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U-Pb ISOTOPE AGES OF GRANITIC PLUTONS NEAR CANANEA, SONORA

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ABSTRACT

The Cananea "granite" crops out in the Cananea mining district, which includes some of the most important known copper deposits in Mexico. The area is in northern Sonora, approximately 100 km. southeast of the twin cities of Nogales, Arizona-Sonora on the international border.

By means of isotopic analyses of U-Pb systems in cogenetic suites of zircon from 2 different phases of the pluton, its interpreted age has been firmly established at 1440 $\pm$ 15 m.y. Cananea "granite", actually a quartz monzonite is lithologically characteristic of a major Precambrian suite of anorogenic, consanguineous plutons of porphyritic granodiorite to granite. Constituents of this previously recognized series, which crop out throughout the southwestern U. S. and into northern Mexico consistently yield zircon radiometric ages within the interval 1425-1475 m.y.

Major younger intrusions in and nearby the Cananea district include Cuitaca granodiorite and Chivato monzodiorite. These bodies yield apparent zircon ages of 64 $\pm$ 3 and 69 $\pm$ 1 m.y. respectively. Although more precise geochronologic relationships between young plutons, the adjacent layered sequence, and cross-cutting, brecciated, quartz porphyry plugs are needed; correlation exists between major plutonism and mineralization.

The Precambrian age of the Cananea "granite" precludes its chronological association with the younger mineralized plugs and should be taken into account in future planning of exploration.

INTRODUCTION

The Cananea "granite" crops out in the Cananea mining district which is in the northern part of the state of Sonora, Mexico and lies roughly between the border towns of Nogales and Douglas - Agua Prieta about 60 km. south of the international border (Fig. 1). More than 1.1 billion kg. of copper, and a significant quantity of molybdenum as well as lesser amounts of zinc, lead, silver, and gold have been produced from the district (Velasco, 1966).

Controversy exists as to the geological age of the Cananea "granite" and its relationship to the Cuitaca granodiorite, which is demonstrably intrusive. The contact between the Cananea "granite" and adjacent strata crudely conforms to the base of the Capote quartzite, which has been correlated with the Bolsa quartzite of Cambrian age in southeastern Arizona (Emmons 1910; Mulchay and Velasco, 1954). Emmons (1910) suggested a Precambrian age for Cananea "granite" based upon his interpretation of an unconformity between the granite and overlying Cambrian quartzite. Valentine (1936) disagreed with this suggestion and argued that the intensely altered Cananea pluton is probably Mesozoic or "Laramide" age. He believed that the Cananea "granite" was derived from the Cuitaca granodiorite and was spatially related to the somewhat younger quartz porphyries which are associated with major mineralization in the district. Recent accounts of the geological relationships within the district are consonant with Valentine's interpretation (Ridge, 1972; R. Ayala and G. A. Salas, personal communication). Isotopic analyses of U-Pb systems in cogenetic suites of zircon from two different phases of the Cananea mass have firmly established the interpreted age at 1440 $\pm$ 15 m.y. Furthermore, our studies suggest that the Cuitaca granodiorite, whose interpreted age is 64 $\pm$ 3 m.y., is more likely to be chronologically related to mineralization.

GEOLOGIC FRAMEWORK AND PREVIOUS STUDIES

Ransome (1904, 1916) made a detailed study of the Bisbee quadrangle and later attempted to correlate Paleozoic sections in various parts of Arizona. This work was complemented by two papers written by Gilluiy (1956) and Gilluly, Cooper and Williams (1954) which deal with the general geology and late Paleozoic stratigraphy and central Cochise County. More recent research carried out by Cooper and Silver (1964) in the Dragoon Quadrangle, provides detailed data pertaining to the older Precambrian rocks as well as the general geology. Radiometric studies by Silver and Deutsch (1963) confirmed the Precambrian age of one of the plutons within the Dragoon Quadrangle and continuing research by Silver (1968) has unravelled the history of magmatism which characterizes this older Precambrian terrane. Livingston and Damon (1968) and De Cserna (1971) provide thorough reviews of known Precambrian rocks in Arizona and Mexico.

The oldest rocks of the Precambrian suite consist of metamorphosed graywackes, slates, and lava flows that form the Pinal schist. Following accumulation, these strata were intruded during two different episodes of plutonism at about 1650 $\pm$ 25 and 1450 $\pm$ 25 m.y. ago. These distinct generations of intrusive rocks are also distinguished by petrographic characteristics. The older plutons consist of equigranular quartz diorite to quartz monzonite whereas the younger group is rather consistently medium to coarse-grained granodiorite to granite with conspicuous large, pink feldspar megacrysts which commonly show rapakivi texture. Numerous localities exist where late Precambrian or early Paleozoic sediments rest unconformably upon this older Precambrian crystalline basement (Shride, 1967).

More recently, considerable effort has been expended in attempts to unravel the stratigraphy of rocks of Mesozoic age which crop out in ranges just north of the international border in southern Arizona (Hayes and Landis, 1964; Hayes, 1970; Hayes and Raup, 1968, Drewes, 1971; Cooper, 1970; and Simons, 1972). In Sonora, we have pursued reconnaissance geologic and geochronologic studies in an attempt likewise to understand the Mesozoic history which is characterized by two cycles of accumulation of volcanic and sedimentary rocks of mid-Mesozoic and late Mesozoic age (Anderson, Silver and Cordoba, 1969; Anderson and Silver, 1974). Each cycle of accumulation is followed by an episode of plutonism, the latter of which is often classed as "Laramide Age." Titley (1972a; 1972b) noted the association of some porphyry copper deposits with the tectonic and depositional patterns of these two Mesozoic cycles. Livingston _et_._al_. (1968) discussed the K-Ar geochronology of porphyry copper deposits in Arizona and Livingston (1973) suggested a provocative model for the generation of the porphyry deposits.

At Cananea only parts of this long history have been recorded. Based on the field work of Emmons (1910), Valentine (1936), Mulchay and Velasco (1954) and Velasco (1966) the geologic history represented at Cananea may be summarized (slightly modified from Velasco, 1966) as follows:

1. Beds of carbonate and clastic rocks accumulated on Precambrian basement during Paleozoic time.

2. Uplift and erosion of the Paleozoic section

3. Accumulation of several thousand feet of volcanic and volcaniclastic rocks whose ages may range throughout the Mesozoic.

4. Intrusion of masses of granodiorite, diorite and syenite which cut both Paleozoic and Mesozoic sequences and which are probably at least late Cretaceous in age.

5. Intense garnetization, alteration, and mineralization that is closely related to the quartz porphry intrusives and controlled by structural features.

THE CANANEA GRANITE

Occurrence and Petrography

The main mass of the Cananea "granite" which comprises two major phases trends west-northwest and underlies an area of a few square kilometers west of the town of Cananea (Fig. 1). One phase, which consists of medium-to-coarse-grained porphyritic quartz monzonite, is characterized by grayish-pink microcline and microperthite, present as subhedral phenocrysts as long as a few centimeters and, as anhedral grains between subhedral to euhedral yellowish-white laths of sericitized plagioclase commonly a few to several millimeters long. Gray quartz is abundant as anhedral grains among the well-formed plagioclase and mafic grains and may be present with plagioclase as inclusions within the microcline phenocrysts. Stubby subhedral to anhedral flakes of dark green biotite, commonly altered to chlorite are the main mafic constituent. Common accessories include opaque minerals, apatite and zircon with rare euhedral to subhedral crystals of sphene as long as 2 mm. Barite is present in small quantity. Table 1, summarizes the mineralogical composition.

Round and oval-shaped grains of quartz characterize the fine grained-phase of the Cananea "granite". This rock may contain phenocrysts of microcline as large as those found in the quartz monzonite in addition to smaller plagioclase crystals. The groundmass consists of anhedral grains of quartz and feldspar commonly a few tenths of a millimeter in widest dimension.

Isotopic Results and Interpreted Age

About 64 kg. pounds of coarse-grained porphyritic quartz monzonite were collected in the upper reaches of Capote Creek and a small block ($\sim$ 2 kg.) of quartz-feldspar porphyry was collected near the southeastern end of the outcrop area (Fig. 1). Fractions from the two cogenetic suites of zircon were selected for isotopic analysis on the basis of their uranium content, with the objective of obtaining the greatest range in the degree of discordance.

The analytical results are given in Tables 2 and 3 and plotted on a Concordia diagram in Fig. 2. Analytical uncertainties in the laboratory at the time the analyses were completed were $\pm$ 1.5 percent for the concentration values. These reflect an estimate of the precision of the particular experiment, compared with the long term precision standard in this laboratory. In Fig. 2 the errors assigned to each analyzed point are represented by an error figure (similar to a zircon shape) whose dimensions are assigned from experience in this laboratory with factors affecting the precision. Overall precision is shown from the fit of the points for the various samples to the straight line drawn through them in Fig. 2. The errors assigned to the interpreted ages are based upon consideration of the overall quality of the analyses made for the various samples.

All of the analyzed zircon suites show some discordance and fall below the curve of the Concordia diagram. The interpreted ages of zircon crystallization are derived from the intersection of the upper end of a chord, defined by the plotted position of analyzed cogenetic zircon fractions, with the Concordia curve.

Four cogenetic fractions from the Cananea porphyritic quartz monzonite yield results which define a linear pattern of discordance and whose upper intersection with the Concordia curve gives an interpreted age of 1440 $\pm$ 15 m.y. These fractions reveal a consistent relationship of higher U content to greater discordance.

Two cogenetic fractions derived from a feldspar-quartz porphyry phase of the Cananea mass define a slightly younger upper intersection with the Concordia curve but which falls within error limits assigned to the main phase. This younger age is also suggested by the plotted positions of the analyzed fractions which lie slightly to the young side of the 4 point chord. These two fractions show a consistent, similar relationship of discordance to uranium content as did the fractions from the porphyritic quartz monzonite.

Geologic Arguments Concerning the Age of the Cananea Granite

Emmons (1910) in the initial comprehensive geological report on the Cananea district correlated the oldest quartzite and carbonate beds with Bolsa quartzite and Abrigo limestone of Cambrian age. This correlation was based on lithologic similarities and comparable thickness to Paleozoic sections in Arizona because no fossils had been discovered in the Cananea rocks. Emmons (1910) noted arkose and conglomerate at the base of the quartzite and he believed the sedimentary rocks rested nonconformably upon Precambrian granite, i.e. the Cananea "granite," which he thought to be distinct from the intrusive Cuitaca granodiorite. Emmons' interpretation as he noted, was contrary to ideas "more or less prevalent among those who have previously studied the district . . ."

Valentine (1936) suggested that the Paleozoic section was Carboniferous age on the basis of Mitchell's (1928) discovery of poorly preserved fossil fragments. However, he argued against the Precambrian age assignment for the Cananea "granite" on the following grounds (p. 58-59):

"1. Although there is a marked tendency for the quartzite bedding to parallel the granite contact from Capote Pass to Kirk Peak (Fig. 1), there are embayments into the quartzite, which cannot be explained without the assumption of faulting, of which there is no evidence.

2. Along this same contact there is at least one place where a granite dike intrudes the quartzite.

3. The granite is definitely intrusive into the Henrietta formation near the point where the sawmill road crosses Huajolote Creek.

4. The granite in the Capote and Oversite Mines is definitely intrusive into sediments and volcanics, and is so intimately associated with the quartz porphyry and diabiase as to suggest that these latter formations were the residual concentrates from the magma which produced the granite."

Mulchay and Velasco (1954) presented a detailed correlation between the Paleozoic section at Cananea and sections which crop out in the Bisbee area and Swisshelm mountains. They agreed with Valentine upon the post-Precambrian age for the Cananea "granite" and added (p. 628):

"Faulting of early age, probably prior to the deposition of the volcanic rocks, may have been responsible for the present position of some of the intrusive rock masses. In the Capote Mine on the third and fourth levels the northwest-striking Ricketts fault zone, with apparent offset of about 800 ft., has been sealed by a dike-like mass of Cananea granite which gradually increases in size with depth. In lower levels of the mine the granite forms a large southeast-plunging mass generally following the course of the Ricketts Zone. The granite is not known southeast of the Capote-Oversight mine areas and the Ricketts fault does not appear in the volcanics southeast of Capote Basin, but several plugs of Colorado quartz porphyry cut the volcanics along the assumed general southeast trend of the Ricketts zone. These porphyritic intrusives may be the upward expression of a batholithic mass of granite deeply buried beneath the volcanic rocks in the southeast end of the district."

Valentine (1936) reported the presence of light-colored dikes and irregular masses of quartz-orthoclase aplite which, where they cropped out along the contact of the Cananea "granite," showed a more distinct intrusive relationship than the granite. Valentine believed that the granite and aplite were the same age. These intrusive dikes provide his strongest geologic arguments pertaining to the age of the granite.

Additional comments by Valentine suggest ambiguities:

"The (Cananea) granite differs in many ways from the other abyssal intrusives. The magma seems to have been more viscous, possibly because of lower temperatures at the time of intrusion, or because of its siliceous composition. The basis for this conclusion is the simple contact between the granite and other formations, whether the boundary is a fault or not. Granite dikes extending into other formations are rare, but the few which have been found prove that it is intrusive and not the basement formation on which the sediments were deposited. Occasionally the aplite dikes, derived from the Cananea granite magma, extend beyond the granite into other formations."

The arguments concerning the relationships of the Cananea "granite" to adjacent units suggest to us that detailed mapping of the granite contact, with rigorous attention paid to genetic and cross-cutting relationships among similar appearing igneous phases, is required. Mingling between Precambrian quartz porphyry and cross-cutting Mesozoic and/or Tertiary porphyries may have resulted in heretofore unrecognized complexity.

Regional Correlation and Geochronological Interpretation

The Cananea "granite" is lithologically and chronologically characteristic of a major Precambrian suite of anorogenic, consanguineous plutons of porphyritic granodiorite to granite (Fig. 3) (Silver, 1968). Constituents of this previously recognized series, which crop out throughout the southwestern United States and into Northern Mexico, consistently yield radiometric ages within the interval 1425-1475, m.y. (Silver and McKinney, 1962; Silver and Barker, 1968 ; Erickson, 1968).

At Cananea, important primary ore deposits are commonly associated with vertical, cylindrical, breccia-filled structures which occur in a roughly elongate northwesterly-trending zone (Fig. 1). Perry (1961) and Velasco (1966) noted the close association of these breccia pipes with quartz porphyry intrusive plugs and suggested that mineralization is closely related to the intrusives. The source of the quartz porphyry has been debated since geologists arrived at Cananea. However, Valentine (1936) suggested that they were probably related to the Cananea "granite" and succeeding summaries (Ridge, 1972; R. Ayala and G. A. Salas, personal communication) have agreed with his interpretation.

The Precambrian age of the Cananea "granite" precludes its chronological association with the cross-cutting quartz-porphyries and those plutonic rocks of the Cananea district which clearly intrude Paleozoic and younger strata.

At La Colorada ore body which, according to Valentine (1936), includes a plug of quartz porphry typical of the latest intrusives, Damon (1965) made K-Ar isotope studies on a phlogopite-molybdenite rock sample. The results yield a date of 58.5 $\pm$ 2.1 m.y. which provides a minimum age for the body whose maximum age, on the basis of geological relationships can be no older than early Mesozoic.

STUDIES OF "LARAMIDE" AGE PLUTONIC ROCKS

Occurrence and Petrography

In an effort to establish the age of major post-Precambrian plutonism in the Cananea district, two plutons which clearly intrude the surrounding Paleozoic and Mesozoic strata were studied.

Outlines of the Cuitaca and Chivato plutons as modified from the map of zone 9 (Survey of Met. Min. Deposits of Mexico, 1969) are shown in Fig. 4. According to Emmons (1910) and Valentine (1936), the Cuitaca mass is characterized by light-pink to gray, medium-to-coarse-grained granodiorite (see Table 4) that becomes finer-grained as contacts are approached.

Along Route 2 west of the town of Cananea where we collected samples for geochronologic studies, it is not unusual for the texture of Cuitaca to be somewhat porphyritic. The rock consists of subhedral to anhedral crystals of andesine which vary from 2 to more than 5 mm in long dimension, scattered flakes of biotite and hornblende, and rare grains of commonly anhedral orthoclase, set in a mosaic of quartz, orthoclase and plagioclase grains for the most part less than .5 mm in diameter. In places optically continuous quartz in the groundmass may be distributed among the feldspar. Quartz in the groundmass tends to be amoeboid and poikilitic although some larger grains have inclusion - poor interiors suggestive of phenocrysts with amoeboid margins.

Chivato monzodiorite (see Table 4) is a medium-gray rock which consists of subhedral laths of plagioclase, whose long dimension varies from about 4 mm to a few tenths of a millimeter. Biotite occurs as subhedral to anhedral flakes usually < 1 mm in greatest dimension. The largest grains of subhedral to anhedral pyroxene are rarely more than 2 mm long and commonly enclose or lie adjacent to opaque grains and apatite. Incipient to advanced alteration of the pyroxene to green amphibole is common. Quartz and perthitic orthoclase occur as interstitial grains as large as 1 mm.

Analytical Results and Age Interpretation

Results of isotopic analyses for two cogenetic fractions from each of the Cuitaca and Chivato plutons are presented in Tables 5 and 6. The behavior of isotope systems for these zircon fractions is analogous to older suites (Banks and Silver, 1966) with the addition that small corrections which fall within the analytical error may be made for any inherited lead which is present. The ratios of Pb^{207}/U^{235} and Pb^{207}/Pb^{206} are sensitive monitors to the effects of inherited lead. This component can be corrected for in a straightforward manner by plotting the lower intersection of a chord, defined by each individual fraction and an assumed old component (for this region $\sim$ 1.8 b.y.), with the Concordia curve. The resulting Pb^{206}/U^{238} ratios can then be interpreted as above. Apparent ages for Cuitaca granodiorite and Chivato monzodiorite are 64 $\pm$ 3 m.y. and 69 $\pm$ 1 m.y. respectively.

CONCLUSIONS

Isotopic studies of zircons from the Cananea "granite" establish its age at 1440 ± 15 m.y. as well as its correlation with a regionally occurring plutonic suite. Its age is also suggested by the simple crudely conformable contact between the granite and overlying Capote quartzite, which was observed by previous workers (e.g. Valentine, 1936, plate 1, section C-C). This is compatible with the regional stratigraphic relationships that exist between Precambrian basement rocks and overlying clastic units as reported by Ransome (1916), Gilluly (1956) and Cooper and Silver (1964), Shride (1967). The existence of large plutons of "Laramide" age in the Cananea district suggests their possible consanguinity with the quartz-porphyry intrusives and associated mineralization. In light of its age and proximity to ore-bearing intrusives, the Cananea "granite" could be mineralized and should be considered as a possible host for additional ore bodies.

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APPENDIX

Analytical Procedure

Fractions of the total zircon populuation were selected for isotopic analysis on the basis of their uranium content, with the objective of obtaining the greatest range in the degree of discordance. The zircon fractions were fused, using about six times their weight of purified sodium tetraborate glass as a flux, for varying time periods depending upon the sample weight. The analytical procedure for extracting lead is the same as that described by Silver and others (1963). The few modifications made of the proven techniques include the substitution of 10 ml pyrex beakers for teflon during the final digestion of the lead dithizonate and a change in loading technique from running PbS on a tantalum filament to $PbNO_3$ in a silica-gel-phosphoric acid medium on a rhenium filament (modified from the procedure of Cameron and others, 1969). Uranium was extracted by normal ion exchange techniques.

Isotopic analyses were made on 12-inch, single focusing, solid source mass spectrometers constructed at the California Institute of Technology. Data obtained on the electron multiplier and simple collector have been corrected for mass discrimination and for very slight nonlinearity in the shunt factors. Mass spectrometer reproducibility is generally $\pm$ 1 percent for radiogenic Pb^{206}/Pb^{204} ratios, and $\pm$ 0.3 percent for the Pb^{206}/Pb^{207}, Pb^{206}/Pb^{208} and U^{235}/U^{238} ratios. Mass spectrometer precision (1σ) for Pb^{206}/Pb^{207} averages about $\pm$ 0.2 percent as does precision for Pb^{206}/Pb^{208} ratios. Uncertainty for Pb^{206}/Pb^{204} is about $\pm$ 0.5 percent.

The common lead blank contributed by reagents and glassware is slightly less than those determined by Silver and others (1963). The use of the silica-gel-phosphoric acid loading technique permits us to run 1 μg quantities of lead that permits significant reduction of sample size. This combined with the smaller amount of flux used (6 x the weight of sample rather than 10 x) can reduce the blank significantly. Contribution of common lead from the rest of the procedure has also been reduced so that the range is about 0.06 to 0.04 μg.

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