA reactor at Denver, Colorado. The neutron dose was determined using track densities in the muscovite detectors and the Cu calibration for SRM 962 (Carpenter and Reimer, 1974). The errors shown for the fission-track dates are ± 2 standard deviations.

ACKNOWLEDGMENTS

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SAMPLE DESCRIPTIONS

1. *P81MH-8a* K-Ar
Olivine basalt (34°30′44″N, 114°04′27″W; S31,T14N,R17W; Buck Mountains SE 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 1.326%, 1.317%, 1.337%; $^{40}Ar^*$ = 2.16 × 10^{-11} mol/gm, 2.09 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 45%, 34%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Gently dipping basalt flow, sequence IV; caps Black Mountain. Holocrystalline subophitic basalt containing phenocrysts of olivine, clinopyroxene, and plagioclase. Age is revised from 10.6 Ma age reported by Nielson (1986).
(whole rock) 11.1 ± 0.3 Ma

2. *JP82MH-23* K-Ar
Silicic tuff (34°27′36″N, 114°33′36″W; S17,T13N,R17W; Parker Dam 15′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 9.03%, 9.06%; $^{40}Ar^*$ = 1.66 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 63%. *Argon analysis:* J. K. Nakata. *Collected by:* J. E. Nielson. *Comments:* Flow-banded tuff, sequence IV, not welded, with sanidine as sole crystals; no lithic clasts present.
(sanidine) 12.7 ± .6 Ma

3. *H81MH-18* K-Ar
Olivine basalt (34°40′55″N, 114°18′42″W; S36,T14N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 1.846%, 1.861%, 1.854%; $^{40}Ar^*$ = 3.87 × 10^{-11} mol/gm, 3.95; × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 62%, 64%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Steeply dipping basalt, sequence II. Overlies intermediate-composition volcanic rocks (sequence I of Nielson, 1986) and underlies steeply dipping arkosic sandstone and conglomerate (sequence III of Nielson, 1986) that contains clasts of the olivine basalt. Intergranular to diktytaxictic texture. Glass content less than 5%. Rock generally fresh. Olivine rimmed by iddingsite. Age is revised from 14.1 Ma age reported by Nielson (1986).
(whole rock) 14.6 ± 0.4 Ma

4. *JP80MH-192* K-Ar
Peach Springs Tuff (34°37′49″N, 114°21′10″W; S22,T15N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 9.09%, 9.06%, 9.08%; $^{40}Ar^*$ = 2.34 × 10^{-10} mol/gm, 2.30 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 72%, 64%. *Argon analysis:* J. K. Nakata. *Collected by:* J. E. Nielson. *Comments:* Salmon-pink crystal-lithic tuff breccia, unwelded, sequence IV; occurs above bedded tuff (altered pumice fragments). Sanidine is dominant crystal. Age is revised from 16.7 Ma and 17.8 Ma ages reported by Nielson (1986).
(sanidine) 17.6 ± 0.4 Ma

5. *P81MH-2* K-Ar
Peach Springs Tuff (34°37′54″N, 114°21′21″W; S22,T15N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 9.36%, 9.35%, 9.32%, 9.46%; $^{40}Ar^*$ = 2.40 × 10^{-10} mol/gm, 2.48 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 67%, 87%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* Strongly welded crystal-lithic rhyolite tuff, sequence II. Phenocrysts are sanidine and lesser biotite, opaques, hornblende, and sphene. Sanidine is euhedral and fresh. Date is revised from 17.4 Ma date reported by Nielson (1986).
(sanidine) 18.0 ± 0.5 Ma

6. *JP81MH-159* K-Ar
Silicic tuff (34°30′41″N, 114°05′11″W; S31,T14N,R17W; Standard Wash 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.04%, 8.05%; $^{40}Ar^*$ = 2.22 × 10^{-10} mol/gm, 2.14 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 37%, 54%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* In fault block that exposes bedded rocks of sequence I of Nielson (1986). Flattened pumice fragments show no preferred orientation. Probably the Peach Springs Tuff, sequence II.
(biotite) 18.7 ± 0.7 Ma

7. *JP81MH-388B* K-Ar
Silicic tuff (34°33′50″N, 114°19′27″W; S11,T14N,R20W; Lake Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 1.19%, 1.17%, 1.18%; $^{40}Ar^*$ = 3.06 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 31%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* Overlies the flow sampled as JP81MH-378. Gently dipping. Ashy matrix contains relatively fresh plagioclase and fused-appearing biotite. Silicified. Flow-banded.
(plagioclase) 17.9 ± 0.5 Ma

8. *JP81MH-378* K-Ar
Andesitic flow (34°35′25″N, 114°21′08″W; S33,T15N,R20W; Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.34%, 8.33%, 8.32%; $^{40}Ar^*$ = 2.34 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 69%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* Fine-grained groundmass with large (6-mm) phenocrysts and clusters of phenocrysts. Contains relatively unaltered biotite in addition to altered plagioclase and clinopyroxene and emphibole.
(biotite) 19.9 ± 0.5 Ma

9. *JP81MH-14a* K-Ar
Basalt (34°39′42″N, 114°14′34″; S3, T13N,R19W; Standard Wash 7.5′ quad., Mohave Co., AZ. *Analytical data:* K_2O = .93%, .92%; $^{40}Ar^*$ = 2.33 × 10^{-11} mol/gm, 2.44 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 37%, 41%. *Argon analysis:* J. K. Nakata. *Collected by:* J. E. Nielson. *Comments:* Flow or dike in sequence I of Nielson (1986). Porphyritic olivine basalt; holocrystalline groundmass. Plagioclase laths, clinopyroxene and olivine in granular opaques and alterations indicate chlorite. Olivine is fine-grained. Age is revised from 17.8 Ma age reported by Nielson (1986).

(whole rock) 17.9 ± 0.7 Ma

10. *P81MH-296* K-Ar
Rhyolite flow (34°35′31″N, 114°22′01″W; S33N,T15N,R20W; Lake Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* (biotite) K_2O = 8.54%, 8.55%; $^{40}Ar^*$ = 2.37 × 10^{-10} mol/gm, 2.03 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 48.9%, 13.8%; (hornblende) K_2O = 0.866%, 0.858%; $^{40}Ar^*$ = 2.03 × 10^{-11} mol/gm, 2.02 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 14%, 10%. *Argon analysis:* J. K. Nakata. *Collected by:* J. E. Nielson. *Comments:* In sequence I of Nielson (1986). Medium-grained matrix with large plagioclase phenocrysts and glomerophenocrysts; mafic phenocrysts are relatively fresh; hornblende is green.

(biotite) 19.2 ± 0.5 Ma
(hornblende) 16.3 ± 0.4 Ma

11. *P80MH-223* K-Ar
Rhyolitic perlite (34°37′31″N, 114°20′02″W; S20,T15N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* (biotite) K_2O = 8.34%, 8.32%; $^{40}Ar^*$ = 2.31 × 10^{-10} mol/gm, × 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 53.5%, 63.6%; (hornblende) K_2O = .82%, .80%; $^{40}Ar^*$ = 2.08 × 10^{-11} mol/gm, 1.93 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 19%, 22%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* Base of rhyolite flow in sequence I of Nielson (1986). Dark, perlitic glass, containing 2-mm-sized biotite. Previously reported as sample JP81-123 (Nielson, 1986).

(biotite) 19.1 ± 0.6 Ma
(hornblende) 17.2 ± 0.7 Ma

12. *JP80MH-139* K-Ar
Rhyolitic perlite (34°28′14″N, 114°12′02″W; S13,T13N,R19W; Standard Wash 7.5′ quad., Mohave Co., AZ). *Analytical data:* (biotite) K_2O = 8.46%, 8.43%; $^{40}Ar^*$ = 2.44 × 10^{-10} mol/gm, 2.35 × 10^{-10} mol/gm, 2.71 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 75%, 66%, 60%; (hornblende) K_2O = 0.710%, 0.694%; $^{40}Ar^*$ = 1.93 × 10^{-11} mol/gm, 1.88 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 10%, 11%. *Argon analysis:* J. K. Nakata. *Collected by:* J. E. Nielson. *Comments:* Base of rhyolite flow in sequence I of Nielson (1986). Glassy, perlitic groundmass with abundant plagioclase and biotite phenocrysts and accessory hornblende.

(biotite) 20.5 ± 1.6 Ma
(hornblende) 18.8 ± 0.5 Ma

13. *JP81MH-361* K-Ar
Silicic volcanic breccia (34°37′57″N, 114°18′34″W; S24,T15N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 7.33%, 7.31%; $^{40}Ar^*$ = 5.12 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 80%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* Breccia contains plagioclase and biotite crystals, recrystallized quartz, clasts of vitrophyre containing plagioclase, biotite, and magnetite phenocrysts, clasts of porphyry containing biotite and altered plagioclase, and clasts of tuff, sequence I. *Date is considered much older than geologically reasonable* and may indicate the presence of xenocrystic biotite.

(biotite) 48.0 ± 1.2 Ma

14. *P80MH-187* K-Ar
Latite (34°37′53″N, 114°21′08″W; S22, T15N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 3.04%, 3.06%, 3.08%, 3.03%; $^{40}Ar^*$ = 8.72 × 10^{-11} mol/gm, 8.75 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 86%, 88%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. E. Nielson. *Comments:* Platioclase-pyroxene-phyric "turkey-track" or "jack-straw" porphyry; holocrystalline. Apatite very abundant. Plots in latite field using normative minerals, may have had andesitic affinities before alteration. High K_2O may indicate potassium enrichment from metasomatism.

(whole rock) = 19.8 ± 0.6 Ma

15. *P81MH-1* K-Ar
Rhyolitic dike (34°36′01″N, 114°21′12″W; S28, T15N,R20W; Lake Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 0.679%, 0.679%, 0.676%; $^{40}Ar^*$ = 0.158 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 53%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Southwestern pinnacle of a line of pinnacles formed by 100-m-thick dike, on west side of Arizona highway 95. Flow-banded rhyolite containing phenocrysts of plagioclase, K-feldspar, quartz, biotite, hornblende, sphene, and apatite. Plagioclase is euhedral and fresh; grain size 1–2 mm. Age is revised from 16.2 Ma age reported by Nielson (1986).

(plagioclase) = 15.1 ± 0.4 Ma

16. *JN-81MH-90-2* K-Ar
Diorite dike (34°33′39″N, 114°06′20″W; S12, T14N,R18W; Buck Mountains SE 7.5′ quad., Mohave Co., AZ). *Analytical data:* (hornblende) K_2O = 0.782%, 0.789%; $^{40}Ar^*$ = 2.57 × 10^{-10} mol/gm, (with flux) 3.06 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 14%; (with flux) 25%. *Argon analysis:* J. K. Nakata. *Collected by:* J. K. Nakata. *Comments:* Northeast trending dike that cuts other nearby dacitic and andesitic dikes. Fine- to medium-grained hypidiomorphic granular texture. Hornblende is fresh with some alteration to chlorite. Second analysis used flux and H_2O-cooled bottle for fusion, and therefore would be expected to be more accurate. *Both dates are suspected to be older than the geologic age of emplacement.*

(hornblende) 22.6 ± 0.7 Ma
(with flux) 26.9 ± 0.7 Ma

17. *JN-81MH-90-2A* K-Ar
Diorite dike (34°33′39″N, 114°06′20″W; S12, T14N,R18W; Buck Mountains SE quad., Mohave Co., AZ). *Analytical data:* K_2O = 0.78%, 0.78%; $^{40}Ar^*$ = 2.46 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 12%. *Argon analysis:* J. K. Nakata. *Collected by:* J. K. Nakata. *Comments:* Same dike as JN-81MH-90-2. Fine-grained hypidiomorphic granular texture.

(hornblende) 21.7 ± 0.7 Ma

18. *BLM-139-8* K-Ar
Andesitic dike (34°34′30″N, 114°08′47″W; S9, T14N,R18W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 1.426%, 1.434%; $^{40}Ar^*$ = 8.9 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 57%. *Argon analysis:* J. K. Nakata. *Collected by:* J. K. Nakata. *Comments:* Trachytic-textured (turkey-track); mafic minerals are altered to chlorite. *Date is considered to be older than the likely geological age of emplacement.*

(plagioclase) 42.7 ± 1.1 Ma

19. *BLM-163-35* K-Ar
Andesitic dike (34°35′45″N, 114°11′15″W; S31, T15N,R18W; Crossman Peak 7.5′ quad., Mohave

Co., AZ). *Analytical data:* K_2O = 2.382%, 2.464%; $^{40}Ar^*$ = 2.83 × 10^{-10} mol/gm, 2.74 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 78%, 78%. *Argon analysis:* J. K. Nakata. *Collected by:* J. K. Nakata. *Comments: Date is considered to be older than the likely geological age of emplacement.*

(whole rock) 78.1 ± 2.0 Ma

20. *BLM-163A* K-Ar
Andesitic dike (34°35′18″N, 114°11′37″W; S26, T15N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 2.20%, 2.15%; $^{40}Ar^*$ = 1.36 × 10^{-10} mol/gm, 1.36 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 70%, 70%. *Argon analysis:* J. K. Nakata. *Collected by:* J. K. Nakata. *Comments: Date is considered to be older than the likely geological age of emplacement.*

(whole rock) 42.9 ± 1.1 Ma

21. *P81MH-15B* K-Ar
Microdiorite dike (34°32′58″N, 114°11′38″W; S13,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 2.83%, 2.80%, 2.87%, 2.85%; 1.77 × 10^{-10} mol/gm, 1.61 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 47%, 45%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Dike 3-m thick, trends NE and dips N. Cuts ore and quartz veins in the Sunset mine. Fine grained, intergranular microdiorite, consisting of plagioclase (altered), brown hornblende, magnetite, interstitial quartz, and secondary epidote, chlorite, and calcite. Color index 25. *Date is considered to be older than the likely geological age of emplacement.*

(whole rock) 39.9 ± 1.0 Ma

22. *H83MH-66* K-Ar
Microdiorite dike (34°33′34″N, 114°05′49″W; S13,T14N,R18W; Buck Mountains SE 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 0.978%, 0.984%; $^{40}Ar^*$ = 4.15829 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 39%. *Argon analysis:* J. K. Nakata. *Collected by:* K. A. Howard. *Comments:* NW-trending dike, east of jeep trail. Cuts gneiss and amphibolite (sampled as H83MH-67). Fine-grained microdiorite consisting of plagioclase, brown hornblende, interstitial epidote and quartz, and secondary calcite. Color index 40. Hornblende is brown, subhedral, acicular; grain size 0.5–2 mm. *Date is suspected to be older than the likely geological age of emplacement.*

(hornblende) 29.2 ± 0.7 Ma

23. *BLM-190-8* K-Ar
Felsic dike (34°32′N, 114°15′W; S22,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* (whole rock, fine fraction) K_2O = 5.23%, 5.22%; $^{40}Ar^*$ = 1.39 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 35%; (whole rock, coarse fraction, acid-treated) K_2O = 5.08%, 5.01%; $^{40}Ar^*$ = 8.23 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 52%. *Argon analysis:* J. K. Nakata. *Collected by:* J. K. Nakata. *Comments:* Acid-treated coarse fraction (−35 +60 mesh) gives younger date than nonacid-treated fine fraction (−60 +140 mesh). Argon may have been lost preferentially over potassium during acid treatment thereby giving a younger date.

(whole rock) 18.4 ± 0.5 Ma
(acid-treated) 11.3 ± 0.3 Ma

24. *H81MH-5* K-Ar
Dacite dike (34°36′19″N, 114°15′32″W; S28, T15N,R19W; Lake Havasu City 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 7.97%, 7.95%, 7.97%; $^{40}Ar^*$ = 2.28 × 10^{-10} mol/gm, 2.30 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 70%, 64%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Microcrystalline groundmass and 25% phenocrysts of altered plagioclase, biotite, and K-feldspar. Biotite is interleaved with chlorite and opaques, and less commonly included with hematite and sphene.

(biotite) 19.8 ± 0.5 Ma

25. *H81MH-39* K-Ar
Dacite dike (34°32′29″N, 114°12′21″W; S24, T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.02%, 8.01%, 7.85%, 8.00%; $^{40}Ar^*$ = 2.24 × 10^{-10} mol/gm, 2.20 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 70%, 66%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Dike 0.5 m thick; cuts augen gneiss. Biotite phenocrysts in microcrystalline matrix; biotite is fresh, subhedral, and has a grain size of 1 mm.

(biotite) 19.8 ± 0.2 Ma

26. *H81WH-62* K-Ar
Dacite dike (34°16′10″N, 114°29′03″W; S8, T2N,R24E; Whipple Mountains SW 7.5′ quad., San Bernardino Co., CA). *Analytical data:* K_2O = 9.07%, 9.09%, 9.07%, 9.08%; $^{40}Ar^*$ = 2.63 × 10^{-10} mol/gm, 2.58 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 79%, 68%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* In Chambers Well dike swarm (Davis and others, 1980; 1982). Beside Chambers Well road in southern exposures of lower plate of the Whipple Mountains detachment fault (Carr and others, 1980). Microcrystalline groundmass contains 25% phenocrysts of plagioclase, biotite, sphene, and altered hornblende. Biotite is fresh, subhedral, and has a grain size 0.5–1 mm.

(biotite) 19.8 ± 0.5 Ma

27. *H82MH-15* K-Ar
Dacite dike (34°36′13″N, 114°11′02″W; S31, T15N,R18W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 7.95%, 7.99%; $^{40}Ar^*$ = 2.43 × 10^{-10} mol/gm, 2.35 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 76%, 71%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Dike 5–8 m thick, beside jeep trail. Intrudes granulitic gneiss (sample H82MH-16). Microcrystalline groundmass and 25% phenocrysts of sericitized plagioclase, biotite, K-feldspar, and opaques. Biotite is interleaved with chlorite and opaques. Age is revised from 19.7-Ma age reported by Nielson (1986).

(biotite) 20.8 ± 0.5 Ma

28. *H81MH-57B* K-Ar
Quartz diorite (34°34′14″N, 114°09′04″W; S9, T14N,R18W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 6.82%, 6.90%, 6.73%, 6.75%; $^{40}Ar^*$ = 2.16 × 10^{-10} mol/gm, 2.08 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 76%, 80%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Dike, associated with leucocratic hornblende quartz diorite. Cuts gneiss. In Burro Canyon. Medium-grained melanocratic biotite-hornblende quartz diorite. Potassium content is slightly low for biotite.

(biotite) 21.5 ± 0.5 Ma

29. *H80MH-310* K-Ar and fission-track
Granite (34°37′21″N, 114°16′36″W; S20, T15N,R19W; Lake Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* (biotite) K_2O = 8.62%, 8.54%; $^{40}Ar^*$ = 2.24 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 57%. *Argon analysis:* M. A. Pernokas. Fission-track (zircon, 6 grains) Ps = 2.69 × 10^6 tracks/cm² (641); Pi = 9.58 × 10^6 tracks/cm² (1144); d = 9.91 × 10^{14} n/cm²; U = 300 ppm. *Counted by:* J. S. Shannon. *Collected by:* K. A. Howard. *Comments:* Small stock of medium-grained sphene-hornblende-biotite monzogranite. Color index 6. Associated with and cuts diorite sampled at station (no. 30) H80MH-311.

K-Ar (biotite) 18.1 ± 0.5 Ma
fission-track (zircon) 16.6 ± 1.7 Ma

30. *H80MH-311* K-Ar
Diorite (34°37′33″N, 114°16′42″W; S20, T15N,R19W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 0.47%, 0.46%, 0.49%, 0.49%; $^{40}Ar^*$ = 0.22 × 10^{-10} mol/gm, 0.22 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 19%, 17%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Medium-grained hornblende diorite in small stock. Intruded by and associated with granite sampled at station (no. 29) H80MH310. Color index 52. Hornblende is euhedral to subhedral, and has brown cores and green rims.
(hornblende) 32.0 ± 1.0 Ma

31. *P81MH-20* K-Ar
Rhyolite dike (34°32′26″N, 114°09′49″W; S20, T14N,R18W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.91%, 8.90%, 8.87%, 8.90%; $^{40}Ar^*$ = 8.10 × 10^{-10} mol/gm, 8.14 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 86%, 84%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* ENE-trending dike 3.5 m thick. Cuts gneiss in the Jupiter mine area. Microcrystalline matrix and 30% phenocrysts of quartz, plagioclase, biotite, microcline, and sphene. Biotite is medium-grained (1–2 mm), subhedral, and intergrown with muscovite and abundant inclusions of apatite, zircon, and calcite.
(biotite) 62.3 ± 1.6 Ma

32. *H81MH-154* K-Ar
Quartz monzodiorite porphyry (34°40′29″N, 114°24′15″W; S1,T15N,R20½W; Topoc 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 7.87%, 7.81%; $^{40}Ar^*$ = 8.24 × 10^{-10} mol/gm, 8.35 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 86%, 83%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Satellitic to Cretaceous granodiorite pluton that underlies Powell Peak. Light gray. Occurs in with similar appearing granite that is cut by Proterozoic(?) pegmatites containing retrograded garnets. Medium grained. Plagioclase mostly euhedral. Color index 6. Biotite is fresh.
(biotite) 72.0 ± 1.8 Ma

33. *P81MH-21B* K-Ar
Sericite-quartz rock (34°31′14″N, 114°14′05″W; S27,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 6.70%, 6.73%, 6.66%; $^{40}Ar^*$ = 5.39 × 10^{-10} mol/gm, 5.35 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 89%, 92%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Highly altered gneiss from shear zone at stope entrance. Pittsburg mine area. Quartz is foliated. Hematite disseminated and fills fractures. Sericite is very fine-grained (0.01–0.1 mm). Sericitic patches may represent altered feldspar.
(sericite) 54.9 ± 1.4 Ma

34. *P81MH-21C* K-Ar and fission-track
Quartz-sericite rock (34°31′14″N, 114°14′05″W; S27,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* (sericite) K_2O = 8.90%, 8.86%, 8.82%; $^{40}Ar^*$ = 8.48 × 10^{-10} mol/gm, 8.40 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 85%, 84%. *Argon analysis:* M. A. Pernokas. Fission-track (zircon, 7 grains) Ps = 12.2 × 10^6 tracks/cm^2 (1209); Pi = 9.85 × 10^6 tracks/cm^2 (454); d = 9.55 × 10^{14} n/cm^2; U = 289 ppm. *Counted by:* J. R. Shannon. *Collected by:* M. A. Pernokas. *Comments:* Veined rock inside stope, Pittsburg mine area. Contains some opaques, K-feldspar, and zircon. Sericite is mostly very fine-grained less than 0.05 mm. Zircons examined for fission tracks strongly zoned; appear to be two populations; date is based on grains having poor intersection and geometry.
K-Ar (sericite) 65.0 ± 1.6 Ma
fission-track (zircon) 78.0 ± 9.0 Ma

35. *P81MH-21A* K-Ar
Sericitized granitic augen gneiss (34°31′14″N, 114°14′05″W; S27,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 10.58%, 10.56%, 10.53%, 10.55%; $^{40}Ar^*$ = 1.44 × 10^{-9} mol/gm, 1.41 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 96%, 94%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Borders a quartz vein near the Pittsburg mine. Highly altered medium- to coarse-grained gneiss. Contains much sericite, clays, and less chlorite and hematite. White mica occurs as fine-grained aggregated crystals (0.1–1 mm grain size).
(white mica) 91.4 ± 2.3 Ma

36. *P82MH-21D* K-Ar
Muscovite-quartz vein (34°31′14″N, 114°14′05″W; S27,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 11.12%, 10.91%, 10.93%, 10.92%; $^{40}Ar^*$ = 1.46 × 10^{-9} = × 10^{-9} mol/gm, 1.44 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 92%, 95%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* White mica concentration along margins of a small quartz vein in augen-gneiss host rock; bottom back side of stope, Pittsburg mine area. White mica averages 0.2 mm in grain size, includes very fine opaques, and occurs as subhedral to anhedral grains.
(white mica) 89.7 ± 2.2 Ma

37. *K81MH-36* K-Ar
Sericitized gneiss (34°32′06″N, 114°10′14″W; S20,T14N,R18W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 10.48%, 10.49%, 10.42%; $^{40}Ar^*$ = 1.42203 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 94%. *Argon analysis:* M. A. Pernokas. *Collected by:* R. D. Knox. *Comments:* Sericitized coatings on joints in sericitized granite gneiss, from hanging wall within 1 m of vein, at prospect near Jupiter mine. Sericite is fine- to medium-grained in gneiss, and joint coatings are coarse-grained muscovite books.
(white mica) 92.0 ± 2.3 Ma

38. *K81MH-62A* K-Ar
Quartz-sericite rock (34°34′33″N, 114°17′04″W; S6,T14N,R19W; Lake Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 11.1%, 11.1%, 11.3%, 11.1%; $^{40}Ar^*$ = 1.66 × 10^{-9} mol/gm, 1.70 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 92%, 96%. *Argon analysis:* M. A. Pernokas. *Collected by:* R. D. Knox. *Comments:* Altered rock near quartz vein, 100 m N of Wing mine. Rock contains opaques. White mica is as coarse as 0.5 mm.
(white mica) 102 ± 2.6 Ma

39. *G81BW-167* K-Ar
Microdiorite dike (34°23′33″N, 114°05′09″W; S12,T12N,R15W; Parker Dam 15′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 0.821%, 0.823%; $^{40}Ar^*$ = 4.16 × 10^{-9} mol/gm, 4.48 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 80%, 86%. *Argon analysis:* M. A. Pernokas. *Collected by:* J. W. Goodge. *Comments:* Cuts augen gneiss. Fine grained hornblende diorite, containing biotite, clinopyroxene, and sphene. Color index 45. Amphibole is concentrated in the dike center, suggesting igneous sorting. Amphibole is green, subhedral, fine grained (0.5 mm), and may be metamorphic.
(hornblende) 332 ± 16.3 Ma

40. *H87MH-29* K-Ar
Augen gneiss (34°33′02″N, 114°13′38″W; S14,T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.4%, 8.39%; $^{40}Ar^*$ = 1.67 × 10^{-10} mol/gm, 2.41 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 95%, 92%. *Argon analysis:* J. K. Nakata. *Collected by:* K. A. Howard. *Comments:* More than 6 m from the nearest dike in a densely diked zone. Hornblende-biotite granodiorite augen gneiss. Color index 8. Biotite is lepidoblastic and fresh.
(biotite) 188 ± 4.7 Ma

41. *H82MH-16* K-Ar
Granulitic gneiss (34°36′11″N, 114°11′05″W; S31, T15N,R18W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.71%, 8.74%; $^{40}Ar^*$ = 7.62 × 10^{-10} mol/gm, 4.91 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 84%, 82%. *Argon analysis:* M. A. Pernokas. *Collected by:* K. A. Howard. *Comments:* Along jeep trail, several dike widths from dike sampled as H82MH-15 (no. 27).

(biotite) 49.2 ± 10.5 Ma

42. *P81MH-6* K-Ar and fission-track
Granodiorite augen gneiss (34°37′12″N, 114°17′17″W; S19,T15N,R19W; Lake Havasu City N 7.5′ quad., Mohave Co., AZ). *Analytical data:* K-Ar (biotite) K_2O = 8.26%, 8.19%, 8.26%, 8.22%; $^{40}Ar^*$ = 7.98 × 10^{-10} mol/gm, 8.13 × 10^{-10} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 74%, 89%. *Argon analysis:* M. A. Pernokas. Fission-track (zircon, 7 grains) Ps = 3.72 × 10^6 tracks/cm² (1190); Pi = 10.10 × 10^6 tracks/cm² (1619); d = 1.03 × 10^{15} n/cm²; U = 304 ppm. *Counted by:* J. R. Shannon. *Collected by:* M. A. Pernokas. *Comments:* Medium grained, seriate gneiss. Color index 10. Biotite occurs as subhedral books, and is fresh except for a few percent interleaved with chlorite.

K-Ar (biotite) 66.7 ± 1.7 Ma
fission-track (zircon) 22.6 ± 1.9 Ma

43. *P81MH-9* fission-track
Granodiorite (34°25′01″N, 114°09′08″W; S16,T13N,R18W; Lake Standard Wash 7.5′ quad., Mohave Co., AZ). *Analytical data:* (zircon, 7 grains) Ps = 3.43 × 10^6 tracks/cm² (839); Pi = 4.40 × 10^6 tracks/cm² (539); d = 1.00 × 10^{15} n/cm²; U = 137 ppm. *Counted by:* J. R. Shannon. *Collected by:* M. A. Pernokas. *Comments:* Dark, medium- to fine-grained biotite-hornblende granodiorite, probably Proterozoic in age. Color index 15. Abundant opaques.

(zircon) 46.4 ± 5.4 Ma

44. *P81MH-22* K-Ar
Porphyritic granite gneiss (34°29′10″N, 114°13′46″W; S10,T13N,R19W; Standard Wash 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 7.97%, 7.96%; $^{40}Ar^*$ = 1.30 × 10^{-9} mol/gm, 1.33 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 87/, 93%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Medium- to coarse-grained biotite syenogranite gneiss. Biotite is olive-colored, anhedral, fine-grained (0.1–1 mm), and includes opaques along cleavage.

(biotite) 111 ± 2.8 Ma

45. *H83MH-67* K-Ar
Amphibolite (34°33′22″N, 114°05′55″W; S13, T14N,R18W; Buck Mountains SE 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 0.412%, 0.415%; $^{40}Ar^*$ = 6.3896 × 10^{-11} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 32%. *Argon analysis:* J. K. Nakata. *Collected by:* K. A. Howard. *Comments:* More than 3 dike widths from the nearest dike. Medium grained. Color index 50. Bears opaques, quartz, epidote. Amphibole is green-brown and is in aggregates consisting of fine (0.1 mm) subhedral grains.

(hornblende) 104 ± 2.6 Ma

46. *P81MH-10* K-Ar
Granite (34°38′24″N, 114°21′27″W; S16, T15N,R20W; Franconia 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 9.06%, 9.03%; $^{40}Ar^*$ = 9.41 × 10^{-9} mol/gm, 9.16 × 10^{-9} mol/gm, 9.09 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 97%, 97%, 97%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Medium-grained monzogranite containing microcline. Color index 5. Biotite occurs as fresh books, locally associated with minor muscovite; some biotite shows pleochroic halos.

(biotite) 597 ± 11 Ma

47. *81MH-155* K-Ar and fission-track
Tonalite (34°40′48″N, 114°24′43″W; S36, T16N,R20½W; Topoc 7.5′ quad., Mohave Co., AZ). *Analytical data:* K-Ar (biotite) K_2O = 8.48%, 8.49%, 8.46%, 8.42%; $^{40}Ar^*$ = 1.32 × 10^{-8} mol/gm, 1.38 × 10^{-8} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 89%, 98%. *Argon analysis:* M. A. Pernokas. Fission-track (zircon, 7 grains) Ps = 4.28 × 10^6 tracks/cm² (1507); Pi = 3.48 × 10^6 tracks/cm² (614); d = 1.01 × 10^{15} n/cm²; U = 107 ppm. *Counted by:* J. R. Shannon. *Collected by:* K. A. Howard. *Comment:* Medium-grained biotite tonalite.

K-Ar (biotite) 863 ± 21.6 Ma
fission-track (zircon) 73.8 ± 7.5 Ma

48. *H81BW-25* K-Ar and fission-track
Gneiss (34°24′20″N, 114°07′14″W; S3, T12N,R18W; Parker Dam 15′ quad., Mohave Co., AZ). *Analytical data:* K-Ar (biotite) K_2O = 8.97%, 8.91%; $^{40}Ar^*$ = 1.72 × 10^{-9} mol/gm, 1.18 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 89%, 84%. *Argon analysis:* M. A. Pernokas. Fission-track (zircon, 7 grains) Ps = 8.358 × 10^6 tracks/cm² (1465); Pi = 6.20 × 10^6 tracks/cm² (544); d = 1.02 × 10^{15} n/cm²; U = 189 ppm. *Counted by:* J. R. Shannon. *Collected by:* K. A. Howard. *Comment:* Medium-grained biotite granite gneiss.

K-Ar (biotite) 130 ± 3.3 Ma
fission-track (zircon) 81.7 ± 8.7 Ma

49. *P81BK-12* K-Ar
Augen gneiss (34°41′32″N, 114°08′19″W; S28, T16N,R18W; Buck Mountains NE 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 8.70%, 8.75%, 8.86%, 8.75%; $^{40}Ar^*$ = 1.5638 × 10^{-9} mol/gm, 1.56103 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 89%, 87%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Inequigranular biotite granodiorite augen gneiss containing medium- to coarse-grained feldspar augen. Biotite and minor epidote are in fine-grained aggregates. Biotite is interleaved with small amount of chlorite.

(biotite) 120 ± 3.0 Ma

50. *P81BK-13* K-Ar
Amphibolite (34°41′50″N, 114°08′22″W; S28, T16N,R18W; Buck Mountains NE 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 1.029%, 1.024%, 1.029%, 1.026%; $^{40}Ar^*$ = 3.15 × 10^{-9} mol/gm, 2.93 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 94%, 94%. *Argon analysis:* M. A. Pernokas. *Collected by:* M. A. Pernokas. *Comments:* Medium grained. Contains quartz and minor opaques, biotite, apatite, and sphene. Hornblende is pale to light greenish brown, and occurs as fresh, subhedral to anhedral grains (0.5–1 mm grain size).

(hornblende) 1372 ± 34 Ma

51. *81BK-7A* K-Ar and fission-track
Granodiorite gneiss (34°39′34″N, 114°09′27″W; S9, T15N,R18W; Buck Mountains 7.5′ quad., Mohave Co., AZ). *Analytical data:* K-Ar (biotite) K_2O = 7.66%, 7.72%, 7.70%; $^{40}Ar^*$ = 3.15 × 10^{-9} mol/gm, 3.14 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 90%, 91%. *Argon analysis:* M. A. Pernokas. Fission-track (zircon, 7 grains) Ps = 7.77 × 10^6 tracks/cm² (1497); Pi = 5.84 × 10^6 tracks/cm² (562); d = 1.03 × 10^{15} n/cm²; U = 176 ppm. *Counted by:* J. R. Shannon. *Collected by:* K. A. Howard. *Comments:* Medium-grained hornblende-biotite granodiorite gneiss. Biotite is unstrained and fresh.

K-Ar (biotite) 264 ± 6.6 Ma
fission-track (zircon) 81.6 ± 8.6 Ma

52. *H87MH-30* K-Ar
Granite gneiss (34°33′13″N, 114°12′33″W; S13, T14N,R19W; Crossman Peak 7.5′ quad., Mohave Co., AZ). *Analytical data:* K_2O = 7.15%, 7.14%; $^{40}Ar^*$ = 1.24 × 10^{-9} mol/gm; $^{40}Ar^*/\Sigma^{40}Ar$ = 71%. *Argon analysis:* J. K. Nakata. *Collected by:* K. A. Howard. *Comments:* Leucocratic biotite granite gneiss. Weathered. Red-brown biotite (1-mm grain size) is partly intergrown with chlorite.

(biotite) 116 ± 3 Ma

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The 1983 revision of this geologic time chart was prepared by the Geologic Names Committee for U.S. Geological Survey use. It supersedes the 1980 chart. Numerical ages of chronostratigraphic boundaries are subject to many uncertainties besides the analytical precision of the dating. The placement of boundary stratotypes and the achievement of international agreements on these ages is a slow process subject to much revision and review. Recent studies and revisions of the geologic time scale of especial interest are reported in *A geologic time scale,* by W. B. Harland, A. V. Cox, P. G. Llewellyn, C. A. G. Pickton, A. G. Smith, and R. Walters, 1982: Cambridge University Press, 132 p.; *The decade of North American geology 1983 geologic time scale,* by A. R. Palmer, 1983: Geology, v. 11, p. 503–504; and *The chronology of the geological record,* N. J. Snelling (ed.), 1985: Blackwell Scientific Publishers, The Geological Society, Memoir No. 10, 343 p.

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