THE SONORAN DESERT HERITAGE PROPOSAL:
AN EVALUATION OF THE MINERAL RESOURCE POTENTIAL OF LANDS PROPOSED FOR WITHDRAWAL FROM MINERAL ENTRY

Jon E. Spencer
Arizona Geological Survey

Big Horn Mountains in the middleground with Harquahala Mountains in the background.

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By

Jon E. Spencer
Senior Geologist | Arizona Geological Survey

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Arizona Geological Survey
416 W. Congress St., #100
Tucson, Arizona 85701
ABSTRACT

In 2011, the Arizona Wilderness Coalition, Sonoran Institute, and The Wilderness Society proposed that the Federal Government designate approximately 1478 square miles (945,885 acres) of Arizona public lands as Wilderness Area, National Conservation Area, and Special Management Area (Marlow and Richins, 2012). These lands are located primarily west of Phoenix in the low deserts of western Arizona. Enactment of this “Sonoran Desert Heritage” proposal would prevent mining and quarrying on these lands, and would prohibit or impede exploration activity such as drilling and geophysical surveying. This report is an evaluation of the mineral resource potential of these lands, but is limited to the following types of deposits: (1) sand and gravel (aggregates), which are used for concrete and asphalt, (2) porphyry copper deposits, which are a specific type of large copper deposit that is common in Arizona (these deposits may yield large amounts of byproduct molybdenum, silver, and gold), (3) gold deposits in veins, some of which contain substantial silver, and (4) manganese deposits, which are present over a large area in western Arizona but, historically, have been too low grade for mining.

The geology of the lands included within the Sonoran Desert Heritage proposal is complex, and varies greatly from range to range. Geologic mapping of almost the entire area, done by Arizona Geological Survey geologists under the joint State-Federal STATEMAP and COGEMAP programs over the past 30 years, allows informed evaluation of mineral resource potential. This report identifies areas that have high potential for future aggregate production, and areas considered favorable for future discovery of porphyry copper deposits, precious-metal vein deposits, and manganese deposits. One area encompassed by the Sonoran Desert Heritage proposal, which includes the Harquahala and Big Horn Mountains, is identified as having high potential for all of these deposit types. Other metallic mineral commodities such as uranium, iron, and rare-earth elements, and industrial minerals such as clay and zeolite, were not evaluated. This report also includes a brief review of USGS designations of proposed SDH lands as “permissive” and “not permissive” for future discovery of several mineral commodities. Finally, it should be noted that evaluations of potential for undiscovered mineral deposits are inherently speculative, and are complicated by the fact that new technologies for mining and quarrying, changing economic conditions, and changes in commodity demand may result in some uneconomic deposits becoming economic, or in previously uninteresting deposits becoming targets for exploration and mining. As a result, removal of even unattractive lands from mining and quarrying can eventually have adverse economic consequences.
INTRODUCTION

Arizona was settled by European-American immigrants in the second half of the 19th century in large part because of the economic attraction of its mineral resources. Copper, lead, zinc, silver, and gold were mined from thousands of deposits. Some of the larger deposits, perhaps uneconomic with 19th century technology, later became huge open-pit copper mines with significant byproduct production of molybdenum, silver, and several other metals. Copper, the most-mined metal in Arizona, is used primarily for electrical applications because of its low resistance to the flow of electricity and its ductility. The building boom that began after World War II required large quantities of pure limestone to make cement, as well as sand and gravel (aggregate) to mix with the cement to make concrete and to mix with tar to make asphalt. Arizona’s abundant limestone and aggregate resources have been more than adequate to support its growing population and infrastructure. Exploitation of Arizona’s abundant metallic and nonmetallic resources continues to provide employment in Arizona, especially in some of its rural communities.

In 2011, the Arizona Wilderness Coalition, Sonoran Institute, and The Wilderness Society proposed that the Federal Government designate approximately 1478 square miles (945,885 acres) of Arizona public lands as Wilderness Area, National Conservation Area, and Special Management Area (Fig. 1; Marlow and Richins, 2012). This “Sonoran Desert Heritage” (SDH) proposal would remove these lands from mining and quarrying, and would prohibit or impede exploration activity such as drilling and geophysical surveying. This report is a brief evaluation of the mineral-resource potential of lands encompassed by the Sonoran Desert Heritage proposal. Preparation of this report is consistent with Arizona Revised Statute 27-152 (2) directing the AZGS to “Inform, advise, and assist the public in matters concerning the geological processes, materials and landscapes and the development and use of the mineral resources of this state.”

Mineral resource potential is evaluated in this report for sand and gravel (aggregate), precious-metal vein deposits, porphyry copper deposits, and manganese. Other types of mineral resources in the SDH proposal area were not evaluated, including rare-earth elements, disseminated precious-metal deposits, crushed stone, limestone (for cement and concrete), and “banded iron formation” rocks that potentially contain base and precious metals. A final figure in this report identifies areas considered to have high potential for development of aggregate resources, and presents an estimate of the potential of proposed SDH lands for precious-metal vein deposits and porphyry copper deposits. The uncertainty in these estimates is high, but is higher for some areas than others. For example, undiscovered porphyry copper deposits and many precious-metal vein deposits could be concealed over large areas by widespread 15-25 million-year-old volcanic rocks. Some of these uncertainties are discussed along with estimates of mineral-resource potential. However, estimates of potential for undiscovered mineral resources are, by nature, speculative.
Figure 1A

Figure 1B

Figure 1. Map of the proposed Sonoran Desert Heritage lands in southwestern Arizona. (A) With counties labeled. (B) With Congressional Districts.
This report is based on thirty years of geologic mapping and study by Arizona Geological Survey geologists in areas that cover almost all of the land proposed for inclusion in the Sonoran Desert Heritage plan - only the Sand Tank Mountains and Sentinel Plain volcanic field were not mapped by the Arizona Geological Survey during this time. This geologic mapping was done primarily under the joint State-Federal COGEOMAP program in the 1980s and STATEMAP program since 1993. The STATEMAP program, a component of the National Geologic Mapping Act of 1992 and administered by the U.S. Geological Survey, awards Federal funds to State Geological Surveys. Funding is provided following successful submission of annual proposals for specific map areas and requires matching funds from States.

SONORAN DESERT HERITAGE (SDH) PROPOSAL AREA

SDH proposal areas are northwest, west, and southwest of Phoenix, Arizona (Figure 1). The boundaries of SDH proposal lands, as represented in this report, were provided by Dave Richins of the Sonoran Institute, and reflect the boundaries as indicated in the Sonoran Desert Heritage Act (H.R. 1799) that was introduced in the U.S. House of Representatives in April 2013. Approximately 682 thousand acres are proposed for National Conservation Area, and 144 thousand are proposed for Special Management Area. Approximately 162 thousand acres are proposed for Wilderness designation, but these areas are within the areas proposed for National Conservation Area. An additional 120 thousand acres that are proposed for Wilderness designation are presently within Sonoran Desert National Monument. Boundaries are somewhat modified from those of Marlow and Richins (2012) and could be modified again by Congressional action. A proposed Special Management Area in the Hieroglyphic Mountains north of Phoenix (Marlow and Richins, 2012) was dropped from H.R. 1799, but is included in this report because proposed designation could be restored.

The proposal areas consist of perhaps a dozen small desert mountain ranges and nearby hills, as well as flanking, low-lying basin areas. The topography is typical of the Basin and Range physiographic province of southwestern North America (this area includes southern and western Arizona, the Mojave Desert region of California, all of Nevada, and western Utah). Complex bedrock geology in the mountain ranges is typically different from range to range. In part because of geologic complexity and diversity, predictions about mineral resource potential are difficult and speculative. Mineral deposits are scattered, and are commonly apparent because of the presence of old mines, typically including prospect pits and small mine shafts and adits. Mineral deposits are grouped into mineral districts based on common styles of mineralization, rather than grouped into mining districts based on geographic proximity. Historic metal production data, grouped by mineral district, are available from Keith et al. (1983).
AGGREGATE RESOURCE POTENTIAL OF THE SONORAN DESERT HERITAGE PROPOSAL AREA

Unconsolidated and weakly consolidated sand and gravel deposits, which are common along and adjacent to large desert washes and major rivers, have yielded abundant high-quality aggregate to support development in Arizona. Rapid population growth in the greater Phoenix metropolitan area over the past several decades required enormous amounts of aggregate for construction of new homes, buildings, roads, and other facilities and infrastructure. Once urban development occurs, however, underlying aggregate resources are no longer accessible, and nearby resources may become inaccessible because of concerns about noise, dust, and truck traffic associated with quarry operations. Transportation costs, a major factor in aggregate costs, increase greatly if aggregate must be imported from distant areas. Future growth of the greater Phoenix metropolitan area will require large amounts of sand and gravel for concrete and asphalt. This will most likely be derived from the nearest areas where aggregate is present and accessible.

Some large desert washes that are likely sites of high quality aggregate are located in lands proposed for inclusion in the Sonoran Desert Heritage conservation plan (Figure 2). These are areas, as with all large desert washes, where intermittent stream flow has carried sand and gravel from upstream sources. Impacts between sand grains and rock fragments ("clasts") during water-driven transport destroy the weakest rocks first so that, after substantial transport, only the strong mineral grains and rock fragments survive. Generally, these survivors are rich in quartz sand and in quartz-rich rock fragments. These materials are ideal for aggregate because of their high strength and low chemical reactivity. Areas 1 through 4 in Figure 2 are locations where major washes flow through or directly adjacent to lands proposed for inclusion in the Sonoran Desert Heritage plan. If the Phoenix metropolitan area grows much larger, these areas may be exploited for aggregate as they will be close to areas of development.

Another source of quality aggregate is bedrock that consists of hard, non-reactive materials, such as quartzite and granitic rocks that contain little mica. Mica is problematic for aggregate because it readily breaks into flakes and so imparts weakness to rock. An uncommon type of granite, known as "leucogranite", contains less than about 2% mica, and generally forms a quality source of aggregate, as do adjacent alluvial materials. For example, a quarry located east of Yuma on the northwest flank of the Gila Mountains exploits quality aggregate from alluvial fan deposits derived from directly adjacent leucogranite (Shipman et al., 2006). The northeastern Harquahala Mountains, an area largely within the Sonoran Desert Heritage proposal, consists primarily of leucogranite and represents an extensive potential source of aggregate, both as crushed rock and alluvial fan deposits (Figure 2; Richard et al., 1994).
Figure 2. Map of the proposed Sonoran Desert Heritage lands in southwestern Arizona, showing locations of five areas where significant aggregate resources could become inaccessible if the Sonoran Desert Heritage plan is enacted with current boundaries. Four of these areas, located on major stream beds and their directly adjacent low-lying areas, are numbered on Figure 2 as follows: (1) Gila River streambed below Painted Rock Dam, (2) Gila River streambed near Gillespie Dam, (3) Harquahala Wash south of Saddle Mountain, and (4) Jackrabbit Wash north of the Belmont Mountains. Also shown is (5) the area around the eastern Harquahala Mountains where resistant, mica-poor granite is present and is flanked by alluvial fans derived from the mica-poor granite.
PRECIOUS-METAL VEIN DEPOSITS

Most historic and active gold and silver mines in Arizona are located on vein deposits, which are sheet-like masses primarily of quartz, with concentrations of gold and silver that may be visible to the unaided eye. Large veins are generally hundreds to thousands of feet long. Veins may form in groups, or represent zones of numerous small veins within fractured host rocks. Adjacent host rocks may also contain disseminated precious metals. Vein deposits are mined either by open-pit methods or by removing the vein material from underground and thus producing a slot-like underground mine. A common problem with mining veins is that they may be fragmented by faults. In some cases, the displaced fragments have not been located despite much exploratory activity, including drilling. At modern gold and silver prices ($1700/oz. gold and $30/oz. silver), the total value of historic production from Arizona's 8 largest precious-metal vein deposits is about $7 billion (Figure 3; Keith et al., 1983). Approximately 93% of this value is from gold derived from the seven western Arizona mines.

For reasons that are still not well understood, precious-metal deposits typically have high gold:silver ratios in western Arizona, and low gold:silver ratios in southeastern Arizona (Titley, 1987). Only the Pearce deposit in southeastern Arizona is in the top eight for the value of precious metal derived from a vein deposit, and it is unique in the list because most of that value came from mined silver rather than gold. Furthermore, all seven gold-dominated vein deposits are from western Arizona in an area that includes only approximately 15% of the State (Figure 3). The Harquahala - Big Horn Mountains area, which include areas proposed for conservation by the SDH plan, is within the western area of high gold:silver ratios and is regionally favorable for the existence of gold-rich vein deposits (Figure 4). The geology of the Harquahala Mountains is similar to that of the adjacent Little Harquahala Mountains, site of the Bonanza vein deposit (Spencer et al., 1985; Richard et al., 1994). The geology of the Big Horn and Belmont Mountains is similar to that of the adjacent Vulture Mountains, site of the Vulture gold mine (Grubensky, 1989; Stimac et al., 1994). The Harquahala - Big Horn part of the SDH Proposal is therefore considered to have high potential for discovery of precious-metal vein deposits with high gold:silver ratios.

Saddle Mountain and the Gila Bend Mountains, both located to the south of the Big Horn Mountains and within the SDH proposal area (Figure 5), are probably within the western area of high gold:silver ratios, but could be on a poorly defined, southeastward transition zone from high to low gold:silver ratios. These two mountain ranges contain abundant 25 to 15 million year old volcanic rocks (Spencer, 1995, Richard et al., 2000), as at the productive Oatman and Union Pass precious-metal vein deposits in Mohave County (Figure 3), but historic production from these ranges has been negligible. The Gila Bend Mountains and Saddle Mountains are thus considered to have moderate potential for discovery of precious-metal vein deposits (high because of rock associations, low because of negligible past production – this averages out to moderate potential).
The Sentinel volcanic field, located south of the Gila Bend Mountains, consists almost entirely of very young basalt (< 3 million years old), with low potential for precious-metal vein deposits except along its western edge where the Painted Rock Mountains consist of 25-15 million year old volcanic rocks with hydrothermal mineralization at the Painted Rock mineral district (Figure 5). Historic production at this mineral district includes 1200 ounces of silver and 10 ounces of gold (Keith et al., 1983), which suggests that this area is within the southeastern Arizona region where gold:silver ratios are low. The Painted Rock Mountains are thus considered to have moderate potential for precious-metal vein deposits.

The Maricopa Mountains, located east of Gila Bend, consist almost entirely of Proterozoic granitic rocks, with very little evidence of younger magmatic or hydrothermal activity (Figures 1, 5; Cunningham et al., 1997). This area is considered to have low potential for precious-metal vein deposits. Finally, both the Sand Tank Mountains, site of proposed SDH Wilderness areas, and the Hieroglyphic Mountains, site of a proposed SDH Special Management Area (Figure 1), contain significant areas of 25 to 15 million year old volcanic rocks, and are considered to have moderate potential for precious-metal vein deposits.
Figure 3. Geologic map of Arizona showing locations and production data for the eight largest precious-metal vein deposits. Production data from Keith et al. (1983) with value based on modern prices. Geologic map base from Richard et al. (2000).

Figure 4 (next page). Map of the Harquahala - Big Horn Mountains area, showing major mines, mineral districts, historic production data, existing BLM wilderness areas, and SDH proposed wilderness and national conservation areas. Production data from Keith et al. (1983).
Total historic production from Little Harquahala, Vulture, and Osborne mineral districts:
506,000 oz gold, 549,000 oz silver, 858 tons copper, 4830 tons lead.
Total historic production from Aguila mineral district:
21,200 tons manganese.
Figure 5. Map of the Gila Bend Mountains area, showing mineral districts, existing BLM wilderness areas, and SDH proposed wilderness and national conservation areas.
PORPHYRY COPPER DEPOSITS

Porphyry copper deposits are a type of copper deposit that is associated with igneous rocks known as "porphyry" or with similar types of igneous rocks, most of which are granitic (Titley, 1995). Arizona is the center of one of the world's three great clusters of porphyry copper deposits (Figure 6; the other two are in northern and central Chile). Total recorded Arizona copper production (1874-2010) is approximately 63 million tons, amounting to 10% of total global production. At a current price of $3.75/lb., total Arizona production would be worth $472 billion. Most copper is used for electrical applications, especially wiring houses, buildings, and motor vehicles, as well as consumer electronics and electric motors and generators.

![Figure 6. Porphyry copper deposits in southwestern North America (modified from Spencer and Titley, 2008).](image)

In Arizona, the igneous rock units associated with porphyry copper deposits are between 50 and 80 million years old, as determined by laboratory analysis for all but one of the deposits (Titley and Zürcher, 2008; note that the copper deposits are the same age as the associated igneous
Areas in Arizona where granitic rocks of this age are present are considered to have high potential for future discoveries of porphyry copper deposits. In this regard, the Big Horn Mountains are underlain by a granitic intrusion that has yielded three radiometric age determinations of 63 to 71 million years, indicating that the granitic intrusion is of the appropriate age for porphyry copper mineralization (Stimac et al., 1994; Figure 7). Historic mining in the Big Horn Mountains yielded millions of pounds of copper and lead (Keith et al., 1983), as might be expected for mineralization peripheral to a porphyry copper deposit (as for example around the Mineral Park porphyry copper deposit north of Kingman; Lang and Eastoe, 1988), or where porphyry copper mineral deposits have been leached and metals re-deposited by younger hydrothermal activity (as for example with the Tiger deposit near the San Manuel porphyry copper deposit; Bideaux, 1980). The Big Horn Mountains are also highly faulted and tectonically extended, and are covered over large areas by 25 to 15 million-year-old volcanic rocks that are much younger than any likely porphyry copper deposits (Stimac et al., 1994; Spencer et al., 1995). As a result, if porphyry copper deposits are present, they could be both fragmented by faulting and buried by volcanic rocks, making them difficult to find. This area is considered to have a high potential for discovery of concealed porphyry copper deposits.

The Gila Bend Mountains – Maricopa Mountains – Sand Tank Mountains area to the south of the Big Horn Mountains contains no known 50-80 million-year-old granitic rocks except for one granitic intrusion in the Sand Tank Mountains (Figure 8). This intrusion is located approximately 20 miles northwest of the Vekol and Pinal Grande mineral districts, which have historic production of approximately a million pounds of copper and a million ounces of silver (Keith et al., 1983). A cluster of small exposures of 50-80 million-year-old granitic rocks is present in these historic mineral districts. The Lakeshore porphyry copper deposit is present another ~20 miles to the east, and the Sacaton porphyry copper deposit is located to the north (Figure 8). The Sand Tank Mountains area is therefore considered to have a high potential for porphyry copper deposits, both because of the presence of appropriate age granitic rocks and because nearby areas have significant mineral deposits. (The Sand Tank Mountains are currently within the Sonoran Desert National Monument, as shown on Figure 8, but would be converted to Wilderness Area by the SDH plan.)

The Gila Bend Mountains (Figures 5, 8) do not contain any known 50-80 million-year old granitic rocks, but much of the area is covered by younger volcanic rocks. The uncertainty in evaluating the possibility of porphyry copper deposits is high because of this cover, which is also true for the Saddle Mountain area to the north (Figure 5). There are enough indications of mineral deposits, including minor production from the Webb district (27,000 lbs. historic copper production reported by Keith et al., 1983) and scattered evidence of historic prospecting and small mines, that this area is considered to have moderate potential for porphyry copper deposits.

Two small Wilderness Areas and a Special Management Area are proposed for the area north of Interstate 8 in and around the Maricopa Mountains (Figure 8). The Maricopa Mountains contain no known granitic rocks younger than Precambrian, and the bedrock is not concealed by younger rocks.)
volcanic rocks. The proposed Special Management Area overlies similar bedrock, but is primarily located on alluvial deposits between the Maricopa Mountains and Sierra Estrella, which adds uncertainty to estimates of mineral resource potential. In general, however, mineral production and mining activity have been negligible in this broad area, including all of the Maricopa Mountains and almost all of the Sierra Estrella. As a result, this area is rated as low potential for porphyry copper deposits.

The Sentinel Plain volcanic field, located south of the Gila Bend Mountains, consists of basalt lava flows with no known mineral deposits. The basalt flows mostly overlie basin-filling sediments. Depth to underlying bedrock is possibly shallow (Richard et al., 2007) but not well known. The nearest porphyry copper deposit, at Ajo, is approximately 40 miles to the south, and none are known to the west or for perhaps a hundred miles to the north. Potential for porphyry copper deposits is uncertain because of lack of exposure of older rocks, but is considered low because of substantial thickness of younger sediments and basalt lava flows which would make any deep deposits difficult to locate and to mine.

The Painted Rock Mountains at the eastern edge of the Sentinel Plain volcanic field consist of ~20 million-year-old volcanic rocks that host the Painted Rock mineral district, with recorded production of 37,000 lbs. copper and 1200 oz. silver (Keith et al., 1983). Older rocks are concealed, so evaluating this area for the potential for porphyry copper deposits is based only on the fact that there are no porphyry copper deposits, nor known granitic rocks of appropriate age, for tens of miles in any direction. Applying this criterion is speculative, however, because almost all of this broad area is covered by volcanic rocks and sedimentary deposits that are much younger than 50 million years. Based on these considerations, the Painted Rock Mountains are considered to have a low potential for concealed porphyry copper deposits, with a high degree of uncertainty in this assessment.
Figure 7. Geologic map of the Harquahala – Big Horn Mountains area, showing location of 50-80 million-year-old granitic rocks (“TKg”) that suggest favorable conditions for porphyry copper deposits.
Figure 8. Geologic map of the Gila Bend Mountains – Sand Tank Mountains area, showing location of 50-80 million-year-old granitic rocks (“TKg”) that suggest favorable conditions for porphyry copper deposits.
The Hieroglyphic Mountains northwest of Phoenix (Figure 1) include the historic Pikes Peak and Red Picacho mineral districts and the more recently discovered Sheep Mountain mineral district (Figure 9). The proposed SDH Special Management Area (dropped from the most recent SDH proposal according to Dave Richins, Sonoran Institute, April 2013, but include here in case it is added to a future version) in the central Hieroglyphic Mountains extends over some of the mineral deposits in the Pikes Peak mineral district. Much of the underlying bedrock consists of schist derived from Precambrian siltstone and sandstone, and includes “banded-iron formation” (Burr, 1991). The potential for undiscovered banded-iron formation deposits of this type is not evaluated here. This very old bedrock is well exposed over the southwestern part of the proposed Special Management Area, whereas much younger, middle Cenozoic volcanic rocks are exposed over the northeastern part.

Granitic intrusions, thought to be between 50 and 80 million years old, are present in the northwestern Hieroglyphic Mountains near the Red Picacho mineral district (Figure 9; Stimac et al., 1987). The Sheep Mountain mineral district, located approximately 7 miles north of the proposed Special Management Area, has been the subject of drilling and evaluation that indicate at least 40 million tons of ore containing average 1.4% copper and 0.035% molybdenum (cutoff grade 0.8% copper equivalent; Arizona Geological Survey file data). The proposed Special Management Area is considered to have moderate potential for undiscovered porphyry copper deposits because granitic rocks of an age appropriate for porphyry copper mineralization are present northwest of the area, and the Sheep Mountain porphyry copper deposit is present north of the area.

The proposed SDH Special Management Area is not rated as high potential because the western areas that are closest to the appropriate-age igneous rocks consist of well exposed older rocks that are not highly disrupted and are well mapped (Capps et al., 1986; Wahl et al., 1988). If these rocks contain evidence of porphyry mineralization, there is a good chance it would have been recognized. Nevertheless, porphyry copper deposits could be deeper and invisible, or could be present farther east and concealed beneath younger volcanic rocks. Because these young volcanic rocks conceal possible porphyry mineralization, there is a high degree of uncertainty in estimating mineral resource potential in this area. It would not be unreasonable to rate this area as having high potential for porphyry copper deposits, but as noted above, it seems likely that if they were present, they would have been noticed. This, however, is speculative, and illustrates the large uncertainties in estimating mineral-resource potential.
Figure 9. Geologic map of the Hieroglyphic Mountains and surrounding areas, showing location of 50-80 million-year-old granitic rocks (“TKg”) that suggest favorable conditions for porphyry copper deposits, and the Sheep Mountain porphyry copper mineral district located about 7 miles north of the proposed Special Management Area (note – this area was dropped from the April 2013 version of the SDH proposal).

TKg = granitic rocks ~50-80 million years old (not including muscovite or peraluminous granites)

Total historic production from Red Picacho and Pikes Peak mineral districts:
4300 oz gold, 3200 oz silver, 73,000 lbs copper.
Total historic production from Black Dome mineral district:
344,000 lbs manganese.
MANGANESE

Numerous manganese deposits, scattered over a large region in western Arizona and extend into southeastern California, collectively form the western Arizona manganese province and represent the largest known domestic deposits of manganese (Figure 10). These deposits are low grade (generally only a few percent Mn) and formed during the past 25 million years. Most historic production occurred between 1953 and 1955 when the US Government purchased manganese at above-market prices. Total historic production is ~100,000 metric tons of manganese (226 million lbs.) from 24 mining districts. Manganese is the fourth-most-mined metal, and is used primarily to make steel. It could become important in electric-vehicle batteries. A recent report by the National Academy of Sciences concluded that manganese was one of the metals of greatest concern to national security because it is essential for steel manufacturing and because foreign sources are considered unstable (National Research Council, 2008).

Figure 10. The western Arizona manganese province and relationship to SDH proposed National Conservation Areas (blue) and Special Management Areas (green).
The Aguila manganese mineral district, with 42 million pounds of historic manganese production, is within the proposed SDH National Conservation Area in the northern Big Horn Mountains (Figure 10). The Black Dome district, with 344 thousand pounds of historic manganese production, is located north of the Hieroglyphic proposed Special Management Area. Manganese in these districts has not been in economic concentrations historically, but could become so if serious supply disruptions occur and/or prices increase sufficiently.

USGS NATIONAL MINERAL RESOURCE ASSESSMENT

The U.S. Geological Survey conducted a national mineral resource assessment that identified areas that are “permissive” for future discovery of each member of a diverse array of deposit types (USGS National Mineral Resource Assessment Team, 2002). Sonoran Desert Heritage proposed lands are within tracts identified as permissive for discovery of 8 deposit types: (1) porphyry copper deposits, (2) porphyry copper-gold deposits, (3) precious-metal quartz veins, adularia type, (4) precious-metal quartz veins, alunite type, (5) hot-spring gold-silver deposits, (6) distal disseminated silver-gold deposits, (7) polymetallic replacement deposits, and (8) skarn copper deposits, type I. The areas identified as having potential for future discovery of these deposit types are identical for types 1 and 2 (Figs. 11, 12), for types 3, 4, and 5 (Fig. 13), and for types 6, 7, and 8 (Fig. 14). Although areas of potential deposit discovery for types 1 and 2 are considered to be identical, these are represented on two figures (Figs. 11, 12, respectively) because porphyry copper deposits (type 1) are so abundant in Arizona that their permissive area was divided into six tracts for more detailed evaluation (Fig. 11).

Porphyry copper deposits, by far the most valuable of Arizona’s metallic mineral resources, were evaluated for the probability of future discoveries in southwestern Arizona (Fig. 11, tract SB11). In the evaluation of this tract, USGS geologists (p. 815) noted that “This tract contains only three mineral districts classified 1a (copper and porphyry) by Keith and others (1983a)…”. One of these mineral districts is located in the Vulture Mountains just east of the SDH proposal lands, and is associated with a granitic intrusion that is highly faulted and tectonically extended (Grubesky, 1989). A highly faulted granitic intrusion of similar age is present nearby in the northern Big Horn Mountains in the SDH proposal area (Stimac et al., 1994). These two intrusions, of age and type associated with almost all Arizona porphyry copper deposits, are two of only eight such intrusions know in tract SB11. Two others are located nearby in the Little Haquahala and Granite Wash Mountains (Spencer et al., 1985; Reynolds et al., 1991). All four of these are associated with mineral districts identified by Keith et al. (1983) as middle Tertiary and containing “gold with or without copper and lead”. Some of the deposits in these districts could be Laramide in age (especially the Little Harquahala and Harquahala districts) and are plausibly peripheral to concealed areas of porphyry copper mineralization. With this in mind, it seems that much, and perhaps most, of the potential for future porphyry copper and porphyry copper-gold
discoveries in tract SB11 is within the small fraction of the tract that is in the Harquahala – Big Horn Mountains area.

Other deposit types are considered permissive for future discoveries in the SDH proposal area. Precious-metal vein deposits are well known in Arizona, with most of the southern and western parts of the State considered to have potential for future discoveries (Fig. 13). For reasons outlined earlier in this report, the Harquahala – Big Horn area is considered to have higher potential for undiscovered precious-metal vein deposits than other areas within the SDH proposed lands. Future discoveries for a diverse set of deposits (distal disseminated silver-gold deposits, polymetallic replacement deposits, and skarn copper deposits) is considered permissive in scattered regions that include the Harquahala Mountains and part of the San Tank Mountains, both areas that are within the SDH proposal area (Fig. 14). The Harquahala and adjacent Little Harquahala Mountains contain several deposits with similarities to distal disseminated silver-gold deposits (Keith et al., 1983, “gold with or without copper and lead” in deposits with uncertain age), but these deposits are diverse and not well understood.

The geology of western Arizona is highly complex, with great variation from range to range. Many mineral deposits have not been studied in sufficient detail for confident classification. The USGS National Assessment simply evaluated all Arizona lands as either permissive or non-permissive for future discoveries, with no consideration of geologic variations that could lead to more probable and less probable designations within the permissive areas, and no indication of the level of confidence in the designations. As a result, the USGS National Mineral Resource Assessment is only a blunt instrument for evaluation of mineral potential in individual proposed SDH parcels or sub-parcels, and should not be a substitute for evaluations based on the geology of each individual area.
Figure 11. Areas identified as permissive for porphyry copper deposits (from USGS National Mineral Resource Assessment Team, 2002). SDH boundaries are those of April 2013 (D. Richins, written communication, 2013).
Figure 12. Areas identified as permissive for porphyry copper-gold deposits (from USGS National Mineral Resource Assessment Team, 2002). SDH boundaries are those of April 2013 (D. Richins, written communication, 2013).
Figure 13. Areas identified as permissive for quartz vein deposits (quartz-adularia type and quartz-alunite type) and hot-spring gold-silver deposits (from USGS National Mineral Resource Assessment Team, 2002). SDH boundaries are those of April 2013 (D. Richins, written communication, 2013).
Figure 14. Areas identified as permissive for disseminated silver-gold deposits, polymetallic replacement deposits, and skarn copper deposits (from USGS National Mineral Resource Assessment Team, 2002). SDH boundaries are those of April 2013 (D. Richins, written communication, 2013).
CONCLUSION

Areas considered here to have high potential for aggregate resources, and for precious-metal vein and porphyry copper deposits, are shown on Figure 15. Potential sources of aggregate within proposed SDH lands are major washes and the Gila River bed and flanking areas. Studies of aggregate characteristics for these specific areas were not identified for this report, but the areas are similar to washes and stream beds farther east in the Phoenix metropolitan area where there are abundant quarry operations. Similarly, studies of the mechanical properties of leucogranite in the eastern Harquahala Mountains and downslope alluvial fan materials were not identified for this report, but the geology is similar to an area of active quarry operations in the northwestern Gila Mountains east of Yuma.

The northern area of high potential for base- and precious-metal deposits encompasses the Big Horn Mountains and Harquahala Mountains. Two precious-metal vein deposits are located nearby in areas of similar geology, and granitic rocks with age appropriate for porphyry copper deposits are also present. The high potential designation for the Big Horn – Harquahala area is therefore based on high potential for both base and precious metals. It also contains significant sub-economic manganese resources. The Sand Tank Mountains in southern Maricopa County are also shown as having high potential for base and precious metals because they include a granitic intrusion of appropriate age for porphyry copper deposits, and because porphyry copper deposits are present nearby. The high potential designation is based largely on porphyry copper potential, as the potential for precious-metal vein deposits is moderate.

The large area of moderate potential for base and precious metals centered on the Gila Bend Mountains and including Saddle Mountain and the Painted Rock Mountains contains no known granitic rocks of appropriate age for porphyry copper mineralization. It does contain, however, scattered locations of minor base and precious mineral deposits, with enough copper production (27,000 lbs. from the Webb mineral district, 37,000 lbs. from the Painted Rock district) to suggest the possibility of porphyry copper deposits that are deep underground. Furthermore, abundant 25 to 15 million-year-old igneous rocks indicate favorable conditions for precious-metal vein deposits, although low gold production from this area, and low gold:silver ratios, suggest that if such deposits are present, they are not gold-rich like the veins farther west and north.

Two areas have low potential for base and precious metals: The Maricopa Mountains consist of very old bedrock that is unaffected by younger magmatic or hydrothermal processes and contains no significant deposits of any type, and Sentinel Plain consists of unmineralized basalt that overlies typically unmineralized basin-filling sediments, with deeply buried bedrock of unknown composition.
Figure 15. Map showing SDH proposed areas and mineral resource potential as estimated in this report.

I conclude by noting that these designations are inherently speculative. If mineral-deposit predictions could be made confidently, mineral-deposit discovery would not be as difficult as it is. Furthermore, changes in technology have made uneconomic deposits economic, and increased the value of previously unattractive commodities. For example, the need for the rare-earth element neodymium for exceptional magnet strength in hard-disk drives, hybrid-car electric motors, and wind-turbine generators has caused a recent surge in exploration activity. Areas such as the Maricopa Mountains that are designated as low potential for base and precious metals in this study possibly contain pegmatite veins with sufficient rare-earth element concentrations to become ore deposits under future market conditions. Even low-silica basalt, as for example beneath Sentinel Plain, has been suggested for use as a CO₂ absorbent in coal-fired power plants. Thus, while the estimates of mineral potential may be needed for land-use decisions, they can’t account for unknown future economic conditions or technological advances that affect mineral production processes or commodity value.
REFERENCES CITED


