



The Pima mining district, Arizona--a geochronologic update

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THE PIMA MINING DISTRICT ARIZONA A GEOCHRONOLOGIC UPDATE*

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INTRODUCTION

The Pima mining district, one of the largest porphyry copper districts in the United States, is located south-southwest of Tucson, along the eastern pediment of the Sierrita Mountains in Pima County, Arizona (fig. 1). The mining district has produced 4.6 billion pounds of copper, 183 million pounds of molybdenum, 87 million pounds of lead, 233 million pounds of zinc, 40 million ounces of silver and 58,000 ounces of gold through 1975 (Keith, pers. commun.). Mineralization, related to Laramide igneous activity, occurs in Paleozoic sedimentary rocks, Mesozoic sedimentary and volcanic sequences, and in Paleocene igneous rocks. Post-mineralization, coarse-grained alluvial-clastic deposits rest in fault contact with Precambrian to Paleocene rocks. Stratigraphic and structural studies by Cooper (1960, 1973), Lacy (1959), Lacy and Titley (1962), Lynch (1968), Titley and Lynch (1968), Weaver (1971) along with geochronologic studies by Creasey and Kistler (1962), Damon and Bikerman (1964), Damon and Mauger (1966) and Marvin and others (1973) have indicated that the geologic complexities of the mining district are far from understood. The eight new K-Ar ages reported here (Table 1) provide additional temporal and spatial constraints on the interpretation of this complex geology. Previously reported K-Ar ages (Table 2) recalculated using constants recommended by Steiger and Jager (1977) are also included for comparison.

GEOLOGY

San Xavier Fault

A geologic map of the district (fig. 2, modified after Cooper, 1973), illustrates the geologic framework of the area and delineates the surface trace of the San Xavier fault, a major low-angle structural feature. The geology of the northeastern part of Figure 2 is only schematic because the area is mainly covered with alluvium, and detailed geologic information from exploration drilling is not available. Figure 3 shows a schematic, northwest cross-section for Twin Buttes to the Pima-Mission mine area. There is little agreement among the various investigators working in this area as to the extent, direction and chronology of movement along the low-angle San Xavier fault. Regional thrusting, low-angle gravitational tectonics and low-angle normal faulting have been suggested in an effort to explain the kinematics of displacement. Typically,

the fault surface is an undulating, irregular gouge zone of variable thickness. The eroded upper plate covers an area more than 100 km² and ranges in thickness from a few meters to approximately 600 m. Three large open pit mines [Pima, Mission, and San Xavier North (fig. 2)] and many small underground mines have been developed in the rocks of the upper plate. Two major hypotheses on the origin and mechanism for low-angle movement of the San Xavier fault have been developed.

Cooper (1960), after extensive geologic mapping, proposed a mid-Tertiary, post-Helmet Fanglomerate age for movement along the San Xavier fault. The Helmet Fanglomerate (Cooper, 1960), a coarse-grained clastic sequence interbedded with volcanics, is indicative of rapid erosion and deposition during the

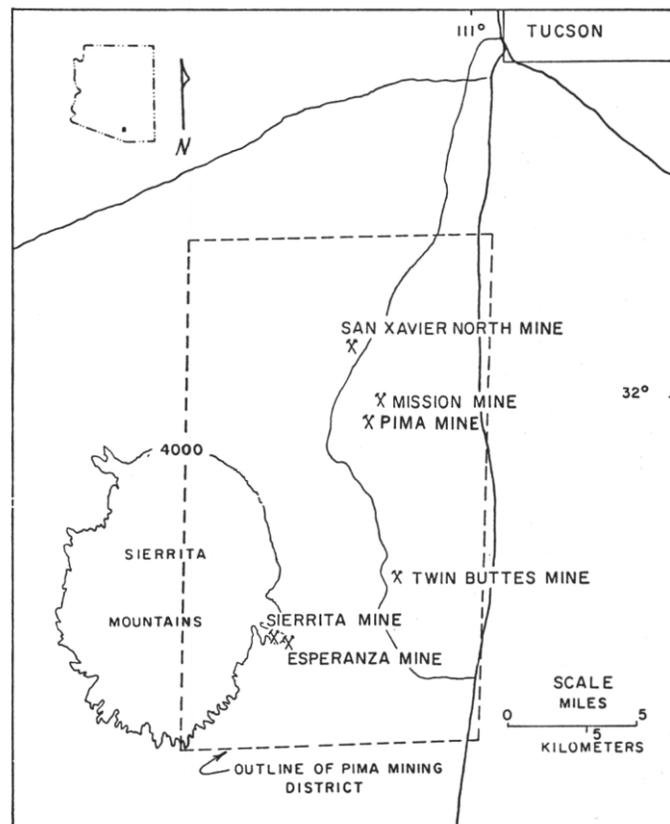


Figure 1. Pima mining district and porphyry copper mines.

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Table 1. K-Ar analytical data on samples from the Pima mining district, Pima Co., Arizona

| Sample No. | Sample description and location | Percent K | Radiogenic argon-40 ($\times 10^{-12}$ mole/g) | Percent atmospheric argon-40 | Age in m.y. |
|----------------|--|-------------------|---|------------------------------|----------------|
| 1) UAKA-78-64 | K-feldspar, mineralized quartz monzonite porphyry. The groundmass is altered, sample from a depth of 138 to 166 meters, drill hole 1SX-18, San Xavier North Mine Lat. $32^{\circ} 01.61'$, Long. $111^{\circ} 04.78'$. | 7.93 | 812.1 806.6 810.9 | 4.7 5.7 5.2 | 58.0 ± 1.2 |
| 2) UAKA-75-118 | Sericite, quartz-sericite-pyrite vein cutting quartz monzonite porphyry at Pima Mine on 2710-ft bench. Lat. $31^{\circ} 59.25'$ N, Long. $111^{\circ} 04.48'$ W. | 8.41 | 847.7 833.9 | 4.8 5.2 | 56.7 ± 1.2 |
| 3) RM-9-63 | Muscovite, albite-muscovite-quartz-beryl pegmatite intrusive in Ruby Star Granodiorite (UAKA-76-46). Lat. $31^{\circ} 59.1'$ N, Long. $111^{\circ} 07.8'$ W. | 8.99 | 825.0 | 3.0 | 52.2 ± 1.1 |
| 4) UAKA-76-46 | Biotite, Ruby Star Granodiorite of Cooper (1973). It is similar to UAKA-75-116 in hand specimen. Lat. $31^{\circ} 52.33'$ N, Long. $111^{\circ} 08.07'$ W. | 7.74 | 700.3 | 22.0 | 51.4 ± 1.2 |
| 5) UAKA-75-116 | Biotite, slightly chloritized, granite from drill core hole A180 at Pima Mine. Sample taken 152 meters below San Xavier fault surface. Lat. $31^{\circ} 59.2'$ N, Long. $111^{\circ} 4.20'$ W. | 7.37 | 653.4 640.2 | 8.2 8.2 | 49.9 ± 1.0 |
| 6) UAKA-76-45 | Biotite, Ruby Star Granodiorite TRS (?) of Cooper (1973) about 4 kilometers WNW of Pima Mine. Lat. $32^{\circ} 00.09'$ N., Long. $111^{\circ} 06.87'$ W. | 7.60 ₅ | 558.2 559.0 554.5 564.6 | 13.8 14.2 12.8 13.0 | 41.9 ± 0.9 |
| 7) UAKA-78-63 | Muscovite granite, San Xavier North Mine from a depth of 616 to 629 m. San Xavier fault is at a depth of 613 meters. The barren basement granite is porphyritic and contains pegmatitic veins. Drill hole 2SX-18. San Xavier North Mine, Lat. $32^{\circ} 01.66'$ N, Long. $111^{\circ} 04.70'$ W. | 7.68 ₄ | 490.5 483.0 480.1 | 7.8 8.0 8.0 | 36.0 ± 0.8 |
| 8) UAKA-74-89 | Biotite, slightly chloritized, porphyritic biotite andesite from drill core hole A414 at Pima Mine. Lat. $31^{\circ} 59.25'$ N, Long. $111^{\circ} 03'$ W. | 6.91 | 316.1 319.6 | 7.91 7.16 | 26.3 ± 0.6 |

Constants used:

$$\lambda_{\beta} = 4.963 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_{\epsilon} = 0.581 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda = 5.544 \times 10^{-10} \text{ yr}^{-1}$$

$${}^0\text{K}/\text{K} = 1.167 \times 10^{-4} \text{ atom/atom}$$

mid-Tertiary magmatic episode. The fanglomerate lies east and north of the San Xavier fault (Cooper, 1973). Cooper interpreted displacement along the fault to be about 10 km, with movement of the upper plate in a north-northwesterly direction. From structural data and gross lithologic similarities, Cooper (1971) concluded that the Pima-Mission ore body represents the displaced upper part of the Twin Buttes ore body which had been translated northward. Based on the apparent lack of offset of andesite dikes across the San Xavier fault in the Twin Buttes area (fig. 2), Cooper deduced that the latest movement on the fault predated these dikes.

Lacy and Titley (1962) and Weaver (1971), on the other hand, proposed an indeterminate amount of eastward displacement along the San Xavier fault, in response to intrusion and doming by the Laramide Ruby Star Granodiorite batholith which forms the northeastern flank of the Sierrita Mountains. This implies Paleocene easterly downslope gliding of the upper plate. Weaver (1971) indicated that a number of small Eocene or Oligocene quartz monzonite porphyry stocks intruded the faulted upper plate.

K-AR AGES FROM THE PIMA MINING DISTRICT

Sampling

Eight new potassium-argon ages provide new data about the age of mineralization and structural history of the Pima mining district.

Sample UAKA 74-89 is from drill hole A414 located near the northeast property boundary of the Pima mine. A biotite concentrate was obtained from primary biotite phenocrysts in an andesite dike that has been cut by a one-half-meter thick gouge zone correlated with the San Xavier fault. The dike is weakly propylitized and does not contain sulfide mineralization. Sample UAKA 75-116 is a primary biotite concentrate from a drill core of weakly propylitized, medium- to coarse-grained microcline granite taken about 150 m below the gouge zone of the San Xavier fault in the Pima mine area. Although some disseminated sulfide was noted in the core, the granite is essentially unmineralized. Sample UAKA 75-118 was collected on the 2,710-ft (826-m) bench of the Pima mine. Sericite was separated from a quartz-sericite-pyrite vein cutting

Table 2. Available K-Ar ages on the Pima Mining district

| Sample No. | | K-Ar Age (m.y.) | | | Mineralization | Relation To San Xavier Fault | Resetting No. | Ref. |
|------------|-------------|--------------------|------------|------------|----------------|------------------------------|---------------|------|
| | | Muscovite Sericite | Biotite | Feldspar | | | | |
| 9 | D1-7 | | 25.0 ± 1.0 | | No | U | No | 2 |
| 8 | UAKA 74-89 | | 26.3 ± 0.6 | | No | U | No | 1 |
| 10 | #2 | | 27.0 ± 1.0 | | No | U | No | 6 |
| 11 | RM-2a-64 | | | 31.4 ± 1.2 | No | U | No | 7 |
| 12 | RM-1-64 | | 28.5 ± 1.1 | | No | U | No | 3 |
| 7 | UAKA 78-63 | 36.0 ± 0.8 | | | No | L | Yes | 1 |
| 13 | #3 | | 36.7 ± 1.0 | | No | O | Yes | 6 |
| 6 | UAKA 76-45 | | 41.9 ± 0.9 | | No | O | Yes | 1 |
| 15 | #5 | | | 48.6 ± 2.0 | Yes | U | Yes | 6 |
| 16 | #6 | | | 48.8 ± 2.0 | Yes | O | Yes | 6 |
| 5 | UAKA 75-116 | | 49.9 ± 1.0 | | No | L | Yes | 1 |
| 4 | UAKA 76-46 | | 51.4 ± 1.2 | | No | O | Yes | 1 |
| 14 | #4 | | 46.7 ± 2.0 | | No | U | Yes | 6 |
| 3 | RM-9-63 | 52.2 ± 1.1 | | | No | O | Yes | 1 |
| 17 | Rm-3-64 | | 54.7 ± 1.9 | | Yes | O | Yes | 4 |
| 2 | UAKA 75-118 | 56.7 ± 1.2 | | | Yes | U | No | 1 |
| 1 | UAKA 78-64 | | | 58.0 ± 1.2 | Yes | U | ? | 1 |
| 20 | #D1-5 | | 58.4 ± 2.0 | | Yes | O | No | 2 |
| 21 | — | | 58.4 ± 2.1 | | Yes | O | No | 5 |
| 22 | D1-6 | | 59.2 ± 2.0 | | No | U | No | 2 |
| 23 | | | 59.9 ± 2.6 | | Yes | O | No | 5 |
| 24 | PED 8-62 | | 60.1 ± 1.9 | | No | O | ? | 8 |
| 25 | #9 | | 61.6 ± 2.0 | 57.5 ± 2.0 | Yes | O | ? | 6 |
| 26 | D1-4 | | 63.1 ± 2.0 | | No | O | No | 2 |
| 27 | RM-3-62 | | 62.0 ± 2.0 | | Yes | O | No | 4 |
| 28 | Rm-1-62 | | 64.0 ± 2.0 | | Yes | O | No | 4 |
| 19 | #11 | | 68.5 ± 2.0 | | No | O | No | 6 |

Reference 1) This paper; 2) Creasey and Kistler, 1962; 3) Damon and Bikerman, 1964; 4) Damon and Mauger, 1966; 5) Kelly, 1976; 6) Marvin and others, 1973; 7) Shafiqullah and others, this guidebook; 8) Damon and others, 1964.

Relation to San Xavier fault—U = upper plate, L = lower plate, O = outside the present outline of the fault.

Constants used:

$$\lambda_{\beta} = 4.963 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_e = 0.581 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda = 5.544 \times 10^{-10} \text{ yr}^{-1}$$

$$^{40}\text{K}/\text{K} = 1.167 \times 10^{-4} \text{ atom/atom}$$

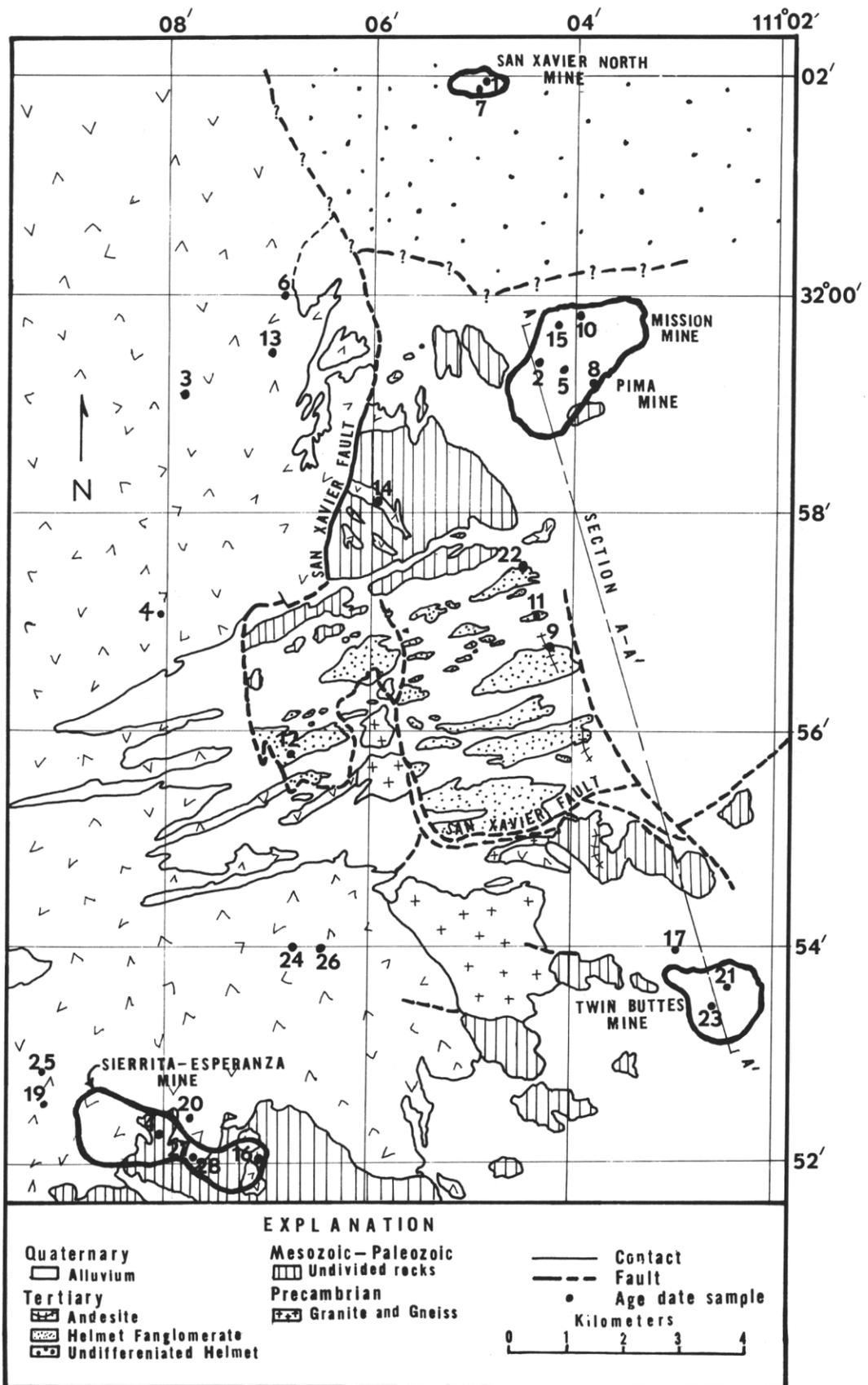


Figure 2. Outline of San Xavier fault in generalized geologic map (after Cooper, 1973). In San Xavier North Mine area, geology is schematic. Location of dated samples refer to samples in Tables 1 and 2. Note that Helmet Fanglomerate is exposed in the upper plate rocks east of fault. Section A-A' is in Figure 3.

THE PIMA MINING DISTRICT

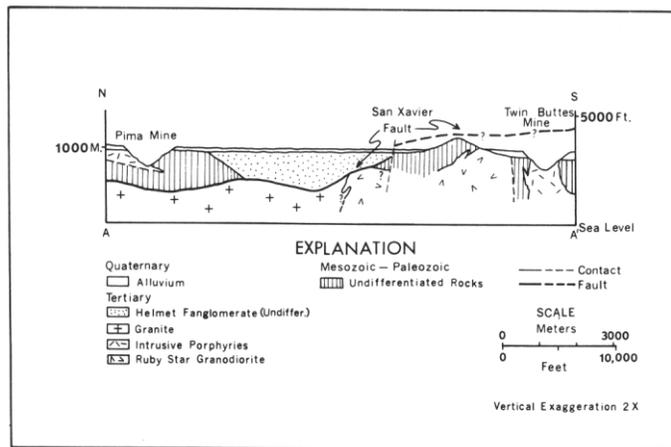


Figure 3. Generalized geologic cross-section along A-A' of Figure 2, showing the relationship of the San Xavier fault relative to the Pima and Twin Buttes area.

a weakly mineralized quartz monzonite porphyry. L. J. Jansen and S. A. Anzalone provided drill cores from the San Xavier North mine from which samples UAKA 78-63 and UAKA 78-64 were taken. UAKA 78-63 is a muscovite separate from a coarse-grained, poorly foliated and propylitized microcline granite which King (1976) considered Precambrian in age. This granite was found in drill hole 2SX-18 at a depth of 613 to 629 m. The drill hole encountered a fault at 613 m which correlates with the San Xavier fault (Jansen, pers. commun.). Sample UAKA-78-64 is a potassium feldspar from a mineralized quartz monzonite porphyry at a depth of 238 to 166 m in drill hole 1SX-18, at the San Xavier North mine.

Age of Mineralization

A Laramide age for mineralization is supported by the 56.7 ± 1.2 m.y. age of sericite alteration at the Pima mine and the 58.0 ± 1.2 m.y. age of K-feldspar from the San Xavier North mine. Mineralization at the Sierrita-Esperanza and Twin Buttes mine has previously been shown to be Laramide (Creasey and Kistler, 1962; Damon and Mauger, 1966; Kelly, 1977; Marvin and others, 1973).

Cooper (1960) pointed out lithologic similarities between the Twin Buttes and Pima-Mission areas. Geologic studies and exploration work within the last several years have shown other similarities such as distribution and control of the type of mineralization (Barter, 1976; Titley and Lynch, 1968; Kelly, 1976; Jansen, 1976; King, 1976). Our radiometric dating work confirms that the various ore bodies within the district are temporally related.

K-Ar ages from mineralized rocks within the mining district range between 55 and 64 m.y. (Table 2). This is too long a period of time for a single episode of porphyry copper emplacement. Mineralization in the Esperanza Sierrita complex appears to have taken place earlier than in other ore bodies, indicating at least two episodes of mineralization-alteration in the district. The 56.7 ± 1.2 m.y. sericite age from the late-stage quartz-sericite-pyrite vein within the mineralized quartz porphyry reflects the termination of mineralization. The age of the Ruby Star Granodiorite batholith suggests a genetic and temporal relationship between the two, with mineralization occurring at the margin of the batholith. Mineralization at the Esperanza-Sierrita complex cuts a quartz monzonite porphyry which, in turn, cuts the Ruby Star Granodiorite.

Age of Cenozoic Basement Rocks

Laramide and post-Laramide plutonic basement rocks range in age from 68 m.y. in the southwestern corner of the area (fig. 2) to 36 m.y. in the San Xavier North mine area (Table 2). In the Pima-Mission complex, the San Xavier fault separates the barren basement granite (49.9 ± 1.0 m.y., no. 5) from the overlying mineralized monzonite (56.7 ± 1.2 m.y., no. 2). Muscovite-beryl-pegmatite (52.2 ± 1.1 m.y., no. 3) and biotite granodiorite (51.4 ± 1.2 m.y. no. 4) exposed west of the mine area (fig. 2) are similar in age to the granite. An age of 52.2 ± 1.1 m.y. (no. 3) determined from a coarse-grained pegmatitic muscovite (nos. 27 and 28) is approximately 10 m.y. younger than the mica age of a mineralized porphyry in the Esperanza pit. However, the Ruby Star Granodiorite, the quartz monzonite porphyry in the Esperanza pit and albite from the pegmatite (no. 3) yield similar initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, suggesting consanguinity (Mauger, 1966). The apparent systematic decrease in K-Ar ages from south to north may be due to partial resetting of the basement rocks during the mid-Tertiary magmatic event in southeastern Arizona or to thermal stresses related to movement along the San Xavier fault. If the granite at the San Xavier North mine is indeed a Precambrian rock (King, 1976), its 36.0 ± 0.8 m.y. apparent age indicates that the radiometric clock has been reset and that radiogenic argon-40 accumulated since Precambrian time has been lost. Lee and others (1970) noted an increase in mica K-Ar ages with distance below the Snake River decollement in Snake Ridge, White Pine County, Nevada. They ascribed thermal stresses and degassing of micas to activity along the thrust fault. 2SX-18 (no. 7) is the only drill hole in San Xavier North to penetrate the San Xavier fault (Jansen, pers. commun.). Ten meters of granite below the fault show evidence of shearing. The intensity of shearing decreases in the granite as depth increases beneath the fault plane. Our sample represents 6 m of weakly sheared granite and 6 m of pegmatitic granite having an apparent age of 36.0 ± 0.8 m.y. Marvin and others (1973) reported a 36.7 ± 1.0 m.y. (no. 13) age on a sheared and altered granodiorite 4 km west of the Pima-Mission mine areas and less than 2 km west of the San Xavier fault trace. Granite (no. 5) 150 m below the fault is 49.9 ± 1.0 m.y. old (no. 5). The possible effect of thermal stress on sample no. 7 is not clear, but its close proximity to the fault and young age may reflect thermal resetting by movement along the San Xavier fault. Both Table 2 and Figure 2 show a crude correlation between reduced K-Ar ages and distance from the fault. Sample no. 14, from a granodiorite porphyry intruded into the sedimentary rocks of the upper plates less than 1 km from the fault trace, has an age of 46.7 ± 2.0 m.y.

The Pima Mining district has a mid-Tertiary tectonic history similar to that of the Rincon-Santa Catalina-Tortolita core complex to the northeast. The cataclastically deformed Ruby Star Granodiorite below the San Xavier fault has a N.75-80°E. lineation (Weaver, 1971), which is similar to that found in cataclastically deformed rocks of the core complexes. The gneisses of the core complexes yield cooling ages of 28 to 22 m.y. (Creasey and others, 1977; Damon and others, 1963; Mauger and others, 1968). The Leaterwood Quartz Diorite was partially to completely reset during this core-complex formation. Mauger and others (1968) noted the reduction of K-Ar ages towards the core of the gneissic complex. Northward reduction of K-Ar ages from the lower plate of the San Xavier fault may reflect proximity to an unexposed gneissic core complex creating a similar situation.

Reduced ages may also be due to diffusional loss of argon during the mid-Tertiary magmatic episode. Damon and Bikerman (1964) noted that magmatism was most intense during an interval of approximately 3 million years, between 25 and 28 m.y. ago within a radius of 80 km centered in the Sierrita Mountains. The presence of rhyodacitic or andesitic dikes in the district and a reduction of K-Ar ages implies a heat source at depth. Mid-Tertiary plutons in southeastern Arizona are not uncommon (Shafiqullah and others, this guidebook). Possible effects of buried heat sources are under investigation.

The ages of feldspar (Table 2) from gangue in the Mission mine and of altered diorite from the Esperanza Mine are 48.6 ± 2.0 m.y. (no. 15) and 48.8 ± 2.0 m.y. (no. 16), respectively (Marvin and others, 1973). A granodiorite dike in Mesozoic rocks in the upper plate yields a similar 46.7 ± 2.0 m.y. age. If the Pima-Mission ore zone is a slide block representing the beheaded segment of the Twin Buttes deposits, then the Esperanza-Sierrita and Twin Buttes areas were probably subjected to the same degree of alteration and argon-loss during the mid-Tertiary episode.

Age of Faulting

We have noted earlier that the San Xavier North and Pima-Mission ore bodies are in the upper plates of the San Xavier fault. Roots or projections of the upper plate lithologies have not been found below the fault by exploration drilling. The fault separates 58.0 ± 1.2 m.y. old (no. 1) mineralized quartz monzonite from a 36.0 ± 0.8 m.y. old (no. 7) barren granite of the lower plate. This relationship suggests post-36 m.y. movement along the fault.

Late Oligocene or early Miocene displacement along at least part of the San Xavier fault is suggested by the 26.3 ± 0.6 m.y. old (no. 8) lamprophyre dike cut by the fault. Structural sections presented on the geologic map of the Twin Buttes quadrangle (Cooper, 1973) show lamprophyre dikes (27.0 ± 1.0 m.y., no. 10) cutting the San Xavier fault in the Mission mine area. This relationship has not been confirmed by the Mission mine geologists (Jansen, 1976, pers. commun.) nor by underground mapping in the Palo Verde shaft at the Eisenhower property (Mackenzie, 1963). Other drill holes in the areas have intersected similar dikes either above or below the gouge zone of the San Xavier fault. The juxtaposition of andesite dikes both above and below the fault in drill hole A414 may be coincidental. The amount of displacement of the dikes along the fault is, at present, indeterminate.

Since 26 to 27 m.y. old dikes are offset and 36 to 50 m.y. old plutonic rocks are present both to the west of and beneath the upper plate, eastward movement along the fault during the Laramide (Paleocene) (Weaver, 1971; Lacy and Titley, 1962) is untenable. Extensive exploratory drilling in the upper plate has disproved Weaver's (1971) idea that a number of Eocene and Oligocene stocks intrude the fault. Creasey and Kistler (1962) used a 25.0 ± 1.0 m.y. old dike (no. 9) to suggest a minimum age for faulting. Since the San Xavier fault does cut an andesite dike in the Pima mine area, it is possible that the 25 m.y. old andesite dikes in the Twin Buttes area may also be cut by the fault.

Andesite flows and tuffs separating the lower and middle Helmet Fanglomerate have biotite K-Ar ages of 28.5 ± 1.1 m.y. (no. 12) and 31.4 ± 1.2 m.y. (Table 2, no. 11). Ages of andesitic and lamprophyric dike swarms in the district range between 25 and 27 m.y. The presence of the Helmet Fanglomerate in the upper plate and its absence west of the San Xavier

fault trace (fig. 2), also suggest post-Helmet Fanglomerate movement along the fault, presumably during the waning of mid-Tertiary magmatism in southern Arizona (Damon, 1971; Damon and Mauger, 1966).

The San Xavier fault is not the only mid-Tertiary fault involved in the structural and mineralogic evolution of an important porphyry-copper deposit in Arizona. The San Manuel mining district lies approximately 90 km to the north-northeast of the Pima mining district. The San Manuel fault intersects and displaces the Kalamazoo and San Manuel porphyry copper deposits (Lowell, 1968; Lowell and Guilbert, 1970). Faulting postdates the 28.3 ± 0.6 m.y. old (Shafiqullah and others, this guidebook) basal Cloudburst Formation (Creasey, 1965, 1967; Lukanuski and others, 1975). It is assumed that movement along the San Manuel fault presumably took place during uplift and doming associated with the formation of the Rincon-Santa Catalina-Tortolita gneissic core complexes during the mid-Tertiary magmatic-tectonic episode and may correlate with movement along the San Xavier fault.

Correlation of Upper and Lower Plates

Cooper (1960, 1971, 1973) suggested that the Pima-Mission mine area, i.e. the upper plate, slid north from the Twin Buttes area. Data from extensive drilling in the area around the San Xavier North mine suggests a lithologic similarity between the San Xavier North and Pima-Mission area. The San Xavier North mine area appears to be an upper part of the Pima-Mission area (Jansen, 1976, pers. commun.).

Cogenetic biotite and feldspar in the Esperanza-Sierrita area have K-Ar ages of 61.6 ± 2.0 and 57.6 ± 2.0 m.y., respectively (Table 2, no. 25), indicating either argon loss from the feldspar or the unlikely presence of excess argon in the biotite. If K-feldspar (no. 1) from altered quartz monzonite at the San Xavier North mine also lost radiogenic argon-40, the monzonite would be older than its 58.0 ± 2.0 m.y. computed age, and would be contemporaneous with rocks in the Sierrita-Esperanza area. It has been suggested that the Pima-Mission and San Xavier North areas represent different plates that slid off the Twin Buttes area. However, their counterparts from the Esperanza-Sierrita area have not been found. We suggest that the Esperanza-Sierrita area may represent the root of the San Xavier North mine area even though the lithologies of the two areas are somewhat different.

Several low-angle faults have been found in southeastern Arizona (Drewes, 1976, 1978; Davis, 1975). It is evident that the mining district consists of at least three plates with the Esperanza-Sierrita and Twin Buttes mines in the lower plate, the Pima-Mission area in a second plate and the San Xavier North mine in a third. The San Xavier fault is thus a complex low-angle fault with a series of imbricate plates.

Generalized contour maps of the San Xavier fault surface and geologic sections through the Pima mine show that the gentle eastward slope of the fault surface may be cut by orthogonally north-northwest striking, westwardly dipping faults (Jansen, 1976; Langlois, 1976). These faults are assumed to be related to a late Cenozoic Basin and Range disturbance that created the Tucson basin to the north and east (Shafiqullah and others, 1976b).

CONCLUSIONS

The geologic complexity of the Pima mining district is largely due to superposition of two magmatic and three tectonic episodes within the last 65 m.y. (Shafiqullah and others,

1976a). The first magmatic and tectonic episode occurred during Laramide time when plutonic rocks ranging in composition from granodiorite to quartz monzonite intruded east-north-east striking, Paleozoic and Mesozoic sedimentary and volcanic sequences, as well as Precambrian granite. The intrusive history culminated in hydrothermal mineralization of some of the stocks from 64 to 57 m.y. ago. The second intrusive and tectonic episode occurred during the mid-Tertiary at which time the coarse-grained clastic Helmet Fonglomerate was being deposited in tectonic basins 31 to 27 m.y. ago. Apparent younging of plutonic rocks toward the north is probably related to diffusional loss of argon-40 resulting from mid-Tertiary magmatic heating. The complex and imbricate San Xavier fault developed at the culmination of the mid-Tertiary magmatic-tectonic episode.

The intrusive quartz monzonite porphyries, the clastic and carbonate sedimentary host rocks for the ore, and the mineralization indicate a relationship between the Pima-Mission, Twin Buttes and San Xavier North areas. Analogous but less obvious lithologic similarities exist between the Esperanza-Sierrita and San Xavier North mines. The K-Ar data suggests that these ore deposits may have been connected prior to low-angle faulting. A third tectonic episode, characterized by normal faulting, occurred during the past 12 m.y. This episode typifies the Basin and Range disturbance and is responsible for the present physiography of the Pima-Mission and San Xavier North mines.

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