UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mineral Resource Assessment of the Kofa National Wildlife Refuge, Arizona

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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Contents

Page

Illustrations

Figures

5. Map showing major geographic areas from which stream-sediment and stream-concentrate samples were anomalous for one or more elements. The areas area: 1) Kofa-North Star, 2) southern Plomosa, 3) Sheep Tank, 4) New Water, 5) Red Rock, 6) Southern Castle Dome, and 7) Northern Castle Dome.

6. Map showing the results of high resolution airborne spectral measurements in the Red Rock Dam area of the KNWR.

7. Map showing a negative Bouger gravity anomaly over the KNWR area. The data for the map are from West and Sumner (1973).

8. Map showing the locations of mining districts in the KNWR area.

9. Gold grade versus tonnage for past production from mining districts in the KNWR compared with grades and tonnages for other selected gold mines in the western United States. Total contained ounces of gold are noted on the diagonal lines. Gold grade is given in both Troy ounces per short ton and parts per million (ppm). One Troy ounce per short ton equals 34.2857 ppm. Data are from Keith, 1978; Bagby and Berger, 1985; Durning and Buchanan, 1984; Walenga, 1986; O'Neil, 1985; and Anonymous, 1986.

10. Map showing the locations and total numbers of unpatented mining claims within the KNWR as of 1984. Patented claims are limited to the Kofa and Castle Dome mining districts (fig. 8) and total 20 in the Kofa district and 26 in the Castle Dome district.

11. Grade and tonnage curves for three mineral deposit types. Deposits within the KNWR that had past productions that were large enough to plot on the curves are identified. The number of deposits used to define the curves is given in the upper right corner of each graph. Grades for precious-metals are given in grams per metric tonne and tonnages are given in millions of metric tonnes. The conversion is: Troy ounce per short ton) x (34.2857) = (grams per metric tonne). A. Grade and tonnage distributions for polymetallic veins (Bliss and Cox, 1986a). B. Grade and tonnage distributions for Comstock epithermal veins (Mosier and others, 1986). C. Grade and tonnage distributions for low sulfide Au-quartz veins (Bliss, 1986).

12. Grade and tonnage distributions for A) hot-spring gold-silver deposits (Berger and Singer, 1987) and B) hot-spring Hg deposits (Rytuba, 1986b).

Tables

INTRODUCTION

The Kofa National Wildlife Refuge (KNWR[1], fig. 1) was created in 1939 to serve as an undisturbed environment for the desert bighorn sheep and other desert fauna and flora. The refuge is managed by the United States Fish and Wildlife Service and presently encompasses 660,000 acres.

In 1974, the Fish and Wildlife Service temporarily withdrew the KNWR from mineral entry; in 1977 they applied to the Bureau of Land Management to withdraw an additional 87,200 acres of public land contiguous with the KNWR as proposed additions to the refuge. In early 1984, the Fish and Wildlife Service entered into an agreement with the U.S. Geological Survey for a two-year mineral survey of the KNWR. The purpose of the survey was to provide a mineral resource assessment of the KNWR that would be of higher certainty than any assessment available at that time and that could be used in the decision-making process regarding the final categorization of the lands. The two agencies agreed that the assessment would require: 1) reconnaissance geologic mapping of the entire area; 2) reconnaissance geochemical sampling of known and (or) suspected mineralized areas; 3) geochemical analyses including both semiquantitative emission spectrographic and atomic absorption methods; 4) thematic mapping by remote sensing in the second year of the agreement only if deemed necessary to augment ground surveys; 5) integration of new data generated under this agreement with any previously available data; and 6) field investigations to begin in the northern proposed additions and end in the southern part of the KNWR.

This mineral assessment of the KNWR was a two-year contract between the U.S. Fish and Wildlife Agency and the U.S. Geological Survey. The contract was outside of continuing U.S.G.S. assessment programs such as CUSMAP and various Bureau of Land Management and U.S. Forest Service Wilderness and roadless area studies. This report was prepared as an account of work done by the U.S. Geological Survey at the request and sponsorship of the U.S. Fish and Wildlife Service. Neither the United States, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, nor any of their employees make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information or interpretations reported herein, or represent that the use of this report would not infringe upon privately owned rights.

GEOLOGIC INVESTIGATIONS

The geologic map (pl. 1) of the KNWR area is a compilation at 1:100,000 from field geologic maps at 1:62,500. The quadrangle geologic maps will be published separately. Map units were simplified for this report by lumping units of similar lithology and tectonic or metamorphic history. The map units shown on plate 1 are discussed below and summarized in the map explanation.

Regional setting

The geologic character of the KNWR region of southwestern Arizona was shaped by a succession of diverse tectonic events and processes: Proterozic

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[1]Throughout the text, KNWR refers to both the present area encompased by the Kofa National Wildlife Refuge and proposed additions. (See figure 1.)

plutonism, Paleozoic cratonic sedimentation, Jurassic continental-arc volcanism and intra-arc sedimentation, Jurassic plutonism and regional metamorphism, Jurassic and (or) Cretaceous thrust faulting, Cretaceous metamorphism, intracontinental basin formation and sedimentation, and late Cenozoic volcanism and crustal extension. The northern third of the region was originally part of the Paleozoic craton of interior southwestern North America, whereas the southern two-thirds is not so closely tied to the craton and is fundamentally part of the Jurassic magmatic arc that extended across the continental margin of southwestern North America (Tosdal and others, 1987). Most of the area of the KNWR is underlain by Jurassic, Cretaceous, and Tertiary rocks.

The age of initial formation of continental crust in southern and western Arizona is about 1,800 to 1,700 m.y. (Anderson and Silver, 1976; Silver, 1978). Proterozoic granite, about 1,700 m.y. old (L.T. Silver, quoted by Miller and McKee, 1971) in the northwestern Plomosa Mountains is the only rock of definite Precambrian age exposed within the KNWR. Variably metamorphosed Paleozoic strata exposed in the Plomosa (Miller, 1966, 1970) and New Water Mountains and in the Alamo Springs area of the northern Kofa Mountains are of the cratonic facies that extends from the Grand Canyon region southwestward at least to the Big Maria Mountains area of southeastern California (Hamilton, 1982; Harding and Coney, 1985), and probably farther south.

Jurassic and Cretaceous rocks in the KNWR can be divided into several units: silicic and intermediate volcanic rocks, largely quartz porphyry; a sedimentary and volcanic rock sequence referred to as the 'rocks of Slumgullion'; the McCoy Mountains Formation, a thick sequence of clastic sedimentary and metasedimentary rocks; granodiorite, granite, and associated pegmatite; and the Orocopia Schist. The first four of these units represent lithologic types that are widespread in southern Arizona and adjacent California and Sonora (Tosdal and others, 1987). The Orocopia Schist occurs chiefly in southern California, and its eastermost exposure is at Neversweat Ridge in the southeast corner of the KNWR (Haxel and Dillon, 1978). The age of the Jurassic(?) and Cretaceous McCoy Mountains Formation (Harding and Coney, 1985; Tosdal and others, 1987) is a major unsolved regional problem. Although Late Cretaceous to early Tertiary granitoid rocks occur in adjacent areas (Reynolds, 1980; Shafiqullah and others, 1980; Davis and others, 1980; Haxel and others, 1984), granitic rocks of this age are probably restricted to one small stock in the KNWR. The significance of several new latest Cretaceous K-Ar dates (see below) is unclear, because partial or complete resetting of K-Ar ages is widespread in southern Arizona and southeastern California (Armstrong and Suppe, 1973; Martin and others, 1982; Shafiqullah and others, 1980). Clarification will require additional K-Ar geochronology, and some U-Pb ages from the KNWR.

Most of the area of the Castle Dome Mountains, Tank Mountains, Kofa Mountains, and New Water Mountains, and parts of the Plomosa Mountains are underlain by middle to late Tertiary volcanic and hypabyssal rocks. Many of the volcanic rocks can be correlated to hypabyssal rocks and the probable location of the vents. The large volume of Tertiary igneous rocks (several tens of cubic kilometers), the abundance of hypabyssal rocks and vents, and the presence of ash flow tuff sheets (Grubensky and others, 1986) demonstrate that this region was a very productive volcanic field. Ash flow tuff in the Picacho Region of southeastern California (Crowe and others, 1979) may have sources in the Kofa and Castle Dome Mountains (Grubensky, and others, 1986). However, correlation of Tertiary rock units even within the KNWR is complicated by mid-Tertiary faulting. The contacts between Tertiary rocks and

Mesozoic supracrustal and plutonic rocks are depositional (unconformities in the Plomosa, northern Kofa, and southern Castle Dome Mountains), high-angle faults (Kofa Mountains), and low-angle faults (northern Kofa Mountains(?), Castle Dome Mountains).

Proterozoic rocks--Map unit Pg

Proterozoic rocks crop out in the northwestern part of the KNWR near and east of Scaddan Mountain. These rocks are shown in plate 1 as map unit Pg and include both the Precambrian quartz monzonite and Precambrian coarse-grained quartz monzonite of Miller (1970). Miller (1970) reported that L.T. Silver obtained a late Early Proterozoic uranium-lead isotopic age of 1,730-1,750 m.y. on zircon from the quartz monzonite.

Miller (1970) described the granitoid at Scaddan Mountain as an even-grained biotite quartz monzonite. Both plagioclase and potassium feldspar are strongly altered. Biotite is variously altered to chlorite and has been recrystallized suggesting metamorphic processes have interacted with the original plutonic rock. Miller (1970) also noted that the southern part of the unit is more leucocratic than the northern part and suggested that they may be two separate intrusions.

The coarse-grained quartz monzonite as mapped by Miller (1970) crops out east of Scaddan Mountain near the confluence of Italian Wash and Apache Wash. This unit is a very coarse-grained biotite quartz monzonite. Some outcrops are medium-grained and contain hornblende. Miller (1970) noted that both feldspars are strongly altered and that biotite and hornblende are chloritized.

Paleozoic rocks--Map unit Pzs

Paleozoic sedimentary rocks crop out in the northwestern portion of the KNWR around Scaddan Mountain, between Scaddan Mountain and Black Mesa, and north of Black Mesa and as calc-silicate and quartzofeldspathic schist and granofels in pendants in Jurassic granodiorite in northeast Kofa Mountains. These rocks are shown as map unit Pzs on plate 1.

Miller (1970) divided the Paleozoic rocks into seven formations based on fossil evidence and correlations of the lithology, sequence, and age of these rocks with other Paleozoic rocks in Arizona. The Cambrian Bolsa(?) Quartzite rests nonconformably on coarse-grained, Precambrian quartz monzonite. This quartzite is relatively pure with well-rounded, coarse quartz grains (Miller, 1970). The Bolsa(?) Quartzite is overlain by the Cambrian Abrigo(?) Formation, a dark purple, green, and black sandy shale with thinly interbedded quartzite lenses. Miller (1970) mapped a disconformity between the Abrigo(?) Formation and the overlying Devonian Martin(?) Formation. The Martin(?) Formation consists of about 100 m of dolomitic limestone, dolomite, and sandy dolomite. The color varies from tan and brown to light gray and black (Miller, 1970). Some outcrops are carbonaceous. The Mississippian Escabrosa Limestone disconformably(?) overlies the Martin(?) Formation (Miller, 1970). The lower half of the Escabrosa Limestone in the KNWR is a massive, light-gray, tan-weathering, sandy dolomite. The upper half is composed of cherty limestone and limestone conglomerate with minor interbedded dolomite (Miller, 1970). Permian units exposed in this area are the Supai Formation, the Coconino Sandstone, and the Kaibab Limestone. The Supai Formation is a maroon quartzite with interbedded limestone and mudstone in its lower half. The Coconino Sandstone is a massively bedded, medium-grained, white to gray vitreous quartzite. The clasts are well-sorted and fairly well-rounded. Large-scale crossbeds occur locally in the upper half (Miller, 1970). The Kaibab Limestone is a light to dark gray, fossiliferous, cherty limestone. The limestone is fine-grained and fossils include Permian brachiopods, corals, and bryozoans.

Miller (1970) mapped Paleozoic(?) rocks south of Interstate 10 on the north flank of Scaddan Mountain. These rocks have experienced a style and degree of deformation unique to this area; the rocks deformed plastically as contrasted to brittly which is common for other rocks in the quadrangle (Miler, 1970). In spite of this deformation, pre-deformation lithologies are recognizable. Miller (1970) correlated these rocks with the unequivocal Paleozoic rocks near Black Mesa. The deformed Paleozoic(?) rocks are included in map unit Pzs in plate 1.

Gneiss--Map unit MzPg

This heterogeneous unit of quartzofeldspathic to amphibolitic, crudely layered gneiss forms the upper plate of the Chocolate Mountains thrust. The gneissic layering predates and is unrelated to the thrust. The protolith(s) of the gneiss is unclear from any evidence within the KNWR. Regionally, the most likely protolith of the gneissic rocks of the upper plate of the Chocolate Mountains thrust are Triassic and (or) Jurassic granitoids (Dillon, 1976; Tosdal, 1986). Some upper-plate gneissic units may be Proterozoic.

Mesozoic rocks

Silicic and intermediate volcanic rocks ('quartz porphyry')--Map unit Jm

This unit consists of variably metamorphosed rhyolitic to dacitic volcanic and associated hypabyssal rocks, commonly quartz porphyry or metavolcanic schist with relict quartz phenocrysts. Welded ash-flow tuff, locally with relict eutaxitic foliation, is common. Other recognizable protolith lithologies include volcanic breccia, hypabyssal intrusions, and volcaniclastic tuff and sandstone. Much of the unit is weakly to strongly foliated meta-quartz porphyry of uncertain protolith.

This unit crops out in the southern Castle Dome Mountains and in the northwestern part of the KNWR. Despite its small area of exposure within the KNWR, the unit is of considerable tectonic significance. Lithostratigraphic units of similar composition and stratigraphic position occur throughout the region of southern Arizona and adjacent Sonora and California. Wherever these volcanic units have been dated by U-Pb isotopic geochronology, they are of Early to Middle Jurassic age (Anderson and Silver, 1978, 1979; Wright and others, 1981). One of these Early to Middle Jurassic U-Pb ages was determined for zircon from quartz porphyry in the central Dome Rock Mountains (the next range west of the northern KNWR) by L.T. Silver (quoted by Crowl, 1979).

The immediate importance of the quartz porphyry unit in the southern Castle Dome Mountains is that it is unequivocally interbedded with the lower part of the 'rocks of Slumgullion' unit. This relation is apparent in the area around the head of the major (unnamed) wash southwest of the Keystone mine, and near Green Cabin, where a welded-tuff several meters thick is interbedded with Slumgullion sandstone, siltstone, and conglomerate. A U-Pb age for these volcanic rocks will provide an age for the 'rocks of Slumgullion' and, by correlation, for the Winterhaven Formation (see below; Haxel and others, 1985).

Sedimentary and volcanic 'rocks of Slumgullion'--Map unit Js

The term 'rocks of Slumgullion' is used to refer to a coherent and regionally extensive unit of slightly to thoroughly metamorphosed Jurassic(?) sedimentary and minor volcanic rocks exposed in the southern Castle Dome Mountains. This informal name, taken from Slumgullion Pass in the southern Castle Dome Mountains, is used pending clarification of the stratigraphic relation of these rocks to the similar Winterhaven Formation of southeasternmost California and southwesternmost Arizona (Haxel and others, 1985).

In the southern Castle Dome Mountains, the 'rocks of Slumgullion' unit is largely argillitic to phyllitic sandstone and siltstone, quartzite, conglomerate, and silicic to intermediate volcanic rocks. Mapping and stratigraphic study of these rocks are still underway, and the only aspects discussed here are two matters that probably will prove to be of regional significance. First, a westward-thickening wedge of sedimentary boulder breccia and conglomerate occurs in the area around Green Cabin. This breccia resembles Tertiary breccia units in the southern Castle Dome Mountains, but two relations indicate that it is part of the 'rocks of Slumgullion' sequence. The sandy matrix of the breccia locally is metamorphosed to sericitic semi-schist or phyllite, whereas the Tertiary breccias are postmetamorphic. Where the breccia wedge thins eastward, it forms several beds of conglomeratic sandstone clearly interbedded with finer-grained sedimentary rocks and minor volcanic rocks of the Slumgullion unit. The tectonic significance of this coarse sedimentary wedge within the 'rocks of Slumgullion' is not yet clear. Second, the 'rocks of Slumgullion' unit crops out in close proximity to the Orocopia Schist, from which it is separated by a middle or late Tertiary detachment fault. Horizontal displacement is probably relatively small, on the order of 1 to 10 km. This spatial association of the Orocopia Schist and 'rocks of Slumgullion' is repeated in the Middle Mountains to the west and at Neversweat Ridge to the east. The close proximity of these two lithotectonic units in southwestern Arizona is consistent with the inference, based on relations in southeastermost California, that the 'rocks of Slumgullion' and Winterhaven Formation were orginally part of the upper plate of the Chocolate Mountains thrust (Haxel and others, 1985).

The 'rocks of Slumgullion' unit is considered Jurassic because both the interbedded volcanic rocks in its basal part and the granitoid rocks that intrude it are believed, based on regional lithologic correlations with U-Pb-dated plutons, to be Jurassic (Haxel and others, 1985).

Sedimentary and metasedimentary rocks--Map units Jp, Jss

In the southwestern Kofa Mountains, Jurassic(?) supracrustal rocks are exposed within a horst block, about 22 km long by 2 to 5 km wide and flanked by Tertiary volcanic and sedimentary rocks, that extends from Engesser mine and Engesser Junction northwest to Big Dick Canyon. The unit consists largely of siltstone and sandstone and their metamorphic derivatives; conglomerate and volcanic rocks are rare. These rocks range from unmetamorphosed siltstone and sandstone through argillite and phyllite to medium- and coarse-grained amphibolite-facies quartzofeldspathic schist. Whether these strata are related to the McCoy Mountains Formation or to the 'rocks of Slumgullion' is unclear. The unmetamorphosed and structually highest sedimentary rocks crop out around Charlie Died Tank; the highest-grade and structurally lowest schists form the small mountain northeast of the Kofa mine, and are accompanied by dikes and intrusive pods of synmetamorphic granite and pegmatite (see below). This progressive increase in textural and mineralogical metamorphic grade takes place over a horizontal distance of about 8 km and through a structural thickness of several km. Some of the details of this remarkable regional-metamorphic progression are obscured by a dense swarm of dikes and small irregular intrusions of Neogene latite, and by small high-angle faults related to the horst-bounding faults. Nonetheless, the rocks in this area can be divided into three readily mappable, intergradational textural metamorphic zones; siltstone and argillite (unit Jss), phyllite, and schist (combined as unit Jp). Metamorphogenic quartz±tourmaline veins, locally containing pyrite, are common through most of the phyllite and schist zones.

In at least one place within the schist zone, quartzofeldspathic schist has been altered to kyanite-bearing quartz-pyrophyllite schist, some of which also contains tourmaline. A pegmatite dike adjacent to this schist contains unusually large and abundant tourmaline crystals. This newly discovered occurence of kyanite in Arizona has several similarities in setting and mineralogy to other occurrences in southwestern Arizona and southeasternmost California (Reynolds and others, 1987). Some of these highly aluminous metasomatic rocks (Wise, 1975) appear to be spatially and possibly genetically associated with gold deposits (e.g. American Girl in the Cargo Muchacho Mountains, California) related to Jurassic plutonism and (or) regional metamorphism (Tosdal and Smith, 1987).

Granitoid rocks--Map unit Jg

Granitic to dioritic rocks of Jurassic or Jurassic(?) age crop out in three areas of the KNWR: the northern Kofa Mountains between Beehive and Red Rock Dam; the southwestern Kofa Mountains, as part of a horst block of crystalline rocks exposed from Engesser Junction and Engesser mine northwest to Big Dick Canyon; and the southern Castle Dome Mountains.

The Jurassic granitoid rocks in the Kofa Mountains comprise three phases: dioritic rocks, granodiorite, and granite. In the southwestern Kofa Mountains, fine-grained, melanocratic dioritic rocks form dikes and small podiform bodies intruding the granodiorite and granite; in the northern Kofa Mountains the mesocratic to leucocratic, fine-grained to pegmatoid dioritic rocks are the oldest phase and form inclusions, in some places gneissic, within the granodiorite and granite. In the northern Kofa Mountains, the outcrop area of the granite is considerably larger than that of the granodiorite; in the southwestern area the two phases are similar in abundance. In the northwestern part of its area of exposure in the southwestern Kofa Mountains, considerable pegmatitie is associated with the granite phase.

The Jurassic granodiorite and granite in the northeastern Kofa Mountains intrude metasedimentary rocks of presumed Paleozoic protolith age. The Jurassic granitoid rocks in the northwestern Kofa Mountains are in contact with the McCoy Mountains Formation, but the nature of this contact is obscured by late Neogene gravel, and possibly some minor faulting. The granodiorite and granite in the southwestern Kofa Mountains intrude the Jurassic(?) supracrustal rocks (units Jss and Jp). These sedimentary rocks are progressively metamorphosed from sandstone, siltstone, and argillite to phyllite and schist (see above). The granitic rocks that intrude the schist, and in a few places those that intrude the phyllite, have been metamorphosed with the schist and phyllite and converted to orthogneiss or, more commonly, schistose metagranite. The abundance of pegmatite dikes and intrusive pods in the highest-grade schist suggests that regional metamorphism and intrusion of the granitic rocks are related; this hypothesis is supported by fabric relations (exposed, for example, in Yaqui Wash) indicating that the granitic phase and associated pegmatite are broadly synmetamorphic.

The Jurassic granitoids in the southern Castle Dome Mountains comprise, from oldest to youngest, mesocratic, texturally and compositionally hetergeneous, dioritic rocks; coarse- to medium-grained K-feldspar-porphyritic hornblende-biotite granodiorite; and coarse- to medium-grained biotite granite, typically rather leucocratic. These granitoids, especially the granodiorite and dioritic rocks, in most areas are somewhat to strongly propyliticallly altered. These granitoid units intrude the sedimentary and volcanic 'rocks of Slumgullion'; intrusive ages relative to metamorphism of the Slumgullion unit are unclear.

The grandiorite, granite, and dioritic rocks of the KNWR are similar, in both lithology and their association with one another, to late Middle to early Late Jurassic granitoid rocks that are common in the region of southeastern California and southern Arizona (Silver, 1971; Powell, 1981; Hamilton, 1982; Dillon, 1976; Tosdal and others; 1987).

Orocopia Schist--Map unit Mzo

Orocopia Schist occurs in the KNWR in three areas: the southeastern Castle Dome Mountains, the southwestern Castle Dome Mountains, and Neversweat Ridge. These three exposures of Orocopia Schist, the structurally lowest lithotectonic unit in southwestern Arizona, probably represent anticlinal culminations along the Chocolate Mountains anticlinorium, which extends eastward into this region from the Chocolate Mountains of southeasternmost California (Haxel and others, 1985). Orocopia Schist in the southern Castle Dome Mountains and at Neversweat Ridge consists almost entirely of biotite-muscovite quartzofeldspathic schist (metagraywacke), with rare semipelitic schist, hornblende schist (metabasalt), ferromanganiferous quartzite (metachert) and siliceous marble, and talc-actinolite rock (probably derived from ultramafic rock). Several of these lithologies have been found only as a single small bodies. The protolith of the Orocopia Schist is Jurassic and Cretaceous(?); its metamorphic age is Late Cretaceous (Haxel and Tosdal, 1986). The quarztofeldspathic schist has flysch-like compositional layering transposed from sedimentary bedding and contains porphyroblasts of black, graphitic albite that are characteristic of the Orocopia and related schists (Haxel and Dillon, 1978). The Orocopia Schist at Neversweat Ridge is strongly intruded and hydrothermally altered by numerous dikes and small irregular intrusive bodies of Tertiary(?) granite and rhyolitic porphyry (unit Tg). This body of Orocopia Schist plus intrusions is surrounded by Quaternary gravel except at its north end, where it is in fault contact with the 'rocks of Slumgullion'.

The Orocopia Schist is overlain by the synmetamorphic Chocolate Mountains thrust, a Late Cretaceous regional fault that extends discontinuously eastward to the southern Castle Dome Mountains from the southeastern corner of California (Haxel and others, 1985, fig. 1). The upper plate of the Chocolate Mountains thrust in the southern Castle Dome Mountains is composed of Mesozoic and (or) Proterozoic gneiss (map unit MzPg); the thrust zone is marked by mylonitic rocks developed largely from the base of the upper plate. In the southeastern Castle Dome Mountains, the thrust has been modified by middle to late Tertiary detachment faulting, in part localized along the thrust (Haxel and Grubensky, 1984). The thrust is entirely or substantially unmodified only along 2 to 3 km of its trace on the east side of the Orocopia Schist.

McCoy Mountains Formation--Map unit KJm

Siliciclastic sedimentary rocks in the northern part of the KNWR originally designated as the Livingston Hills Formation by Miller (1966, 1970) have been reassigned to the McCoy Mountains Formation by Harding and Coney (1985). Harding (1982) suggested a lithologic correlation of low-grade metasedimentary rocks in the northwestern corner of the Kofa Mountains with the Winterhaven Formation of southeasternmost California, but these rocks actually have much stronger affinities and closer association with the McCoy Mountains Formation, from which they are separated only by the few kilometers of alluvium between the southeastern corner of the Livingston Hills and Beehive.

The McCoy Mountains Formation in the northwestern Kofa Mountains consists of moderately metamorphosed sandstone, siltstone, and conglomerate. Lithologically similar rocks in the northern Plomosa Mountains include some metamorphosed quartz porphyry, as interbedded volcanic rocks, hypabyssal intrusions, or both. These silicic igneous rocks may be of use in obtaining a U-Pb isotopic age for the McCoy Moutains Formation.

The age(s) of the McCoy Mountains Formation is a major unsolved regional geologic problem. The upper part of the formation contains fossil angiosperm wood, indicating a middle Cretaceous or younger age (Pelka, 1973; Tosdal and others, 1987). On the other hand, the base of the formation is interbedded with volcanic quartz porphyry of probable Early or Middle Jurassic age (Harding, 1982), paleomagnetic data indicate a Jurassic age (Harding and others, 1983), and the formation is intruded by dioritic dikes of probable Jurassic age (R.M. Tosdal, U.S. Geological Survey, 1984). The solution to this dilemma is not apparent. Perhaps the most likely possibility is that the McCoy Mountains Formation as presently defined actually includes two separate units (Tosdal and others, 1987). The lower of these two units would be of Early to Middle Jurassic age and approximately correlative with the continental redbeds of Miller (1970) and the Winterhaven Formation and 'rocks of Slumgullion' (see above). The upper unit would be of Late Cretaceous age. Whether this scheme is compatible with the internal stratigraphy and deformational and metamorphic history of the McCoy Mountains Formation remains to be determined (Tosdal and others, 1987). Resolution of the problem will require U-Pb isotopic ages for several igneous rocks in contact with the McCoy Mountains Formation.

Granite and granodiorite--Map unit KJg

This unit comprises two granitic masses that are distinct from one another in composition and appearance but consistently occur together. These crop out in the southeastern Castle Dome Mountains. The older rock type is medium- to coarse-grained biotite granite and subordinate granodiorite, in part chloritically altered and locally porphyritic. A spotted appearance in outcrop is typical. This lithology is intruded by coarse- to medium-grained, highly leucocratic, relatively quartz-rich granite, typically less altered. A similar pair of granitic units crops out in the northernmost Mohawk Mountains, 40 km to the southeast. The age and regional affinities of these granitoids are unknown.

Alaskitic granite--Map unit Kg

This highly leucocratic muscovite-bearing granite crops out as a single small stock in the southwestern Castle Dome Mountains. The medium-grained to pegmatitic granite is intruded by pegmatite dikes. The main granite body and sparse associated dikes of pegmatite and granite intrude the Orocopia Schist.

Tertiary rocks

Tertiary igneous rocks in the KNWR are of three compositional types. Silicic rocks (rhyolite, rhyodacite, and dacite) are most abundant, forming non-welded and welded tuff, vitrophyre, lava flows, and dikes, plugs, and domes. In the Plomosa Mountains, andesite lava flows and massive, coarse andesite breccia cover large areas. Basalt flows are exposed in the New Water and northeastern Kofa Mountains; these flows lie stratigraphically above most of the silicic rocks and are the youngest igneous rocks in the region.

Granite and rhyolitic porphyry--Map unit Tg

This granite and related porphyry intrude and hydrothermally alter the Orocopia Schist at Neversweat Ridge. These intrusive rocks form several small stocks about 1 km in largest map dimension, and a northwest-southeast trending dike swarm (not mapped). The granite is fine- to medium-grained, contains biotite and subordinate hornblende, and is unfoliated. The rhyolitic to latitic porphyry is densely to sparsely porphyritic, with phenocrysts of feldspar and, less commonly, quartz. There appear to be all gradations from rhyolitic or latitic porphyry through granitic porphyry to equigranular granite. The granite and porphyry at Neversweat Ridge are similar to the Tertiary(?) granite ("quartz monzonite") of Mt. Barrow, exposed in southeasternmost California (Dillon, 1976; Haxel, 1977).

Welded and non-welded tuff--Map unit Tt

Partially to densely welded tuffs occur throughout the silicic, lower portion of the Tertiary section in the Castle Dome, Tank, Kofa, and New Water Mountains. Outcrops of welded tuff weather buff to dark brown and range from several meters to more than 450 m thick. Rocks in some areas are fresh and glassy whereas rocks in others areas are mildly to strongly altered.

The thickest welded tuff is exposed along the southwestern escarpment of the Kofa Mountains. Near Palm Canyon this tuff appears uniform and unlayered, though close inspection reveals variation in the content, size, and composition of the included lithic clasts. To the east of Palm Canyon, near Polaris Mountain, individual layers within the tuff are increasingly apparent due to variation in degree of welding. This layering within the tuff indicates rapid deposition of 20 or more pulses of ash-flow tuff which then formed a single cooling unit. The increase in differential welding toward Polaris Mountain indicates that the vent area for these rocks was west of there. The tuff probably cooled slightly as it traveled so that deposits farther from the vent did not weld as thoroughly.

The welded tuffs are rhyolitic to rhyodacitic in composition. These rocks vary from mildly to strongly porphyritic, with phenocrysts of plagioclase, biotite (often oxidized), and, locally, quartz and sanidine. Lithic fragments range from sparse to abundant, small and well-sorted to poorly sorted with blocks as much as 1 m in size, and from uniform composition similar to that of the tuff matrix to heterogeneous assortments including various volcanic, metamorphic and granitic fragments. Clasts typically are angular. Pumice lapilli range from a few percent to nearly 40 percent of the rock, from mildly elongate to intensely flattened, and from fresh to variably altered.

Massive layers of non-welded devitrified silicic tuff are interlayered with layers of welded tuff and silicic lava flows. Minor non-welded rhyolite tuff, chalky white where mildly altered, and light buff, pale gray, and white where glassy, occurs within basalt flows in the northeastern New Water Mountains, the Bear Hills, and at the northeastern edge of Ranegras Plain. The devitrified non-welded tuff is commonly mottled yellow, light green, chalky white, and tan. Original features and mineralogy are largely obscured by alteration (probably developed during cooling) but locally it is possible to distinguish the original ashy nature, often with lapilli- and (or) block-size clasts which have altered in a manner similar to that of the matrix and were probably also silicic and glassy. Where fresh, the matrix contains anhedral to euhedral, commonly broken phenocrysts of plagioclase; strongly oxidized dark orange-brown flakes of biotite; anhedral, roundish grains of clinopyroxene; and fine, elongate glass shards.

Rhyolite and rhyodacite flows--Map unit Ts

Rhyodacite lava flows form layers several m to over 70 m thick. They occur mainly in the upper two-thirds of the silicic portion of the Tertiary section, but silicic flows also occur among basalt flows that overlie the main volume of silicic rock. Typical occurrences in most of the Kofa Montains are as moderately thin flows separated by altered, non-welded tuff. North of Tunnel Mine Canyon (northeast Kofa Mountains) and west of Stagecoach Pass (northeastern tip of the Castle Dome Mountains) these flows reach great thickness.

Some silicic flows are massive, others have pronounced flow-banding which may be regular or broadly curving on a large scale and planar to convoluted on a small scale. Some flows have basal vitrophyres which vary from glassy to strongly devitrified.

All silicic lava flows contain phenocrysts of anhedral to euhedral plagioclase, and fresh to oxidized biotite. Some flows also include subhedral to euhedral hornblende, and fresh to oxidized, subhedral to rarely euhedral clinopyroxene. Mild to strong oxidation has stained many rocks a light pink or purplish to dark red and has altered mafic phenocrysts in many rocks. This alteration was part of devitrification since plagioclase, biotite, hornblende, and clinopyroxene phenocrysts in associated fresh vitrophyres are not oxidized. Thin, silica-filled veinlets and small whitish silica spherules are common, and silica-lined gas cavities locally weather-out to yield creamy-white agate roses and hollow orbs.

Silicic plugs and domes--Map unit Tp

Plugs and domes of rhyolite to dacite intrude Tertiary volcanic rocks in several places. Rhyolite occurs as fresh, light gray glass and chalky white to light tan devitrification products, is massive to finely flow-foliated, and is finely porphyritic with fresh subhedral to euhedral phenocrysts of plagioclase, biotite, and hornblende. Rhyolite forms small plugs intruding silicic tuffs and flows and tilted basalt flows high in the section.

Dacite forms intrusive bodies with exposed areas from several hundred meters across to about 3 by 6 km. Several of these, including a body forming Squaw Peak and a large body extending from Tunnel Mine Canyon to Burro Canyon, have a distinctive, coarsely plagioclase-porphyritic texture. Subhedral to euhedral plagioclase phenocrysts (many broken) are up to 1 cm in size. Biotite, as dark orange and black, highly oxidized flakes, is the next most abundant phenocryst, and anhedral to euhedral hornblende, also strongly oxidized, occurs in lesser amounts. Quartz and sanidine(?) are minor constituents locally. The dacite is massive, forming olive tan, light brown, and locally purplish-gray outcrops. Coarse boulder-debris piles and debris avalanche deposits were shed where some of these intrusions breached the surface. Several large intrusive bodies of dacite are exposed in the southern and central Castle Dome Mountains and are part of a volcanic center that includes dacitic to andesitic flows, flow breccias, and dikes. Another dacitic volcanic dome or plug underlies Courthouse Mountain near Engesser Pass in the Tank Mountains.

Basalt and andesite--Map unit Tb

Roughly 1,000 m of andesite lava flows overlie and are possibly interlayered with the top of about 800 m of coarse, massive andesite breccia in the Plomosa Mountains (Miller, 1970). Tuffaceous deposits are locally interbedded with the andesite flows, especially near their base. The breccia contains angular blocks of andesite to 15 m across. The light pink, light orange, and gray andesite weathers orange to red-brown and contains phenocrysts of plagioclase, biotite, and commonly hornblende. Pyroxene occurs in some of these rocks.

Basaltic lava flows, with minor scoria and ash beds, are interlayered with and cap the silicic volcanic hypabyssal rocks in the Kofa, New Water, Tank, and Castle Dome Mountains. The older basalt flows are tilted along with the underlying silicic rocks, whereas the youngest basalt flows are essentially flat-lying. The basalts are dark gray, massive to vesicular and amygduloidal, and commonly contain small phenocrysts of olivine altered to secondary minerals and rare phenocrysts of plagioclase, clinopyroxene, and orthopyroxene and plagioclase microphenocrysts.

Tertiary and Quaternary(?) sedimentary rocks--Map units Tc, Tbx

Extensive deposits of unconsolidated and poorly-to-mostly consolidated alluvium cover more than 130 km^2 in the Plomosa, New Water, and Kofa Mountains. These deposits consist of unsorted to locally poorly sorted fanglomerate composed of angular, locally-derived pebbles, cobbles, and boulders in a sandy matrix. Internal stratification is slight or absent. Older alluvial deposits are locally interlayered with or underlie basalt flows about 17 m.y. old at Black Mountain. Most of these alluvial deposits are probably early Miocene in age but some may post-date all volcanic activity. "Older" alluvial deposits are distinguished from "younger" ones by their being tilted, by the presence of interbedded basalt flows, and by their degree of erosional dissection. The older alluvium is commonly veneered by, and locally grades into, younger alluvium.

Quaternary alluvium--Map unit Qa

Extensive areas of the KNWR are covered by Quaternary alluvium. Talus slopes are common in areas of steep topography, and valleys and ravines contain sand and gravel in ephemeral streams. By far the largest alluvial areas are covered by gently sloping alluvial fans which coallesce into broad plains (bajadas), in part with well-developed desert pavement. This pavement grades locally into sandy flatlands, such as that northeast of the New Water Mountains. The lithology and internal structure of the younger fan deposits is essentially the same as that of the older alluvium.

Potassium-argon isotopic geochronology

Several K-Ar isotopic ages have been published previously for volcanic rocks in the KNWR (table 1). These data indicate that volcanism and hypabyssal intrusion in the region of the Kofa and Castle Dome Mountains occurred chiefly between about 25 and 18 m.y. ago.

New ages determined for this study are presented in table 2. Seven ash-flow tuffs sampled in four mountain ranges in the KNWR are between 22 and 23 m.y. old based on K-Ar ages done on feldspar and biotite. Sample no. KG-289 (22.7 ± 0.5 m.y.) is presumably from the same location (Honkidori Hill) as a sample previously dated by Gutmann which yielded an age of 25.7 m.y. (Gutmann, 1981). We are not sure about the significance of the disagreement between these determinations. Tertiary volcanism elsewhere in southeastern California and southwestern Arizona commenced sometime between 25 and 35 m.y. ago (e.g., Crowe and others, 1975) but it remains unclear whether any volcanic rocks this old are present in the KNWR.

Extensional tectonism has affected most, if not all, areas in the KNWR, and one result has been regional tilting of strata. The dated 22-23 m.y. old ash-flow tuffs are moderately tilted at most locales, with dips ranging from 20-45^{o}; locally, as at Red Rock Dam, the strata are nearly vertical. In contrast, sample KRK160B (19.9 ± 0.4 m.y.; see table 2) is from flat-lying basalt that overlies the steeply tilted tuff units, indicating that tilting was over by about 19-20 m.y. ago. Dahm and Hankins (1982) reported an age of 19.5 m.y. from the steeply dipping section near the Kofa Mine, an age that is inconsistent with our data and with ages determined by Shafiqullah and others (1980) from other exposures of the same rock sequence. Several of the generally latitic to rhyolitic dikes that are common in certain parts of both the Kofa and Castle Dome Mountains yield K-Ar ages of 19 or 20 m.y. Field relations in the southern Castle Dome Mountains (Logan and Hirsch, 1982; G.B. Haxel, U.S. Geological Survey, unpublished mapping) indicate that detachment faulting is largely younger than, and may be in part contemporaneous with, these dikes.

The Tertiary granite at Neversweat Ridge is similar to the granite from the Polomas Mountains (PM 454, table 2) which was dated at 23.2 m.y., and similar to the granite ("quartz monzonite") of Mt. Barrow (as discussed earlier in this paper). The Mt. Barrow granite is considered to be about 26 m.y. (Dillon, 1976). We expect that the ages of the granite from Neversweat Ridge is within or close to this age range.

The K-Ar date obtained on vein adularia from the North Star precious-metal deposit is 22.5 m.y. (see table 2). The adularia occurs as a gangue mineral in the North Star vein that cuts silicic volcanic rocks. This date falls within the range in ages (22-23 m.y.) determined for seven ash-flow tuffs in the KNWR. The date indicates that epithermal mineralization processes were contemporaneous with volcanism in the KNWR and suggests that volcanic heat sources provided the energy to drive hydrothermal systems.

The 63.8 m.y. K-Ar date for muscovite in the Au-W-quartz veins of the Livingston mine is somewhat equivocal in terms of the regional geology. The veins appear to be metamorphogenic and formed during presumed Mesozoic metamorphism of the McCoy Mountains Formation sedimentary rocks. The date obtained is too young to reflect the age of metamorphism and too old to reflect Tertiary volcanic-hydrothermal activity. This date may be interpreted as either an uplift and cooling age or a partially reset Mesozoic metamorphic date. More radiometric age data are required to clarify the problem.

Mineralization systems and episodes

Introduction

Geologic mapping, isotopic geochronology, and mineral deposit modeling allow mineral occurrences within the KNWR to be studied within the context of a coherent geologic history, rather than as isolated mineral occurrences of uncertain significance. Results of our work in the KNWR indicate that there were at least nine mineralization processes (or systems) that led to the formation of mineral deposits based on inferred genesis and inferred or presumed time of formation of the known mineral occurrences. The nine processes resulted in the formation of the following types of deposits: (1) pyrite- and chlorite-bearing quartz veins in Proterozoic granite, (2) high temperature tourmaline- and (or) pyrite-bearing quartz veins in high-grade, Precambrian or Mesozoic schists, (3) Jurassic(?) porphyry copper mineralization with associated skarn, (4) Neogene epithermal precious-metal-bearing quartz-adularia-calcite veins and fluorite-bearing black calcite veins containing manganese, silver, and lead, (5) gneiss- or schist-hosted and (or) detachment-fault-related(?) precious-metal deposits, (6) high temperature hot-spring deposits, (7) sedimentary-rock-hosted, disseminated precious-metal deposits, (8) Cenozoic placer deposits containing gold and gold- and silver-rich galena, and (9) rhyolite-hosted Sn deposits.

These nine mineral deposit types include the known and suspected mineral deposits in the KNWR. However, there are several other mineral deposit types addressed in this assessment: uranium in Tertiary volcanic and volcaniclastic rocks; massive sulfide mineralization in Precambrian metasedimentary or metavolcanic rocks; pegmatites associated with Mesozoic plutonism and metamorphism as sources of Be, Ta, Nb, REE, and other lithophilic elements; aluminum in areas of kyanite-and pyrophyllite-bearing aluminous alteration in schists; tungsten; geothermal energy; and oil and gas. This section is limited to mineralization processes that occurred in the KNWR and that resulted in the formation of known and suspected types of mineral deposits.

Quartz vein systems in Proterozoic granite

North-striking quartz veins cut Proterozoic granite (map unit Pg) near Scaddan Mountain, east of the Plomosa placers in the southwestern Plomosa Mountains. These veins typically contain cubic pyrite and black chlorite with minor galena. Specular hematite is present in small amounts. Geochemical analyses (Au, $<$0.05-2.0 ppm; Ag, $<$0.05-200 ppm; and Cu, $<$10-$>$20,000 ppm) and fluid inclusion petrography suggest that these veins are the source lode from which the Plomosa placers were derived. Primary fluid incluions in quartz from these veins and in quartz associated with galena in the Plomosa placers contain three phases at room temperature. These phases are H_2O (liq), CO_2 (liq), and CO_2 (vap). The presence of these three phases in room temperature fluid inclusions indicate a high density CO_2-rich fluid that formed at depths of about 5 km or greater.

These veins are younger than the Proterozoic granite, but their age is otherwise unknown. The Proterozoic granite is weakly metamorphosed (low greenschist facies) as shown by the formation of chlorite at the expense of biotite. Metamorphism of Paleozoic rocks in the region is Jurassic and Cretaceous in age. The quartz veins could have formed during either one or both metamorphic events or could be the products of late stage hydrothermal fluids produced during crystallization of the magma. Our reconnaissance field work was insufficient to determine either age(s) of quartz veins in the granite or their genesis.

Quartz vein systems in metamorphic rocks

Quartz veins containing tourmaline and (or) pyrite cut metamorphic rocks in the KNWR. These veins occur in at least three places: in schist derived from the McCoy Mountains Formation (map unit KJm) in (1) the Livingston Hills and in phyllite and schist of the 'rocks of Slumgullion' (map unit Js), in (2) the southwestern Kofa Mountains, and in (3) the southern Castle Dome Mountains. The veins in the Livingston Hills contain both tourmaline and pyrite and were W-rich (see table 8). Some of these veins also contain siderite and sericite where exposed in prospects and small mine workings. Pyrite cubes are typically oxidized to goethite pseudomorphs or rimmed by goethite. A goethite pseudomorph of pyrite from the Livingston mine has tiny (about 1-2 microns across) blebs of metallic gold in small vugs in the surface of the pseudomorph (fig. 2). Other elements associated with the gold in the pseudomorph are tungsten, silver, antimony, arsenic, copper, zinc, iron, and silicon. The gold particles were presumably liberated from the pyrite during oxidation.

In the southern Kofa Mountains, quartz-tourmaline veins appear where Jurassic(?) strata were progressively converted from siltstone and argillite to phyllite by Jurassic regional metamorphism and related plutonism. These metamorphic veins are common, and locally abundant, throughout the phyllite and schist zones. Some of these veins are pyrite-bearing with copper oxide staining and a number of small gold prospects and mines were developed in the past along the veins. The relation of the metamorphic quartz veins to the nearby epithermal gold mineralization is unclear. The Jurassic veins may be precursors in the sense that they represent an initial introduction or concentration of gold that was further concentrated to form the Neogene epithermal deposits.

Quartz in veins of this type contain liquid+vapor fluid inclusions at room temperature indicating that they did not form at as great a depth as those in Proterozoic granite. Both primary and secondary fluid inclusions are present and common. There appears to be no petrographic differencs in fluid inclusion types in quartz from veins cutting phyllite or schist.

The quartz veins in Proterozoic granite and in metamorphosed sedimentary rocks where both mined for their Au and (or) W content (see tables 6 and 8). Although the veins formed at different depths in different host rocks, the resultant mineral deposits are similar and may be classified as low sulfide Au-W-quartz veins (see table 8).

Porphyry copper and associated skarn systems

Porphyry-copper-type alteration and mineral assemblages occur in a Jurassic(?) granodioritic to granitic composite pluton (map unit Jg) in the Alamo Springs area of the northern Kofa Mountains. The granodiorite is medium-grained, holocrystalline and contains plagioclase, alkali feldspar, biotite, hornblende, and quartz. The pluton is weakly altered as manifested by alteration of plagioclase to white mica (petrographic determination) and of mafic silicates to chlorite and magnetite, even in the megascopically freshest outcrops. A large, weak to strong, propylitically altered area defined by sparse epidote+quartz veinlets and pervasive epidote+chlorite+pyrite alteration surrounds argillically altered granodiorite. Oxide mineralogy in the argillically altered rocks consists of malachite, minor azurite, chrysocolla, pitch limonite, goethite, and jarosite in granitic rock. Chalcopyrite, pyrite, and minor bornite are present in samples from a small dump surrounding a shift. Geochemical analyses of dump samples are given in table 6. Fluid inclusions in quartz veins from a small zone (100'x200') of stockwork veins associated with the above oxide mineralogy contain liquid, vapor, and solid phases at room temperature. The solid phase is acicular, highly birefringent, and may be an iron chloride based solely on room temperature petrographic techniques (Dennis P. Cox, U.S. Geological Survey, oral commun., 1986). Although no porphyritic phases of the pluton where recognized, the alteration mineralogy in the granodiorite and the fluid inclusions in quartz veins associated with the alteration indicate the prior existence of a weakly developed, porphyry copper mineralization system.

Calcareous metasedimentary rocks, of presumed Paleozoic age, that were intruded by the pluton are now marble and calc-silicate schist and gneiss. Small, Cu-bearing skarn deposits were observed in these calc-silicate rocks indicating the past occurrence of a porphyry copper and copper skarn mineralization system.

Epithermal precious- and base-metal mineral systems

Epithermal veins in Tertiary volcanic and hypabyssal rocks are the source of most of the metal production from the KNWR area. Map units that contain deposits of this type are Tb, Ts, Tt, Jg, Jp, Pzs, KJm, MzPg, Js, Kg, and Mzo. The epithermal veins cross-cut dikes and volcanic rocks with K-Ar dates between about 17 and 25 m.y. and adularia from a quartz+adularia vein sample from the dump of the North Star mine has a K-Ar date of 22.5 ± 0.7 m.y. The epithermal precious-metal vein deposits are either gold-rich or silver-rich. Gold-rich veins are best developed at and around the North Star and Kofa deposits. The veins are characterized by quartz and adularia with minor calcite at the North Star and by calcite with minor quartz at Kofa. These veins are typical of epithermal, high-grade deposits; such deposits decrease rapidly in grade and tonnage with increasing depth. The deposits in the Kofa district are Comstock-type, epithermal veins as outlined by Mosier and others (1986b).

The second type, silver-rich epithermal precious-metal deposits, is characterized by black, manganiferous calcite with minor chalcedony. These veins are silver-rich and in some places contain galena. The Sheep Tank deposit is probably the largest deposit of this type in the KNWR area. These deposits are classified as epithermal Mn deposits as in Mosier (1986a, b).

Other silver- or lead-bearing veins occur locally in Tertiary volcanic rocks and in Jurassic metasedimentary and metagranitic rocks east of the Kofa mine. The argentiferous galena-bearing epithermal veins in the Castle Dome district and the Ramsey deposit are examples of the silver-rich epithermal polymetallic deposits. These polymetallic veins contain fluorite, calcite, and barite, with minor quartz as gangue minerals.

Base-metal epithermal veins in the KNWR area are of two types: galena and chalcopyrite (mostly oxidized) associated with quartz and calcite gangue and manganese associated with calcite gangue. Both types occur in Tertiary volcanic rocks (map units Ts, Tt). These veins are small and occur sporadically throughout the KNWR area. Some of the copper- and lead-rich veins were mined in the past for their precious-metals. These occurrences are of unknown epithermal type because of the lack of information on their mineralogy and production. The Ocotillo mine group in the Kofa Mountains exemplifies these deposits (see table 8).

Quartz in the volanic-hosted, epithermal deposits is generally euhedral and either free of fluid inclusions or is dusted with wispy trails of fluid inclusions. Quartz crystal growth zones defined by fluid inclusions are common. Primary fluid inclusions in epithermal quartz veins are small (about 5-10 microns) and have variable ratios of liquid to vapor in two phase, liquid+vapor inclusions at room temperature. These variable ratios are difficult to interpret without the benefit of heating-freezing experiments. They may represent boiling but most likely are an artifact of necking-down of inclusions.

The variety of epithermal deposits (Comstock veins, epithermal Mn, polymetallic veins and replacements) indicate that the chemistry of fluids during epithermal mineralization processes were spatially variable resulting in the deposition of different metallic and gangue minerals. All of these epithermal vein deposits are of similar age since they occur in volcanic rocks with ages between 17 and 25 m.y.

Gneiss- or schist-hosted, detachment fault-related(?) gold systems

Recent exploration in southeastern California and southwestern Arizona has resulted in recognition of a "new" type of gold deposit. Examples of this deposit type include Mesquite, Picacho Peak, and American Girl (Manske and others, 1987; Drobeck and others, 1986; Liebler, 1987; Guthrie and others, 1987; Tosdal and Haxel, 1985; Tosdal and Smith, 1987). Of these, the Mesquite deposit in California is probably the largest and most well known. The gold in these deposits is generally hosted by gneiss or schist. Detachment faults occur at and near Picacho Peak but are absent at Mesquite. The present state of understanding of these deposits is insufficient to unequivocally characterize the mineralization processes responsible for their formation. For example, it is unclear whether or not detachment faults are important genetic aspects of these deposits or whether they simply served as fluid conduits. In addition, the host rock may or may not play an important part in the genesis of these deposits. Enough is known, however, to identify geologic terranes that are favorable environments for deposits of this type based on host rock lithology.

A minor detachment fault between schist and Tertiary volcanic rocks is intruded by a Tertiary porphyritic dike east of the Colorado mine workings in the Castle Dome district. The lower plate of this fault is mapped as MzPg. Our geochemical sampling of veins and altered rock in the MzPg unit beneath the intruded fault indicate anomalous values for Ag (1.5-20 ppm), Ba (700-3,000 ppm), Au (0.05-0.45 ppm), and As (20-120 ppm). The result of the geochemistry together with the close association with Tertiary porphyritic dikes suggest that the schist-hosted veins are similar to epithermal vein deposits in the KNWR.

Quartz from veins that cross cut the MzPg unit beneath the detachment fault and cutting the intrusive dike have fluid inclusions characteristic of the epithermal vein deposits throughout the KNWR. This observation supports the interpretation that the weakly developed mineral occurrence hosted by schist at the detachment fault near the Colorado mine is associated with shallowly-emplaced porphyritic dikes.

These observations result in the interpretation that schist- or gneiss-hosted deposits near detachment faults in the KNWR are the results of epithermal mineralization processes. This is the same conclusion reached by Manske and others (1987) for the Mesquite deposits and by Liebler (1987) for the Picacho deposit. The mineralization systems that formed volcanic- or metamorphic-rock-hosted precious-metal deposits were similar; they were epithermal systems.

High temperature hot-spring systems

The presence of chalcedonic sinter covered by Quaternary gravels (map unit Qa) in colluvial deposits on the western margin of the Castle Dome Mountains is evidence that high temperature, silica-bearing hot-spring systems were active in the KNWR. The chalcedonic sinter exposed at the surface contains sparse, discontinuous bands of sulfide-bearing chalcedony. This suggests that the geothermal waters were carrying H_2S, a gas that Henley (1985) believes is an important constituent of gold-bearing hot-spring systems. Stream-sediment samples from near the sinter contain anomalous Au which suggest that the hot-spring system was also Au-bearing.

The Republic mine in the New Water district in the northeastern part of the proposed addition to the KNWR is another example of a hot-springs deposit. At this location, opaline(?) silica occurs as veins and vug fillings in a clay-altered, scoriaceous basalt (map unit Tb). Geochemical analyses of opaline(?) silica and altered host rock from the Republic mine yield high values (ppm) for certain hot-spring related trace elements: As, 2,700; Ba, 5,000; Sb, 300; Hg, 0.56; Tl, 240. These values are extremely high, even for some well-studied geothermal systems. Gold values ranged between <0.05 and 0.9 ppm. The presence of the opaline silica and the clay alteration, together with detectable Au and other high trace element values are evidence of the presence of a paleo hot-spring system. (The deposit is marked by Keith (1978, fig. 14) as a mine with Cu as the reported mineral occurrence. The deposit warranted no discussion by Keith.)

Sedimentary-rock-hosted, disseminated precious-metal systems

Sedimentary-rock-hosted, precious-metal deposits (also referred to in the literature as Carlin-type deposits and carbonate-hosted Au-Ag) in Nevada are producing the bulk of the gold presently being mined in the United States. These deposits are generally low grade, high tonnage deposits that are amenable to bulk-mining methods (Bagby and Berger, 1985). Host rocks are characteristically silty carbonaceous limestones or dolomites or finely laminated, calcareous siltstones and shales. Favorable host rocks in the KNWR occur in map units Pzs, Jss, and possibly Js. The Escabrosa Limestone and the Martin(?) Formation as mapped by Miller (1970) in the northwestern part of the KNWR near Scaddan Mountain are included in map unit Pzs. The Martin(?) Limestone consists of dolomitic limestone, dolomite, and sandy dolomite. The

Escabrosa Limestone is a light gray, sandy dolomite. Both of these formations are included in map unit Pzs and each is an ideal host for Carlin-type gold mineral deposits.

Our rock geochemical sampling near the polymetallic replacement deposit (Black Mesa mine) on the northwestern flank of Black Mesa, at the contact of basaltic flows with underlying Escabrosa Limestone sandy dolomite indicates a significant increase over background values of pathfinder trace elements that are typically associated with sedimentary-rock-hosted, disseminated precious-metal deposits (see table 6). For example, unaltered carbonaceous, sandy dolomite contains the following trace element concentrations (ppm): Au, <0.05; Ag, <0.5; As, <5; Sb, 2; Hg, 0.04. In contrast, altered, limonite-bearing, brecciated dolomite in the Escabrosa Limestone has anomalously enriched trace element values (ppm): Au, 0.7; Ag, 100; As, 510; Sb, 650; Hg, >10. These geochemical values and the type of host rock indicate that an epithermal system similar to those that formed Carlin-type deposits in Nevada occurred at the locality sampled.

Gold and galena placer-depositing processes

Placer deposits occur in map units Qa and possibly Tc in the Plomosa Hills, in the Kofa and Castle Dome districts, and in the eastern part of the KNWR area, just outside of the Refuge boundary. The Plomosa placers are rich in argentiferous gold and galena. Gold occurs as separate grains and as inclusions within galena crystals. The placer deposits are hosted by Quaternary alluvium, and the angularity of the galena crystals suggests a nearby source.

Quartz associated with galena from these placer deposits has fluid inclusion characteristics at room temperature that are identical to quartz from the pyrite-chlorite bearing quartz veins in the Proterozoic granite. This suggests that the lode source for the placers is the pyrite-chlorite quartz veins. It is apparent, therefore, that erosional and sedimentary processes occurred to produce the placer deposits.

Rhyolite-Sn mineralization systems

The presence of high silica rhyolites and stream-sediment samples containing anomalous Sn, Bi, and Mo indicate that magmatic-hydrothermal processes were active during volcanic activity in the Tertiary. These processes may have formed rhyolite-hosted Sn deposits. However, there are no known occurrences of this deposit type in the KNWR.

Other types of mineralization processes

Several other types of mineralization systems may have occurred in the KNWR. These include: (1) epithermal processes resulting in deposits of uranium in volcanic and volcaniclastic rocks, (2) magmatic processes that concentrated lithophilic elements with pegmatites, (3) metamorphic-leaching processes that may have concentrated aluminum in kyanite-pyrophylite alteration zones in Jurassic schists, (4) exhalative processes may have formed massive sulfide deposits in Precambrian rocks, and (6) geothermal and diagenetic processes may have formed reservoirs of the energy resources of geothermal heat, oil, and gas. The geologic map and our geochemical sampling indicate that, with the exception of oil, gas, and massive sulfide deposits, the above deposits and geothermal energy may have formed as a result of these processes.

RECONNAISSANCE GEOCHEMICAL INVESTIGATIONS IN THE KNWR

Introduction

In 1984 and 1985, a reconnaissance geochemical survey was conducted in the KNWR to aid in the evaluation of the mineral resource assessment of the area. The focus of the 1984 field season was the proposed northern addition to the KNWR, the New Water Mountains, and the northern Kofa Mountains. In 1985, we completed the survey in the remainder of the KNWR which included the southern Kofa Mountains, the western portion of the Tank Mountains, and the Castle Dome Mountains.

Methods of study

Sample media

Minus-80-mesh stream sediments and heavy-mineral, panned concentrates derived from stream sediments, were selected as primary sample media because they represent a composite of rock and soil exposed in the drainage basin upstream from the sample site. Chemical analysis of sediments provides information useful in identifying those basins which contain unusually high concentrations of elements that may be related to mineral occurrences. In addition, studies have shown that heavy-mineral concentrates derived from stream sediments are a very useful sample medium in arid or desert environments, or in areas of rugged topography, where mechanical erosion is predominant relative to chemical erosion (Overstreet and Marsh, 1981; Bugrov and Shalaby, 1975).

Some of the stream sediments and heavy-mineral concentrates in the KNWR were processed from alluvium that was clearly contaminated by mine or prospect dumps. We assume that any contamination in a given drainage basin resulted from dump material mined within that basin. Thus, for a reconnaissance study such as this, the chemical effects of prospecting and mining activity are not considered complicating factors in assessing the mineral potential of the study area since we were able to predict where this contamination would occur, based on knowledge of the location of previous mining activity.

Rock samples were also collected throughout the study area. Samples which appeared fresh and unaltered in hand sample were collected to provide information on geochemical background values (see table 5). Altered and (or) mineralized samples in the vicinity of mines and prospects were collected to determine suites of elements associated with the observed alteration or mineralization (see table 6).

Sample collection

Stream sediment-related samples were collected at 493 sites (Adrian and others, 1986). At nearly all of these sites, both a stream-sediment sample and a heavy-mineral, panned concentrate sample were collected. Both sample types consisted of composited, active alluvium that represent 30 to 50 ft of channel length.

A total of 656 rock samples were collected (Adrian and others, 1986). Areas that contain mineralized rock were sampled by collecting chip composites from several sites across mineralized zones. At sites where fresh, unaltered rock occurs, samples were taken for determination of geochemical background values by collecting a single grab sample if the rock was fine-grained and homogeneous. Chip samples of unaltered rock were collected if the rock was coarse-grained or had an inhomogeneous distribution of minerals.

Sample preparation

The dry stream-sediment samples were sieved through 80-mesh (0.17-mm) stainless-steel sieves. The minus-80-mesh fraction was retained for analysis.

To produce the heavy-mineral concentrate, bulk stream sediment was first sieved through a 10-mesh (2.0-mm) screen. Approximately 10 to 15 lbs of the minus-10-mesh sediment were panned to remove most of the quartz, feldspar, organic materials, and clay-sized material. The panned concentrate was then separated into light and heavy fractions using bromoform (heavy liquid, specific gravity 2.8). The light fraction was discarded. The material of specific gravity greater than 2.8 was further separated into three fractions (highly magnetic, weakly magnetic, and nonmagnetic) using a modified Frantz Isodynamic Separator[2]. The nonmagnetic fraction was hand-ground and saved for analysis. These procedures result in a sample that represents a concentration of a mineral assemblage that may be rich in ore and ore-related minerals such as pyrite, galena, cassiterite, sphalerite, chalcopyrite, stibnite, free gold, barite, and scheelite. This selective concentration of ore-related minerals permits determination of some elements that are not easily detected in bulk stream-sediment samples.

Rock samples were crushed and then pulverized to minus 0.15 mm with ceramic plates prior to analysis.

Sample analysis

The heavy-mineral concentrate and rock samples were analyzed for 31 elements using a semiquantitative, direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). The elements analyzed and their lower limits of determination are listed in table 3. In addition, the rock and sediment samples were analyzed by more sensitive and precise techniques as summarized in table 4. The minus-80-mesh stream sediments were analyzed for a suite of seven elements thought to be possible pathfinders associated with epithermal precious-metal deposits. These elements and techniques are also summarized in table 4. A complete listing of all analyses, as well as a brief description of all rock samples, is given in Adrian and others (1986).

Results

Rock geochemistry

Threshold values, defined as the upper limit of normal background values, were determined for each element by inspection of frequency distribution histograms plotted for (1) fresh rocks, (2) altered rocks, (3) vein samples, and (4) a combination of all three. A geochemical value higher than the

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[2]Use of the brand name of equipment does not constitute endorsement by the U.S. Geological Survey.

threshold values is considered anomalous and worthy of scrutiny as a possible indication of mineralization. The threshold values for selected elements in rocks are given in table 5.

As discussed above, it appears that at least nine dominant mineralization processes or systems operated in the KNWR. Analyses of mineralized rock from mineral occurrences of each of these mineralization systems enables us to determine the geochemical signature characteristic of a particular mineralization type. Table 6 shows selected analyses of "high-grade" samples considered typical of the mineralization systems. All samples shown in table 6 were taken from the KNWR with one exception. The samples listed as representative of gneiss- or schist-hosted, detachment-fault-related(?), precious-metal mineralization were taken from the Picacho mine in eastern Imperial County, California.

Stream-sediment geochemistry

Threshold values for minus-80-mesh stream sediments and nonmagnetic heavy-mineral concentrates from stream sediments were determined by inspection of frequency distribution histograms (figs. 3 and 4, respectively). Plate 2 is a map showing the locations of drainage basins that are representative of the areas sampled by either stream sediment (minus-80-mesh fraction), heavy-mineral concentrates, or both, that contain anomalously high trace element concentrations for one or more elements. Of the 493 basins sampled, 231 (47 percent) contain samples with anomalous trace elements. Only 36 (16 percent) of those anomalous basins contain known major mineral deposit occurrences.

Discussion

A proviso defined by the scale of sampling for this compilation is that moderate-sized deposits could be indicated by only one sample locality, or perhaps even missed. Nevertheless, the number of anomalous drainage basins and the trace elements for which they are anomalous, certainly reflect the known types of mineral deposits in the area. In addition, the geochemistry results indicate and support the permissive occurrences of undiscovered deposits of different types in areas within the KNWR where no known mineral deposits occur. Anomalous basins occur throughout the KNWR. As a generalization, these basins may be grouped geographically for purposes of discussion. However, when individual anomalous basins are used together with geology to delineate assessment domains, the power of the reconnaissance sampling becomes evident. The seven geographic anomalies are shown in figure 5 and are briefly discussed here.

King of Arizona-North Star anomaly (1)

This strong anomaly is reflected by anomalous values of gold, silver, arsenic, antimony, thallium, and zinc in minus-80-mesh stream sediments and by anomalous gold, silver, arsenic, antimony, tungsten, bismuth, tin, lead, copper, and zinc in nonmagnetic heavy-mineral stream-sediment concentrates.

The obvious origin of this anomaly is the epithermal gold-silver deposits at the King of Arizona and North Star mines, and the low Au-W-quartz veins at the Evening Star and Tungsten Group mines. Both the magnitude of the anomalies and the number of elements found in anomalous concentrations are undoubtedly high due to mining activity. This activity has exposed large quantities of mineralized rock to mechanical breakdown and subsequent transport as sediment, thus contaminating the stream channels.

This anomaly is of interest for comparative purposes in that it provides a measure of the composition, size, and intensity of anomalous values in the vicinity of known deposits. The southeastward-pointing "tail" on the anomaly as defined primarily by arsenic and gold in minus-80-mesh sediments suggests that not all of the anomaly is caused by the presence and exploitation of known mineral deposits.

Southern Plomosa anomaly (2)

The Southern Plomosa anomaly is reflected by anomalous values of lead, silver, tungsten, copper, zinc, bismuth, and arsenic in nonmagnetic heavy-mineral concentrates and by silver and arsenic in minus-80-mesh stream sediments. This anomalous area includes most of the southern portion of the Plomosa mining district as defined by Keith (1978). The high geochemical values are believed to be indicative of as many as four deposit types: (1) placer Au-PGE deposits; (2) low-sulfide Au-W-quartz deposits; (3) epithermal precious-metal deposits; and (4) sedimentary-rock-hosted, disseminated precious-metal deposits.

Sheep Tank anomaly (3)

This very localized anomaly is marked by high values of arsenic, lead, copper, silver, and zinc in heavy-mineral concentrates and by arsenic, silver, and zinc in minus-80-mesh stream sediments. The Sheep Tank mine is located at the center of the area and the epithermal mineralization associated with this deposit is responsible for the anomalous geochemical values.

New Water anomaly (4)

The New Water anomaly is a rather poorly defined area based on scattered values of silver, arsenic, and lead in heavy-mineral concentrates and arsenic, antimony, silver, and zinc in minus-80-mesh sediments. The area overlaps portions of the New Water and Plomosa mining districts. Known mineral deposits in this area are epithermal veins that contain silver, gold, manganese, lead, and copper.

Red Rock anomaly (5)

This anomaly, named for its proximity to Red Rock Dam, is delineated by anomalous arsenic in minus-80-mesh sediment from two sites draining an area of granodiorite with porphyry copper alteration.

Southern Castle Dome anomaly (6)

This anomaly is delineated by anomalous values of gold, arsenic, thallium, and silver in minus-80-mesh sediments and by lead, silver, zinc, arsenic, and scattered gold values in heavy-mineral concentrates. The strongest anomalies extend from the western front of the Castle Dome Mountains in the vicinity of the Castle Dome and Hull mines eastward to the Big Eye mine and Keystone mine. Known mineral deposits in this area includes polymetallic argentiferous galena-fluorite-barite veins closely associated with dacite porphyry and rhyolite porphyry dikes. However, many of the anomalous basin in this area contain no known mineral deposits (see pl. 3).

Northern Castle Dome anomaly (7)

This anomaly is defined primarily on the basis of gold values in minus-80-mesh sediments. In addition, scattered values of thallium and zinc are found in the sediments and scattered values of tin, arsenic, silver, zinc, lead, antimony, and bismuth in concentrates.

In the northern portion of the northern Castle Dome anomaly, scattered anomalous values for gold, arsenic, thallium, and bismuth occur in close proximity to an outcrop of chalcedonic sinter.

Scattered anomalous basins occur throughout the Kofa Mountains, Livingston Hills, and Tank Mountains (pl. 2). Although some of these anomalies may be explained by the presence of known mineral deposits, many of the basins drain areas where there are no known mineral occurrences. The anomalous basins in these areas are defined by anomalous values of mercury, gold, arsenic, with some tin, zinc, and lead. These are pathfinder elements for certain mineral deposit types and thus, the anomalies were used to delineate domains.

GEOPHYSICAL DATA

As part of this mineral resource assessment, the U.S. Geological Survey contracted with GER, Inc. to fly high resolution airborne spectral measurements in the visible and near infrared (0.4-2.5 um) wavelengths of rock and soil in one area of the KNWR. The spectra obtained from these measurements identify specific minerals such as kaolinite and other clay minerals that may be genetically related to hydrothermal alteration associated with mineral deposits.

The area chosen by the U.S. Geological Survey for investigation by this method exhibits alteration and mineralization typical of the oxidized portions of a porphyry copper occurrence. This alteration consists of widespread propylitic alteration (epidote, calcite, and pyrite) surrounding a central core area of supergene acid alteration consisting of clay minerals and abundant jarosite along fractures and associated with web stockwork quartz veins (see porphyry copper and associated skarn, systems above). The mineralized zone was drilled in the late 1960's. This drilling indicated that the mineralized zone extends to a depth of about 274 ft and averages 1 percent Cu, 0.05-1 ounce Ag per ton, and trace gold (J.A. Russell, claim owner, oral commun., 1986). Associated mineralized skarns may occur in the Paleozoic(?) calcareous sedimentary rocks intruded by the granodiorite. This porphyry copper mineralized area is located in the northern Kofa Mountains near Red Rock Dam and is shown on plate 3.

Figure 6 shows the results of 11 flight lines over the area of interest. It is apparent from the spectral character of the measurements that surface clay alteration is limited to a small, 4 mi^2 area surrounding the main outcrops of recognizable alteration. However, isolated zones of clay minerals were identified on several flight lines up to about 4 mi away from the main altered area. These may be interpreted as either local windows of alteration exposed through younger volcanic and volcaniclastic rocks or they may reflect altered Tertiary volcanic rocks.

The Bouger Gravity Anomaly Map of Arizona (West and Sumner, 1973) shows a large negative gravity anomaly centered beneath the northern part of the

Castle Dome Mountains on the western margin of the KNWR (fig. 7). Basement rocks do not outcrop within the region outlined by the steep margin of the gravity low. Gutmann (1981) interpreted the anomalous area as a subsided block, possibly the result of cauldron collapse. C.L.V. Aiken (quoted in Gutmann, 1981) modelled the gravity low by removing the effects of high-level density contrasts due to Basin and Range faulting and determined a model that suggests a low-density mass with a bottom at 20 km depth and a top at 8 km depth. This model could be interpreted as a silicic batholith extending from the base of the crust to about 8 km depth (Gutmann, 1981). Sauck (1972) noted that aeromagnetic anomalies centered in the gravity low are subdued and he suggested that these are due to an elevated Curie isotherm. C.L.V. Aiken (quoted in Gutmann, 1981) modelled the depth to the 500^{o} C isotherm at 7 to 8 km depth compared to an average depth to this isotherm in northern Arizona of 20 km (Byerly and Stolt, 1977). A deep magnetotelluric survey across the gravity low indicates anomalously low electrical conductors (Aiken and Ander, 1981). These geophysical anomalies in the area may be used to 1) interpret the crustal structure of the area which aids in mineral resource assessment and 2) provide information for assessing geothermal resource potential of the area (see KNWR assessment section below).

REVIEW OF MINING AND EXPLORATION ACTIVITY AND TYPES OF MINERAL OCCURRENCES

Past production

The geographic area encompassed by the KNWR was the site of considerable mining activity in the past. This activity was concentrated within eight mining districts (fig. 8). Each district consisted of several mines and (or) prospects. However, in most districts, the majority of the production resulted from only one or two deposits or from closely spaced mines located on one large deposit. For example, major producers in the Kofa district were the Kofa and North Star mines although the district included several other smaller mines such as the Black Dahlia and Quartette mines.

Past production for these districts is summarized in tables 7 and 8, based on data compiled by Keith (1978). The tables are an attempt to give total known production by district and by deposit from discovery through 1974. There has been little or no production from most of these districts since 1974. Keith (1978) summarizes the geology and provides a short description of the larger mineral deposits for each district.

All of the districts shown in figure 8, except the Plomosa district, lie entirely within the KNWR or largely within it with minor extensions outside the area. The Plomosa district is divided into northern and southern areas by Keith (1978). Only the southern area (fig. 8), which includes parts of the Plomosa and New Water mountains and the Livingston Hills, is within the proposed addition to the KNWR. The production for the Plomosa district given in table 7 includes both parts of the district. The majority of the lode gold and essentially all of the copper production for this district came from the northern Plomosa district outside of the KNWR. Zinc produced in the Plomosa district accounts for 65 percent of the zinc produced in the Kofa area. Unfortunately, it is difficult to determine whether this zinc was produced in either the northern or southern portions of the district since lead- and zinc-bearing veins occur in both areas.

The Kofa and Castle Dome districts were by far the largest producers of ore in the wildlife refuge area. The Kofa district produced 82 percent, and the Castle Dome district 13 percent, of the total tonnage of ore produced in this area. In addition, the Kofa district produced 88 percent and 25 percent of the lode gold and manganese, respectively, whereas the Castle Dome district produced 65 percent, 98 percent, 37 percent, and 43 percent of the lode silver, lead, zinc, and manganese, respectively. These two districts were also substantial producers of placer gold and silver; Kofa produced 22 percent of the placer silver and Castle Dome produced 25 percent of the placer gold in the KNWR area.

The major producer of placer gold and silver in the KNWR area was the Plomosa district. This district produced 65 percent and 78 percent of the placer gold and silver, respectively. This production was from the Plomosa placers located in the northwestern part of the northern proposed addition to the refuge.

The only other district in the refuge area that had any significant production is the Sheep Tanks district. This district produced 8 percent, 5 percent, and 27 percent of the lode gold, silver, and manganese, respectively. The other districts in the area, Alamo Springs, Tank Mountains, Neversweat, and New Water, all were small producers.

The manganese production in this area was sold to the government at subsidized, inflated, prices during the period immediatly following World War II. Even at the inflated price, a total of only 930 long tons was produced, all of which was low grade ore.

The total combined tonnage of all types of ore produced in this area was 944,326 tons. This tonnage is small when compared to currently operating precious-metal mines in the United States (see fig. 9). For example, the smallest presently operating gold mines in Nevada contain roughly one million tons whereas porphyry copper mines in Arizona have over 100 times this tonnage. Thus, when put into the perspective of today's mines, deposits in the Kofa area are small in terms of both tonnage and contained metal (see fig. 9).

Recent activity

Although mineral deposits in the Kofa area were of low tonnage, grades were historically high. This is appealing to small operators and prospectors. In addition, the potential for low grade, large tonnage mineral deposits in and around the old high-grade precious-metal deposits has attracted the interest of larger mining companies. Thus, exploration activity at some localities within and near the wildlife refuge has increased over the past few years.

These activites can be divided into separate categories: 1) actual mining and production of ore, 2) evaluation drilling and sampling at nonoperating mines, and 3) the location of currently valid mining claims in the area.

Exploitation of the Plomosa placers and the tailings at the North Star mine are the only currently active mining ventures in the area. The placers are worked during the winter by several different groups. One group is a family operation that is producing gold and minor silver from the patented Plomosa placer claim block. Other placer operators are working different areas of the same gold-bearing gravels. These groups are predominantly weekend dry placer enthusiasts.

The tailings at the North Star mine are being reworked for gold by a small company under contract to owners of the mine. Epler (1987) reported that sampling of tailings and a placer deposit at the North Star property by Langguth and Associates and Gold and Minerals Inc. indicates about 7 million short tons of material that grades 0.035 troy oz of gold per ton. An operation is presently planned to process 2,000 tons per day at a recovery rate of about 2,200 oz of gold per month.

Two different mines are currently being evaluated for possible reopening as either large-tonnage, low-grade, bulk-minable or as underground, higher grade operations. These are the North Star mine in the Kofa district and the Ramsey mine in the Plomosa district. The Anaconda company was dewatering the North Star mine in the winter of 1984 in order to provide access to the lower parts of the mine in preparation for geologic mapping, sampling, and possible underground drilling to evaluate the extent, grade, and tonnage of mineralization. This work was done in a joint venture with Caprock Energy, Ltd. In 1985, Anaconda sold its interest in the North Star mine and a new company, Yuma Gold Mines Ltd., is the present operating partner to Caprock Energy, Ltd. George Phelps (Yuma Gold Mines, Ltd., oral commun., 1986) indicates that 2 exploration holes drilled in 1985 cut an extension of the North Star structure at its intersection with a cross structure. Results of the drilling were inconclusive, however, with respect to ore. Additional drilling and continued underground exploration is planned.

The Ramsey silver mine is being evaluated by Exploration Ventures Company, Inc. Their evaluation is based on underground mapping, sampling, and drilling. The company has indicated reserves of >1.5 million tons grading 3.0 ounces of silver per ton (John Hite, Exploration Ventures Company, Inc. oral commun., 1986). In addition, the company notes that mineralization is presently open-ended and that surface mapping suggests a target of about 5-10 million tons of 3.0 ounces of silver per ton. The company anticipates continued evaluation of the property.

Prospected areas

The location and density of unpatented mining claims in an area gives a reasonable indication of exploration interest and activity. Mitcham (1972) produced a preliminary survey of mining claims in the KNWR for the Bureau of Land Management. His compilation includes only the wildlife refuge and not the proposed northern additions. (His data base included claims that had been filed since 1961. However, he only included those that were valid between 1970 and 1971.) Mitcham's (1972) report indicates that the majority of the mining claims occur in districts with major past production. In 1972, the Castle Dome district had 32 percent and the Kofa and Tank Mountains districts each had 19 percent of the mining claims for a total of 69 percent of the unpatented claims in the refuge. The other 31 percent of the unpatented claims were scattered between the Neversweat, Alamo Springs, and Sheep Tank districts.

A more recent analysis of mining claims in the Kofa area is presented in figure 10. Data used in compiling this figure are from the Bureau of Land Management (Phoenix, Arizona office) computer file of mining claims. We requested information in February, 1984 for a listing of claims within the wildlife refuge and its proposed additions. The total number of claims is 448. This is a substantial reduction from the 1,050 claims that Mitcham compiled in 1972. Claims are still concentrated in the areas of greatest past production. The majority of claims, however, occur in a northwest-striking alignment in the Ramsey mine area. Claims in this area are aligned along a lineament that may be the fault along which ore occurs at the Ramsey mine. These claims account for 57 percent of the total active unpatented claims in the entire wildlife refuge area. Most of the rest of the claims are divided between the Castle Dome (16 percent), Plomosa placers (15 percent), Kofa (3 percent), and Sheep Tanks (3 percent) districts. The few other claims are widely scattered over the refuge.

It appears that prospectors have allowed their claims to lapse since 1972. However, it is difficult to pinpoint the actual reason for this drop in number of mining claims in light of 1) the substantially increased prices for precious-metals since 1972 and 2) the temporary withdrawal of federal lands from mineral location in 1974. In addition to the temporary withdrawal (which did not affect Arizona state lands within the KNWR), the Federal Land Policy and Management Act of 1976 significantly changed the recording procedure for mineral location. Thus, it is possible that a combination of these regulatory factors is the reason for fewer unpatented claims in the area in 1984 versus 1972.

Patented mining claims are limited to the Kofa and Castle Dome mining districts (see fig. 8 and caption to fig. 10).

Mineral occurrences

Mineral deposits occur throughout the KNWR. Plate 3 shows the locations of known mineral deposits according to type. There is a total of 48 known mineral deposits of which 41 can be assigned with confidence to one of nine specific mineral deposit types (see table 8). The assignment of the mineral deposits to a particular type was in part based on descriptions in Keith (1978) of host rocks, mineralogy, and past production.

There are seven small epithermal mineral occurrences for which there is not enough information to assign them to a specific epithermal type (table 8, pl. 3). These occurrences all had minor precious-metal production. The occurrences are small calcite-silica veins hosted by Tertiary silicic volcanic rocks in fracture zones. Alteration of host rocks is limited to very near the veins. Apparently, the hydrothermal system(s) that formed the deposits was either not hot enough or there was not enough water available to produce larger alteration zones and deposits. However, the occurrence of these small deposits and recognition of their epithermal nature is important information for the mineral resource assessment because it indicates that precious-metal-bearing epithermal systems were active in this area (see pl. 3).

The past production data in table 8 were used to plot several of the deposits on grade and tonnage curves (fig. 11). The grade and tonange curves are from grade and tonnage models for specific mineral deposit types from Cox and Singer (1986). The only KNWR mineral deposits plotted in figure 11 are those with large enough tonnages and high enough grades to plot on the curves for Comstock epithermal veins, low sulfide Au-quartz veins, and polymetallic veins. The curves were developed using data for mineral deposits worldwide of specific types. The grades and tonnages for KNWR mineral deposits shown in figure 11 are thus easily compared with the grade and tonnage distributions for those model types.

Many mineral occurrences in the KNWR either have no recorded production or their production was too small to plot on the grade and tonnage curves for their mineral deposit type. This was true for most of the Comstock epithermal vein deposits, the low sulfide Au-quartz veins, the polymetallic replacement, hot-springs, porphyry copper, and the small epithermal precious-metal occurrences of unknown type.

The epithermal Mn mineral deposits are of particular interest because of their silver and gold contents. The Sheep Tanks deposit (see pl. 3) has geologic and mineralogic characteristics that place it in the epithermal Mn model of Mosier (1986a). The geochemical characteristics of that mineral deposit model are Au and Ag, the two main products from the Sheep Tanks mine. The mineral deposits used by Mosier (1986b) to construct the grade and tonnage models for epithermal Mn deposits contain Ag. Mosier (1986b) used 59 deposits in the grade and tonnage models; six of these had reported grades and tonnages that range from about 500 to 2,000,000 tonnes with grades between 1-139 grams Ag per tonne and 1-8 grams Au per tonne (D.L. Mosier, U.S. Geological Survey, oral commun., 1987). The grades for Au and Ag and the tonnage at the Sheep Tanks deposit are at the low end of the ranges defined by these other epithermal Mn deposits.

MINERAL RESOURCE ASSESSMENT

Definitions

There is a certain terminology required to communicate the results of mineral surveys to assure that data, concepts, and interpretation are communicated to the primary audience (in this case, the U.S. Fish and Wildlife Service) in a clear, and concise manner so that the survey satisfies the purposes for which it was undertaken. Mineral survey terminology is certainly not universal and thus, definitions of terms and phrases used in this assessment are provided herein.

The following definitions are either modified or taken directly from the noted reference in each case.

Mineral resource--A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such a form and amount that economic extraction of a commoditiy from the concentration is currently, or potentially, feasible (Goudarzi, 1984).

Mineral resource assessment--An evaluation (or estimation) of the likelihood for the occurrence of undiscovered resources in an area (Goudarzi, 1984).

Mineral occurrence--A concentration of a mineral that is considered valuable by someone, somewhere or that is of scientific or technical interest (Cox and Singer, 1986).

Mineral deposit--A mineral occurrence of sufficient size and grade that it might under favorable circumstances be considered to have economic potential (Cox and Singer, 1986). For some types, the mineral deposits can be defined by a grade and tonnage distribution.

Ore deposit--A mineral deposit that has been tested and is known to be of sufficient size, grade, and accessibility to be producible to yield a profit (Cox and Singer, 1986).

Mineral deposit type--A conceptual model developed from a specific group of mineral deposits with similar geologic characterisitics and grades and tonnages that define an identifiable statistical distribution (see Cox and Singer, 1986).

Domain--An area that has been delineated according to the types of mineral deposits that the geology, geochemistry, and (or) geophysics will permit (Singer, 1975).

Assumptions

There are certain assumptions that are either implied or expressed in a mineral resource assessment. The following assumptions were made for the mineral assessment of the KNWR:

-there were no assumptions made regarding the effects of past, present, or future metal prices or on the economics of exploitation to the delineation of domains in the KNWR;
-no assumptions were made about the present or future demands for any metals or minerals (although the definition of a mineral resource indicates that the mineral is, or may become, economic);
-the assumption that different types of mineral deposits are formed in specific (unique) geologic environments was the guiding assumption for assigning known mineral occurrences to specific mineral deposit types and for delineating domains.

The completeness and degree of certainty of the KNWR mineral resource assessment is therefore dependent upon 1) the available geologic information and the accuracy of that information for the area 2) the completeness of mineral deposit models, and 3) the extent of our understanding of the geologic variation within a given deposit model and our ability to extend mineral deposit model concepts to either different or similar geologic environments.

The KNWR mineral assessment procedure

The procedure for this assessment of the mineral potential of the KNWR draws upon diverse sets of geologic data. These include geologic mapping, geochemistry, known mineral occurrences, past mine production (grades and tonnages of mineral deposits), recent exploration and mining activity, and the application of mineral deposit models to geologic terranes. These geologic data were combined to provide a resource assessment based on three steps as shown by Singer (1975; 1984). The three steps are: 1) delineation of domains that are permissive for the occurrence of specific mineral deposit types, 2) comparison of the grades and tonnages for known mineral deposit occurrences in the KNWR with grade and tonnage models of specific mineral deposit types where possible, and 3) an estimation of the number of undiscovered mineral deposits within the delineated domains.

At least one previous mineral resource assessment of the KNWR area is available. That assessment was done by Geoexplorers International, Inc. under contract to the U.S. Bureau of Land Management. The report is entitled, "Geology, Energy, and Mineral Resources Assessment of the Kofa Area, Arizona" by Jan Krason, Antoni Wodzicki, and Susan K. Cruver, December, 1982. The report includes discussions of regional geology, known mineral occurrences and past production, and an assessment of mineral resource potential of different areas. That report was used in part as background information in this present study.

Quadrangle geologic mapping was completed by USGS geologists during this mineral resource assessment. The mapping was done to provide an up-to-date geologic foundation for resource assessment. Interest in the regional geology of southwestern Arizona by the geologic community (academic, industry, government) is presently experiencing a renaissance. The quadrangle geologic mapping completed as part of this project and the map compilation at 1:100,00 that accompanies this report incorporates these new concepts and interpretations of southwestern Arizona geology. The compiled geologic map serves as the basis for dividing the KNWR into domains amenable to mineral resource assessment. (The quadrangle maps will be published separately.) In addition, isotopic age data were compiled and new data were obtained in an effort to help separate igneous, metamorphic, and mineralization events within the KNWR (see tables 1 and 2).

Regional and district geochemical data bases for the KNWR area were used to provide information on the geochemical signatures of mineralized rock in the KNWR and of the locations of mineralized areas. We examined the National Uranium Resource Evaluation (NURE) geochemical data base for the area and found it unsuitable for use in this resource assessment. The NURE data were collected on the basis of 2° quadrangles. The KNWR falls at the junction of four 2° quadrangles. Since the NURE samples were collected and analyzed by 2° quadrangles for logistical purposes, the collection and chemical analytical procedures were usually different for each quadrangle. Thus, the data set for the KNWR is a mixed set and not suitable for our purposes. In addition, many of the pathfinder and indicator elements for gold are not part of the NURE data base.

We implemented a geochemical sampling program to provide a complete data set for the assessment. The data set consists of: 1) regional stream-sediment heavy concentrate analyses, 2) regional stream-sediment (minus-80-mesh fraction) analyses, 3) regional background (rock sample) analyses for different lithologies, and 4) analyses of altered and mineralized rocks from known mineral occurrences. The power of this data set is that, 1) the rock samples provide an indication of trace elements associated with mineral deposits in the KNWR and 2) the stream sediment minus-80-mesh and heavy concentrate samples give a regional picture of areas with possible altered rocks and mineral deposits. In addition, the rock samples (both background and altered or mineralized samples) provide a basis within which to interpret the stream-sediment geochemical data.

Past production of mines in the area, current exploration and mining activites, and known mineral occurrences were also used to build the available data base.

The geophysical data base consists of regional gravity surveys. In addition, we used thermal IR remote sensing over an area in the northern part of the KNWR to help identify the extent of hydrothermal alteration associated with a porphyry copper mineral occurrence.

Mineral deposit descriptive and grade and tonnage models used in the assessment are those published by Cox and Singer (1986). In addition, models based on newly recognized types of gold deposits in southwestern Arizona and southeastern California were used.

The procedure followed for the KNWR assessment was to use the data available from the above sources to delineate domains within the KNWR which are permissive for the occurrence of specific mineral deposit types. An estimation of the number of undiscovered mineral deposits was then formulated for those domains. It is important to explicitly state that the assessment of those domains refers to undiscovered mineral deposits and that a test of the estimation is through either more detailed geologic research or detailed exploration.

Assessment domains

Several factors were involved in delineating domains within the KNWR for mineral resource assessment. The guiding step was specification of mineral deposit type. Once a mineral deposit type was selected, geologic, geochemical, and geophysical (if available and applicable) data, together with knowledge of past production and locations of mineral occurrences, were used to identify domains for which the data indicated favorability for the occurrence of that mineral deposit type. This procedure resulted in domain delineation for 8 mineral deposit types. Additional deposit types are discussed but domains were not delineated for specific reasons in each case. All domains are shown on plate 4, 5, and 6 and summarized in table 9.

Domain I: gneiss- or schist-hosted, epigenetic precious-metal deposits (pl. 4)

Delineation of a domain for gneiss- or schist-hosted, epigenetic precious-metal deposits is based on the presence of low to high-grade Mesozoic metamorphic rocks (map units MzPg, Jp, Mzo Kg, Js, Jss, Jm, Jp, KJm, Jg (near Kofa mine only)). The model for this type of deposit is ill-defined, and there is a wide range of ideas regarding the genesis of deposits of this type. Thus, delineation of domain I for deposits of this type is broadly defined. We have proceeded to delineate the domain by combining characteristics of known deposits (e.g. Mesquite, American Girl, CA) that are grouped within this deposit type. It is not clear, at least within the KNWR, exactly what the differences are between what some geologists may classify as epithermal deposits and others classify as gneiss- or schist-hosted deposits. However, Tosdal and Smith (1987) have separated epithermal gneiss-hosted deposits (Mesquite) from kyanite-gold deposits (American Girl). The descriptive models of Tosdal and Smith (1987) provide the basis of estimation of undiscovered deposits of gneiss or schist-hosted type.

Grade and tonnage models for deposits that may fit into this category have not been developed because of the widespread controversy regarding what to include and what not to include in a possible model. The Mesquite deposit contains at least 48 million metric tonnes that grade 1.71 grams of Au per tonne and the American Girl--Padre y Madre deposits together contain 6.89 million metric tonnes that grade 2.73 grams of Au per tonne (Frost and others, 1986; Guthrie and others, 1987). These grades and tonnages reveal the relative sizes of deposits that fit in this category. Based on the models of Tosdal and Smith (1987) and the above grade and tonnage models, we estimate that there is a 50 percent chance of 1, and a 10 percent chance of 2 or more gneiss-hosted kyanite gold deposits in domain I. There is a 90 percent chance of 1, a 50 percent chance of 2, and a 10 percent chance of 4 or more gneiss-hosted epithermal gold deposits in domain I. The numbers of undiscovered gneiss-hosted epithermal gold deposits are higher because of the known past epithermal activity in the KNWR. Deposits of either type are most likely to occur where metamorphic rocks are shattered along and near faults.

Domain II: Generic epithermal precious-metal-bearing deposits; includes Comstock epithermal veins, hot-spring Au and hot-spring Hg deposits, and epithermal Mn deposits (pl. 4)

Epithermal mineral deposits occur in Tertiary volcanic rocks throughout the western United States. Host rock lithologies range in composition from basalt to high silica rhyolite. Domain II is drawn to delineate areas in the KNWR that are permissive for the occurrence of precious-metal-bearing epithermal mineral deposits. The boundaries to domain II were drawn using a combination of favorable host rocks (map units Ts, Tt, Tb, Tbx) and the outlines of drainage basins from which samples were collected that contained anomalous concentrations of pathfinder elements (Au, Ag, As, Sb, Tl, Hg). There are two areas delineated that satisfy only one of the boundary criteria: 1) the Tb and Ts map units around the Republic mine and 2) the Tt map unit southeast of the Kofa mine. The Tertiary rocks near the Republic mine were included because of the occurrence of hot-spring alteration and Au anomalies at the Republic mine. Stream sediment were not anomalous in this area. The Tertiary rocks in fault contact with Jurassic rocks southeast of the Kofa mine were included because of the possibility of faulted extensions of the Kofa deposit in this area. Fault zones within and along the boundaries of domain II are particularly favorable sites for the occurrence of epithermal precious-metal deposits.

Hot-spring Au and Hg deposits are formed by water-dominated geothermal systems that occur in areas with a source of precious-metals, that are hot enough to carry the metals, and that last long enough to deposit precious-metals in sufficient quantities. High angle faults commonly serve as loci for geothermal systems. Geologic evidence of fossil geothermal systems are siliceous sinter (opaline or chalcedonic), hydrothermal explosion breccias, and paleo surface alteration (silicification and argillization). Geochemical pathfinder elements are Hg, As, Sb, Tl, Au, and Ag.

Grade and tonnage distributions for hot-springs Au deposits and hot-springs Hg deposits are shown in figure 12. The distributions provide a model for estimating number of deposits of these two types in domain II. There is a 90 percent chance of 1, 50 percent chance of 2, and a 10 percent chance of 3 or more undiscovered hot-spring gold deposits in domain II. There is a 90 percent chance of 1, 50 percent chance of 2, and a 10 percent chance of 3 or more undiscovered hot-spring Hg deposits in domain II.

The majority of the past production from epithermal precious-metal deposits in the KNWR was from Comstock-type epithermal vein deposits (deposit model of Mosier and others, 1986b). The main producers were the Kofa North Star mines (see fig. 11). Host rocks for these deposits in the KNWR are map units Tt. Deposits of this type commonly occur in subaerial volcanic terranes. The deposits are usually localized along high angle faults as massive veins consisting of quartz, calcite, barite, fluorite, and an assemblage of sulfides dominated by pyrite. Arsenic and antimony sulfides such as arsenopyrite, realgar, orpiment, and stibnite also occur. Stockwork quartz veinlets extend into hangwall rocks away from the main vein. Recent research on epithermal deposits (see Berger and Bethke, 1985 for a review) stresses the analogy between active and fossil geothermal systems. We used the analogy in this assessment for including epithermal Comstock vein deposits in domain II. The dominant factors that make domain II permissive for Comstock-type, epithermal vein deposits are: 1) favorable structures and host rocks, 2) application of K-Ar dating of vein adularia and volcanic rocks to provide knowledge of paleo heat sources which were necessary to drive circulating geothermal systems, 3) a source of metals implied by presence of mineral deposits and 4) the presence of anomalous pathfinder elements in widespread drainage basins. In view of the regional geologic framework of the KNWR, the entire area of exposed volcanic rocks cut by high angle faults could conceivably be considered to have high potential for epithermal, precious-metal deposits. However, we have attempted to more narrowly delineate domains by considering the coincidence of favorable host rocks and geochemistry.

Epithermal, precious-metal deposits were discovered and mined during the latter part of the nineteenth century and the first half of the twentieth century in the KNWR. It was during this period that deposits of this type were recognized in terms of their geologic characterisitcs and epithermal models were developed (e.g., Lindgren, 1933). Cenozoic volcanic terranes throughout the western United States were heavily prospected during that time for deposits of this type. We feel that chances are good that the KNWR was thoroughly explored during that period and that any obvious, high grade deposits with well-exposed surface alteration would have been discovered.

This assertion is supported by the number of known epithermal deposits in this region. Areas of past major production from Comstock-type epithermal deposits in the KNWR provide a baseline for estimating numbers of unknown deposits that may be bulk-minable. In light of this knowledge, we estimate that there is a 90 percent chance of 0, 50 percent chance of 1, and a 10 percent chance of 3 undiscovered Comstock-type epithermal vein deposits in domain II. It is likely that any of the 3 deposits will be smaller than the Kofa or North Star deposits (see fig. 11).

Domain II is also permissive for the occurrence of epithermal Mn deposits. All of the known Mn deposits of this type in KNWR are small; their past Mn production is too low to plot on the epithermal Mn grade and tonnage curves (see fig. 13). The Sheep Tanks deposit is classified as this type. It was a major producer of Au and Ag in the KNWR region. However, its grades of Au and Ag are small compared to Au and Ag grades in other deposits of this type (see the section above on mineralization systems and episodes). We estimate that there is a 90 percent chance of 0, a 50 percent chance of 1, and 10 percent chance of 2 undiscovered epithermal Mn deposits in domain II that will "fall onto" the grade and tonnage distribution for this deposit type.

Domain III. sedimentary-rock-hosted, disseminated precious-metal deposits (pl. 5)

Sedimentary-rock-hosted, disseminated, precious-metal deposits are also referred to in the literature as Carlin-type deposits or carbonate-hosted Au-Ag deposits (Berger, 1986a) and polymetallic replacement deposits. However, the term Carlin-type deposit usually implies gold-rich deposits only, whereas we prefer to include silver-rich deposits (e.g., Taylor, Nevada) as well (Bagby and Berger, 1985). The deposit model used for this type is that developed by Bagby and Berger (1985) and Berger (1986a). According to the model, thinly bedded, calcareous shales and siltstones and carbonaceous, silty limestones or dolomites are the most favorable host rocks for this type of deposit. Other less favorable host rocks are phyllites and argillites. Other necessary geologic factors are 1) structural preparation of host rocks and structural conduits that could have served as hydrothermal fluid pathways, 2) a heat source for driving a circulating hydrothermal system, 3) water, and 4) a source of precious-metals. Geochemical pathfinder elements are Au, Ag, As, Sb, Hg, and Tl. This model was used to delineate domains within the KNWR that are favorable for the occurrence of sedimentary-rock-hosted disseminated, precious-metal deposits.

The sedimentary-rock-hosted domain (domain III, pl. 5) includes Paleozoic and Mesozoic sedimentary rocks that, in some cases, are of low metamorphic grade. The most favorable host rocks in the map units used to delineate the domain (see table 9) are calcareous; either silty dolomites and limestones or calcareous siltstones and argillites. These rock types are not mapped separately and thus, the domains include other rock types (e.g. sandstone and schist) that are not favorable host rocks. In addition to favorable host rocks in domain III, faults, and fractured zones associated with faults, are highly favorable areas. Stream-sediment samples from basins overlying domain III contain pathfinder elements (Au, Ag, Sb, As, Tl, Hg) in anomalous concentrations. Thus, the reconnaissance geochemistry supports the delineation of domain III.

There is a 90 percent chance of 1, 50 percent chance of 2, and a 10 percent chance of 4 or more undiscovered sedimentary-rock-hosted, disseminated precious-metal deposits in domain III. Of the estimated number of deposits at the 10 percent level of confidence, half should be above and half below the median grade and tonnage for this type of deposit (see fig. 14).

Domain III is also permissive for polymetallic replacement deposits (model of Morris, 1986). One known deposit of this type, the Black Mesa mine, occurs within the domain (see table 8, pl. 3, and pl. 5). There is a 90 percent chance of 0, 50 percent chance of 1, and a 10 percent chance of 3 or more undiscovered polymetallic replacement deposits in domain III.

Domain IV: porphyry copper and associated skarn deposits (pl. 5)

Deposits of this type are genetically related to the shallow emplacement, differentiation, and cooling of intermediate to felsic magmas in the crust (Cox, 1986a). Where porphyry copper-generating magmas are intruded into limestone sequences, metal-rich copper skarns are commonly formed (Cox, 1986b). Oxidation of exposed porphyry-copper deposits produces characteristic iron oxide minerals that, when recognized, provide evidence of this type of mineralization. In addition, fluid inclusions in quartz veins associated with porphyry copper mineralization commonly have daughter minerals that also help characterize the deposit type.

A small, weakly developed porphyry copper occurrence crops out in the northeastern portion of the KNWR, north of Red Rock dam (see pl. 3). The occurrence is hosted by a medium-grained holocrystalline, biotite-hornblende granodiorite. The occurrence is strongly oxidized, and supergene acid leaching was intense in some parts. The oxide mineralogy is predominantly jarosite and pitch limonite with copper oxides and silicates. This assemblage occurs in the central part of the exposed granodiorite and is surrounded by a zone of propylitic alteration consisting of epidote, calcite, and pyrite. Quartz vein stockworks occur in both alteration types. Fluid inclusions in these veins contain a daughter mineral that is possibly an iron chloride based on room temperature petrographic study. The domain that is permissive for deposits of this type is delineated by inclusion of the map unit (Jg) in which the host plutonic rock occurs as well as map units KJg, JS and Jg, Tg, and Tp. Small areas of calcsilicate rock (map unit Pzs) near plutonic contacts are included in this domain.

The porphyry copper occurrence in this domain was drilled in the past, when exploration for porphyry copper deposits in Arizona was active. The drilling apparently indicated a noneconomic deposit at that time. However, only the central outcrop area was tested and zones beneath younger cover have not been examined. The weak development of the exposed alteration at the occurrence suggests that any undiscovered deposits are small.

The grade and tonnage distribution for porphyry copper deposits are shown in figure 15. Based on the size of the known occurrence and the extent of alteration mapped by remote sensing (see fig. 6), we estimate that there is a 10 percent chance of 0 or more undiscovered prophyry copper deposits in domain IV that have grades and tonnage which will plot on the curves in figure 15.

Domain V: placer gold deposits (pl. 6)

The KNWR has had past production of placer gold, with some silver. These placer deposits occur in Quaternary alluvium (map unit Qa). The Plomosa, Kofa, and Castle Dome placer deposits were the major gold-producing placer deposits in the KNWR (see pl. 3 and table 8). Other minor placer deposits are reported to occur in drainages in the Sheep Tanks and Neversweat Ridge districts. These placer deposits are small and no accurate location is available; they are not shown on plate 3. Our geologic mapping and identification of lode sources for the Plomosa placer deposits indicates that Tertiary colluvium (map unit Tc) is also a permissive geologic terrane for the occurrence of placer deposits.

We have delineated three subsets of the placer deposit domain on plate 6. These domain subsets are labelled VA, VB, and VC. Domain VA outlines the extent of known placer deposits in the Plomosa, Kofa, and Castle Dome districts. Extensions to known productive gravels in domain VA are likely. Domain VB contains downstream extensions of domain VA. In the Plomosa district, domain VB is arbitrarily cut off at the KNWR boundary. In the Kofa district, the boundary for domain VB is more problematic since it is difficult to definitely outline the domain without the benefit of studies on the transport of gravels in this area.

Domain VC includes all Tertiary gravels (map unit Tc) in the KNWR. The presence of low sulfide Au-W-quartz veins in most of the pre-Tertiary rocks indicates that erosion of the pre-Tertiary rocks may have formed placer deposits in Tertiary gravels. Map unit Tc occurs throughout the northern KNWR and is a unit containing different types of sedimentary rocks including conglomerates, sandstones, and breccias. Conglomerate beds that may represent sedimentary deposits formed from the erosion of pre-Tertiary rocks and that occur near, or at the base of, map unit Tc, are the most likely sedimentary rocks to contain placer deposits in domain VC. However, none of map unit Tc may be excluded for the occurrence of placer deposits without the benefit of more detailed geologic maps of the unit. Therefore, although domain VC is large, the actual domain with the highest likelihood of the occurrence of placer deposits is much smaller.

Estimated numbers of undiscovered placer deposits in domain VA are that there is a 90 percent chance of 0, a 50 percent chance of 1, and a 10 percent chance of 2 or more undiscovered placer deposits. For domain VC there is a 90 percent chance of 1, a 50 percent chance of 3, and a 10 percent chance of 5 or more undiscovered placer deposits.

Numbers of undiscovered placer deposits were not estimated for domain VB because of lack of confidence in explicitly defining the domain boundary.

Domain VI: rhyolite-hosted Sn deposits (pl. 6)

Although there are no known deposits of this type in the KNWR, a domain may be delineated which is permissive for the occurrence of these deposits. The descriptive model of rhyolite-hosted Sn deposits by Reed and others (1986) notes that Sn concentrations of >1,000 ppm in panned stream sediment concentrates is the most valuable exploration guide in high silica rhyolite terranes. Anomalous Sn values in stream-sediment samples in the KNWR are any value >150 ppm; some concentrates contain >2,000 ppm Sn. Other elements associated with the Sn-anomalous samples in the KNWR are Mo and Bi, both of which are enriched in deposits of this type.

We have delineated domain VI as permissive for rhyolite-hosted Sn deposits. The domain boundaries were drawn by including only those Sn-anomalous drainage basins that occur over rhyolites (map units Tt and Ts). Where Sn anomalies occurred in known mine areas (e.g. Kofa district) the area was excluded on the assumption that the Sn was contamination from mine dumps. Likewise, Sn-anomalous basins over metamorphic rocks were excluded on the interpretation that the Sn in these cases were derived from low sulfide Au-W-quartz veins.

Grade and tonnage distribution for rhyolite-hosted Sn deposits are shown in figure 16. These distributions show that this type of deposit is small. In some cases, Sn-bearing placers formed by erosion of rhyolite-hosted Sn deposits in Mexico constituted the economic deposits. We estimate that there is a 90 percent chance of 1, a 50 percent chance of 3, and a 10 percent chance of 5 undiscovered rhyolite-hosted Sn deposits in domain VI.

Domain VII: Low sulfide Au-W-quartz veins (pl. 6)

Metamorphogenic quartz veins in Proterozoic granite and in metamorphic rocks in the KNWR contain minor Au and W. These veins are separated in table 8 and on plate 3 based on major production. However, since their mineralogical characteristics are similar, they are lumped for purposes of domain delineation and resource assessment. These veins are discontinuous and are classified as low sulfide Au-W-quartz veins based on Berger's (1986b) model of low sulfide Au-quartz veins. Domain VII was delineated by outlining permissive map units (see table 9). Importantly, many drainage basins overlying the permissive rocks contain anomalous concentrations of Au and W in sediment samples.

Two occurrences of this type in the KNWR plot on the grade and tonnage curves for this type of deposit (fig. 11 and table 8). Note that both deposits are lower than the median Au grade and tonnage and that they plot at the high and low ends of the Ag distribution.

Veins of this type form bold outcrops and were easy targets for early exploration and mining. Many small prospects scattered throughout the KNWR were developed on veins of this type. This knowledge, together with the small sizes of known occurrences in the KNWR affect our estimate. We estimate a 90 percent chance of 0, a 50 percent chance of 1, and a 10 percent chance of 3 undiscovered low sulfide Au-W-quartz veins in domain VII. These undiscovered deposits can be expected to be below the median grade and tonnage as shown in figure 11.

Deposit types for which no domains were delineated

Polymetallic veins (e.g. Castle Dome district) were major past producers of Ag and Au in the KNWR. As shown in figure 11, grades and tonnages for polymetallic veins in the KNWR are mostly small, with only the Ramsey deposit at the median tonnage the Castle Dome district above the median tonnage. The polymetallic vein deposits in the KNWR occur in almost any type of host rock. However, there appears to be a strong correlation between Tertiary porphyritic dikes cutting Mesozoic metamorphic rocks (e.g. the Castle Dome district) and the occurrence of deposits of this type. Importantly, the Neversweat Ridge area is more deeply eroded than the Castle Dome district area; larger bodies of Tertiary granite are exposed in Neversweat Ridge and polymetallic vein deposits are essentially nonexistent. Thus, the polymetallic veins are epithermal and deep erosion destroys the deposits.

Dikes were not compiled on the geologic map (pl. 1). This would be necessary in order to delineate a terrane permissive for the occurrence of polymetallic veins. Therefore, it is not possible to estimate numbers of undiscovered deposits of this type on the KNWR. However, based on the surface exploration history of the area, the grade and tonange relations shown in figure 11, and the assumption that the largest epithermal deposits are found first, it is unlikely that any significant polymetallic vein deposits remain to be found in the KNWR.

Other mineral deposit types that may occur in the KNWR but for which no domains were delineated due to lack of information include: 1) uranium in volcanic rocks, 2) lithophilic elements such as the REE, Li, and Be, associated with pegmatites, and 3) aluminum in kyanite-pyrophylite alteration zones. Neither the lithologies nor the structure of the KNWR are favorable for massive sulfide deposits nor oil and gas, and we conclude that the geologic environment of the KNWR is not permissive for these deposit types.

Geothermal energy resources may occur in the area. Gutmann (1981) suggests that the Castle Dome area is underlain by a silicic batholith about 20 m.y. old. Such a batholith could supply geothermal energy provided that reservoir rocks occur at depth. Gutmann (1981) indicated that reservoir rocks are provided by the metasedimentary rocks in the region. Although detailed geophysical measurements are necessary to properly assess the geothermal resource potential of the area, Gutmann (1981) concluded that the Castle Dome area is "geothermally attractive".

Areas of the KNWR underlain by Quaternary alluvium have unknown favorability for mineral deposits of the types considered above. The geophysical data for the region are inconclusive with respect to the occurrence of mineral resources beneath the alluvial cover. Detailed, more closely-spaced geophysical surveys of several types would be necessary to evaluate undiscovered mineral resource deposits in these alluviated areas.

SUMMARY

This mineral resource assessment of the KNWR identifies seven domains which are permissive for the occurrence of: placer Au deposits; sedimentary-rock-hosted, disseminated precious-metal deposits; polymetallic replacement deposits; hot-spring precious-metal and Hg deposits; porphyry copper and associated skarn deposits; epithermal Mn deposits; Comstock-type epithermal veins; low sulfide Au-W-quartz veins; rhyolite-hosted Sn deposits; and gneiss- or schist-hosted, precious-metal deposits. Probabilistic estimates are made for the numbers of undiscovered mineral deposits in the delineated domains and are summarized in table 10. Many of the domains are delineated over the same map units and thus overlap. This reflects the fact that epithermal deposits (the majority of the types considered) are epigenetic and may cross-cut any older rock types. The only way to more specifically delineate domains and to more accurately separate permissive areas for different epithermal mineral deposit types is through detailed mapping and larger-scale compilation.

The assessment indicates the possibilities of the occurrence of undiscovered deposits of different types within the KNWR (table 10). The relative importance of deposits of the various types depends upon 1) the degree of certainty for the estimation of numbers of undiscovered deposits for each type and 2) the probable value of a deposit, if discovered.

Hot-spring precious-metal deposits, sedimentary-rock-hosted precious-metal deposits, and gneiss- or schist-hosted epithermal precious-metal deposits are of the highest importance because they have a high probable value and the likelihood of their occurrence in the KNWR is also high.

Those of intermediate importance are Comstock-type veins, gneiss-hosted kyanite gold deposits, Au-W-quartz veins, hot-spring Hg deposits, rhyolite-hosted Sn deposits and placer Au deposits. These deposits are considered intermediate in importance because they have either high probable value but a low likelihood of occurrence or vice versa. Those deposits of intermediate importance with high probable value are gneiss-hosted kyanite gold deposits, Comstock-type veins, and low sulfide Au-W-quartz veins. Those with low to moderate probable value but a higher likelihood of occurrence are hot-spring Hg deposits, placer gold deposits and rhyolite-hosted Sn deposits.

Undiscovered deposits in the KNWR of low importance are epithermal Mn deposits, porphyry copper and associated skarn deposits, and polymetallic replacement deposits because they have both a low likelihood of occurrence and a low probable value if discovered.

There are several deposit types that were discussed but for which no domains were delineated and thus, no estimates of undiscovered deposits were given. These are polymetallic veins, uranium in volcanic rocks, lithophilic elements in pegmatites, and aluminum in kyanite-pyrophylite alteration zones. It is unlikely that there are any significant undiscovered deposits of these four types in the KNWR. Thus, they are of low importance.

REFERENCES CITED

Adrian, B.M., Smith, D.B., Vaughn, R.B., and Delaney, T.A., 1986, Analytical results and sample locality maps of stream-sediment, heavy-mineral-concentrate, and rock samples from the Kofa National Wildlife Refuge, Yuma and La Paz Counties, Arizona: U.S. Geological Survey Open-File Report 86-199.

Aiken, C.L.V., and Ander, M.E., 1981, A regional strategy for geothermal exploration with emphasis on gravity and magnetotellurics: Journal of Volcanology and Geothermal Research, v. 9, no. 1, p. 1-28.

Anderson, C.A., and Silver, L.T., 1976, Yavapai series--A greenstone belt: Arizona Geological Society Digest, v. 10, p. 13-26.

Anderson T.H., and Silver, L.T. 1978, Jurassic magmatism in Sonora, Mexico: Geological Society of America Abstracts with Programs, v. 10, p. 359.

_____1979, The role of the Mojave-Sonora megashear in the tectonic evolution of northern Sonora, in Anderson, T.H., and Roldan-Quintana, Jaime, eds., Geology of northern Sonora, Guidebook-Field trip no. 27, 1979, Annual Meeting of the Geological Society of America: Instituto de Geologia U.N.A.M., Hermosillo, Sonora, Mexico, and Pittsburgh, Penn., The University of Pittsburgh, p. 59-68.

Anonymous, 1986, Homestake's McLaughlin gold mine: One of the largest U.S. gold mines comes on stream in 1985: Mining Engineering, v. 38, no. 1, p. 24-26.

Armstrong, R.L., and Suppe, John, 1973, Potassium-argon geochronometry of Mesozoic igneous rocks in Nevada, Utah, and southern California: Geological Society of America Bulletin, v. 84, p. 1375-1392.

Bagby, W.C., and Berger, B.R., 1985, Geologic characteristics of sediment-hosted, disseminated precious-metal deposits in the Western United States, in Berger, B.R., and Bethke, P.M., eds., Geology and geochemistry of epithermal systems: Society of Economic Geologists, Reviews in Economic Geology, v. 2, p. 169-202.

Bagby, W.C., Menzie, W.D., Mosier, D.L., and Singer, D.A., 1986, Grade and tonnage model of carbonate-hosted Au-Ag, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175-177.

Berger, B.R., 1986a, Descriptive model of carbonate-hosted Au-Ag, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175.

_____1986b, Descriptive model of low-sulfide Au-quartz veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 239.

Berger, B.R., and Bethke, P.M., eds., 1985, Geology and geochemistry of epithermal systems: Society of Economic Geologists, Reviews in Economic Geology, v. 2, 298 p.

Berger, B.R., and Singer, D.A., 1987, Grade-tonnage model of hot-spring gold-silver: A supplement to U.S. Geological Survey Bulletin 1693: U.S. Geological Survey Open-File Report 87-272C, 5 p.

Bilodeau, W.L., and Lindberg, F.A., 1983, Early Cretaceous tectonics and sedimentation in southern Arizona, southwestern New Mexico, and northern Sonora, Mexico, in Reynolds, M.W., and Dolly, E.D., eds., Mesozoic paleogeography of the west-central United States: Rocky Mountain Ssection, Society of Economic Paleontologists and Mineralogists, p. 173-188.

Bliss, J.D., 1986, Grade and tonnage model low-sulfide Au-quartz veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposits models: U.S. Geological Survey Bulletin 1693, p. 239-243.

Bliss, J.D., and Cox, D.P., 1986, Grade and tonnage model polymetallic veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125-129.

Bouley, B.A., 1986, Descriptive model of gold on flat faults, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 251.

Bugrov, V.A., and Shalaby, I.M., 1975, Geochemical prospecting in the Eastern Desert of Egypt, in Elliott, I.L., and Fletcher, W.K., eds., Geochemical exploration, 1974: Rexdale, Ontario, Association of Exploration Geochemists, p. 523-530.

Byerly, P.E., and Stolt, R.H., 1977, An attempt to define the Curie Point isotherm in northern and central Arizona: Geophysics, v. 42, p. 1394-1400.

Centanni, F.A., Ross, A.M., and DeSesa, M.A., 1956, Fluorometric determinations of uranium: Analytical Chemistry, v. 28, p. 1651.

Cox, D.P., 1986a, Descriptive model of porphyry Cu, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76.

_____1986b, Descriptive model of porphyry Cu, skarn-related deposits, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 82.

_____1986c, Descriptive model of polymetallic veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposits models: U.S. Geological Survey Bulletin 1693, 379 p.

Crowe, B.M., Crowell, J.C., and Krummenacher, Daniel, 1979, Regional stratigraphy, K-Ar ages, and tectonic implications of Cenozoic volcanic rocks, southeastern California: American Journal of Science, v. 279, p. 186-216.

Crowl, W.J., 1979, Geology of the central Dome Rock Mountains: Tucson, University of Arizona, M.S. thesis, 76 p.

Dahm, J.B., and Hankins, D.D., 1982, Preliminary geology of a portion of the Southern Kofa Mountains, Yuma County, Arizona, in Frost, E., and Martin, D., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River Region, California, Arizona, and Nevada: San Diego, Calif., Cordilleran Publishers, p. 459-469.

Davis, G.A., Anderson, J.L., Frost, E.G., and Shackelford, T.J., 1980, Mylonitization and detachment faulting in the Whipple-Buckskin-Rawhide Mountains, southeastern California and western Arizona, in Crittenden, M.D., Jr., Coney, P.J., and Davis, G.H., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 79-129.

Dillon, J.T., 1976, Geology of the Chocolate and Cargo Muchacho Mountains, southeasternmost California: Santa Barbara, University of California, Ph. D. thesis, 575 p.

Drobeck, P.A., Hillemeyer, F.L., Frost, E.G., and Liebler, G.S., 1986, The Picacho mine: A gold mineralized detachement in southeastern California, in Beatty, Barbara and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the southwest: Arizona Geological Society Digest, v. 16, p. 187-221.

Durning, W.P., and Buchanan, L.J., 1984, The geology and ore deposits of Oatman, Arizona, in, Wilkins, Joe, ed., Gold and silver deposits of the Basin and Range Province, western U.S.A.: Arizona Geological Society Digest Volume XV, p. 141-158.

Epler, William, 1987, Firm acquires Arizona gold property: Southwestern Pay Dirt, no. 576, p. 18A.

Frost, Erick, Drobeck, Peter, and Hillemeyer, Bud, 1986, Geologic setting of gold and silver mineralization in southeastern California and southwestern Arizona, in Cenozoic stratigraphy, structure and mineralization in the Mojave Desert: Geological Society of America Guidebook and Volume, Trips 5 and 6, Cordilleran Section, 82nd Annual Meeting, March 25-28, 1986, Los Angeles, California, p. 71-144.

Goudarzi, G.H., 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84-787, 42 p.

Grimes, D.J., and Marranzino, A.P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Grubensky, M.J., Sherrod, D.R., Koch, R.D., Pickthorn, L.B.G., and Bagby, W.C., 1986, Late Oligocene-early Miocene calderas in the Kofa area, southwestern Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 2, p. 111.

Guthrie, J.O., Cockle, A.R., and Branham, A.D., 1987, Geology of the America Girl-Padre y Madre gold deposits, Imperial County, California: Society of Mining Engineers of A.I.M.E. preprint 87-87, 4 p.

Gutmann, J.T., 1981, Geologic framework and hot dry rock geothermal potential of the Castle dome area, Yuma County, Arizona: Los Alamos Scientific Laboratory Report, LA-8723-KDR, VC-66b, 23 p.

Hamilton, Warren, 1982, Structural evolution of the Big Maria Mountains, northeastern Riverside County, southeastern California, in Frost, E.G., and Martin, D. L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, Calif., Cordilleran Publishers, p. 1-28.

Harding, L.E., 1982, Tectonic significance of the McCoy Mountains Formation, southeastern California and southwestern Arizona: Tucson, University of Arizona, Ph. D. thesis, 197 p.

Harding, L.E., Butler, R.F., and Coney, P.J., 1983, Paleomagnetic evidence for Jurassic deformation of the McCoy Mountains Formation, southeastern California and southwestern Arizona: Earth and Planetary Science Letters, v. 62, p. 104-114.

Harding, L.E., and Coney, P.J., 1985, The geology of the McCoy Mountains Formation, southeastern California and southwestern Arizona: Geological Society of America Bulletin, v. 96, p. 755-769.

Haxel, Gordon, 1977, The Orocopia Schist and Chocolate Mountain thrust, Picacho-Peter Kane Mountain area, southeasternmost California: Santa Barbara, University of California, Ph. D. thesis, 277 p.

Haxel, Gordon, and Dillon, John, 1978, The Pelona-Orocopia Schist and Vincent-Chocolate Mountain thrust system, southern California, in Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 453-469.

Haxel, G.B., and Grubensky, M.J., 1984, Tectonic significance of localization of middle Tertiary detachment faults along Mesozoic and early Tertiary thrust faults, southern Arizona region [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 6, p. 533.

Haxel, G.B., and Tosdal, R.M., 1986, Significance of the Orocopia Schist and Chocolate Mountains thrust in the late Mesozoic tectonic evolution of the southern California-southwestern Arizona region: Extended abstract, in Beatty, Barbara, and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest, v. 16, p. 52-61.

Haxel, G.B., Tosdal, R.M., and Dillon, J.T., 1985, Tectonic setting and lithology of the Winterhaven Formation, a new Mesozoic stratigraphic unit in southeasternmost California and southwestern Arizona: U.S. Geological Survey Bulletin 1599, 19 p.

Haxel, Gordon, Tosdal, R.M., May, D.J., and Wright, J.E., 1984, Latest Cretaceous and early Tertiary orogenesis in south-central Arizona: Thrust faulting, regional metamorphism, and granitic plutonism: Geological Society of America Bulletin, v. 95, p. 631-653.

Henley, R.W., 1985, The geothermal framework of epithermal deposits in, Berger, B.R., and Bethke, P.M., eds., Geology and geochemistry of epithermal systems: Society of Economic Geologists, Reviews in Economic Geology, v. 2, p. 1-24.

Hopkins, D.M., 1977, An improved ion-selective electrode method for the rapid determination of fluorine in rocks and soils: U.S. Geological Survey Journal of Research, v. 5, no. 5, p. 583-593.

Hubert, A.E., and Chao, T.T., 1985, Determination of gold, indium, tellurium, and thallium in the same sample digest of geological materials by atomic-absorption spectroscopy and two-step solvent extraction: Talanta, v. 32, no. 7, p. 568-570.

Hubert, A.E., and Lakin, H.W., 1973, Atomic-absorption determination for thallium and indium in geologic materials, in Jones, M.J., ed., Geochemical Exploration Symposium 1973: Institution of Mining and Metallurgy, London, England, p. 383-387.

Keith, S.B., 1978, Index of mining properties in Yuma County, Arizona: Arizona Bureau of Geology and Mineral Technology Bulletin 192, Bureau of Geology and Mineral Technology, State of Arizona, 185 p.

Krason, Jan, Wodzicki, Antoni, and Cruver, S.K., 1982, Geology, energy, and mineral resources assessment of the Kofa area, Arizona: Geoexplorers International, Inc., prepared for the United States Department of the Interior, Bureau of Land Management, 207 p.

Liebler, G.S., 1987, Geology and gold mineralization at the Picacho mine, Imperial County, California [abs.]: Geological Society of Nevada Bulk Mineable Precious Metal deposits of the Western United States Program with Abstracts, p. 53.

Lindgren, Waldemar, 1933, Mineral Deposits: McGraw Hill, New York, 930 p.

Logan, R.E., and Hirsch, D.D., 1982, Geometry of detachment faulting and dike emplacement in the Southwestern Castle Dome Mountains, Yuma County, Arizona, in Frost, E., and Martin, D., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River Region, California, Arizona, and Nevada: San Diego, Calif., Cordilleran Publishers, p. 599-607.

Manske, S.L., Matlack, W.F., Springett, M.W., Strakele, A.E., Jr., Watowich, S.N., Yeomans, B., and Yeomans, E., 1987, Geology of the Mesquite deposits, Imperial County, California: Society of Mining Engineers of A.I.M.E. preprint-87-107, 9 p.

Martin, D.L., Krummenacher, Daniel, Frost, E.G., 1982, K-Ar geochronologic record of Mesozoic and Tertiary tectonics of the Big Maria-Little Maria-Riverside Mountains terrane, in Frost, E.G., and Martin, D.L., eds. Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, Calif., Cordilleran Publishers, p. 518-549.

Meier, A.L., 1980, Flameless atomic absorption determination of gold in geological materials: Journal of Geochemical Exploration, v. 13, p. 77-85.

Miller, F.K., 1966, Structure and petrology of the southern half of the Plomosa Mountains, Yuma County, Arizona: Stanford, Calif., Stanford University, Ph. D. thesis, 107 p.

_____1970, Geologic map of the Quartzite quadrangle, Yuma County, Arizona: U.S. Geological Survey Quadrangle Map GQ-841, scale 1:62,500.

Miller, F.K., and McKee, E.H., 1971, Thrust and strike-slip faulting in the Plomosa Mountains, southwestern Arizona: Geological Society of America Bulletin, v. 82, p. 717-722.

Mitcham, R.T., 1972, Mineral report on preliminary survey of mining claim concentrations and cursory evaluation of validity, Kofa Game Range, for Bureau of sport fisheries and wildlife: Bureau of Land Management, Kofa Project 2017.

McNerney, J.J., Buseck, P.R., and Hanson, R.C., 1972, Mercury detection by means of thin gold films: Science, v. 178, p. 611-612.

Morris, H.T., 1986, Descriptive model of polymetallic replacement deposits, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 99-100.

Mosier, D.L., 1986a, Descriptive model of epithermal Mn, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 165.

_____1986b, Grade and tonnage model of epithermal Mn, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 166-167.

Mosier, D.L., Sato, Takeo, and Singer, D.A., 1986a, Grade and tonnage model of Comstock epithermal veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposits models: U.S. Geological Survey Bulletin 1693, p. 151-153.

Mosier, D.L., Singer, D.A., and Berger, B.R., 1986b, Descriptive model of Comstock epithermal veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 150.

O'Leary, R.M., and Viets, J.G., 1986, Determination of antimony, arsenic, bismuth, cadmium, copper, lead, molybdenum, silver, and zinc in geologic materials by atomic absorption spectrometry using a hydrochloric acid-hydrogen peroxide digestion: Atomic Spectroscopy, [in press].

O'Neil, T.O., 1985, Asamera's Cannon mine is the largest North American underground gold mine to become operational this year: Mining Engineering, v. 37, no. 12, p. 1355-1358.

Overstreet, W.C., and Marsh, S.P., 1981, Some concepts and techniques in geochemical exploration: Economic Geology 75th Anniversary Volume, p. 775-805.

Pelka, G.J., 1973, Geology of the McCoy and Palen Mountains, southeastern California: Santa Barbara, University of California, Ph. D. thesis, 162 p.

Powell, R.E., 1981, Geology of the crystalline basement complex, eastern Transverse Ranges, southern California: constraints on regional tectonic interpretations: Pasadena, California Institute of Technology, Ph.D. dissertation, 441 p.

Reed, B.L., Duffield, Wendell, Ludington, S.D., Maxwell, C.H., and Richter, D.H., 1986, Descriptive model of rhyolite-hosted Sn, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 168.

Reynolds, S.J., 1980, Geologic framework of west-central Arizona, in Jenny, J.P., and Stone, Claudia, eds., Studies in western Arizona: Arizona Geological Society Digest, v. 12, p. 1-16.

Reynolds, S.J., Richard, S.M., Haxel, G.B., Tosdal, R.M., and Laubach, S.E., 1987, Geologic setting of Mesozoic and Cenozoic metamorphism in Arizona, in Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States, Rubey Volume 7, Prentice Hall [in press].

Rytuba, J.J., 1986a, Descriptive model of hot-spring Hg, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 178.

_____1986b, Grade and tonnage model of hot-spring Hg, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 178-179.

Sauck, W.A., 1972, Compilation and preliminary interpretation of the Arizona Aeromagnetic Map: Tucson, University of Arizona, Ph.D. dissertation, 147 p.

Shafiqullah, M., Damon, P.E., Lynch, D.J., Reynolds, S.J., Rehrig, W.A., and Raymond, R.H., 1980, K-Ar geochronology and geologic history of southwestern Arizona and adjacent areas: Arizona Geological Society Digest, v. 12, p. 201-242.

Silver, L.T., 1971, Problems of crystalline rocks of the Transverse Ranges [abs.]: Geological Society of America Abstracts with Programs, v. 3, p. 193-194.

_____1978, Precambrian formations and Precambrian history in Chochise County, southeastern Arizona, in Callender, J.T., Wilt, J.C., and Clemons, R.E., eds., Land of Chochise: New Mexico Geological Society, 29th Field Conference, Socorro, Guidebook, p. 157-164.

Singer, D.A., 1975, Mineral resource models and the Alaskan Mineral Resources Assessment Program, in Vogely, W.A., ed., Minerals Materials Modeling, A state of the art review: Baltimore, John Hopkins University Press, p. 370-382.

Singer, D.A., 1984, Mineral resource assessments of large regions: Now and in the future, in Geological Survey of Japan, ed., U.S.-Japan joint seminar on resources in the 1990's: Earth Resources Satellite Data Analysis Center, Tokyo, Japan, p. 32-40.

Singer, D.A., and Mosier, D.L., 1986, Grade and tonnage model rhyolite-hosted Sn, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 169-171.

Singer, D.A., Mosier, D.L., and Cox, D.P., 1986, Grade and tonnage model of porphyry Cu, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 77-81.

Thompson, C.E., Nakagawa, H.M., and Van Sickle, G.H., 1968, Rapid analysis for gold in geologic materials, in Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-B, p. B130-B132.

______1986, Mesozoic ductile deformations in the southern Dome Rock Mountains northern Trigo Mountains, Trigo Peaks, and Livingston Hills, southwestern Arizona; and the Mule Mountains, southeastern California, in Beatty, Barbara and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the southwest: Arizona Geological Society Digest, v. 16, p. 62-71.

Tosdal, R.M., and Haxel, G.B., 1985, Lithologic associations of gold deposits, southeastern California and southwestern Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 17.

Tosdal, R.M., and Haxel, G.B., and Wright, J.E., 1987, Jurassic geology of the Sonoran Desert region, southern Arizona, southeastern California, and northernmost Sonora: Construction of a continental-margin magmatic arc, in Reynolds, S.J., and Jenney, J.P., eds., Summary of Arizona Geology: Arizona Geological Society Digest, v. 17 [in press].

Tosdal, R.M., and Smith, D.B., 1987, Gneiss-hosted kyanite gold and gneiss-hosted epithermal gold: A supplement to U.S. Geological Survey Bulletin 1693: U.S. Geological Survey Open-File Report 87-272b, 6 p.

Vaughn, W.W., and McCarthy, J.H., Jr., 1964, An instrumental technique for the determination of submicrogram concentrations of mercury in soils, rocks, and gas, in Geological Survey research 1964: U.S. Geological Survey Professional Paper 501-D, p. D123-D127.

Viets, J.G., 1987, Determination of silver, bismuth, cadmium, copper, lead, and zinc in geologic materials by atomic absorption sepctrometry with tricaprylylmethylammonium chloride: Analytical Chemistry, v. 50, p. 1097-1101.

Walenga, Karen, 1986, Tonkin Springs gold mine comes on line quickly, cheaply: Rocky Mountain Pay Dirt, no. 76, p. 8A-9A.

Welsch, E.P., 1983, A rapid geochemical spectrophotometric determination of tungsten with dithiol: Talanta, v. 30, p. 876-878.

West, R.E., and Sumner, J.S., 1973, Bouger gravity anomaly map of Arizona, scale 1:500,000, Laboratory of Geophysics, Department of Geosciences, University of Arizona, Tucson, Arizona.

Wise, W.S., 1975, The origin of the assemblage: Quartz + Al-silicate + rutile + Al-phosphate, Fortschritte der Mineralogie, v. 52, p. 151-159.

Wright, J.E., Haxel, G.B., Tosdal, R.M., and May, D.J., 1981, Early Jurassic uranium-lead isotopic ages for Mesozoic supracrustal sequences, Papago Indian Reservation, southern Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 13, p. 115.

Yeend, W.E., 1986, Descriptive model of placer Au-PGE, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 261.

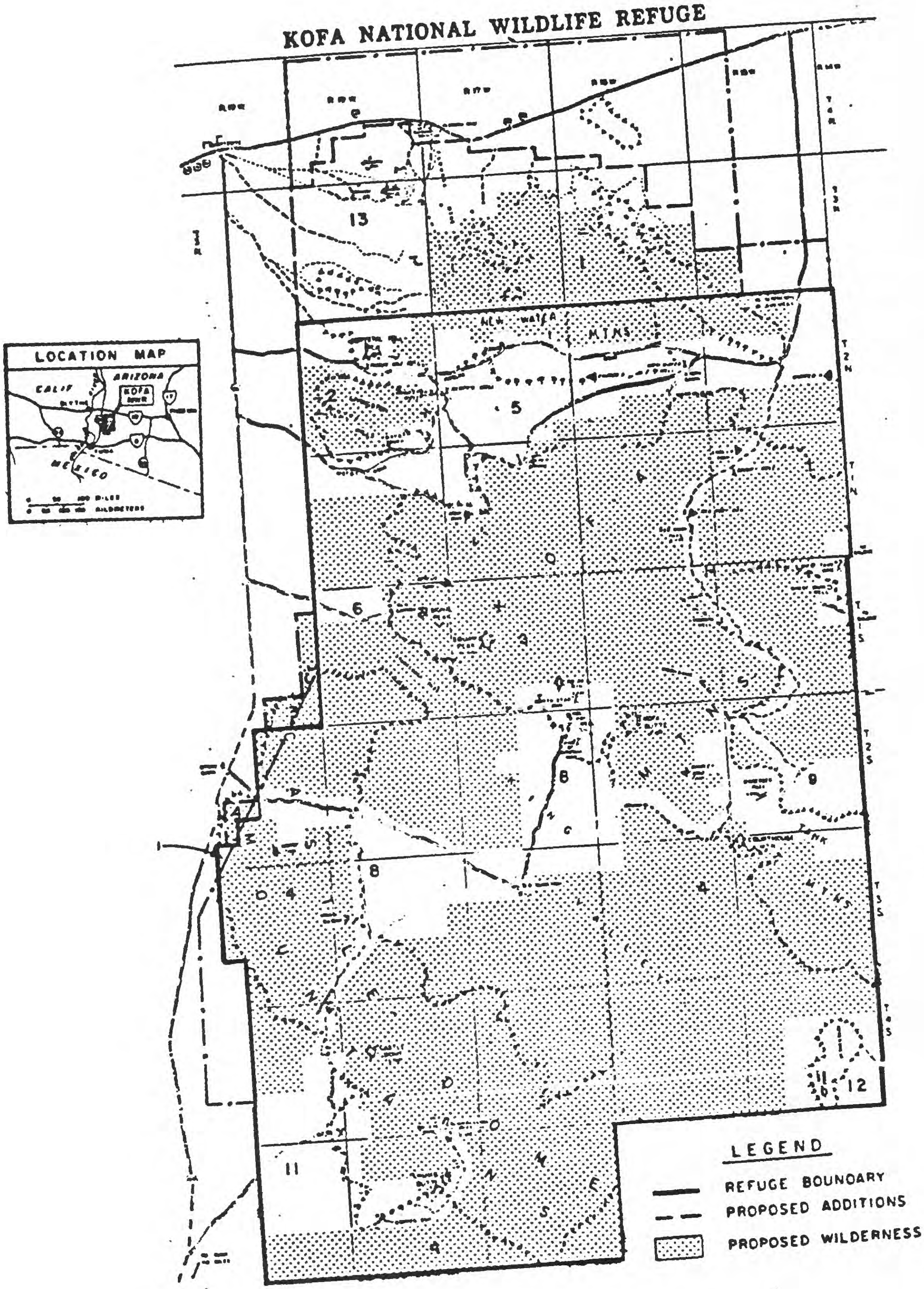
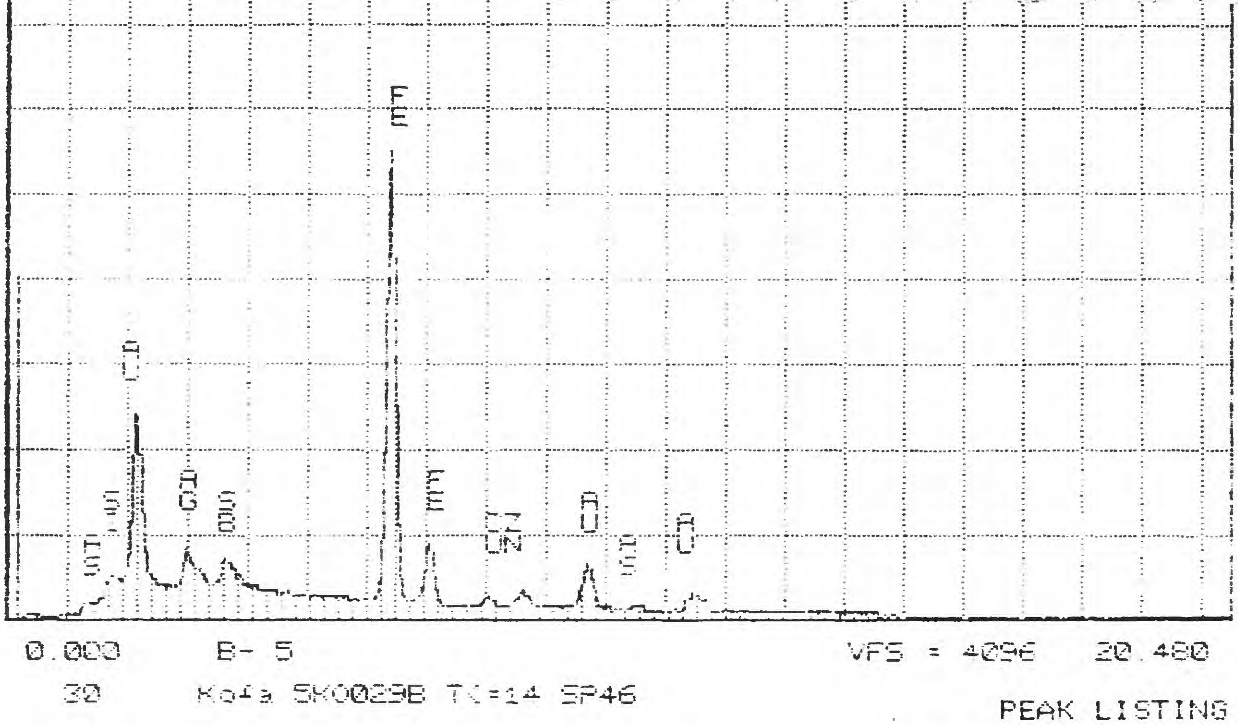

KOFA NATIONAL WILDLIFE REFUGE
LOCATION MAP
CALIF
ARIZONA
KOFA
MEXICO
LEGEND
REFUGE BOUNDARY
PROPOSED ADDITIONS
PROPOSED WILDERNESS

Figure 1



	PEAK LISTING		
	ENERGY	AREA	EL. AND LINE
1	0.375	186	UNIDENTIFIED
2	1.300	188	AS LA
3	1.729	725	SI KA
4	2.159	7758	AU MA
5	2.990	1295	AG LA
6	3.637	1140	SB LA
7	6.405	22096	FE KA
8	7.055	2956	FE KB
9	8.045	563	CU KA
10	8.626	882	ZN KA
11	9.703	2138	AU LA
12	10.527	259	AS KA
13	11.478	711	AU LB

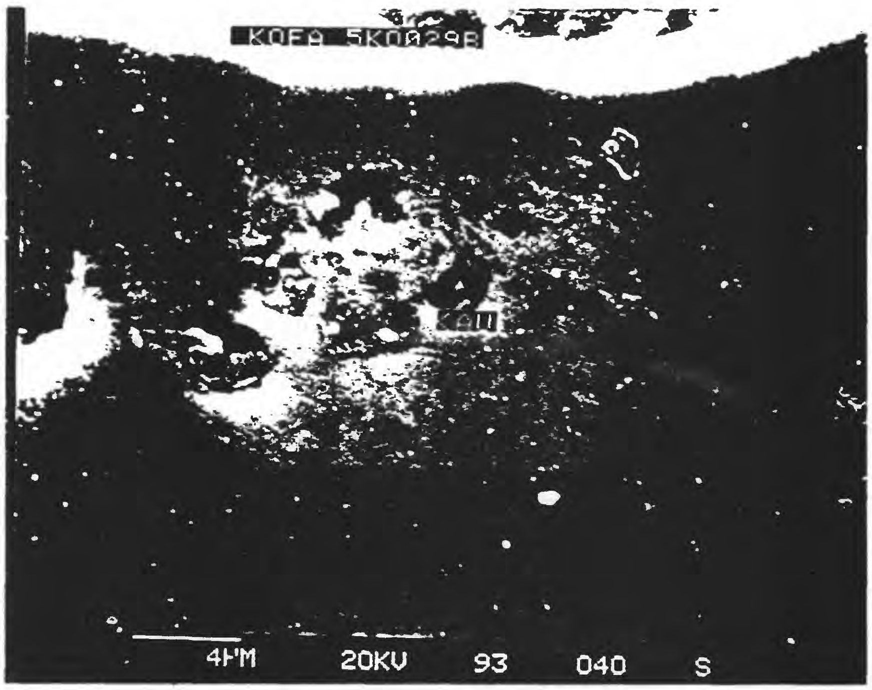
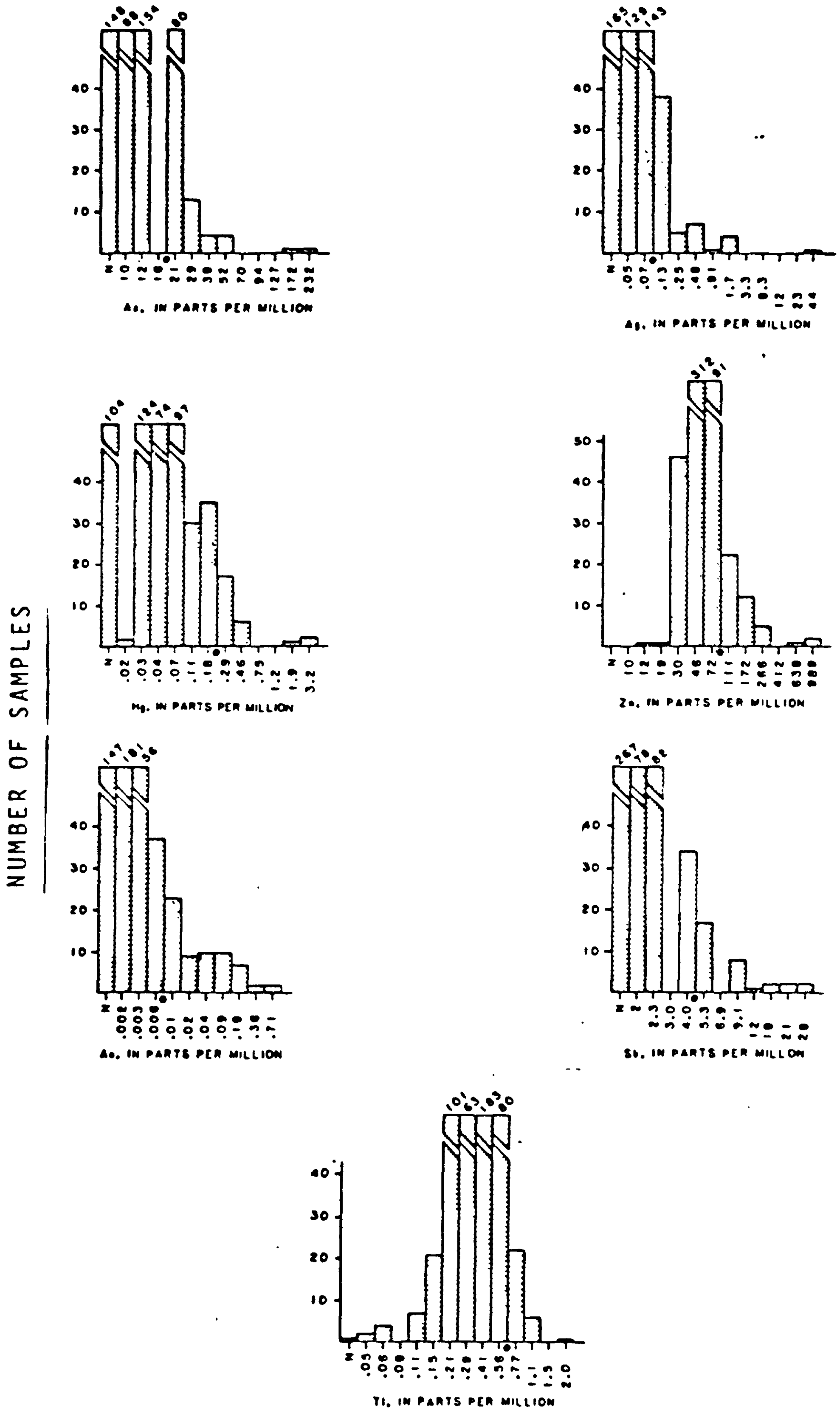
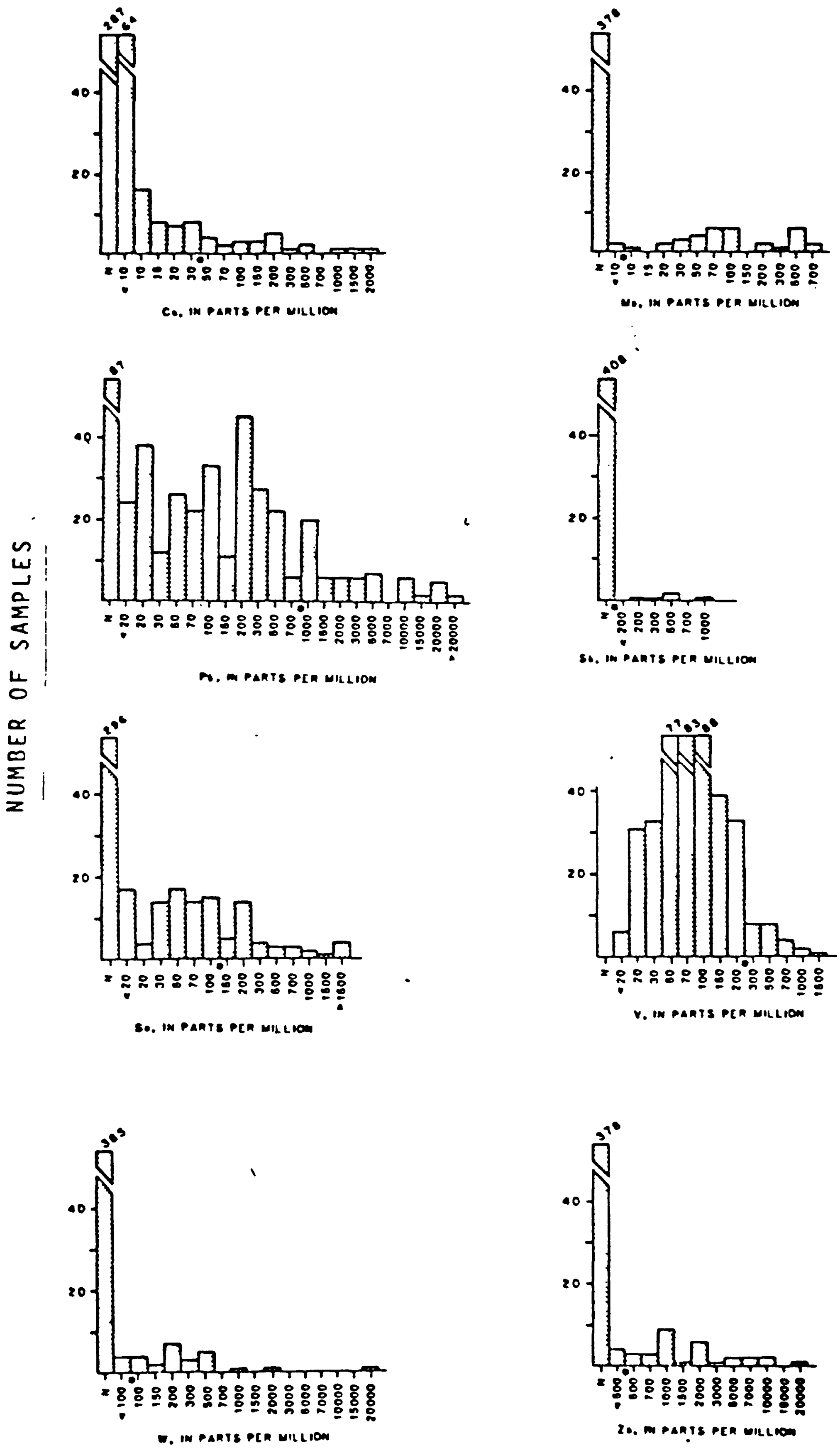


Figure 2



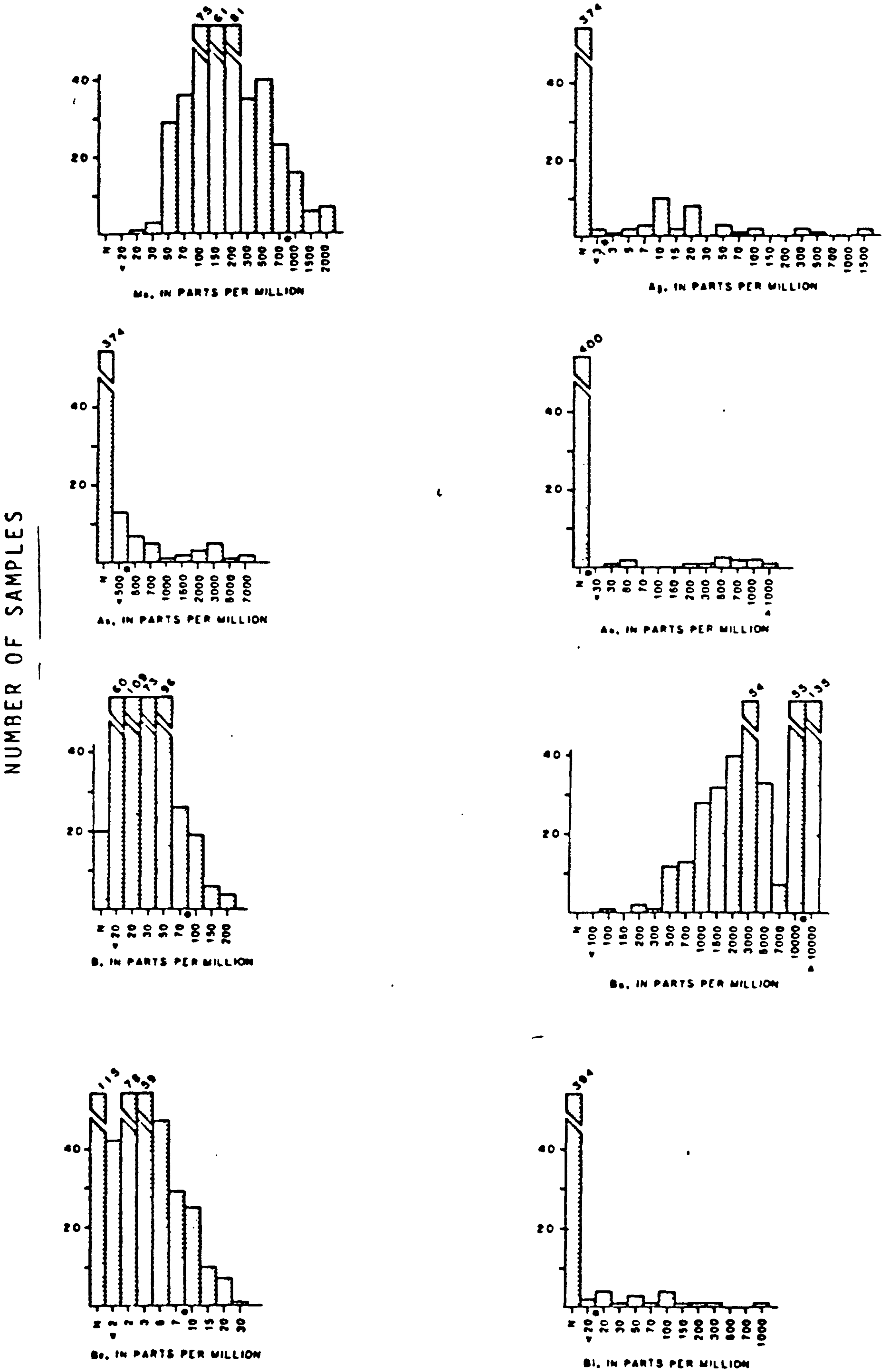
Asterisk(*) indicates threshold value.

Figure 3



Asterisk(*) indicates threshold value.

Figure 4



Asterisk(*) indicates threshold value.

Figure 4 (con'd)

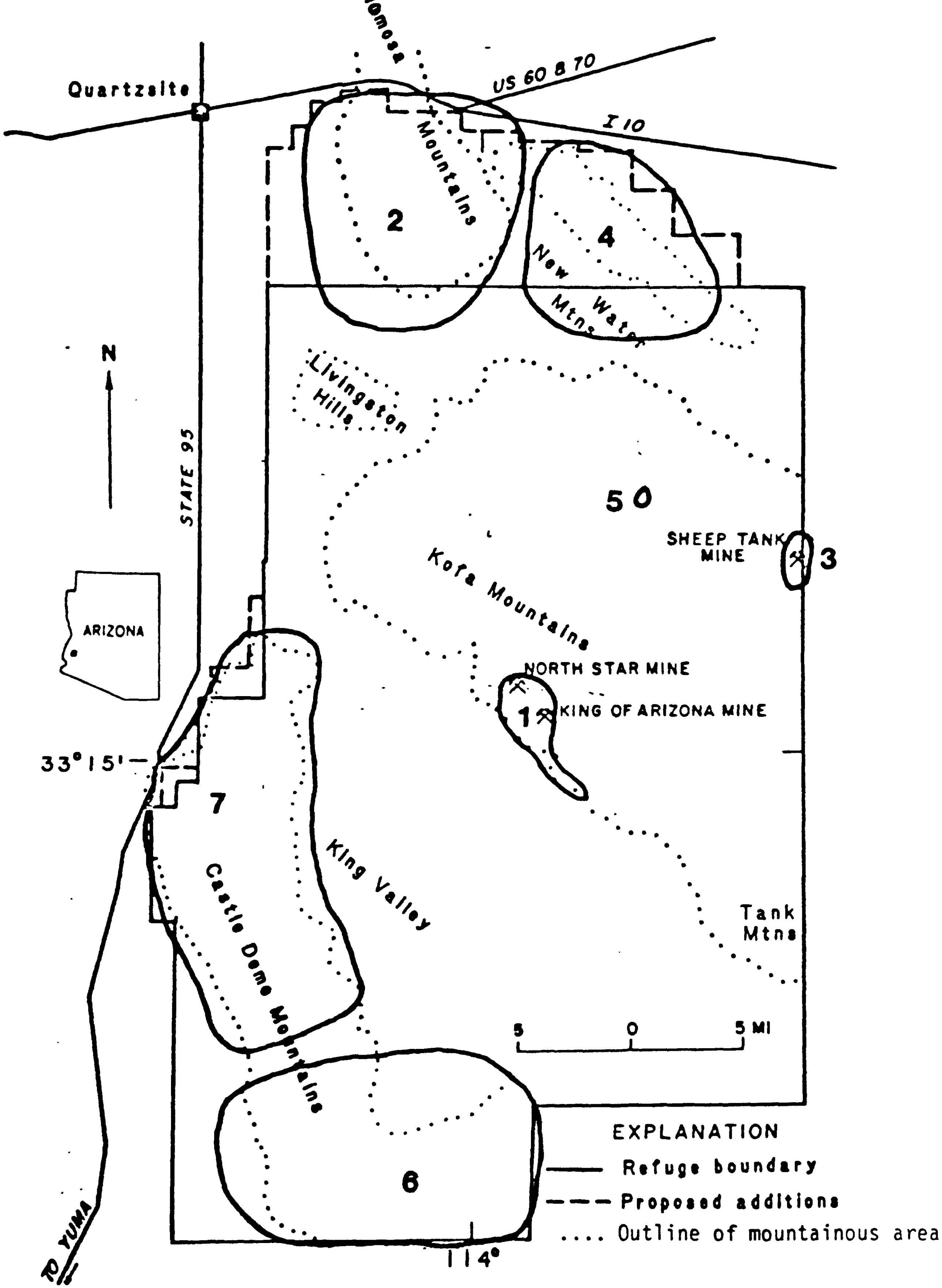
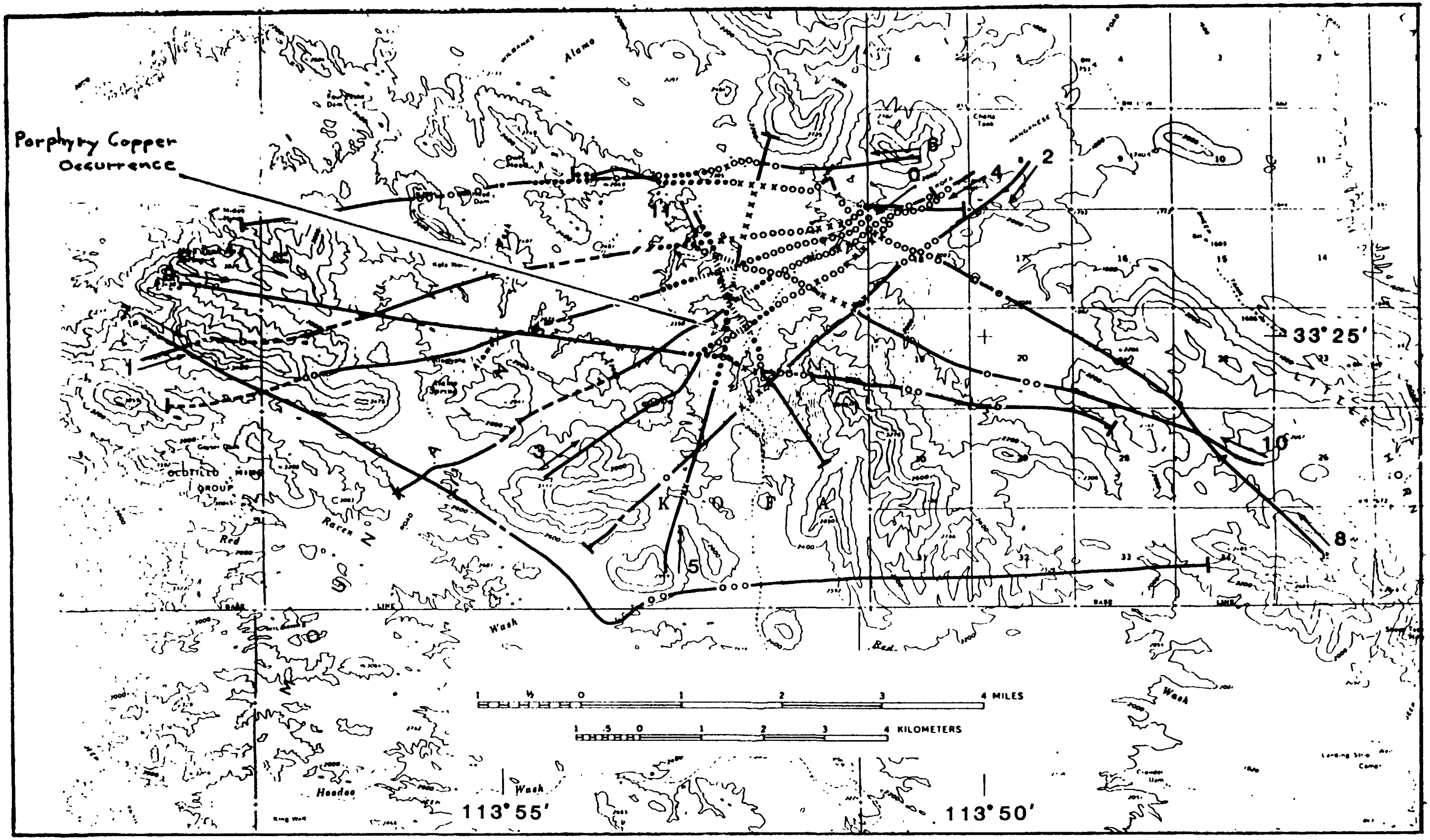

Quartzsite
US 60 & 70
I 10
Mountains
2
4
New Water Mtns
N
Livingston Hills
STATE 95
5
SHEEP TANK MINE
3
Kofa Mountains
ARIZONA
NORTH STAR MINE
1
KING OF ARIZONA MINE
33°15'
7
Castle Dome Mountains
King Valley
Tank Mtns
5 0 5 MI
6
EXPLANATION
Refuge boundary
Proposed additions
.... Outline of mountainous area
114°
TO YUMA

Figure 5



EXPLANATION

- ||||||||| High intensity 2.26 and 2.35 micron bands (epidote/calcite)
- xxxxx Low to high intensity kaolinite bands
- oooooo Low to medium intensity 2.2 micron clay bands
- ••••••• Medium to very high intensity 2.2 micron and 2.35 micron bands
- ——— Background clay
- ------ Shadows
- ←3 Flight line direction and number

Figure 6

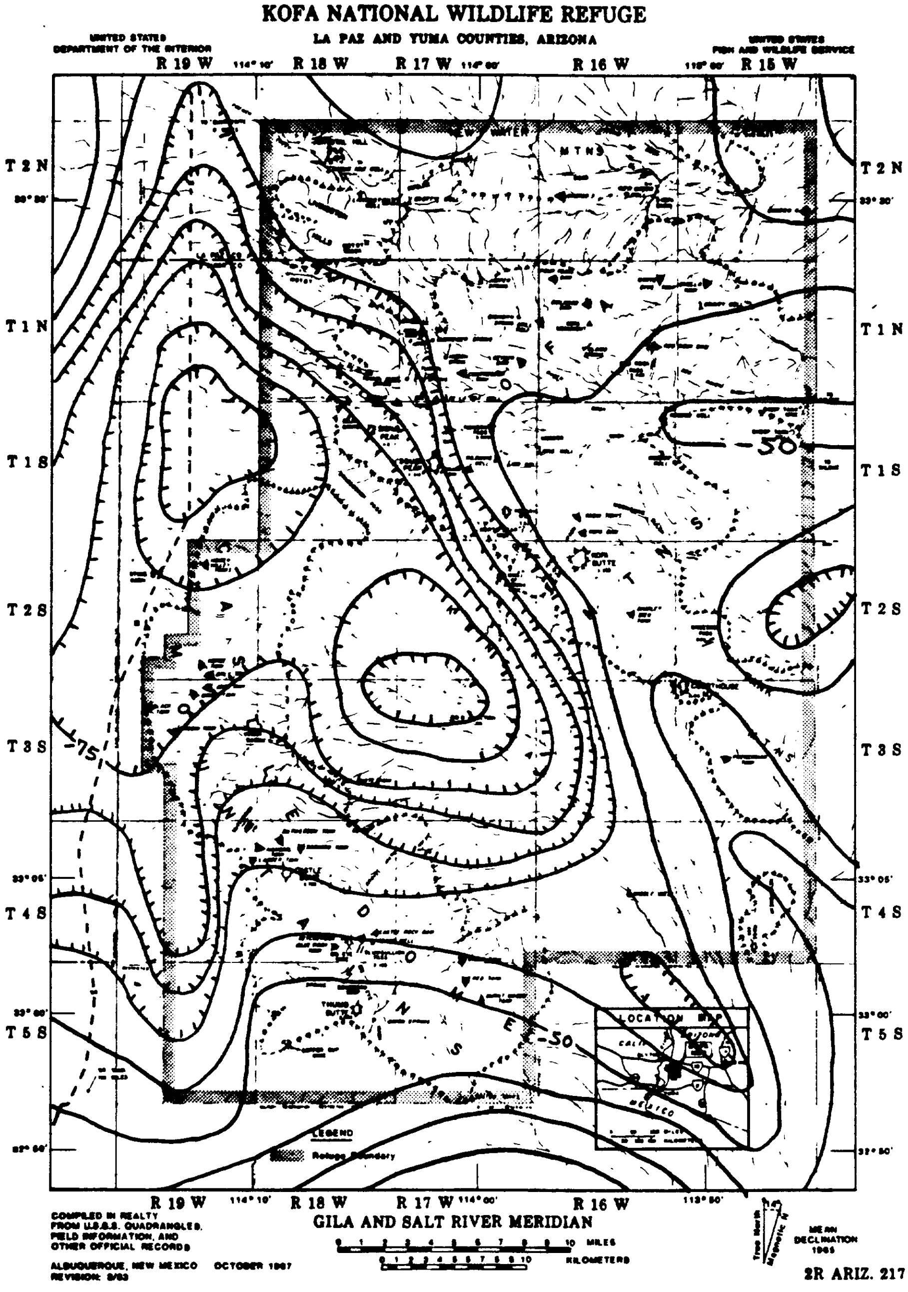

KOFA NATIONAL WILDLIFE REFUGE
LA PAZ AND YUMA COUNTIES, ARIZONA
UNITED STATES DEPARTMENT OF THE INTERIOR
UNITED STATES FISH AND WILDLIFE SERVICE
R 19 W
R 18 W
R 17 W
R 16 W
R 15 W
T 2 N
T 1 N
T 1 S
T 2 S
T 3 S
T 4 S
T 5 S
-50
-75
-50
LOCATION MAP
LEGEND
Refuge Boundary
GILA AND SALT RIVER MERIDIAN
MILES
KILOMETERS
MEAN DECLINATION
2R ARIZ. 217

Figure 7

KOFA NATIONAL WILDLIFE REFUGE

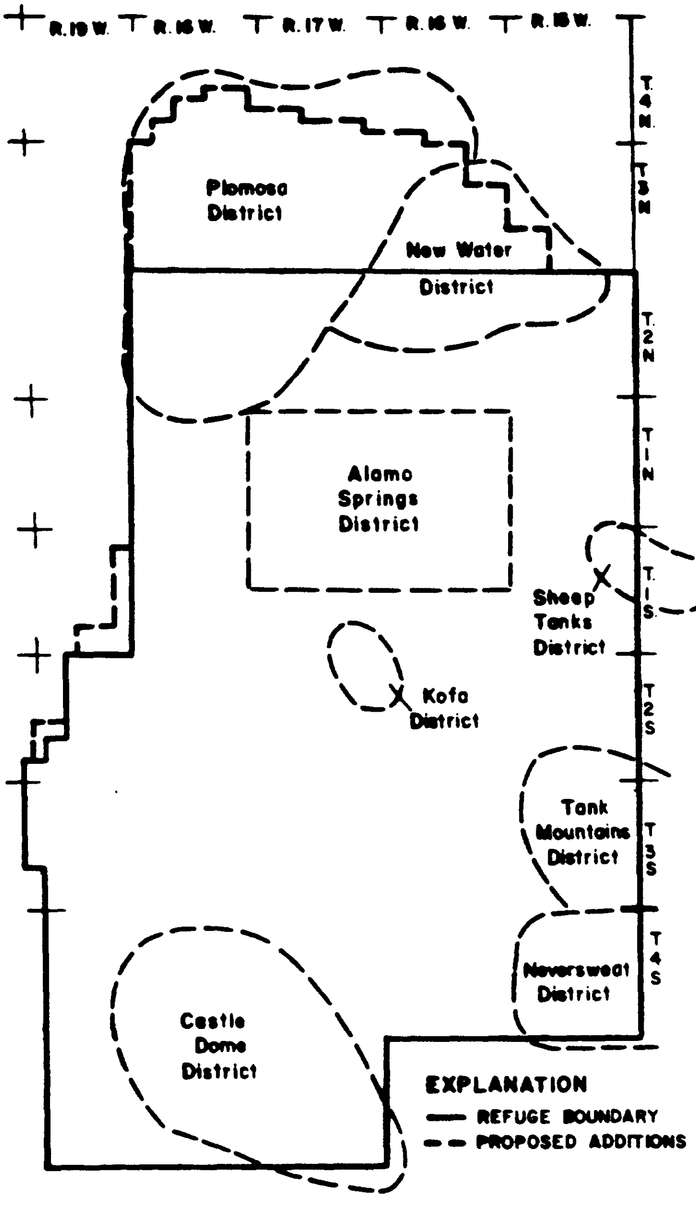


Figure 8

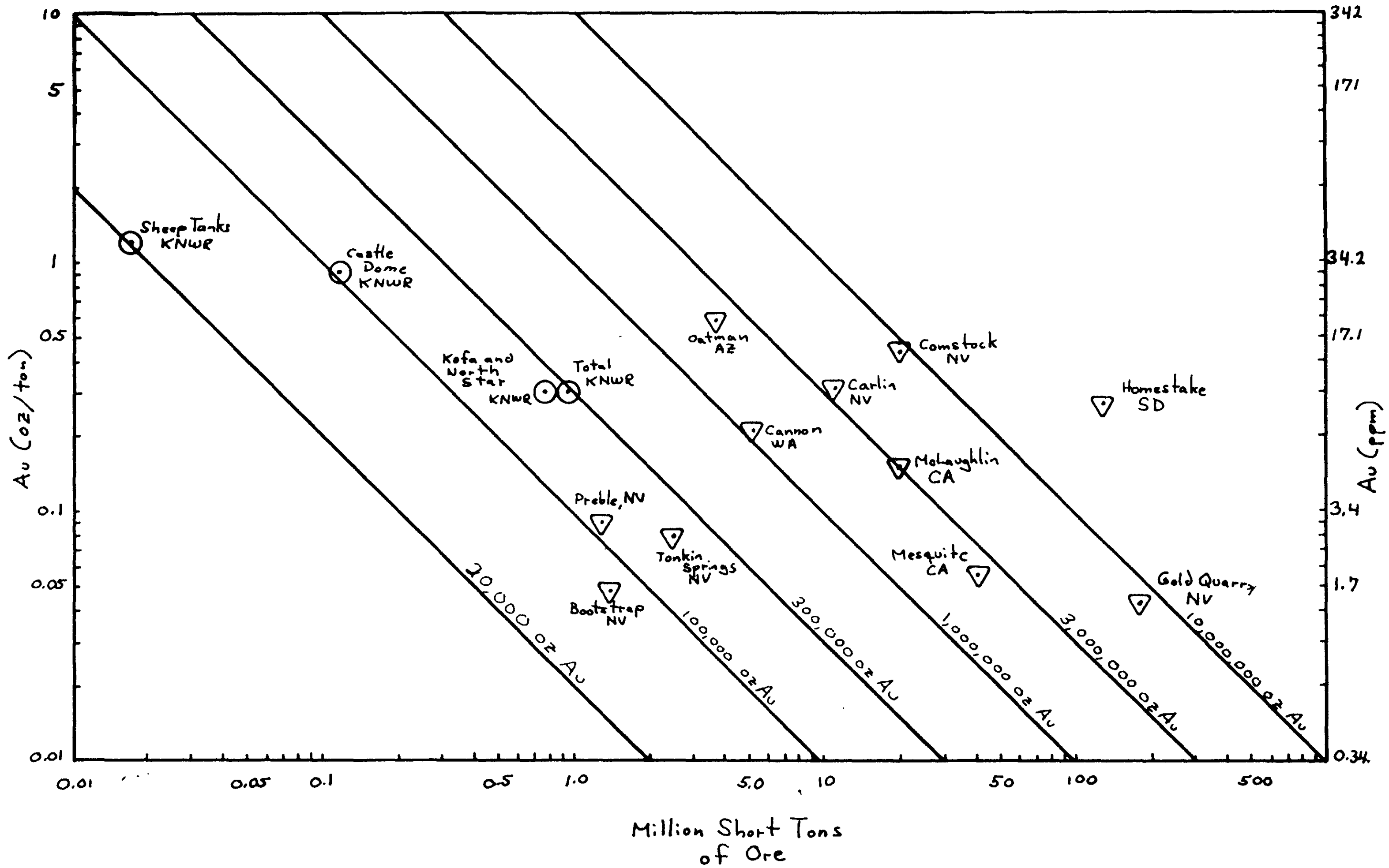

Au (oz/ton)
10
5
1
0.5
0.1
0.05
0.01
Au (ppm)
342
171
34.2
17.1
3.4
1.7
0.34
0.01
0.05
0.1
0.5
1.0
5.0
10
50
100
500
Million Short Tons of Ore
Sheep Tanks KNWR
Castle Dome KNWR
Kofa and North Star KNWR
Total KNWR
Oatman AZ
Comstock NV
Carlin NV
Homestake SD
Cannon WA
McLaughlin CA
Preble, NV
Tonkin Springs NV
Mesquite CA
Bootstrap NV
Gold Quarry NV
20,000 oz Au
100,000 oz Au
300,000 oz Au
1,000,000 oz Au
3,000,000 oz Au
10,000,000 oz Au

Figure 9

KOFA NATIONAL WILDLIFE REFUGE

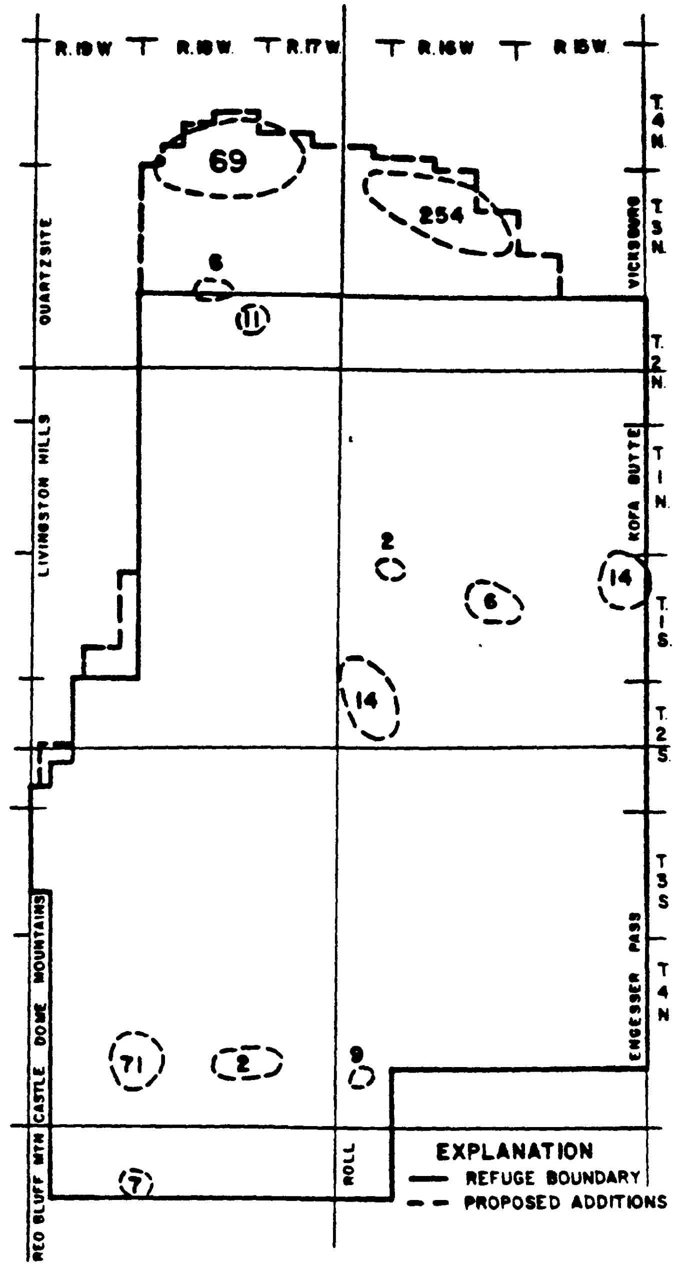


Figure 10

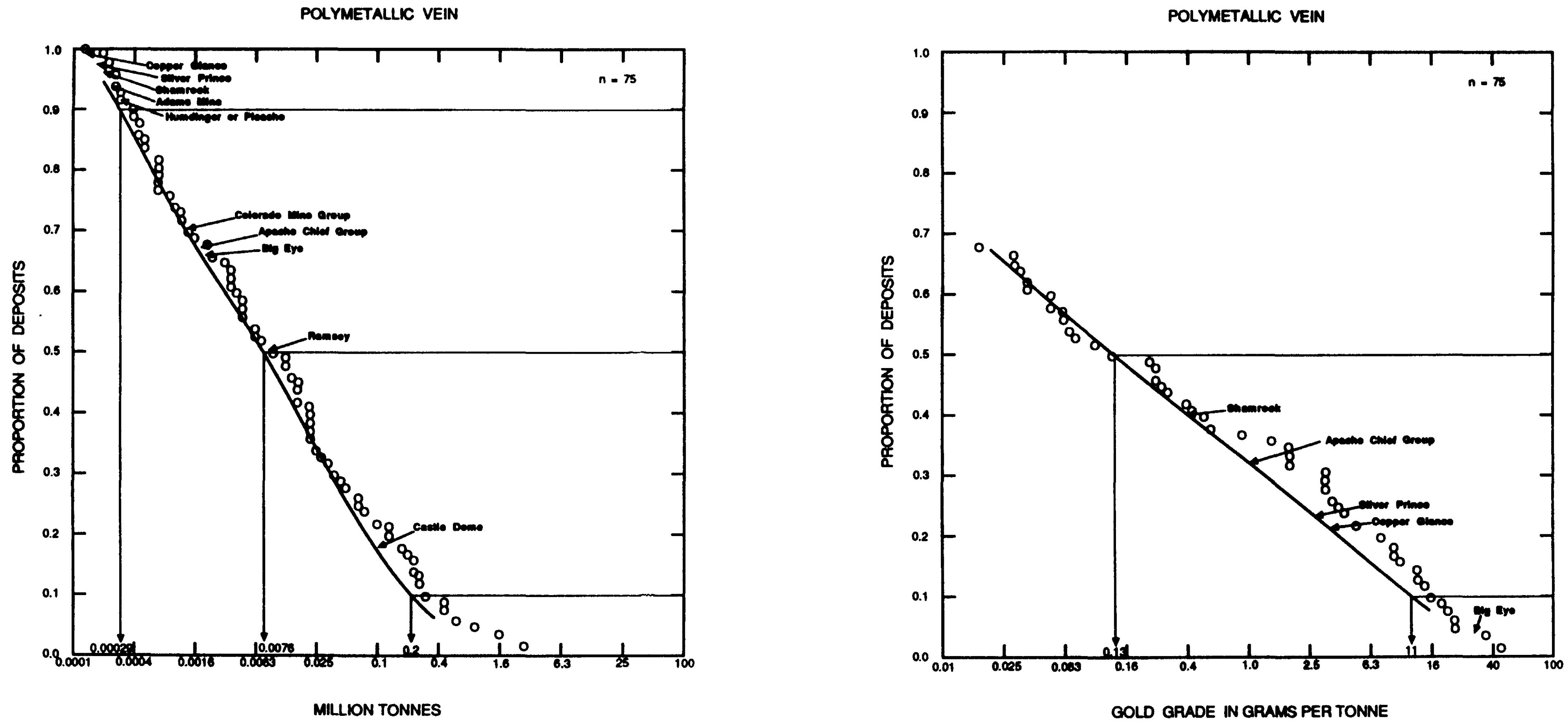
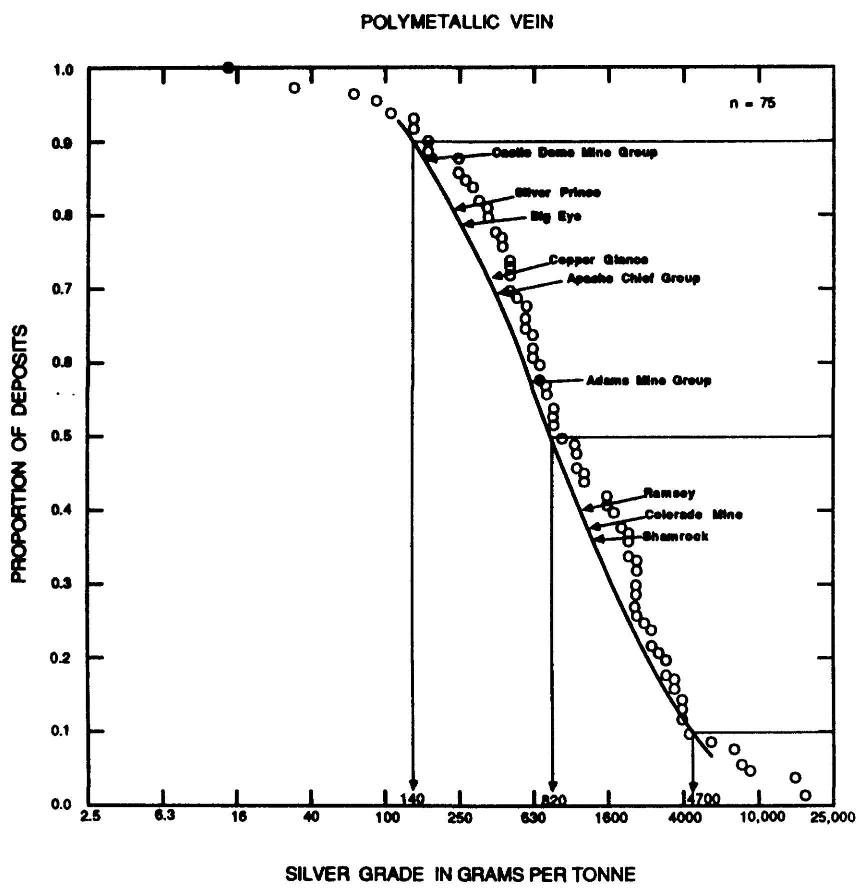

POLYMETALLIC VEIN
PROPORTION OF DEPOSITS
MILLION TONNES
n = 75
Copper Glance
Silver Prince
Shamrock
Adams Mine
Humdinger or Pisacho
Colorado Mine Group
Apache Chief Group
Big Eye
Ramsey
Castle Dome
0.00029
0.0076
0.2
POLYMETALLIC VEIN
PROPORTION OF DEPOSITS
GOLD GRADE IN GRAMS PER TONNE
n = 75
Shamrock
Apache Chief Group
Silver Prince
Copper Glance
Big Eye
0.13
11

Figure 11A



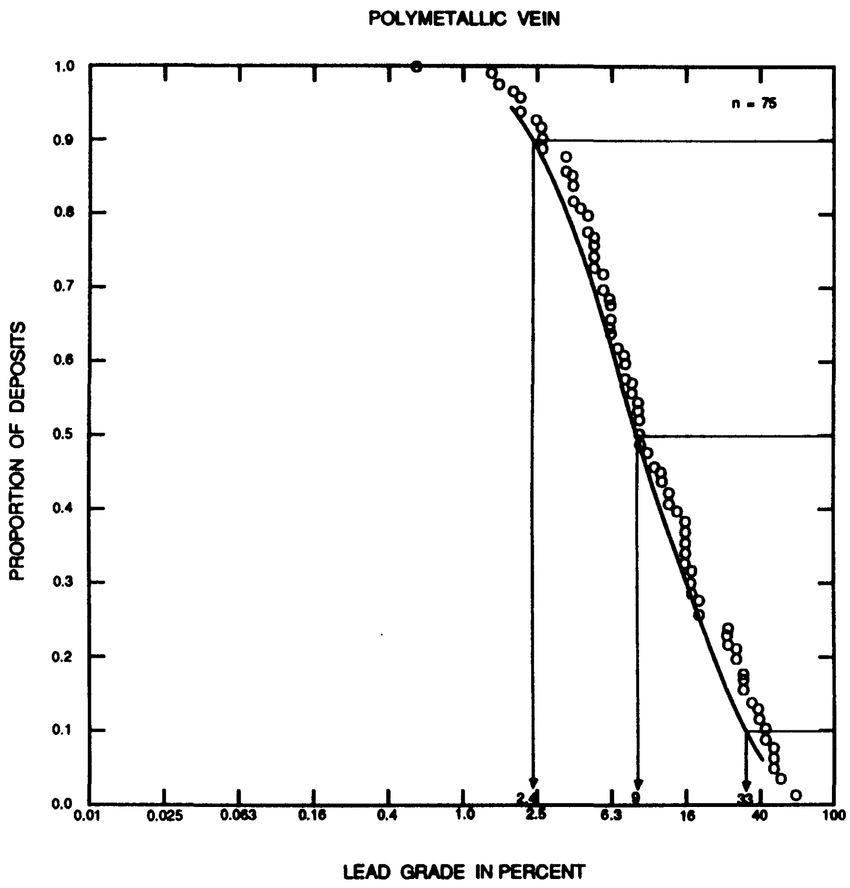


Figure 11A (con'd)

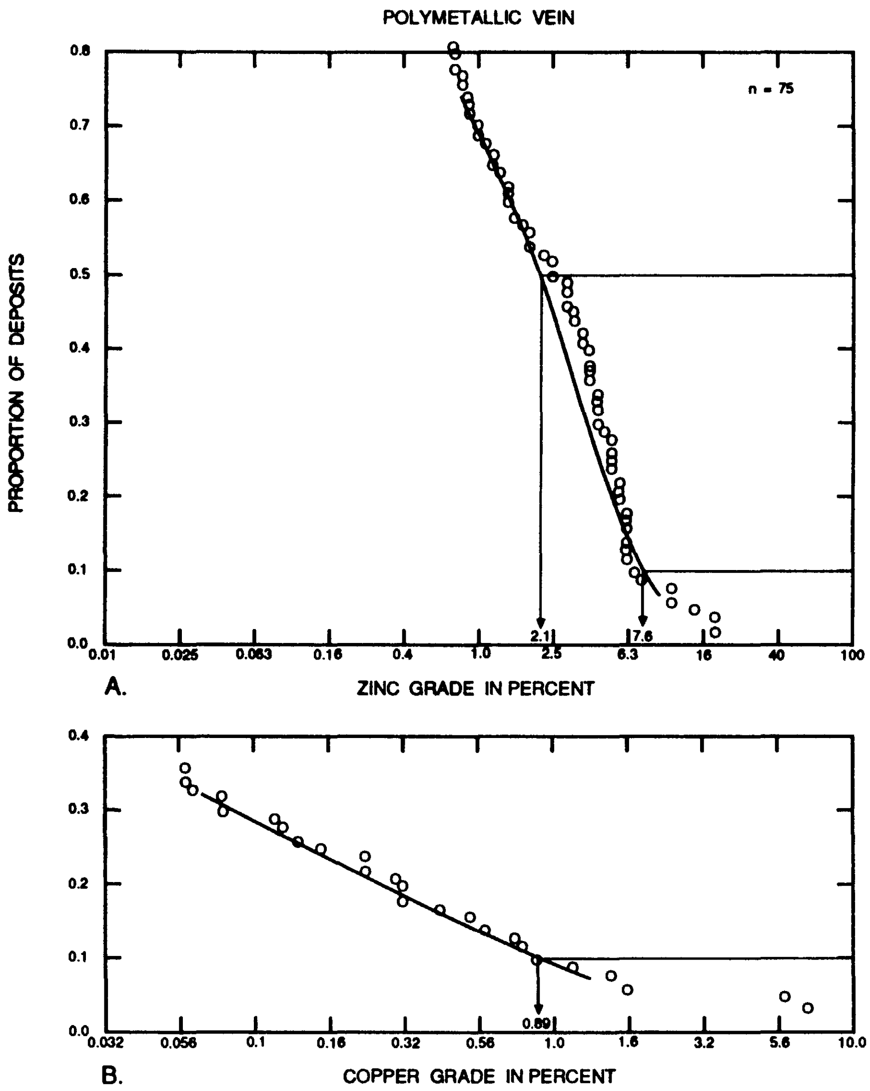
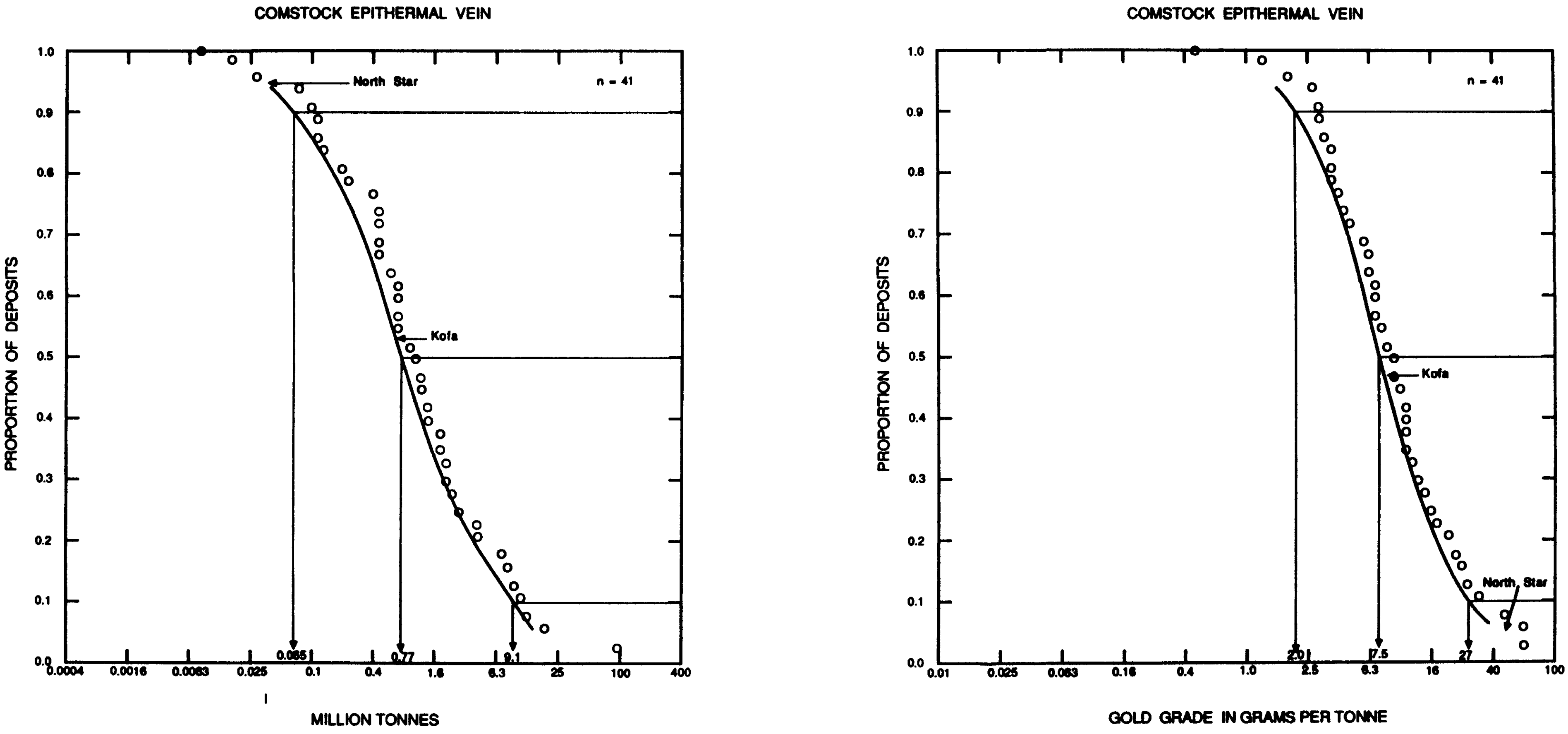


Figure 11A (con'd)



COMSTOCK EPITHERMAL VEIN
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
n = 41
North Star
Kofa
0.065
0.77
9.1
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
MILLION TONNES
COMSTOCK EPITHERMAL VEIN
PROPORTION OF DEPOSITS
n = 41
Kofa
North Star
2.0
7.5
27
0.01
0.025
0.063
0.16
0.4
1.0
2.5
6.3
16
40
100
GOLD GRADE IN GRAMS PER TONNE

Figure 11B

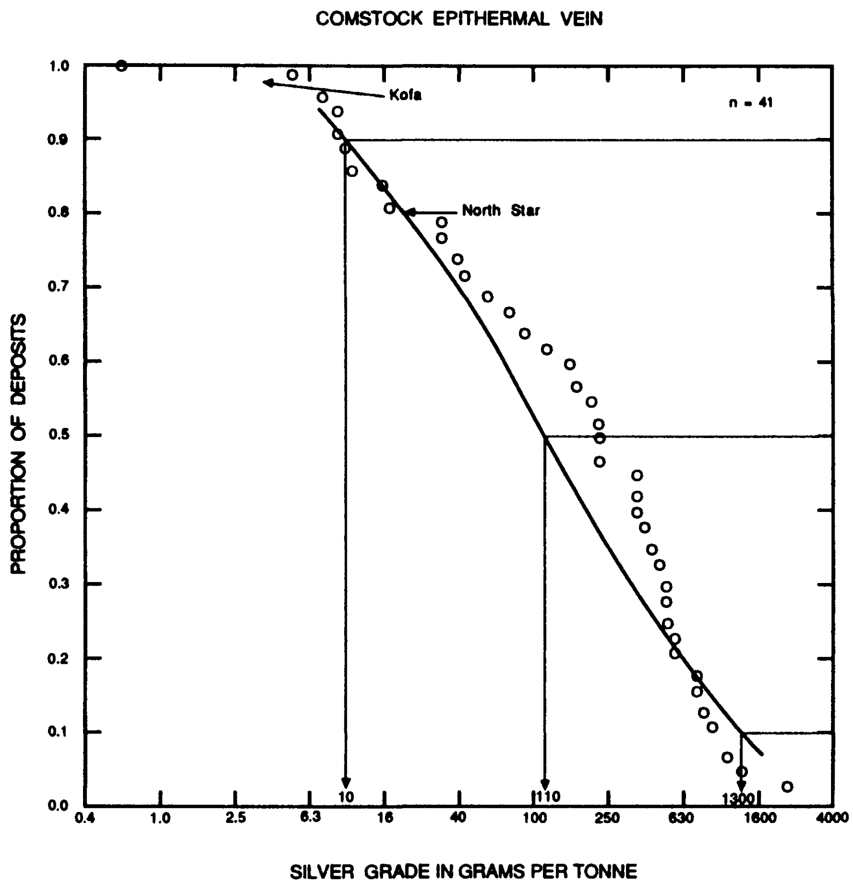


Figure 11B (con'd)

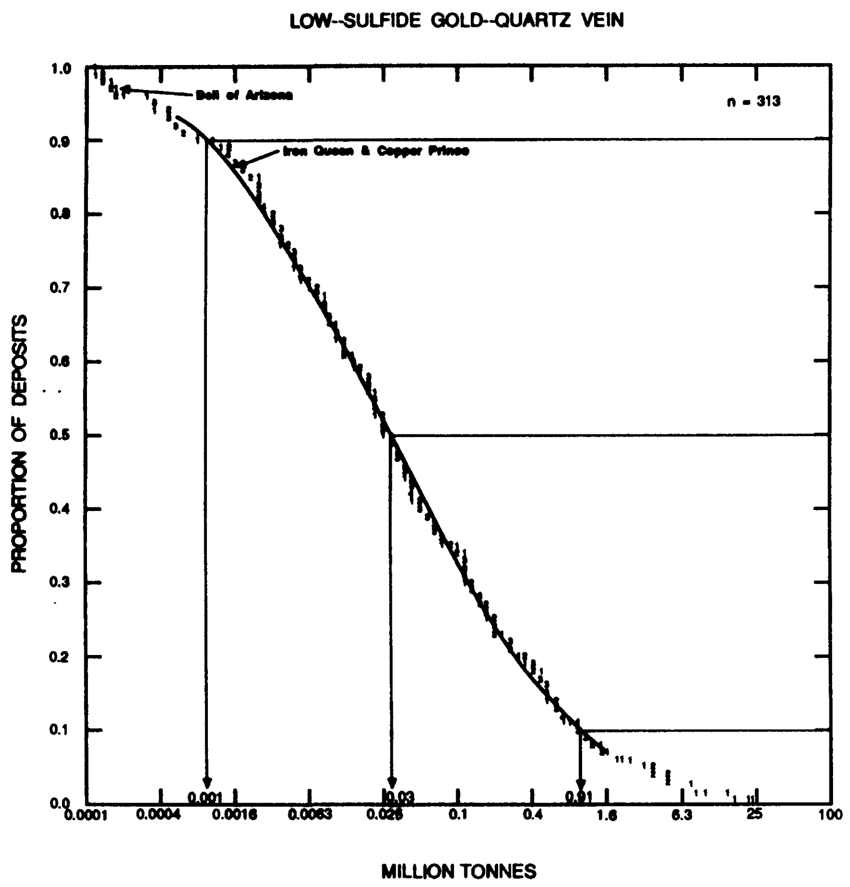
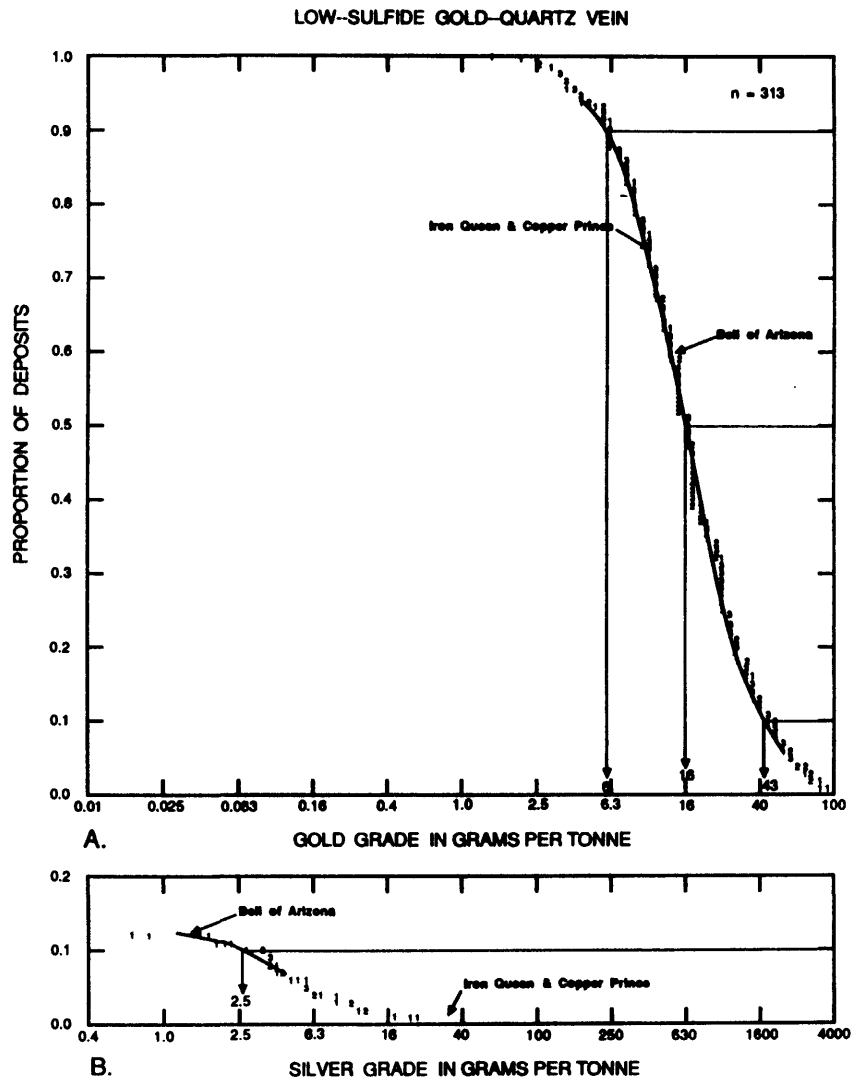
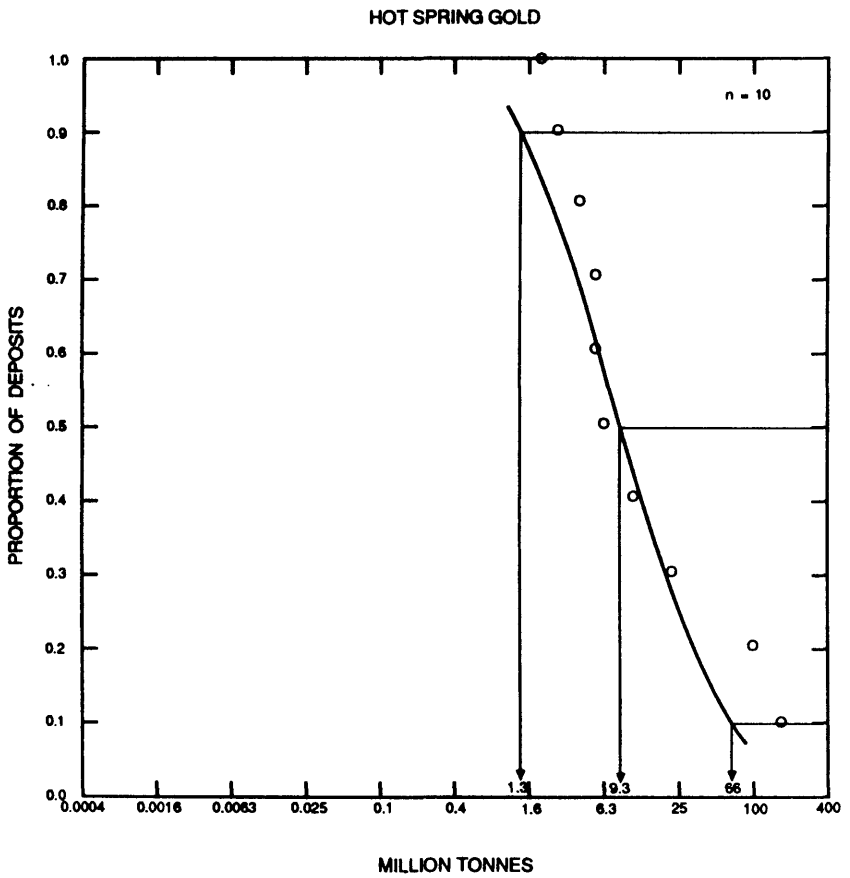

LOW-SULFIDE GOLD-QUARTZ VEIN
n = 313
Bell of Arizona
Iron Queen & Copper Prince
PROPORTION OF DEPOSITS
MILLION TONNES
0.001
0.03
0.91
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100

Figure 11C


LOW-SULFIDE GOLD-QUARTZ VEIN
n = 313
Iron Queen & Copper Prince
Bell of Arizona
PROPORTION OF DEPOSITS
A.
GOLD GRADE IN GRAMS PER TONNE
0.01
0.025
0.063
0.16
0.4
1.0
2.5
6.3
16
40
100
B.
SILVER GRADE IN GRAMS PER TONNE
2.5
0.4
1.0
2.5
6.3
16
40
100
250
630
1600
4000


HOT SPRING GOLD
n = 10
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.3
19.3
66
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
MILLION TONNES

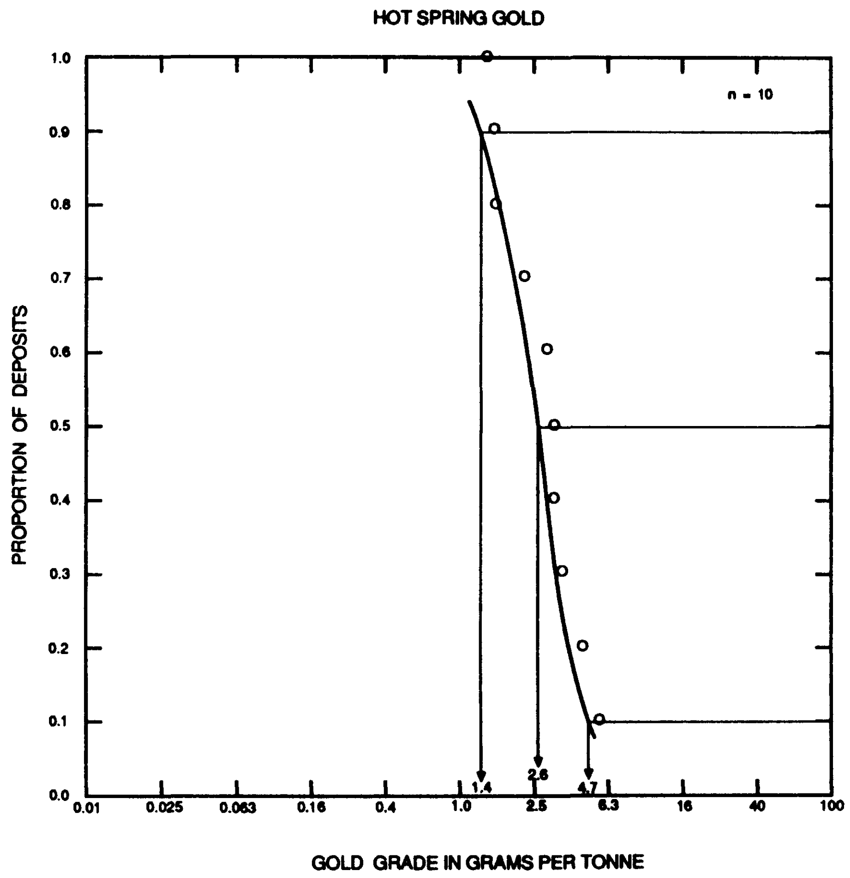

HOT SPRING GOLD
n = 10
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.4
2.6
4.7
0.01
0.025
0.063
0.16
0.4
1.0
2.5
6.3
16
40
100
GOLD GRADE IN GRAMS PER TONNE

Figure 12A

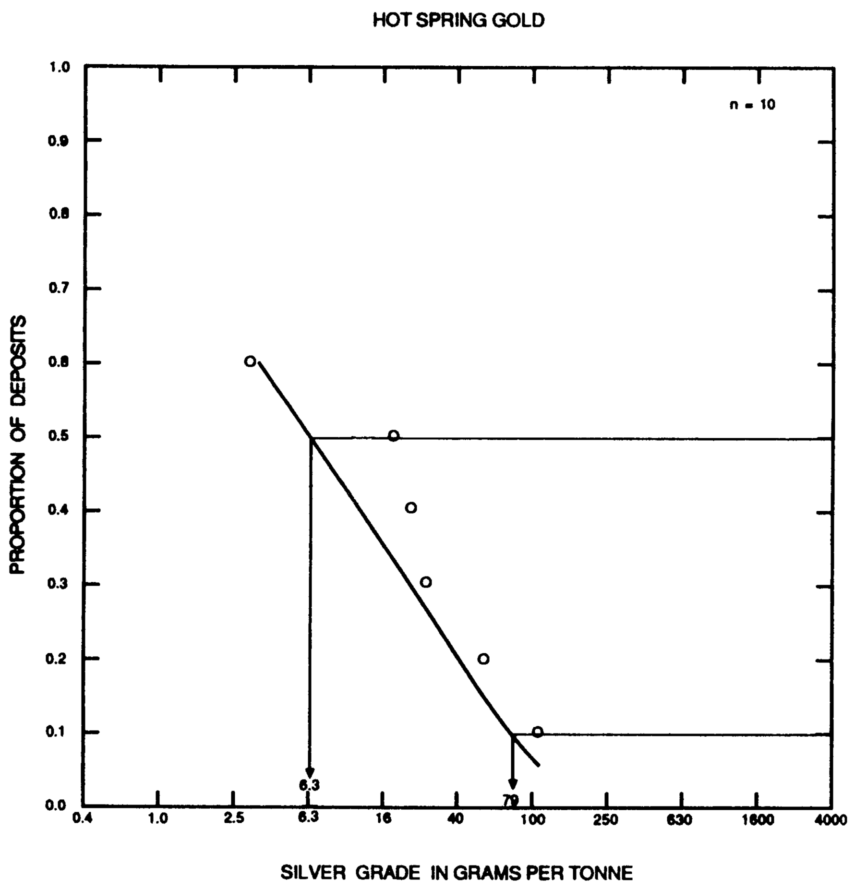


Figure 12A (con'd)

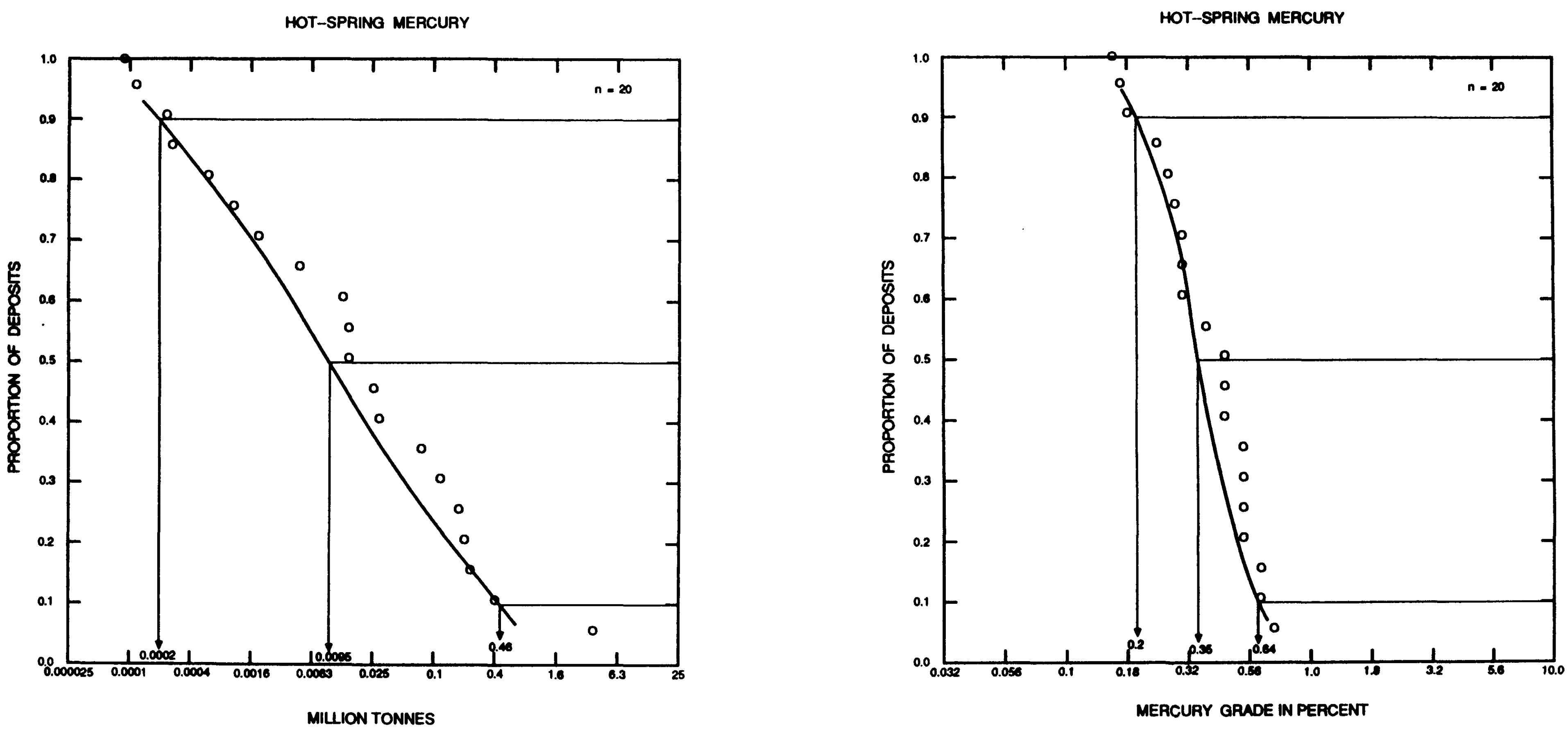

HOT-SPRING MERCURY
n = 20
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.000025
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
0.0002
0.0095
0.46
MILLION TONNES
HOT-SPRING MERCURY
n = 20
PROPORTION OF DEPOSITS
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
0.2
0.36
0.64
MERCURY GRADE IN PERCENT

Figure 12B

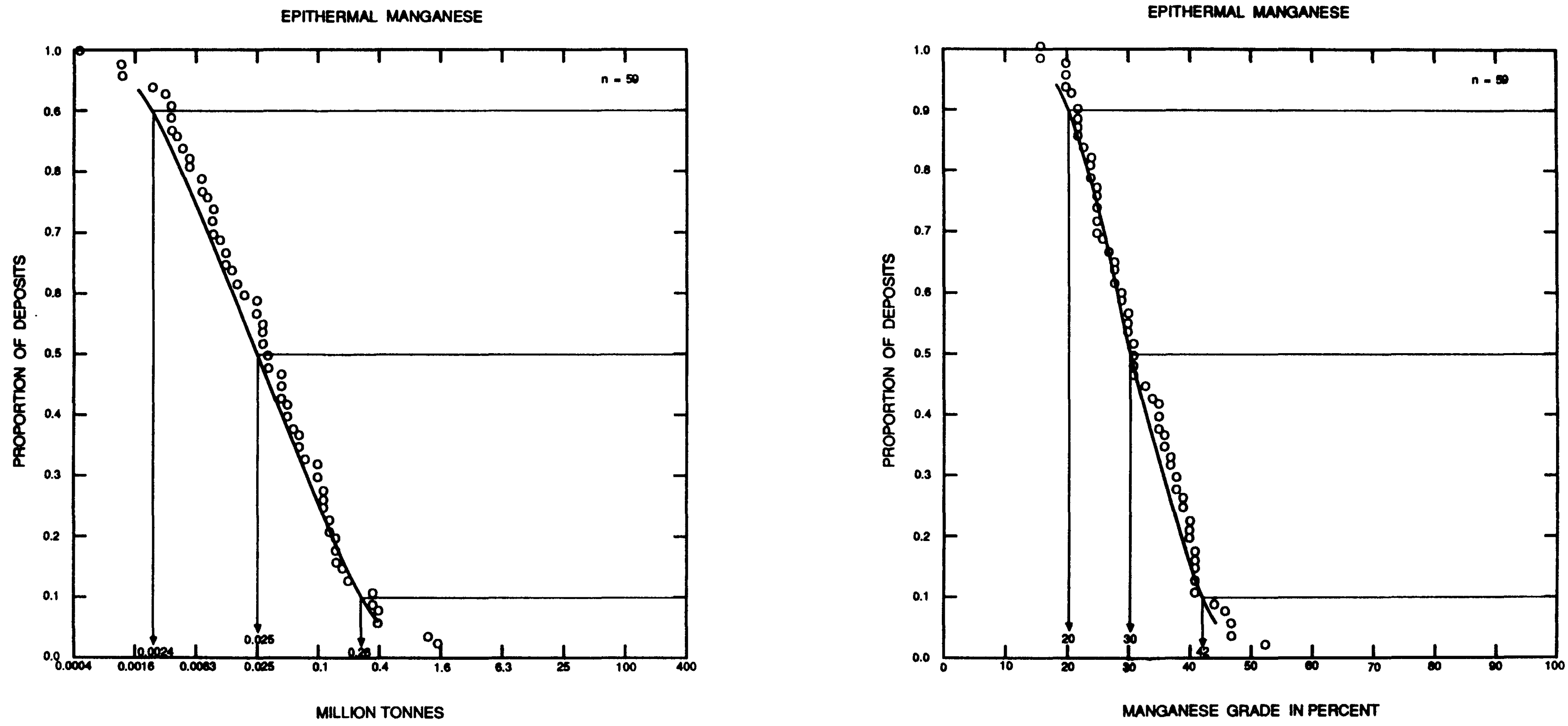

EPITHERMAL MANGANESE
n = 59
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0024
0.025
0.26
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
MILLION TONNES
EPITHERMAL MANGANESE
n = 59
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20
30
42
0
10
20
30
40
50
60
70
80
90
100
MANGANESE GRADE IN PERCENT

Figure 13

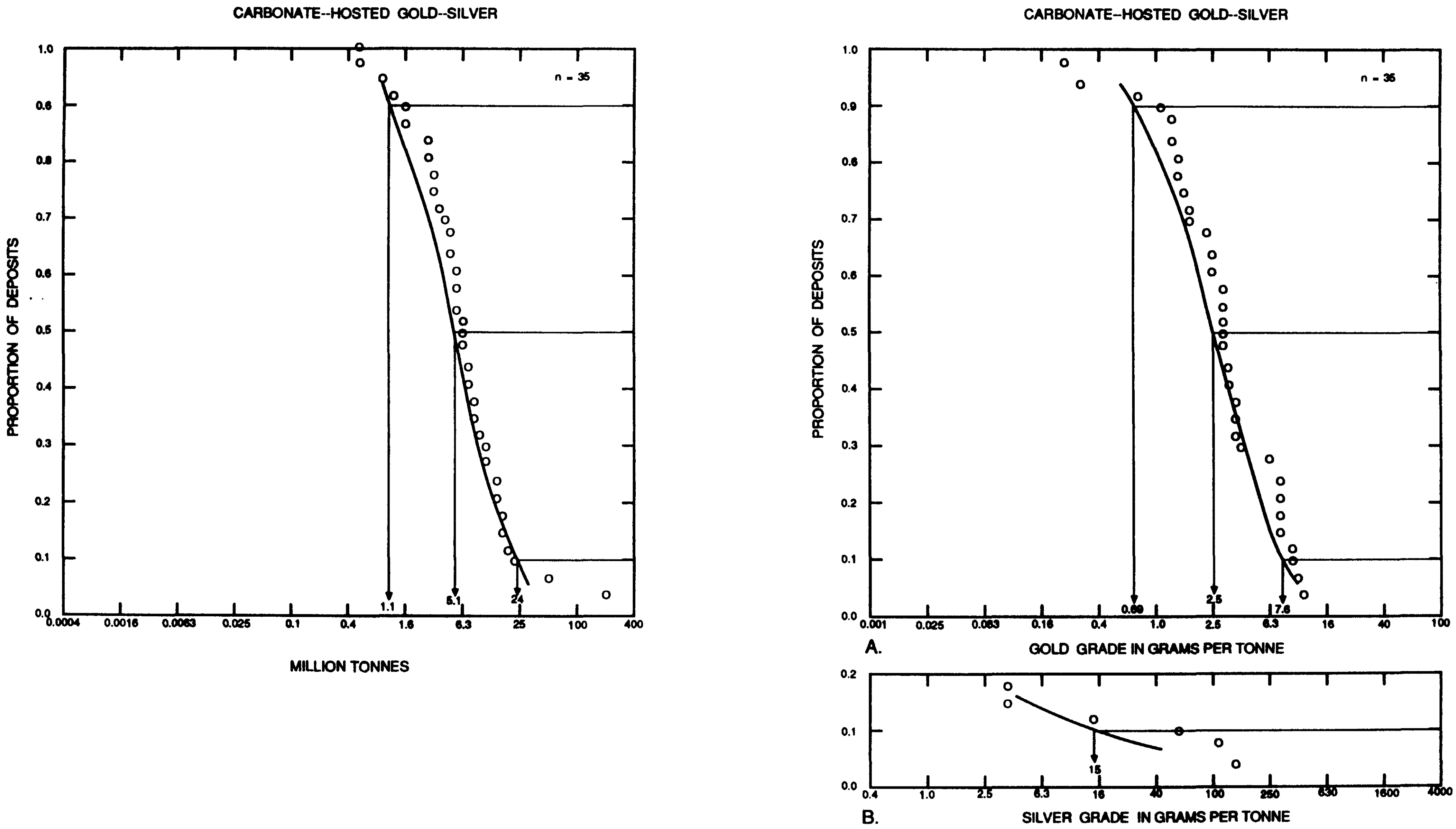

CARBONATE--HOSTED GOLD--SILVER
n = 35
PROPORTION OF DEPOSITS
1.1
5.1
24
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
MILLION TONNES
CARBONATE--HOSTED GOLD--SILVER
n = 35
PROPORTION OF DEPOSITS
0.69
2.5
7.6
0.001
0.025
0.063
0.16
0.4
1.0
2.5
6.3
16
40
100
A.
GOLD GRADE IN GRAMS PER TONNE
15
0.4
1.0
2.5
6.3
16
40
100
250
630
1600
4000
B.
SILVER GRADE IN GRAMS PER TONNE

Figure 14

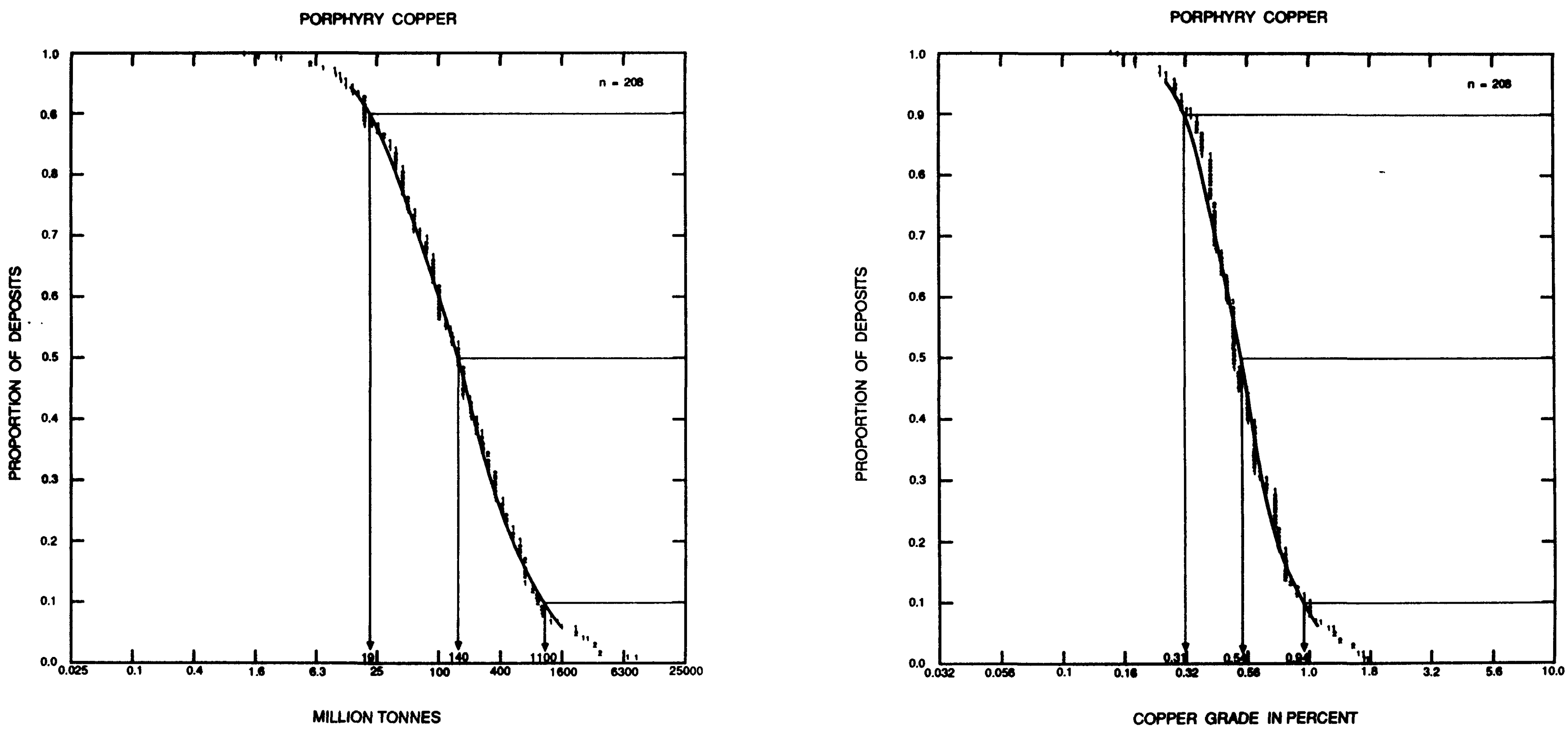

PORPHYRY COPPER
n = 208
PROPORTION OF DEPOSITS
MILLION TONNES
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25000
19
140
1100
PORPHYRY COPPER
n = 208
PROPORTION OF DEPOSITS
COPPER GRADE IN PERCENT
0.032
0.056
0.1
0.16
0.32
0.56
1.0
1.8
3.2
5.6
10.0
0.31
0.54
0.94

Figure 15

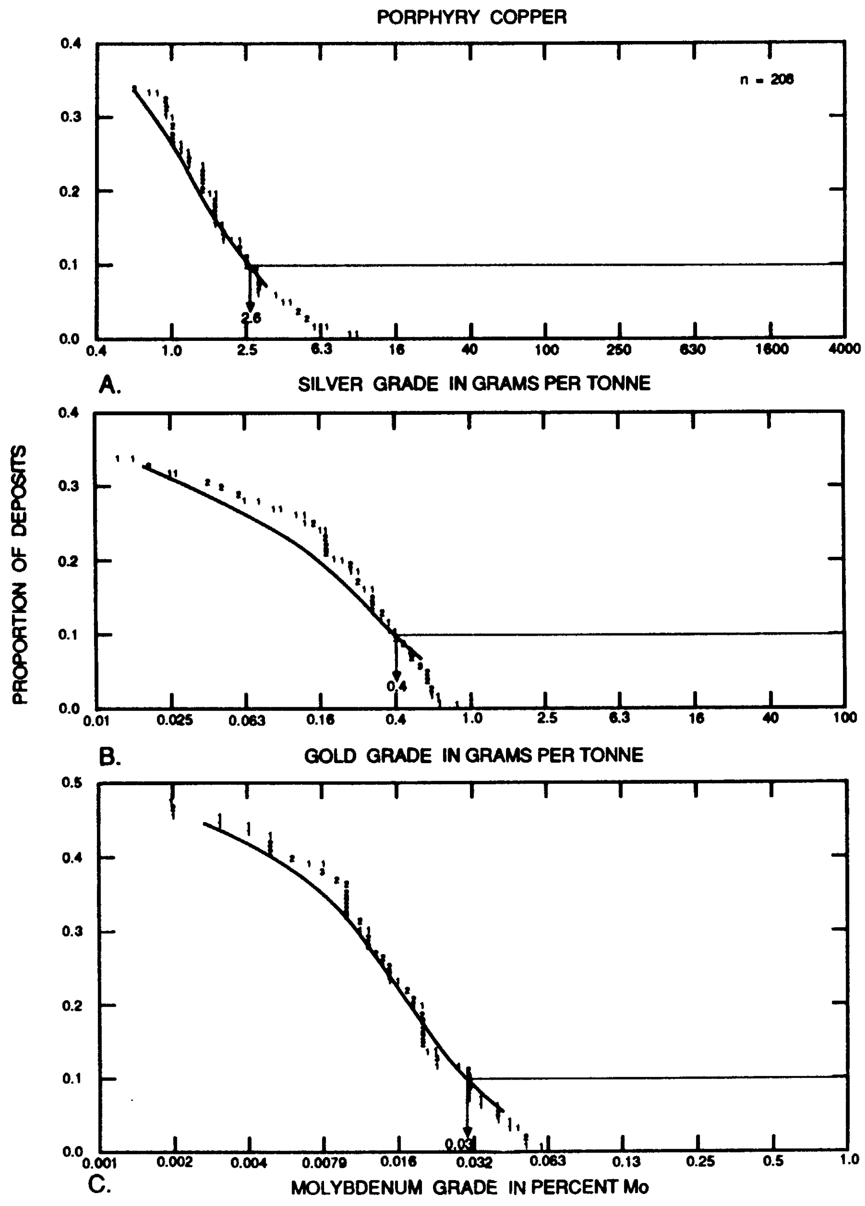
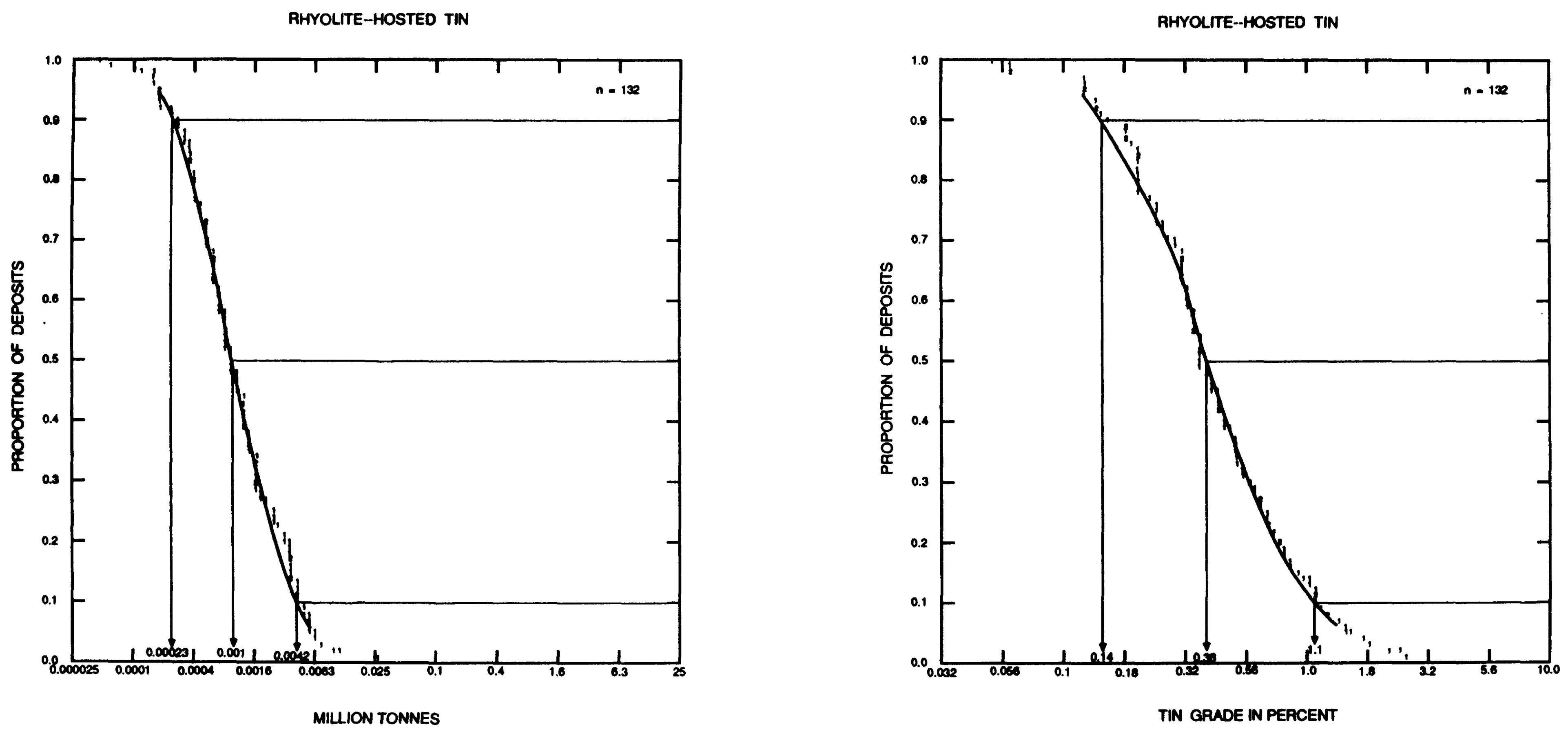


Figure 15 (con'd)



RHYOLITE--HOSTED TIN
n = 132
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.00023
0.001
0.0042
0.000025
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
MILLION TONNES
RHYOLITE--HOSTED TIN
n = 132
PROPORTION OF DEPOSITS
0.14
0.38
1.1
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
TIN GRADE IN PERCENT

Figure 16

Table 1.--Summary of published K-Ar isotopic dates, KNWR region, southwest Arizona
[--, not available; USGS, U.S. Geological Survey, Menlo Park, CA; U. of AZ, University of Arizona, Tucson, AZ; CSUSD, San Diego State University, San Diego, CA]

Number	Range, location	Latitude	Longitude	Rock type sample number	Material	K_2O (wt%)	$^{40}Ar^*$ / ^{40}Ar total	$^{40}Ar^*$ ($\times10^{-11}$ mole/g)	Age (m.y.)	Laboratory	Reference	Remarks
1	Plomosa Mtns.	--	--	Rhyodacite	Hornblende	0.906	0.358	2.57	19.6±0.6	USGS Menlo Park, CA	Miller, McKee, 1971	Ages recalculated with new decay constants. Rhyodacite is older than thusting, younger than strike-slip faulting.
2					Biotite	8.44	.720	25.3	20.7±0.6		Do.	
3	Kofa Mtns.	33°29'N	113°53'W	Basaltic andesite UAKA 73-108	Whole Rock	2.151 2.173	.387 .399	5.830 5.622	18.31±0.42	U. of AZ	Shafiqullah and others, 1980	Flat-lying minimum age of tilting.
4	Kofa Mtns.	33°27.97'N	113°57.20'W	Rhyolite ash-flow tuff UAKA 73-18	Biotite	8.41 8.49	.384 .392	29.80 27.96	23.6±0.62	U. of AZ	Do.	Steeply dipping.
5	Kofa Mtns.	33°27.50'N	113°54.08'W	Basalt UAKA 73-19	Whole Rock	1.309 1.305	.735 .731 .733	3.98 4.13 4.18	21.68±0.57	U. of AZ	Do.	Moderately dipping.
6	Kofa Mtns.	--	--	Volcanic flow	--	--	--	--	19.5±0.3	CSUSD	Dahm and Hankins, 1982	Near base of volcanic section near the North Star Mine. Steeply dipping.
7	Kofa Mtns.	--	--	Younger volcanics	--	--	--	--	17.3±0.5	CSUSD	Do.	Postdates deformation.
8	Kofa Mtns.	33°16'45"N	113°57'58"W	Andesite porphyry dike KA2533	Whole Rock	2.94	.53	--	25.4±0.5	CSUSD	Hankins, written commun., 1984	
9	Kofa Mtns.	33°16'50"N	113°57'58"W	Dacite porphyry dike KA2535	Plagioclase	4.17	.64	--	19.8±0.9	CSUSD	Do.	
10	Kofa Mtns.	33°15'40"N	113°57'34"W	Welded tuff KA2560	Plagioclase	4.94	.81	--	21.9±1.5	CSUSD	Do.	
11	Castle Dome Mtns. Honkidori Hill	32°58.78'N	114°09.08'W	Dacite tuff CD-85	Biotite	7.60 7.42	.567 .520	28.60 27.45	25.7±1.0	Geochron Laboratories	Gutmann, 1981	Age recalculated with new decay constants.
12	Castle Dome Mtns. Little White Tanks	33°08.49'N	114°06.61'W	Rhyolite ash-flow tuff CD-75	Biotite	7.61 7.53	.518 .547	26.62 26.32	24.1±0.9	Geochron Laboratories	Do.	Do.
13	Castle Dome So. of Stone Cabin	33°13.78'N	114°14.98'W	Rhyolite ash-flow tuff CD-92	Biotite	--	--	--	22.28±0.47	U. of AZ	Do.	
14	Castle Dome Mtns. Stone Cabin	33°15.99'N	114°14.67'W	Rhyolite flow CD-77	Biotite	--	--	--	22.20±0.47	U. of AZ		
15	Castle Dome Mtns. Base of range east side	33°03.45'N	113°57.65'W	Basaltic andesite CD-72	Plagioclase	--	--	--	20.39±0.43	U. of AZ	Do.	
16	Castle Dome Mtns.	33°02.10'N	114°09.85'W	Dacite porphyry dike CD-2	Plagioclase	5.43	.28	--	19.0±1.2	CSUSD	Logan and Hirsch, 1982	Actually older than CD-9 Restricted to lower plate of detachment fault.
17	Castle Dome Mtns.	33°02.10'N	114°09.85'W	Rhyolite porphyry dike CD-9	Whole Rock	10.45	.45	--	20.4±0.6	CSUSD	Do.	Upper and lower plates of detachment fault.
18	New Water Mtns. Black Mesa	33°35.16'N	114°02.49'W	Rhyolite vitrophyre breccia UAKA 74-38	Biotite	8.90 8.90	.176 .175	24.74 25.25	19.41±0.47	U. of AZ	Shafiqullah and others, 1980	Tilted.
19	New Water Mtns. Black Mesa	33°35.27'N	114°02.01'W	Olivine basalt flow UAKA 74-37	Whole Rock	1.621 1.627	.278 .266	4.017 4.075	17.24±0.43	U. of AZ	Do.	Only slightly tilted.

Table 2.--New K-Ar isotopic dates, KNWR region, southwest Arizona

Range, location	Latitude	Longitude	Rock type, sample no.	Material	K_2O (Wt. %)	$^{40}Ar^*$ / $^{40}Ar_{total}$	$^{40}Ar^*$ ($\times 10^{-11}$ moles/g)	Calculated age	Assigned age
New Water Mtns.	33°35'03"	113°54'07"	Rhyolite flow	Biotite	8.75	0.618	25.36	20.1	19.8±0.4
			KRK353B		8.70	0.613	24.61	19.5	
Kofa Mtns.	33°23'26"	113°54'01"	Basalt	Whole rock	1.369	0.664	3.890	19.7	19.9±0.4
			KRK160B		1.367	0.469	3.952	20.0	
					1.356				
Kofa Mtns.	33°24'47"	113°56'51"	Rhyolite plug	Sanidine	10.89	0.810	32.22	20.5	20.4±0.4
			KS4-66		10.86	0.856	32.15	20.4	
Castle Dome Mtns.	33°15'29"	114°08'53"	Ash flow tuff	Biotite	7.94	0.690	25.29	22.0	22.1±0.4
			KG291		7.98	0.607	25.60	22.3	
					7.89				
Kofa Mtns.	33°19'25"	114°00'22"	Ash flow tuff	Biotite	8.72	0.736	27.84	22.1	22.1±0.3
			KRK146B		8.67	0.727	27.88	22.1	
Livingston Hills	33°27'51"	114°04'27"	Ash flow tuff	Plagioclase	1.151	0.654	3.710	22.4	22.2±0.6
			KRK165A		1.164	0.492	3.618	21.9	
					1.123				
					1.131				
Kofa Mtns.	32°20'04"	113°53'06"	Ash flow tuff	Sanidine	7.59	0.787	24.70	22.4	22.3±0.4
			KG572		7.61	0.678	24.51	22.3	
Tank Mtns.	33°08'27"	113°48'39"	Ash flow tuff	Biotite	8.76	0.729	28.50	22.4	22.3±0.4
			KRK150A		8.78	0.467	28.26	22.2	
			Do.	Plagioclase	1.191	0.481	3.495	20.4	20.7±0.5
					1.198	0.390	3.571	20.9	
					1.167				
					1.173				
Castle Dome Mtns.	33°15'28"	114°08'38"	Ash flow tuff	Biotite	6.98	0.447	22.33	22.1	22.4±0.5
			KG292		6.94	0.431	22.85	22.6	
					7.00				
					6.98				
Castle Dome Mtns.	32°58'43"	114°09'09"	Ash flow tuff	Biotite	6.44	0.617	21.23	22.7	22.7±0.5
(Honkidori Hill)			KG289		6.47	0.450	21.13	22.6	
					6.44				
					6.46				
North Star mine	33°17'50"N	113°58'18"	Vein	Adularia	15.55	0.581	50.03	22.2	22.5±0.4
			KO24F		15.59	0.787	51.50	22.8	
Livingston mine	33°33'12"N	114°5'35"	Vein	Muscovite	10.54	0.825	97.95	63.6	63.8±1.0
			KO13E		10.42	0.559	98.50	63.9	
					10.58				
					10.51				
Kofa Mtns.	33°15'00"	113°55'04"	Metamorphic	Sericite	10.95	0.880	86.35	54.0	53.5±0.8
			quartz-sericite		10.95	0.899	84.79	53.0	
			vein in schist						
			KO53A						
Palomas Mtns.	33°00'24"	113°36'37"	Pumice Block	Biotite	8.74	0.706	27.70	21.8	21.8±0.4
			from a rhyolite		8.76				
			tuff PM423						
			Do.	Hornblende	1.016	0.459	3.104	21.0	21.0±0.6
					1.014				
					1.031				
Palomas Mtns.	33°58'36"	113°40'42"	Granite	Biotite	7.06	0.615	23.87	23.2	23.2±0.5
			PM454		7.12				
Palomas Mtns.	32°58'13"	113°35'51"	Rhyolite Dike	Biotite	8.16	0.714	26.78	22.6	22.6±0.4
			PM466		8.21				
			Do.	Hornblende	0.469	0.226	1.686	24.5	24.5±1.4
					0.475				
					0.478				

Table 3.--Detection limits for the spectrographic analysis of rocks and stream sediments in the KNWR, based on a 10-mg sample
[The spectrographic limits of determination for heavy-mineral-concentrate samples are based on a 5-mg sample, and are therefore two reporting intervals higher than the limits given for rocks and stream sediments]

Elements	Lower determination limit	Upper determination limit
	Percent	
Iron (Fe)	0.05	20
Magnesium (Mg)	.02	10
Calcium (Ca)	.05	20
Titanium (Ti)	.002	1
	Parts per million	
Manganese (Mn)	10	5,000
Silver (Ag)	0.5	5,000
Arsenic (As)	200	10,000
Gold (Au)	10	500
Boron (B)	10	2,000
Barium (Ba)	20	5,000
Beryllium (Be)	1	1,000
Bismuth (Bi)	10	1,000
Cadmium (Cd)	20	500
Cobalt (Co)	5	2,000
Chromium (Cr)	10	5,000
Copper (Cu)	5	20,000
Lanthanum (La)	20	1,000
Molybdenum (Mo)	5	2,000
Niobium (Nb)	20	2,000
Nickel (Ni)	5	5,000
Lead (Pb)	10	20,000
Antimony (Sb)	100	10,000
Scandium (Sc)	5	100
Tin (Sn)	10	1,000
Strontium (Sr)	100	5,000
Vanadium (V)	10	10,000
Tungsten (W)	50	10,000
Yttrium (Y)	10	2,000
Zinc (Zn)	200	10,000
Zirconium (Zr)	10	1,000
Thorium (Th)	100	2,000

Table 4.--Chemical methods used for geochemical analysis of samples from the KNWR [AA = atomic absorption; I = instrumental; SI = specific ion; S = spectrophotometry; and F = fluorometry]

Element or constituent determined	Sample type	Method	Determination limit (micrograms/ gram or ppm)	References
Tellurium (Te)	Rocks	AA	0.05	Hubert and Chao, 1985.
Gold (Au)	Rocks	AA	0.05	Thompson and others, 1968.
Thallium (Tl)	Rocks and sediments	AA	0.1 or 0.2	Hubert and Lakin, 1973.
Gold (Au)	Sediments	Graphite Furnace AA	0.002-0.008	Meier, 1980.
Mercury (Hg)	Rocks and sediments	I	0.02	Modification of McNerney and others, 1972, and Vaughn and McCarthy, 1964.
Arsenic (As)	Rocks and sediments	AA	5 or 10	O'Leary and Viets, 1986.
Antimony (Sb)	Rocks and sediments	AA	2	O'Leary and Viets, 1986.
Zinc (Zn)	Rocks and sediments	AA	5	Viets, 1987.
Bismuth (Bi)	Rocks	AA	1	Viets, 1987.
Cadmium (Cd)	Rocks	AA	0.1	Viets, 1987.
Silver (Ag)	Sediments	AA	0.05	Viets, 1987.
Fluorine (F)	Rocks	SI	100	Hopkins, 1977.
Tungsten (W)	Rocks	S	0.5	Welsch, 1983.
Uranium (U)	Rocks	F	0.05	Modification of Centanni and others, 1956.

Table 5.--Threshold values for selected elements based on the distribution of concentration in different sample media from the KNWR

Element	Threshold concentration (ppm)		
	Rock samples	Stream-sediment samples	Panned concentrate samples
Ag	0.5	0.10	2.1
As	30	19	475
Au	0.05	0.008	21
B	1,000	--	85
Bi	5	--	17
Cu	300	--	40
Hg	0.20	0.23	--
Mo	10	--	10
Pb	70	--	850
Sb	6	4.7	140
Tl	10	0.65	--
W	10	--	85
Zn	100	92	475
Sn	--	--	125
Ba	--	--	10,000

Table 6.--Selected analyses of ore and altered rock samples considered representative of mineral deposit types in the Kofa National Wildlife Refuge

[All values in parts per million unless indicated otherwise. N, not detected at the lower limit of determination shown in parentheses]

1. Low sulfide Au-W-quartz veins

A. Quartz veins in Proterozoic granite. (Samples collected near Scaddan Mountain, east of the Plomosa placers in the southwestern Plomosa Mountains.)

Sample No.	Au	Ag	As	Sb	Hg	Cu	Pb	Zn	W
KR2024R	1.3	30	N(5)	18	0.14	700	20,000	140	N
KR2025R	38	5	N(5)	8	0.14	70	5,000	680	N

B. Quartz veins in metamorphic rocks (Livingston mine)

Sample No.	Au	Ag	As	Sb	Hg	Cu	B	Bi	Mo	W
KR2000R	0.10	N(.5)	10	8	0.02	500	>2,000	5	<5	29
7R2002R	0.15	1	20	300	0.40	150	1,000	500	500	1,500

2. Porphyry copper occurrence

Sample No.	Au	Ag	As	Hg	Cu	Mo
KR2062R	1.7	10	270	0.42	>2%	100
KR2050R	N(.05)	N(.5)	100	0.02	150	10

3. Epithermal precious- and base-metal deposits

A. Comstock epithermal vein (North Star and Kofa mines)

Sample No.	Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mn	W
KR2031R	2.5	10	120	2	0.02	10	150	10	100	22
KR5081R	0.7	5	220	2	N(0.02)	10	20	45	500	0.5
KR1140R	1.8	20	15	4	1.1	70	150	140	2,000	6.0

B. Polymetallic vein (Ramsey mine)

Sample No.	Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mn	W
KR2020R	<0.05	150	210	150	0.50	700	2,000	1,500	>5,000	45
KR2021R	0.10	1,000	45	22	3.8	100	5,000	5,000	>5,000	18

C. Polymetallic vein (Castle Dome district)

Sample No.	Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mn	W	F
KR2110R	0.20	1,000	N(10)	220	5.4	7,000	>2%	220	20	4.0	11,000
KR2111R	N(0.05)	20	N(10)	96	0.06	2,000	>2%	>1%	>5,000	0.5	3,600

D. High temperature hot-springs systems (Republic mine)

Sample No.	Au	Ag	As	Sb	Hg	Mo	Ba	Pb	Cu	Tl	Sr	Zn
KR0012RC	0.90	N(0.5)	2,000	80	0.02	1,000	>5,000	>2%	1,500	73	>5,000	890
KR5074R	<0.05	N(0.5)	1,800	130	0.56	1,500	>5,000	2%	2,000	240	>5,000	500

E. Epithermal Mn (Black Dahlia mine)

Sample No.	As	Sb	Hg	Tl	Cu	Pb	Zn	Mo	W	Mn	Be
KR2026R	850	2,000	6.0	4.1	150	500	550	100	300	>5,000	100
KR2027R	30	90	0.54	0.3	7	100	20	N(5)	24	>5,000	5

F. Epithermal Mn (Sheep Tank mine)

Sample No.	Au	Ag	As	Sb	Hg	Tl	Cu	Pb	Zn	Mn	Mo	W
KR2042R (Tailings)	0.25	200	240	16	5.0	2.4	150	1,000	1,900	>5,000	10	25
KR2043R	N(0.05)	15	1,000	50	>10	4.5	200	1,000	>2,000	>5,000	50	100
KR2044R	0.10	10	30	16	0.34	2.0	15	100	660	2,000	N(5)	24
KR2045R	0.10	10	50	22	1.3	3.2	15	200	220	500	N(5)	19

4. Gneiss- or schist-hosted, detachment fault-related (?) gold

Picacho mine, Imperial County, California

Sample No.	Au	Ag	As	Sb	Hg	W
BPP-012	0.50	<0.5	330	18	<0.02	48
BPP-015	0.20	N(0.5)	130	60	0.02	43
BPP-017	7.5	2	150	18	0.96	36

5. Polymetallic replacement (Black Mesa mine)

Sample No.	Au	Ag	As	Sb	Hg	Bi	Cu	Pb	Zn
KR2011R	0.70	100	510	650	>10	100	1,500	5,000	7,000
KR2012R	0.60	20	500	750	6.3	52	3,000	5,000	5,000

6. Gold- and galena-bearing placers

Concentrate collected from sluice box at Plomosa placers

Sample No.	Au	Pb
KR2005	100	2%

Table 7.--Past production tabulated according to mining district from mineral deposits in the KNWR

[All production data are from Keith (1978). t, short tons; lt, long tons; oz, troy ounces. Percentages are percentage of total production for the KNWR]

District	Gold (oz)	Silver (oz)	Copper	Lead	Zinc	Manganese	Placer	Ore (tons)	Notes
Alamo Springs	80 --	-- --	-- 0.91 t	-- --	-- --	-- --	-- --	100 65	District includes Alamo-Alonak mine groups and Cemitosa, Ocotillo (Rand, Geysers (Silent King) IXL, Regal, COD, Big Horn). There is no recorded production from the Ocotillo group. Gold produced from the Kofa Queen, copper from the Alamo-Alonak mine groups.
Castle Dome	by prod minor (0.8%)	478,000 1,465 (64.7%)	by prod 9 t (1.6%)	10,500 t minor (96.6%)	38 t -- (36.9%)	400 t of 26-30% -- (43%)	7,000 oz Au, unknown Ag -- (25.3%)	119,000 150 (12.9%)	Major ore bodies were argentiferous galena, sediments associated with a dike swarm. Veins and dikes strike NW. Ore was limited to local shoots 200 to 300 ft maximum depth. The different tonnages and grades given here are from different mines in the district.
Kofa	226,654 (88.2%)	103,257 (13.4%)	1 t	3.5 t	--	230 1 t 24.7%)	2,500 oz Au, 500 oz Ag (9%, 21.7%)	779,000 (82.5%)	Two largest producers are Kofa and North Star mines. Kofa produced $3.5 million in Au-Ag bullion and North Star produced $1.1 million.
Plomosa	6,984 (2.7%)	127,405 (16.5%)	529 t (93.9%)	343 t (3.2%)	65 t (63.1%)	--	18,000 oz Au, 1,800 oz Ag (65%, 78.3%)	25,514 (2.7%)	Note that the district totals given here include the north Plomosa district, north of the Kofa game refuge. Also produced from this district were: 500 t iron ore, 2,700 t barite ore, 1 t bentonite and 1 t tungsten concentrates.
Sheep Tanks	20,904 (8.1%)	39,731 (5.2%)	1 t	--	--	250 1 t (26.9%)	few ounces of Au	17,400 (1.8%)	Wide breccia fault filled by quartz-carbonate veins. Shoots of gold and silver and locally chrysocolla and lead minerals. Mineraliztion appears shallow.
Tank Mountains	50	10	--	--	--	50 1 t (5.4%)	200 oz Au, minor Ag (0.7%)	50	Gold bearing, quartz-carbonate veins with iron oxides and copper and iron sulfides in Mesozoic schist with dioritic and rhyolitic dikes. Gold placers are present.
Neversweat	111	1438 (0.2%)	4.5 t (0.8%)	21.5 t (0.2%)	--	--	--	187	Veins of barite, fluorite, gypsum with irregular pods of Ag-galena and oxidized Pb and Ag mineralization. Only the Silver Prince produced.
New Water	--	480	18 t (3.2%)	--	--	--	--	480 (0.1%)	Spotty, scattered oxidized copper associated with limonite. No continuous bodies of economic mineralization known.
TOTALS	256,933	770,786	563.41	10,868	103	930	27,700 oz Au, 2,300 oz Ag	944,326	
	GOLD (OZ)	SILVER (OZ)	COPPER	LEAD	ZINC	MANGANESE	PLACER	ORE (TONS)	

Table 8.--Past production from individual mineral deposits in the KNWR as classified by mineral deposit type
[The production data are from Keith (1978); oz, troy ounces. See pl. 3 for locations]

	Mine	District	Map unit	Host	Production
Type = Comstock Epithermal vein					
1	Kofa	Kofa	Tt	Rhyolite and silicified andesite breccias	739,300 tons @ 0.23 oz Au and 0.1 oz Ag
2	North Star	Kofa	Tt	Dacite and silty shale	38,735 tons @ 1.4 oz Au and 0.6 oz Ag
3	Iron Wood	Kofa	Tt	Rhyolite	534 tons @ 0.5 oz Au and 0.4 oz Ag
4	Quartette	Kofa	Jp	Diorite	550 tons @ 1.3 oz Au and 2 oz Ag and 0.2% Cu
5	Rob Roy	Kofa	Tt	Rhyolite and dacite	435 tons @ 0.1 oz Au snd 0.05 oz Ag
Type = Epithermal Mn					
6	Black Dahlia	Kofa	Jg	Gneissic granodiorite	230 tonnnes of 27% Mn
7	Sheep Tanks	Sheep Tanks	Ts, Tt	Rhyolitic tuff and trachyte	17,400 tons @ 0.39 oz Au and 8.3 oz Ag
8	Unknown name	Kofa	Ts	Silicic flow	Not recorded
9	National Debt	Plomosa South	Ts	Rhyolitic flows	815 tonnes @ 20% Mn
10	Black Beauty	Plomosa North	Ts	Dacitic flows	490 tonnes @ 20% Mn
11	Black Joe	Castle Dome	Ts	Dacitic flows	Ore grade @ 8% Mn
12	Black Top	Castle Dome	Tt	Dacitic flows	384 tonnes @ 26% Mn
13	Engesser Pass	Tank Mountains	Jg	Gneissic granodiorite	<50 tonnes @ 25-30% Mn
14	Black King	Tank Mountains	Ts, Tb	Dacitic flows and basalt	<50 tonnes @ 25-30% Mn
Type = Low sulfide Au-quartz vein					
15	Evening Star	Kofa	Jp	Schist and trachyte dikes	Small amount gold
16	Bell of Arizona	Plomosa South	Pg	Quartz monzonite	205 tons @ 0.4 oz Au and 0.1 oz Ag
17	Iron Queen & Copper Prince	Plomosa South	Pg	Schistose granite	1,720 tons @ 0.3 oz Au and 1.0 oz Ag and 0.6% Cu
18	Poorman & Goodman	Plomosa South	Pzs	Schist	100 tons @ 3.8 oz Au end 0.8 oz Ag
19	Renegade	Plomosa South	KJm	Schistose sandy shales	90 tons @ 0.6 oz Au snd 0.8 oz Ag and 0.4% Pb
Type = W-quartz veins					
20	Midnight	Kofa	Jp	Schist; trachyte and pegmatite dikes	40 tons of WO_3 from 1% ore
21	Tungsten mine group	Kofa	Jp	Schist and trachyte dikes	54 tons of WO_3 from 1% ore
22	Bright Star	Plomosa South	Pg	Gneissic granite	17 tons WO_3
23	Livingston	Plomosa South	KJm	Schistose siltstone	Few tons of 15-60% WO_3 minor Au, Ag, and Cu

Table 8.--Past production from individual mineral deposits in the KNWR as classified by mineral deposit type--(Continued)

	Mine	District	Map unit	Host	Production
Type = Polymetallic vein					
24	Apache Chief group	Plomosa South	Pzs, KJm	Marble and dioritic dikes	2,100 tons @ 0.03 oz Au, 12 oz Ag, and 11% Cu
25	Gold Nugget	Plomosa South	Pzs	Quartzite	100 tons @ 1 oz Au, 2 oz Ag, 1% Pb, and 0.1% Cu
26	Humdinger or Picacho	Plomosa South	KJm	Schistose siltstone	300 tons of high grade Pb-Ag ore
27	Ramsey	Plomosa South	Tt, KJm	Rhyolitic tuff, limestone, shale, sandstone and quartzite	8,400 tons @ 35 oz Ag, 1% Pb, 0.5% Zn, 0.1% Cu and minor Au
28	Shamrock	Plomosa South	Ts	Andesite	210 tons @ 6% Cu, 39 oz Ag, 0.01 oz Au
29	Adams mine group	Castle Dome	MzPg	Gneiss trachyte dikes	240 tons @ 49% Pb, 18 oz Ag, little Au and Cu
30	Big Eye	Castle Dome	Js	Quartzite and rhyolite dikes	2,370 tons @ 0.9 oz Au, 8 oz Ag, minor Cu & Pb
31	Castle Dome mine group	Castle Dome	Kg, MzPg, Mzo, Js	Schist, granitoids, phyllite; all cut by trachyte dikes	106,000 tons @ 10% Pb, 5 oz Ag, minor Au, Cu, and Zn; 3,300 tons fluorspar
32	Colorado mine group	Castle Dome	MzPg, Js	Siltstone, gneiss argillite	1,400 tons @ 43% Pb, 38 oz Ag
33	Copper Glance	Castle Dome	Js	Schist, shale sandstone	135 tons @ 7% Cu, 11 oz Ag, 0.1 oz Au, and 0.2% Pb
34	Silver Prince	Neversweat	Mzo	Schist cut by trachyte dikes	187 tons @ 14% Pb, 7 oz Ag, 2% Cu, and 0.08 oz Au
Type = Polymetallic replacement					
35	Black Mesa	Plomosa South	Pzs	Limestone and dolomite	51 tons @ 25% Pb, 13 oz Ag, 2% Cu, and 0.02 oz Au
Type = Hot Spring precious metal					
36	Unnamed prospect	Unnamed district	Ts, Qa	Rhyolitic flows covered by alluvium	None
37	Republic	Plomosa South	Tb	Basaltic andesite	Not recorded
Type = Porphyry copper					
38	Unnamed	Alamo Springs	Jg	Granodiorite	Unknown
Type = Placer Au-PGE					
39	Plomosa placers	Plomosa South	Qa	Alluvium	18,000 oz Au 1,800 oz Ag
40	Castle Dome Au placers	Castle Dome	Qa over Js, Jg	Alluvium	7,000 oz Au
41	Kofa placers	Kofa	Qa	Alluvium	2,500 oz Au
Epithermal precious-metal veins of unknown type					
42	Ocotillo mine group	Alamo Springs	Tt	Rhyolitic tuff	Not recorded
43	Cemitosa	Alamo Springs	Ts	Rhyolitic tuff	Not recorded
44	Alamo group	Alamo Springs	Ts	Rhyolitic tuff	Not recorded
45	Kofa Queen	Alamo Springs	Ts	Rhyolitic tuff	Not recorded
46	Tunnel Springs	Alamo Springs	Ts	Rhyolitic tuff	Not recorded
47	Big Horn	Alamo Springs	Tt	Rhyolitic tuff	Not recorded
48	Stafford	Plomosa South	Ts	Rhyolitic tuff	Not recorded

Table 9.--Assessment domains in the Kofa National Wild Refuge

Domain	Map units	Host rock description	Descriptive mineral deposit model	Known occurrences	Geochemistry	Remarks on domain boundaries
I. Gneiss- or schist-hosted epigenetic precious-metal deposits	MzPg, Kg, Js, Jss, Jm, Jp, MzO, KJm, Jg (near Kofa only) KJg, Js and Jg	Gneissic granodiorites, schist, and phylites. Fractures and breccias developed along fault zones serve as loci for mineral deposits.	Gold on flat faults model of Bouley (1986), Mesquite, California deposit (Manske, 1987; Tosdal and Haxel, 1985), and the American Girl-Padre y Madre deposits (Guthrie and others, 1987; Tosdal and Miller, 1987).	No known occurrences in KNWR. Quartz veins in schist footwall of minor detachment fault is a possible minor occurrence northeast of the Colorado mine group in the Castle Dome district.	Stream-sediment samples from these map units are anomalous in Au, As, Tl, and Ag.	Domains were delineated using geologic boundaries (faults and contacts) between permissive map units and non-permissive units.
II. Generic epithermal precious-metal-bearing deposits that include a) Comstock epithermal veins, b) hot-spring Au and Hg deposits, and c) epithermal Mn deposits.	See IIa, b, c.	See IIa, b, c.	See IIa, b, c.	See IIa, b, c.	Drainage basins that contain samples with anomalously high concentrations of Au, Ag, As, Sb, Tl, or Hg.	Domains were delineated on the basis of favorable geochemistry (anomalous Au, Ag, As, Tl, Sb, or Hg) in drainage basins and permissive geology (host rocks). Faults within or at the margins of domains are particularly favorable.
a. Hot-spring gold and (or) silver and hot-spring Hg deposits.	Qs, Tb	Qs: chalcedonic sinter interbedded with silicified or clay-altered colluvium and alluvium. Tb: porphyritic, scoriaceous basalt and andesite.	Hot-spring Au-Ag of Berger (1986) and hot-spring Hg of Rytuba (1986a)	Republic mine. 113°55'53" W and 33°37'55" Chalcedonic sinter on west flank of Castle Dome Mountains 113°11'47" W and 33°17'55"	Highly anomalous values of Au, Ag, Tl, Hg, Ba, and Sr in hydrothermal altered (opaline-bearing) basalt.	See II.
b. Precious-metal-bearing quartz, adularia epithermal veins.	Tt, Jp	Silicic tuffaceous volcanic rocks. Fault zones in phyllite.	Comtock epithermal veins of Mosier and others (1986)	Major occurrences are the Kofa and North Star mines.	Veins contain Au, Ag, Ba, As, Sb, Hg.	See II.
c. Silver and manganese-bearing epithermal veins	Jg, Ts, Tt	Silicic flows and domes and tuffaceous volcanic rocks. Granodiorite serves as a host where brecciated by faults.	Epithermal Mn model of Mosier (1986).	Major occurrances are the Ramsey mine and the Sheep Tanks district. Other, smaller occurrences noted on the occurrence map.	Highly anomalous Mn and Ag with sporadic Au. The Mn usually occurs as Mn oxide or in manganiferous calcite.	See II.
III. Sedimentary-rock-hosted, disseminated precious-metal deposits, and polymetallic replacement deposits.	Pzs, Js, Jss, Jp, Js and Jg	Pzs: Escabrosa Limestone and Martin(?) Formation. Permissive host rocks are dolomitic limestone, dolomite, sandy dolomite and cherty limestone. Js: siltstone and argillite are permissive host rocks. Jss: siltstone and mudstone, particularly where calcareous varieties occur. Jp: semipelitic phyllite.	Carbonate-hosted Au-Ag of Berger (1986b). Sediment-hosted disseminated precious-metal of Bagby and Berger (1985).	Black Mesa mine on the northwestern flank of Black Mesa 114°1'42" W. and 33°36'02". This deposit is a polymetallic replacement deposit. However, our geochemical analyses and the alteration present at the mine support the favorability of rocks in this area for sedimentary-rock-hosted, disseminated precious-metal deposits (see table 6).	Anomalous values of Au, Ag, As, Sb, Hg, Bi, Cu, Pb, Zn in altered sandy dolomite. Some streams that drain basins developed on these map units contain anomalous values of As, Au, Tl, and Sb; all of which are associated with deposits of this type.	Domains are delineated on the basis of map units Js, Jss, Jp, and Pzs. Although domain boundaries include all rock types in each map unit, only certain rock types are permissive (see text).
IV. Porphyry copper and associated skarn	KJg, Jg, Js and Jg, Tg, Tp Pzs	KJg, Js and Jg: Holocrystalline, medium to coarse-grained, hornblende-biotite granodiorite. Tg, Tp: Porphyritic to medium-grained granite and rhyolitic subvolcanic intrusions. Pzs: calc-silicate metamorphic rock, developed at the contact between the intrusion and calcareous sedimentary rocks.	Porphyry Cu of Cox (1986).	Stockwork-quartz veined granodiorite with sericitic alteration and jarosite along fractures at 113°52'43" W and 33°25'03" N. The occurrence is unnamed.	High Cu, Mo, and Zn in altered rocks from unnamed occurrence. There are no base-metal-anomalous stream-sediment samples over these map units.	Rocks in Jg are too deeply formed to contain substantial porphyry copper deposits. Domain boundary includes all of Jg and the Js, Jg unit in southeastern Castle Mountains. Although Tg and Tp are not known to contain porphyry-type alteration, the porphyritic texture of the rocks make this map unit a permissive environment.

Table 9.--Assessment domains in the Kofa National Wild Refuge--(continued)

Domain	Map units	Host rock description	Descriptive mineral deposit model	Known occurrences	Geochemistry	Remarks on domain boundaries
V. Placer gold	Qa, Tc	Qa: unconsolidated to poorly consolidated, poorly- to moderately-sorted conglomerate, sandstone, and breccia; includes alluvial fan deposits and active alluvium in arroyos. *Tc: poorly to well-indurated heterolithic conglomerate, sandstone and breccia.*	Placer Au-PGE of Yeend (1986).	Plomosa placers 114°6'57" W and 33°38'10", Kofa placers and Castle Dome placers.	Stream sediments in the Plomosa placers contain anomalous Au.	Domain boundaries are arbitrarily defined outboard from presumed lode sources constrained by known placer occurrences and presumed possible maximum transport distance. The outboard boundary is dashed to represent uncertainty of transport distance. Domain VA in map unit Qa represents areas of known placers; domain VB also in unit Qa represents possible extensions to these placers. Domain VC includes only Tc for which there are no known placer occurrences.
VI. Rhyolite-hosted Sn	Ts, Tt	High silica rhyolite domes, flows, tuff breccias, and tuffs.	Rhyolite-hosted Sn of Reed and others (1986).	None.	Anomalous stream sediment concentrate samples with Sn values from 150 ppm to >2,000 ppm. Some of these samples are also anomalous in Mo and Bi.	The domains are drawn where Sn-anomalous drainage basins occur over map units Ts and Tt. Drainage basins with Sn-anomalous samples over Tertiary volcanic rocks with known epithermal precious-mineral deposits were excluded under the assumption that the Sn in these cases was associated with Au-Ag. Likewise, basins with Sn-W-anomalous samples over metamorphic rocks were excluded under the assumption the the Sn and W are associated elements in low sulfide Au-quartz veins.
VII. Metamorphogenic, gold-bearing quartz veins and pyrite-chlorite-bearing quartz veins.	Pg, Pzs, Jss, Jp, Js, Jg, Mzo, KJm, Jm, MzPg	Proterozoic quartz monzonite at Scadden Mountain and Jurassic, gneissic granitic rocks. Argillites, phyllites, schists and amphibolites. All of these rock types contain low sulfide quartz veins that range from centimeters to meters in width.	Low-sulfide Au-quartz veins of Berger (1986b).	Several known occurrences scattered throughout the KNWR in metamorphic and granitic rocks. The occurrences shown as either W- or Au-rich on the occurrence map.	Veins of this type contain sporadically anomalous contents of Au, Ag, As, Fe, Cu, Pb and Zn. Some occurrences are W-rich. Drainage basins over some metamorphic rocks in KNWR contain samples with anomalous Au, W, Sn, B, As, Cu, Pb, Zn.	Domain boundaries contain all Proterozoic granite and all low to medium grade metamorphic rocks. Foliated, gneissic granitic rocks are also included since quartz veins in these rocks contain anomalous gold.
VIII. Silver and minor gold in base-metal-rich veins with quartz, fluorite, calcite, and barite.	Pzs, KJm, Tt, Ts, MzPg, Js, Kg, Mzo	Any rock type may host this mineral deposit type.	Polymetallic vein model of Cox (1986c).	The Castle Dome district in the southern KNWR contains many occurrences of this type.	Highly anomalous Ag and minor Au associated with Pb, Zn, and Cu. Drainage basins in areas of known occurrences contain poly elemental anomalies.	No domains were delineated for this deposit type due to the localized occurrences yet the possibility that veins of this type can occur in any rock in the KNWR (see text).

Table 10.--Summary of estimates of the numbers of undiscovered mineral deposits in the KNWR

Deposit type	Domain	Probabilistic estimates of number of undiscovered deposits		
		90% chance	50% chance	10% chance
Gneiss-hosted epithermal gold	I	of 1 or more deposits	of 2 or more deposits	of 4 or more deposits
Gneiss-hosted kyanite gold	I	of 0 or more deposits	of 1 or more deposits	of 2 or more deposits
Hot-spring Au	II	of 1 or more deposits	of 2 or more deposits	of 3 or more deposits
Hot-spring Hg	II	of 1 or more deposits	of 2 or more deposits	of 3 or more deposits
Comstock-type vein	II	of 0 or more deposits	of 1 or more deposits	of 3 or more deposits
Epithermal Mn	II	of 0 or more deposits	of 1 or more deposits	of 2 or more deposits
Sedimentary-rock-hosted precious-metal	III	of 1 or more deposits	of 2 or more deposits	of 4 or more deposits
Polymetallic replacement	III	of 0 or more deposits	of 1 or more deposits	of 3 or more deposits
Porphyry copper	IV	of 0 or more deposits	of 0 or more deposits	of 0 or more deposits
Placer gold	VA	of 0 or more deposits	of 1 or more deposits	of 2 or more deposits
Placer gold	VC	of 1 or more deposits	of 3 or more deposits	of 5 or more deposits
Rhyolite-hosted Sn	VI	of 1 or more deposits	of 3 or more deposits	of 5 or more deposits
Low sulfide Au-W-quartz veins	VII	of 0 or more deposits	of 1 or more deposits	of 3 or more deposits
Polymetallic vein	Not delineated	No estimates made but unlikely that undiscovered deposits occur.		
Uranium in volcanic rocks	" "	"		
Lithophilic elements in pegmatites	" "	"		
Aluminum in kyanite-pyrophylite zones	" "	"		