

# Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada

Edited by Steve Ludington

Prepared in cooperation with the Nevada Bureau of Mines and  
Geology and the University of Nevada, Las Vegas



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Cover photograph: View of the Newberry Mountains southeast of Searchlight, Nevada. The rugged dark peaks are composed of Miocene trachyandesite and trachydacite of the lower unit of the volcanics of the Highland Range.

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# Chapter A. Introduction

By Steve Ludington

Mining has been a part of the economy in southern Nevada since before Nevada became a state. Miners in the late 19<sup>th</sup> century found evidence that miners from New Spain and Mexico and perhaps Native Americans, had recovered gold and turquoise here for centuries. However, southern Nevada has not been as comprehensively studied by professional economic geologists as the northern part of the state. There are only a few important studies of mineral resources that describe the areas we assessed (Ransome, 1907; Hill, 1916; Hewett and others, 1936; Vanderburg, 1937; Callaghan, 1939; Hewett, 1956; Longwell and others, 1965), and no significant studies of the mineral deposits have been published for the past 40 years.

During 2004—2006, the U.S. Geological Survey (USGS) conducted a mineral resource assessment of selected areas administered by the Bureau of Land Management (BLM) in Clark and Nye Counties, Nevada. The purpose of this study is to provide the BLM with information for land planning and management and, specifically, to determine mineral resource potential in accordance with regulations in 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 (Public Law 107-282) temporarily withdraws a group of areas designated as Areas of Critical Environmental Concern (ACECs) from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This study provides information about mineral resource potential of the ACECs.

Existing information was compiled about the ACECs, including geology, geophysics, geochemistry, and mineral-deposit information. Field examinations of selected areas and mineral occurrences were conducted to determine their geologic setting and mineral potential.

In February of 2004, USGS and BLM officials met in Las Vegas, Nevada, to determine the appropriate format of reports that would best meet the needs of BLM. It was determined that reports should be in a format similar to BLM's own mineral assessment reports and should use subjective assessment methods. In addition, all the reports have been technically reviewed by BLM staff.

## Partners

The assessment was conducted in partnership with the Nevada Bureau of Mines and Geology (NBMG), a part of

the University of Nevada, Reno (UNR), and the University of Nevada, Las Vegas (UNLV).

Dr. Stephen B. Castor of the NBMG provided expertise in the field of industrial mineral deposits, which account for the bulk of the mineral resources produced in Clark County. His wide experience, coupled with the results of his field and laboratory investigations, has made the completion of this study possible.

Two postdoctoral research scholars at the University of Nevada, Las Vegas contributed materially to this study. Dr. Brett T. McLaurin, supervised by Dr. Andrew D. Hanson, studied the composition and stratigraphy of alluvial fans to help constrain the timing of mineralizing events and to elucidate the geologic history of the area. This information contributed to the assessment of the ACECs for aggregate materials, and Dr. McLaurin conducted that part of the assessment. Dr. Haroldo L. Lledó, supervised by Dr. Jean S. Cline, is studying the interaction between magmatic and hydrothermal processes during the formation of the gold deposits of the Searchlight mining district. Although his tenure began too late to permit him to contribute to the writing of the reports, his insights in the field have contributed materially to our understanding of the area during the latter stages of the project.

## Areas Studied

A total of 24 Areas of Critical Environmental Concern (ACECs) were identified by the BLM as the object of this study. They range in area from less than 1 km<sup>2</sup> to more than 1,000 km<sup>2</sup>. The majority of these areas are not adjacent to or near known mineral deposits and required a minimum of extended study and field examination. What follows here is a brief description and summary of the assessment for each area. The locations of the study areas are shown on figure 1.

### Piute-Eldorado Tortoise ACEC (Chap. B)

The Piute-Eldorado Tortoise ACEC is the largest in the study (about 1,330 km<sup>2</sup>) and is an area where the complex geology and the unusual nature of the mineral deposits are still not well understood. The area consists primarily of Piute and Eldorado Valleys, which are both relatively thinly covered with surficial sediments; bedrock is less than 1,000 m below the surface in most of the ACEC. There are two large excluded

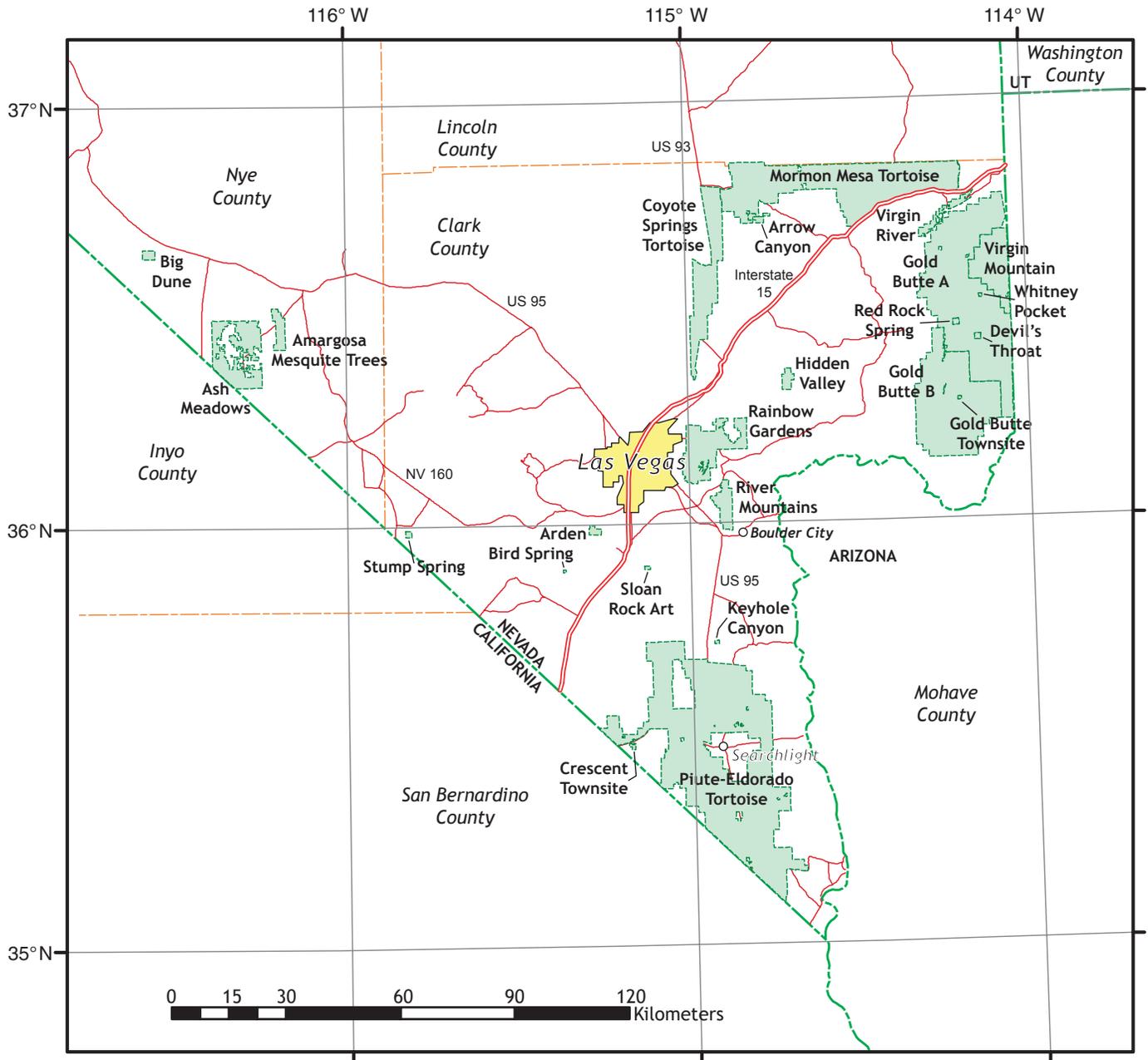
areas, one for the northern part of the Highland Range, and one that contains the town of Searchlight and much of the historic Searchlight mining district. An important question is whether the mineralized system at Searchlight extends beneath a thin veneer of surficial deposits into the surrounding Piute-Eldorado Tortoise ACEC. Other gold-bearing vein deposits occur throughout the area, particularly in the western part of the ACEC in the Crescent mining district. There is potential for undiscovered gold deposits within the ACEC, in both the Searchlight and Crescent mining districts.

**Crescent Townsite ACEC (Chap. B)**

The Crescent Townsite ACEC covers less than 2 km<sup>2</sup>. It is within the Crescent mining district, and has potential for undiscovered gold deposits.

**Keyhole Canyon ACEC (Chap. B)**

The Keyhole Canyon ACEC is small (less than 1 km<sup>2</sup>) and is located in the Eldorado Mountains about 55 km



**Figure 1.** Locations of Areas of Critical Environmental Concern (ACECs; shaded in green), Clark and Nye Counties, Nevada.

southeast of Las Vegas. This ACEC contains no known mineral deposits.

### **Gold Butte ACEC (parts A and B) and Virgin Mountain ACEC (Chap. C)**

These three ACECs are contiguous and have a combined area about as large as the Piute-Eldorado Tortoise ACEC. Gold Butte part A is about 750 km<sup>2</sup> in area; Gold Butte part B is about 490 km<sup>2</sup>; and Virgin Mountain is about 145 km<sup>2</sup>. The northern part of the area, in Gold Butte part A, includes some unusual Proterozoic mineral deposits that contain substantial amounts of platinum group elements (PGE). Nearby, a group of beryllium-bearing pegmatites is found within the Virgin Mountain ACEC. In the southern part of the area, in both Gold Butte parts A and B, a series of copper deposits hosted in Paleozoic carbonate rocks are classified as Kipushi type and resemble much larger deposits elsewhere in the world. These deposits may contain important amounts of the strategic metals gallium and germanium. In Gold Butte part B, low-sulfide gold-quartz vein deposits that have not been previously studied thoroughly occur over a wide area. Also in Gold Butte part B, vermiculite was mined in the past, and a major mining company is evaluating these deposits for renewed production. These ACECs may contain undiscovered Ni-Cu-Au-PGE deposits, beryllium-bearing pegmatite deposits, Kipushi-type copper deposits, low-sulfide gold-quartz vein deposits, and vermiculite deposits.

### **Red Rock Springs ACEC, Whitney Pocket ACEC, and Devil's Throat ACEC (Chap. C)**

These three very small ACECs (each is less than 3 km<sup>2</sup>) are all surrounded by Gold Butte part A. In the Devil's Throat ACEC, a remarkable vertically walled sinkhole in the alluvium poses a natural hazard. None of the three areas contains important mineral deposits.

### **Gold Butte Townsite ACEC (Chap. C)**

This very small area (less than 1 km<sup>2</sup>) is entirely surrounded by Gold Butte part B. It contains low-sulfide gold-quartz veins similar to those found in Gold Butte part B.

### **Mormon Mesa Tortoise ACEC, Coyote Springs Tortoise ACEC, and Arrow Canyon ACEC (Chap. D)**

These three areas are contiguous, and are located in the northeast part of Clark County, north of Interstate 15. Mormon Mesa Tortoise is about 610 km<sup>2</sup> in area; Coyote Springs Tortoise is about 210 km<sup>2</sup>; and Arrow Canyon is about 8 km<sup>2</sup>. The three areas are underlain primarily by

Paleozoic limestones, and limestone is the most important mineral commodity.

### **Arden ACEC (Chap. E)**

The Arden ACEC, about 6 km<sup>2</sup> in extent, is on the southern edge of Las Vegas. Silica was mined in the ACEC in the past and there may be undiscovered silica deposits.

### **Bird Spring ACEC (Chap. E)**

The Bird Spring ACEC, a small area of less than one km<sup>2</sup>, is southwest of Las Vegas. The ACEC contains no known mineral deposits.

### **Sloan Rock Art ACEC (Chap. E)**

A small area of less than 2 km<sup>2</sup>, this ACEC is within the North McCulloch Wilderness area, and is underlain by Miocene volcanic rocks. The ACEC contains no known mineral deposits.

### **Ash Meadows ACEC and Amargosa Mesquite ACEC (Chap. F)**

These two areas in Nye County contain unique biological habitats that support rare fish, bird, and plant species. Ash Meadows ACEC is about 150 km<sup>2</sup> in area, and Amargosa Mesquite ACEC is about 27 km<sup>2</sup>. Clays and zeolite minerals been mined there in the past, and additional deposits of this type may exist.

### **Virgin River ACEC (Chap. G)**

The Virgin River ACEC is about 30 km<sup>2</sup> in area, is located along the Virgin River, south of Interstate 15 in northeastern Clark County, and exposes primarily recent sedimentary deposits. Sand and gravel aggregate is the most important commodity found in the ACEC.

### **Hidden Valley ACEC (Chap. H)**

The Hidden Valley ACEC is in the Muddy Mountains, about 40 km northeast of Las Vegas, and has an area of about 14 km<sup>2</sup>. Small amounts of building stone were mined from this ACEC in the past, but undiscovered high-quality stone deposits are unlikely.

### **Rainbow Gardens ACEC (Chap. I)**

Rainbow Gardens ACEC is an area of about 160 km<sup>2</sup> and is located immediately east of the city of Las Vegas. A very

large gypsum mine is adjacent to the area, and gypsum has been mined within the ACEC in the past. Some areas within the ACEC may contain undiscovered gypsum deposits.

### **River Mountains ACEC (Chap. J)**

River Mountains ACEC is an area of about 45 km<sup>2</sup> on the southeast edge of the Las Vegas urban area, near Boulder City. The area is underlain by Miocene volcanic rocks. In the past, manganese was mined adjacent to the north end of the ACEC, but there is little potential for undiscovered manganese deposits. There may be undiscovered perillite deposits in the ACEC.

### **Stump Spring ACEC (Chap. K)**

Stump Spring is a small area (less than 3 km<sup>2</sup>) near the California border, west of Las Vegas. The ACEC contains no known mineral deposits.

### **Big Dune ACEC (Chap. L)**

The sand dunes in this area of about 8 km<sup>2</sup> in Nye County do not host any important mineral deposits.

## **Assessment Methods**

At the request of the BLM, an assessment methodology is used in this report that relies on subjective assessment. Areas are assigned high, medium, and low mineral resource potential according to the degree of likelihood that geologic processes operated in an area in such a way as to permit accumulation of resources. The definitions of these levels of resource potential are given in Goudarzi (1984). A useful way to interpret the levels might be that most mining companies would be willing to risk exploration dollars in an area with high potential, whereas very few would be willing to take a risk on a low potential area, even though a deposit might possibly exist. An area of medium potential might be attractive to some optimistic investors, but not to more conservative ones.

For most locatable and leasable minerals, the designation of an area as having high potential does not necessarily imply that deposits that might be discovered there could be developed and operated successfully. When information is available about resource quality that might bear on the economic viability of deposits, it is presented separately from the potential designation. However, for some industrial commodities, most notably crushed rock and sand and gravel aggregate, resource quality and location are essential parts of the definition of a deposit. For aggregate deposits, and for some other industrial mineral deposits, we therefore took resource quality and potential exploitation costs into account in designation of levels of mineral

resource potential. In most cases, we also assigned a high, moderate, or low level of certainty to the designations of mineral resource potential, using the terminology defined in Goudarzi (1984).

## **Acknowledgments**

Any geologic study rests on the shoulders of those who have gone before. In the present study, we have been fortunate enough to have personal interactions with some of the most important experts in Clark County geology. Special thanks for teaching us the geology of the region go to Dr. Calvin Miller of Vanderbilt University, Dr. Jonathan Miller of San José State University, Dr. James Faults of the Nevada Bureau of Mines and Geology, and L. Sue Beard, Tracey J. Felger, and Keith A. Howard of the U.S. Geological Survey. Drs. Jean S. Cline, Andrew D. Hanson, and Eugene I. Smith, of the University of Nevada, Las Vegas, gave valuable advice in the field and in the office. Joe Tingley of the Nevada Bureau of Mines and Geology offered his vast experience with Nevada mineral deposits and helped us collect information on active mining claims. Gary Johnson, information systems specialist at the Nevada Bureau of Mines and Geology, helped with digital cartography. Joyce Lum, of the Water Resources office of the U.S. Geological Survey in Henderson, Nevada, and Mary Hinson, Assistant Superintendent of Lake Mead National Recreation Area, provided extra administrative support. Melanie J. Hopkins, now of the University of Chicago, gave important support in the field and office in the early stages of the project.

Various parts of the reports have been reviewed and improved by Ted McKee, Alan Wallace, Peter Vikre, and Keith Howard, of the U.S. Geological Survey, by Dr. Calvin F. Miller of Vanderbilt University, and by Haroldo Lledó of the University of Nevada, Las Vegas.

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# Chapter B. Mineral Resource Potential of the Piute-Eldorado Tortoise, Crescent Townsite, and Keyhole Canyon Areas of Critical Environmental Concern, Clark County, Nevada

By Steve Ludington, Stephen B. Castor, Brett T. McLaurin, Kathryn S. Flynn, and James E. Faulds

## Summary and Conclusions

The Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC) contains areas related to the Searchlight mining district with both high and moderate potential for Searchlight-type gold-bearing vein deposits. Also related to the Searchlight mining district are areas with moderate and low potential for porphyry copper deposits. The ACEC also contains areas related to the Crescent mining district with high potential for gold-bearing polymetallic vein deposits and also additional moderate potential for detachment-fault-related gold deposits. A large area in the Piute-Eldorado Tortoise ACEC has moderate potential for perlite deposits; a very small area has high potential for perlite deposits. Potential for other deposits of locatable or leasable minerals is low.

The Piute-Eldorado Tortoise ACEC contains areas that have high, moderate, and low potential for crushed-stone aggregate deposits. It has large areas that have high potential for sand and gravel aggregate deposits, as well as smaller areas with moderate potential.

The Crescent Townsite ACEC has high mineral resource potential for gold-bearing polymetallic veins, and part of it has additional moderate potential for detachment-fault-related gold deposits. The ACEC has moderate potential for crushed-stone aggregate deposits, and high potential for sand and gravel aggregate deposits.

The Keyhole Canyon ACEC has low potential for locatable or leasable mineral deposits. The ACEC contains areas with both high and moderate mineral resource potential for crushed-stone aggregate deposits. It has high potential for sand and gravel aggregate deposits.

All three areas will likely see continued production of decorative stone from private inholdings within the ACECs.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43

CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Piute-Eldorado Tortoise, Crescent Townsite, and Keyhole Canyon Areas of Critical Environmental Concern (ACECs) were studied in the field for several months to confirm descriptions of the geology that are published in the scientific literature. Reconnaissance mapping was conducted in the many areas that had not yet been geologically mapped at scales appropriate to this assessment. More than 200 samples were collected and analyzed (Ludington and others, 2005), and representatives of companies with mining and mineral exploration operations in and near the areas were contacted.

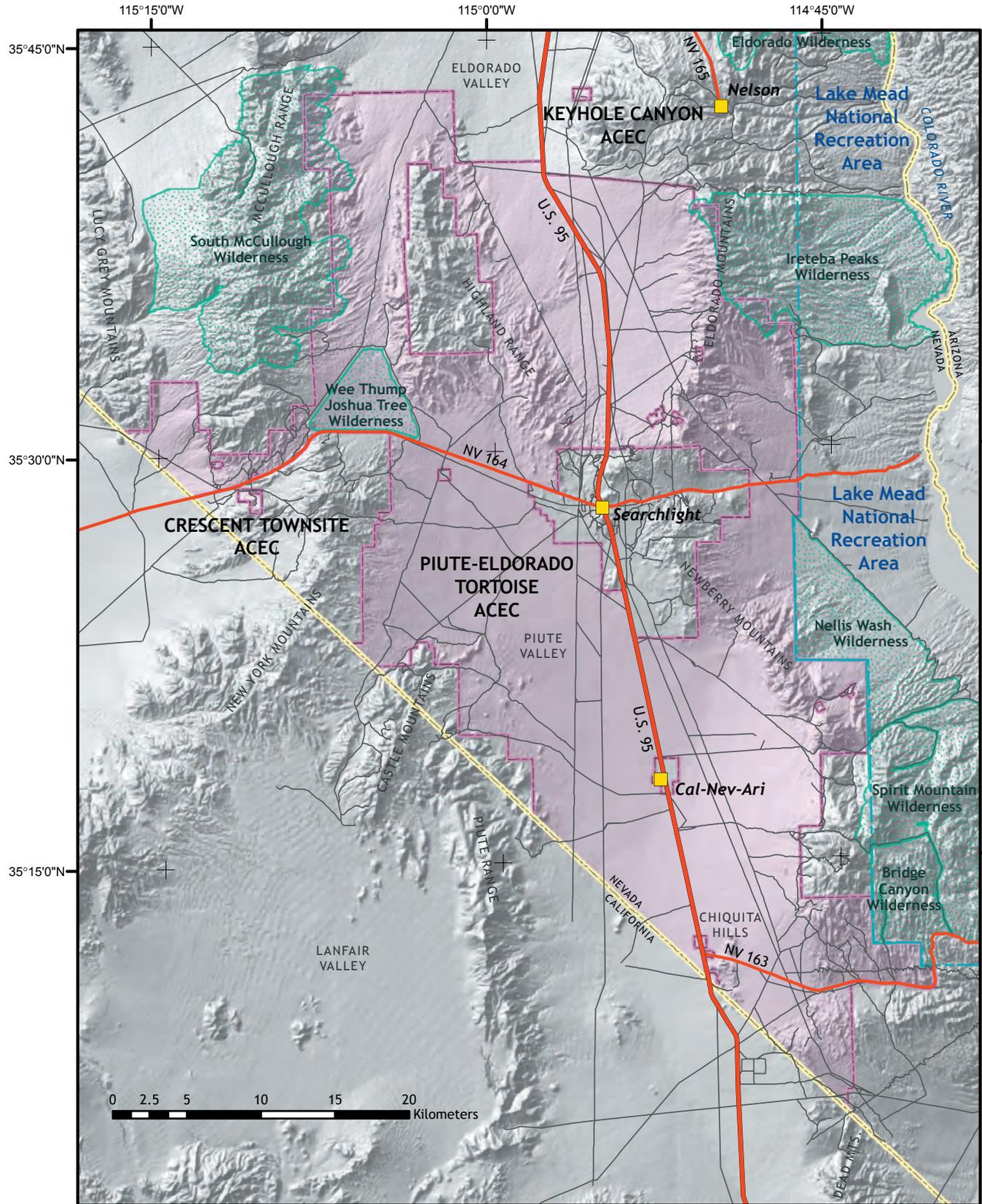
Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

This report describes three areas of critical environmental concern (ACECs), the Piute-Eldorado Tortoise, the Crescent Townsite, and the Keyhole Canyon. The small Crescent Townsite ACEC is near the western part of the Piute-Eldorado Tortoise ACEC, a few hundred meters away from the boundary. The Keyhole Canyon ACEC is about 4 km north of the north boundary of the Piute-Eldorado Tortoise ACEC. Together, these three ACECs will be referred to in this report as the Piute-Eldorado ACECs (fig. 1). A legal description of these lands is included in appendix 2.

The Piute-Eldorado Tortoise ACEC consists primarily of the valley floors of Eldorado and Piute Valleys that drain north and south, respectively, from a drainage divide near the town of Searchlight (fig. 1). A small part of Ivanpah Valley is also included, adjacent to the California border west of Crescent townsite. Two large islands of land are excluded from the Piute-Eldorado Tortoise ACEC, one in the northwest part to

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**Figure 1.** Index map, showing boundaries of Areas of Critical Environmental Concern (ACEC; outlined in pink), wilderness areas (outlined in turquoise), and access roads throughout the Piute-Eldorado ACECs. The boundary of the Lake Mead National Recreation Area is shown as a broken green line.

exclude the rugged peaks of the northern Highland Range, and one in the east-central part to exclude the town of Searchlight and some parts of the Searchlight mining district. The ACEC has an area of about 1,316 km<sup>2</sup>. It is bisected in a north-south direction by U.S. Highway 95 and in an east-west direction by Nevada State Highway 164. Access is via an extensive network of secondary roads that lead to various parts of the ACEC from these highways (fig. 1).

The Keyhole Canyon ACEC has an area of slightly less than 1 km<sup>2</sup> and includes the mouth of Keyhole Canyon, on the west margin of the Eldorado Mountains, and a part of Eldorado Valley. It is accessed by secondary roads from U.S. Highway 95, about 3 km to the west.

The Crescent Townsite ACEC has an area of about 1.8 km<sup>2</sup> and is near the head of Big Tiger Wash, a tributary valley to Ivanpah Valley. It is apparently intended to preserve the historic site of the mining town of Crescent, although existing maps indicate that the townsite is mostly north of the ACEC, probably on private land. The ACEC is accessed by a secondary road off Nevada State Highway 164.

The Piute-Eldorado Tortoise ACEC is bordered on the east by the Lake Mead National Recreation Area. It also includes all or part of three existing wilderness areas and borders three more (fig. 1).

Along the northwest boundary of the ACEC, small parcels of land that are part of the South McCullough Wilderness are included within the ACEC. The U.S. Geological Survey and U.S. Bureau of Mines studied this area in the late 1980s (Close, 1987; Barton and Day, 1988; DeWitt and others, 1989).

Along the northeast boundary of the ACEC, several square kilometers of land that are part of the Ireteba Peaks Wilderness are included within the ACEC. The U.S. Geological Survey and the U.S. Bureau of Mines also studied this area in the late 1980s (Causey, 1988a,b; McHugh and others, 1989; Conrad and others, 1991).

In the western part of the ACEC, the Wee Thump Joshua Tree Wilderness was designated in 2002, without study for mineral resources.

The ACEC is bordered on the east by the Nellis Wash Wilderness, the Spirit Mountain Wilderness, and the Bridge Canyon Wilderness, all designated in 2002 without study for mineral resources. These three Wilderness Areas are within the Lake Mead National Recreation Area.

## Physiographic Description

Elevations in the Piute-Eldorado ACECs range from about 550 m to more than 1,600 m. The lowest areas are along the east margin of the Piute-Eldorado Tortoise ACEC, on the alluvial fan that drops from the Newberry Mountains down to the Colorado River (about 550 m) and on the north end of Eldorado Valley and the south end of Piute Valley (about 750 m). The highest areas are the crests of the Ireteba Peaks (about 1,500 m) in the northeast part of Piute-Eldorado Tortoise ACEC and on the east flank of the McCullough Range north-east of Crescent townsite (more than 1,600 m).

The majority of the area is occupied by the Eldorado Valley that drains to the north and the Piute Valley that drains to the south. The climate is extremely dry and subject to extreme temperature variations; there are no perennial streams. The sediments that fill both the Eldorado and Piute Valleys are relatively thin compared to other valleys in the Basin and Range physiographic province (Jachens and Moring, 1990). These valleys are not grabens, and the alluvial fill in the Piute Valley is no deeper than about 700 m. The northern part of the Eldorado Valley (outside the ACEC) is somewhat deeper, but large parts of the east margin of the valley are covered by less than 1,000 m of alluvium. Pediments are relatively wide, especially on the west flank of the Eldorado and Newberry Mountains, and in Big Tiger Wash (fig. 2). In the south half of the ACEC, most of the Piute Valley is covered by less than 500 m of deposits.

The vegetation is strongly zoned according to altitude, and the lower parts of the area are typical of much of the desert southwest of the United States. Some details about the vegetation can be found in Longwell and others (1965).

## Geologic Setting

The areas studied are located in the northern Colorado River extensional corridor, a term first used by Faulds and others (2001). The corridor is characterized by closely spaced normal faults that originally formed as near-vertical tensile fractures and then rotated to low angles during progressive extension. This region occupies the area between the tec-



**Figure 2.** View of McCullough Range from the west, looking toward Big Tiger Wash, showing subdued topography and pediment surface.

tonically stable Colorado Plateaus region to the east and the Mojave Desert province to the west, which is bounded by two large strike-slip fault zones, the Garlock and the San Andreas. The rocks exposed in the Piute-Eldorado area include large areas of Proterozoic metamorphic and igneous rocks that are overlain by varied late Tertiary volcanic and sedimentary rocks. Cretaceous granitoid rocks were emplaced into the Proterozoic rocks and Miocene intrusions cut both the Proterozoic and Tertiary rocks.

## Geology

Rocks and mineral deposits in the Piute-Eldorado ACECs range in age from Early Proterozoic to Recent. Proterozoic sedimentary and volcanic rocks were probably deposited between about 1.7 and 1.8 Ga and then deformed and metamorphosed between about 1.76 and 1.68 Ga (Wooden and Miller, 1990; Howard and others, 2003; Hook and others, 2005). Although no Paleozoic rocks are exposed in the area, it is likely that they were present but stripped off by erosion from early Eocene to middle Miocene time, when the area was uplifted as a broad arch (Bohannon, 1984). Tertiary volcanic rocks (and minor sedimentary rocks) range in age from the 18.5 Ma Peach Springs tuff (Nielson and others, 1990) to about 11 Ma (mafic rocks of the Mt. Davis volcanics; Faulds, 1995).

## Proterozoic Rocks

Proterozoic rocks, mostly schists, gneisses, and granitoid rocks, are exposed in the McCullough Range and the northern New York Mountains, on the west margin of the Piute-Eldorado Tortoise ACEC, and in the Eldorado and Newberry Mountains,



**Figure 3.** Proterozoic gneiss outcrop in Eldorado Mountains.

on the east margin of the ACEC. On the basis of sparse regional isotopic ages, Volborth (1973) speculated that the schists and gneisses in the Piute-Eldorado area formed at 1.7 Ga, but he also reported younger isotopic ages that he believed were reset during recrystallization in Cretaceous and Tertiary time. Volborth described the schists and gneisses in the Eldorado, Newberry, and Dead Mountains as granulite facies rocks containing almandine, sillimanite, cordierite, feldspar, quartz, and some pyroxene and biotite. He further noted the presence of numerous small gabbroic and ultramafic intrusions, as well as abundant pegmatite and aplite masses in some areas.

Anderson and others (1985) mapped and described Early Proterozoic metamorphic rocks in the McCullough Range as low-pressure granulite-facies paragneisses with garnet, sillimanite, and cordierite. The gneiss also includes abundant coarse leucogranite bodies and local masses of amphibolite and meta-ultramafic rock that is reportedly similar to that in the Virgin Peak-Gold Butte area. It is intruded by Proterozoic granitic to dioritic rocks that were emplaced late in the metamorphic history of the region. Regional research in the eastern Mojave Desert (Wooden and Miller, 1990), which included sampling in the McCullough Mountains, has shown that the oldest supracrustal Proterozoic rocks give minimum ages of 1.9 to 2.3 Ga, and these were intruded by 1.72 to 1.76 Ga plutons. The metamorphism and deformation were named the Ivanpah orogeny by Wooden and Miller (1990, 1991), who also reported age data for 1.63- to 1.69-Ga postorogenic intrusive rocks in the region. Mapping of these Proterozoic rocks in the New York Mountains and the south end of the McCullough Mountains (Miller and Wooden, 1993) showed that Early Proterozoic gneiss exposed along the west border of the Piute-Eldorado Tortoise ACEC is complexly mixed with postorogenic intrusive rock along the eastern border of an extensive area of plutonic rocks. Miller and Wooden (1993) subdivided these postorogenic rocks, which are mostly composed of granodiorite and leucocratic granite, into the 1.68- to 1.69-Ga New York Mountain complex in California and the subcircular 1.66- to 1.68-Ga Big Tiger Wash complex in the Crescent region.

Large areas of porphyritic Precambrian granitic rocks (hornblende-biotite monzogranite and syenogranite), commonly partially crushed and recrystallized, were mapped in the Eldorado and Newberry Mountains by Volborth (1973) and correlated with the Gold Butte Granite 70 km to the northeast. Volborth referred to these rocks as “pseudo rapakivi” granites, on the basis of their resemblance to similar Precambrian rocks in Finland. Bingler and Bonham (1973) mapped a large mass of similar rock, which they called augen gneiss, in the north part of the Lucy Gray Mountains. Kwok (1983) and Anderson and Bender (1989) studied some of the porphyritic granites in the Newberry and Dead Mountains, confirming Volborth’s correlation. They proposed that the hornblende-biotite granitoids in the Newberry, Dead, and Lucy Gray Mountains, along with the Gold Butte granite, were part of a transcontinental 1.45-Ga zone of anorogenic granitic plutonism. They also included abundant occurrences of similar granitic rock in nearby

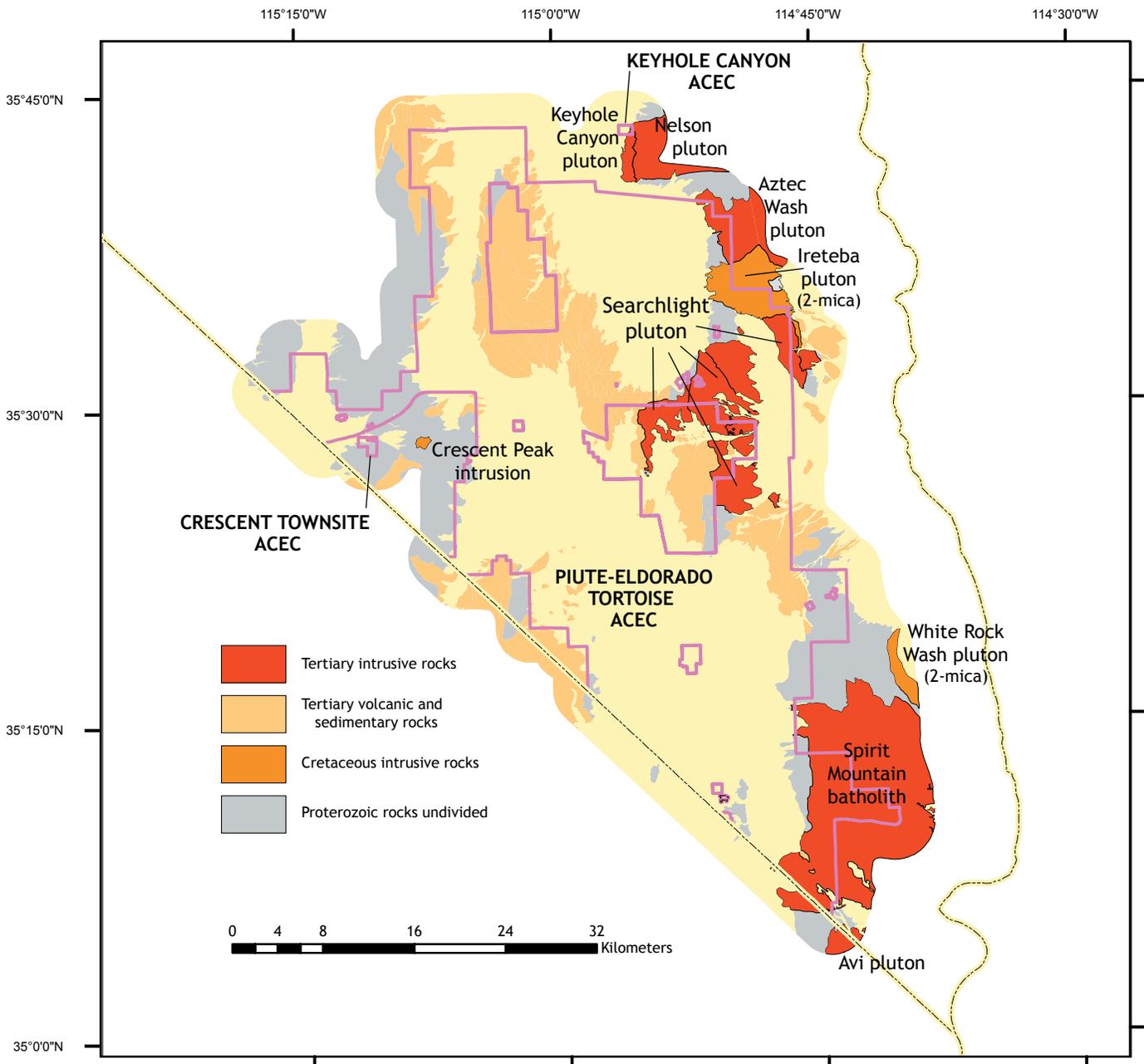
southeastern California and western Arizona in this zone. The Eldorado Mountains also contain some strongly foliated felsic gneisses that appear to be the host rock for the porphyritic granites (fig. 3) and can be presumed to be older than 1.4 Ga.

### Cretaceous Plutonic Rocks

Three Cretaceous plutons occur in or near the Piute-Eldorado ACECs: the White Rock Wash pluton, the Ireteba pluton, and an unnamed intrusion in the Crescent mining district (fig. 4).

### White Rock Wash Pluton

The White Rock Wash pluton is located on the east flank of the Newberry Mountains, along the Colorado River a few kilometers east of the Piute-Eldorado ACEC (fig. 4). It has been dated by Rb-Sr methods at about 65 Ma (Haapala and others, 2005) and by U-Pb methods at 68.5 Ma (Miller and others, 1997), and its age may actually span the Cretaceous-Paleocene time boundary. It is a medium- to coarse-grained two-mica granite, consisting of plagioclase more abundant than orthoclase, quartz, biotite, and muscovite. Accessory



**Figure 4.** Index map showing named plutons exposed in Piute-Eldorado Areas of Critical Environmental Concern (ACECs; outlined in pink). Miocene plutons are in red, Cretaceous plutons are in orange.

minerals include magnetite, apatite, zircon, and rare garnet. Both neodymium and strontium isotopic studies indicate the pluton formed from melting of Proterozoic crustal rocks (Haapala and others, 2005). It is part of a suite of peraluminous granites of latest Cretaceous age found throughout the Cordillera that show a strong crustal isotopic signature and probably formed by melting of the crust at depths greater than 35 km (Miller and Bradfish, 1980; Miller and Barton, 1987; Miller and others, 2003).

### Ireteba Pluton

The Ireteba pluton is located north of Searchlight, where it occupies the crest of the Eldorado Mountains, intruding Proterozoic metamorphic rocks (fig. 4). Dates obtained by U-Pb methods constrain the age of the pluton to be 69 to 64 Ma, nearly the same as the White Rock Wash pluton (Kapp and others, 2002). Most of the rock is granite, between about 72 and 77 percent SiO<sub>2</sub>. The major minerals of the granite are plagioclase, quartz, K-feldspar, biotite, primary muscovite, and garnet. Accessory minerals include magnetite±ilmenite, apatite, zircon, and monazite. In the southeastern part of the pluton, abundant mafic dikes and inclusions indicate a zone of extensive interaction with mafic magmas. Neodymium and strontium isotope studies show the same crustal signature as the White Rock Wash pluton (Kapp and others, 2002).

### Granodiorite in Crescent Mining District

A medium-gray equigranular biotite granodiorite that is exposed in limited outcrops in the Crescent mining district (fig. 4) has a hypabyssal texture, and it may be related to the porphyry copper prospect at Crescent Peak. Biotite from this rock was dated by conventional K-Ar methods at about 94 Ma (Miller and Wooden, 1993), but little more is known about this rock.

### Tertiary Volcanic and Sedimentary Rocks

The stratigraphy of the northern Colorado River extensional corridor is characterized by thick sections (generally >3 km) of Tertiary volcanic and sedimentary strata that rest directly on Proterozoic and Late Cretaceous metamorphic and plutonic rock. Although preserved to the north, east, and west of the region, Paleozoic and Mesozoic strata are missing from all but the northernmost part of the corridor. Wherever Tertiary rocks can be observed in contact with Proterozoic basement, they are separated by a profound nonconformity that reflects a relatively subdued topography that had been created by Miocene time. Tertiary sections in the bulk of the northern Colorado River extensional corridor are dominated by Miocene volcanic rocks, including felsic to mafic lavas, volcanic breccia, and ash-flow tuffs, which are interlayered with lesser amounts of clastic sedimentary rocks and rock avalanche deposits.

### Conglomerate (Pre-Peach Springs Tuff)

The oldest Tertiary rocks in the area consist of a thin layer of poorly sorted arkosic conglomerate that is found sporadically throughout the area (Faulds and others, 2001). This unit varies in thickness from 0 to no more than about 100 m. Its age is bracketed between about 24 and 18.3 Ma (Beard, 1996; Faulds and others, 1995, 2001). Nearby, in other parts of the Colorado River Extensional Corridor, there are pre-Peach Springs Tuff mafic and intermediate-composition lavas (Faulds and others, 2001), but none of these crop out within the Piute-Eldorado ACECs.

### Peach Springs Tuff

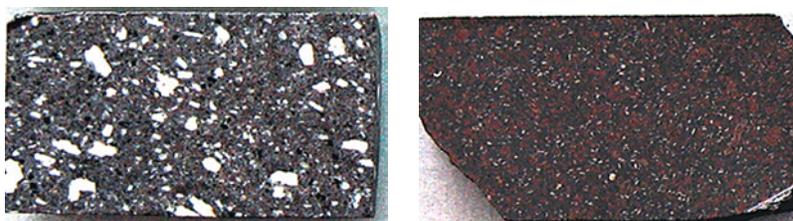
The 18.5 Ma Peach Springs Tuff is widely distributed throughout western Arizona and the eastern part of the Mojave Desert (Glazner and others, 1986; Nielson and others, 1990). It is a massive moderately welded rhyolitic ash-flow tuff characterized by abundant large sanidine phenocrysts that commonly exhibit blue adularescence. In the study area, it is a distal outflow facies tuff whose source, although a matter of much discussion, is still unknown. The source was interpreted to be in the Colorado River trough near the south tip of Nevada by Glazner and others (1986), on the basis of systematic variations in thickness. A study of magmatic anisotropy as an indicator of flow direction in the tuff reached the same conclusion (Hillhouse and Wells, 1991). It is an important marker bed because of its wide distribution.

### Volcanics of the Highland Range

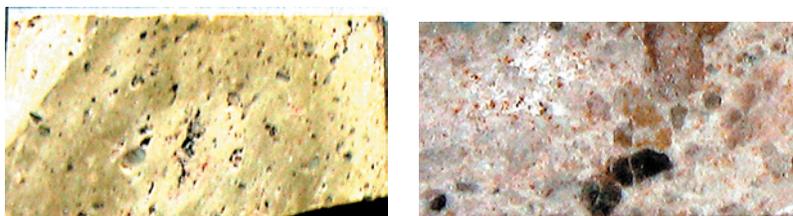
A volcanic and sedimentary sequence of early to middle Miocene rocks as thick as 4 km makes up the Highland Range in the northern part of the Piute-Eldorado Tortoise ACEC. These rocks have been mapped and studied extensively by Faulds and others (2002a, b). They mark the site of the Miocene Searchlight volcanic center, and host the important gold deposits of the Searchlight district.

*Lower Intermediate-Composition Unit.*—Lying directly on Peach Springs Tuff or Proterozoic basement rocks is a 1.5-km-thick sequence of trachydacite and trachyandesite lavas that range in age from 18.5 to about 16.3 Ma (Faulds and others, 2002a,b). The rocks range from about 55 percent to about 67 percent SiO<sub>2</sub> (Faulds and others, 2002a; Ludington and others, 2005) and straddle the boundary between alkaline and subalkaline compositions. Grain size ranges from coarse to fine (fig. 5); some, but not all, of the rocks are porphyritic, most commonly with phenocrysts of plagioclase, with some phenocrysts of hornblende. It is seldom possible to map individual flows more than about 100 m, but scattered measurements of layering indicate that the attitudes are consistent within any one area.

*Middle Felsic Unit.*—Above the intermediate-composition rocks is a sequence of rhyolite flows, tuffs, and tuffaceous sediments, as much as 1 km thick. The unit also contains



**Figure 5.** Unaltered trachyandesite, coarsely porphyritic on the left (sample 5-061106); finer-grained on the right (sample 5-061108). Images are approximately actual size.



**Figure 6.** Rhyolite, unaltered flow on the left (sample 4-050511); alunite-altered breccia on the right (sample 4-043006). Images are approximately actual size.

some subvolcanic intrusions. The silica content of these rocks ranges from about 67 percent to more than 77 percent  $\text{SiO}_2$ , with most analyses between 73 and 77 percent (Ludington and others, 2005; Faulds and others, 2002a). Age dates obtained by  $^{40}\text{Ar}/^{39}\text{Ar}$  methods (Faulds and others, 2002b) indicate the unit was emplaced between about 16.3 and 16.0 Ma, whereas more recent U-Pb dates (Dodge and others, 2005) are as young as 15.9 Ma. North of the Searchlight district, some outcrops of glassy rhyolite vitrophyre occur, but most of the rhyolite is crystalline (fig. 5). In the hills immediately west of the Searchlight district, most of the rhyolite has been hydrothermally altered to quartz and alunite (figs. 6, 7).



**Figure 7.** Rhyolite outcrops on hills in the western part of the Searchlight district. Most of these rocks bear abundant alunite.

*Upper Mafic Unit.*—Overlying the felsic unit is a unit that is as much as 1.2 km thick, composed mostly of basaltic trachyandesite flows (fig. 8). The unit thickens northwestward toward the central part of the Highland Range where apparent remnants of a small stratovolcano that was the source of these flows are exposed. These rocks generally contain between about 56 and 60 percent  $\text{SiO}_2$  and have ages between about 16.0 and 15.2 Ma (Faulds and others, 2002a,b).

### Patsy Mine Volcanics

Originally defined by Longwell (1963), this sequence of rocks is correlative with the volcanics of the Highland Range, with dates ranging from 18.5 to 15.3 Ma (Gans and Bohrsen, 1998). The name, Patsy Mine Volcanics, was originally applied to the volcanic rocks exposed in the northern Eldorado Mountains, on the north side of the Nelson mining



**Figure 8.** Basaltic trachyandesite of upper part of the volcanics of the Highland Range overlying rhyolite of the middle part, directly north of the Searchlight district, within the Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC).

district. Within the Piute Eldorado ACECs, these rocks are found in the McCullough Range south of McCullough Pass. There are also exposures about 3 km beyond the northeast margin of the Piute-Eldorado Tortoise ACEC and about 4 km northeast of the Keyhole Canyon ACEC. These rocks were divided by Hansen (1962) and Anderson (1971) into three informal parts, the lower, middle, and upper. The lower part is up to about 2,700 m thick and consists of andesite and basaltic andesite lava flows, flow breccias, and explosion breccias. The middle part is predominantly rhyolite lava flows and is about 300 to 800 m thick. The upper part is relatively thin (about 500 m) and consists mostly of dark basaltic andesite flows (Anderson, 1971).

The petrology and age of these rocks are similar to that of the volcanics of the Highland Range, and whereas the lower part of the sequence probably had a local source, possibly the Nelson pluton, the uppermost part of both sequences may have had some of the same source areas in the central Highland Range (Faulds and others, 2002a).

## Tuff of Bridge Spring and Tuff of Mount Davis

The 15.2 Ma tuff of Bridge Spring and the 15.0 Ma tuff of Mount Davis are compositionally similar, regionally extensive ash-flow tuffs that are exposed in the northwestern part of the Piute-Eldorado Tortoise ACEC. The tuff of Bridge Spring was first distinguished and described by Anderson (1971), whereas the tuff of Mount Davis was not described until the report of Faulds (1995). The two tuffs are both rhyolitic in composition and can be confused in the field, because the tuff of Mount Davis commonly lies directly on the tuff of Bridge Spring. Together, they form an important marker horizon in the area. The source of the tuff of Bridge Spring is interpreted to be a caldera in the northwestern part of the Eldorado Mountains, about 15 km northwest of Nelson (Gans and others,



**Figure 9.** Tuff of Bridge Spring on McCullough Pass road, near the northwest corner of the Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC). Note prominent large (up to 10 cm) fiamme (flattened pumice fragments) on rock face.

1994). The source of the tuff of Mount Davis is unknown, but it may have been erupted from the same caldera (Faulds and others, 2002a,b). Both tuffs are rhyolitic in composition, and some outcrops of the tuff of Bridge Spring exhibit distinctive fiamme (flattened pumice fragments) (fig. 9).

## Conglomerate, Megabreccia, and Sandstone

Megabreccias (landslide deposits) that commonly contain abundant clasts derived from Proterozoic rocks are found throughout the synextensional part of the volcanic section. Such rocks are found directly beneath the tuff of Bridge Spring, between the tuff of Bridge Spring and the tuff of Mount Davis, and within a thick unit of conglomerate and sandstone that overlies the tuff of Mount Davis. Conglomerate and sandstone in the Highland Range appear to be the distal part of a large fanglomerate sheet that was partly derived from the southern McCullough Range.

## Younger Volcanic Rocks

The Mount Davis Volcanics were first described by Anderson (1971) and consist of synextensional and late extensional basalt and basaltic andesite flows interbedded with minor amounts of sedimentary rocks (sandstones and conglomerates). They are exposed just east of the northeastern part of the Piute-Eldorado ACECs in the northern part of the McCullough Range and in a few localities in the central and northern Highland Range. Their age is bracketed between 15.2 and 12.8 Ma (Faulds, 1995; Faulds and others, 1995; 2002a,b).

In the surrounding area, younger volcanic rocks include tholeiitic basalts with ages between 11.9 and 8.9 Ma, basaltic andesites with ages between 10.6 and 8.0 Ma, and alkalic basalts with ages between 6.0 and 4.5 Ma (Faulds and others, 2001). These young rocks do not crop out within the Piute-Eldorado ACECs, but an 11-Ma basalt flow is exposed directly to the east on the east flank of the southern Eldorado Mountains.

## Tertiary Intrusive Rocks

A series of Miocene intrusive bodies are emplaced into the Proterozoic basement and Miocene volcanic rocks in the Black, Newberry, and Eldorado Mountains. From south to north, they are designated the Avi pluton, the Spirit Mountain batholith, the Searchlight pluton, the Aztec Wash pluton, the Keyhole Canyon pluton, and the Nelson pluton (fig 4).

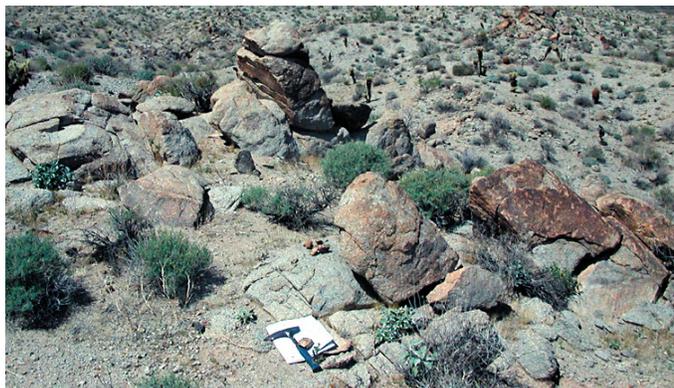
### Avi Pluton

This pluton is located just to the south of the Piute-Eldorado Tortoise ACEC (fig. 4), and it has not been studied in detail, nor dated. We took one sample (4-101201) that has a silica content of about 67 percent (Ludington and others,

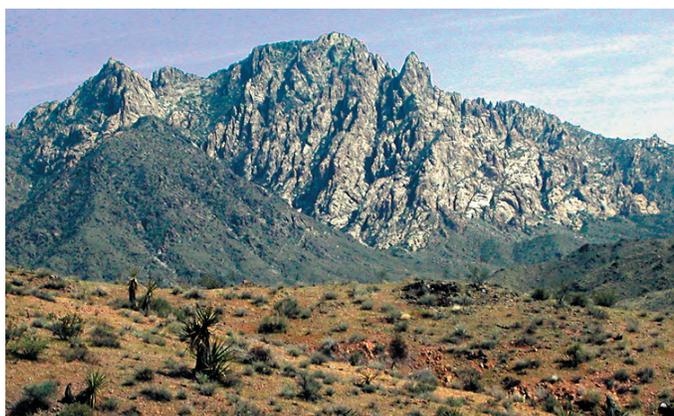
2005) and is classified as a quartz monzonite. We infer that it is about the same age as the Spirit Mountain batholith, or slightly older. No apparent mineralization was associated with the emplacement of this pluton.

## Spirit Mountain Batholith

The Spirit Mountain batholith has an outcrop area of about 250 km<sup>2</sup> (figs. 10, 11) and consists of Miocene intrusive rocks that were emplaced over a 2 million-year time span (17.4 to 15.3 Ma) (Walker and others, 2005; Walker, 2006). Rämö and others (1999) determined a whole-rock Rb-Sr age of about 20 Ma for the granite. The compositions range from high-silica granite (about 77 percent SiO<sub>2</sub>) near the roof of the body (fig. 12) to quartz monzonite (about 63 percent SiO<sub>2</sub>) in the interior. Most of the batholith is composed of granite that was emplaced in a somewhat more restricted time interval between about 17.0 and 16.0 Ma (Walker, 2006). Fine- to medium-grained diorite is common in the eastern part of the batholith, occurring as dikes and pod-like intrusions. No hydrothermal mineralization can be directly attributed to the emplacement of the Spirit Mountain batholith.



**Figure 10.** Outcrops of massive granite of Spirit Mountain batholith, near the southernmost tip of the Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC).



**Figure 11.** Spirit Mountain, at the north end of the Spirit Mountain batholith.



**Figure 12.** Granite from near the roof of the Spirit Mountain batholith. Sample 4-101103 has about 76 percent SiO<sub>2</sub> (Ludington and others, 2005). Image is approximately actual size.

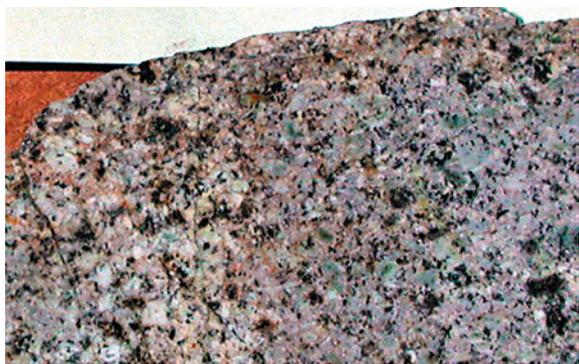
At about 15.3 Ma, numerous granitic dikes were injected into the Spirit Mountain batholith. These have been called the Newberry Mountains dike swarm, and they represent the last pulse of the magmatic system that formed the Spirit Mountain batholith (George and others, 2005). These dikes all strike nearly north, and dip east at 40 to 60 degrees. They have been rotated westward 30 to 50 degrees from their original near-vertical attitude. This rotation has been documented using paleomagnetic techniques by Faulds and others (1992). Because tectonic tilting in the region is documented to have begun as early as 16 Ma (Faulds and others, 2001), the Newberry Mountains dike swarm may have been emplaced very rapidly during the tectonic extension.

## Searchlight Pluton

The Searchlight pluton has a surface outcrop area of about 80 km<sup>2</sup> in the southern Eldorado and northern Newberry Mountains (fig. 4) and consists of Miocene intrusive rocks that were emplaced over a period of at least 1 million years (16.9 to 15.7 Ma) (Cates and others, 2003). The pluton has been classified into three lithologically distinct units by Bachl and others (2001).

*Upper Quartz Monzonite Unit.*—The uppermost unit is primarily relatively fine-grained quartz monzonite (fig. 13) that generally contains about 64 to 68 percent SiO<sub>2</sub> but ranges from a low of about 58 percent to a high of about 70 percent (Ludington and others, 2005). This unit intrudes the lower intermediate-composition unit of the volcanics of the Highland Range and lies in all cases just below the productive precious-metal veins of the Searchlight district. The major minerals are plagioclase, potassium feldspar, quartz, biotite, and hornblende. Accessory minerals include titanomagnetite, sphene, apatite, allanite, and zircon (Bachl and others, 2001).

In the roof zone of the upper unit, porphyritic rocks with a very fine-grained groundmass are common (fig. 14).



**Figure 13.** Quartz monzonite from very near the roof of the upper unit of the Searchlight pluton. This is sample 4-031004, which contains about 64 percent  $\text{SiO}_2$  (Ludington and others, 2005). Note the faint green color of some of the plagioclase crystals, indicating mild hydrothermal alteration to illite and/or clay minerals. Image is approximately actual size.



**Figure 14.** Fine-grained porphyritic phase of upper unit of the Searchlight pluton. Sample 4-033102 contains about 58 percent  $\text{SiO}_2$  (Ludington and others, 2005). Image is approximately actual size.

Outcrops are generally poor in this region, and it is usually impossible to observe crosscutting relationships. However, a few contacts were observed, and this fine-grained rock appears to always be cut by the phaneritic quartz monzonite and to intrude the volcanic rocks of the roof. This earliest intrusive phase of the Searchlight pluton may be representative of the composition of the original magma.

*Middle Granitic Unit.*—Structurally below the quartz monzonite is a coherent unit of granite that contains about 70 to 77 percent  $\text{SiO}_2$ . Much of this granite formed as a cumulate and it exhibits a weak magmatic foliation in some exposures (fig. 15). The major minerals are potassium feldspar, plagioclase, quartz, and biotite. Accessory minerals include titanomagnetite, sphene, apatite, zircon, and allanite (Bachl and others, 2001).

*Lower Unit.*—The lowermost unit of the Searchlight pluton crops out in the eastern part of the Piute-Eldorado Tortoise ACEC, and consists primarily of coarse-grained mafic quartz monzonite that contains the same mineral assemblage as the upper unit but in different proportions. Hornblende is commonly as abundant as biotite, and large euhedral sphene crystals are particularly prominent and abundant. The lower unit is characterized by a magmatic planar fabric defined by subparallel arrangement of all elongate minerals (Bachl and others, 2001), which is overprinted by a subsolidus, mylonitic fabric. Pods of mafic rock (mostly diorite) are present throughout the unit, commonly with dimensions of meters to hundreds of meters. The field evidence, coupled with paleomagnetic studies (Faulds and others, 1998) and hornblende geobarometry clearly indicate that the entire plutonic complex is steeply tilted to the west, and that the rocks in the lower mafic unit represent the floor of the pluton at a paleodepths of about 13 km (Bachl and others, 2001).

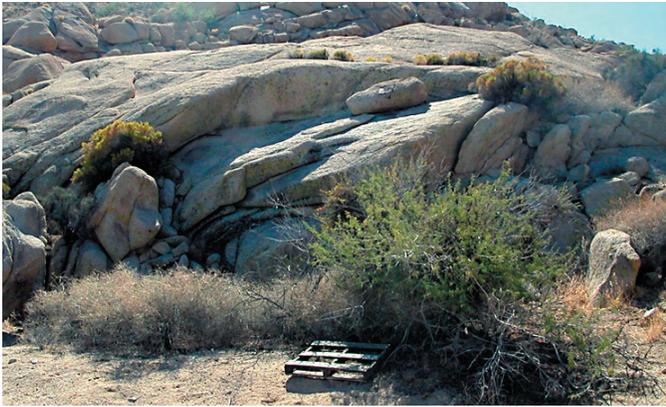
The overall composition of the pluton is closely similar in composition to the lower intermediate-composition and middle rhyolitic parts of the volcanics of the Highland Range, and the various parts of the pluton appear to represent the preserved subvolcanic magma bodies that fed the volcanic rocks. However, only limited parts of the pluton were fluid and erupting at any one time. The overall time span exhibited by the rocks is more than 2 million years, and the complex pluton and the various layers of volcanic rock are the end result of a long series of individual magmatic events.

Faulds (1999) and Faulds and others (2002a) suggested that the altered and mineralized rocks of the Searchlight mining district represent the hydrothermal halo around the roof of the Searchlight pluton within a stratovolcano complex. The middle and lower units, in general, were not affected by hydrothermal alteration, but the upper parts of the upper unit, near the roof, commonly exhibit varying degrees of alteration, primarily of the feldspars to illite and clay minerals, and of the mafic minerals to chlorite and epidote (fig. 13). All the rocks of the pluton have been tilted steeply to the west during extension.

## Aztec Wash Pluton

The Aztec Wash pluton has a surface outcrop area of about 50 km<sup>2</sup> in the northern Eldorado Mountains (fig. 4) and consists of Miocene intrusive rocks that were emplaced and crystallized over a somewhat shorter time period than the two large plutons to the south (about 15.8 to 15.5 Ma) (Cates and others, 2003; Koteas and others, 2003). Although there are a multitude of rock types in this pluton, it is convenient to divide it into three units (Falkner and others, 1995).

About 30 percent of the pluton is composed of the main granite, a medium-grained granite that is mostly between about 70 and 74 percent  $\text{SiO}_2$ . The major minerals are sodic plagioclase, quartz, potassium feldspar, and biotite. Accessory minerals include sphene, apatite, allanite, zircon, and opaque oxide minerals. Small miarolitic cavities characterize the unit, and they are most common at the pluton margins (Falkner and others, 1995).



**Figure 15.** Foliated outcrops of the granitic middle unit of the Searchlight pluton. The sample taken here (4-100802) contains about 73 percent  $\text{SiO}_2$  (Ludington and others, 2005).

The heterogeneous zone constitutes nearly 70 percent of the pluton and is composed of diverse rocks that range in composition from mafic gabbros to felsic granites. These different rock types are interspersed on centimeter to 100-meter scales, and they locally grade into each other. The unit appears to have formed by the deposition of prograding tongues of mafic material into partially solidified granite. It occupies the interior of the pluton and is largely enclosed in older granite (Harper and others, 2005).

A third lithologic type is present as a north-trending dike swarm that is most prominent in the eastern part of the pluton. These dikes were described by Falkner and others (1995) to be bimodal in composition, but most are granitic and may be originally horizontal sheets that have been tilted into a steep attitude.

The Aztec Wash pluton contains the trace of the Black Mountain accommodation zone as delineated by Faulds and others (2002b). The pluton is divided into two parts by the Tule Wash Fault of Volborth (1973); the northeastern part of the pluton has been tilted to the east during Miocene extension, whereas the southwest part of the pluton has been tilted to the west (Falkner and others, 1995). The only mineral deposit that may be related to the Aztec Wash pluton is the silver-rich breccia zone at the Bmb No. 1 claim (see below), which appears to have been localized by the Tule Wash Fault.

## Nelson Pluton

The Nelson pluton is an elongate intrusion that is mostly quartz monzonite in composition. It is located about 1 to 2 km north of the northeast boundary of the Piute-Eldorado Tortoise ACEC (fig. 4). The elongate outcrop pattern of the pluton is due to repetition by west-dipping low-angle faults that have rotated it and the volcanic section on its north side to near-vertical attitudes. This pluton is the host for many of the epithermal precious-metal deposits in the Eldorado district and may be the source of the metals (Hansen, 1962). The age of the Nelson pluton has not been studied extensively by modern

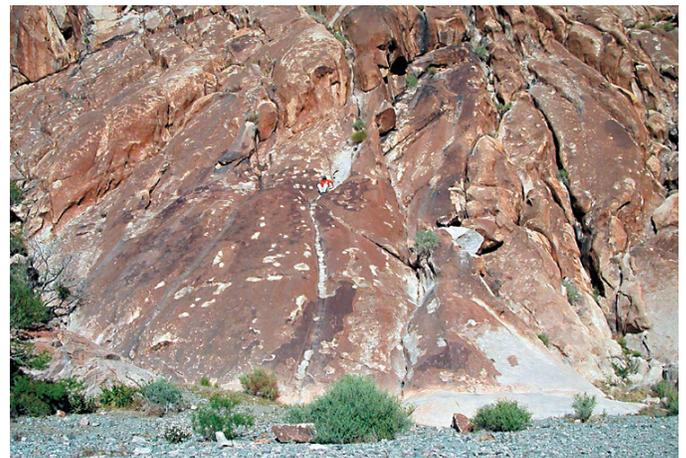
radiometric methods, although Faulds and others (1992) determined a conventional K-Ar age of 16.9 Ma on biotite, and Lee and others (1995) report an age of 16.3 Ma. The pluton is older than the Aztec Wash pluton on the basis of intrusive relationships. It appears to intrude a volcanic section that includes the upper parts of the Patsy Mine Volcanics, which may be as young as 15.3 Ma (Gans and Bohrsen, 1998); however, these may be mostly fault contacts. It seems likely that the Nelson pluton was emplaced during the time interval between about 17 and 15 Ma, nearly contemporaneous with the Searchlight pluton.

## Keyhole Canyon Pluton

The Keyhole Canyon pluton has been studied petrologically only by Hansen (1962). It is a relatively homogenous leucocratic granite that consists of orthoclase (commonly greater than 50 percent by volume), quartz, and plagioclase. Biotite is commonly no more than 1 percent of the rock, therefore qualifying as an accessory mineral along with magnetite and sphene. This pluton is tilted to the east. The western (lower) part of the pluton is less leucocratic and has more biotite. The upper (eastern) part of the pluton is characterized, like parts of the granitic unit of the Aztec Wash pluton, by abundant miarolitic cavities. It intrudes the Nelson pluton, and two samples were dated with conventional K-Ar methods by Armstrong (1970) at 15.4 and 14.9 Ma. The Keyhole Canyon ACEC includes the northernmost tip of this pluton (fig. 16), which is not associated with any known hydrothermal mineral deposits.

## Dike Swarms

Three voluminous swarms of Miocene dikes generally postdate all of the plutonic rocks described above. These dike swarms represent continued magma production and intrusion during brittle extension.



**Figure 16.** Massive outcrops of granite of the Keyhole Canyon pluton in the Keyhole Canyon Area of Critical Environmental Concern. Note geologist (sitting, with red shirt) in the center of photograph for scale.

A swarm of dozens of mostly felsic dikes, termed the Eldorado dike swarm by Steinwinder and others (2004), extends from the Aztec Wash pluton nearly 20 km south, where the dikes cut the Searchlight pluton (fig. 17). These dikes trend a few degrees west of north and are typically 2 to 5 m thick. Individual dikes can be traced for at least a few kilometers. Most of these dikes, particularly in the north, are nearly vertical and have not been tilted significantly. Farther south, near the Searchlight pluton, some of the dikes have been rotated westward at least 45 to 55 degrees, as evidenced by paleomagnetic studies (Faulds and others, 1992; 1998). Many of these dikes are granitic in composition (about 73 percent  $\text{SiO}_2$ ), but some are as mafic as diorite (see Steinwinder and others, 2004; and analyses in Ludington and others, 2005). A single U-Pb date of 15.5 Ma has been reported by Cates and others (2003). This dike swarm is almost entirely within the northeast part of the Piute-Eldorado Tortoise ACEC.

A contrasting swarm of generally west-trending dikes is found in the upper part of the Searchlight pluton and the lower intermediate-composition unit of the volcanics of the Highland Range, southeast of the town of Searchlight, in the eastern part of the Piute-Eldorado Tortoise ACEC (Ruppert, 1999; Ruppert and Faulds, 1998). These consist of both trachydacite porphyry dikes dated at about 16.6 Ma and rhyolite dikes dated at about 16.0 Ma (Hodge and others, 2006). Analyses in Ludington and others (2005) show that the rhyolite dikes range in composition from about 68 to 77 percent  $\text{SiO}_2$  and have compositions similar to the middle granitic unit of the Searchlight pluton. These dikes record a short period prior to the major east-west extension when the least principal stress in the region was oriented north-south during the emplacement history of the Searchlight pluton. The rhyolite dikes were emplaced at about the same time that the gold mineralization at Searchlight was occurring, that is, just before major east-west extension.

To the south, the Newberry Mountains dike swarm that cuts mostly rocks of the Spirit Mountain batholith has been



**Figure 17.** Granite porphyry dike from the Eldorado swarm that cuts the middle unit of the Searchlight pluton. Sample 4-043007 contains about 73 percent  $\text{SiO}_2$  (Ludington and others, 2005). Image is approximately actual size.

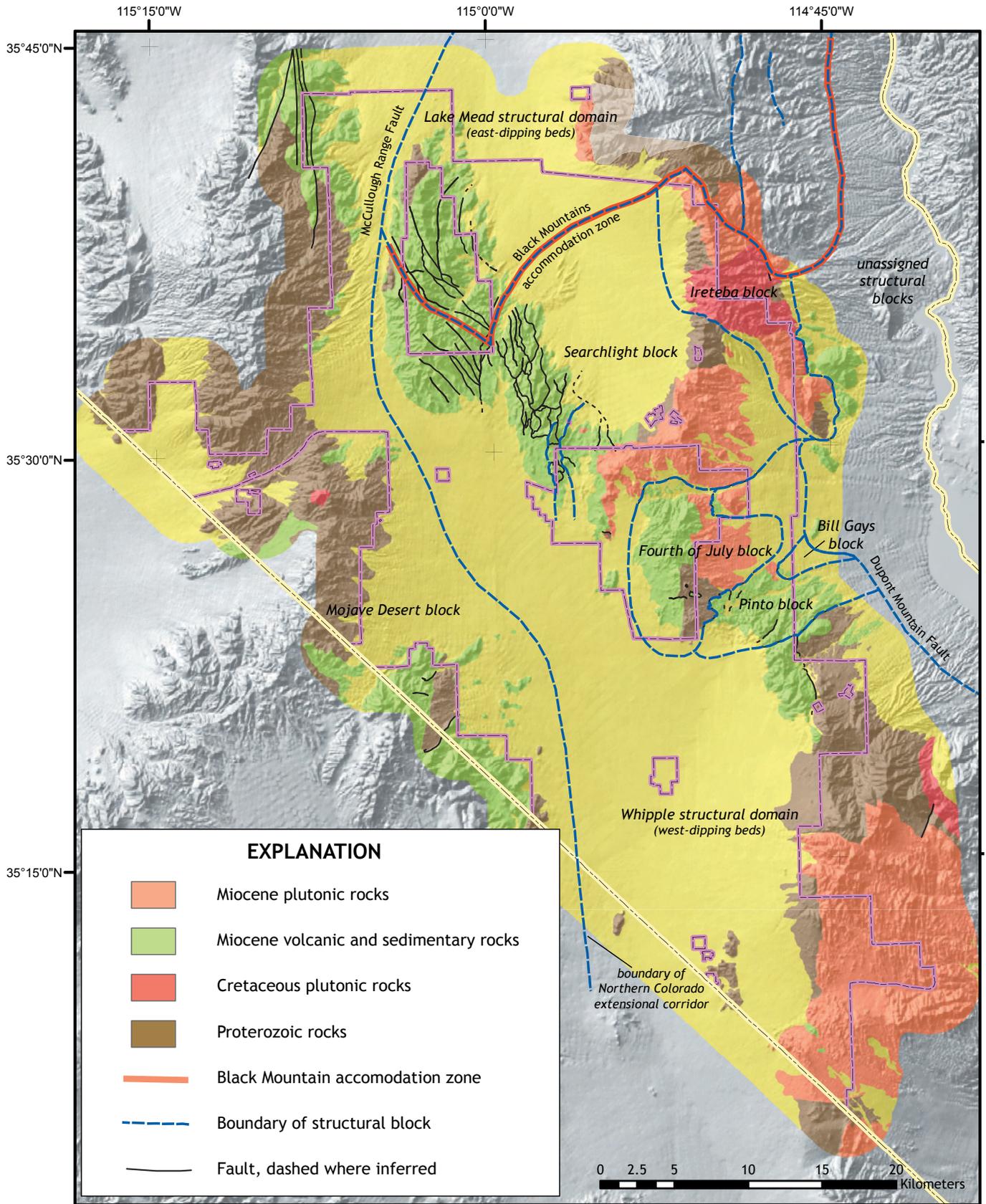
described by George and others (2005) as synextensional granite (about 73 percent  $\text{SiO}_2$ ) dikes that are commonly rotated westward about 30 to 50 degrees. This swarm was emplaced at about 15.3 Ma. Some of these dikes extend into the Proterozoic metamorphic rocks as much as 5 km north of the Spirit Mountain batholith.

## Structure

The Piute-Eldorado ACECs are mostly within the northern Colorado River extensional corridor, a 70- to 100-km-wide region of moderately to highly extended crust along the eastern margin of the Basin and Range Province in southern Nevada and northwestern Arizona. The Colorado River extensional corridor was first recognized by Howard and John (1987), and the distinct nature of the northern part, which extends from about the latitude of the south tip of Nevada to the Lake Mead area, was first highlighted by Faulds and others (1990). Recent and ongoing research on the structural and magmatic history of the region now permits a major reinterpretation of the mid-Miocene hydrothermal mineralization and its structural framework in the study area. The discussion that follows is based largely on a summary of the Cenozoic evolution of the region by Faulds and others (2001), as well as incorporation of ongoing work in the area. Figure 18 illustrates the structural setting of the area.

Magmatism swept northward through the Piute-Eldorado area beginning before 18 Ma (for example, the Avi pluton) in the south and at about 13 to 15 Ma (for example, the Boulder City pluton and volcanic rocks in the River Mountains-Hoover Dam area) in the north. Much of the area experienced simultaneous and nearly continuous igneous activity between about 17.5 Ma and about 15 Ma (Spirit Mountain batholith, Searchlight pluton, Aztec Wash pluton, Nelson pluton, Keyhole Canyon pluton, volcanics of the Highland Range, and Patsy Mine Volcanics). As evidenced by the east-west orientation of several early Miocene dike swarms and mineralized veins, much of the early magmatism coincided with mild north-south extension.

Major east-west extension followed the inception of magmatism by 1 to 4 million years, beginning at the south tip of Nevada at about 19 Ma, at about 16 Ma in the vicinity of Searchlight, and at about 14 Ma in the Boulder City area, north of the Piute-Eldorado ACECs. Throughout the region, the extension has resulted in the steep tilting of Miocene volcanic and sedimentary strata (commonly as much as 90 degrees, sometimes overturned) (Faulds and others, 2001). In much of the southern part of the area, rocks older than 16 Ma dip steeply west. The Black Mountains accommodation zone extends across the northern part of the Piute-Eldorado ACEC, dividing west-dipping rocks to the south from east-dipping rocks to the north. Here, oppositely dipping normal fault systems and their resulting tilt-block domains terminate in a belt of overlapping fault tips and extensional anticlines and synclines. The area north of the Black Mountains accommodation zone is termed the Lake Mead domain and the area to the south is termed the Whipple domain.



**Figure 18.** Map showing structural blocks and Black Mountains accommodation zone in relation to generalized geology in Piute-Eldorado Areas of Critical Environmental Concern (ACECs).

Because major east-west extension and associated tilting postdated emplacement of most of the plutons, the plutons in the Piute-Eldorado ACECs are also appreciably tilted. They are exposed from top, where they generally have intruded their own volcanic ejecta, to bottom, where they are exposed at paleodepths of 10 km or more, in what was the ductile middle crust.

The McCullough Range Fault is a poorly exposed east-dipping fault zone that essentially bounds the extensional corridor on the west. South of the study area, it links with a major breakaway zone that forms the west boundary of the extensional corridor in California (Spencer, 1985). To the west of this fault, the rocks are not steeply tilted; the southern Eldorado and Newberry Mountains and part of the Highland Range are the upthrown eastern parts of west-tilted fault blocks in the hanging wall of the McCullough Range Fault.

For convenience in discussing structural features of the study area, we have informally named a number of structural blocks, shown on figure 18. In the southern part of the area, in the Whipple domain, the boundaries of these blocks are east-dipping normal faults. These faults separate the uppermost crust of the area into discrete west-dipping structural entities. From west to east, they are here referred to as the Searchlight block, the Fourth of July block, the Pinto block, and the Bill Gays block. In the order named, each block is structurally higher than the previous one. The Searchlight, Fourth of July, and Pinto blocks each expose the upper contact of the Searchlight pluton in cross section, with each section having been east of the other prior to extension. Many additional east-dipping faults have been mapped by Faulds and others (2002a) in the Searchlight block; each of these is downthrown on the east and locally repeats parts of the stratigraphic section. Two of these are portrayed in dashed blue lines on figure 18; their northern and southern extensions pass under alluvial cover and the entire boundaries of the blocks they bound cannot be reconstructed, but they played an important role in increasing the number of exposures of the mineralized rocks above the Searchlight pluton in the Searchlight mining district.

## Mining History

The history of mining within and near the Piute-Eldorado ACEC extends as much as 700 years into the past and includes prehistoric Native American activity and Spanish (or Mexican) mining that likely predated the 19th century. Except for Native American mining, the earliest mining was focused on deposits near the Colorado River, the most well traveled route at the time. The history of each of the five mining districts in this large area is given separately below in order of discovery.

### Crescent District

The earliest activity in this district was prehistoric mining of turquoise by Native Americans. Turquoise is the most important commodity that has been produced in the

district, and Morrissey (1968) estimated that its total value (excluding prehistoric mining) may have been in excess of \$1 million. Although gold, silver, lead, and copper were mined here between 1894 and 1941, the total recorded value of metal production is small, at about \$62,000 (Longwell and others, 1965).

In more modern times, turquoise was discovered in 1889 or 1890 on the south flank of Crescent Peak (about 3 km southeast of the Piute-Eldorado ACEC) by George Simmons who picked up blue rock fragments but discarded them after they failed to give strong indications of copper (Morrissey, 1968). However, following a visit to a turquoise mine in New Mexico, Simmons recognized the value of his find and returned for more thorough prospecting. He found that the turquoise source was a vein in an abandoned prehistoric mine, complete with stone tools and a primitive lapidary shop. Later work by archeologists put the date of abandonment at about A.D. 1300 (Morrissey, 1968). Most of the turquoise produced at Crescent Peak was mined from this property (known as the Toltec or Simmons Mine) between 1894 and 1906. In 1906, a 320-carat stone valued at \$2,600 was found (Vanderburg, 1937). In later years, mining became sporadic because of rising mining costs and lower turquoise prices and ceased as a commercial enterprise in the 1960s. The Morgan (Iron Door) Mine, which is inside the Crescent Townsite ACEC, was worked around 1906, but produced much smaller amounts of turquoise than the Toltec Mine (Morrissey, 1968).

Early metal mining in the Crescent district took place sporadically between 1894 and 1932, followed by more consistent production between 1934 and 1941 (Longwell and others, 1965). Early metals production, between 1905 and 1907, was mostly from the Nippeno, Big Tiger, Calavada (Lily), and Double Standard Mines (Vanderburg, 1937). However, Ransome (1907), who visited the district in the winter of 1905-06, described only the Big Tiger and Calavada properties, and reported the presence of the "little settlement of Crescent, consisting of a dozen tents and wooden buildings...7 miles southeast of Nipton, on the road to Searchlight." During the 1930s, the Nippeno, Budget, Double Standard, and Colonel Sellers Mines were active (Vanderburg, 1937). Vanderburg reported that mining at the relatively remote Double Standard Mine was done by hand methods in the 1930s and the ore was packed, at the rate of three tons per day, for a mile down a steep mountain by burros and then trucked to Searchlight for treatment. On the basis of data in Longwell and others (1965), the Nippeno was the largest Crescent district producer at about \$20,000, followed by the Double Standard at an estimated \$15,000, and the Budget at about \$10,000. However, Vanderburg (1937) reported that "production from the Nippeno property is said to have been about \$40,000, mostly in shipping ore."

Two major mining companies explored the area near Crescent Peak in search of porphyry copper deposits in the late 1950s and early 1960s, and they drilled at least 6 core holes (Archbold and Santos, 1962). Prospecting for gold during the 1980s and 1990s included exploration programs for detach-

ment-fault-related gold deposits by major mining companies, but that work has yielded no important discoveries despite the report of platinum-group elements (PGEs) by Lechler (1988).

Several former gold mines are now being exploited for decorative stone for landscaping. Current or recently active operations include those at the Lucky Dutchman, Modoc, and Nipton Red Mines and in Big Tiger Wash.

## Eldorado District

Based on recorded production, about 2.3 million ounces of silver and 100,000 ounces of gold were produced from mines in the Eldorado district, mainly between 1915 and 1920 and again between 1926 and 1943 (Hansen, 1962; Longwell and others, 1965). Total value of this production was about \$4.6 million, including minor copper, lead, and zinc credits. Ransome (1907) estimated production from the 19th century to the time of his visit in 1906 at \$2 million to \$5 million, and Vanderburg (1937) believed that most of this mining took place between 1864 and 1900. Vanderburg further noted that, based on a compilation by Yeoman Briggs, of Nelson, Nevada, production from the area was about \$10 million. However, Vanderburg warned that “Briggs obtained his data from many sources, and due allowances must be made for old production figures, which have a way of increasing with time.” The same caution might be applied to Ransome’s (1907) estimate.

Old arrastras and prospect holes found in the 1860s were reported as evidence that the Spanish were mining in the Eldorado district prior to the recorded discovery of precious metals in 1857 at the Honest Miner claim. A mining district was organized in 1861, and the most important property, the Techatticup Mine, opened in 1863 and had produced an estimated \$3.5 million by the mid 1930s (Vanderburg, 1937; Hansen, 1962). Mining continued there until 1942, but production records for the property are not available (Longwell and others, 1965). Longwell and others (1965) reported two other significant properties in the district, the Wall Street and Eldorado Rand Mines, with estimated productions of \$1.75 million and \$1.0 million, respectively. Vanderburg (1937) reported at least 12 other mines or prospects in the district and cited a production figure encompassing 11 mines in 1935. In addition, 1:24,000-scale topographic maps show several hundred workings scattered over an area of more than 100 km<sup>2</sup> in the district.

The Eldorado district is centered on the small village of Nelson, which was once an active mining town with a reputation for lawlessness. The town and most of the productive gold mining sites in the district are in Eldorado Canyon, a steep-sided canyon that empties eastward into the Colorado River. As noted by Ransome (1907), “It is a little surprising that a district once alive with activity should have attracted so little outside notice. This, however, is partly accounted for by the overshadowing performance of...other districts noted in the early history of mining in Nevada and by the

isolation of Eldorado Canyon.” Ransome also noted that rich ore was shipped down the Colorado River by boat during the district’s early days, and that even by 1906 there were no regular means of communication with the district except for a road from Searchlight. Prior to the turn of the century, the Eldorado district was dominated by the Southwestern Mining Company, which owned nearly all of the productive properties (including the Techatticup and Wall Street Mines), along with several mills, and operated its own fleet of river boats (Vanderburg, 1937).

According to Smith and Tingley (1983) the Eldorado district was actively explored during the “1981 gold rush;” however, these authors saw no major exploration activity in the area in late 1982. Reports by the Nevada Bureau of Mines and Geology (Nevada Mineral Industry) show that the area was subject to local speculation and development during the 1980s and 1990s, but no gold production has been reported in that period, or since. Exploration during that period was carried out by Intermountain Exploration, Amselco, Exxon, Weaco, Homestake, Zephyr Resources, and Alta Gold (Robinson, 1996). In 1993, a bulk-mineable deposit with a resource of about 1.2 million short tons at a grade of 0.044 opt (troy ounces/short ton) was drilled out near the sites of the old Wall Street and Black Hawk Mines, but the deposit was not developed (Robinson, 1996).

## Newberry District

The Newberry district is larger and less focused than any of the other districts in the Piute-Eldorado ACEC area. The history of mining in the area has been sketchily recorded, but 1:24,000-scale topographic maps show several widely spaced areas that contain concentrations of two to 20 individual workings. Longwell and others (1965) included some mines northeast of Searchlight in the district, but Tingley (1992) assigned these properties to the Searchlight or Eldorado districts and constrained the Newberry district to the area southeast of Searchlight. Production was estimated by Vanderburg (1937) at about \$170,000, with \$150,000 coming from mines of the Homestake group. This figure is based entirely on hearsay and is probably generous.

The mines of the Homestake group, which are on the east slope of the Newberry Mountains, 32 km southeast of Searchlight, were reported by Vanderburg (1937) to have been discovered and worked in the early 1860s by soldiers from Fort Mohave, Arizona. The mines were later active intermittently on a small scale between 1910 and 1937. The mines at Camp Thurman were discovered in 1906. Mines in the Roman Mine area were active in the 1930s. The history of other properties, such as the Juniper and Cottonwood Mines and the extensively prospected Superfluous-Gibraltar area in the Chiquita Hills, are not known.

The Roman Mine is being operated at present as a source of decorative stone, although the claims were apparently originally located primarily for silver.

## Searchlight District

On the basis of recorded production, the Searchlight district was the second leading precious-metal mining district in Clark County (behind the Goodsprings district) with total production of about 250,000 ounces of gold (table 1). However, the Eldorado district may have been more productive if estimates of unrecorded early production of gold and silver are correct, as discussed above. Silver, copper, and lead were also produced at Searchlight, but they were relatively insignificant in terms of value. Longwell and others (1965) reported total recorded production for Searchlight at about \$7 million.

In a U.S. Geological Survey bulletin on the Searchlight district, Callaghan (1939) reported production from 12 mines in the main part of the Searchlight district (which he mapped at a scale of 1:24,000) and in its extension as much as 8 km to the east. Callaghan provided detailed descriptions of many of the mines along with the carefully executed plan maps and cross sections typical of mining district publications of the era; consequently, Searchlight district gold deposits are the most thoroughly documented deposits in and near the Piute-Eldorado ACEC. Reid (1998) wrote a detailed history of the Searchlight area, with information on mining activity to nearly the present time.

The Searchlight district was discovered relatively late in the mining history of Clark County. According to Ransome (1907), who visited the district in 1906, ore was discovered in 1898 at the site of the Duplex Mine, but Callaghan (1939) reported 1897 as the discovery year. Reid (1998) noted that early settlers and their descendants claim discovery took place in 1896. The original discoverer of Searchlight ore was apparently J.C. Swickard, who was grubstaked by F. Dunn of Needles, California (Reid, 1998). The first recorded production in the Searchlight district was in 1902 (Longwell and others, 1965). However, Ransome (1907) reported that the Duplex Mine was the first to ship ore, although the Quartette Mine had opened in 1898. In 1902, the Quartette erected a stamp mill on the Colorado River that was shortly thereafter connected to the mine by 15 miles of narrow-gauge railway. In 1903, water was encountered in the mine workings and a new mill constructed near the mine, leading to abandonment of the riverside mill and of the railroad, which operated for less than 2 years. During his visit in 1906, Ransome reported production from the Quartette, Duplex, and Blossom Mines, and noted the presence of several other mines in various stages of exploration or development.

This was the era of maximum growth in the district, and activity was intense, even in mines whose names and locations have not survived. The population of Searchlight probably peaked prior to the 1910 census when it held 613 souls, and figures as high as 1,500 were reported in 1906 (Reid, 1998). The following quotations, from "The Mining World" (Anonymous, 1906) give an indication of the emotional state of the district at the time. "During the past week sinking in the main shaft of the Searchlight Treasurer has disclosed definite walls, the shaft being all in ore. This shaft, which was started at a

45-degree dip, following the ledge, is materially straightening up. Considerable copper stained sugar quartz has been struck at 50 feet, which runs \$42 per ton... The shaft of the Venus is all in ore, and tracts have been let to sink to the 400-foot level. Stations are to be cut at the usual intervals, and a 15-h.p. hoist will supplant the whim now in use. Drifting both east and west will be continued on the 100-foot level, to determine the length of the ore body." The identity of the Searchlight Treasurer and the Venus are unknown.

The Quartette Mine was the largest producer in the Searchlight district, particularly of gold and copper, and Callaghan (1939) estimated the total at \$2.8 million, mainly between 1903 and 1910, the boom years of the district. Relatively low production came from the Quartette after 1910, and leasers operated the mine after 1917. Except for relatively high production in 1917 and the late 1930s (the latter increase was likely due to the higher gold price), annual district production never approached that attained during the district's heyday years. According to Callaghan (1939), the Duplex Mine was the district's second leading producer (gold, silver, and lead) at about \$1 million, mostly during the early 20th century boom period. The Blossom Mine was probably the third leading district producer at a reported \$325,000, mostly before 1906, and the Big Casino and Good Hope Mines had significant but lesser production (Longwell and others, 1965).

During the mining resurgence in the 1930s, a custom mill was built in Searchlight for the treatment of ore from mines in Searchlight and elsewhere in the region. In addition, a new cyanide plant was erected to treat tailings from the Quartette Mine (Vanderburg, 1937). There is little information about productivity of individual mines during this period, but ore was mined from the Quartette, Duplex, and Blossom Mines on the basis of information from Vanderburg (1937) and Callaghan (1939), with minor production from other mines.

Searchlight district production declined during the gold-mining ban of World War II (WW II) and rebounded weakly between 1948 and 1952. Little or no metal mining has taken place in the district since then. Longwell and others (1965) reported small but unspecified amounts of gold production until 1962, most likely from the Quartette Mine where Reid (1998) reported production until the 1960s. More recently, there was exploration by at least one major company and some minor activity by local individuals and at least one small company. During 1979–82, Felmont Oil (later Homestake Mining Company) conducted an exploration program designed to locate a large low-grade gold deposit in the western part of the Searchlight district. No gold resource was found, but the results led Homestake to suspect that a porphyry copper deposit might lie under the western part of the district. This target was not pursued at the time. Also in the late 1970s and early 1980s, a surge in development and exploration activity by private owners and independent operators took place, particularly at or near the Duplex, Blossom, Good Hope, and Big Casino Mines, but no production resulted (Smith and Tingley, 1983).

During the 1990s, development work was conducted on several claims (Blossom Consolidated, Whist, John, and

**Table 1.** Recorded production from the Searchlight district (reproduced from Callaghan, 1939).

Year	Ore (short tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1902	10,910	6,147	1,175	0	0
1903	19,522	19,275	27,691	0	0
1904	16,750	18,400	13,498	0	0
1905	38,069	19,329	28,528	22,808	12,064
1906	45,668	25,145	11,543	11,182	9,655
1907	45,921	23,441	7,494	37,063	38,113
1908	52,193	13,137	10,883	14,954	44,857
1909	68,931	16,237	13,544	22,916	36,209
1910	27,331	10,406	11,489	93,848	45,847
1911	1,850	966	2,136	12,095	7,659
1912	4,158	2,237	2,562	10,126	10,032
1913	5,989	6,654	5,903	53,971	61,006
1914	3,057	3,999	2,855	5,556	21,919
1915	7,766	4,985	3,546	20,970	35,562
1916	6,322	3,903	4,340	24,392	9,951
1917	12,866	3,445	9,073	98,923	59,453
1918	1,700	2,649	8,395	44,477	77,863
1919	6,980	2,854	5,502	18,074	39,307
1920	2,131	3,432	5,275	44,941	91,436
1921	1,182	3,601	9,877	31,128	98,048
1922	1,441	1,661	5,024	12,847	44,375
1923	1,142	1,007	2,708	22,150	47,651
1924	850	830	1,267	5,801	46,050
1925	2,833	3,314	2,586	14,974	86,768
1926	1,881	1,879	1,720	7,430	81,977
1927	106	335	306	1,429	10,415
1928	77	224	252	2,968	9,464
1929	184	105	58	654	2,743
1930	124	19	27	0	0
1931	20,855	3,276	5,826	6,022	274,687
1932	2,973	2,018	4,853	4,353	355,458
1933	2,996	913	1,182	2,261	12,040
1934	6,701	1,746	8,478	2,237	4,951
1935	29,617	3,829	12,317	9,195	72,271
1936	16,705	6,403	36,116	5,580	53,857
1937	5,692	5,456	28,688	500	12,600
1938	4,646	4,066	6,871	3,000	9,400
1939	2,035	1,471	1,682	9,400	14,200
1940	3,565	3,815	6,462	18,000	14,000
1941	4,092	3,908	4,524	2,100	5,000
1942	1,017	897	2,205	0	200
1943	117	139	1,454	3,000	4,100
1944	52	21	308	5,200	2,100
1945	401	852	5,708	2,000	1,200
1946	393	785	5,937	6,000	4,000
1947	405	737	2,768	20,300	7,500
1948	13,436	1,582	1,487	7,800	100
1949	16,399	1,007	4,109	700	4,500
1950	18,967	1,620	4,152	1,700	600
1951	24,850	2,041	5,352	4,800	800
1952	14,466	667	2,405	5,800	2,400

Sanford) near the Blossom Mine by Coyote Mines, Inc., which is controlled by the descendants of William S. Shuler, who bought the claims in 1906. A resource of nearly 100,000 short tons was estimated, with a gold content of about 13,000 oz (400 kg) of gold and about 19,000 oz (590 kg) of silver. Small amounts of this material were produced from 2 underground levels at that time, but the mine is currently inactive.

Perlite was discovered north of Searchlight about 1946 by B.L. Tanner, who operated a mine and a small perlite plant under the name Searchlight Insulation Products until the early 1960s. Perlite was also mined from 1948 to 1954 at the Nu-Lite Mine just outside the Piute-Eldorado Tortoise ACEC near the California border.

More recently, a number of mining claims that were patented for precious-metals are being exploited for decorative stone, which is sold for landscaping in metropolitan Las Vegas. A relatively large operation is conducted at the north end of the district, at the site of the Pompeii Mine, by Startel, Inc.

## Sunset District

According to Smith and Tingley (1983) The Sunset district was established in 1897, when the Lucy Gray Mine, the only productive property in the district, was opened. However, Hewett (1956) reported discovery of the Lucy Gray in 1903, and Vanderburg (1937) reported it in 1905. Several other workings and prospects are shown in the area on the 7.5-minute topographic map, but information on their history could not be found.

Production for the district was estimated at about \$50,000 (Vanderburg, 1937). Hewett (1956) reported that the mine was active between 1905 and 1918. Recorded production from 1911 to 1941 was about \$13,000 (Longwell and others, 1965). According to Smith and others (1983), a small cyanide-leaching plant was operating by 1912 and production continued until 1919. Minor, intermittent operation took place between 1919 and 1941. Some exploration at the property took place in the early 1980s (Smith and Tingley, 1983), and again in 1991 by Golden Sunset Mining Co., but the property remains idle.

## Hart District, California

Recent large-scale gold mining took place in the Hart district in California, about 8 km southwest of the Piute-Eldorado Tortoise ACEC. Gold was discovered in the Hart district in 1907 during the heyday of Searchlight mining, and mining continued until 1913, producing an estimated \$10,000 (Hewett and others, 1936). Clay was mined from the district beginning in the 1920s; and, as at Searchlight, gold mining resumed in the 1930s and ended during WW II.

In the 1980s, the Hart district was explored extensively, and the Viceroy Gold Mine commenced production in 1992 (Reid, 1998). Announced reserves by the Viceroy Gold Corp. were about 2 million ounces of gold in about 34 million metric tons of ore in a cluster of six deposits (Crowe and others,

1996). The mine operated for 10 years, and it was California's largest gold producer for several years, producing a total of about 1.2 million ounces. The mine has been inactive for several years, and closure obligations are expected to be met in 2006 (Quest Capital Corp., 2005).

## Mountain Pass District, California

Since 1954, rare-earth minerals and chemicals have been produced from Molycorp's Mountain Pass Mine and plant, which is about 25 km west of the Piute-Eldorado ACECs (Castor and Nason, 2004). Rare-earth minerals were discovered in the district in 1949 by uranium prospectors in samples from the small Sulphide Queen Gold Mine, which had been worked on a small scale in the 1930s (Olson and others, 1954). In terms of value, the Mountain Pass operation has been the most important mineral producer in the region. For at least 30 years, Mountain Pass was the world's leading supplier of rare-earth elements, which were mined from a unique Proterozoic carbonatite orebody. However, mining ceased in 2001 because of environmental problems and competition from China, and only minor amounts of rare earths are currently being sold from stockpile. The company, now a subsidiary of Chevron Corporation, may reopen the mine in the future.

## Mineral Deposits

There are numerous mineral deposits within and near the three ACECs. The area contains part or all of 5 Nevada mining districts as defined by Tingley (1992), the Searchlight, Eldorado, Newberry, Crescent, and Sunset districts. In addition, there are a number of deposits that are not within defined districts, and a number of deposits of leasable and salable minerals that are unrelated to established mining districts.

## Classification of Deposits

The area contains several different types of metallic mineral deposits. Because specification of deposit models is important in mineral potential assessment, we discuss a number of pertinent mineral-deposit models below.

## Porphyry Copper Deposits

The generalized porphyry copper deposit model includes various subtypes, all of which contain chalcopyrite in stock-work veinlets in hydrothermally altered porphyritic intrusions and adjacent country rock. Copper is generally the most important commodity produced, but the deposits may contain important amounts of Mo, Au, Ag, Pb, and Zn. The deposits are associated with high-level intermediate-composition and felsic intrusions or cupolas of batholiths contemporaneous with volcanism along convergent plate boundaries. Surficial

exposures in the southwestern United States are generally leached to barren hematite/limonite outcrops that may locally contain copper carbonates or silicates and secondary copper sulfide minerals, such as covellite and chalcocite. Hydrothermal alteration patterns associated with porphyry copper deposits commonly exhibit zoning outward from sodic or potassic alteration (feldspar and biotite) through phyllic (sericite and pyrite) zones to distal propylitic alteration.

Porphyry copper deposits can be very large and productive; there are nearly 100 in the United States. The majority of them are Laramide (late Cretaceous and Paleocene) in age, but a few, including the giant Bingham Canyon deposit in Utah, are middle Tertiary. The nearest deposits to the Piute-Eldorado area are the modest Mineral Park (about 1,360 metric tons of copper production per year) and large Bagdad (about 91,000 metric tons per year) deposits (both of Laramide age) about 50 km east and 150 km southeast of the Piute-Eldorado ACECs, respectively. The closest Tertiary-age deposits are the Oligocene Copper Canyon deposit and a few Oligocene porphyry copper prospects, about 600 km north of the Piute-Eldorado ACECs, in northern Nevada.

## Epithermal Precious-Metal Deposits

Epithermal precious-metal deposits are veins or groups of veins that formed near the surface of the Earth, contain significant amounts of gold and silver, and occur primarily in volcanic rocks. They are extremely common throughout the Basin and Range Province, where they formed from about 40 Ma to the present. These deposits are commonly subdivided into several types. The most widely agreed upon subdivision of epithermal deposit types is into low sulfidation (quartz-adularia) and high-sulfidation (quartz-alunite) types. Low-sulfidation deposits are typified by the presence of quartz fissure veins that may exhibit banded and crustiform textures, commonly with carbonate or lamellar quartz after carbonate, and K-feldspar (adularia) as an alteration product in wall rock or as a vein mineral. Alteration may also include clay minerals and propylitic mineral assemblages. Ore minerals include electrum and acanthite, with variable amounts of base-metal sulfides with or without silver sulfosalts. Pyrite may be common or sparse, but it is generally present. In addition to gold, silver, and base metals, low-sulfidation epithermal deposits may have elevated concentrations of As, Sb, Hg, Tl, Mo, W, Bi, and Te.

High-sulfidation epithermal deposits may contain quartz fissure veins, but they are generally typified by resistant "ledges" of country rock replaced by quartz. Carbonate is not present in main-stage mineral assemblages. Primary sulfate minerals, such as barite and alunite-group minerals, are typically present, and other vein and alteration phases may include pyrophyllite, diaspore, andalusite, and topaz. Clay mineral alteration is typified by the presence of kaolinite and dickite, and widespread propylitic alteration is generally present. Ore minerals include gold, enargite-group minerals, silver sulfosalts, telluride minerals, and base-metal sulfides. Pyrite is generally abundant. Some deposits, such as Goldfield, Nevada,

have low silver contents; others, such as Paradise Peak, Nevada, are high in silver. In addition to gold and silver, high-sulfidation deposits typically have elevated concentrations of Cu, Pb, Zn, As, Sb, Bi, Te, and Sn.

The vein deposits in the Searchlight district have been termed epithermal in the past, but several characteristics of these deposits are significantly to somewhat different than classic epithermal deposits. Veins at Searchlight (1) contain more base metals than many epithermal deposits, (2) have higher gold to silver ratios than many epithermal deposits, (3) are closely related spatially to the Searchlight pluton, and (4) are characterized by hematite as the chief iron-bearing mineral, rather than pyrite. For these reasons, in this report, we classify the Searchlight veins as gold-rich polymetallic veins, even though we are quite certain that they formed relatively close to the surface.

Adularia (an important indicator of low-sulfidation epithermal deposits) was reported in the veins in the northern part of the district by Callaghan (1939). We have determined that there is abundant secondary K-feldspar and albite in the wall rocks of these veins, and that minor amounts of adularia are also present in some of the veins. Studies are underway to determine the age of this adularia by the  $^{40}\text{Ar}/^{39}\text{Ar}$  method.

The vein deposits in the Eldorado district near Nelson are much closer to the classic definition of epithermal precious-metal deposits, being relatively silver-rich and base-metal-poor. We consider them to be low-sulfidation epithermal deposits. On the basis of production records, the mines at Nelson produced similar amounts of ore to Searchlight, but only about half as much gold, nearly ten times as much silver, and less than one-tenth the amount of copper and lead. They are, however, closely associated spatially with the Nelson pluton.

Other nearby epithermal precious-metal deposits include the Katherine Mine (Lausen, 1931), about 15 km east of the Piute-Eldorado Tortoise ACEC, and the Oatman district (DeWitt and others, 1991), about 20 km to the southeast.

The large Mesquite deposit, about 230 km south of the Piute-Eldorado ACECs, near the Salton Sea in California, produced nearly 3 million ounces of gold (about 90 metric tons). At one time, it was thought to be a detachment-fault-related deposit (see below), but it is now considered an epithermal deposit that formed during strike-slip faulting (Willis and Tosdal, 1992). It consists of Oligocene quartz-adularia and carbonate veins in metamorphic and granitic rocks. It contains native Au associated with rutile, hematite, arsenopyrite, magnetite, pyrite, and chalcopyrite (Frost and Watowich, 1989; Mine Development Associates, 2004). Available data indicate deposition from boiling, low-salinity fluids largely controlled by moderately to steeply dipping faults that were later cut by shallowly dipping faults (Frost and Watowich, 1989).

## Gold-Bearing Polymetallic Vein Deposits

Polymetallic vein deposits consist of quartz or quartz-carbonate veins with gold and silver and associated base metals (Cox, 1986). They occur in sedimentary and metamorphic rocks

and are commonly associated with hypabyssal igneous intrusions. Many small vein-type precious-metal and base-metal deposits have been assigned to this group, which has become a convenient catch-all model for vein type deposits of varied mineralogy, geochemistry, and geologic setting. The model was defined on the basis of many small deposits (maximum size about 5 million tons) in the western United States and Canada (Bliss and Cox, 1986), and there appear to be two subtypes, one with significant precious-metal values and one without. Vein mineralogy includes gold (or electrum) with pyrite and sphalerite; other base-metal sulfides, hematite, acanthite, and silver sulfosalts may be present. Vein textures suggest that some polymetallic veins are of epithermal origin, but associated deposit types may include porphyry deposits and other pluton-related deposits. Alteration generally consists of widespread propylitic alteration and restricted near-vein envelopes of sericite and clay alteration.

### Detachment-Fault-Related Gold Deposits

Gold deposits related to detachment faults were mined in California and Arizona, mainly during the 1980s and 1990s. The best-known deposits assigned to this model are probably Picacho (0.6 million oz gold), which is about 280 km south of the Piute-Eldorado area, and Copperstone (0.5 million oz gold, 270 km southeast), both in Arizona. A number of smaller deposits occur in the Whipple Mountains of California, about 190 km south. The Mesquite Mine, near the Salton Sea in California, produced nearly 3 million oz of gold and at one time was widely believed to be related to extension, but this relationship has now been largely discredited (Willis and Tosdal, 1992). Information on detachment-fault-related deposits used in the following discussion comes primarily from Drobeck and others (1986), Spencer and Welty (1986), Mine Development Associates (2000, 2004) and Losh and others (2005). The state of knowledge at the time was summarized by Long (1992), but the model remains controversial, and questions have been raised about the classification of many examples of the type.

The deposit model is mostly based on descriptions of small (less than 1 million short tons of ore) base- and precious-metal deposits in California and Arizona that generally contain specular or earthy hematite, copper oxide minerals such as chrysocolla, native gold or electrum, and manganese oxides (Wilkins and Heidrick, 1982; Long, 1992). Copper, lead, and zinc sulfide minerals may be present, generally in chlorite-altered rocks beneath the fault surfaces. Upper-plate rocks are typically affected by potassium metasomatism and oxidized, yielding the characteristic red color. Oxide minerals such as specular hematite are considered primary. The deposits generally have nearly equal amounts of gold and silver, but otherwise have variable mineralogy and trace element chemistry. Fluid inclusion data indicate variable fluid temperatures (110° to 350°C) and salinities (1 to 23 equivalent weight percent NaCl).

At Copperstone, the gold occurs in quartz-hematite veins and in breccias containing quartz, hematite, magnetite, barite, calcite, and chrysocolla (Durning and Hillemeier, 1986). In addition, calcite, siderite, manganese oxides, adularia, sericite,

and fluorite were reported, as well as banded open-space fillings of quartz + specular hematite (Mine Development Associates, 2000). The Copperstone Fault, which dips 25 to 45 degrees, was the main ore control, but steep faults in its hanging wall may also have controlled mineralization.

The Picacho Mine exploited four orebodies in metamorphic rocks and granite associated with a regional detachment fault (Drobeck and others, 1986). The ore mineral is gold-bearing pyrite and the deposit is characterized by high Sb, Hg, and As, with low Cu and base metals (Losh and others, 2005). Fluid-inclusion data indicate that it was formed by low-salinity fluids somewhat different from those reported for the model. However, like most of the detachment-fault-related deposits, it does contain primary specular hematite.

The model for gold deposits related to detachment faults was developed primarily during exploration in the 1970s and onward. Geologists noted the association of some gold deposits with detachment faults with shallow dips in the desert regions of southern California and Arizona and formulated an exploration model that was vigorously pursued for about a decade. More recently, the failure to find many large economic deposits of this type has cooled interest, but many smaller low-grade deposits were found in the last 20 years. Deposits of this type are presently being explored in the Dead Mountains in California, about 50 km south of the Piute-Eldorado Tortoise ACEC.

### Deposits in the Eldorado District

Most of the mineral deposits in the Eldorado district are from 1 to 10 km north of the Piute-Eldorado Tortoise ACEC and 3 to 15 km east of the Keyhole Canyon ACEC. The geology of the district is dominated by the late Miocene Eldorado pluton, which is composed primarily of quartz monzonite and granodiorite. On the north side of the pluton, the wall rocks are primarily Miocene volcanic rocks, whereas Proterozoic igneous and metamorphic rocks make up the south wall of the pluton. This area is north of the Black Mountains accommodation zone (Faulds and others, 1990), and the rocks have been tilted steeply to the east, so that the deepest exposures in the district are at the west end and the shallowest at the east. The deposits here are emplaced in Proterozoic metamorphic rocks, Miocene volcanic rocks, and, most commonly, in the Eldorado pluton. Craw and McKeag (1995) studied some veins in the district and suggested that meteoric waters were the source of the mineralizing fluids, but the fluid inclusions they studied were all secondary, and this inference is not reliable.

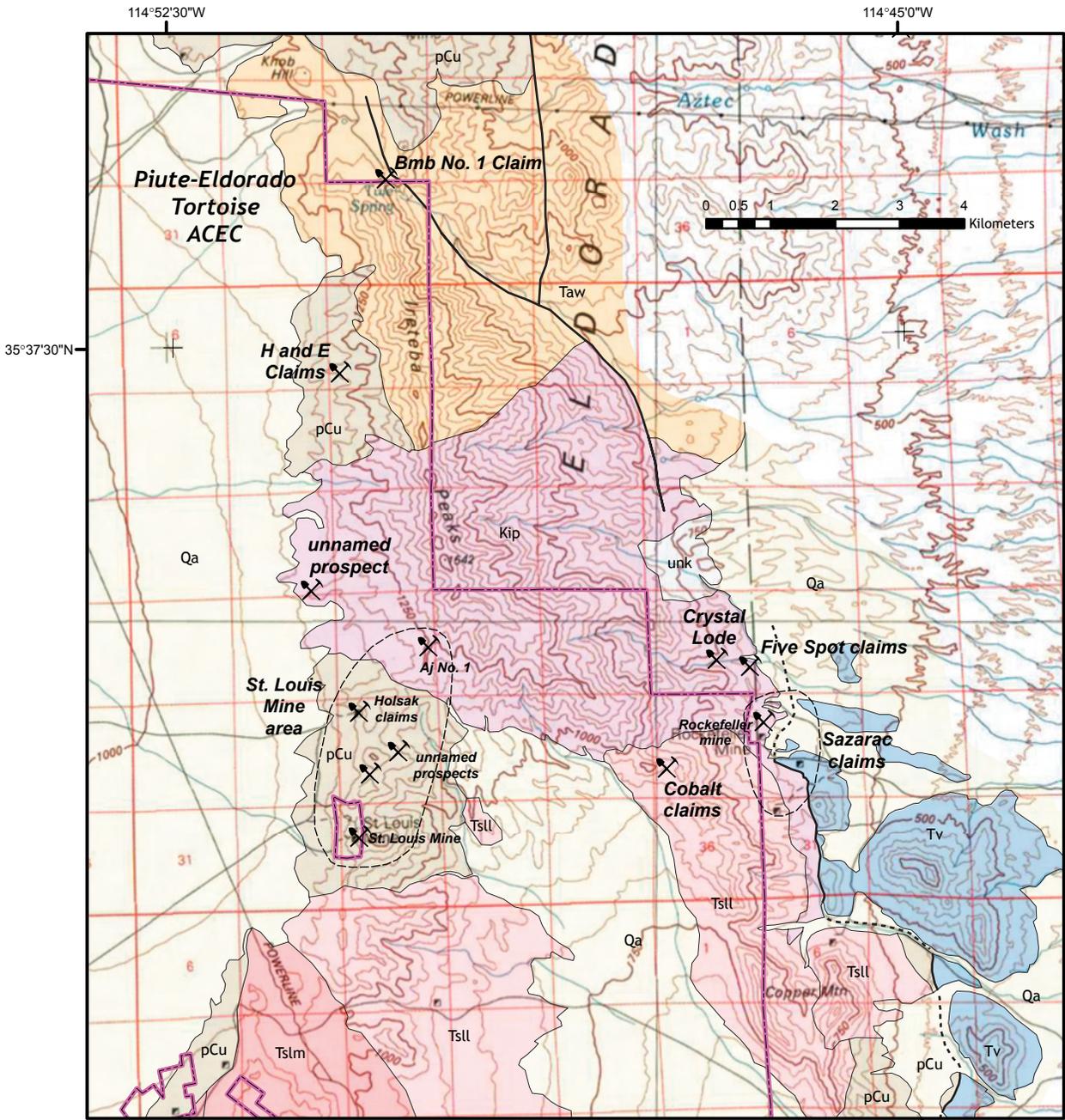
### Deposits in the Southern Eldorado Mountains Between Aztec Wash and Searchlight

Mines in this area were mostly located in the early part of the 20<sup>th</sup> century, and most have no recorded production. Those in the northernmost part of the area are usually considered to be part of the Eldorado district, while those farther south have been described as belonging to either the Searchlight or

Newberry districts. The St. Louis Mine (fig. 19) produced a few thousand troy ounces of gold between 1921 and 1948, and mines in the Camp Dupont area may have produced similar small, but unrecorded, amounts of gold (Causey, 1988a). The northern part of the area consists of Proterozoic gneiss intruded by the Miocene Aztec Wash pluton, whereas the south part consists of Proterozoic gneiss intruded by the Miocene Searchlight pluton. A large part of the center is occupied by the Cretaceous peraluminous granite of the Ireteba pluton.

Deposits in this area are primarily of two types, gold-bearing polymetallic veins (St. Louis Mine area) and detachment-fault-related gold deposits (Sazarac and Cobalt claims).

Four entries in the MRDS (Mineral Resource Data System) database (U.S. Geological Survey, undated) (Eldorado Mine, Eldorado project, West We Go, and Willoro project) have reported locations on the floor of Eldorado Valley, near U.S. Highway 95. Cactus Gold Corp. (see section on mineral exploration) maintains a facility near some of these locations,



**Figure 19.** Mineral deposits in and near the Piute-Eldorado ACECs between the Eldorado and Searchlight mining districts. Geology compiled for this report: pCu—undivided Proterozoic rocks; Kip—Cretaceous granite of the Ireteba pluton; Taw—Miocene Aztec Wash pluton; Tslm—Miocene Searchlight pluton, middle unit; Tssl—Miocene Searchlight pluton, lower unit; Tv—Miocene mafic volcanic rocks; Qa—Quaternary alluvium.

but we do not know if all of the database records refer to this installation. All were compiled from the Directories of Mine Operations for 1987, 1988, and 1991 produced by the Nevada Division of Mine Inspection.

### Bmb No. 1 Claim

This mineral deposit is on the northeastern border of the Piute-Eldorado Tortoise ACEC. It also appears to be within the Ireteba Peaks Wilderness. On the 1:24,000-scale topographic map, it is designated the Belmont-Phoenix Mine, but it appears certain that the Belmont-Phoenix (formerly the Oro Plata) is about 2.5 km north, in the Eldorado mining district. The Bmb No. 1 is at the head of the deep canyon that drains south-eastward from Tule Spring, and consists of a breccia zone in granite of the Aztec Wash pluton, cemented by quartz and calcite. During study of the Ireteba Peaks Wilderness, Causey (1988b) collected samples that contained as much as 665 ppm (parts per million) silver, as well as large amounts of lead and zinc, and low, but anomalous, amounts of gold. He inferred that subeconomic resources of silver are present on the claim. The high silver to gold ratio at this deposit suggests it is more closely related to the Eldorado district to the north than to the Searchlight district. However, the fact that the mineralized rock is hosted in fault breccias related to the Tule Wash Fault suggests that it formed after major extension and thus may not be directly related to the Eldorado district deposits.

### H and E Claims

This area consists of a number of small pods of copper- and gold-bearing quartz that both cut and are concordant with the metamorphic foliation of the Proterozoic gneiss. Malachite and chrysocolla are visible, along with iron-oxide minerals. Many of the grab samples reported by Causey (1988a) contained more than 1 percent copper, and several contained anomalous molybdenum (> 60 ppm). One sample contained 1.4 ppm gold. The mineralized rock is exposed over an area of about 250 m by 30 m, elongate in a north-south direction and parallel to the foliation of the metamorphic host rock.

### Unnamed Prospect

About 3 km south of the H and E claim block, a small unnamed prospect at the range front is hosted in granite of the Ireteba pluton. No description exists, and we did not visit it, but Causey (1988a) collected samples that contained as much as 400 ppm copper and 500 ppm zinc, though no significant gold or silver was detected.

### St. Louis Mine Area

The St. Louis Mine (fig. 20) is on the west side of the Eldorado Mountains, about 12 km northeast of Searchlight and about 4 km southwest of the high point of the Ireteba

Peaks (fig. 19). Patented claims cover the specific site, which is excluded from the Piute-Eldorado Tortoise ACEC, but mine workings extend north along the range front for more than 2 km and include the Holsak claims of Causey (1988a). At the St. Louis Mine, Causey reported a quartz vein with hematite pseudomorphs after pyrite and minor malachite that trends N35W. We suspect this is a transcription error, as we measured the 1.5-m-wide vein's strike at N35E. Causey's two samples contained as much as 13 ppm gold, with abundant copper and lead. Our sample of the vein (4-030901) contained 1.6 ppm gold and 3 ppm silver and about 1,000 ppm copper, 2,000 ppm lead, and 1,700 ppm zinc (Ludington and others, 2005). A sample collected by Tingley (1998) about 200 m north of the mine contained 1.6 ppm gold, 1,500 ppm copper, 2,000 ppm lead, and 400 ppm zinc. Samples collected on the Holsak claims about 1,600 m north of the St. Louis Mine contained as much as 0.4 ppm gold, 5 ppm silver, and 1,200 ppm copper (Causey, 1988a). Samples collected by Causey (1988a) at the AJ No. 1 claim, about 1,200 m northeast of the Holsak claims, contained no more than 0.07 ppm gold.

The country rock is Proterozoic gneiss, intruded by numerous dike-like bodies of granite that probably correspond to the middle part of the Searchlight pluton. The veins here are not associated with a detachment fault, and they are probably best characterized as polymetallic veins. The vein we observed



**Figure 20.** Portal of St. Louis Mine.

at the St. Louis Mine strikes northeast and is near-vertical, although the host rocks appear to have been tilted at least 45 degrees to the west since the beginning of extension; thus, this vein may be younger than the veins in the Searchlight district.

## Sazarac Claims

The Sazarac block of patented claims includes the Rockefeller Mine; the area is about 17 km northeast of Searchlight, along the northeast boundary of the Piute-Eldorado Tortoise ACEC and the south boundary of the Ireteba Peaks Wilderness (fig. 19). Longwell and others (1965) refer to the entire area, including the Cobalt claims and the 5 Spot claim, as the Camp Dupont group. Thirty-five short tons of ore were produced in 1935. The seven claims were patented in 1913 and have been the subject of sporadic exploration since that time. During study of the Ireteba Peaks Wilderness, Causey (1988a) collected samples that contained as much as 7.6 opt (260 ppm) gold in a 9-ft chip sample, but only weakly anomalous amounts of silver, copper, molybdenum, copper, lead, and zinc. Tingley (1998) reported 21 ppm gold from a sample about 100 m west of the area. Causey described the area as containing many small veins and iron-oxide stained faults and fractures, filled primarily with quartz and some barite. Chrysocolla and malachite are common, and free gold was noted. The area is within the Dupont Mountain detachment fault zone, and the geology has not been mapped in detail, but the veins seem to occur in both the hanging wall (Miocene mafic and intermediate-composition volcanic rocks) and the footwall (granite of the Ireteba pluton and lower part of the Searchlight pluton). Most veins, however, are cut by the detachment fault. The geochemical signature (high gold to silver ratio, low base metals other than copper) and the structural setting suggest that the appropriate mineral deposit model for much of this area may be detachment-fault-related deposits.

## Cobalt Claims

About a kilometer west of the Rockefeller Mine area, a number of precious- and base-metal-bearing quartz and quartz-barite veins crop out over an area of less than 1 km<sup>2</sup>. A large claim block was established here in 1983 and an exploration program carried out during the 1980s. When the U.S. Bureau of Mines studied the mineral resources of the area, Causey (1988a) collected samples that contained as much as 6.6 ppm gold, 7 ppm silver, as well as anomalous amounts of lead and zinc, and copper. The principal vein, hosted in granodiorite and diorite of the lower Searchlight pluton, trends about N40W and extends for about 500 m.

## 5 Spot Claim

This area adjoins the Sazarac claim block on the northwest. Causey (1998a) found only low gold values in the samples he took.

## Crystal Lode Claim

About 700 m northwest of the Sazarac claim block, the Crystal Lode claim area is within the granite of the Ireteba pluton, and Causey (1988a) did not find high gold values in the samples he took.

## Searchlight District

Mineral deposits in the Searchlight mining district are a group of Au-bearing veins that are hosted primarily in Miocene volcanic rocks. These veins occur in zones that are draped over the top of the Searchlight pluton. The most important mines in the main part of the district occur in a narrow band about 6 km long from north to south, just to the west of U.S. Highway 95 (fig. 21).

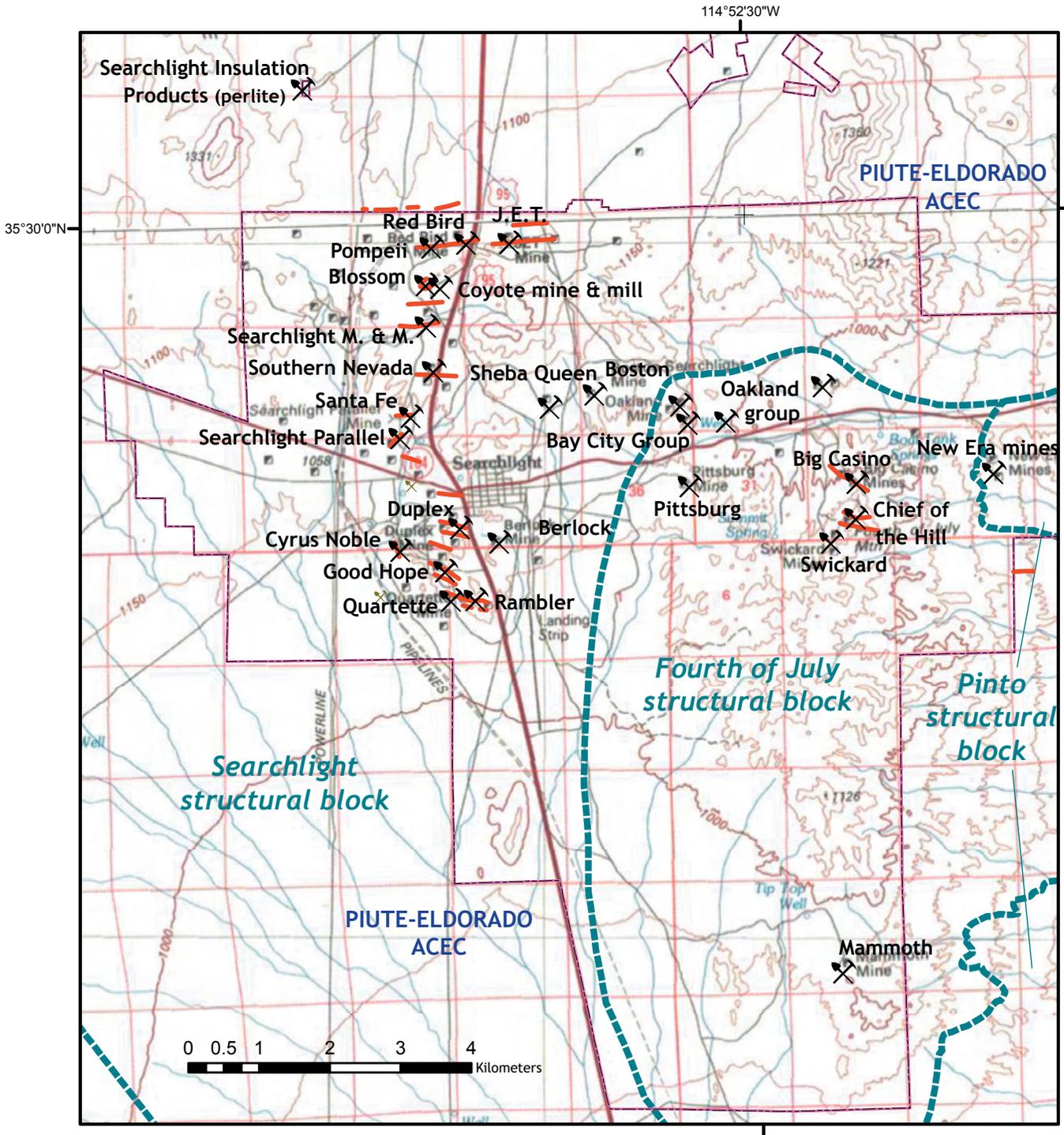
The productive parts of almost all known veins are in the lower intermediate-composition part of the volcanics of the Highland Range, within a few hundred meters above the upper contact with the Searchlight pluton (fig. 22). The J.E.T. vein, in the northern part of the district, is in the upper part of the Searchlight pluton, and small veins and stockwork zones are common within the upper part of the Searchlight pluton, but none of them produced important amounts of gold.

## Major Mines of the Searchlight District

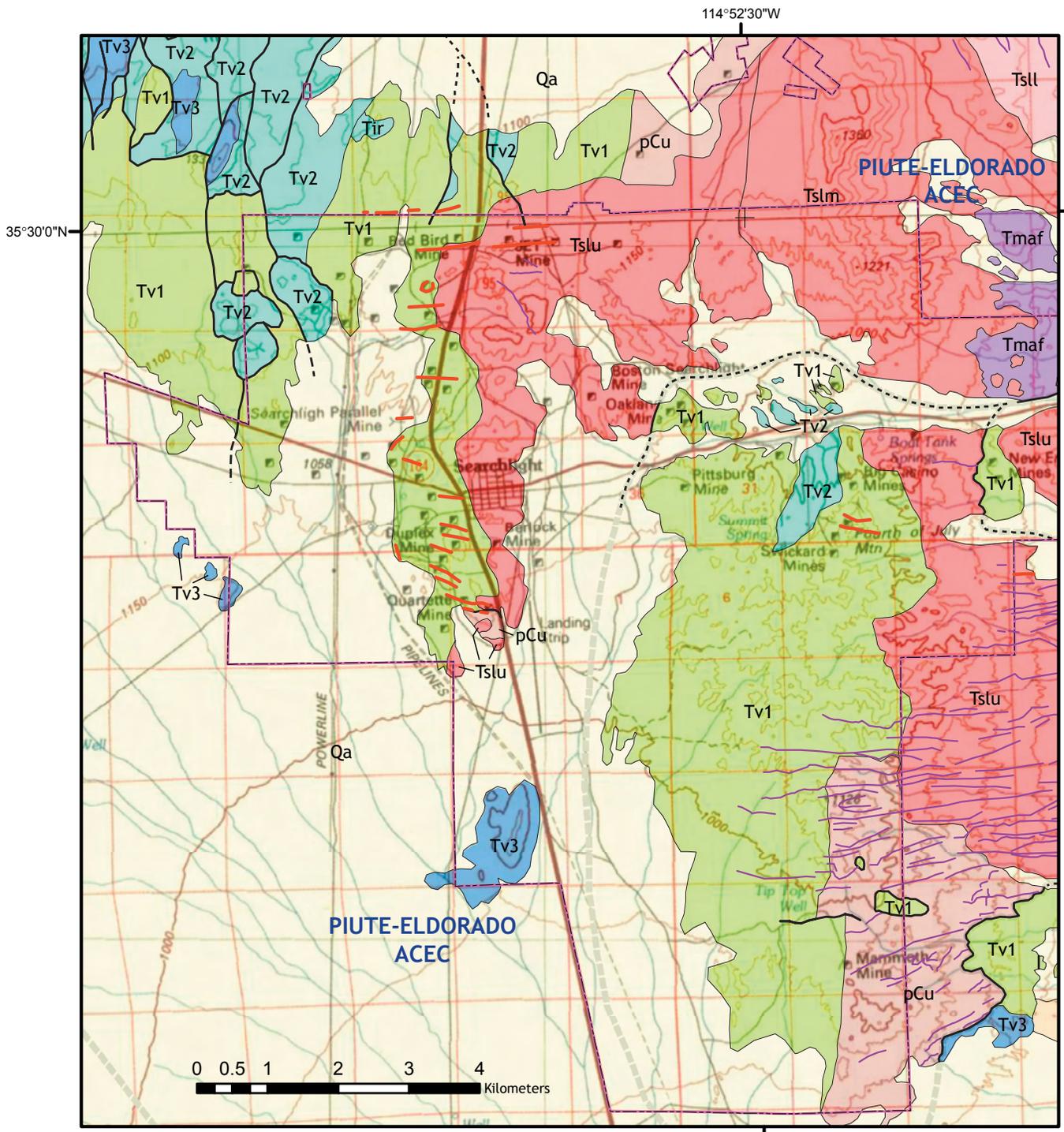
At Searchlight, the most important mine by far was the Quartette, which produced nearly half the gold from the entire district. The Duplex and the Blossom were the other productive mines. As far as is known, other mines shown on figure 21 produced relatively minor amounts of ore, and most are now in disrepair (fig. 23). However, individual mine production records are almost nonexistent.

Of the mines distant from the main part of the Searchlight district, in the Fourth of July and Pinto structural blocks, only the Big Casino is known to have had substantial production. Although our samples show that it apparently contains substantial gold, the Chief of the Hills is not recorded to have produced much ore. Many of the mines received a large initial investment and then closed when the first excavations failed to yield profitable ore.

Although detailed production records for most individual mines have not been preserved, relationships among the various metals produced vary widely, both between the various mines and within individual mines. For example, ore from the Quartette commonly contained 3 times as much gold as silver, but these relationships were reversed for ore from some parts of the mine (Callaghan, 1939). Only the Quartette, Duplex, Good Hope, and Big Casino produced considerable lead and copper. Copper predominated in the Quartette, whereas lead was dominant in the Duplex. Further details are in Callaghan (1939). The results of sampling during this study (Ludington and others, 2005) are discussed below, in the section on geochemical zoning.



**Figure 21.** Location map of major mines of the Searchlight district. Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC; boundary outlined in pink). Boundaries of structural blocks are in heavy teal broken lines. The traces of productive veins, modified from the map of Callaghan (1939), are shown as heavy red lines.



**Figure 22.** Generalized geology of the Searchlight district, compiled for this report. Units as follows: pCu—undivided Proterozoic schist, gneiss, and metaplutonic rocks; Tv1—lower intermediate-composition unit of volcanics of the Highland Range; Tv2—middle felsic unit of volcanics of the Highland Range; Tir—intrusive rhyolite; Tv3—upper mafic unit of volcanics of the Highland Range; Tslu—upper part of Searchlight pluton; Tslm—middle part of Searchlight pluton; Tssl—lower part of Searchlight pluton; Tmaf—mafic pod in Searchlight pluton. Qa—Quaternary alluvium. Heavy black lines are faults, dashed where concealed.

## Vein Mineralogy and Structure

An excellent description of the veins, one that is still valid for most of the veins in the Searchlight district, was given by Ransome (1907), “The lodes contain very little solid quartz and do not outcrop prominently. Toward the west they either pinch out or pass beneath alluvium. They are essentially mineralized fault zones in which the original character of the mineralization has been obscured by repeated movement and by oxidation. The lode material is generally a soft mass of shattered or crushed country rock colored by chrysocolla and oxides of iron and carrying free gold as its valuable constituent. Quartz is common in vugs, druses, and veinlets.”

According to Ransome (1907), cerussite was a characteristic constituent of the ore and was associated with wulfenite, cuprodescloizite, and leadhillite. Other lode minerals are specular hematite, malachite, azurite, and calcite. The only sulfides noted at that time were chalcocite, galena, and pyrite, which are present only in small quantities.

Visible copper minerals, primarily chrysocolla, were important guides to gold ore, and copper grades of several percent and lead and zinc grades near one percent were common in some parts of the veins. Today, virtually no base-metal sulfide minerals are present at the surface; we observed only pyrite and galena macroscopically, and have identified sphalerite and covellite microscopically. These sulfides were found at only three sites in the entire district. The most common gangue is quartz and specular hematite (fig. 24), sometimes accompanied by epidote. Historic published accounts of the vein mineralogy are cursory, as no geologist appears to have studied the mines between Ransome’s short visit in 1906 and Eugene Callaghan’s equally brief visits in 1931 and 1934. Callaghan (1939) prepared a summary of all earlier work and listed 17 ore minerals, including gold, chrysocolla, cuprite, chalcocite, leadhillite, wulfenite, vanadinite, and rarely, galena. It appears that sulfides were rare, not just at the surface, but to depths as great as 260 m below the present ground surface.



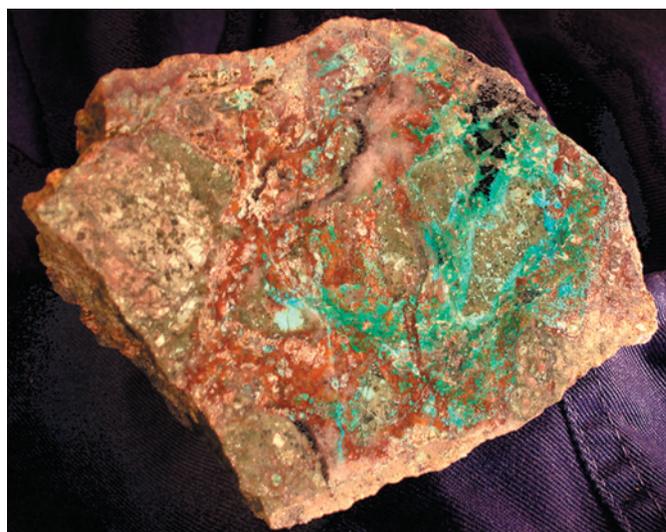
**Figure 23.** Remains of mining equipment at Southern Nevada Mine.

On the basis of petrographic studies of thin sections and analysis with a scanning electron microscope (SEM) using energy-dispersive X-ray analysis (EDX), we identified galena, anglesite ( $\text{PbSO}_4$ ), cerussite ( $\text{PbCO}_3$ ), plumbogummite ( $\text{PbAl}_3[(\text{OH})_5](\text{PO}_4)_2] \cdot \text{H}_2\text{O}$ ), pyromorphite ( $\text{Pb}_3[\text{Cl}(\text{PO}_4)_3]$ ), and covellite in partially oxidized ore from the Quartette Mine. We also found small (<50 microns) blebs of chalcopyrite adjacent to primary specular hematite in quartz veins in samples from the Quartette Mine (fig. 25), as well as galena and sphalerite blebs as much as 100 microns across.

The deposits in the northern part of the Searchlight district, including the Blossom and Searchlight M&M areas, differ from those in the Quartette Mine area. They contain thin quartz veins that consist mostly of granular to comb quartz and often occur in stockworks. Ransome (1907) stated that the Blossom Mine ore, which was mostly mined from a nearly horizontal blanket of stockwork veins, was generally not visibly mineralized but that the best ore contained free gold associated with limonite and specularite. Copper minerals are rare, although we found small amounts of blue secondary copper minerals at the Blossom Mine, and sparse chalcopyrite in quartz veins from dumps at the Searchlight M&M Mine.

During SEM examination, we noted that pyrite is partially to wholly replaced by hematite, galena, and electrum in a sample from the Blossom Mine. The electrum, which has weight percent Au:Ag of about 60:40 on the basis of semi-quantitative SEM/EDX analysis, seems to have been deposited late as irregular grains and flakes along quartz grain boundaries and fractures (fig. 26).

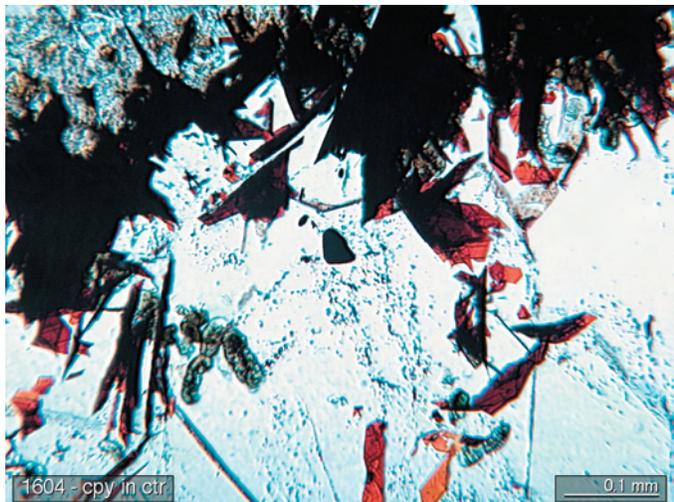
As noted by Callaghan (1939), adularia is an abundant alteration product in the wall rock near veins in the north part of the Searchlight district, and poorly formed overgrowths of



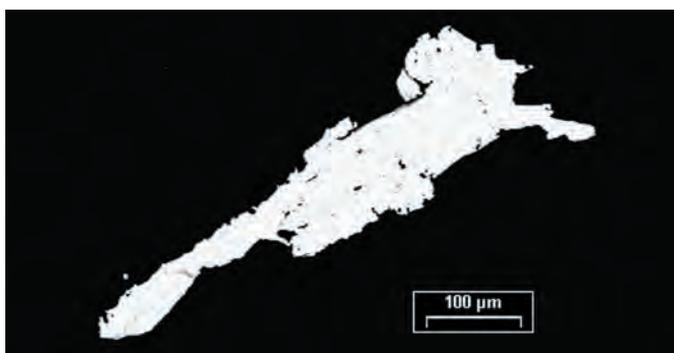
**Figure 24.** Sample of ore from dump of Rambler Mine, demonstrating abundant bright greenish-blue chrysocolla. Note also specular hematite and quartz in upper central part of photograph. Sample is about 8 cm across.

clear adularia occur in some veins and veinlets (fig. 27). However, on the basis of our samples, adularia occurs only rarely within the veins from the north part of the Searchlight district as sharp rhomb-shaped crystals as much as 0.5 mm across (fig. 28). Callaghan reported lamellar calcite in the Searchlight

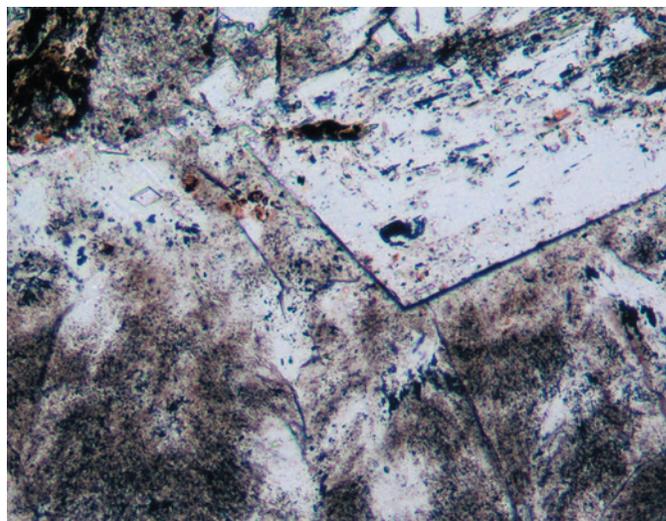
M&M and Blossom veins, but we did not see it there. However, we did observe ghost blade texture (quartz after bladed calcite) in a sample from the Chief of the Hills Mine, about 5 km east of the main part of the Searchlight district, in the Fourth of July structural block.



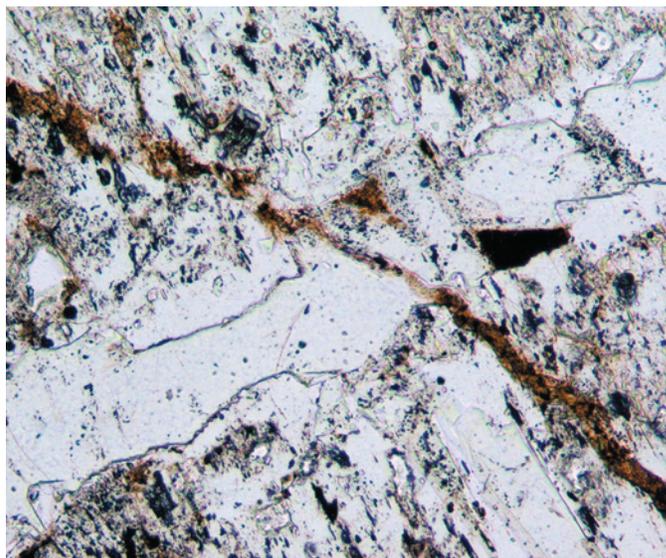
**Figure 25.** Top: Plane-polarized photomicrograph of specularite (pale red to black) blades and chalcopryrite (rounded opaque mineral in center of photo) in a quartz vein sample from the Quartette Mine. ▶ Right: Back-scattered electron scanning electron microscope image of the same specimen showing specularite (hem), chalcopryrite (cpy), and chlorite (chl) in quartz vein adjacent to wall rock.



**Figure 26.** Secondary-electron SEM image of relatively coarse electrum in a quartz vein from the Blossom Mine (Sample AP-254A). The electrum occurs as irregular grains along grain boundaries and cracks in comb quartz.



**Figure 27.** Plane polarized photomicrograph of a quartz-adularia veinlet from the Blossom Mine (sample 5-031601). Overgrowths of clear adularia as much as 200 microns across occur along the border of the quartz vein, and the wall rock contains large amounts of secondary K-feldspar. The quartz-adularia vein is cut by a brown limonitized fracture. Horizontal field of view is about 0.6 mm.



**Figure 28.** Plane-polarized photomicrograph of relatively clear rhombs of adularia in inclusion-crowded comb quartz near the border of a quartz vein from an unnamed prospect about 1 km west of the main part of the Searchlight district (sample 4-050601). The large adularia rhomb on the right is about 0.4 mm long; the tiny rhomb to the left of it is about 30 microns long. Vein border is at upper left.

The fact that the veins have the same spatial relationship to the upper contact of the Searchlight pluton, no matter which structural block they are in, suggests strongly that the extension-related low-angle faults that separate the structural blocks were active after the mineralized veins were formed, in other words, that the district was dismembered after it formed and that mineralization largely preceded extension (Faulds and others, 2002a). Most veins strike west or slightly north of west and have varying but fairly steep dips. This is probably not their original attitude. All the rocks in the district appear to have been tilted steeply to the west as a result of middle Miocene extension. The result of this rotation is that the east-west elongate surface exposures of the veins in the district are tilted cross sections, with tops to the west. The veins, which in map view appear to be peripheral to the Searchlight pluton, actually occur in a zone that arcs above its roof. The exposures in the Fourth of July block (Big Casino, Chief of the Hills, and Swickard) may simply be the eastern part of the Duplex, Good Hope, and Quartette mineralized structures, and the New Era Mines may be the eastern fringe of these same structures. The nearly horizontal mineralized zone at the Blossom Mine would have been a vertical, north-striking structure. These relations suggest that the Searchlight district provides a cross-sectional view of a hydrothermal system that is genetically related to the Searchlight pluton, as originally surmised by Faulds and others (2002a).

Sympathetic movements during this extensional faulting appear to have reactivated the mineralized structures and contributed to their crushed and disrupted state. Callaghan (1939), although not cognizant of the rotation, emphasized the brecciation of the veins by post-mineral movements, particularly in the mines in the southern part of the district.

Callaghan (1939) noted a difference in mineralization style between the deposits north and south of State Highway 164. The mines south of the highway, particularly the Quartette, Cyrus Noble, Good Hope, and Duplex, are characterized by significant amounts of the base metals copper, lead, and zinc, whereas the mines to the north of the highway did not produce important amounts of these metals. The mines in the south were the main source of the base-metal oxide minerals described above.

## Hydrothermal Alteration

Three principal types of hydrothermal alteration are present in the district—(1) propylitic alteration and hornfels formation adjacent to the Searchlight pluton, (2) hydrothermal alteration peripheral to the gold-bearing veins, and (3) supergene alteration and oxidation.

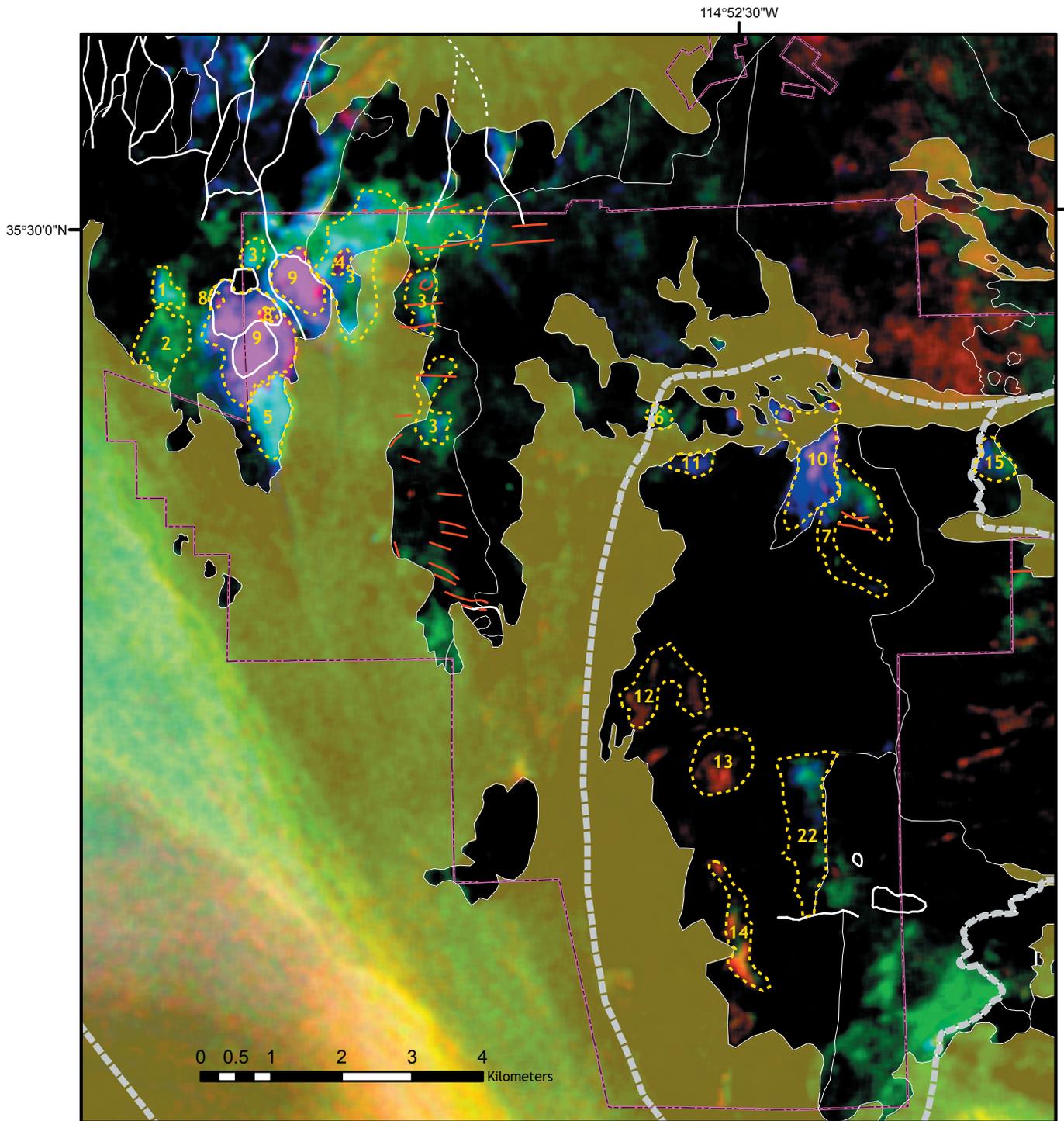
Within a few hundred meters of the contact with the Searchlight pluton, the volcanic rocks have been recrystallized into a rock that can be termed hornfels. The original minerals in the andesite and dacite have largely been converted to quartz, epidote, magnetite, biotite, and chlorite, and much of the original texture of the rock has been destroyed. Callaghan (1939) has an extended discussion of this alteration type.

Superimposed on this metamorphic imprint is a hydrothermal alteration assemblage associated with the gold-bearing veins. Although Callaghan (1939) did not map hydrothermal alteration zones in detail, he noted that alteration was negligible in the southern part of the district, specifically at the Quartette Mine, whereas adularia was a significant alteration mineral in the northern mines. He also stated that propylitic alteration (chlorite + albite + epidote + pyrite) is found in a few places in the north half but is difficult to separate megascopically from the metamorphism adjacent to the pluton. He also noted that pyrite is unusually rare in the altered rocks of the district.

We studied the distribution of hydrothermally altered rock with ASTER (Advanced Spaceborne Thermal Emission and Reflectance), which is a 14-band multispectral satellite imaging system (Rowan and others, 2003). Figure 29 shows an image of the district that shows the areas containing alteration minerals that can be detected with ASTER. The areas enclosed with dashed lines are interpreted to be hydrothermally altered rock, and samples from these areas were analyzed by X-ray diffraction (XRD) and portable infrared mineral analysis (PIMA) to confirm the nature of the alteration. Table 2 summarizes the spectral characteristics of each of the areas designated on figure 29, and tabulates their alteration characteristics. Petrographic studies are continuing in order to characterize the various alteration zones in more detail. The figure clearly shows abundant hydrothermal alteration in the north half of the main part of the district, and almost none in the southern part.

The bright pink colors indicate the areas characterized by alunite-bearing assemblages. This large area of quartz-alunite alteration was previously unreported in the geologic literature and occurs in an area as much as 1.5 km wide and 3 km long in the western part of the Searchlight district, as well as in a smaller area to the east of Searchlight. On the basis of XRD and PIMA, this alteration is characterized by the presence of alunite and kaolinite-group clay minerals (including dickite), along with locally strong quartz flooding and locally abundant topaz and pyrophyllite. The altered rock is typified by bleached white to orange and red colors, with the latter colors due to the presence of abundant jarosite and hematite. Alunite separates prepared from three samples have sulfur isotope ( $\delta^{34}\text{S}$ ) ratios of 14.6 to 15.9 per mil, which is consistent with a magmatic-hydrothermal or magmatic steam origin. These alunites will be dated using  $^{40}\text{Ar}/^{39}\text{Ar}$  to determine the age relationship between the high-sulfidation quartz-alunite alteration and low-sulfidation quartz-adularia mineralization to the east.

The turquoise color indicates the style of alteration characteristic of the productive veins in the north half of the main part of the district. For the purposes of this assessment, areas 1 and 2 are particularly significant, as they show that the alteration type that is characteristic of productive veins has been repeated by normal faulting and is exposed to the west of the alunite-bearing rhyolite hills, within the Piute-Eldorado Tortoise ACEC (fig. 30).



**Figure 29.** Advanced Spaceborne Thermal Emission and Reflectance (ASTER) image of the Searchlight district using bands 7 (red), 5 (green), and 4 (blue). The numbered areas outlined in yellow dashed lines are discrete hydrothermally altered areas described in table 2. Heavy gray dashed lines are structural block boundaries—see figures 18 and 21. Medium-weight red lines are trace of productive veins, modified from the map of Callaghan (1939). Yellow overprint indicates areas covered by Quaternary alluvium. Fuschia line is the boundary of the Piute-Eldorado Tortoise Area of Critical Environmental Concern. Image covers same area as figures 21 and 22.

**Table 2.** Description of hydrothermally altered areas mapped in figure 25.

[PIMA is portable infrared mineral analysis; XRD is X-ray diffraction.]

Area	Description	Spectral Character
1	Two samples characterized by PIMA and XRD to have smectite and illite	Strong adsorption in bands 6, 8, and 9
2	Two samples characterized by PIMA and XRD to have smectite and illite	Strong adsorption in band 8; moderate adsorption in band 6
3	Multiple samples characterized by PIMA and XRD to have smectite and illite	Strong adsorption in band 8; moderate adsorption in bands 6 and 9
4	No samples; spectral similarity to area 9 suggests advanced argillic alteration with alunite	Strong adsorption in bands 5 and 6
5	Two samples characterized by PIMA and XRD to have smectite and illite	Strong adsorption in bands 6, 8, and 9
6	No samples; possibly mostly smectite	Moderately strong adsorption in bands 7 and 8
7	No samples; possibly mostly smectite	Strong adsorption in bands 7 and 8
8	No samples; possibly advanced argillic alteration without alunite	Strong adsorption in band 5; moderate adsorption in band 6
9	Multiple samples characterized by PIMA and XRD to contain abundant alunite	Strong adsorption in bands 5, 6, and 8
10	No samples; spectral similarity to area 9 suggests advanced argillic alteration with alunite	Strong adsorption in bands 6 and 8; moderately strong adsorption in band 5
11	No samples; spectrum is unlike any others	Strong adsorption in bands 6; moderately strong adsorption in bands 7 and 8
12	No samples; spectrum is unlike any others and may represent unaltered rhyolite (?)	Moderately strong adsorption in band 9; moderate adsorption in band 8
13	No samples; spectrum is unlike any others and may represent unaltered rhyolite (?)	Moderately strong adsorption in band 9; moderate adsorption in band 8
14	No samples; spectrum is unlike any others and may represent unaltered rhyolite (?)	Moderately strong adsorption in band 9; moderate adsorption in band 8



**Figure 30.** View of alunite-bearing rhyolite hills from the west. Altered rocks of lower intermediate-composition unit of volcanics of Highland Range in foreground.

### Geochemical Zoning

As noted above, we and others have drawn a contrast between the northern and southern parts of the Searchlight district, based on vein mineralogy and the nature and intensity

of associated hydrothermal alteration. The geochemistry of altered and mineralized rocks reflects these and other distinctions. Table 3 records some simple statistics for geographic subgroups of mineralized samples from the district. Figure 31 shows the location of these subgroups.

**Table 3.** Summary statistics for mineralized samples from main part of Searchlight district.

[All data in parts per million (ppm). Complete data is in Ludington and others (2005). All values rounded to 2 (or 3) significant figures.]

	Ag	Au	Cu	Pb	Zn	Bi	Cd	Mo	As	Sb	SO <sub>3</sub>	Cu+Pb+Zn	Au/Au+Ag
<b>Bill Gays structural block (n=1)</b>													
	<0.5	0.01	8	21	10	<0.05	<0.1	1.6	5.0	0.3	1.70	39	ND
<b>Fourth of July structural block (n=6)</b>													
Median	23	3.3	420	23	63	0.14	1.30	7.6	9.5	3.1	0.07	466	0.22
Mean	17.3	5.4	650	340	130	0.14	1.30	14.3	16.2	5.4	0.17	1,110	0.19
SD	14.4	7.1	740	490	200	0.08	1.27	20	17.8	6.0	0.27	1,310	0.17
Max	28	15	1,730	1070	540	0.25	2.2	51	52	14.3	0.72	2900	0.35
Min	1	0.01	20	13	4	0.04	0.40	0.3	5	0.5	0.02	108	0.01
<b>Pinto structural block (n=3)</b>													
Median	NA	0.00	23	27	49	0.83	NA	2.0	15	1.8	0.17	96	NA
Mean	NA	0.01	24	27	47	0.83	NA	1.9	15.3	1.8	0.36	98	NA
SD	NA	0.00	5	3	16	0.51	NA	0.6	3.5	0.2	0.41	12.5	NA
Max	NA	0.01	30	30	62	1.19	NA	2.4	19	2.0	0.82	112	NA
Min	NA	0	20	23	31	0.47	NA	1.3	1	1.7	0.07	88	NA
<b>Northern Searchlight district (n=36)</b>													
Median	4.2	0.45	61	85	123	0.13	0.58	1.6	10	2.3	0.10	300	0.28
Mean	15.1	12.3	104	250	340	0.54	2.8	3.0	11	3.6	0.49	690	0.31
SD	30	25	128	300	430	0.89	5.6	3.8	7	4.7	0.74	750	0.26
Max	150	95	570	950	1,560	2.9	26	16.4	29	23.5	2.3	2,700	0.79
Min	1	0	4	6	4	0.02	0.10	0.3	2	0.1	0.01	31	0.00
<b>Searchlight pluton (n=7)</b>													
Median	5	0.02	48	80	105	0.53	0.50	1.1	11	4	0.02	230	NA
Mean	15.3	0.07	320	2,700	430	4.4	0.70	7.6	12.9	6.5	0.05	3,400	NA
SD	21	0.13	630	6,700	690	9.1	0.72	11.3	6.7	6.8	0.05	7,400	NA
Max	39	0.34	1,740	17,800	1,950	25	1.90	30	23	20	0.15	20,000	0.01
Min	2	0	1	11	36	0.05	0.10	0.5	3	1.1	0.01	48	NA
<b>Rhyolite of Searchlight district (n=22)</b>													
Median	NA	0.00	26	30	9	0.53	0.15	3.4	9.5	0.8	5.4	77	NA
Mean	NA	0.01	29	33	33	1.54	0.20	6.2	18	1.2	7.4	92	NA
SD	NA	0.01	21	23	40	2.9	0.14	9.6	23	1.3	7.4	60	NA
Max	NA	0.02	80	110	112	13.2	0.40	47	93	6.9	24	230	NA
Min	NA	0.00	5	2	1	0.04	0.10	0.8	3	0.4	0.12	17	NA
<b>Southern Searchlight district (n=13)</b>													
Median	6	0.18	670	290	161	2.6	4	11.6	8.5	1.0	0.62	1,260	0.02
Mean	53	0.43	8,300	11,400	1,320	24	5.9	28	8.5	7.0	3.0	21,000	0.06
SD	63	0.60	19,900	24,000	2,600	39	6.7	37	4.7	15.8	3.9	32,000	0.08
Max	150	1.63	73,000	79,000	8,400	119	20	119	15.0	57	9.8	83,000	0.18
Min	0.90	0.00	13	12	14	0.05	0.50	1.1	1.7	0.2	0.02	44	0.00
<b>Western Searchlight district (n=16)</b>													
Median	2.0	0	46	23	68	0.24	0.20	2.5	14.0	1.2	0.15	176	NA
Mean	3.3	0.02	1,310	25	69	0.73	0.19	3.6	18.9	2.5	0.70	1,400	NA
SD	3.2	0.06	4,900	10	58	0.97	0.08	3.4	16.9	4.3	1.57	4,900	NA
Max	7.0	0.22	19,700	45	179	3.5	0.30	12.5	59	18.3	6.3	19,800	NA
Min	1.00	0.00	5	8	1	0.04	0.10	0.6	3	0.8	0.01	19.5	NA

The data from the northern Searchlight district are dominated by a number of gold-rich vein samples from the Blossom Mine. These samples have the highest gold and some of the highest silver values in the district but relatively low amounts of the minor elements molybdenum and bismuth. The Au:Ag ratio in strongly mineralized samples ranges from about 0.4 to 0.8. The combined base-metal content (Cu+Pb+Zn) is also low, generally less than 2,000 ppm. Samples in this area also contain

somewhat more potassium than the less-altered samples in the southern part of the district, probably reflecting the adularia present in many of the samples.

The southern Searchlight district data include only 13 samples, and 7 of them are from the Quartette Mine and its eastern extension, the Rambler. These samples are characterized by higher silver values and much higher base-metal contents than samples from the other parts of the district. The

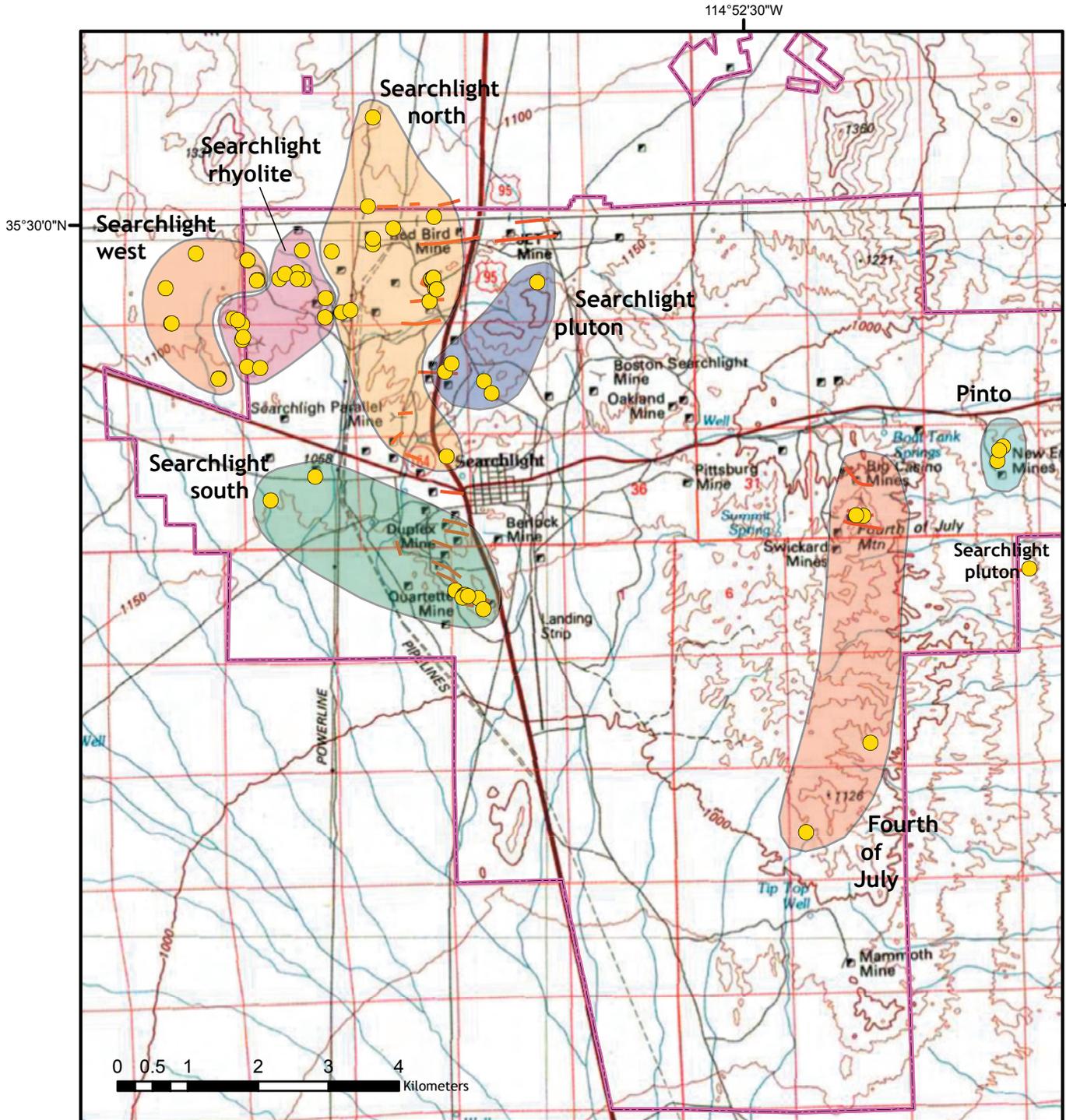


Figure 31. Location of samples summarized in table 3 and used to construct figure 32.

combined base-metal contents of many of the mine samples is in excess of 2 percent. They also contain distinctly more bismuth, molybdenum, and cadmium, and they are also modestly enriched in arsenic, antimony, tellurium, and tungsten. The Au:Au+Ag ratio in strongly mineralized samples is much lower than in the north, ranging up to only about 0.2. Four samples from the western part of this area have between 4 and 9 percent SO<sub>3</sub>, and apparently represent the southernmost exposures of the alunite-altered rocks to the north. Three of these rocks were determined to contain alunite by PIMA.

The data for rhyolites show much different patterns than either of the areas related to the productive veins. These samples come from the large area of alunite alteration west of the northern Searchlight district. Silver was not detected in any of the samples, and gold does not exceed 0.02 ppm. Combined base-metal values are almost all less than 200 ppm. The sulfate contents are, however, quite high, with many samples containing more than 10 percent SO<sub>3</sub>. The presence of abundant alunite also results in generally elevated K<sub>2</sub>O contents. Phosphorous is elevated in these rocks, being generally higher than 1,000 ppm, and iron is locally high due to the presence of hematite, limonite, and jarosite. Rubidium was strongly depleted during the hydrothermal alteration.

The western Searchlight district data are important because they demonstrate that alteration and mineralization typical of the productive part of the district are found to the west of the alunite area. It is possible that these rocks are in a lower, as-yet undelineated structural block. Two samples have 2 ppm silver or more, and two samples have more than 0.01 ppm gold. Except for one sample, all these rocks have low base metals and trace metals.

The data for samples from the Searchlight pluton and related dike rocks are quite varied, although most have elevated gold contents greater than 0.02 ppm. Two samples have high total base metals, and several have elevated trace metals, with bismuth contents as high as 25 ppm and molybdenum as high as 30 ppm.

The data for samples from the Fourth of July structural block are highlighted by two samples from the Chief of the Hills Mine that are quartz-rich vein material with very high gold contents and relatively high Au:Au+Ag. They are geochemically quite similar to the samples from the Blossom Mine, except that they have high molybdenum contents (13 and 51 ppm) and moderate bismuth contents (about 0.2 ppm).

The data for the three samples from the Pinto structural block (all taken near the New Era Mines) are only weakly mineralized, with both precious and base metal contents being relatively low. One sample does contain nearly 1 percent SO<sub>3</sub>. These samples are of hydrothermally altered material but were not taken from mine dumps.

The single sample from the Bill Gays structural block is from an oxidized rhyolite breccia. It appears to be significantly enriched only in sulfur.

A study by Al-Shaieb (1969) yields additional information about the differing alteration and mineralization styles in various parts of the district. The study was designed to

examine the distribution of ore and trace elements in the wall rocks of veins from the district, but because the samples were collected from underground exposures that are no longer accessible, the research provides important information about the geochemistry of the veins. Traverses were made, collecting samples from the veins and at regular intervals away from the veins. Samples were analyzed for gold, silver, copper, lead, and zinc.

The Al-Shaieb samples were collected from underground at both the Chief of the Hills and Duplex Mines. The samples from the vein at Chief of the Hills had compositions closely similar to the ones we collected at the surface, with total base-metal contents of a few hundred ppm, gold contents of 10 to 30 ppm, and Au:Au+Ag of 0.3 to 0.5. The Duplex Mine samples had total base-metal contents of 1 to 5 percent, gold contents of 1 to 10 ppm, and Au:Au+Ag of 0.1 to 0.4, compositions similar to those we report for the Quartette-Rambler vein system.

In summary, as shown in figure 32, the veins in the northern part of the Searchlight district have low base metals, high gold contents, and high Au:Au+Ag; their wall rocks are generally altered to adularia and, farther from the vein, to smectite-illite assemblages. The veins in the southern part of the district have high base metals, moderate gold contents, and low to moderate Au:Au+Ag; their wall rocks are not strongly altered. Our geochemical results generally confirm the descriptions made by Callaghan (1939), except for the low gold contents and metal ratios of our Quartette and Rambler samples. Much of the ore mined from the Quartette had extremely high gold contents, and Callaghan (1939) reports that "the product of the Quartette Mine was highly variable but mostly contained three times as much gold as silver by weight."

A possible implication of this contrast between the two areas might be that there are several hydrothermal systems present at Searchlight, each of a different age and mineralization style. Based on limited evidence, Callaghan (1939) discarded this idea, saying that "there appears to be a gradual transition from one to the other." More detailed mapping and radiometric dating will be necessary to determine if a single hydrothermal system was responsible for mineralization in the Searchlight district. If the transition from south to north represents simple zoning, it is decidedly eccentric with respect to the upper contact of the Searchlight pluton. It is possible that the northern and southern parts of the district are also in two structural blocks. It is also possible that the deposits in the northern part of the district may be more intensely weathered. This could account for the enhanced Au:Au+Ag, but the absence of visible supergene minerals and the presence of unoxidized pyrite south of the Blossom Mine argue against this.

The north-to-south variations discussed above are important because they are related to the metallogeny of gold-bearing veins. More important to understanding the hydrothermal system as a whole is the east-to-west (originally bottom-to-top) zoning. In the uppermost part of the Searchlight pluton and in the first few hundred meters above the pluton, alteration

is primarily to illite and other clay minerals, and sulfur-bearing minerals are not abundant, although small amounts of jarosite are common. About 700 to 1,500 m higher in the section, and coinciding with the appearance of rhyolitic lithologies, the alteration assemblage changes abruptly to one characterized by alunite, and sulfur contents of these rocks are several percent (Ludington and others, 2005). This upper alteration zone is characteristic of high-sulfidation epithermal deposits, but the scarcity of pyrite in the lower clay-illite zone is not. Overall, the distribution and amount of hydrothermal alteration is similar to that in large pluton-related mineral deposits such as porphyry copper deposits, but the specific mineral assemblages present at Searchlight do not correspond well to any accepted deposit models. Nevertheless, it seems clear that the gold-bearing veins are the result of hydrothermal fluids derived from the cooling Searchlight pluton.

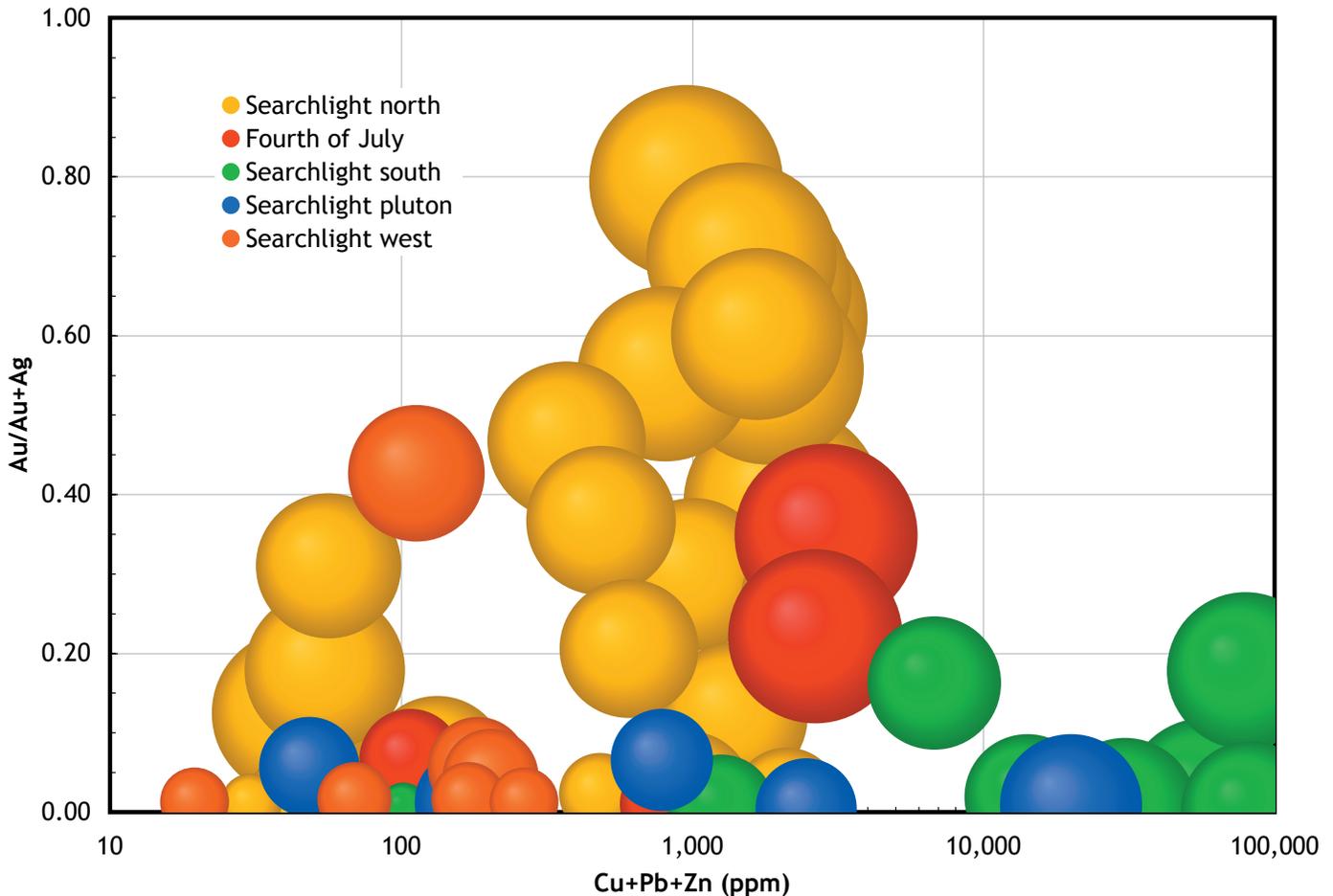
Our interpretation of the original geometry of and zoning patterns in the Searchlight district, while critical to an assessment of the possibilities for new discoveries, is

far from settled. Additional work is underway that should lead to a great improvement in our picture of this enigmatic mineral district.

### Newberry District

The deposits grouped into the Newberry district are probably unrelated. Most of them can be classified as polymetallic vein deposits, although quartz veins do not occur at all sites. They are structurally controlled, primarily by steep west-trending shear zones and faults. The absolute age of the deposits is unknown, as most of them cut only Proterozoic rocks, but we presume that they are of Miocene age and generally contemporaneous with the deposits in the Searchlight district. The hydrothermal alteration assemblage associated with the deposits is most commonly quartz, specular hematite, and illite. In at least 2 of the locations, the alteration and mineralization persists over strike lengths of several kilometers. Viewed in the context of the structural tilting that characterizes this area,

### Searchlight district, Clark County, Nevada



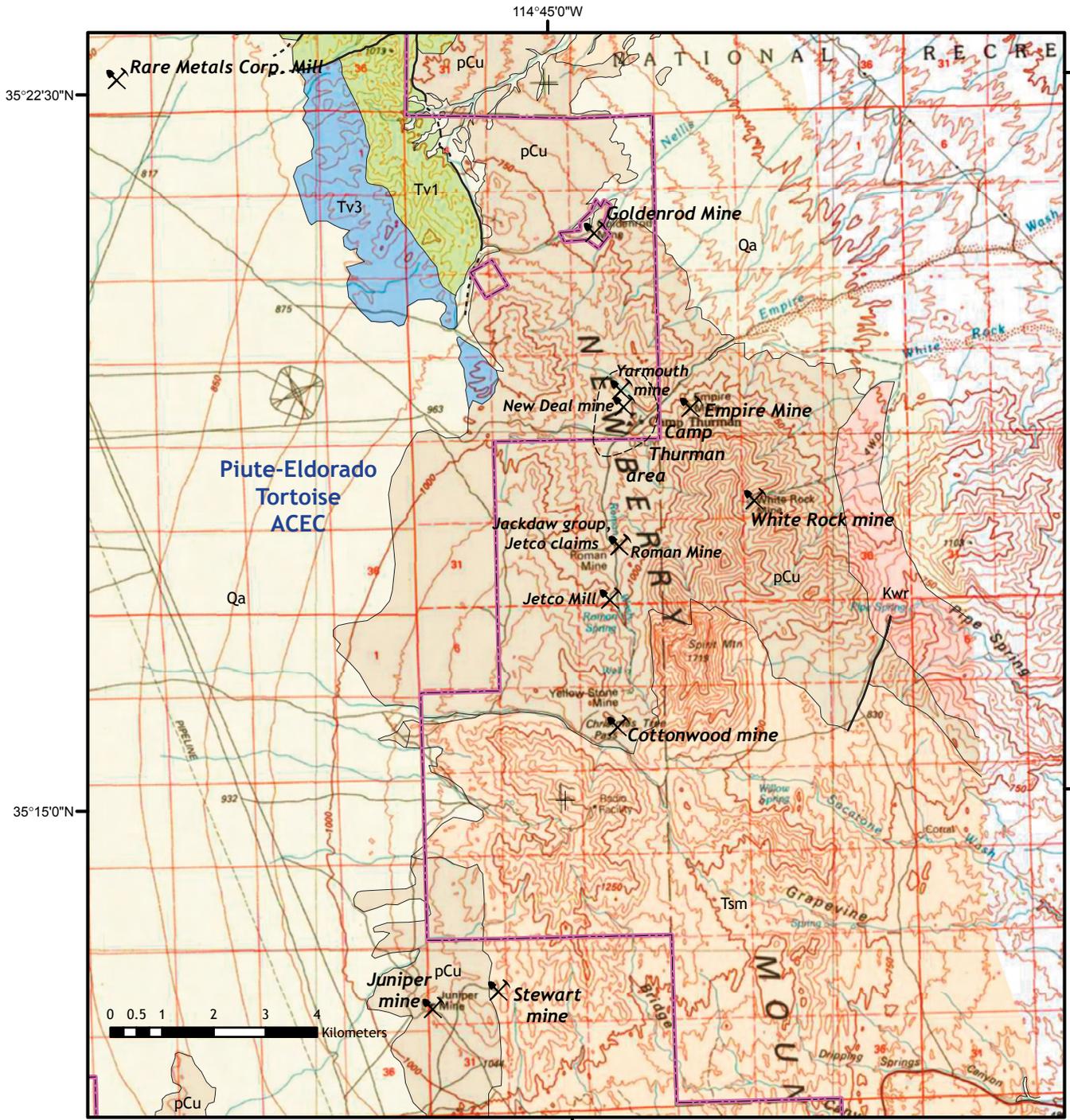
**Figure 32.** Plot showing contrast in metallogenic character of samples from different areas of the Searchlight district. Size of symbols is proportional to the logarithm of the gold content of samples, in parts per billion.

the suggestion is that some of these structures exhibit mineralized rock over a vertical range of at least 3 km.

The Rare Metals Corporation mill (fig. 33) was reportedly located on the floor of Piute Valley about 12 km southeast of Searchlight (Nevada Division of Mine Inspection, 1990), but there is neither any trace of any activity at the site, nor the remains of any road construction near this area.

### Goldenrod Mine

The Goldenrod Mine is located at the point where Nellis Wash issues from the Eldorado Mountains, and it is in an inholding of private land within the Piute-Eldorado Tortoise ACEC (fig. 33). Longwell and others (1965) mislocated this mine, putting it at the site of the Roman Mine (see below).



**Figure 33.** Mineral deposits in and near the Piute-Eldorado Areas of Critical Environmental Concern (ACECs; boundaries in pink) that are assigned to the Newberry mining district. Geology compiled for this report: pCu—undivided Proterozoic rocks; Kwr—Cretaceous granite of White Rock Wash pluton; Tv1—Miocene intermediate-composition volcanic rocks; Tv3—Miocene mafic volcanic rocks.

Vanderburg (1937) described two shafts and stated that a “small amount” of ore had been mined and treated locally. He also described a near-vertical quartz vein that cuts Proterozoic granite, strikes N60E, and is about 10 to 40 cm wide. We did not see this vein, but we sampled some 1-cm wide quartz veins that appeared to have oxidized casts of former sulfide minerals. This sample (5-061003; Ludington and others, 2005) did not yield anomalous values of precious or base metals. Another small private inholding is about 2 km southwest of the Goldenrod Mine, but we saw no evidence of mineralized or altered rock there.

## Camp Thurman

The area called Camp Thurman on topographic maps is shown on 1:24,000-scale topographic maps to contain the workings of the Potential Mine (fig. 33). Claims in this area were designated by Longwell and others (1965) to be the Jackdaw Group of claims, which were described by Vanderburg (1937). However, Vanderburg clearly stated that the Jackdaw Group was formerly known as the Old Roman Mine, which is likely to be the Roman Mine shown 2.5 km to the south on topographic maps. Thus, the only description of mines at this location seems to be that of Lawrence (1963), who describes the New Deal (or Polyanna) Mine and the Yarmouth Mine at this location. The mines were reportedly located 18 miles southeast of Searchlight and 2 miles northeast of Newberry Peak in sec. 21(?), T30S, R65E. This questionable legal location puts the property in the Camp Thurman area; however, the other location data suggest that it might be a few kilometers southwest of Camp Thurman. The workings at Camp Thurman consist of three shafts that were driven down a near vertical vein that strikes N65E and has been segmented by displacement along vertical faults that strike N25W. The deposits are described as being last worked in 1933, for silver, lead, antimony, and probably zinc. The antimony is described as occurring in tetrahedrite. We took two samples at this site, AP-047 (a 65-cm chip sample) and 4-050304 (Ludington and others, 2005). AP-047 contained only weakly anomalous values of precious or base metals, but 4-050304 contained 9.1 ppm gold, 3 ppm silver, and about 1,700 ppm lead (table 4). We also visited the Empire Mine, about 1 km to the east, but saw no signs of significant mineralized rock.

On ASTER images, there is a linear feature that extends about N70W from the Camp Thurman area to the range front in Piute Valley (fig. 34). The signature is similar to the illite- and smectite-bearing rocks in the Searchlight district, and this alteration style was confirmed by PIMA analysis. The country rock here is Proterozoic gneiss, and there is abundant limonite. Three samples were taken within this area (5-103002, 5-103003, 5-103004; Ludington and others, 2005). Sample 5-103003 contains visible pyrite and is weakly anomalous in barium, lithium, molybdenum, and zinc, whereas 5-103004, which contains small quartz-specular hematite veins, is mildly anomalous in phosphorous, tin, and yttrium. All of these samples have low gold and silver contents; 5-103004 contains 3 ppb (parts per billion) palladium.

## Roman Mine Area

About 2.5 km to the south of Camp Thurman, but outside the Piute-Eldorado Tortoise ACEC, the Roman Mine (also known as the Jetco claims and the Jackdaw group) is presently being worked for decorative stone instead of precious metals. The Jackdaw group was described by Vanderburg (1937), who reported a quartz vein with malachite and azurite. At that time, the mine was being worked on a small scale and recent production was estimated at \$15,000.

Samples from the Roman Mine area have elevated gold, as well as the highest silver, copper, and base-metal values in the Newberry district. A quartz vein sample with malachite and azurite from the Roman Mine was reported by Smith and Tingley (1983) to contain high Au, Ag, Cu, Pb, Zn, As, and Sb (sample 1342, table 4). We did not sample this site.

The Roman Mine is near the eastern part of another area of hydrothermal alteration inferred from ASTER imagery (fig. 34) that extends to the west and northwest from the mine area to the range front, inside the Piute-Eldorado Tortoise ACEC.

About one kilometer south and southwest of the Roman Mine are unnamed prospects shown as a shaft and tunnel on the 1:24,000-scale topographic map. Smith and Tingley (1983) collected three samples in this area (samples 1338, 1339, and 1341, table 4), and reported values as high as 11 ppm gold, with high silver, copper, lead, and zinc. The shaft is about 300 m east of the altered area.

## Cottonwood Mine Area

Longwell and others (1965) described the Cottonwood Mine as being located in section 18 of T31S, R65E, and as being hosted by Proterozoic gneisses. No Proterozoic rocks crop out in section 18, and there are no workings at the location indicated. On the basis of the geologic description, we believe the area referred to is in section 9, where Smith (1982a) described the Christmas Tree Pass workings as exploring a steeply dipping west-trending shear zone in Proterozoic gneiss with small quartz veins and oxidized sulfide minerals. The Yellow Stone Mine is shown on the 1:24,000 scale topographic map about a kilometer to the northwest. Samples from the Cottonwood Mine area and about 2 km to the west contain 2.5 and 3.4 ppm gold, respectively, with high silver, molybdenum, and lead (Smith and Tingley, 1983; table 4). Like the Roman Mine area, this area is also outside the ACEC boundary (fig. 33).

## Stewart Mine

This mine is referred to in the literature only by a listing in Nevada Division of Mine Inspection (1977), where it is reported to have been a silver deposit, with minor lead. A small pit in the uppermost part of the Spirit Mountain pluton exposes granite that is pervasively stained with manganese oxides in an area about 100 m across. Our sample of this material (4-030703,

**Table 4. Precious- and base-metal contents of mineralized samples from the Newberry district.**

[Analyses of samples 1333 through 1343 are from Smith and Tingley, 1983; Ag, Ba, Bi, Cu, Mo, and Pb by semi-quantitative emission spectroscopy; As, Au, Sb, and Zn by atomic absorption. Other analyses are from Ludington and others, 2005. All analytical data are in ppm, nd = no data.]

Sample no.	Location	Ag	As	Au	Bi	Cu	Mo	Pb	Sb	Zn	Description
5-061003	Goldenrod Mine	<1	1	0.00	0.0	4	1	6	0.3	13	Quartz vein
AP-047	Camp Thurman	<1	2	0.03	0.3	30	1	68	0.3	19	Quartz vein, 65-cm chip
AP-048	Camp Thurman	1	3	<.01	0.1	24	0	66	0.7	44	Pegmatite, grab
1343	Camp Thurman	2	<10	0.30	<10	70	<5	100	4.0	20	Quartz vein with Fe-oxide after pyrite and Mn-oxide
4-050304	Camp Thurman	3	2	9.09	0.3	134	16	1732	0.5	41	Quartz vein with pyrite
5-103002	West of Camp Thurman	<1	1	0.00	0.0	4	0	27	0.4	14	Quartz veins
5-103003	West of Camp Thurman	<1	2	0.00	0.1	8	15	22	0.8	161	Quartz veins
5-103004	West of Camp Thurman	<1	2	0.01	0.2	8	2	10	0.2	54	quartz-hematite vein
1342	Roman Mine	200	110	0.90	<10	1000	<5	5000	840	250	Quartz vein with Cu-oxide
1338	South of Roman Mine	10	<10	0.55	<10	15000	10	1000	5.0	600	Sheared intrusive with Fe-Mn-oxide and Cu-oxide
1341	South of Roman Mine	200	<10	11.0	15.0	5000	<5	15000	3.0	>2000	Quartz vein with py, cpy, ga, and Cu-oxide
1339	South of Roman Mine	<1	<10	<.05	<10	200	<5	70	2.0	10	Quartz vein with sulfides and Mn-oxide
1336	Cottonwood Mine area	15	<10	2.50	<10	30	5	500	4.0	40	Quartz vein and sheared rock with pyrite and chalcopyrite
1337	West of Cottonwood Mine	3	<10	3.40	<10	20	500	70	4.0	35	Silicic rock with pyrite and quartz vein
1340	Yellow Stone Mine	<1	<10	<.05	<10	10	<5	50	nd	nd	Quartz vein and sheared rock with limonite
4-030703	Stewart Mine	2	<1	0.12	2.6	322	5	2160	0.1	9990	Granite with Mn-oxide
5-050703	North of Juniper Mine	<1	1	0.01	0.1	31	3	11	0.5	35	Quartz vein stockwork
AP-049	Juniper Mine East shaft	<1	<1	1.07	<.04	14	1	18	0.2	35	Quartz vein, grab
AP-050	Juniper Mine ore pile	<1	<1	0.18	0.4	31	47	32	0.3	94	Quartz vein in altered gneiss, ore pile grab
4-030704	Juniper Mine	<1	3	0.01	0.5	1	1	134	1.0	136	Granite with Fe-oxide
1335A	Juniper Mine	70	<10	60.0	<10	7	<5	20	3.0	45	Quartz vein with oxidized pyrite
1335B	Juniper Mine	1	<10	0.20	<10	200	<5	200	3.0	60	Siliceous dike with oxidized pyrite
4-030701	Prospect southeast of Juniper Mine	<1	1	0.28	0.1	7	2	136	0.3	32	Aplite with Fe-oxide
1334	Superfluous claims	1	<10	10.0	<10	70	<5	200	3.0	80	Quartz vein and sheared rock with specular hematite, Mn-oxide
AP-051	Gibraltar claims	1	25	0.92	0.2	42	14	166	5.9	191	Hematized shear zone in granite, 1-m chip
1333	Gibraltar claims	7	90	6.60	<10	30	70	1000	4.0	130	Siliceous dike with Fe-Mn-oxide
4-033103	Unknown	2	14	0.03	3.0	73	50	20	0.2	6	Quartz veins

table 4) contains high Ag, Au, Bi, Cu, Pb, and Zn, as well as elevated beryllium, cadmium, and nearly 6 percent manganese (Ludington and others, 2005). The style of mineralization is enigmatic; no structures were observed, and the association of beryllium with precious metals is uncommon.

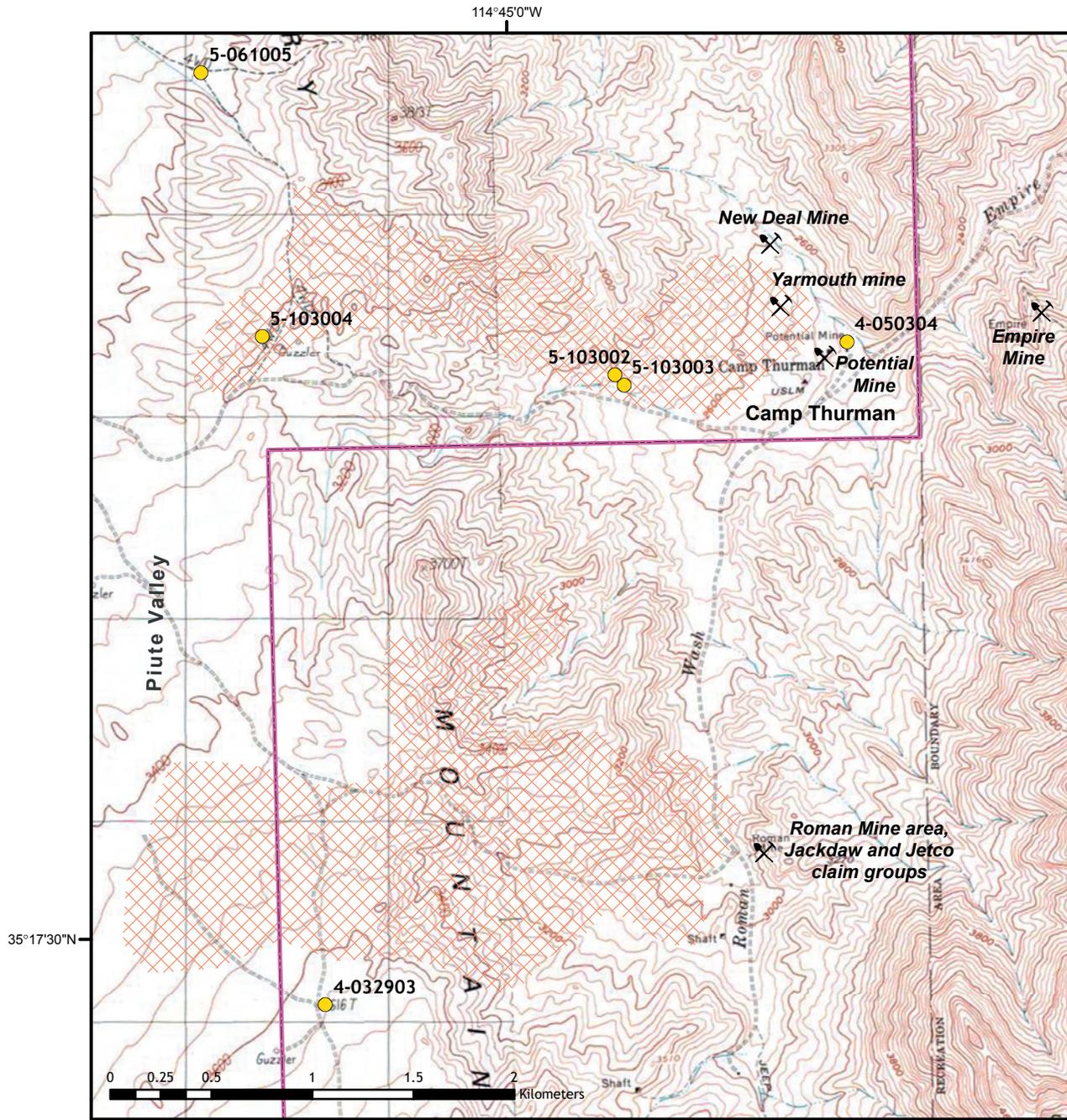
## Juniper Mine

The Juniper Mine is about 12 km south of Camp Thurman on the west flank of the Newberry Mountains (fig. 33), and consists of two shafts along a west-trending structure that

apparently dips steeply north. The west shaft is 30 m deep or more. Some minor veins with similar orientations are exposed in shallow surface diggings between the shafts. The veins cut Proterozoic granite and fine-grained metamorphic rock. Grab samples of loose vein material contain as much as 1 ppm Au (sample AP-049; Ludington and others, 2005). A sample collected by Smith and Tingley (1983) from the dump of the Juniper Mine contains 60 ppm gold and 70 ppm silver, and a second sample has moderately elevated gold, copper, and lead (samples 1335A and 1335B, table 4).

### White Rock Mine

The White Rock Mine is shown on both 1:100,000 and 1:24,000-scale topographic maps, about 2 km southeast of the Camp Thurman area, outside the Piute-Eldorado Tortoise ACEC, and inside Lake Mead National Recreation Area. The USGS's MRDS database (U.S. Geological Survey, undated) lists the major commodities as copper, gold, and silver. This database also gives Volborth (1973) as a reference, but there is no mention of the mine in that report. It seems likely that

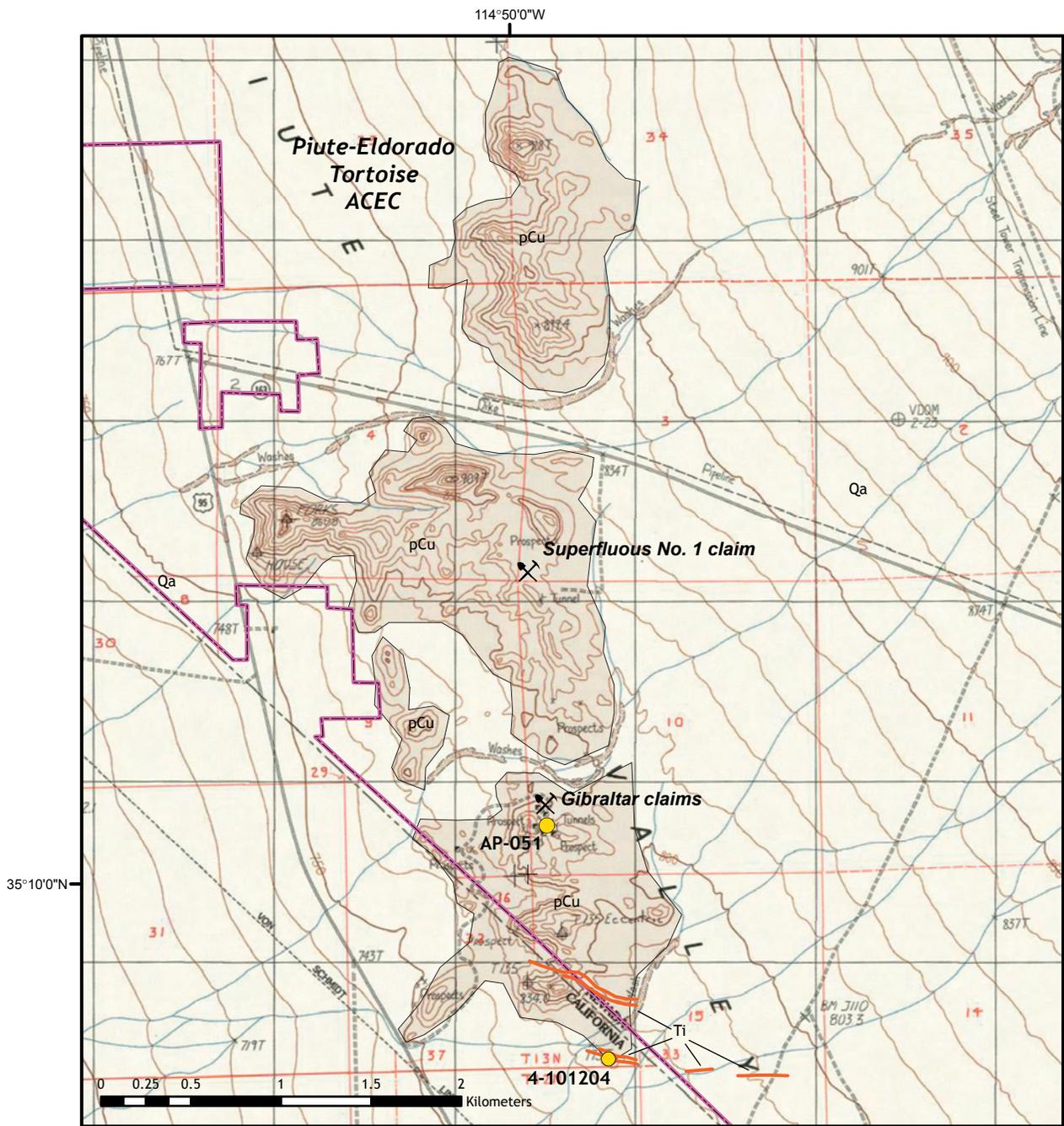


**Figure 34.** Map showing location of hydrothermally altered rocks identified by Advanced Spaceborne Thermal Emission and Reflectance (ASTER) imagery near Camp Thurman and Roman Mine areas (red cross hatch). Analyzed samples shown by yellow circles.

this is the site described by Vanderburg (1937) as the Home-stake Group, 9 miles north of Hiko Springs. Vanderburg reported that there were 3 east-west veins, the largest being as wide as 6 m, dipping about 50 degrees to the north, and that the major commodities were gold, with small amounts of silver (no mention of copper). He also reported that the mine had been worked intermittently from 1910 until the middle 1930s. We did not visit the White Rock Mine.

## Superfluous and Gibraltar Claims

The Superfluous and Gibraltar claims are in the Chiquita Hills, immediately east of U.S. Highway 95 at the junction with Nevada State Highway 163 (fig. 35). Both sites are characterized by gold-bearing vein deposits similar to others in the Newberry district, and both contain shear zones in Proterozoic gneiss with hematite. They are briefly described by Smith (1982b,c).



**Figure 35.** Map showing location of Superfluous and Gibraltar claims in the Chiquita Hills. Analyzed samples shown by yellow circles. Geology compiled and mapped for this study: pCu—undifferentiated Proterozoic metamorphic and igneous rocks; Ti—porphyritic granite dikes; Qa—Quaternary alluvium.

The Superfluous claims may have been originally prospected for uranium (Garside, 1973), but Smith and Tingley (1983) reported a sample with 10 ppm gold and moderately elevated silver and lead (sample 1334, table 4) from a steeply northeast-dipping, quartz-cemented shear zone with calcite, sulfides, and hematite.

The Gibraltar claims were staked just inside California, but workings extend into Nevada. In Nevada, the property is marked by several closely spaced shafts according to the 1:24,000-scale topographic map. Our examination disclosed an open pit about 20 m long that exposes old adits along a fault in Proterozoic gneiss and granite that strikes N70E. In the pit, the fault dips to the north about 45 to 75 degrees (fig. 36), but about 50 m to the west, the fault dips only 25 degrees to the north. The granite is cut by a fine-grained rhyolite dike that dips gently to the north, and both the granite and rhyolite contain abundant hematite adjacent to the fault. Sample AP-051, a 1-m chip across the sheared and altered rock along the fault, contains about 1 ppm each of gold and silver, along with slightly elevated molybdenum, lead, and zinc (sample AP-051, table 4; Ludington and others, 2005). A sample reported in Smith and Tingley (1983) from the same area has 6.6 ppm gold, along with high lead, zinc, and molybdenum (table 4). In addition to the workings, the Gibraltar site has the remains of a small but fairly modern mill in a vigorous state of disrepair (fig. 37).

To the north, the Superfluous area exposes mineralized rock of similar appearance but containing carbonate, specular hematite, and drusy quartz. We took no samples here, but Smith and Tingley (1983) reported a sample from this area with 10 ppm gold and moderately high silver and lead (sample 1334, table 4).



**Figure 36.** Small open-pit mine with old underground working along north-dipping fault. Sample AP-051 was collected from the shattered zone below the hammer.

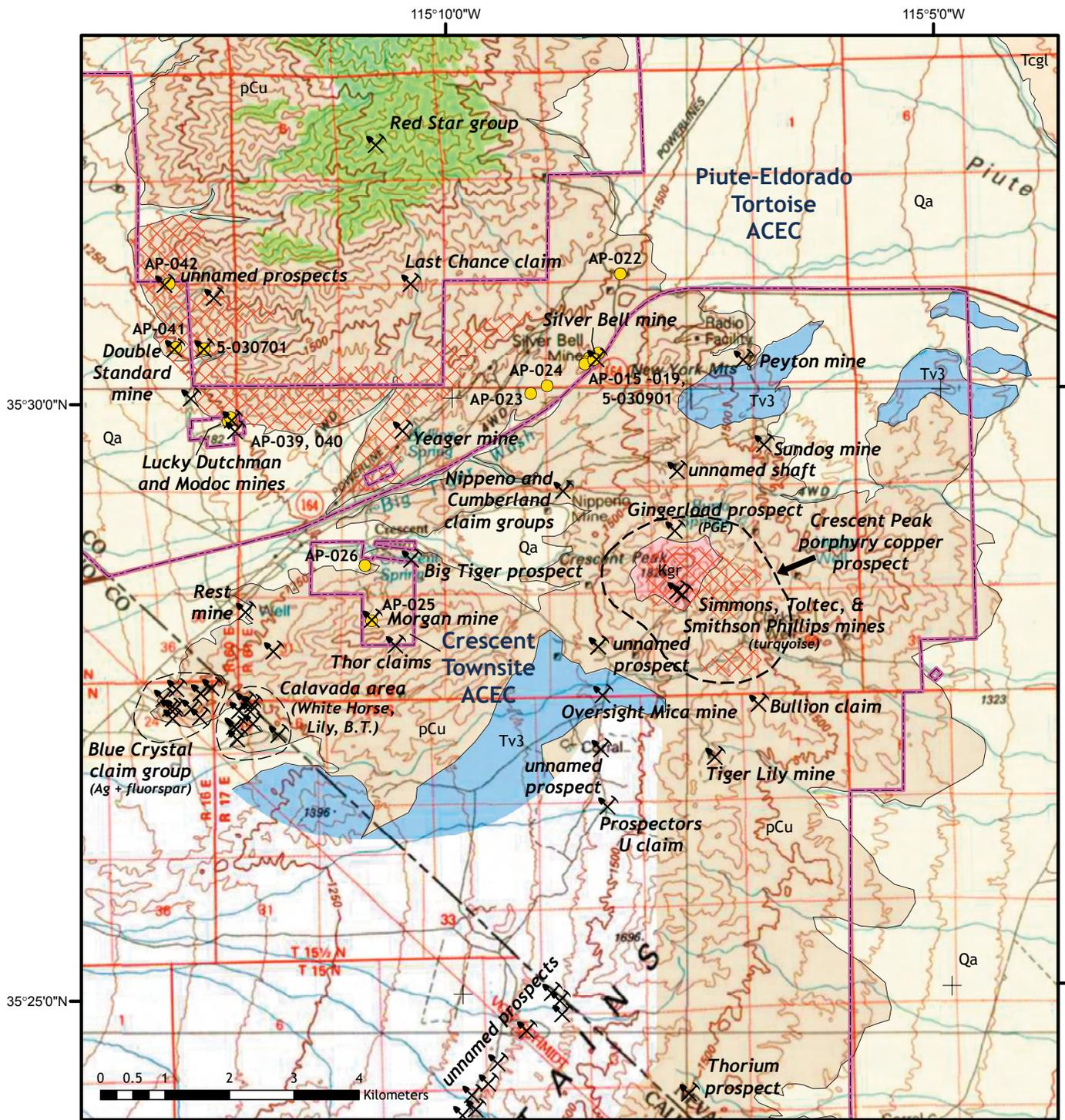
## Crescent District

The Crescent district was originally exploited for turquoise, but gold was discovered in 1905, and there was considerable activity until 1942. There has been only limited geologic study of the area, and, for many of the deposits that are briefly described in the literature, the locations are uncertain. The country rock in the region is primarily Proterozoic schist, gneiss, and meta-igneous rocks (Longwell and others, 1965; Miller and Wooden, 1993). The east half of the district is dominated by the north end of a large pluton of Proterozoic biotite leucocratic granite with an age of about 1672 Ma (Miller and Wooden, 1993). A few small plutons and dikes of Cretaceous granodiorite occur. One large altered area that encompasses Crescent Peak was explored as a porphyry copper prospect during the 1960s, and it probably is related to the Cretaceous igneous rocks (Archbold and Santos, 1962). Miocene volcanic rocks are found at the southwest end of the district, primarily in California, and at the extreme east end of the district, where the volcanic rocks lie unconformably on the Proterozoic gneisses. Miocene structure, which is probably key to understanding the geology of the mineral deposits, is poorly understood in the Crescent district.

There are many mines in the district, and most of them are outside the Piute-Eldorado Tortoise and Crescent Townsite ACECs. We describe only some of the principal ones and the ones we visited and sampled (see fig. 38, table 5). At least four types of mineral deposit exist in the district: (1) porphyry copper deposit (Crescent Peak), (2) metal-bearing fluorspar veins (Blue Crystal), (3) gold-rich polymetallic veins (Peyton, Sundog, Double Standard, Nippeno, Cumberland), and (4) detachment-fault-related deposits (Silver Bell, Big Tiger-Rest,



**Figure 37.** Remains of a mill near the site of sample AP-051. The small blue shaking table at right suggests that gravity recovery of gold was planned. The mill appears abandoned, but the presence of modern excavation equipment indicates recent activity.



**Figure 38.** Mines and prospects in the Crescent district. Yellow circles are analyzed samples listed in table 5. Geology is modified from Stewart and Carlson (1978): pCu—Proterozoic metamorphic and igneous rocks; Kgr—Cretaceous granite; Tv—Miocene mafic volcanic rocks; Qa—Quaternary alluvium. Red cross-hatch indicates areas of hydrothermal alteration identified with Advanced Spaceborne Thermal Emission and Reflectance (ASTER) imagery. Boundaries of Areas of Critical Environmental Concern (ACECs) shown in pink.

Calvada, Lucky Dutchman). Several of the deposits are difficult to classify because of the limited information available, and they may be either gold-rich polymetallic veins or detachment-fault-related deposits.

## Silver Bell Mine

The Silver Bell Mine is located within the Piute-Eldorado Tortoise ACEC, adjacent to Nevada State Highway 164 (fig. 38). Although it is shown on both 1:24,000 and 1:100,000-scale topographic maps, it is not mentioned in the geologic literature. It is possible that this is because it was discovered and developed subsequent to 1937, when the last primary geologic investigations in the area were carried out (Vanderburg, 1937).

The mine workings at the Silver Bell expose northeast-striking veins and shear zones with shallow northwest dips that consist mainly of bleached and silicified rock. Abundant quartz and manganese oxide were identified in hand specimen, along with local galena and secondary copper minerals. The samples have high gold (as much as 18 ppm), silver (as much as 12 ppm), copper, lead, and zinc along with moderately high molybdenum and antimony (table 5). This mineralized rock occurs along a N30E- to N65E-striking structure that is nearly horizontal in places and dips as much as 35 degrees northwest



**Figure 39.** Shallowly northwest-dipping sheared, altered, and silicified gold-bearing zone (behind hammer) in an adit at the Silver Bell Mine. Site of samples AP-015 and AP-015C.

elsewhere (figs. 39, 40). The mineralized structure cuts Proterozoic gneiss and barren quartz veins (for example, sample AP-015Q, table 5). To the southwest and northeast, and approximately along strike with the Silver Bell structure, are occurrences of similar rock along structures that are horizontal or dip 40 degrees to the northwest. Some samples of this material (AP-022 through AP-024C, table 5) have elevated metal values similar to those of the Silver Bell samples. Sample AP-024C is of interest because it is an ore grade chip sample (with about 4 ppm Au, or 0.1 troy ounce per ton) across 1.2 m of sheared and altered rock from a near-horizontal zone adjacent to an old open stope (fig. 40).

On the basis of petrographic and SEM/EDX studies, samples from the Silver Bell Mine contain several manganese oxide phases, including an iron and manganese mineral (fig. 41), a manganese and lead mineral (coronadite?) (fig. 42), an unknown phase containing manganese, potassium, and lead, and a rare mineral that contains manganese, lead, and antimony. Other secondary phases include an iron oxide mineral and hemimorphite ( $Zn_4[(OH)_2Si_2O_7] \cdot H_2O$ ) (figs. 43, 44). Primary sulfides include galena, pyrite, sphalerite, and chalcocopyrite, along with rare acanthite and imiterite ( $Ag_2HgS_2$ ). Although galena is present in some samples, late vein- and breccia-filling manganese-oxide phases may be the only lead-bearing minerals in others (fig. 45). Barite is present in minor amounts. Electrum was found as grains as much as 60  $\mu$  across in one sample (fig. 44).

## Peyton and Sundog Mines

The Peyton and Sundog Mines are in the northeast end of the Crescent district, about 3 km east of the Silver Bell and about 1 and 2 km respectively south of the Piute-Eldorado

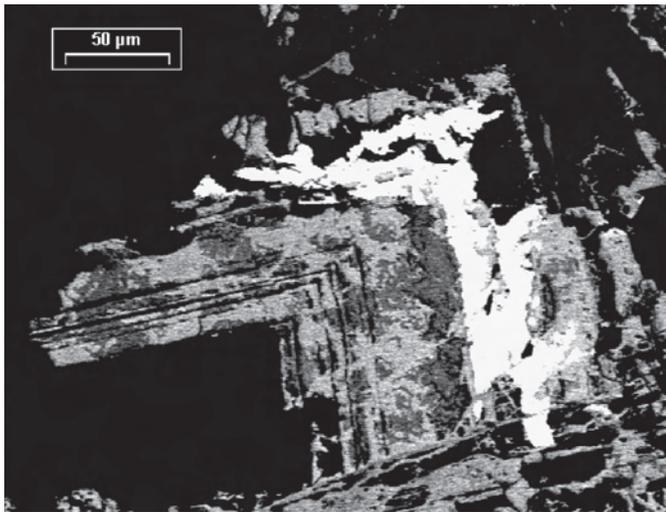


**Figure 40.** Shallowly-dipping sheared, altered, and mineralized zone southwest of the Silver Bell Mine. AP-024C is a chip sample taken from the hammer (right of opening) downward 1.2 m across the sheared and limonitic rock to the top of unoxidized greenish gneiss below.

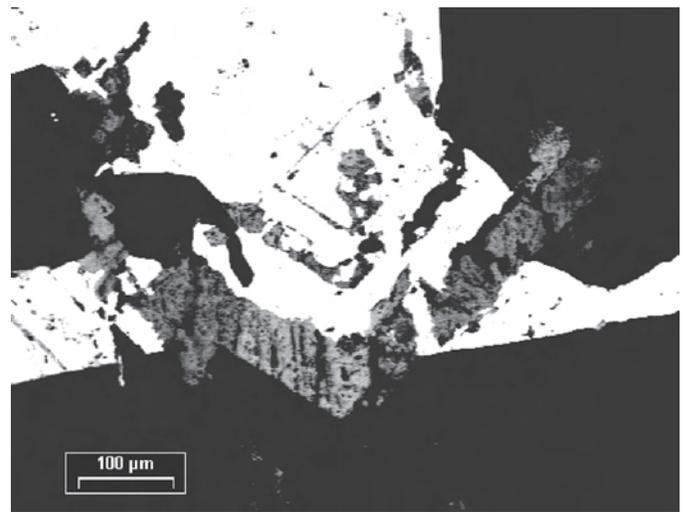
**Table 5.** Samples from vein and shear zone deposits and occurrences in the Crescent district.

[All values in ppm, rounded to 2 or 3 significant figures.]

SAMPLE	LOCATION	Au	Ag	Mo	Cu	Pb	Zn	As	Sb
AP-015	Silver Bell Mine	6.0	4.2	13	133	2,500	570	34	3.2
AP-015C	Silver Bell Mine	0.20	1.0	10.8	35	1,430	480	7	0.6
AP-015Q	Silver Bell Mine	0.01	0.1	0.5	2.3	14.9	12	0.6	0.2
AP-019	Silver Bell Mine	18.1	12.7	28.2	1,150	>10,000	7,800	8.9	34
5-030901	Silver Bell Mine	0.002	<0.5	2.5	19	16	49	2	0.6
AP-022	unnamed adit	0.26	14.8	28.7	>10,000	580	149	126	52
AP-022B	unnamed adit	0.00	<0.1	3	23	16.7	70	<0.5	0.1
AP-023	unnamed adit	1.52	2.9	74.3	89	3745.9	1830	4.1	2.4
AP-024	unnamed stope	4.1	6.5	17.6	200	>10,000	5300	21	7.0
AP-024C	unnamed stope	1.25	7.5	29	370	8,100	>10,000	22	4.1
AP-039	Lucky Dutchman Mine	0.04	0.1	0.5	48	34	17	1.2	0.5
AP-040	Lucky Dutchman Mine	0.00	0.1	0.4	95	14.7	13	2.8	0.4
AP-041	Double Standard Mine	11.6	154	219	1,780	>10,000	5,700	1,300	43
5-030701	Dump east of Double Standard Mine	0.26	<0.5	3.7	10	9	7	9	0.7
AP-042	unnamed shaft	4.8	64	11.3	30	500	180	194	4.1



**Figure 41.** Back-scattered electron image of barite (bright) interlayered with a manganese-oxide mineral (dark gray) that is intergrown with an iron and manganese oxide mineral (light gray) that replaced an unknown crystalline phase. Dark background is mostly quartz. Sample AP-015, Silver Bell Mine.

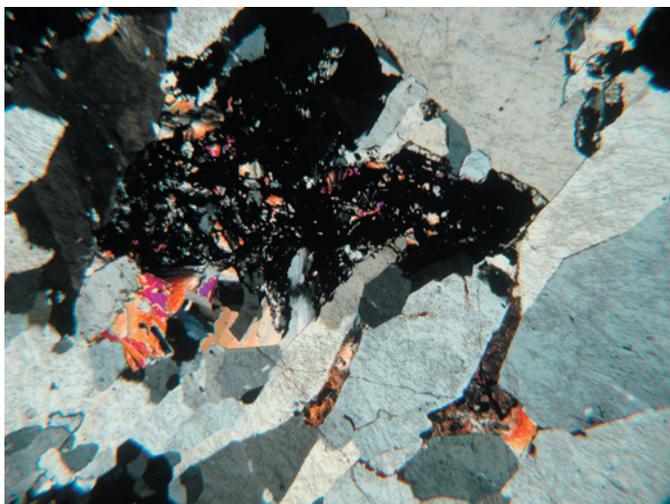


**Figure 42.** Back-scattered electron image of galena (bright) partially replaced by lead-bearing manganese-oxide mineral, possibly coronadite (gray). Dark background is mostly quartz. Sample AP-019, Silver Bell Mine.

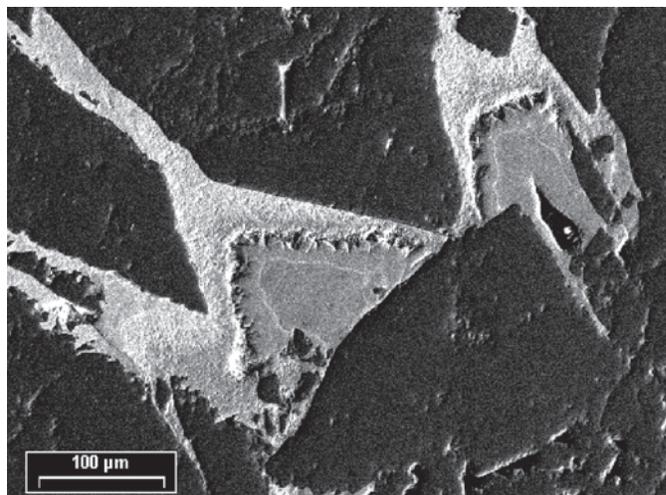
Tortoise ACEC (fig. 38). The Peyton Mine explores a quartz-galena-chalcopyrite vein that strikes north and dips 45 degrees to the west (Hewett, 1956). It has no recorded production. The Sundog Mine exploited quartz veins that contain bornite, chalcopyrite, and copper-oxide minerals, and it probably had a small amount of production, though none was recorded (Longwell and others, 1965).

### Big Tiger Prospect and Rest Mine

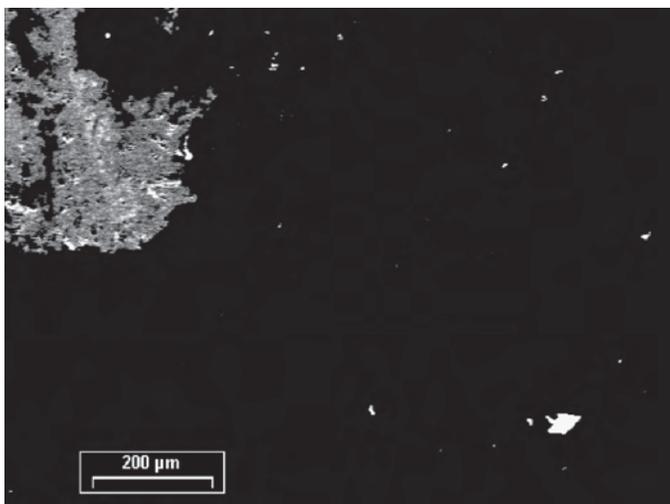
A linear band of enigmatic hydrothermal quartz-flooded rock extends from the Big Tiger prospect just east of the Crescent Townsite ACEC, slightly south of west a total of nearly 4 km to just west of the Nipton Red decorative stone quarry (fig. 46). This quarry occupies the site of a small gold opera-



**Figure 43.** Cross-polarized photomicrograph of hemimorphite (mostly birefringent in orange and red colors) with opaque manganese oxide minerals in comb quartz, sample AP-019, Silver Bell Mine. Horizontal field of view is about 3 mm.



**Figure 45.** Secondary electron image of manganese-oxide minerals in sample AP-024. Dark gray area is mostly quartz, the late medium gray mineral is an unknown manganese-oxide phase with lead and potassium, and the bright mineral is a lead-bearing manganese-oxide phase, possibly coronadite.



**Figure 44.** Backscattered electron image showing electrum grains in lower right and a gray mass of hemimorphite with bright inclusions of acanthite and silver and mercury sulfide (imiterite?) in upper left. Quartz (black) contains some tiny bright grains of Fe-bearing sphalerite near the hemimorphite mass. Sample AP-019, Silver Bell Mine.



**Figure 46.** The Nipton Red decorative stone quarry, the apparent site of the Rest Mine in 1979. This is the west end of the band of silica-rich alteration that extends eastward to the Big Tiger prospect. Note abundant red hematite alteration.

tion that was apparently active in the late 1970s, the Rest Mine (Nevada Division of Mine Inspection, 1977). In 1982, Crescent Mining Ltd. was conducting a small cyanide heap leach operation less than a kilometer away (Gese, 1984), but we have no direct information that it was treating material from the Rest Mine.

The Big Tiger prospect was the chief area of interest in 1905-6, when Crescent was visited by Ransome (1907). He interpreted the mineralized rocks to be a “mass of shattered

quartzite that has been recemented by quartz and carries more or less gold and silver.” He reported that assays indicated values as high as \$12 per short ton (corresponding to about 0.6 opt or 20.5 ppm gold at the 1907 price). There is abundant hematite and rare malachite in the matrix of this breccia. Ransome also reported similar material at the Calavada property, which is described as being “3 miles southwest of Crescent, on the other side of a gneiss ridge.” This description would put the location well into California, in an area where

only Tertiary mafic volcanic rocks crop out. If he meant road miles, the location is likely the same as what is now known as the Lily Mine, the White Horse Mine, and the B.T. prospect (U.S. Bureau of Mines, 1990). Rocks at these deposits were described as silicified breccias by Gese (1984) and U.S. Bureau of Mines (1990) and yielded gold values as high as 0.48 opt (about 16 ppm) gold in select samples. This area was probably the focus of the large exploration program by Newmont Exploration, Inc., in the early 1990s, in sections 31 and 32 of T28S, R61E and section 6 of T29S, R61E.

## Lucky Dutchman Mine

Today the Lucky Dutchman Mine is being exploited for decorative stone, but it was exploited prior to 1927 for gold (Hewett, 1956). It is about 3 km northwest of Crescent (fig. 38), and it exposes altered and silicified gneiss with abundant hematite that contains moderately southward-dipping calcite-, barite-, and fluorite-bearing veins. Two samples analyzed by Tingley (1998) contain about 11 and 5 ppm gold, with relatively low silver and base metal contents. Our samples (table 5) of barite-quartz and barite-fluorite veins have low precious- and base-metal contents.

## Double Standard Mine

The Double Standard Mine is about 1.5 km northwest of the Lucky Dutchman (fig. 38) and within the Piute-Eldorado Tortoise ACEC. A sample there (AP-041, table 5) from a steeply north-dipping bleached and limonite-stained structure cutting gneiss contains 11.5 ppm gold, 154 ppm silver, and nearly 1,300 ppm arsenic. An unnamed small dump about 400 m east of the Double Standard yielded a sample (5-030701, table 5) that contains 1.6 ppm gold but low silver and arsenic. About a kilometer north of the Double Standard, an unnamed prospect yielded a sample (AP-042, table 5) that contains 4.8 ppm gold, 150 ppm silver, 500 ppm lead, 194 ppm arsenic, and 14 ppm antimony.

## Red Star Group and Last Chance Claim

These two prospects are located about 4 km east of the Double Standard, within the Piute-Eldorado Tortoise ACEC (fig. 38). The Red Star is described by Longwell and others (1965) as a quartz vein in Proterozoic rocks. We did not visit either of these areas.

## Nippeno and Cumberland Claim Groups

These two vein deposits are in close proximity about a kilometer southeast of the Piute-Eldorado Tortoise ACEC boundary and about 2 km east of the Crescent Townsite ACEC, between Nevada State Highway 164 and Crescent Peak (fig. 38). The Nippeno was a small producer in the

1930s, with a total production for that period of 538 oz of gold and 294 oz of silver (Longwell and others, 1965; Hewett, 1956). The Cumberland had a very small production of about \$1,000 (Vanderburg, 1937). Both deposits are gold-rich quartz veins with moderate amounts of base-metal sulfides.

## Crescent Peak Porphyry Copper Prospect

During both the 1950s and 1960s, the area centered on Crescent Peak was explored as a porphyry copper prospect (fig. 38). Most of our information about this prospect is from Archbold and Santos (1962). A large area about a kilometer in diameter is characterized by coarse sericitic hydrothermal alteration in a medium- to coarse-grained granite that is probably Proterozoic in age. In the center of the altered area is a zone of argillic alteration where clay minerals occur along with fine-grained sericite. Milky quartz veins 5 to 30 cm thick occur throughout the area as well. Boxwork casts of former sulfides are found throughout this altered area, and traces of copper-oxide minerals are found in a few places. Surface sampling yielded scattered values of copper in the hundreds of parts per million and molybdenum in the tens of parts per million. The age of this mineralized system has not been directly determined, but it is likely that it is related to the Cretaceous granodiorite intrusions dated by Miller and Wooden (1993) at 94.4 Ma using conventional K-Ar methods.

Six diamond drill holes in the system penetrated to depths of as much as 300 m. Individual 10-ft intervals contained as much as 0.11 percent copper, but values of a few hundred parts per million were most common. Similarly molybdenum values as high as 0.12 percent were encountered, but most intervals contained between 50 and 150 ppm.

On the north side of the porphyry system, the Gingerload prospect appears to explore a polymetallic vein rich in gold and platinum-group elements (PGE) that is peripheral to the porphyry system. The determination by Lechler (1988) of values of as much as 650 ppb platinum in samples from the Gingerload resulted in a flurry of interest in the area, but no PGE resources have been discovered.

## Fluorspar and Silver Deposits Southwest of Crescent

At the southwest margin of the district, primarily in California, there are a number of small (most less than 3 cm wide) fluorspar veins that cut the Proterozoic gneiss, strike about N80E, and dip nearly vertically (Gese, 1984). Most are unnamed but have been known collectively as the Mc Dermott fluorspar deposit, the Blue Crystal prospect, and the Nipton prospect. The Blue Crystal block of 67 claims was active in 1982, but no mining was underway. The veins contain copper-oxide and carbonate minerals, and some veins contain as much as about 1 ppm gold and 1,000 ppm copper (Gese, 1984). The age of these veins relative to the gold deposits in silicified and brecciated gneiss is not known.

## Sunset District

This district contains only one major deposit, the Lucy Gray, which is about 2 km outside the boundary of the Piute-Eldorado Tortoise ACEC. The Lucy Gray is a polymetallic vein deposit of unknown age that has received repeated attention in the second half of the 20<sup>th</sup> century. Most recently, the Wild Bill Nos. 1, 6, and 7 were located by William Fuller in 1995 and are still active in 2005. These claims are at least partly within the Piute-Eldorado Tortoise ACEC. The Lucy Gray itself, although showing some promise during earlier exploration efforts, is too far from the ACEC boundary to impact potential resources in the ACEC.

## Hart District

The Hart district is mostly in California, but several of the deposits are quite near the west boundary of the Piute-Eldorado Tortoise ACEC and the host rocks for the deposits in the district are exposed in the Castle Mountains, immediately adjacent to the ACEC, in the western part of the region. Although there was minor gold mining in the district in the early part of the 20<sup>th</sup> century, the Viceroy Mine was the most important producer. Mining at the Viceroy Mine from 1992 until 2001 recovered about 1.2 million troy ounces of gold. The deposit can be classified as a low-sulfidation epithermal deposit and consisted of several discrete orebodies, with gold in quartz stockwork veins. The deposit was briefly described by Linder (1989), and the geologic setting of the district was described by Capps and Moore (1997).

## Other Deposits of Locatable Minerals

A number of minor metal prospects were described by Close (1987) in the McCullough Range, mostly several kilometers west of the Piute-Eldorado Tortoise ACEC. The War Lord prospect, the nearest one (1 km) to the ACEC boundary, was described as a northeast-striking quartz vein in Proterozoic gneiss containing small amounts of malachite and scheelite. The Hacienda prospect, which is adjacent to the northeastern part of the Piute-Eldorado Tortoise ACEC, appears to be an oxidized gold-rich polymetallic vein that strikes northwest in Proterozoic gneiss and was traceable for about 200 m.

The Mammoth Mine, located about 9 km southeast of the town of Searchlight, is a small shaft located at the contact between Proterozoic gneiss and overlying Peach Springs Tuff. The mine is known only from its presence on the 1:24,000-scale topographic map. We saw no evidence of mineralized rock on the small dump, and a sample of Peach Springs Tuff taken nearby showed no anomalous metals.

## Perlite

Nevada has large perlite resources and several deposits that were mined extensively in the past. The Hollinger Mine near Pioche in Lincoln County was the largest producer,

with production of as much as 40,000 short tons per year in the 1950s. However, current Nevada perlite production is restricted to relatively small-scale mining of two deposits. In Lincoln County, Wilkin Mining and Trucking, Inc., mines perlite from the Tenacity (Mackie) Mine and has a small plant that produces relatively coarse expanded perlite useful in horticultural applications. It currently produces about 1,500 to 2,000 short tons of expanded perlite per year. Eagle-Picher Minerals, Inc., produces expanded perlite that is marketed as filter aid from perlite mined in northern Nevada. The plant capacity is reportedly about 8,000 tons per year (Castor, 2005a). By contrast, the largest domestic perlite producer is a mine at No Agua Peaks in New Mexico that yields about 200,000 short tons per year. Other mines in New Mexico, Oregon, and Utah produce more than 20,000 short tons per year (Barker and Santini, 2006).

Two perlite deposits are in or near the Piute-Eldorado Tortoise ACEC. Both are in rhyolite flows or domes in Miocene (15 to 16 Ma) volcanic rock sequences. Neither is being mined currently, but each has had production in the past.

The Searchlight Insulation Products (Perlite Ridge) Mine, which is about 5 km north of the town of Searchlight, is in a small inholding of private land within the Piute-Eldorado Tortoise ACEC (fig. 21). It produced 300 to 600 short tons of crude perlite annually in the 1950s, and consists of three small open pits (fig. 47). The largest is the north pit, which is about 30 m long, 10 m wide, and 5 m deep. Most of the perlite here is hard, gray, granular rock that occurs as clasts in friable white perlite. It contains trace amounts of purplish devitrified material in small masses and discontinuous veinlets. The north pit is near the northeast end of a mass of perlite that is bounded on the northwest by a near-vertical fault. About 300 m to the southwest is a 35 m x 10 m x 3 m pit in similar perlite that appears to be part of the same mass. A smaller pit



**Figure 47.** Aerial photograph of Searchlight Insulation Products property, showing north and south pits.

containing nearly pure granular perlite lies between the two pits. On the basis of our field examination, the perlite mass that contains these pits is about 600 m long and 100 m wide. It extends south-southwest into the ACEC. It is likely a rhyolitic flow that dips steeply to the northwest. We estimate reserves at about 1.2 million short tons to a depth of 10 m with little waste removal. Cochran (1951) estimated indicated reserves of good quality, granular perlite at about 10 million short tons, but reported that the deposit consisted of two masses, one 1,500 ft x 240 ft x 21 ft and a second 2,600 ft x 500 ft x 100 ft.

Perlite that we collected from the Searchlight Insulation Products deposit (AP-301 and AP-302, table 6) is light-gray granular rock with sparse feldspar and biotite phenocrysts, silica contents (72.6 to 74.0 percent) typical of rhyolite, and

LOI (loss on ignition) of 3.6 to 5.1 percent. In these samples, LOI values mostly represent combined water contents, and perlite is defined as having 2 to 5 percent combined water (Barker and Santini, 2006). Our samples from the Searchlight deposit have high expanded density when compared with perlite from the large No Agua perlite deposit in New Mexico and with other Nevada perlites (table 6). Sinks (unexpanded material) for Searchlight perlite are moderate to high and coarse expanded perlite sizes are low. Brightness is low relative to the No Agua perlite, but comparable to other Nevada perlites. The results do not show that perlite from the deposit is noncommercial, but they suggest that it would find limited markets. For example, it would likely not be usable in horticultural or loose-fill insulation applications, which require relatively

**Table 6.** Physical and chemical properties of perlite samples.

[Test data are for perlite expanded at 1300°F without preheat using -50+100 mesh samples. Sieve analyses of expanded perlite are reported as percent of sample retained at each mesh size. Testing by New Mexico Bureau of Geology and Mineral Resources. The testing parameters (for example, temperature, sizing) are optimized for testing perlite from No Agua; somewhat different results might be obtained using a modified methodology.]

Sample	SiO <sub>2</sub> (%)	LOI (%)	Furnace Yield (%)	Expanded Density (lbs/ft <sup>3</sup> )	Avg. Bright (%)	Sinks (%)	Percent Expanded Retained (Tyler Mesh)						
							+20	+30	+50	+70	+100	+140	-140
AP-10A	73.6	4.0	77	1.94	52.1	22.2	1.0	9.4	30.5	14.2	10.8	11.4	22.7
AP-10B	71.0	5.1	88	2.27	55.5	9.6	1.9	17.9	41.1	10.5	7.4	6.8	12.4
AP-45	73.3	4.3	68	1.97	60.1	8.4	0.6	6.0	29.9	17.2	12.5	13.0	20.8
AP-119	72.3	3.8	92	2.06	52.5	4.8	20.1	34.0	33.7	5.6	2.5	1.3	2.8
AP-120	72.8	3.4	96	2.05	50.8	9.0	1.0	8.4	33.1	16.8	12.0	10.3	18.4
AP-121	74.1	3.8	86	2.04	52.8	12.0	2.4	16.7	34.5	16.1	9.8	2.1	17.4
AP-122	73.1	4.0	85	2.52	57.2	7.0	16.2	27.4	38.7	7.5	35.0	1.9	4.8
AP-124	72.1	4.0	96	3.05	42.4	0.6	8.1	42.1	42.9	3.2	1.1	5.0	2.1
AP-186	70.8	5.1	95	2.26	57.2	10.2	16.8	33.3	36.0	8.4	3.3	2.1	3.1
AP-301	72.6	5.1	84	3.03	56.0	26.2	1.0	12.1	35.9	16.5	11.7	7.7	15.1
AP-302	74.0	3.6	90	2.80	59.2	11.4	2.8	12.5	35.1	16.5	10.3	9.5	13.3
AP-303	73.3	3.7	90	3.79	62.3	14.2	1.6	21.8	52.0	11.4	4.0	3.0	6.2
Std.			99	1.87	72.4	6.8	9.9	41.0	37.4	2.9	2.1	4.0	2.7
Std.			99	1.54	70.6	2.4	19.4	42.5	30.7	3.2	1.9	1.5	0.8

Sample locations and descriptions:

- AP-10A—grab sample, friable perlite, Nu-Lite Mine, Clark County, Nevada
- AP-10B—5-m chip, friable perlite, Nu-Lite Mine, Clark County, Nevada
- AP-45—select grab sample, granular perlite, NW, Searchlight Perlite Mine, Clark County, Nevada
- AP-119—grab sample, granular perlite, Tenacity pit, Mackie Mine, Lincoln County, Nevada
- AP-120—select grab sample, onionskin perlite, Mackie Mine underground, Lincoln County, Nevada
- AP-121—grab sample, granular perlite, main pit, Hollinger Mine, Lincoln County, Nevada
- AP-122—grab sample, granular perlite, east pit, Hollinger Mine, Lincoln County, Nevada
- AP-124—grab sample, granular perlite with obsidian cores, Lovelock perlite pit, Pershing County, Nevada
- AP-186—select grab sample, granular perlite with phenocrysts, River Mountains, Clark County, Nevada
- AP-301—grab sample, granular perlite, north pit, Searchlight Perlite Mine, Clark County, Nevada
- AP-302—grab sample, granular perlite, south pit, Searchlight Perlite Mine, Clark County, Nevada
- AP-303—grab sample, granular perlite, outcrop east of north pit, Searchlight Perlite Mine, Clark County, Nevada
- Std.—perlite from two No Agua, New Mexico, deposits

coarse perlite (Barker and Santini, 2006). It would not be useful in most construction applications, which require perlite with expanded densities of less than 2.5 lbs/ft<sup>3</sup> (M. Houseman, oral commun., 2006). Perlite from this deposit could find applications in uses that do not require low expanded density and large particle size, such as in filter aids. It might find markets in uses that require fine perlite, but its low brightness might preclude its use in some products.

Perlite at the Searchlight deposit occurs in a rhyolite flow of the middle rhyolitic unit of the volcanics of the Highland Range (Faulds and others, 2002a). Our reconnaissance of these rocks revealed that perlite is locally abundant, but most of the perlite that we found was moderate to dark-gray rock with relatively high phenocryst contents. A sample from a 30- to 60-m-wide perlite zone about 0.5 km northwest of the Searchlight deposit (AP-45, table 6) had similar brightness and expanded size distribution to perlite from the Searchlight deposit but considerably lower expanded density. However, this sample was selected to represent the purest material available, and much of the perlite in this mass contains variable amounts of non-glassy rock, particularly in the form of spherulites (fig. 48) that would decrease its value as commercial perlite.

The Nu-Lite Perlite Mine is on the east flank of the Castle Mountains about 17 km southwest of Searchlight near the California State line. It is about 200 to 300 m outside the Piute-Eldorado Tortoise ACEC. The deposit was mined between 1948 and 1954 by Nu-Lite Insulated Homes, Inc., and produced as much as 600 short tons of crude perlite annually. The mine consists of a shallow open pit about 20 m in diameter in a west-northwest striking and shallowly north dipping, possibly intrusive mass that is nearly 1 km long and 100 m wide. Other small open cuts occur in this zone. In addition, perlite occurs as a shallowly dipping rhyolite flow as much as 50 m thick that occurs in places atop a thick sequence of light colored bedded tuffs and beneath a



**Figure 48.** Spherulites in perlite near the Searchlight perlite deposit.

sequence of devitrified rhyolite flows and domes. Capps and Moore (1997) reported ages of about 15 Ma for these rhyolites. They have mapped the perlite within a unit of rhyolite autoclastic breccias, block and ash flows, and pumice flows. The perlite-bearing unit has been locally prospected both in Nevada and California, in places by underground workings. Neither our mapping or that of Capps and Moore (1997) shows any nearby exposures within the Piute-Eldorado Tortoise ACEC, although these same rhyolites crop out in the ACEC about 3 km to the northeast.

We collected two samples of perlite from the small Nu-Lite pit. Both are of friable, light-gray to white perlite that ranges from breccia (fig. 49) to nicely flow-banded rock (fig. 50). Testing of these samples yielded expanded density approaching that of the No Agua perlite; but the Nu-Lite perlite has similar expanded size distribution to, and lower brightness than, expanded Searchlight Insulation Products perlite (table 6). These data suggest that it would face some



**Figure 49.** Perlite breccia, Nu-lite Mine. Fragments of light-gray, moderately resistant perlite in white friable perlite.



**Figure 50.** Pure, friable, flow-banded perlite, Nu-lite Mine.

of the same marketing challenges faced by the Searchlight perlite, but its low expanded density indicates that it could be used in construction applications.

## Stone

Crushed stone is mined from several deposits in private inholdings within and areas adjacent to the Piute-Eldorado ACECs. The stone is used as decorative landscape rock in Las Vegas where the market is relatively large because Clark County imposed a ban on grass front lawns for newly constructed residences in 2003. This has resulted in a substantial market for crushed stone in the Las Vegas metropolitan area. Colored decorative aggregate from quarry locations as distant as Searchlight now commands a price of \$8/short ton or more (depending on color) at quarry sites, and selected boulders sell for as much as \$30/short ton (Castor, 2005b). Prices are higher for material delivered in Las Vegas where single decorative boulders sell for as much as \$400.

The largest decorative crushed stone producers in the Las Vegas region are the El Dorado operation of Rinker Materials at Railroad Pass and the Rainbow Quarries of Las Vegas Rock north of Goodsprings. Exact tonnages of decorative stone produced at these operations are not known, but we estimate them to be on the order of 200,000 short tons per year. In addition to use in residential and commercial landscaping projects, crushed stone from these operations is used along newly constructed highways in the Las Vegas area. The operations are commonly on old patented gold mining claims and thus on lands under private ownership. They include moderate sized operations at the Roman Mine in the Newberry Mountains, which is on unpatented claims about 2 km from the boundary of the Piute-Eldorado Tortoise ACEC (fig.

34), and at the Pompeii Mine directly north of Searchlight, which is about 100 m south of the ACEC boundary (figs. 21, 51). The rock from these operations is of various colors, including gray, light yellowish gray, and pale red. Smaller operations include at least three producers in the Crescent district—the John Yeager operation; the Lucky Dutchman Mine (figs. 38, 52); and the Modoc Mine (fig. 38). These operations are apparently all within the boundaries of old mining claims that were patented as gold claims. In addition, there is an inactive operation on private land just south of the Crescent townsite. Most of the rock from these producers is pale red, light pink, and purplish gray, colors that apparently bring premium prices in Las Vegas and are due to the presence of hematite in altered Proterozoic rocks.

## Turquoise

Turquoise was mined extensively from the Simmons (Toltec) Mine on the south side of Crescent Peak about 3 km outside the Piute-Eldorado ACEC beginning in the late 1890s (fig. 38). According to Morrissey (1968), the total value of turquoise taken from this mine may have exceeded \$1 million, and the deposit showed evidence of prehistoric Native American mining.

A less-productive turquoise mine, the Morgan (Iron Door) Mine is within the Crescent Townsite ACEC (fig. 38). Our examination disclosed a small open pit and an adit (fig. 53). The turquoise, which is light blue to greenish blue, occurs as irregular veins as much as 5 mm thick in white to brown altered and limonitized granitic rock (fig. 54). Several hundred pounds of gem-quality turquoise were produced from the mine in 1906 (Morrissey, 1968). Turquoise such as that shown in figure 54 can still be found on the dumps at this site.



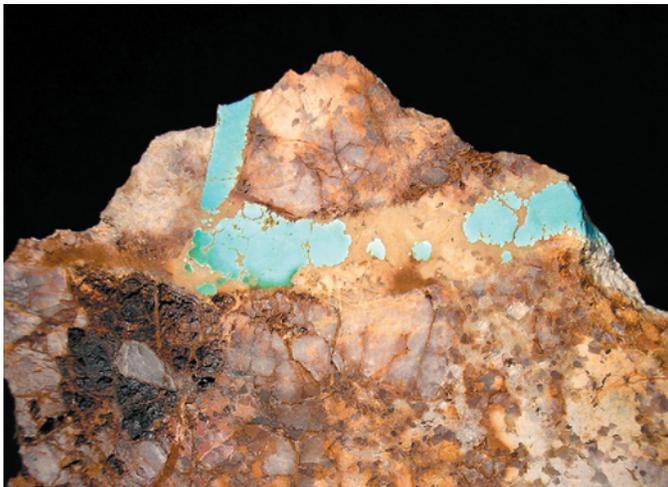
**Figure 51.** Quarries and access roads at a decorative stone operation north of Searchlight. The Piute-Eldorado Tortoise Area of Critical Environmental Concern lies just to the north of the northern pit.



**Figure 52.** Crushing and screening equipment with light pink to purplish-gray decorative stone stockpiled at the Lucky Dutchman Mine, Crescent district.



**Figure 53.** Portal of the Iron Door (Morgan) Turquoise Mine in the Crescent Townsite ACEC. A small open pit is out of the picture on the upper right.



**Figure 54.** Turquoise vein in altered and limonitized granitic rock, Iron Door Mine, Crescent Townsite ACEC. Horizontal field of view about 5 cm.

## Mineral Exploration and Development

Although most metal mining activity has been greatly reduced since World War II, the Piute-Eldorado ACECs have been the site of a number of mineral exploration programs since that time, and they are still the focus of some mineral exploration today. There are a number of current and recently current mining claims in the area. Our information was gathered in the Spring of 2006.

### Crescent District

Most of the mineral exploration and development in this area appears to have taken place since the visit of Vanderburg (1937), as he did not mention most of the patented claims now present in the district.

A prominent area of hydrothermally altered rocks centered on Crescent Peak was explored during the 1950s and early 1960s as a porphyry copper prospect. Drilling of at least seven holes to depths of more than 300 m was conducted at that time by Bear Creek Mining Company and Homestake Mining Company. No ore-grade material was found, but sporadic occurrences of copper values  $>1,000$  ppm and molybdenum values  $>300$  ppm in the analyzed drill core seems to confirm the existence of a large mineralized body that can be characterized as a porphyry copper deposit. Although analyses for precious metals were made only on 50-foot composite samples, the precious-metal content of the rock appears to be low. Widespread phyllic alteration and some anomalous copper concentrations in surface samples were the basis for the exploration effort. Curiously, the age of this mineralization is still completely unknown. No radiometric age determinations have been made, and the geologists working in the area at that time were unable to map a post-Proterozoic intrusion within the altered area. Miller and Wooden (1993) mapped and dated a Cretaceous granodiorite about 4 km to the west, and they tentatively suggested that this rock may be present within the mineralized area at Crescent Peak.

Most of this area is about 3 km outside the boundaries of the Piute-Eldorado Tortoise and Crescent Townsite ACECs. Subsequently, Houston International Minerals held claims in this area from 1983 to 1993, but we have found no documentation of their exploration activity or findings. A small company proposed mining gold ore from the surface just north of Crescent Peak in the early 1980s, but they apparently never conducted the operation. The 1988 publication that platinum-group elements were present in mineralized rock from the Gingerload Mine (Lechler, 1988), on the north flank of Crescent Peak, sparked renewed activity. In section 23 of T28S, R61E, near the Sundog Mine on the northeast flank of Crescent Peak, about 2 km outside the Piute-Eldorado Tortoise ACEC, drilling was conducted in 1989 by Francis Friestad and Mark Davis, with unknown results. In 1991, Westland Mineral Exploration Company drilled two holes just west of Crescent Peak, between the Gingerload and Nippeno Mines, with

unknown results. Subsequent attempts to organize mining and exploration ventures at Crescent Peak have been unsuccessful.

In the early 1990s, Newmont Exploration Ltd., in conjunction with Westland Minerals Exploration Co. and Stena Resources, conducted exploration on a large claim block about 4 km southwest of Crescent townsite, near the California border. The results of the work are unknown, but the exploration was probably for gold in the area described by Ransome (1907) as the Calavada claims. In 1992, a resource of 390,000 short tons at 0.05 opt gold, or 3.3 million short tons at 0.022 opt gold was reported by Westland Minerals Exploration Co. for their Crescent properties, but we do not know exactly to what deposit(s) they referred (Nevada Bureau of Mines and Geology, 1994).

At about the same time, a company called Nevada Noble Metals explored the Susie Q claim block that is partly within the Piute-Eldorado Tortoise ACEC, about 2 km north of the Silver Bell Mine in sections 9 and 10 of T28S, R61E. Immediately to the west, Eldorado Mining Co. explored the Silver Lady claims, as well as an area between the Silver Bell and Nippeno Mines. Also within the Piute-Eldorado Tortoise ACEC, Houston International Minerals conducted exploration on the alluvium-covered area between the Lucky Dutchman Mine and the Crescent townsite in 1983. We have no information on the nature of the target or of the results for any of these exploration programs.

In 2005, there were 43 current lode claims and 3 current millsite claims along the corridor where Nevada State Highway 164 crosses the south end of the McCullough Range. Many of these are at least partially within the Piute-Eldorado Tortoise and Crescent Townsite ACECs. At the east end of the district, in sections 10, 15, 16, and 21 of T28S, R61E, the Rainbow's End group of 31 claims is owned by Stanley Pierce, Michael Sean, Katherine Pierce Denos, and Diana Kirtley; these have been maintained for nearly 15 years, and we presume their target is gold. In addition, in section 25 of T28S, R60E, the Silver Crescent millsite claim has been maintained since 1994 by Norma Pierce Oppenheimer. In section 20 of T28S, R62E, two millsite claims have been maintained by James Skidmore since 1983. A single claim in section 10 of T28S, R61E has been maintained by Saylor Dean since 2001. Two claims in section 21 of T28S, R61E have been maintained by Fuller Gulliosa since 2001. The Gold Nos. 11, 14, and 15 have been maintained in section 30 of T28S, R61E by John and Sally Denton since 1984. At the west end of the district, at the south end of the Lucy Gray Mountains in sections 10 and 16 of T28S, R60E, 3 claims (the Wild Bill group) have been maintained by William Fuller since 1995.

## Searchlight District

Interest in the Searchlight district has never totally disappeared, and there are a number of active mining claims in the area, some of them reflecting the interests of mining and exploration companies, and others the interests of individual

prospectors. Two areas on the margins of the Searchlight district within the Piute-Eldorado Tortoise ACEC are the objects of active exploration programs by mining companies.

A large block of more than 100 claims (45 in our database) was located in 2003–2005 by Desert Pacific Resources, Inc., in sections 15, 16, 17, 20, and 29 of T28S, R63E. This claim block (the 'VES' group) is partly within the Piute-Eldorado Tortoise ACEC, immediately north and west of the Searchlight district, and it is known as the Copper Hill project. The claims are presently (spring, 2006) under option to Great Western Minerals Group Ltd., and are being actively explored.

A group of 20 claims were located in 2004 by William R. Stanley, within the Piute-Eldorado Tortoise ACEC, directly north of the Searchlight district, in sections 14 and 15 of T28S, R63E. This claim block (the Searchlight Bonanza group) is being explored by Atna Resources Ltd. In addition, Coyote Mines, Inc., has held 1 claim nearby in sections 14 and 15 of T28S, R63E since 1994.

A major exploration program was mounted by Southwestern Exploration Associates, Inc., on behalf of the Felmont Oil Corporation in 1979–81. Homestake Mining Company acquired Felmont Oil during this effort. A large area west of the historic part of the Searchlight district was mapped at 1:6,000 scale, several hundred surface geochemical samples were collected and analyzed, and a total of 29 holes were drilled using reverse circulation methods. Only sporadic gold anomalies were encountered in these holes, which were designed specifically to test the possibility for disseminated low-grade precious-metal ore. A more surprising result was elevated levels of copper in several of the holes, at depths of about 100 m. Intervals containing in excess of 200 ppm copper were encountered in 6 of the holes, compared to background values of less than 50 ppm.

## Areas North of Searchlight

Two claims (Canaan), located by Pete Baldonado and Richard H. Culmer, near the north end of the Highland Range, in sections 26 and 27 of T26S, R62E, have been current since 1985. A claim located by Joan Sullivan in the Eldorado Mountains near the Rockefeller Mine and Cobalt claims, in section 25 of T27S, R64E, has been current since 2003. A placer claim, located by Robert Anderson and Douglas E. Noland, near Nevada State Highway 164 west of the Searchlight district, in section 29 of T28S, R63E, has been current since 1994. Doris Atchison and a group of four other individuals hold a placer claim in section 7 of T28S, R 64E that was newly located in 2005. The claim is within the Piute-Eldorado Tortoise ACEC, about 10 km northeast of the town of Searchlight.

## Areas South of Searchlight

Three placer claims located by James E. Tinnell are near the Roman Mine in the Newberry Mountains, in section 21 of T30S, R65E. They have been current since 2003. A placer

claim and a millsite claim, located by Thomas E. Smigel, near Hiko Spring, in the southeasternmost part of the Piute-Eldorado Tortoise ACEC, have been current since 1997. The claims are in section 12 of T32S, R65 SE.

A group of 10 claims (the Big John group), located by Misra Shruti, along the west flank of the Newberry Mountains about 2 km north of the Juniper Mine, has been current since 1999. The claims are in section 24 of T31S, R64E. We took a single sample here of quartz-veined Proterozoic gneiss (5-050703) that did not contain anomalous metals (Ludington and others, 2005).

Four claims (the Search group) were located by four individuals in 1980 and were still current in 2005. These claims are in section 6 of T31S, R65E, on the pediment along the front of the Newberry Mountains about 2 km northwest of Christmas Tree Pass. We noticed some small pits in the areas but saw no evidence of hydrothermal mineralization. Two claims (the Blue Cloud group) were located in 2001 by Leslie W. Hopper, in section 32 of T31S, R65E. These claims are in granite of the Spirit Mountain batholith about 2 km southeast of the Juniper Mine.

A group of 9 claims (the Treasure Trove group) were located by Michael Steven and Stanley Pierce in 1981 and 1998, in sections 9, 10, and 16 of T32S, R64E. These claims are 2 to 3 km southeast of the junction of U.S. Highway 95 and Nevada State Highway 163 in the Chiquita Hills. They are, at least in part, within the Piute-Eldorado Tortoise ACEC and remained current in 2005.

## Placer Claims in Piute and Eldorado Valleys

In addition, most of the surface of Piute and Eldorado Valleys in the Piute-Eldorado Tortoise ACEC is covered by a group of hundreds of association placer claims staked in 1986, 1989, 1990, 1993, 1994, 1996, 1997, 1999, and 2000 under a variety of names. The claims appear to be all controlled by a group known as Cactus Gold Corp., of Surrey, British Columbia. The intention of this group is to recover precious metals that might occur in late Tertiary and Quaternary sediments. Their activities and exploration model came to our attention after field and laboratory studies for this assessment were complete.

## Mineral Resource Potential

### Locatable minerals in Piute-Eldorado Tortoise ACEC

The complex structural environment of the Piute-Eldorado Tortoise ACEC means that relating inferences about the size and shape of the original preextension mineral deposits is difficult and subject to different interpretations. The mineral resource potential tracts described in this section are subject to this caveat. Furthermore, because of suspected low-angle

faults with large displacements in the subsurface, these tracts are valid to depths of no more than a few hundred meters. As structural interpretations improve, it may become possible to identify tracts at greater depths. The tracts were delineated in the context of the entire mineralized system; those that are not within the ACECs are identified as such.

### Searchlight-Type Gold-Bearing Vein Deposits (Searchlight Area)

Many of the mines in the Searchlight District were abandoned because of changing economic conditions, and it is likely that modern exploration methods could find significant quantities of additional ore in the known part of the district. However, reassessment of the district in the light of our present understanding of the structural context for these veins, combined with the geochemical sampling we conducted, leads to the identification of additional areas that have the potential for the discovery of gold ore. Figure 55 shows areas that have potential for Searchlight-type gold-bearing vein deposits, as well as some other types of deposits.

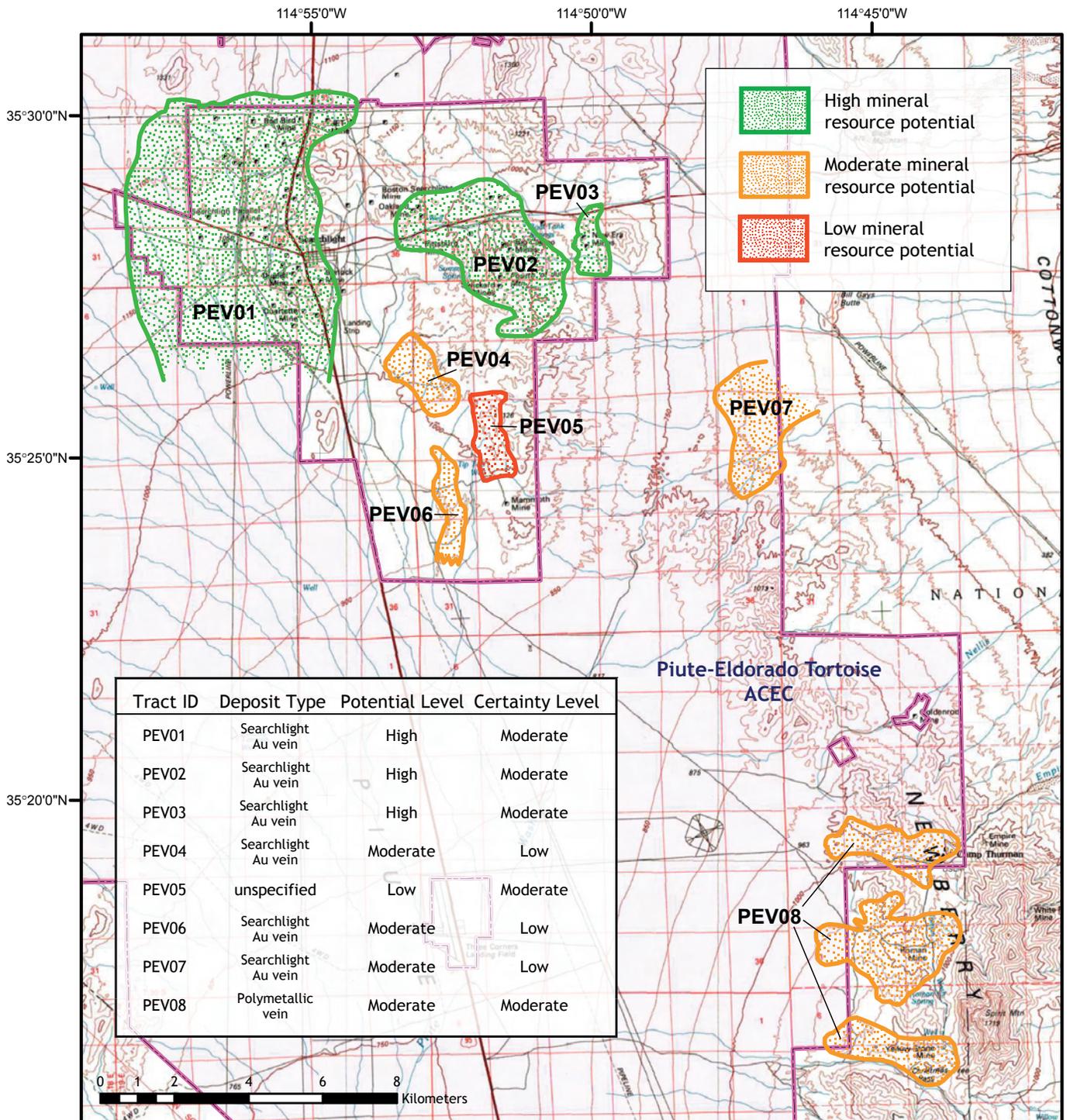
Tract PEV01 includes the mines that were productive in the 20th century, but it also includes areas to the west, originally above the roof of the Searchlight pluton. The tract has high potential for undiscovered Searchlight-type gold-bearing vein deposits, with a moderate level of certainty, and it includes all the environments where gold might have been deposited, based on studies of hydrothermal alteration (fig. 29) and geochemistry (fig. 31). Most of the area is outside the Piute-Eldorado Tortoise ACEC, but much of the outer parts of the tract are within the ACEC. The tract includes the hills underlain by alunite-bearing rhyolite west of the main part of the Searchlight district, and, although we found no significant amounts of precious metals in this altered rock, the rocks of the lower intermediate-composition unit of the volcanics of the Highland Range, which commonly host gold veins in the district, may underlie these hills at shallow depths. The position of the western limit of the tract is guided by the hydrothermal alteration west of the rhyolite hills and by the presence of >0.2 ppm gold in sample 5-110201 (Ludington and others, 2005). To the south, the identified rocks pass under Quaternary alluvium, and we lack any subsurface information that would allow the delineation of the southern limits of the tract. Further geochemical sampling near the margins of this tract would be required to raise the certainty level.

Tract PEV02 (fig. 55), which is centered on the Fourth of July Mountain area, is our interpretation of where this same environment is located in the Fourth of July structural block. It has high potential for undiscovered Searchlight-type gold-bearing vein deposits, with a moderate level of certainty. The samples taken at the Chief of the Hills Mine (5-031702 and 5-031703; Ludington and others, 2005) contain some of the highest gold values we obtained in this study, >15 ppm and 6.5 ppm, respectively. The area to the west of this mine is characterized by intense hydrothermal alteration, both illite

and quartz-alunite (fig. 29), and the limits of the tract are delineated primarily on the basis of this alteration, the high gold values obtained, and the structural setting just above the contact with the Searchlight Pluton. This tract is entirely outside the Piute-Eldorado Tortoise ACEC, but the south end is within 150 m of the ACEC boundary. Further geochemical

sampling could help modify the boundaries and increase the certainty level of this tract.

Tract PEV03 (fig. 55), about 2 km east of Fourth of July Mountain, includes the New Era Mines, delimits the analogous environment in the Pinto structural block, and has high potential for undiscovered Searchlight-type gold-bearing vein



**Figure 55.** Mineral resource potential tracts for gold-bearing deposits in the Searchlight area (Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC)).

deposits, with a moderate level of certainty. The volcanic rocks just above the quartz monzonite in the upper member of the Searchlight Pluton are altered to smectite clays, and the tract is delineated primarily on the basis of this alteration and the structural setting just above the contact with the Searchlight Pluton. None of the samples we took contained substantial amounts of precious or base metals, but they are variously anomalous in arsenic, antimony, and tellurium (Ludington and others, 2005). Interestingly enough, all the samples in this tract contained detectable platinum or palladium, although at levels less than 2 ppb. This tract is entirely outside the Piute-Eldorado Tortoise ACEC, but the south end is within 100 m of the ACEC boundary. Sampling in this area was sparse, and further geochemical samples could change the boundaries and certainty level for this tract.

Two areas in the Fourth of July structural block have moderate potential for undiscovered Searchlight-type gold-bearing vein deposits, with a low level of certainty (tracts PEV04 and PEV06, fig. 55). The northern one, PEV04, is about 2 km east of the Searchlight airport, and its boundaries are delineated primarily on the basis of inferred hydrothermal alteration, based on ASTER imagery (fig. 29). We did not sample this area. The other one (PEV06) is about 3 km further south, just to the south of Tip Top Well. The boundaries of this tract are similarly delineated using inferred hydrothermal alteration based on ASTER imagery, and passes to the south under the sediment that fills Piute Valley. Neither of these tracts is within the Piute-Eldorado Tortoise ACEC. These areas have been little studied, and field visits and geochemical sampling could help modify the tract boundaries and raise the certainty level.

Tract PEV05 (fig. 55) is also delineated on the basis of ASTER imagery, as well as petrographic studies. Rocks in this area seem to have abundant, but very fine-grained drusy quartz filling myriad internal fractures, but are otherwise little altered. One sample, 5-061103 contains only mildly anomalous precious-metal values (1 ppm silver and 0.01 ppm gold; Ludington and others, 2005). We designate the tract based on the coherent area of silica addition but have difficulty assigning a mineral deposit model. The tract has low potential with a moderate level of certainty; it is also not within the Piute-Eldorado Tortoise ACEC.

Tract PEV07 (fig. 55) also has moderate potential for undiscovered Searchlight-type gold-bearing vein deposits, but with a low level of certainty. It lies partially within the Pinto structural block and partially within the Bill Gays structural block. It is delineated on the basis of inferred hydrothermal alteration based on ASTER imagery, on the structural setting, and on some curious geochemistry in the only sample we took from the area (5-060702, Ludington and others, 2005). This sample is a brecciated rhyolite that has been subjected to strong argillic alteration. Kaolinite is the chief alteration mineral. The sample contains 0.68 percent sulfur and 24 ppm tungsten. The area is mostly within the Piute-Eldorado Tortoise ACEC and partly within the Lake Mead National Recreation Area and Nellis Wash Wilderness. Further study of this remote area is necessary to refine the assessment.

## Gold-Bearing Vein Deposits North and South of Searchlight

Tract PEV08 (fig. 55) also has moderate potential for undiscovered gold-rich polymetallic vein deposits with a moderate level of certainty. This tract is well to the southeast (20 km) of Searchlight, and it is entirely in Proterozoic granitic and metamorphic rocks. It contains the area surrounding Camp Thurman, where the mines are known variously as the Potential Mine, the Yarmouth Mine, and the New Deal Mine. A sample from the dumps in this area contained 9 ppm gold and 3 ppm silver (4-050304; table 4 and Ludington and others, 2005). ASTER imagery shows a linear band of hydrothermal alteration extending from Camp Thurman west to the range front, an area about 3.5 km long and about 800 m wide. Two areas farther south, near the Roman Mine, show similar ASTER signatures. Our field examination and PIMA studies of these areas confirmed that the rocks are altered to clays and illite and stained with iron oxide. Chemical analyses of rocks from these areas show only weakly anomalous Ba, Li, Mo, Zn, P, Sn, and Y. None of the samples (aside from one from the Potential dump) showed elevated precious metals. Many areas within the tract show scattered quartz veining. Parts of all three areas delineated as tract PEV08 extend into the Piute-Eldorado Tortoise ACEC. The parts within the ACEC were not sampled, and further study could help refine the tract boundaries and raise the certainty level.

Although the area has been prospected to a moderate degree in the past, the deposits at the Sazarac patented claim group (Rockefeller Mine) and the Cobalt claims (figs. 19, 56) have yielded gold values that merit the designation of mineral resource potential for the area. Tract PEV19 (fig. 56) has moderate potential for detachment-fault-related gold deposits, with a moderate level of certainty. The tract is partially within the Piute-Eldorado Tortoise ACEC and partly within the Lake Mead National Recreation Area. More detailed geochemical sampling could help refine the boundaries of this tract and increase the certainty level.

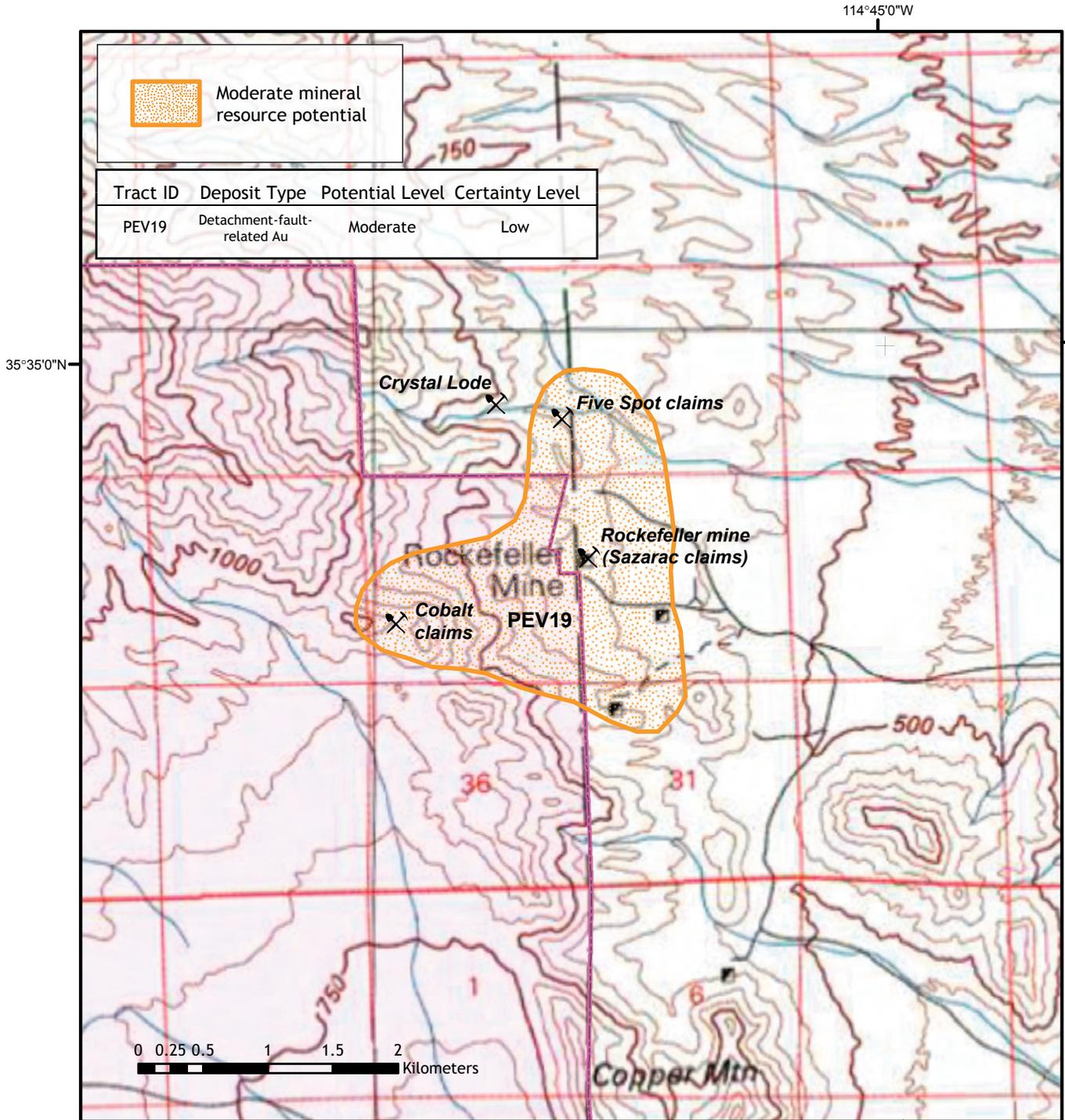
Significant gold values are also present in samples from the Juniper Mine (fig. 33), and from the Superfluous and Gibraltar claims (fig. 35), and these areas definitely have potential for the development of additional resources. Tract PEV18 (fig. 57) has moderate potential for gold-bearing polymetallic vein deposits, with a low level of certainty. The low level of certainty applies to the spatial accuracy of the delineation; this is because no large area of hydrothermally altered rock is associated with these deposits, and we can identify no other features to guide the delineation of tracts.

## Porphyry Copper Deposits (Searchlight Area)

Evaluation of the possibility for existence of a porphyry copper deposit beneath the Searchlight mining district is based primarily on results of the exploration program carried out by Felmont Oil Corporation and Homestake Mining Company

in 1979–81. They conducted an extensive surface sampling program to complement the 41 shallow drill holes. The surface sampling and the drill holes yielded disappointing results for gold and silver, as no indications of low-grade disseminated deposits were found. However, several of the drill holes intersected zones of copper mineralization, and one in particular revealed more than 30 m with greater than 1,000 ppm copper and a corresponding increase in sodium and decrease in potas-

sium. Drill logs suggest that the copper-rich zone is in a rhyolite breccia altered to a quartz-alunite-topaz assemblage. Pyrite is found in this lower zone, instead of hematite. Although it is critical to the structural interpretation, it is not clear whether this breccia is intrusive and post-tilting or not. We interpret the mineralization to be pre-tilting like the gold mineralization, and therefore, any porphyry deposit would be rotated 90 degrees and lying on its side.

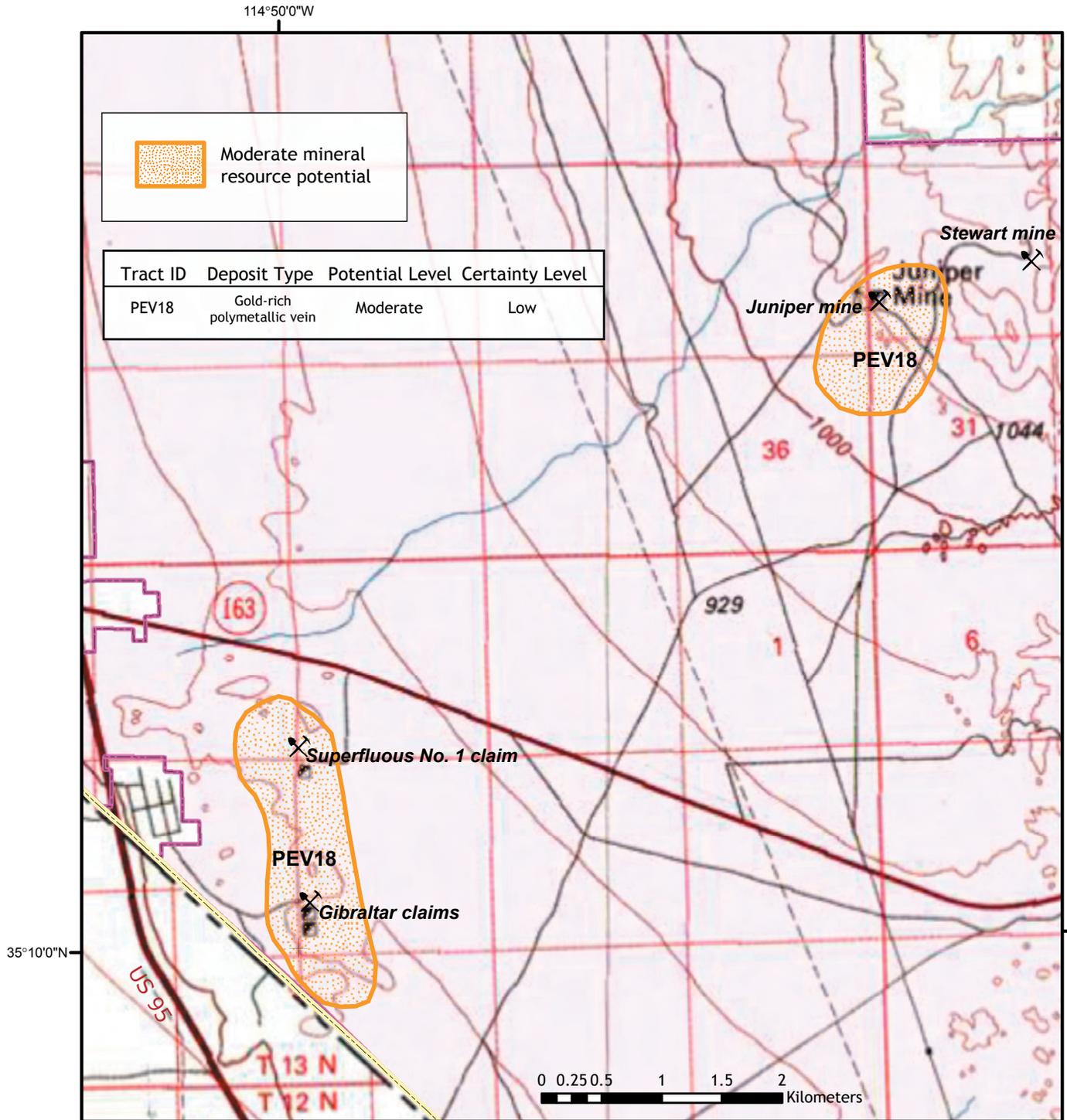


**Figure 56.** Mineral resource potential tract for detachment-fault-related gold deposits near the Rockefeller Mine, in the northern part of the Piute-Eldorado Tortoise Area of Critical Environmental Concern ACEC). Boundary of ACEC is in pink.

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The copper mineralization encountered in these drill holes leads us to designate three tracts in the area with potential for porphyry copper deposits, albeit with a low level of certainty. Tract PEV10 (fig. 58) has moderate potential with a low degree of certainty and represents our interpretation of where porphyry copper mineralization may be found in the subsurface in the main part of the

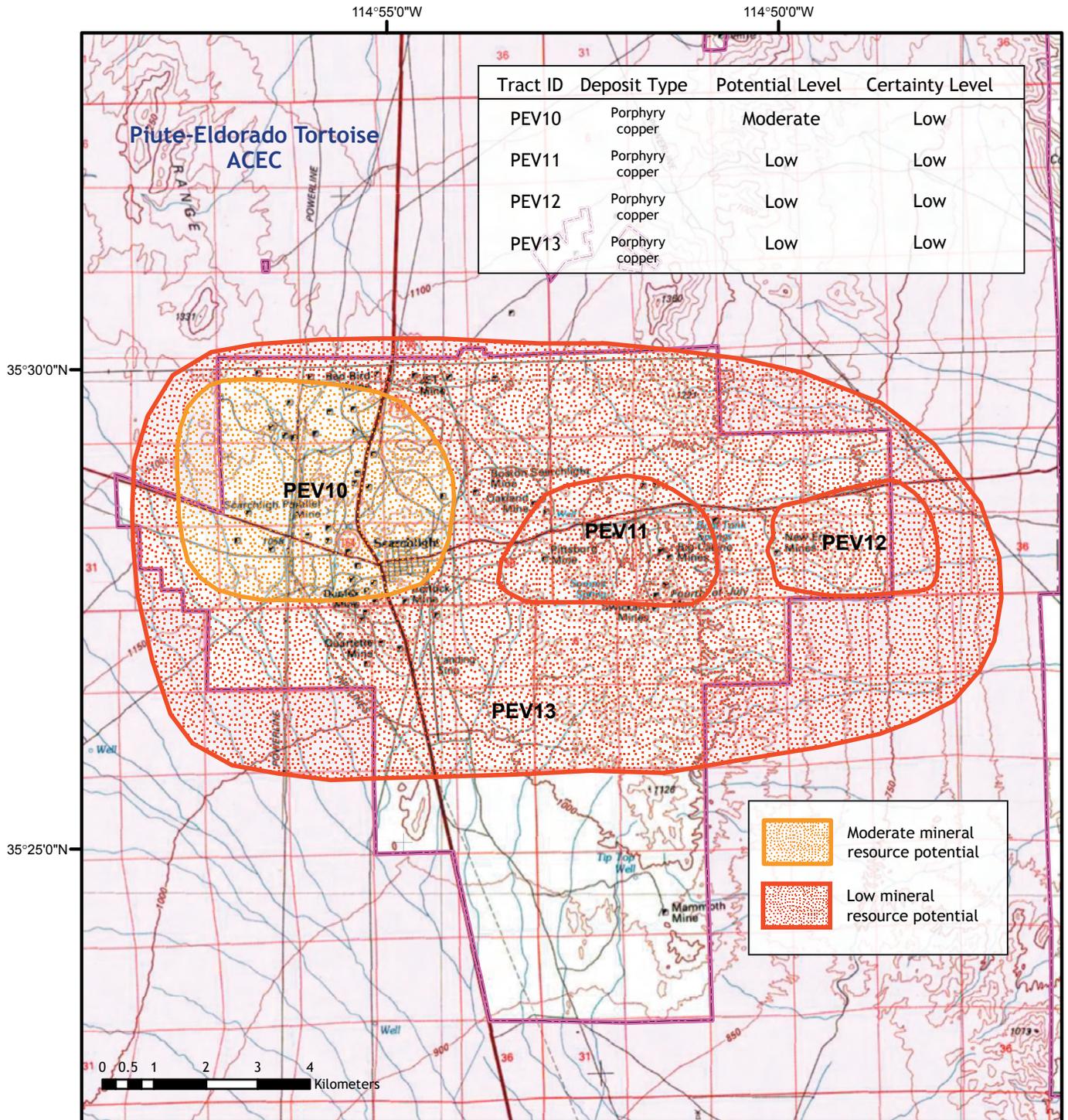
Searchlight district, in the Searchlight structural block. It includes a small area within the Piute-Eldorado Tortoise ACEC west of the rhyolite hills on the north side of Nevada State Highway 164. Additional drilling and petrographic study of subsurface rocks, more radiometric dating, and detailed structural studies would be necessary to further refine this assessment.



**Figure 57.** Mineral resource potential tract for gold-bearing polymetallic vein deposits in the southern part of the Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC). Boundary of ACEC is in pink.

Tracts PEV11 and PEV12 (fig. 58) have low potential with low certainty. They represent where the analogous porphyry environment may occur in the Fourth of July and Pinto structural blocks. PEV12 includes a small part of the Piute-Eldorado Tortoise ACEC south of Nevada State Highway 164, east of the town of Searchlight. In addition, we designate a more generalized tract, PEV13 (fig. 58),

also with low potential and low certainty, to reflect the uncertainty in the structural interpretation of the area; it simply encloses all areas where a possible porphyry copper deposit might underlie the area. Tracts PEV11, 12, and 13 lack any direct evidence for copper mineralization and are based on extrapolation from porphyry copper deposit models.

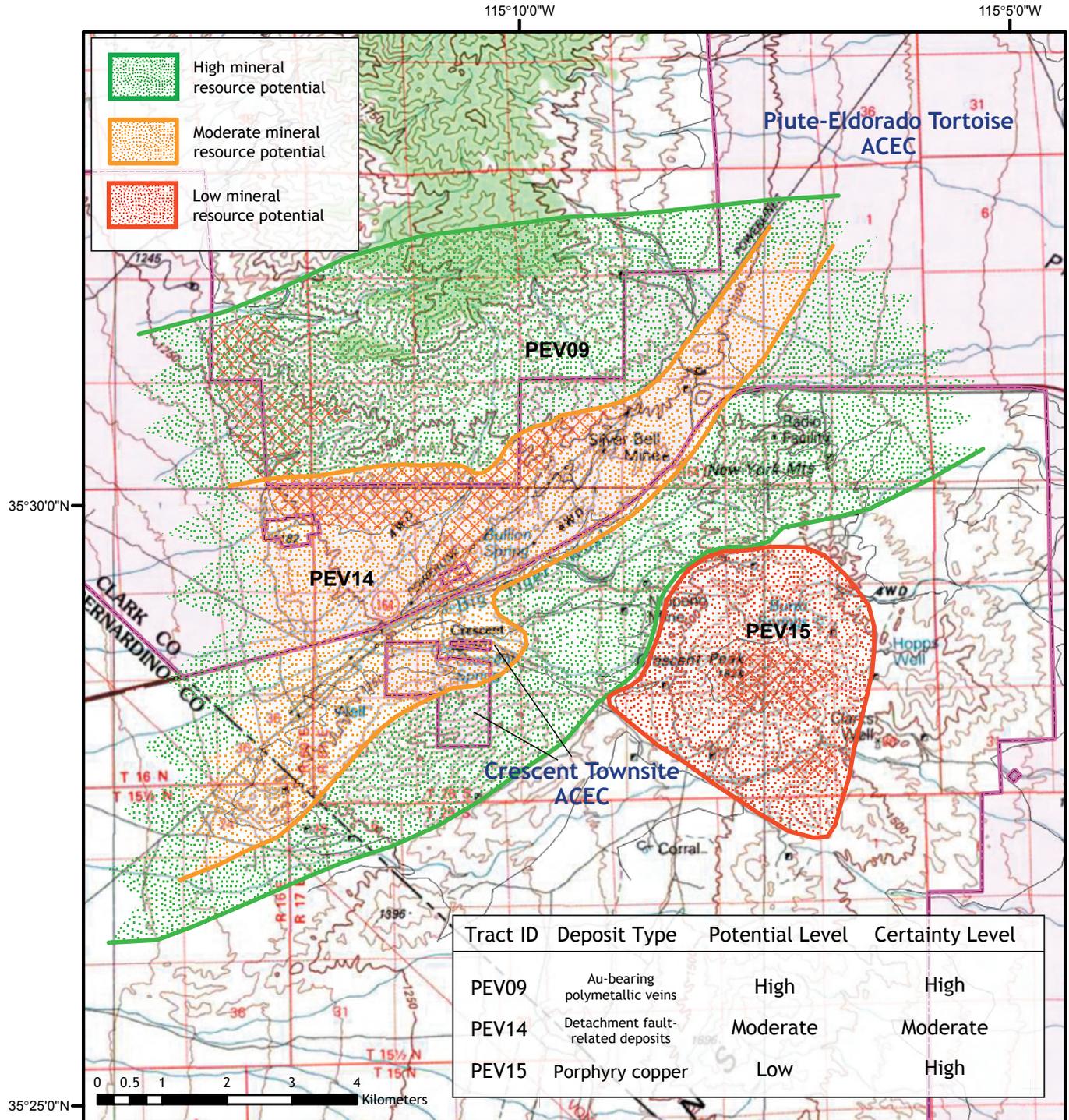


**Figure 58.** Mineral resource potential tracts for porphyry copper deposits in Searchlight area (Piute-Eldorado Tortoise Area of Critical Environmental Concern(ACEC)).

### Gold-Bearing Polymetallic Vein Deposits (Crescent Area)

A number of deposits that contain significant amounts of gold in both veins and shear zones are found in the Crescent

district. Because we are uncertain of the classification of many of these deposits, we designate two tracts to represent the mineral potential of these deposits, one (PEV09) for gold-bearing polymetallic veins and one (PEV14) for detachment-fault-related gold deposits (fig. 59).



**Figure 59.** Map showing mineral resource potential tracts for gold-bearing polymetallic veins, detachment-fault-related gold deposits, and porphyry copper deposits in the Crescent area of the Piute-Eldorado Tortoise and Crescent Townsite Areas of Critical Environmental Concern (ACECs). Red cross hatch indicates areas of hydrothermal alteration identified with Advanced Spaceborne Thermal Emission and Reflectance (ASTER) imagery. Boundaries of ACECs are in pink.

Tract PEV09 includes all the gold-bearing deposits in the Crescent area, so we designate it as high potential, with a high level of certainty for gold-bearing polymetallic veins. A remarkable proportion of the samples we took in this area contained significant gold values. The tract includes a large area on both sides of Nevada State Highway 164, and it also extends both eastward and westward under cover of Quaternary alluvium; we do not have information to delimit the western and eastern limits of this tract. Large areas of the tract are within the Piute-Eldorado Tortoise ACEC, and the Crescent Townsite ACEC is entirely within the tract. More exhaustive geochemical sampling of rocks within the ACEC could help refine the boundaries of the tract; petrographic studies of these samples could help refine the deposit classification.

### Detachment-Fault-Related Gold Deposits (Crescent Area)

Tract PEV14 (fig. 59) is designed to represent the potential area for deposits we interpret to be detachment-fault-related gold deposits. It is entirely enclosed within tract PEV09, and has moderate potential with moderate certainty. Note that this is not meant to represent an area with lower potential within tract PEV09. Deposits within this tract could also be gold-bearing polymetallic veins; the designation of this tract reflects our lower confidence in the classification of some of the deposits, not overall lower mineral potential. The boundaries of this tract are guided by the distribution of silicified rocks related to low-angle faulting and by the mapping of Miller and Wooden (1993). Most of this tract is not within either the Piute-Eldorado Tortoise or Crescent Townsite ACEC. Detailed structural mapping of this area could help raise the level of certainty for application of the detachment-fault-related model.

### Porphyry Copper Deposits (Crescent Area)

Tract PEV15 (fig. 59) has low potential with a high degree of certainty for porphyry copper deposits. The exploration of the deposit at Crescent Peak was done nearly 50 years ago. However, the drilling showed that some areas do not contain significant mineralization, and, unless there are important structural complications related to low-angle faulting, there is little room left in the prospective area to contain a porphyry copper deposit. The tract does not impinge on the Piute-Eldorado Tortoise or Crescent Townsite ACECs.

### Perlite

Two tracts in the Piute-Eldorado Tortoise ACEC have potential for perlite deposits. A small area (Tract PEV16, fig. 60) that includes the Searchlight Insulation Products perlite mine has high potential, with a moderate level of certainty. Perlite was produced in small amounts from this area in the 1950s, and significant reserves remain. However, it is not

clear that perlite from this property would be competitive in current markets. Part of the high potential area is in a private inholding, but the perlite mass that was mined and the tract we designated both extend into the ACEC.

A much larger tract (PEV17, fig. 60) has moderate potential for perlite deposits, with a moderate level of certainty. This tract includes areas mapped as middle Miocene rhyolite lavas (Faulds and others, 2002), which is the same rock unit that contains perlite in the high potential perlite area. On the basis of our field examination, this unit contains local exposures of perlite that might have commercial potential. None of the perlite occurrences that we examined outside Tract PEV16 were as large or as pure as the perlite in the Searchlight Insulation Products deposit, but undiscovered deposits may exist.

Perlite deposits that had past production, including the Nu-Lite Mine, are in the Castle Mountains just west of the Piute-Eldorado Tortoise ACEC. However, no perlite occurs within the Piute-Eldorado Tortoise ACEC, and we do not designate any potential tracts in this area.

### Leasable Minerals in Piute-Eldorado Tortoise ACEC

None of the Piute-Eldorado Tortoise ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Piute-Eldorado Tortoise ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

### Salable Minerals in Piute-Eldorado Tortoise ACEC

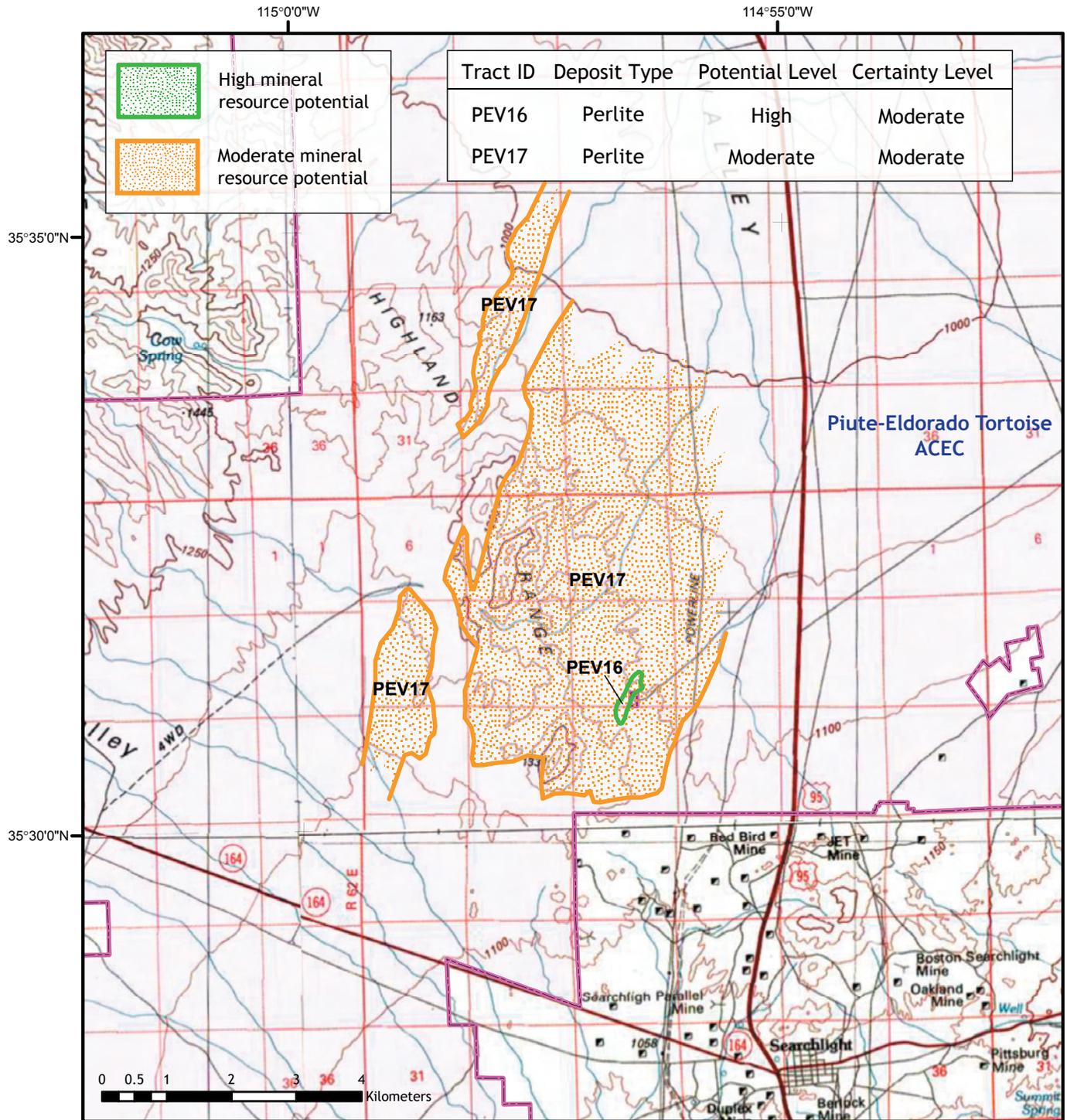
*Crushed Stone.*—High quality crushed stone resources occur mostly in the northern and eastern parts of the ACEC in parts of the Highland Range, Eldorado Mountains, and Newberry Mountains. Tract APET01 (fig. 61) has high potential for crushed rock aggregate resources, with a moderate level of certainty. Isolated areas of high potential resources are also scattered along the northeast flank of the New York Mountains on the southwest side of Piute Valley. The rock types that were used to define high potential areas include Miocene basaltic andesite and basalt in the Highland Range, northern McCullough Range, northeastern New York Mountains, and parts of the Newberry Mountains, as well as Miocene and Cretaceous granites within the Searchlight and Ireteba plutons.

Most of the rock outcrops in the ACEC were designated to have moderate potential for crushed-stone aggregate deposits, with a moderate level of certainty (Tract APET02, fig. 61). Volcanic rocks with moderate potential are so designated primarily based on the occurrence of volcanic glass. Although the glassy intervals may be interbedded with

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higher-quality volcanics, selective mining in such a case would probably not be feasible. Other volcanic units, particularly hydrothermally altered, intermediate-composition units of volcanics of the Highland Range are also considered to have moderate potential. Plutonic rocks classified as moderate aggregate potential include most of the Newberry

Mountains, along with parts of the Eldorado Mountains and McCullough Range. Many of these granitic rocks commonly weather to gneiss, and the porphyritic nature of these granitic rocks can result in rapid mechanical breakdown of the aggregate, which would be considered deleterious for many aggregate applications.

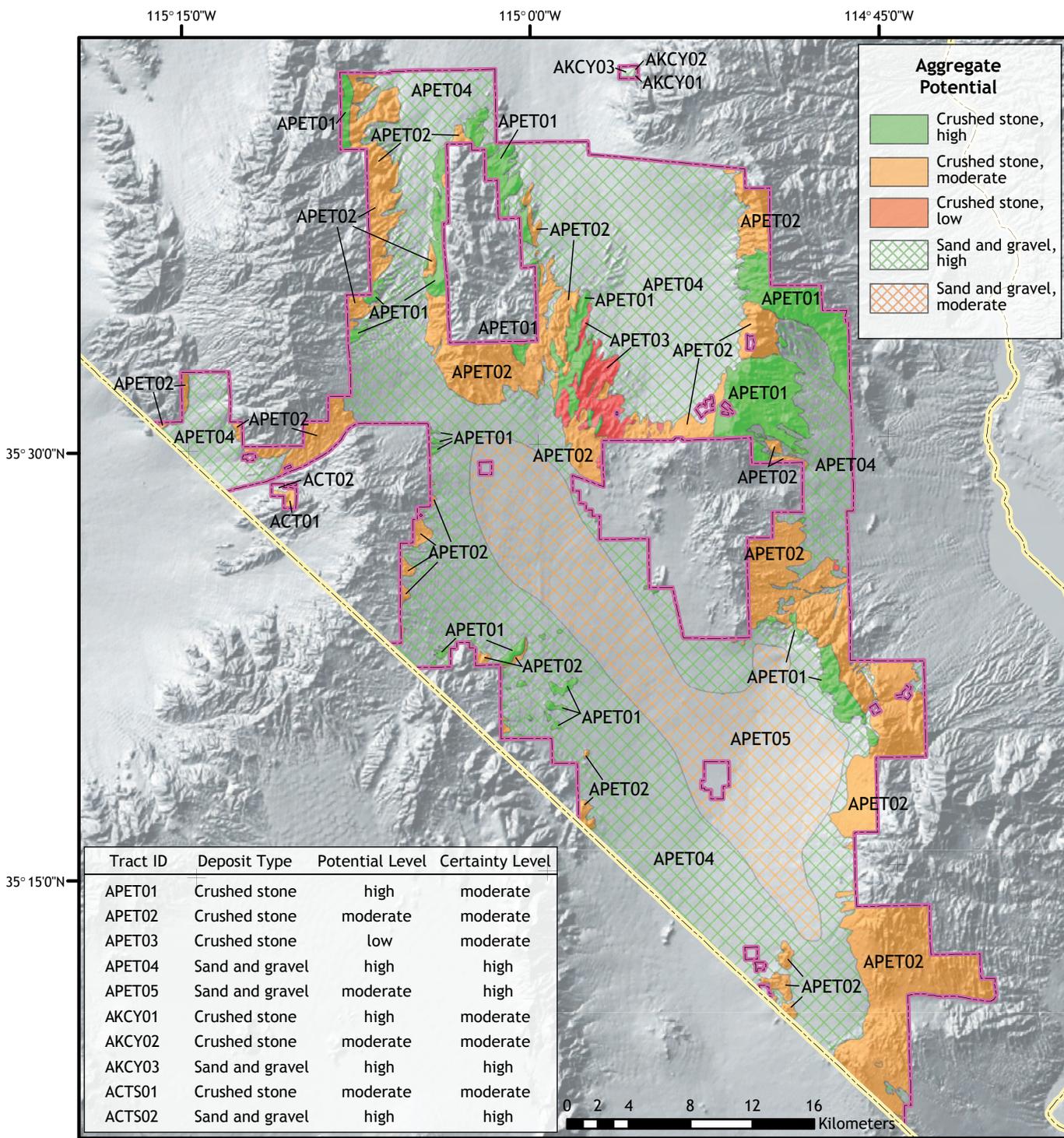


**Figure 60.** Mineral resource potential tracts for perlite deposits in the Piute-Eldorado Tortoise Area of Critical Environmental Concern (ACEC). ACEC boundary is in pink.

The lowest quality rocks in the area occur in the southern Highland Range to the northwest of Searchlight (Tract APET03, fig. 61). These rocks are felsic volcanics that are both unsound and commonly contain abundant glass, which would severely limit their use in aggregate applications.

Tract APET03 has low potential for crushed-stone aggregate deposits, with a moderate level of certainty.

*Sand and Gravel.*—High quality sand and gravel deposits occur on the alluvial fans and washes along the margins of both Eldorado and Piute Valleys. Farther down slope, rock



**Figure 61.** Mineral resource potential tracts for crushed-stone and sand and gravel aggregate in the Piute-Eldorado Tortoise, Keyhole Canyon, and Crescent Townsite Areas of Critical Environmental Concern (ACECs). ACEC boundaries are in pink.

materials are commonly broken into smaller and smaller fragments, eventually to mostly coarse sand with only minor amounts of material coarser than 4.75 mm, which is the necessary size for most aggregate applications. The width of the zone of high quality deposits is controlled by composition and mechanical properties of the source rock. Coarse, porphyritic-type granites and granite gneisses are distinctly more rapidly affected by mechanical breakdown than basalts, thus the transition from coarse- to fine-grained deposits is closer to the mountain front for the porphyritic and micaceous rocks, whereas large basalt clasts can be found many kilometers from their source. Tract APET04 (fig. 61) has high potential for sand and gravel aggregate deposits with a high level of certainty. Tract APET05 (fig. 61), which occupies the central parts of Piute Valley, has moderate potential for sand and gravel aggregate deposits, with a high certainty level.

*Decorative Stone.*—Decorative stone is generally considered a saleable commodity and is a subset of the crushed-stone category. The Las Vegas metropolitan area is an excellent decorative stone market. Decorative stone, which is mostly used for landscaping, does not need to meet standards for high-quality construction aggregate, such as concrete or asphalt aggregate. Therefore, almost any rock type has potential as decorative stone, and it is difficult to assess its suitability on the basis of physical properties. However, it should be relatively sound and resistant to weathering, and it is generally sold on the basis of appearance. Pink or pale red stone seems to be the most marketable material in Las Vegas, but yellow, gray, white, brown, and black stone are also used. Therefore, marketability of decorative stone is based on the customer's personal taste. Sandstone, granitic rock, volcanic rock, carbonate rock, and metamorphic rock are all utilized. Hydrothermally altered rock that contains hematite and (or) limonite is also suitable, providing that it is relatively sound.

With the exception of the Roman Mine, which is on unpatented mining claims directly east of the ACEC, decorative stone mines active in the vicinity of the Piute-Eldorado Tortoise ACEC are on patented mining claims. Mining on fee land obviates the necessity for BLM contracting and oversight, and reduces cost to the producer. Because it is difficult to assess the suitability of any rock unit or rock type for decorative stone, we have not delineated potential areas for these deposits.

## Locatable Minerals in Crescent Townsite ACEC

All of the Crescent Townsite ACEC is within tract PEV09 (fig. 59), which has high potential, with a high level of certainty for gold-bearing polymetallic veins. A remarkable proportion of the samples we took in this area contained significant gold values. The northern part of the ACEC is also within tract PEV14 (fig. 59), which has additional moderate potential with moderate certainty for detachment-fault-related gold deposits.

## Leasable Minerals in Crescent Townsite ACEC

None of the Crescent Townsite ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Crescent Townsite ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Crescent Townsite ACEC

*Crushed Stone.*—Bedrock areas within this ACEC have moderate potential for crushed-stone aggregate deposits, with a moderate certainty level (tract ACTS01, fig. 61). Although much of the southern part of the ACEC is granodiorite, there are zones of hydrothermal alteration and shearing, both of which reduce the quality of any potential crushed-stone deposits.

*Sand and Gravel.*—The northern part of the ACEC has high potential for sand and gravel aggregate deposits with high certainty in Big Tiger Wash (tract ACTS02, fig. 61). Although relatively thin, the sand and gravel deposits contain abundant coarse clasts of resistant metamorphic and igneous rocks.

*Decorative Stone.*—Decorative stone is generally considered a saleable commodity and is a subset of the crushed-stone category. The Las Vegas metropolitan area is an excellent decorative stone market. Decorative stone, which is mostly used for landscaping, does not need to meet quality standards for high-quality construction aggregate, such as concrete or asphalt aggregate. Therefore, almost any rock type has potential as decorative stone, and it is difficult to assess its suitability on the basis of physical properties. However, it should be relatively sound and resistant to weathering, and it is generally sold on the basis of appearance. Pink or pale red stone seems to be the most marketable material in Las Vegas, but yellow, gray, white, brown, and black stone are also used. Therefore, marketability of decorative stone is based on the customer's personal taste. Sandstone, granitic rock, volcanic rock, carbonate rock, and metamorphic rock are all utilized. Hydrothermally altered rock that contains hematite and (or) limonite is also suitable, providing that it is relatively sound.

Decorative stone mines active in the vicinity of the Crescent Townsite ACEC are on patented mining claims. Mining on fee land obviates the necessity for BLM contracting and oversight, and reduces cost to the producer. Because it is difficult to assess the suitability of any rock unit or rock type for decorative stone, we have not delineated potential areas for these deposits.

## Locatable Minerals in Keyhole Canyon ACEC

Although it is relatively close to the Eldorado mining district, the Keyhole Canyon ACEC has no areas with high or moderate potential for metallic mineral deposits or any other locatable minerals.

## Leasable Minerals in Keyhole Canyon ACEC

None of the Keyhole Canyon ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Keyhole Canyon ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Keyhole Canyon ACEC

*Crushed Stone.*—The granite in the north end of the Keyhole Canyon pluton is quite competent and has high potential for crushed-stone aggregate deposits, with a moderate level of certainty (tract AKCY01, fig. 61). The Proterozoic gneiss and schist north of the granite has moderate potential for crushed-stone aggregate deposits with a moderate level of certainty (tract AKCY01, fig. 61).

*Sand and Gravel.*—Deposits of high quality sand and gravel aggregate in the alluvial fan that empties Keyhole Canyon constitute tract AKCY03 (fig. 61), which has high potential for sand and gravel aggregate, with a high certainty level. These deposits are a mixture of Keyhole Canyon granite and Proterozoic metamorphic rocks.

*Decorative Stone.*—Decorative stone is generally considered a saleable commodity, and is a subset of the crushed-stone category. The Las Vegas metropolitan area is an excellent decorative stone market. Decorative stone, which is mostly used for landscaping, does not need to meet quality standards for high-quality construction aggregate, such as concrete or asphalt aggregate. Therefore, almost any rock type has potential as decorative stone, and it is difficult to assess its suitability on the basis of physical properties. However, it should be relatively sound and resistant to weathering, and it is generally sold on the basis of appearance. Pink or pale red stone seems to be the most marketable material in Las Vegas, but yellow, gray, white, brown, and black stone area also used. Therefore, marketability of decorative stone is based on the customer's personal taste. Sandstone, granitic rock, volcanic rock, carbonate rock, and metamorphic rock are all utilized. Hydrothermally altered rock that contains hematite and (or) limonite is also suitable, providing that it is relatively sound.

Decorative stone mines active in the vicinity of the Keyhole Canyon ACEC are on patented mining claims. Mining on fee land obviates the necessity for BLM contracting and oversight, and reduces cost to the producer. Because it is difficult to assess the suitability of any rock unit or rock type for decorative stone, we have not delineated potential areas for these deposits.

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# Chapter C. Mineral Resource Potential of the Gold Butte A, Gold Butte B, Virgin Mountain (Gold Butte C), Whitney Pocket, Red Rock Spring, Devil's Throat, and Gold Butte Townsite Areas of Critical Environmental Concern, Clark County, Nevada

By Steve Ludington, Gordon B. Haxel, Stephen B. Castor, Brett T. McLaurin, and Kathryn S. Flynn

## Summary and Conclusions

The Gold Butte A Area of Critical Environmental Concern (ACEC) contains areas with high potential for the occurrence of nickel-copper-platinum group element (PGE) deposits and Kipushi-type sedimentary-rock-hosted copper deposits. Exploration in the Bunkerville district could reveal a significant resource of nickel, copper, gold, and PGE. Exploration for Kipushi-type sedimentary-rock-hosted copper deposits could reveal significant amounts of the strategic metals gallium and germanium. Technological developments to improve recovery could transform these small copper deposits into important sources of germanium and gallium. There are also areas with moderate potential for Kipushi-type sedimentary-rock-hosted copper deposits, for uranium deposits in sedimentary rocks, and for gypsum deposits. The potential for other undiscovered deposits of locatable or leasable mineral deposits is low. The Gold Butte A ACEC contains regions with high, medium, and low potential for crushed-rock aggregate deposits and areas with high, medium, and low potential for sand and gravel aggregate deposits.

The Gold Butte B ACEC has areas with high potential for low-sulfide gold-quartz vein deposits, high and moderate potential for Kipushi-type sedimentary-rock-hosted copper deposits, high and moderate potential for vermiculite deposits, moderate potential for nickel-copper-PGE deposits, and moderate potential for uranium deposits in sedimentary rocks. Exploration of small gold-bearing veins might reveal deposits that could be mined successfully. Exploration for Kipushi-type deposits could reveal significant amounts of the strategic metals gallium and germanium. Technological developments to improve recovery could transform these small copper deposits into important sources of germanium and gallium. The potential for other undiscovered deposits of locatable or leasable mineral deposits is low. The Gold Butte B ACEC contains regions with high, medium, and low potential for crushed-

rock aggregate deposits and areas with high, medium, and low potential for sand and gravel aggregate deposits.

The Virgin Mountain ACEC has areas with high potential for the occurrence of nickel-copper-PGE deposits and for beryllium-bearing pegmatite deposits. Additional exploration in the Bunkerville district could reveal a significant resource of nickel, copper, gold, and PGE. There are also regions with moderate potential for mica deposits. The potential for other undiscovered deposits of locatable or leasable mineral deposits is low. The Virgin Mountain ACEC contains areas with high, medium, and low potential for crushed-rock aggregate deposits and small areas with high potential for sand and gravel aggregate deposits.

The Whitney Pocket ACEC contains no mineral deposits, and the potential for undiscovered deposits of locatable or leasable mineral deposits is low. This ACEC contains areas with moderate and low potential for crushed-rock aggregate deposits and areas with high potential for sand and gravel aggregate deposits.

The Red Rock Spring ACEC contains no mineral deposits, and the potential for undiscovered deposits of locatable or leasable mineral deposits is low. This ACEC contains areas with low potential for crushed-rock aggregate deposits and areas with high and low potential for sand and gravel aggregate deposits.

The Devil's Throat ACEC contains no mineral deposits, and the potential for undiscovered deposits of locatable or leasable mineral deposits is low. This ACEC contains areas with low potential for crushed-rock aggregate deposits and areas with high potential for sand and gravel aggregate deposits.

Most of the Gold Butte Townsite ACEC has high potential for gold vein deposits. A small part of it has moderate potential for Kipushi-type copper deposits. There are regions with medium potential for crushed-rock aggregate deposits and areas with high potential for sand and gravel aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

Several months of field examinations were conducted in the area, with a special focus on the nickel and platinum-group-element (PGE) deposits in the Bunkerville district (Virgin Mountain ACEC) and on the gold-bearing vein deposits in the Gold Butte district (Gold Butte B ACEC). A number of samples were collected and analyzed. Individuals with mining interests and representatives of companies with mining operations in and near the areas were contacted.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

This report describes a total of seven areas of critical environmental concern (ACECs) that are all contiguous. They are Gold Butte part A, Gold Butte part B, Virgin Mountain, Whitney Pocket, Red Rock Spring, Devil's Throat, and Gold Butte Townsite. Collectively, we refer to them as the Gold Butte–Virgin Mountain ACECs (fig. 1). These areas collectively cover about 1,394 km<sup>2</sup> south of Interstate 15, east of the Virgin River, and west of the Arizona–Nevada border. A secondary road that leads south from Interstate 15 near Riverside townsite accesses all areas. The exit is about 120 km (75 mi) northeast of Las Vegas. A legal description of these lands is included in appendix 2.

Gold Butte A (749 km<sup>2</sup>) and Gold Butte B (493 km<sup>2</sup>) are the largest of these ACECs, and they enclose Devil's Throat, Whitney Pocket, Red Rock Spring, and Gold Butte Townsite ACECs.

The Virgin Mountain ACEC (145 km<sup>2</sup>) encompasses the highest elevations in the area, more than 2,400 m. It is south of the town of Mesquite, Nevada, and adjoins Gold Butte A ACEC.

The Whitney Pocket ACEC covers an area of less than 1 km<sup>2</sup> and occurs within Gold Butte A ACEC, immediately south of the Virgin Mountains.

The Red Rock Spring ACEC, with an area of 2.6 km<sup>2</sup>, contains a perennial spring. When visited in November of 2004, the southwest-trending wash was flowing for several hundred meters downstream from the spring.

The Devil's Throat ACEC, with an area of 2.6 km<sup>2</sup>, is a very small rectangular area that is nearly flat, except for the Devil's Throat sinkhole in its center. This sinkhole is about 25 m in diameter and about 60 m deep.

The Gold Butte Townsite ACEC is also less than 1 km<sup>2</sup> and is apparently meant to include the remains of the town of Gold Butte, which thrived briefly in the early part of the 20<sup>th</sup> century. Curiously, most of the original townsite, including the site of the Post Office, is several hundred meters outside (south of) the ACEC.

These areas incorporate two existing wilderness areas, the Lime Canyon Wilderness, in the northwest part of Gold Butte B, and the Jumbo Spring Wilderness in the southeast part of Gold Butte B (fig. 1). Lime Canyon was studied extensively by the U.S. Geological Survey (Winters, 1988; McHugh and Nowlan, 1989; McHugh and others, 1989; Bullock and others, 1990; and Evans and others, 1990). The Jumbo Spring Wilderness was designated in 2002, and its mineral resources were not studied at that time.

In addition, two areas were studied for possible wilderness designation, the Million Hills Wilderness Study Area (Causey, 1988; McHugh and Nowlan, 1989; McHugh and others, 1989; Moyle and Buehler, 1990; and Bergquist and others, 1994) in the southern part of Gold Butte A and the eastern part of Gold Butte B ACECs, and the Virgin Mountains Instant Study Area (Hose, 1980; Carlson and Cooley, 1981; and Hose and others, 1981) in the central part of the Virgin Mountain ACEC (fig. 1).

## Physiographic Data

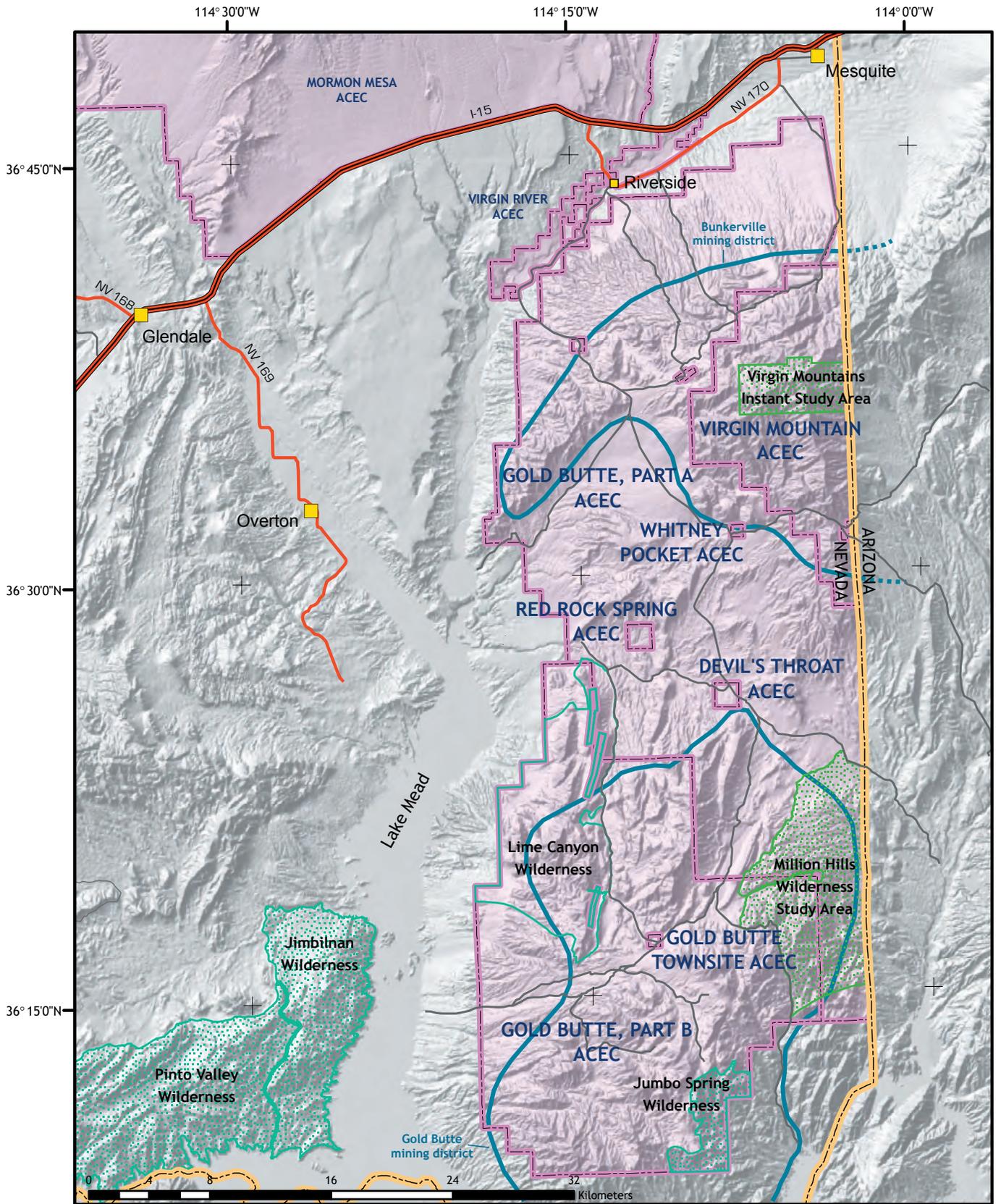
The Gold Butte–Virgin Mountain ACECs range in elevation from about 500 m to more than 2,460 m. The low areas are on the west boundary of Gold Butte B, just above the shoreline of Lake Mead and on the northwest boundary of Gold Butte A, along the Virgin River (fig. 2). The high point is the summit of Virgin Peak (about 2,460 m), in the Virgin Mountain ACEC. Many of the valley floors, including the broad flat area in the southern part of Gold Butte A that includes Red Rock Spring and Devil's Throat, lie between about 700 and 800 m elevation.

Because of the dry climate and the temperature extremes prevalent here, the physiography of the mountain ranges commonly reflects the composition of the bedrock. Limestones form rugged, linear ridges, whereas sandstone, shale, and tuffaceous rocks form less regular and more subdued shapes. The crystalline rocks in the Virgin Mountains and in parts of the Gold Butte B area are resistant, irregularly dissected, and form massive mountains (fig. 3).

Most of the area drains southwest, west, and northwest, into the Virgin River or its extension, the Overton Arm of Lake Mead, but there are few perennial streams other than the Virgin River.

## Geologic Setting

These seven ACECs are on the western margin of the tectonically stable Colorado Plateaus region, and at the eastern margin of the Basin and Range Physiographic Province, a region



**Figure 1.** Index map, showing boundaries of Areas of Critical Environmental Concern (ACECs; outlined in pink), wilderness areas (blue-green), wilderness study areas (yellow-green), and mining districts (teal).



**Figure 2.** View north from high in the Virgin Mountains, showing the town of Mesquite and the Virgin River.



**Figure 3.** View of Virgin Mountains from northwest. Highest point on skyline (right) is Virgin Peak. Light area in middleground is workings of the Key West Mine.

characterized by extensive Tertiary deformation. Much of the bedrock in the area is composed of unmetamorphosed Paleozoic and Mesozoic sedimentary rocks, but there are two large areas of Proterozoic metamorphic rock—one in the north, in the Gold Butte A and Virgin Mountain ACECs, and one in the south, in Gold Butte B. A third, smaller area of Proterozoic rock is exposed in the Gold Butte B ACEC. There are also extensive exposures of Tertiary rocks in the Gold Butte A ACEC.

## Geology

Rocks and mineral deposits in the Gold Butte–Virgin Mountain ACECs range in age from Early Proterozoic to Recent. Early deformation and metamorphism took place in

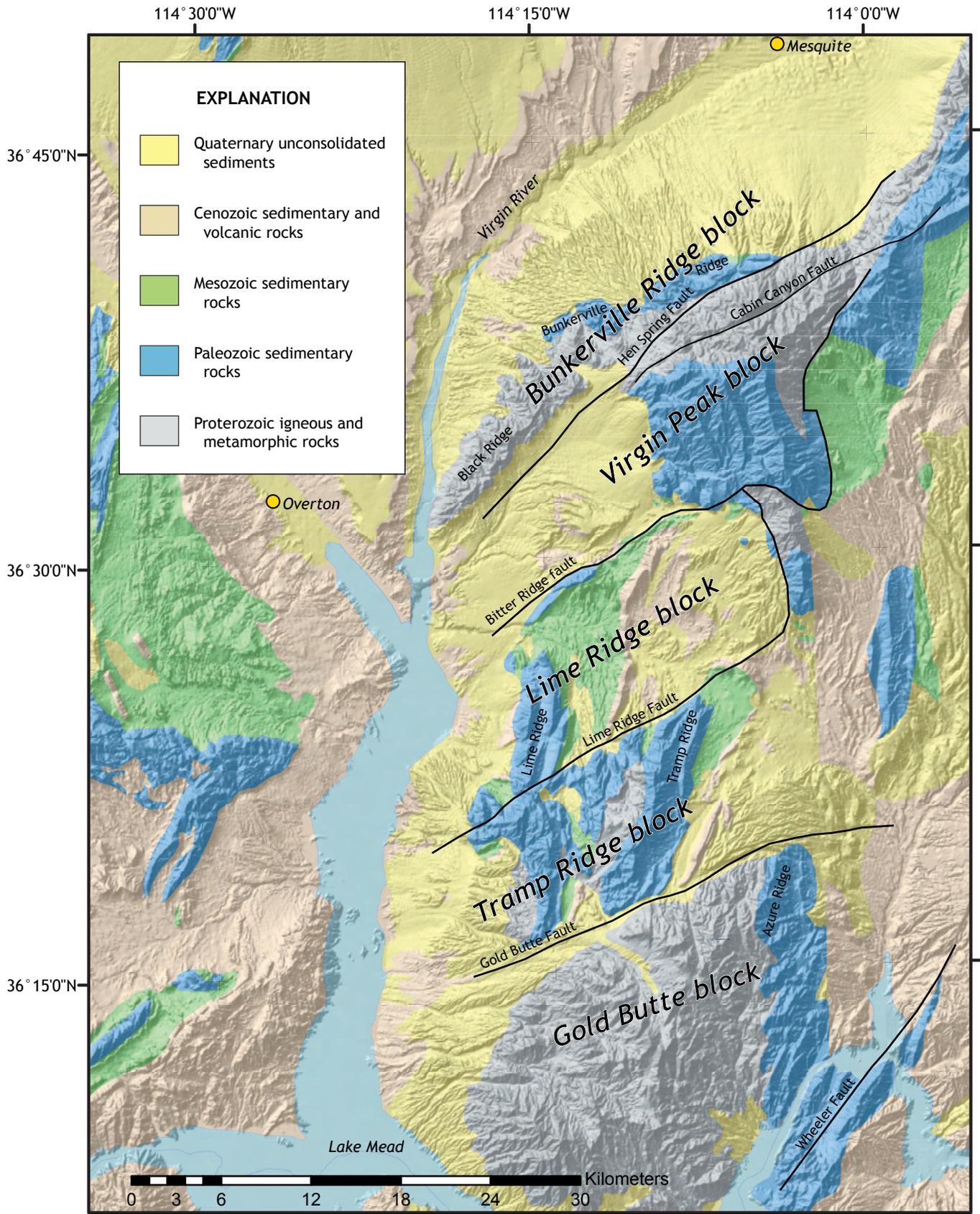
the Proterozoic before about 1.6 Ga. The front of the Sevier thrust belt, which was active in late Mesozoic time, lies to the west and north, and therefore only minor Mesozoic deformation is recorded in the rocks of the area. The Paleozoic to Cenozoic rocks were mainly deformed after 16 Ma during a period of large-scale regional extension (primarily east-west) (Duebendorfer and others, 1998). Major faults active during this period subdivided the bedrock areas into several major structural blocks that are the first evidence of Basin-and-Range-style extensional faulting west of the Colorado Plateaus (fig. 4). From north to south, the blocks are referred to as Bunkerville Ridge, Virgin Peak, Lime Ridge, Tramp Ridge, and Gold Butte (Beard, 1996; Deubendorfer and others, 1998).

The direction of movement along some of these major faults is a matter of debate. The Hen Spring and Bitter Ridge Faults on the north (fig. 4) are considered left-lateral faults that merge with the Lake Mead Fault Zone (Anderson, 1973; Beard, 1996). The Lime Ridge and Gold Butte Faults to the south, also interpreted as left-lateral faults (Beard, 1996), may be more complex features that also accommodated right lateral and (or) normal movements (Fryxell and others, 1992; Brady and others, 2000).

## Proterozoic Rocks

Proterozoic metamorphic and igneous rocks are exposed in three principal areas. They form the core of the northeast-trending northern part of the Virgin Mountains and are also exposed in a small area in the southernmost part of the Virgin Mountains. They are exposed in two areas near Lime Ridge, one at the south end of the ridge and one in the valley to the east, between Lime and Tramp Ridges. Further south, all but the extreme east margin of the Gold Butte block is made up of Proterozoic rocks. These crystalline rocks record a prolonged Proterozoic history of multiple phases of metamorphism, ductile deformation, and granitic magmatism. They are depositionally and tectonically overlain by deformed but unmetamorphosed Paleozoic strata of continental shelf facies. The postmetamorphic brittle deformation of the basement and the Paleozoic and Mesozoic strata is probably mostly Tertiary in age.

In the Bunkerville Ridge and Virgin Peak blocks, the rocks exposed are quartzofeldspathic and granitic gneiss, pegmatite, and lesser amounts of schist and amphibolite (Beal, 1965; Beard, 1993; Williams and others, 1997; Quigley and others, 2002). North and west of the Hen Spring Fault (fig. 5), the rocks are relatively leucocratic and consist of biotite- and garnet-bearing gneisses. South and east of the fault, the rocks are much more mafic and consist of mostly dark granodiorite gneiss with abundant amphibolite. Quigley and others (2002) describe the Virgin Mountains shear zone (fig. 5), a northeast-trending deformation zone that is exposed throughout most of the length of the northern Virgin Mountains. This zone was active primarily during the waning stages of the Early Proterozoic high-grade metamorphic episode in the Virgin Mountains.



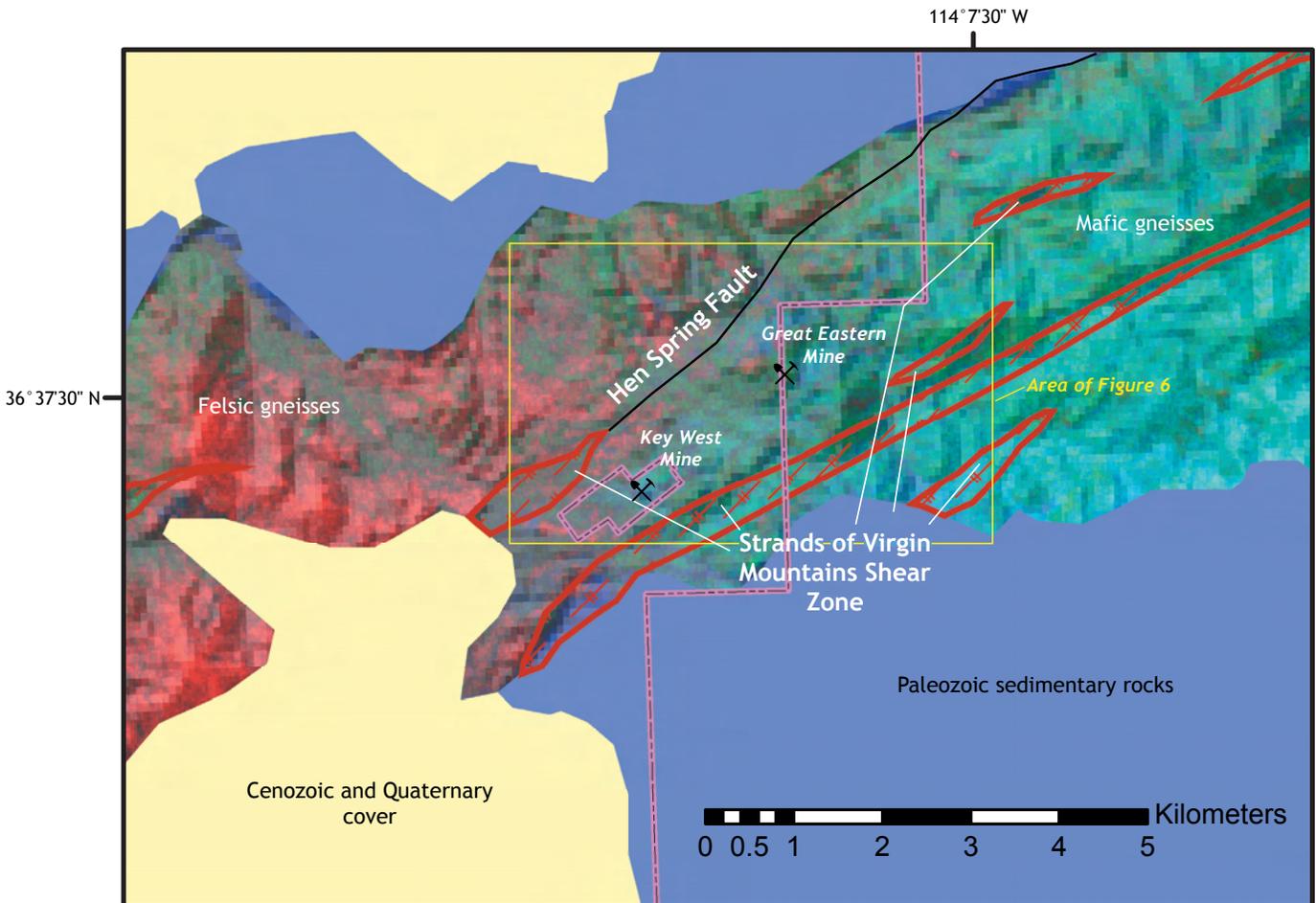
**Figure 4.** Structural blocks of the Virgin Mountains and areas to the south, southeastern Nevada and northwestern Arizona. Geology modified from Stewart and Carlson (1978) after Beard (1996).

The rocks in the Proterozoic outcrops south and east of Lime Ridge are granitic gneisses intruded by the biotite-hornblende granite of Lime Wash. In the Gold Butte block, there are four main types of metamorphic rock: (1) a garnet-bearing cordierite-sillimanite paragneiss, (2) a charnockitic gneiss that contains hypersthene and clinopyroxene in addition to quartz, feldspar, and biotite, (3) syntectonic foliated metagranitoid rocks, and (4) ultramafic intrusive rocks (Fryxell and others, 1992). Radiometric dating of similar rocks in surrounding areas of Arizona and the Mojave Desert in California suggest that the age of the protoliths for these rocks is about 1.8 to 1.7 Ga (Hook and others, 2005). The age of prograde metamorphism and polyphase deformation is about 1.76 to 1.68 Ga (Hook and others, 2005; Howard and others, 2003).

The metamorphic rocks are cut by a series of early and middle Proterozoic plutons, some of considerable size. The Gold Butte Granite, which makes up a large part of the Gold Butte block, is conspicuous for its large potassium feldspar phenocrysts and rapakivi texture (Volborth, 1962). It is about 1.45 Ga in age (Anderson and Bender, 1989; Howard and others, 2003) and is representative of the anorogenic granites

of that age that are widely distributed in the Western U.S. Cordillera (Anderson, 1983). The youngest Proterozoic rocks are a series of mafic intrusions composed of diabase, diorite, and gabbro that are found as both plutons and dikes (Volborth, 1962).

Proterozoic pegmatite and aplite dikes and sills occur widely in the gneissic rocks and are locally abundant. Volborth (1962) recognized three generations of aplite-pegmatite in the Gold Butte block—early, conformable, lens-like bodies and two younger generations of crosscutting dikes. Rubidium-strontium ages of 1.70 and 1.63 Ga were reported on muscovite and potassium feldspar from large lens-shaped pegmatites (Volborth, 1962). In the Virgin Peak block, Beal (1965) described small, concordant lit-par-lit pegmatites; larger, concordant, lens-shaped pegmatites; and massive, tabular pegmatites that “may or may not be concordant with the host rocks.” A minimum K-Ar age for muscovite from a massive pegmatite at the Taglo Mine in the Virgin peak block was reported as 1.37 Ga (Beal, 1965). Howard and others (2003) speculated that aplite dikes cutting the Gold Butte Granite might have been emplaced in the Mesozoic.



**Figure 5.** Geologic relations in part of the Virgin Peak and Bunkerville Ridge blocks, showing relations between mafic and felsic gneisses, Hen Spring Fault, and Virgin Mountains shear zone. Proterozoic rocks are portrayed with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery (Hook and others, 2005), using bands 4, 6, and 8. Reddish colors are silica-rich rocks. Pink line is boundary between Gold Butte A (left) and Virgin Mountain (right) Areas of Critical Environmental Concern (ACECs).

Proterozoic mafic and ultramafic intrusive rocks occur in the gneisses in the Bunkerville Ridge, Virgin Peak, and Gold Butte blocks. The largest of the intrusive bodies is an irregular mass of ultramafic rock north of Mica Peak in the Gold Butte block that averages about 600 m wide and is about 1,800 m long. It is mainly composed of mica-bearing peridotite, hornblendite, and pyroxenite that have been partially altered to serpentine and vermiculite (Leighton, 1967). Volborth (1962) mapped 20 relatively large lens-like bodies of this rock type in the Gold Butte block, and presented evidence indicating that they were emplaced before intrusion of the Gold Butte Granite. He also noted many smaller mica-bearing bodies with lamprophyric appearance, which he interpreted to be originally diabase dikes. Beal (1965) mapped several large masses of hornblendite as much as 90 m wide and 300 m long in the Bunkerville district, and noted that many smaller masses, some with gneissic textures, were also present in the area, generally in association with pegmatite. In addition, parts of the granodiorite gneiss found in the Virgin Peak block are distinctly rich in hornblende and at least as mafic as diorite.

Because of their relevance to nickel-copper-PGE deposits in the Bunkerville district, we studied Proterozoic mafic and ultramafic dikes in the Virgin Mountains extensively. The Bunkerville district features a regionally uncommon type of mineralization—nickel and platinum group elements (PGE) in pyrrhotite-bearing ultramafic dikes. The district includes two small deposits at the Key West and Great Eastern Mines, as well as a few surrounding prospects (fig. 6).

Pyrrhotite mineralization in the Bunkerville district is associated with a swarm of Paleoproterozoic mafic to ultramafic dikes. Within the variably metamorphosed dikes of this swarm we have identified four major protolith rock types: (1) augite-hornblende gabbro; (2) gabbro-related hornblendite (GRH); (3) olivine hornblendite (OHB); and (4) altered olivine hornblendite, some of which is pyrrhotite-rich. Gabbro and GRH are far more abundant than OHB. At one place we observed these different types of dike in contact; there, OHB intrudes gabbro and GRH.

## Gabbro Dikes

Gabbro and GRH dikes are largely metamorphosed to amphibolite and extensively intruded by leucogranite and pegmatite. They form boudins within the regional gneissic foliation. Bodies of amphibolite or relict gabbro and GRH range in size from a decimeter thick and a few meters long to several hundred meters in largest surface dimension. Their shapes and sizes are partially inherited from original intrusive forms, but they more directly represent the cumulative effects of several episodes of deformation.

GRH is a minor phase or facies of a few gabbroic dikes and presumably formed by local crystal accumulation. Mesocratic gabbro grades into hornblendite through melanocratic gabbro and feldspathic hornblendite. Gabbro-GRH dikes only locally contain accessory or vein phlogopite. GRH typically is coarse grained and characterized by euhedral, lath-shaped horn-

blende. It does not contain olivine. In gabbro and GRH, whole-rock concentrations of Ni, Pd, and Pt are broadly basaltic (table 1, fig. 7). Gabbro and GRH lack primary pyrrhotite, only locally contain secondary pyrrhotite, and evidently are only indirectly or incidentally associated with mineralization. Data for all analyzed elements is reported in Ludington and others (2005).

## Olivine Hornblendite Dikes

Olivine hornblendite (OHB) is common or dominant on mine dumps and in many prospects, but uncommon in natural exposures. This dike rock is distinctive in appearance, especially on weathered surfaces of outcrops and loose cobbles. Typically, differential weathering of olivine and hornblende produces a rough or pitted surface with a finely mottled dark green and brown appearance (fig. 8).

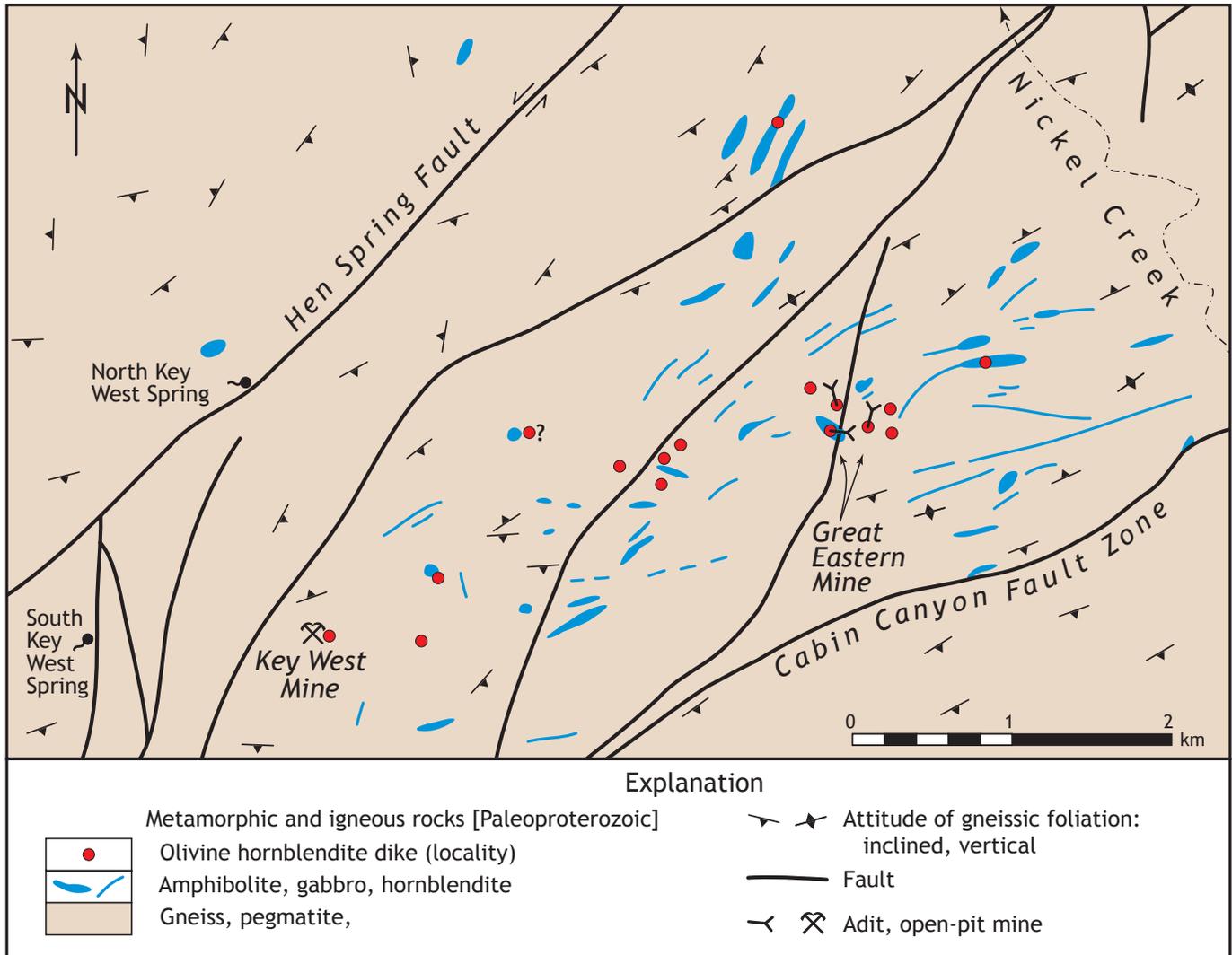
Petrographically, OHB dikes are mostly fine- to medium-grained olivine hornblendite, olivine-clinopyroxene hornblendite, or clinopyroxene hornblendite; subordinate varieties include phlogopite hornblendite and hornblende clinopyroxenite. Virtually all OHB dikes have primary accessory pyrrhotite, and most have accessory phlogopite. Phlogopite may be uniformly distributed or concentrated in diffuse veins or patches. Hornblende generally is equant and subhedral, as well as lighter colored and less strongly pleochroic (presumably more magnesian) than the hornblende in gabbro and GRH. These dikes are not foliated.

## Altered Olivine Hornblendite Dikes

Altered OHB is characterized by the presence of substantial phlogopite, along with various combinations and proportions of serpentine, secondary amphibole, and carbonate. Some, but not all, of these altered rocks contain a few to as much as about 20 percent pyrrhotite, plus other subordinate sulfide minerals, particularly chalcopyrite (fig. 8). Pyrrhotite and other sulfides form veinlets and diffuse patches or clusters, intergrown with phlogopite, amphiboles, and serpentine. Phlogopite alteration and pyrrhotite mineralization are almost entirely restricted to OHB dikes; rarely do they occur in gabbro-GRH dikes or country rocks.

## Geochemistry

Most samples of unaltered and altered OHB (excluding pyrrhotite-rich OHB) contain approximately 44 percent SiO<sub>2</sub>, 22 percent MgO, 0.1 to 0.7 percent S, 900 ppm (parts per million) Ni, and 10 to 200 ppb (parts per billion) Pd and Pt (table 1 and fig. 6; Ludington and others, 2005). Palladium and platinum are considerably more variable than nickel. Median concentrations of palladium and platinum slightly to significantly exceed global averages for several major types of ultramafic rocks. Overall, Pt/Pd is slightly below average. Nickel is less abundant in unaltered OHB than in many or most ultramafic rocks; consequently, OHB has unusually high Pd/Ni.



**Figure 6.** Geologic sketch map of part of the Bunkerville district in the Virgin Mountains (see figure 5 for location). Olivine hornblendite dikes, typically only a few meters wide, are too small to map at this scale; localities are indicated by red dots. The dikes and other intrusions mapped in blue are predominantly medium-grained amphibolite, but also include medium- to coarse-grained mesogabbro, melanogabbro, hornblendite, feldspathic hornblendite, metagabbro, metahornblendite, and rare microgabbro. The gneiss and pegmatite unit comprises chiefly granitic and granodioritic gneiss, quartzofeldspathic gneiss and schist, pelitic or aluminous gneiss and schist, and fine-grained amphibolite. All of these metamorphic rocks are intruded by abundant pegmatite and leucogranite, and minor granite, mostly foliated but locally unfoliated. Only a small fraction of the many hundreds of bodies of amphibolite or gabbro and related rocks within the map area are shown. Dip of foliation is steep to locally moderate. Elevations range from about 1,050 m in the northwest part of the map area to about 1,600 m along a ridge between the Great Eastern Mine and Nickel Creek and near the southeast corner of the map area. Sources: Needham and others, 1950; Beal, 1965; Beard, 1993; Williams and others, 1997; and minor remapping by G.B. Haxel in 2004 and 2005.

**Table 1.** Median concentrations of Ni, Pd, and Pt, and median Pd/Ni and Pt/Pd, in dike rocks of the Bunkerville district compared with global averages for basaltic and ultramafic rocks, CI carbonaceous chondrites, and several earth reservoirs.

[Values rounded to two significant figures. MORB is mid-ocean ridge basalt; OIB is oceanic island basalt; OHB is olivine hornblende.]

	Ni (ppm)	Pd (ppb)	Pt (ppb)	(Pd/Ni)×10	Pt/Pd	References
Bunkerville district, medians						
Gabbro and related hornblende (n = 5)	340	3	9	8.8	2.0	
OHB, unaltered and altered (n=11)	950	25	37	25	0.89	
OHB, unaltered (n=5)	880	13	13	22	0.93	
OHB, altered (n=6)	990	49	46	40	0.81	
OHB, altered, pyrrhotite-rich (n=4)	3,100	690	620	280	0.91	
						Crockett, 2002; Mungall, 2005
Mafic and ultramafic rocks, global averages						
MORB	140	0.46	0.41	3.3	0.89	
MORB	110	0.26	0.30	2.5	1.1	
OIB	370	4.6	4.3	12	0.93	
OIB, alkalic	150	0.75	0.95	5.1	1.3	
OIB, tholeiitic	190	2.4	3.6	13	1.5	
OIB, picritic	–	7.3	5.9	–	0.81	
Continental flood basalt	85	8.8	6.2	10	0.70	
Island arc picrites and boninites	~400	~3–10	~3–10	?	?	
Boninite	520	4.5	5.7	11	1.3	
Island arc picrite	–	2.4	3.0	–	1.2	
Island arc andesite	–	0.38	0.95	–	2.5	
Basalt associated with komatiite	330	12	15	36	1.2	
Komatiite	1,200	10	10	8.3	1.0	
Alpine lherzolite	2,100	7.4	10	3.5	1.4	
Alpine harzburgite	2,400	3.8	5.1	1.6	1.3	
Ophiolitic harzburgite	2,200	6.0	8.3	2.7	1.4	
Spinel lherzolite nodules	2,100	2.8	4.4	1.3	1.6	
Harzburgite nodules	2,400	2.0	5.6	0.83	2.8	
CI carbonaceous chondrites	11,000	560	990	51	1.8	Anders and Grevesse, 1989
Bulk silicate Earth	2,000	3.9	7.1	2.0	1.8	McDonough and Sun, 1995
Primitive mantle	1,900	3.3	6.6	1.8	2.0	Palme and O'Neill, 2004
						Rudnick and Gao, 2004
Continental crust						
Bulk	59	1.5	1.5	25	1.0	
Lower	88	2.8	2.7	32	0.96	
Middle	34	0.76	0.85	22	1.1	
Upper	47	0.52	0.51	11	0.98	Peucker-Ehbrink and Jahn, 2001
	56	0.4	0.4	7.1	1.0	Wedepohl, 1995

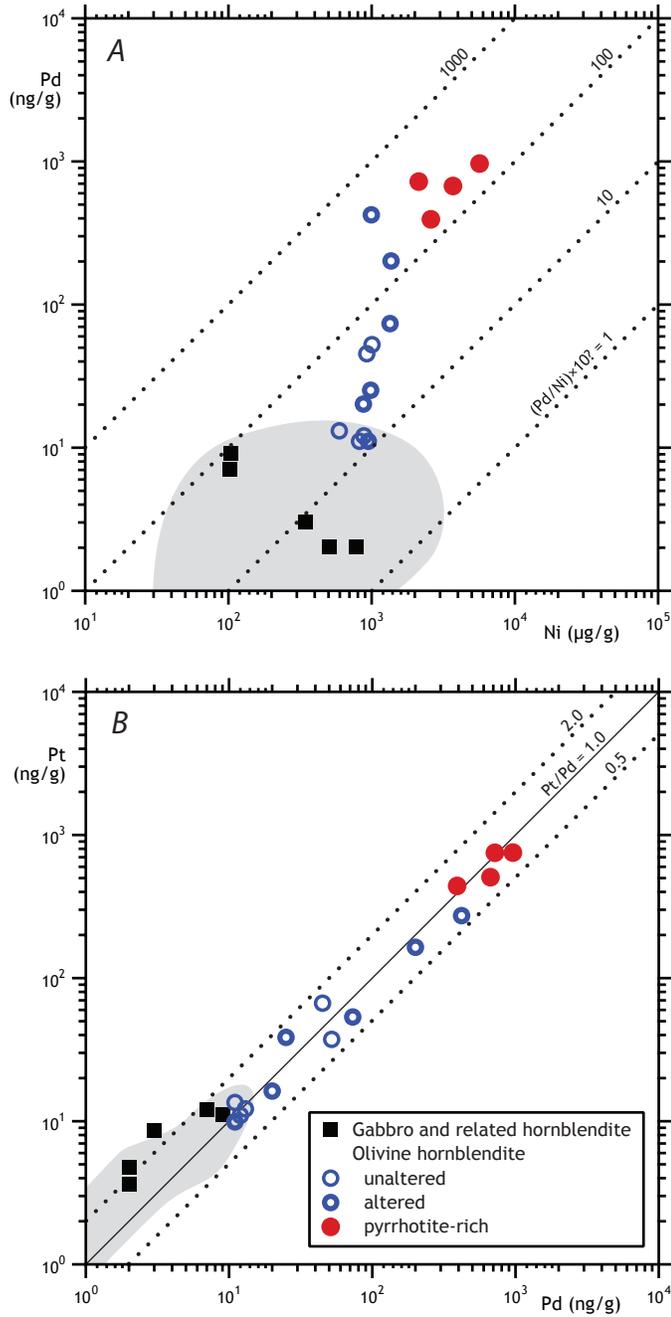
Four samples of pyrrhotite-rich altered OHB contain about 400 to 1,000 ppb palladium and platinum. Concentrations of nickel are about 3,000 ppm. Palladium and platinum are enriched over their abundances in average upper continental crust by factors of about  $10^3$ , but nickel by only a factor of about 50.

Figure 9 demonstrates the progressive enrichment of Pd and Pt in altered OHB and pyrrhotite-rich altered OHB, relative to unaltered OHB. As already noted, enhancement of Ni is considerably less pronounced. Progressive enrichment in Cu, Au, and (surprisingly) Bi mimics that of Pd and Pt. The other 10 metals plotted in figure 9 show little or no systematic variation. The unaltered OHB compositions are similar to mid-ocean ridge basalt (MORB) and perhaps typical of ultramafic rocks worldwide, except for slight enrichment in the chalcophile elements nickel, copper, platinum, palladium, and gold. Dikes of this composition are not common in the Proterozoic rocks of North America.

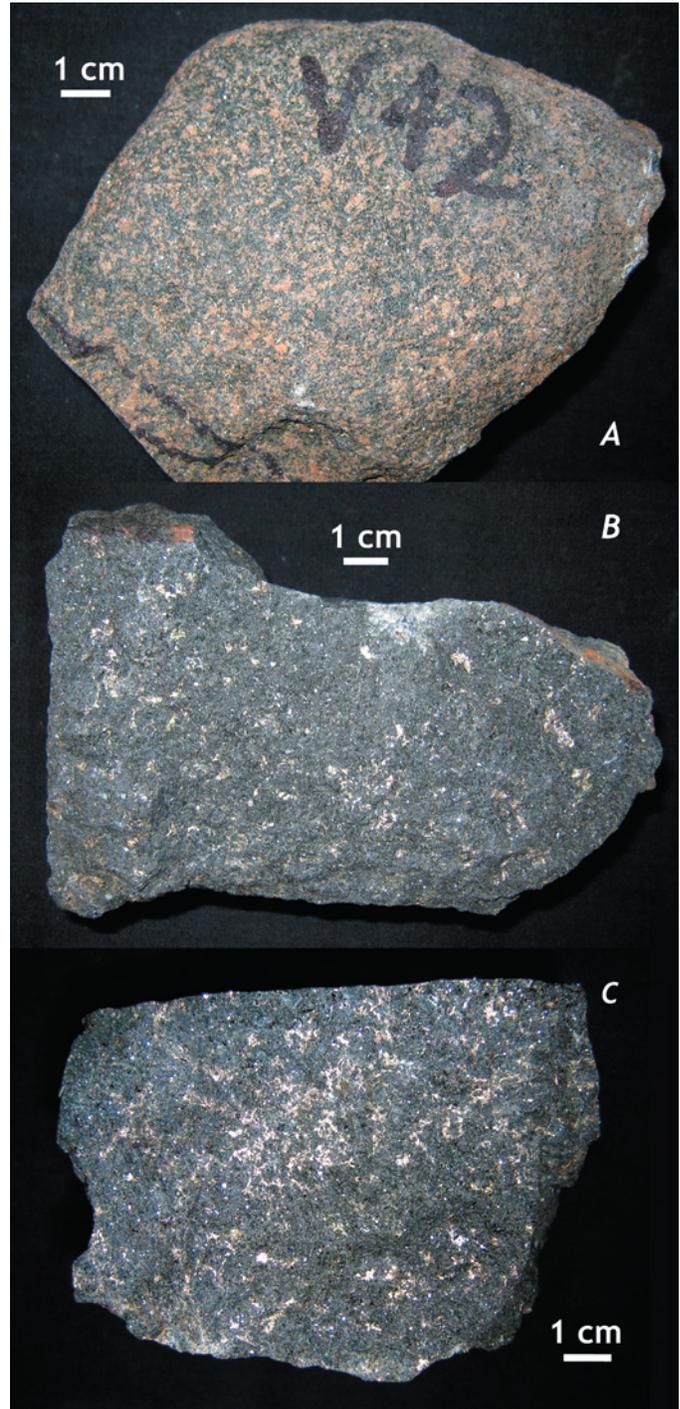
## Paleozoic Rocks

Lying unconformably on the Proterozoic rocks is a series of marine sedimentary rocks of Cambrian through Permian age. These are primarily carbonate rocks, including both limestone and dolomite, with lesser amounts of siliciclastic rocks. The Paleozoic rocks are exposed primarily in a series of elongate, north-northeast-trending ridges in the Lime Ridge and Tramp Ridge blocks (fig. 4). They also crop out on the north side of the Bunkerville Ridge block, in the Virgin Peak block, and along the eastern edge of the Gold Butte block. Some Paleozoic units in the Gold Butte–Virgin Mountain ACECs have been assigned different names depending on whether they are correlated with the Grand Canyon or southern Great Basin stratigraphic section (table 2).

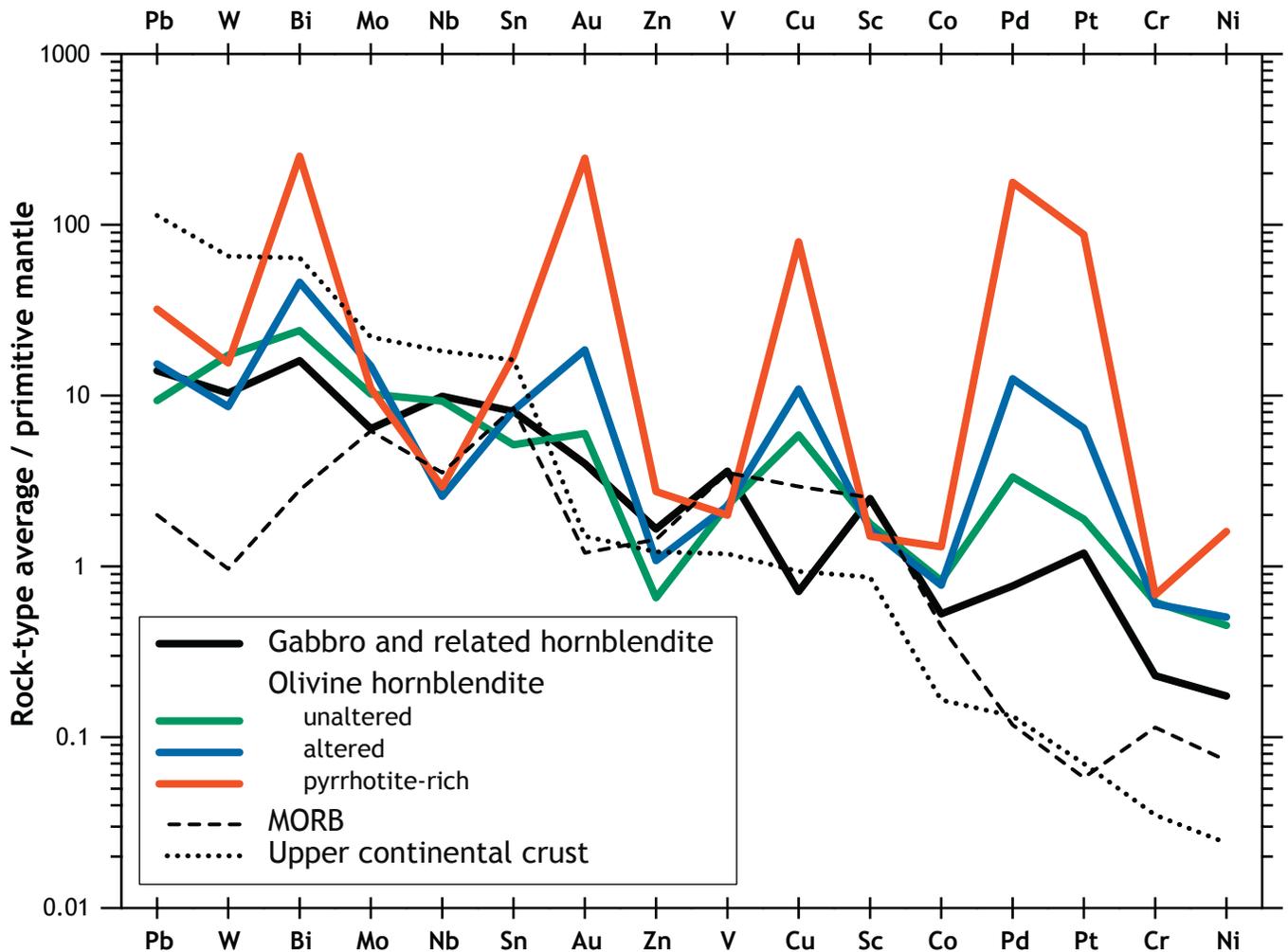
Basal Paleozoic (lower and middle Cambrian) rocks are primarily shale and sandstone. A Cambrian carbonate rock section overlies these. Ordovician and Silurian rocks are



**Figure 7.** Covariation of nickel with palladium (A) and platinum (B) in Neoproterozoic gabbroic and olivine hornblendite (OHB) dikes in the Bunkerville district. Light gray indicates the approximate composition fields of common ultramafic, mafic and intermediate igneous rock types, based upon the data summarized in table 1. Because palladium and platinum are geochemically much alike and have subequal mantle and crustal abundances (table 1), concentrations of the two elements will be similar in most rocks. In B, the two dotted lines indicate deviations of a factor of two from a Pt/Pd ratio of unity (thin solid line). Nearly all of the Bunkerville samples plot within these limits.



**Figure 8.** Hand specimens of olivine hornblendite (OHB) from the Bunkerville district. A, Weathered surface of typical fine-grained OHB, from a prospect near the Key West Mine (sample V42). Darker, slightly raised areas are chiefly hornblende; lighter colored, slightly depressed areas are partially altered or weathered olivine. B, C, Pyrrhotite-rich altered olivine hornblendite, upper dump, Great Eastern Mine (B, sample V83; C, sample V40).



**Figure 9.** Median abundances of 16 metals in gabbroic dikes and olivine hornblende (OHB) dikes in the Bunkerville district, compared with average mid-ocean ridge basalt (MORB) (Sun and McDonough, 1989) and average upper continental crust (McLennan, 2001). Concentrations are normalized to those in Earth's primitive mantle (McDonough and Sun, 1995). Elements are arranged (left to right) in order of increasing compatibility in partitioning between the present upper continental crust and the primitive mantle as indicated by the ratio of concentrations in these two reservoirs (Hofmann, 1988).

missing, and the Cambrian rocks are overlain by Devonian to Permian carbonate and siliciclastic units. Above these is a thick Permian redbed section, and marine carbonate rocks overlie the redbeds. Chert is common throughout much of the Paleozoic section and is especially prominent in the Mississippian, Pennsylvanian, and Permian carbonate rocks.

## Mesozoic Rocks

Mesozoic rocks mainly crop out in the Lime Ridge and Tramp Ridge structural blocks. The Bunkerville Ridge and Virgin Peak blocks contain only minor areas of Mesozoic rock exposures. The Mesozoic rocks are dominated by the thick Triassic Moenkopi Formation, a varied unit of carbonate rock, shale, and sandstone, locally gypsiferous. Rocks in this unit record the transition from a marine environment to a continen-

tal one. The Moenkopi is overlain by sandstone and siltstone of the Moenave and Kayenta Formations. Capping the Triassic succession is the colorful eolian sandstone of the Jurassic Aztec Formation.

## Cenozoic Rocks

Late Oligocene to Middle Miocene rocks of the Horse Spring Formation lie with slight angular unconformity on the Mesozoic rocks (Beard, 1996). In contrast to the Muddy Mountains and Rainbow Gardens areas to the west, the Virgin Mountain–Gold Butte area contains only the two lowest units in this formation, the Rainbow Gardens and Thumb Members (Bohannon, 1984). The Rainbow Gardens Member includes a basal conglomerate and overlying carbonate rocks with some sandstone and minor tuff, and the Thumb Member is domi-

**C12 Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada**
**Table 2.** Stratigraphic correlation chart for Paleozoic and Mesozoic sedimentary rocks in the Gold Butte–Virgin Mountain ACECs.

<b>Age</b>	<b>Formation</b>	<b>Grand Canyon correlate</b>	<b>Great Basin correlate</b>	<b>Lithology</b>
Cretaceous	<b>Baseline Sandstone</b>	—	—	Sandstone, conglomerate, siltstone
Early Cretaceous	<b>Willow tank Formation</b>	—	—	Claystone, siltstone, carbonaceous shale, sandstone, conglomerate
Early Jurassic	<b>Aztec Sandstone</b>	Navajo Sandstone	—	Eolian sandstone
Early Jurassic	<b>Kayenta and Moenave Formations</b>	—	—	Gypsiferous sandstone, siltstone, claystone, and conglomerate
Late Triassic	<b>Chinle Formation</b>	—	—	Mudstone, fine-grained sandstone, limestone, conglomerate
Early and Middle Triassic	<b>Moenkopi Formation</b>	—	—	Mudstone, siltstone, sandstone, limestone, dolomite
Early Permian	<b>Kaibab Formation</b>	—	—	Limestone dolomite, gypsum, siltstone, chert
Early Permian	<b>Toroweap Formation</b>	Coconino Sandstone	—	Calcareous siltstone and sandstone, gypsum, limestone and dolomite, chert
Early Permian	<b>Hermit Formation</b>	—	—	Sandstone, siltstone
Early Permian	<b>Esplanade Formation</b>	—	Queantoweap Sandstone	Sandstone, mudstone, siltstone
Pennsylvanian and Permian	<b>Pakoon Limestone</b>	Supai Group	Bird Spring Group	Dolomite, gypsum, chert
Pennsylvanian and Permian	<b>Calville Formation</b>	Supai Group	Bird Spring Group, Illipah Formation	Limestone, calcareous sandstone, dolomite, chert
Mississippian	<b>Redwall Limestone</b>	—	Monte Cristo Limestone, Rogers Spring Limestone	Limestone, dolomite, chert
Devonian	<b>Temple Butte Limestone (Sultan)</b>	—	Sultan Limestone, Muddy Peak Limestone, Guilmette Limestone	Limestone, dolomite, chert
Late Cambrian	<b>Nopah Formation</b>	—	—	Shale, siltstone, dolomite
Late Cambrian	<b>Muav Formation</b>	—	Frenchman Mountain Dolomite, Bonanza King Formation	Limestone, dolomite
Early and Middle Cambrian	<b>Bright Angel Shale</b>	—	Chisolm Shale, Lyndon Limestone, Pioche Shale	Shale, sandstone
Early and Middle Cambrian	<b>Tapeats Sandstone</b>	—	—	Sandstone

nantly sandstone and conglomerate with some gypsum-rich sequences and some carbonate rocks near the base. Beard (1996) proposed that the Thumb Member was deposited in two basins, one corresponding with the present Wehech Basin in the northeast part of the Lime Ridge structural block, and another in the Horse Spring–Garden Spring area in the northeast part of the Tramp Ridge structural block. Deposition of the Thumb Member was, at least in part, synchronous with Miocene extension (Beard, 1996; Brady and others, 2000).

## Mining History

The Virgin Mountain–Gold Butte group of ACECs is the site of two large mining districts. The Gold Butte district, organized in 1873, occupies most of the Gold Butte B ACEC and extends into the south part of the Gold Butte A ACEC (Tingley, 1992). The Bunkerville district (also known as the Key West or Copper King district) includes almost all of the Virgin Mountain ACEC and a large area in the north part of the Gold Butte A ACEC. A statement by Beal (1965) in a report on the Bunkerville district is applicable to all of these seven ACECs: “the mining history of the district is characterized by much development and exploration but little production.” Beal went on to note that only limited amounts of copper, nickel, cobalt, platinum, tungsten, mica, and beryllium were produced in the Bunkerville district. Minor amounts of gold, silver, copper, lead, zinc, and mica were produced in the Gold Butte district (Longwell and others, 1965).

Copper was discovered in the Bunkerville district around 1900 at the site of the Key West Mine, which produced a little more than 3,000 short tons of copper-nickel-cobalt-platinum ore sporadically between 1908 and 1929 (Beal, 1965). According to Hewett and others (1936), recorded metal production for the Bunkerville district up to 1935 was about 128,000 pounds of copper, 1,700 pounds of nickel, 982 troy ounces of silver, 52 troy ounces of gold, 10 troy ounces of platinum, and 177 troy ounces of palladium. Unsuccessful attempts were made to put the Key West Mine into production again in the 1930s

and 1950s. There is no recorded production from the nearby Great Eastern Mine, which was located and opened between 1910 and 1920. From 1939 to 1941, the U.S. Bureau of Mines conducted underground exploration (sampling, drifting, and drilling) for nickel at the Great Eastern (Needham and others, 1950). All underground workings in both mines are now flooded and inaccessible.

Between 1900 and 1919, the average grade of ore produced in the Bunkerville district was reported to be 2.55 percent copper, 3.29 percent nickel, and 0.183 opt (troy ounces per short ton) platinum (Tingley and LaPointe, 2001). Exploration by Falconbridge Exploration U.S., Inc., and Superior Oil, Minerals Division, in the 1980s resulted in an estimate for surface and underground resources of 226,000 t at average grades of 1.5 percent copper, 1.1 percent nickel, 0.4 percent cobalt, 0.06 opt platinum, 0.68 opt palladium, 0.01 opt gold, and 0.34 opt silver (Tingley and LaPointe, 1999).

Around 1999–2000, Freeport Resources Canada, Inc., in cooperation with Royal Standard and Falconbridge, planned to further explore the district based on new targets resulting from detailed geophysics provided by Falconbridge, but the work was never carried out. Trend Mining Co., of Coeur d’Alene, Idaho, was also active at the time, holding claims northeast and southwest of the Key West and Great Eastern Mines, on the trend of the dikes. Their last claims lapsed in 2004.

Tungsten was found in 1947 east of the Key West Mine area at what became the Walker (or Silver Leaf) Mine. In 1953 Tri-State Metals Inc. erected a small mill near the Virgin River and operated the Walker Mine until 1956. Recorded production was reported to be only 27 units of  $WO_3$  (equivalent to about 7 kg of tungsten metal) in 1953 and 1954, and an additional 7 units produced in 1953 was probably from the same area (Longwell and others, 1965). At least 150 units of  $WO_3$  reportedly were produced in the Bunkerville district as a whole (Beal, 1965).

Metal mining began in the Gold Butte district when gold was discovered in 1905 and copper in 1907 (fig. 10). Recorded production of gold through 1965 was 1,669 troy ounces, mostly between 1935 and 1941 from the Lakeshore Mine about 1 km south of the Gold Butte B ACEC (Longwell and



**Figure 10.** Gold Butte Post Office, March, 1907. Image courtesy of Utah State Historical Society.

others, 1965). Recorded copper production from the district, about 150,000 pounds, was mostly before 1932 from the Azure Ridge, Lincoln, and Tramp Mines.

The Treasure Hawk Mine has a long history, although the actual year of discovery is not known. By 1913, when Hill (1916) visited the area, the mine, then known as the New Era group of claims, consisted of one shaft about 35 m deep and numerous smaller workings. In 1937, when it was known as the Webster group, the shaft had been deepened, and about 150 short tons of ore had been produced, with an average grade of about 1 opt (Vanderburg, 1937). In the 1980s, Dexter and others (1983) reported that the mine had been operated for 10 years by Eddie Bounsall, who had used heap leaching methods to recover gold from alluvium and from crushed lode-vein material that commonly contained from 0.5 to 0.75 opt of gold. The property was purchased from Bounsall's heirs in the late 1990s and has been rehabilitated by Cutthroat Mining Corporation (Lear, 2000, 2004); production was scheduled to begin again in March of 2006.

The Lakeshore Mine, just outside the south boundary of Gold Butte B ACEC, was worked from 1934 to 1937, producing about 1,800 short tons of ore that contained approximately 1,000 troy ounces of gold. Much of this ore was shipped by barge across Lake Mead, where it was loaded into railroad cars for shipment to a smelter (Vanderburg, 1937).

Pegmatites were explored in the Virgin Mountains and Gold Butte areas in the late 1800s. Muscovite-bearing pegmatites were found near Gold Butte in 1873 (Volborth, 1962). According to Longwell and others (1965), a few shipments of mica were made from mines in pegmatite in the "South Virgin Mountains" (Gold Butte B ACEC) in the 1890s and early 1900s. According to Beal (1965), sheet mica was reportedly mined from "pegmatites several miles northeast of Virgin Peak" (probably in the Taglo Mine area), and a minor amount of beryl ore was produced from the Mica Notch area in 1935. The Taglo Mine (or Santa Cruz Mine), which was developed in the 1950s, reportedly consisted of three adits with about 500 ft (150 m) of underground workings and several shallow open cuts (Longwell and others, 1965). Mica was also produced from the Mica Notch area in the Virgin Mountain ACEC, and in 1958 a small mica separation plant was erected at the town of Riverside along the Virgin River to the north. One trial carload of mica from this plant was shipped to Los Angeles (Beal, 1965).

In 1960, Beryllium Associates of Salt Lake City leased claims in the Mica Notch area and evaluated them extensively by surface and underground methods (Beal, 1965). Development work consisted of two adits totaling 250 m and a number of trenches and pits. The only recorded production was about 410 kg of beryl ore (Beal, 1965). The U.S. Bureau of Mines also investigated the Mica Notch beryllium deposits in the early 1960s (Holmes, 1963). These deposits were explored actively in the 1960s, until the beryllium mine at Spor Mountain, Utah, was opened in 1970. Spor Mountain has remained the largest source of beryllium in the United States since that time (Lindsey, 1998).

Vermiculite was mined near Mica Peak in the Gold Butte ACEC in the 1940s, and several carloads of unprocessed

vermiculite were shipped beginning in 1942. A 25-ton-per-day mill was completed in 1945; however, the production rate was no more than 5 short tons per day, and the operation soon ceased (Leighton, 1967). A small open pit remains, along with several bulldozed trenches, but we noted no sign of the mill in 2005 (fig. 11). The size of the pit and tailings indicates that no more than a few hundred tons of vermiculite concentrate was produced (Hindman, 1995). In the 1980s, the area was examined for vermiculite by the Oglebay Norton Co. In 2000, International Vermiculite LLC, a joint venture between Nevada Vermiculite and Stansbury Holdings Corp., announced plans to drill a deposit near Mica Peak (Castor, 2001). In 2001, Stansbury Holdings decided to abandon the Mica Peak project to concentrate on vermiculite in Montana. In 2004, IBI Corporation signed an option to acquire the claims (IBI Corporation, 2004). In April of 2006, IBI signed a letter of agreement with Rio Tinto America Industrial Minerals Inc. that grants Rio Tinto an option to acquire a 100 percent interest in the claims. Mark Whitmore of Las Vegas currently holds the vermiculite deposits in the Mica Peak area under claim.

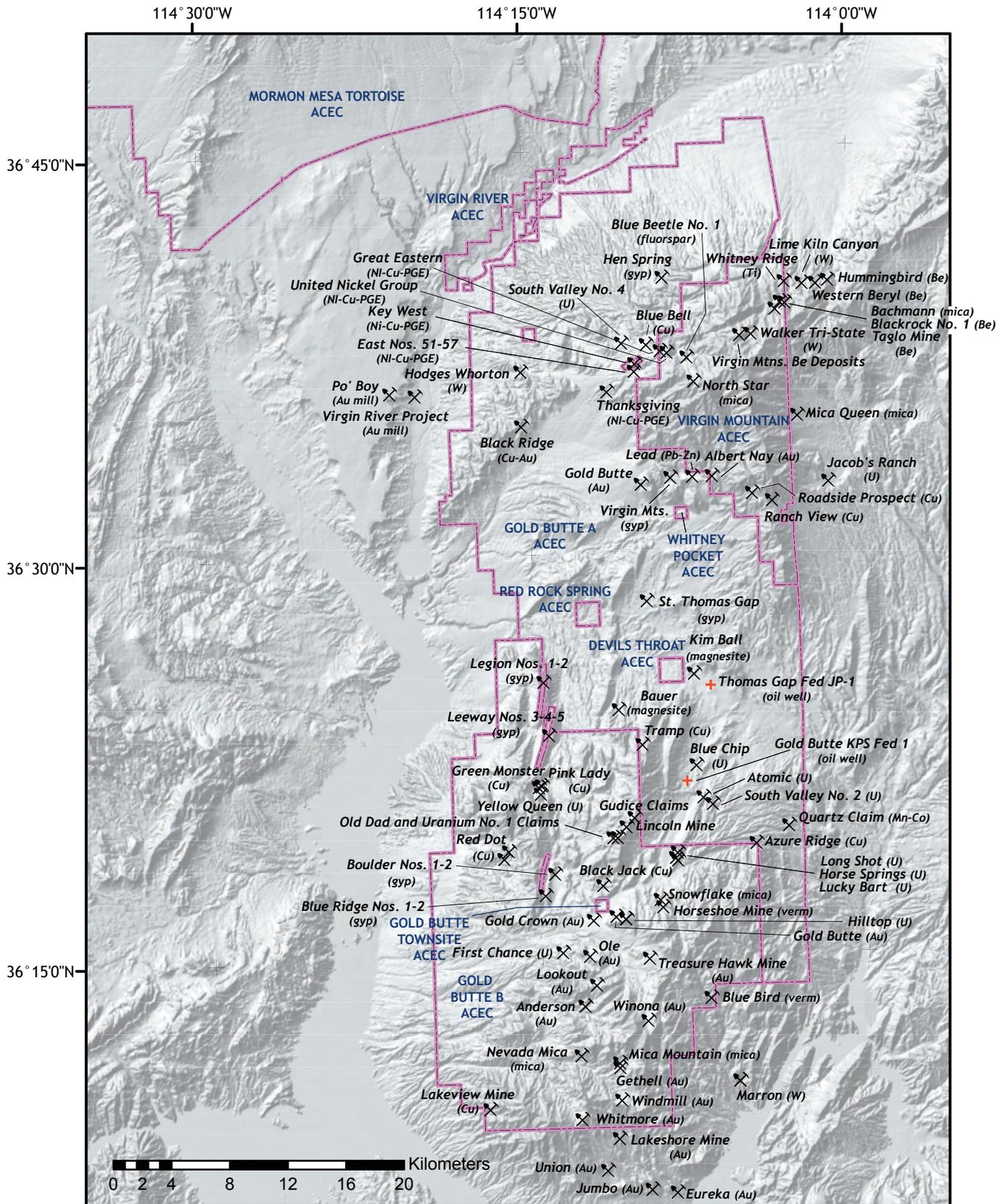
The Bauer magnesite prospect was located in 1922 in the Gold Butte A ACEC, but has had no recorded production (Longwell and others, 1965). Gypsum was prospected by trenching and pitting in two areas in the Gold Butte A ACEC, but there has been no production (Papke, 1987), and it is not known when this prospecting took place.

## Mineral Deposits

A wide variety of mineral deposits and occurrences are within and near the seven ACECs addressed in this report. Many of the deposits are uncommon and do not lend themselves easily to standard mineral-deposit models. We have grouped the deposits into a number of categories based on commodities and formation processes, and we describe them according to these categories. The locations of the mines and prospects discussed below are shown on figure 12.



**Figure 11.** View of trenches and a small open-cut pit at the Gold Butte Vermiculite Mine (the western wall of the pit is in the right middle ground at the base of the hill). The vehicle is parked at the approximate site of the old vermiculite mill.



**Figure 12.** Locations of mines and prospects in Gold Butte–Virgin Mountain Areas of Critical Environmental Concern (ACECs; boundaries in pink). Commodity sought or mined is in parentheses under each name (gyp=gypsum, verm=vermiculite). Red crosses are exploratory oil wells.

## Platinum-Bearing Ni-Cu Deposits

The most important mineral deposits in the area are Ni-Cu-Au-PGE deposits in the Bunkerville (or Copper King) district, in the Gold Butte A and Virgin Mountain ACECs. The Key West (fig. 13) and Great Eastern Mines contain significant amounts of platinum-group elements (PGE), which continue to create interest in the deposits.

The deposits were discovered in the late 1890s as copper deposits; their nickel and PGE contents were noticed later. Episodic production between 1908 and 1935 yielded about 128,000 pounds of copper, 1,700 pounds of nickel, 982 troy ounces of silver, 52 troy ounces of gold, 10 troy ounces of platinum, and 177 troy ounces of palladium (Bancroft, 1910; Knopf, 1915; Longwell and others, 1965).

The deposits are hosted in Paleoproterozoic schist and gneiss, primarily the dark granodiorite gneiss that is found southeast of the Hen Spring Fault (figs. 5, 6). The ore at the

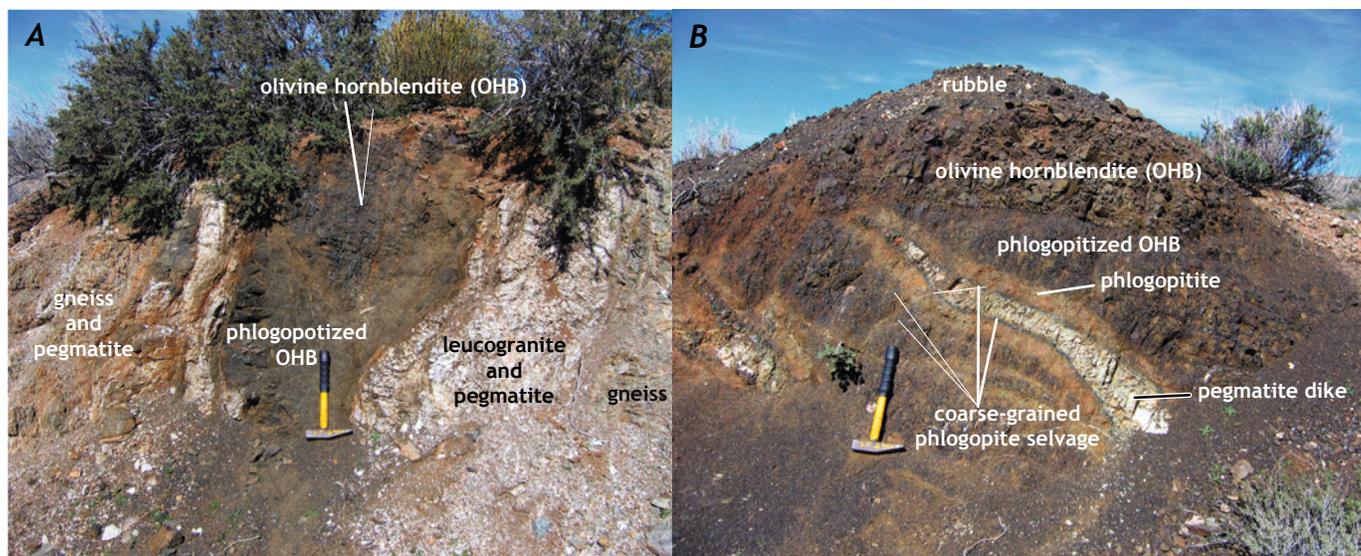


**Figure 13.** View of Key West Mine area, looking southwest; Black Ridge in middle distance.

Key West and Great Eastern deposits consists of pods, disseminations, and veinlets of pyrrhotite and other sulfide minerals that occur within and in close association with the olivine hornblendite (OHB) dikes that characterize the deposits. These dikes, and the other mafic dikes that are not directly associated with mineralized zones, trend about N60°E, generally parallel with the trace of metamorphic foliation. The OHB dikes and the mineral deposits are also confined to the area northwest of the main strand of the Virgin Mountains shear zone (see fig. 5), as mapped by Quigley and others (2002).

At the Great Eastern deposit, all of the principal adits and shafts are associated with OHB dikes, and a large majority of the rocks in the mine dumps are OHB, altered OHB, or pyrrhotite-bearing altered OHB. Variably altered OHB dikes at the Key West Mine are almost invariably associated with pyrrhotite. Throughout the district, most of the larger prospects and many of the smaller prospects target OHB or altered OHB. Altered OHB is the only significant host for pyrrhotite mineralization. From these facts, we infer that OHB dikes are the principal or sole agent or antecedent of pyrrhotite mineralization. Other geologists, some of whom had access to the deposits during exploration or small-scale mining, previously reached similar conclusions (Bancroft, 1910; Lindgren and Davy, 1924; Needham and others, 1950; Longwell and others, 1965).

Alteration of OHB and pyrrhotite mineralization of altered OHB are related but, to some extent, independent. Evidence pertaining to the origin of altered OHB can be observed in several prospects and at the Key West Mine. In these exposures, phlogopitized OHB forms a shell that envelops OHB and separates it from granitic country rock (fig. 14A). In another revealing exposure, a small pegmatite dike intruding OHB is surrounded by a sheath of phlogopitite (a rock com-



**Figure 14.** Phlogopitized olivine hornblendite (OHB) dikes in a prospect pit about 0.6 km southwest of the Great Eastern Mine. Hammer for scale is 35 cm long. *A*, OHB dike intruding gneiss, gneissic leucogranite and pegmatite. The dike consists of an outer zone of strongly phlogopitized OHB and a core of less altered OHB. *B*, Small pegmatite dike intruding OHB. The pegmatite dike is surrounded by a sheath of phlogopitite, which grades outward into phlogopitized OHB, which in turn grades (abruptly) into minimally altered OHB. Weathering and light Fe-oxide staining accentuate the color contrasts between these three zones.

posed almost entirely of phlogopite mica), grading outward into phlogopitized OHB (fig 14B). From these observations, we infer that altered OHB was produced by metasomatic reactions between the ultramafic OHB dikes and the quartzofeldspathic rocks that enclose or intrude them.

Pyrrhotite-rich altered OHB is observed only in mine dumps; the process by which this mineralized rock formed apparently is not visible at the surface, in either natural or artificial exposures. We suspect (but cannot demonstrate) that formation of large quantities of pyrrhotite in some altered OHB also was caused by thermal and chemical interaction of ultramafic magma with silicic country rock (Gianfagna and Tuzi, 1988; Li and Naldrett, 2000).

Relations of OHB and pegmatite are somewhat perplexing. In general, OHB dikes are unfoliated, apparently unmetamorphosed, and not intruded by leucogranite or pegmatite. Locally, the situation is more complicated. On the ridge east of the Great Eastern Mine, gabbro and amphibolite are, as usual, abundantly intruded by multiple generations of foliated and unfoliated pegmatite and leucogranite dikes. In contrast, OHB there is completely free of such intrusions, suggesting that it postdates all granitic magmatism associated with regional metamorphism. However, in exposures around adits at the Great Eastern Mine, OHB is intruded by at least two small nonfoliated pegmatite dikes (similar to the one shown in figure 14B). During underground exploration at the Great Eastern Mine, Needham and others (1950) noted an apparent association of pegmatite dikes with OHB: "Numerous granite pegmatite dikes converge with the main [hornblende] dike at various angles and ... places." Beal (1965) noted the same relationship. Did intrusion of ultramafic OHB magma cause local melting, now manifest as small pegmatite dikes? This possibility, though seemingly improbable, must be considered.

The relation between gabbro, gabbro-related hornblende (GRH), and OHB is important in assessing PGE-Ni potential. Despite the fact that gabbro and GRH are much more abundant than OHB, all the mafic to ultramafic rocks clearly appear to belong to the same dike swarm. Though typical GRH and typical OHB are petrographically distinct, there are several dikes that seem to be texturally and geochemically intermediate. Gabbro, GRH, and unaltered OHB have generally similar abundance patterns for both ore and other metals and incompatible elements (fig. 9). Thus, gabbro, GRH, and OHB probably are petrogenetically related. However, all other information suggests that gabbro and GRH are not responsible for nor directly involved in pyrrhotite mineralization. Only OHB is closely associated with sulfide minerals.

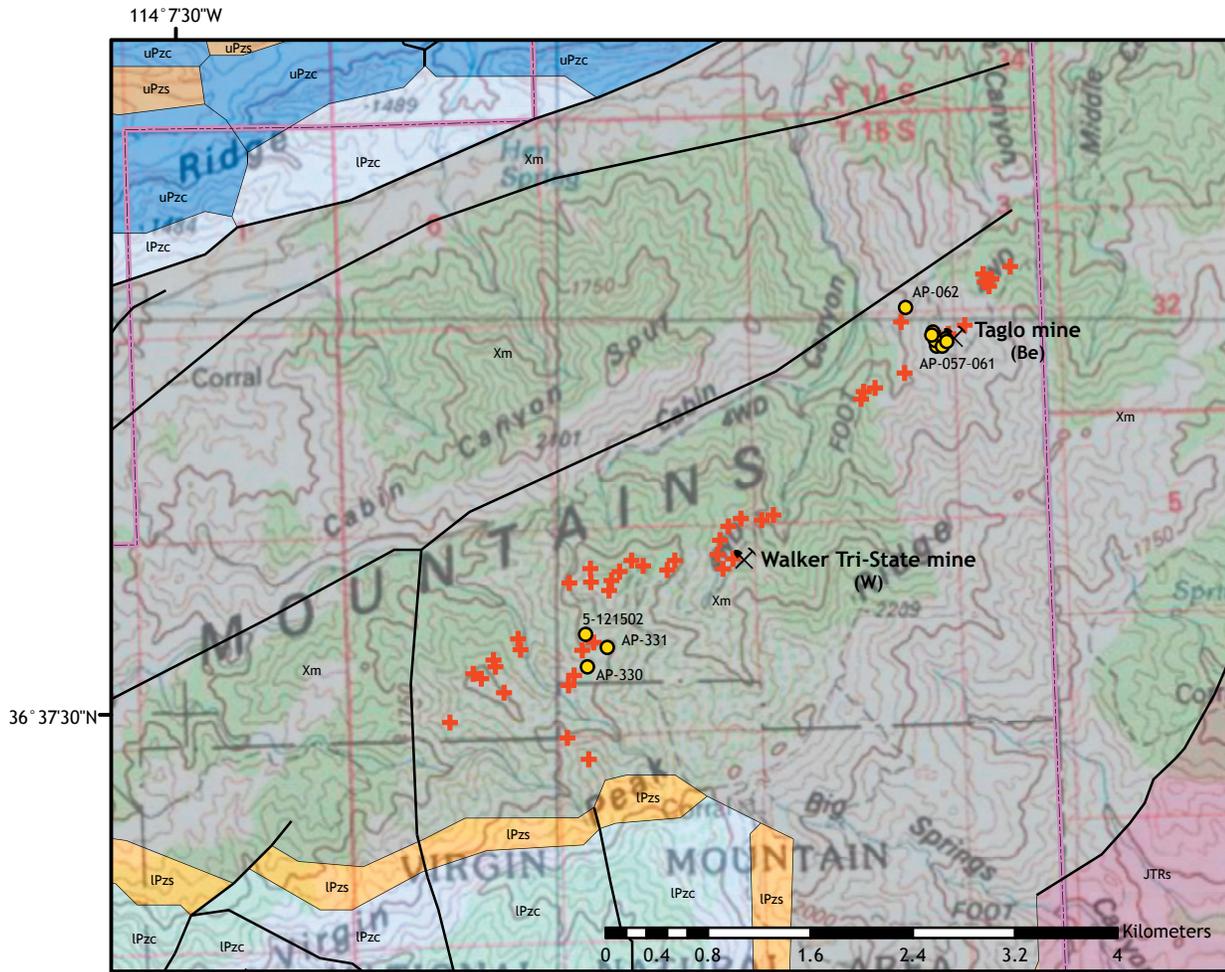
The distribution of OHB, shown on figure 6, appears to form an east-northeast-trending belt that passes through the Key West and Great Eastern Mines. The dikes are conspicuous and weather to a distinctive dark soil, so it is reasonable to expect that we have identified all the surface expressions. However, dikes of this lithology that do not intersect the present erosion surface may be present at shallow depths, as well as a possible larger gabbro body.

Detailed magnetic and electromagnetic data indicated to industry geologists that "a structural zone is the locus for several large, altered dikes and a source pluton which could host a Sudbury-type offset dike environment for magmatic and remobilized hydrothermal Cu-Ni-PGE mineralization" (Freewest Resources Canada, Inc., 1999). This deposit type is described by Rickard and Watkinson (2001) and Lightfoot and Farrow (2002) and is dependent on local concentration of sulfides by flow differentiation. We concur that this deposit model is applicable to the Bunkerville deposits. Less-detailed regional geophysical data (Langenheim and others, 2000) show positive features beneath the Bunkerville area for both isostatic gravity and magnetism.

The ultramafic intrusions in the Gold Butte block are not known to contain copper, nickel, and PGE ore. However, Volborth (1962) reported copper and tungsten mineralization in the contact zone of a large body of pyroxene hornblende at the Blue Bird Mine in the southeastern part of the Gold Butte B ACEC. Some of the Gold Butte block ultramafic rocks have nickel contents similar to those in unaltered OHB. Olivine-pyroxene hornblende sampled at the Blue Bird Mine contains as much as 870 ppm nickel and 0.02 ppm gold, and similar rock collected 1.5 km to the northeast has as much as 1,025 ppm Ni (Dexter and others, 1983). Rock samples from both localities contain <0.01 ppm palladium and <0.05 ppm platinum. In addition, samples of olivine- and pyroxene-bearing rock from the large body north of Mica Peak contain about 950 ppm nickel (samples AP-192 and AP-195A, Ludington and others, 2005).

### Beryllium-Bearing Pegmatite Deposits

Beryllium deposits have been identified and evaluated in the Virgin Mountain ACEC (fig. 15). The beryllium mostly occurs as beryl and chrysoberyl in pegmatite dikes or sills as much as 20 m thick, but it has also been reported as disseminated chrysoberyl in schist with small pegmatite stringers (G.W. Hansen, written commun., 2005). The most extensively studied area is the Mica Notch area, also known as the Virgin Mountain chrysoberyl property, which was the site of 41 unpatented mining claims in the 1960s (Holmes, 1964). In this area, beryllium-bearing pegmatites occur as sills, dikes, and irregularly shaped bodies that cut garnet-mica-quartz feldspar schist and locally cut amphibolite. Most of the pegmatite bodies appear to be steeply dipping, but some have shallowly dipping contacts with the host rocks (fig. 16). In addition to beryl and chrysoberyl, the pegmatites contain quartz, microcline, sodic plagioclase, muscovite, garnet, and tourmaline. Greenish-yellow chrysoberyl locally makes up as much as 10 percent of the rock, and light-green to nearly colorless beryl crystals as much as 10 cm in diameter are also present (Beal, 1965). The pegmatite bodies are mainly elongate bodies and sills, concordant with structure in the surrounding schist, that strike northeast, dip steeply to the southwest, and occur in a northeast-trending zone 1,800 m by 750 m (Holmes, 1964). Strike lengths of individual pegmatites are as much as 150 m and widths as much as 8 m.



**EXPLANATION**

- JTRs** Sedimentary rocks (Triassic and Jurassic)—Shale, mudstone, siltstone, sandstone, and carbonate rock; some sparse volcanic rock. Includes Lower Jurassic Glen Canyon Group and Chinle and Moenkopi Formations
  
- uPzc** Carbonate rocks (Mississippian to Permian)—Limestone, dolomite, and some shale. May include Kaibab, Callville, Monte Cristo, Pakoon, and Redwall Limestones
  
- lPzc** Dolomite and Limestone (Cambrian to Devonian)—Dolomite, limestone, and minor amounts of sandstone, shale, and siltstone. May include Temple Butte and Sultan Limestones, Frenchman Mountain Dolomite, Bonanza King Formation
  
- lPzs** Sedimentary rock (Cambrian)—Sandstone, shale, and limestone. May include Pioche Shale, Tapeats Sandstone, Bright Angel Shale, and Bonanza King, Muav, and Nopah Formations.
  
- Xm** Metamorphic rocks (Paleoproterozoic)—Undivided metasedimentary, metavolcanic, and gneissic rocks, including locally abundant amphibolite, and pegmatite. May also include Paleoproterozoic granitoid rocks
  
- contact
- fault
- mine or prospect
- sample location, with sample number
- beryllium-bearing pegmatite

**Figure 15.** Beryllium-bearing pegmatites in the Virgin Mountain Area of Critical Environmental Concern (ACEC; boundary in pink), showing sample locations. Geology modified from Stewart and Carlson (1978).

The U.S. Bureau of Mines collected 95 samples by percussion drilling and blasting or by outcrop chip sampling. Sample widths were as much as 3 m, and BeO contents ranged between 0 and 2.98 percent (Holmes, 1964), averaging (weighted by width) about 0.28 percent. Samples that we collected in the area contained as much as 0.115 percent BeO

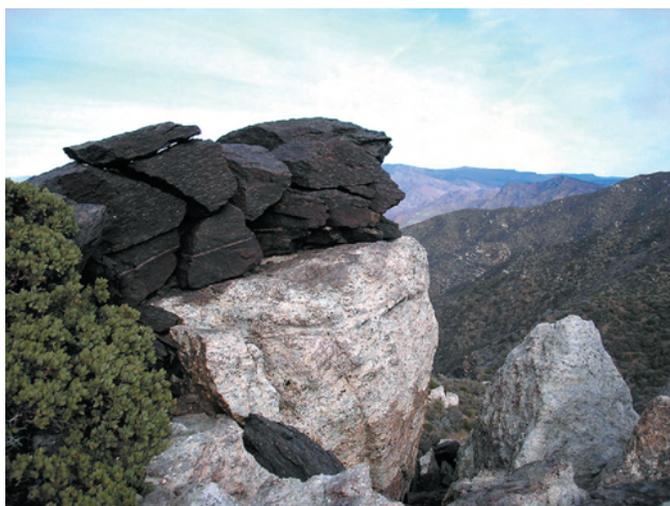
(table 3; Ludington and others, 2005). Beal (1965) reported that Beryllium Associates estimated a resource of 7,700 short tons of chrysoberyl ore averaging more than 1 percent BeO or 190,000 short tons averaging 0.35 percent BeO in an area of about 800 m by 300 m. This resource amounts to a total BeO content of about 665 short tons.

**Table 3.** Beryllium contents of samples from the Taglo Mine and Mica Notch areas, Virgin Mountain ACEC.

[BeO percent calculated as  $2.78 \times (\text{Be ppm})/10,000$ .]

Sample	Description	Sample type	Be (ppm)	BeO (%)
AP-057	Taglo Mine, pegmatite dike, no Be minerals noted	grab	89	0.025
AP-057A	Taglo Mine, thin quartz-tourmaline vein	grab	1	0.000
AP-058	Taglo Mine, 1.5-m wide dike, chrysoberyl + beryl	1-m chip	121	0.034
AP-059	Taglo Mine, 2-m wide dike with chrysoberyl	1.5-m chip	61	0.017
AP-330	Mica Notch, 10-m wide pegmatite dike with beryl	0.5-m chip	415	0.115
AP-331	Mica Notch, 7-m wide dike with chrysoberyl	1-m chip	56	0.016
5-121502	Mica Notch, 20-m thick sill with chrysoberyl	chip	99	0.028

The Taglo Mine area (fig. 17) is about 1 km northeast of the Mica Notch area and is likely an extension of the same pegmatite zone. This area consisted of 20 unpatented claims in the 1960s (Holmes, 1964). Here, minor amounts of beryl, chrysoberyl, and possibly phenakite occur in steeply dipping, northeasterly trending pegmatite dikes. The pegmatites are mainly composed of quartz and K-feldspar and are as much as 2 m thick. Some outer zones contain abundant muscovite in books as much as 5 cm across (fig. 18). Pinkish-red to brown garnet and black tourmaline occurs locally. We found chrysoberyl as yellow-green plates as much as 1.4 cm across and 0.2 cm thick (fig. 19), mainly in inner zones of white feldspar

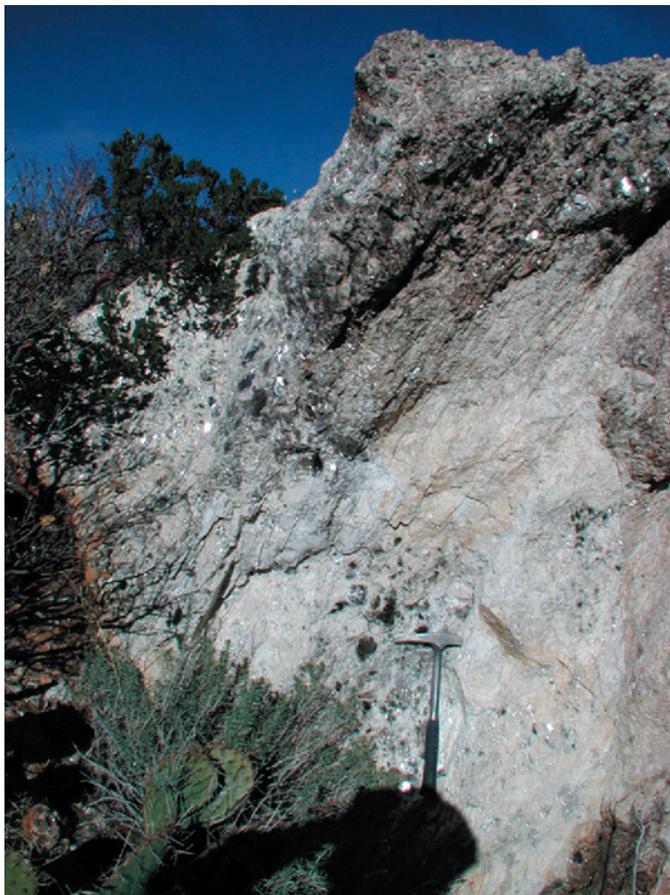


**Figure 16.** Shallowly dipping upper contact of a beryllium-bearing pegmatite in the Mica Notch area. Sample 5-121502 was taken in the core of the pegmatite, which is about 20 m thick here.



**Figure 17.** View looking southwest from the Taglo Mine area. The main pegmatite is in the immediate foreground, and a possible extension of this steeply dipping pegmatite is on the next hill to the southwest. The Mica Notch pegmatite area is on the vegetated ridge behind this that extends to the skyline.

+ quartz rock. We also found minor amounts of light-gray to pale bluish-gray beryl. According to Beal (1965) pale-bluish-green to green beryl crystals as much as 2 cm in diameter are present. The amount of beryl and chrysoberyl in Taglo Mine



**Figure 18.** Detail of 1.5-m-wide pegmatite at sample site AP-058, Taglo Mine, showing coarse muscovite books in the border zone of the dike (bright areas at top of view).



**Figure 19.** Platy crystals of yellow-green chrysoberyl in feldspar-rich pegmatite from the Taglo Mine at sample site AP-058. The largest crystal in this image is about 1.4 cm across.

pegmatites was estimated at 0.25 percent or less (Beal, 1965). Grab and chip samples that we collected from pegmatites and veins in the area contain only 1 to 121 ppm beryllium (table 3; Ludington and others, 2005). The average BeO content of 22 samples collected by the U.S. Bureau of Mines was 0.10 percent, and the range was 0 to 0.62 percent (Holmes, 1964). No estimate is available for the amount of beryllium-bearing rock in the Taglo Mine area.

The area also contains pegmatites as much as 4 m thick that contain garnet and tourmaline, but they do not seem to contain beryllium minerals. In addition, the area contains quartz-tourmaline veins without visible beryllium minerals.

Other areas of Be-bearing pegmatites are along trend with the Mica Notch prospects and the Taglo Mine and extend northeastward several kilometers into Arizona. A sample that came from the Walker-Condle claims between the Mica Notch and Taglo areas is a 5-m chip sample that contains about 0.07 percent BeO (Holmes, 1964). Beal (1965) showed many occurrences scattered over an area of about 1.3 x 2.8 km in the Nevada portion of this pegmatite belt.

## Other Pegmatite Deposits

Radioactive pegmatite occurrences in the Gold Butte B ACEC were studied and sampled by Dexter and others (1983) during the National Uranium Resource Evaluation (NURE) program. They concluded that, although several occurrences had elevated contents of uranium, thorium, tantalum, and niobium, they were unlikely to be of sufficiently high grade or large size to be significant sources of uranium or rare metals.

The Hilltop Mine is probably the best known radioactive pegmatite occurrence in the area and reportedly yielded 14 kg of samarskite (niobium oxide with variable amounts of uranium, tantalum, iron, and rare earth elements) from an underground location (Longwell and others, 1965). Dexter and others (1983) were unable to verify the presence of samarskite, but did report the rare-earth minerals allanite and monazite. Our examination showed that the Hilltop Mine pegmatite, a moderately east dipping dike at least 60 m long and as much as 14 m wide, has locally high radioactivity (as much as 35 times background). The high radioactivity corresponds with concentrations of a greenish gray to black vitreous mineral that occurs sparsely in a 1.5- to 3-m-thick zone near the foot-wall of the dike. Based on analyses reported by Dexter and others (1983), the Hilltop Mine pegmatite has high thorium and tantalum contents, moderate uranium (about 100 ppm), and relatively low niobium.

## Tungsten Deposits

Several small tungsten-bearing deposits and prospects occur in and near the Gold Butte–Virgin Mountain ACECs (fig. 12). All of them are hosted in Proterozoic metamorphic rocks. Two of them, the Walker Tri-State Mine and the Lime

Kiln Canyon prospect (which is outside the Virgin Mountain ACEC in Arizona), are located in the same rock unit that contains the beryllium pegmatites described above. These two tungsten deposits contain scheelite in quartz veins. The Walker Tri-State Mine was worked from 1953 to 1957, but production of only 34 units (245 kg) of tungsten trioxide was recorded (Longwell and others, 1965). The Hodges-Wharton prospect, also in the Virgin Mountains, is in the silica-rich gneisses north and west of the Virgin Mountain shear zone. No production has been recorded, and our examination showed no evidence for large amounts of mineralized rock. We took no samples at any of these tungsten occurrences.

The Marron tungsten prospect is in the southeast part of the Gold Butte block, about 4 km from the boundary of the Gold Butte B ACEC. Here, scheelite and powellite occur in joints and fractures in the Proterozoic gneiss and are spatially associated with concentrations of granitic dikes related to the Gold Butte pluton. No production has been recorded.

## Gold-Bearing Vein Deposits

In the Gold Butte block, a number of northeast-trending quartz veins cut the Gold Butte granite and its wall rocks on the west side of its outcrop. Figure 20 shows the locations of mines and prospects that explore these veins and the relationship of the veins to the granite of the Gold Butte pluton. From north to south, the deposits are the Gold Crown, Gold Butte, Treasure Hawk, Ole, Lookout, Anderson, Winona, Gethell, Windmill, and Whitmore, all within the Gold Butte B ACEC, and the Lakeshore, Union, Jumbo, Eureka, and Joker, all within a few kilometers of the south boundary of the ACEC.

These deposits have been described briefly by Hill (1916), Lincoln (1923), Vanderburg (1937), and Longwell and others (1965). All of the prospects we visited consist of milky-white quartz veins, from a few centimeters to nearly a meter in thickness. In some cases the veins are spatially related to, or grade into, tabular pegmatites.

The Gold Butte Mine was among the first gold discoveries in the Gold Butte district, and was explored as early as 1905 (see fig. 10). Here, small quartz veins strike north and northeast and cut Proterozoic Gold Butte Granite (Hill, 1916).

Dexter and others (1983) sampled an adit in the Golden claim group, which was staked near or over the Gold Butte Mine, and reported a high-grade quartz vein sample containing 14.2 ppm gold and 8 ppm silver. A second quartz vein sample of questionable origin from the dump of the same adit was reported to have 9.4 ppm gold and 137 ppm silver with high copper, lead, and bismuth, and to contain abundant sulfide minerals, including galena and chalcopyrite. Samples from an area about a kilometer south of the Gold Butte Mine had gold values of 0.38, 0.59, and 4.26 ppm. Winters (1988) reported five samples from the Golden claim group, on the northwest side of the road, about a kilometer northwest of the Gold Butte Mine, with gold values of 0.06, 0.095, 0.23, 0.43, and >10 ppm.

The nearby Gold Crown Mine and mill were reportedly active in the 1970s (Nevada Department of Industrial Relations, 1975) but are not mentioned in earlier reports, so the origin of any ore processed there is unknown.

The vein at the currently active Treasure Hawk Mine trends N85°E, and is exposed for a length of nearly 2 km (Longwell and others, 1965). The area has been described in the past under the names Radio Crystal Mine and Webster Mine. These are simply names for two different workings on the same vein. The width of the vein varies, but is commonly less than 1 m; the vein dips steeply to the south. It is primarily composed of quartz, but pyrite, galena, and fluorite have also been identified (Dexter and others, 1983). A grab sample from this vein (sample 5-020403, Ludington and others, 2005) contained 0.73 ppm gold, 1.4 ppm tellurium, and 28.5 ppm molybdenum; silver was not detected. Dexter and others (1983) reported samples from the Treasure Hawk Mine with 1.01 to 10.5 ppm gold, undetectable (<3 ppm) to 4 ppm silver, and variably high copper, lead, and fluorine.

The Ole Mine (fig. 21) was originally called the Big Thing Tunnel, which was driven by Olli Rosson before 1913 (Hill, 1916). Longwell and others (1965) reported that the tunnel had been lengthened, but no production had been recorded. This vein is also less than 1 m wide and trends N35°E to N45°E. Sulfide minerals in the vein are pyrite, chalcopyrite, galena, and sphalerite. A grab sample (4-110202) from the mouth of the tunnel yielded values of greater than 5 ppm gold, 55 ppm silver, 2,600 ppm lead, about 45 ppm molybdenum, and about 36 ppm tellurium (Ludington and others, 2005).

The Lookout prospect is about 1 km south of the Ole Mine. There, a small quartz vein trends northeast and dips to the southeast; no production was recorded (Longwell and others, 1965).

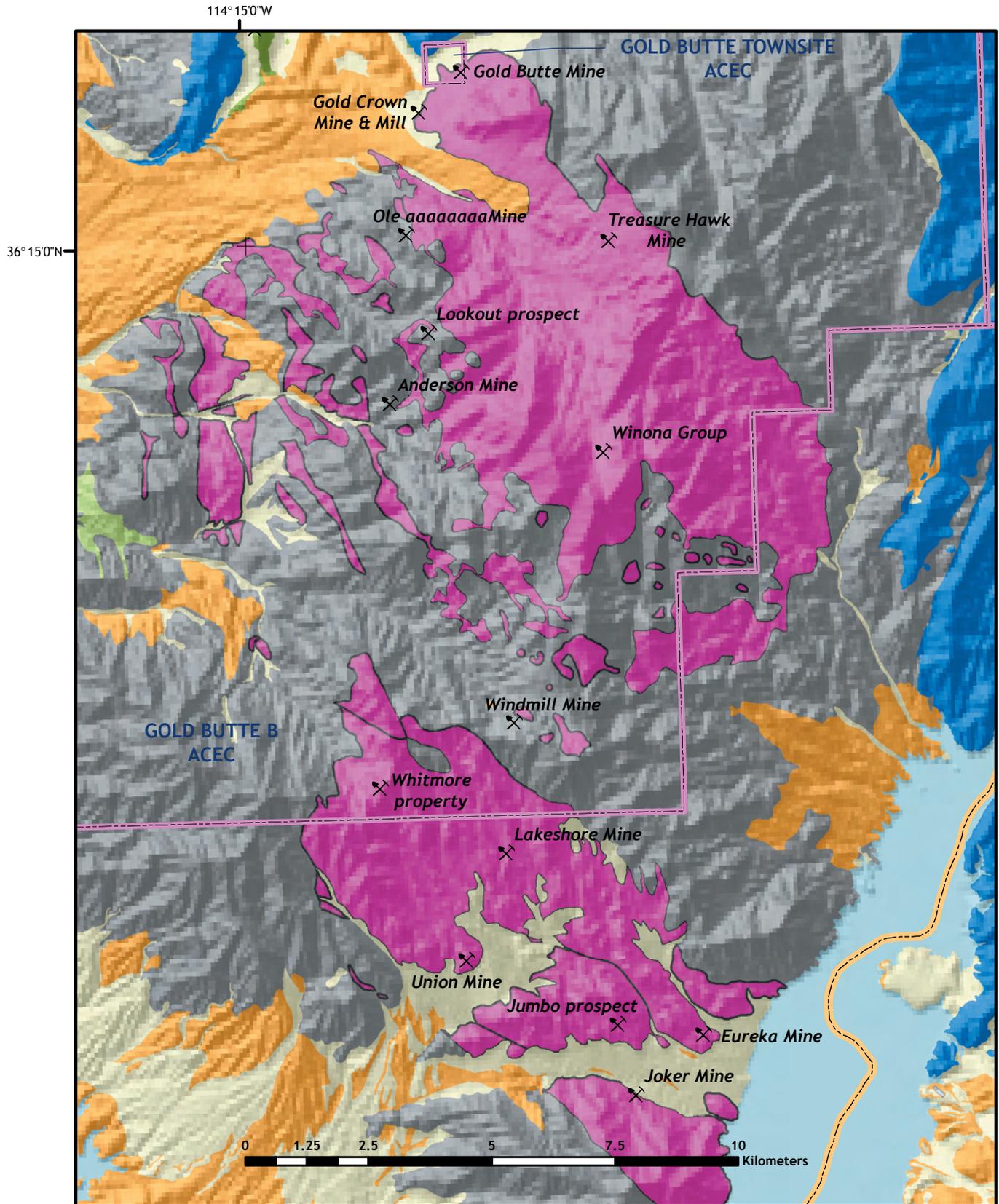
The Anderson Mine is a vertical quartz vein with unreported strike; it contains pyrite, chalcopyrite, bornite, azurite, and chrysocolla (Longwell and others, 1965). There was apparently no production. We were unable to find any evidence for this deposit at the indicated location.

The Winona group of claims were on a quartz vein apparently seen only by Hill (1916). He observed a quartz vein striking N65°E, with sparse pyrite and chalcopyrite. We visited this site, but found no evidence of workings, only white quartz and pegmatitic material.

The Windmill Mine, known in 1913 as the Finance group of claims, exposes veinlets of white quartz striking N35°E. Hill (1916) noted pyrite, chalcopyrite, galena, and sphalerite. There has been no recorded production. Dexter and others (1983) reported gold values of 0.96, 3.01, and 3.82 ppm for samples they took from this mine.

The Whitmore property, also called the Greenhorn Mine, is a quartz vein with unknown strike that carries pyrite, chalcopyrite, bornite, and chrysocolla (Longwell and others, 1965). There is no recorded production.

The Lakeshore Mine, less than 1 km south of the Gold Butte B ACEC, was the largest producer of this entire group; between 1934 and early 1937, more than 2,500 short tons of



**Figure 20.** Mines and prospects on gold-bearing quartz veins in the Gold Butte block. Pre-Gold Butte granite metamorphic rocks are shown in gray, Gold Butte granite is dark pink, Paleozoic carbonate rocks are blue, Tertiary sedimentary rocks are gold, and Quaternary alluvium is pale yellow.



**Figure 21.** Mouth of adit at Ole Mine. The sample (4-110202) containing >5 ppm gold was selected from the pile in the foreground.

gold ore were produced here (Vanderburg, 1937). Ore was trucked to the shore of Lake Mead, loaded on barges, and towed to the docks near Saddle Island, where it was again shoveled into trucks for a 6-mile trip to the railroad at Boulder City. One shipment of about 60 short tons averaged about 1.55 opt gold and 0.78 opt silver. The vein is notable because it dips only about 8°. The Union, Jumbo, Eureka, and Joker Mines explored similar gold-bearing quartz veins, beginning before 1913, but they are located 3 to 7 km south of the ACEC boundary. Only the Eureka and Joker produced ore, and only in very small quantities.

The characteristics of these deposits are suggestive of a type of mineral deposit termed low-sulfide gold-quartz veins, characterized by gold in massive, persistent quartz veins in shear zones in regionally metamorphosed volcanic and sedimentary rocks (Berger, 1986; Drew, 2003). The typical mineral assemblage is quartz, pyrite, galena, sphalerite, and chalcopyrite, along with native gold. The most prominent examples in North America are the Mesozoic quartz veins of the Mother Lode in California, but these deposits are common in Proterozoic metamorphic rocks throughout the western United States. These veins typically persist over large vertical ranges, forming most commonly at paleodepths ranging from 4 to 12 km (Drew, 2003).

Because the entire Gold Butte block is dipping to the east at about 45°, it presents a singular continuous exposure of an intact Proterozoic through Miocene crustal section that reaches paleodepths of about 15 km at the western edge (Fryxell and others, 1992; Fitzgerald and others, 1991; Reiners and others, 2000). From this perspective, the distribution of the low-sulfide gold-quartz vein deposits in the Gold Butte block (fig. 20) makes an understandable pattern. The deposits are all within about 5 to 13 km southwest of the exposed unconformity

between Proterozoic and Paleozoic rocks. Corrected for dip, this means they occur at paleodepths of 3 to 8 km below the unconformity. Adding about 2 km of crust that was eroded between 1.4 Ga (the approximate age of formation of the veins) and 600 Ma (the beginning of Paleozoic deposition) results in an inferred depth interval at the time of formation of 5 to 10 km.

The style and inferred genesis of these gold-bearing veins indicates that, though relatively small, they are best classified as low-sulfide gold-quartz veins. Trace-element signatures of the samples we took from the Ole Mine and from the Treasure Hawk Mine were both anomalous in molybdenum and tellurium, also typical of the deposit type (Drew, 2003).

There are two reported gold deposits in the Gold Butte–Virgin Mountain ACECs that are not spatially related to the Gold Butte pluton—the Albert Nay prospect and the Gold Butte prospect, both of which are in Paleozoic sedimentary rocks about 2 km north of the Whitney Pocket ACEC (fig. 12). Both are reported only by Hose and others (1981), and it is possible that they have been mislocated; examination of detailed aerial photography of the areas shows no sign of any surface disturbance.

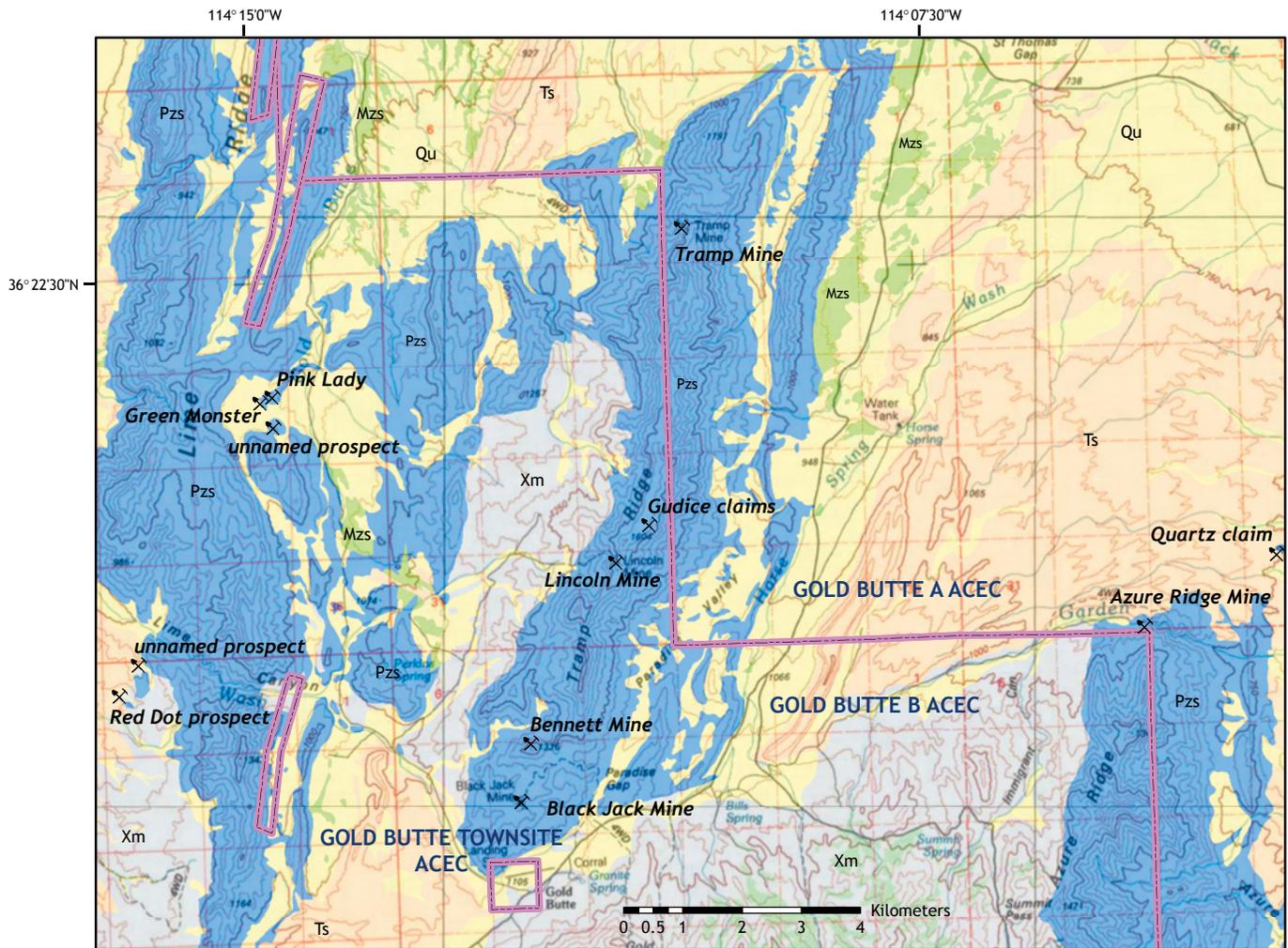
## Copper Deposits in Sedimentary Rocks

A number of copper mines and prospects are located within the Gold Butte–Virgin Mountain ACECs, and about 150,000 pounds of copper was produced from mines in the Gold Butte district between 1907 and 1956. The most important mines were the Tramp, Lincoln, Bennett, and Black Jack, all in the Tramp Ridge block, along with the Azure Ridge Mine (Bonella properties), in the Gold Butte block (fig. 22).

These deposits are all hosted in Paleozoic limestone and consist primarily of small concentrations of hematite, limonite, base-metal oxides, and base-metal carbonates. Copper minerals noted in the various mines include malachite, azurite, cuprite, chalcocite, chalcopyrite, and bornite. Other minerals noted include smithsonite ( $\text{ZnCO}_3$ ), aurichalcite ( $(\text{Zn,Cu})_3[(\text{OH})_3\text{CO}_3]_2$ ), and cerussite ( $\text{PbCO}_3$ ). The distribution of the mineralized rock in all of these deposits is structurally controlled.

These deposits appear to form a continuum between two end-member structural styles. One end member, displayed at the Black Jack Mine, consists of chalcocite veins in slightly brecciated limestone. The other end member, the Tramp Mine, is characterized by limestone breccia cemented and mineralized by base-metal carbonate minerals. The deposits we observed at the Azure Ridge Mine, though dominated by chalcocite veins, display more brecciation of the host limestone than do those at the Black Jack Mine. The Lincoln Mine is intermediate in character between the Black Jack and Azure Ridge and the Tramp.

Stratigraphically, the Tramp, Lincoln, Black Jack, and Bennett Mines are situated near the contact between the Devonian Temple Butte Formation and the overlying Mississippian



**EXPLANATION**

Qu	Quaternary sediments, undivided	
Ts	Tertiary sedimentary rocks	mine or prospect
Mzs	Mesozoic sedimentary rocks	
Pzs	Paleozoic carbonate and siliclastic rocks	
Xm	Paleoproterozoic igneous and metamorphic rocks, undivided	

**Figure 22.** Locations of copper deposits in Gold Butte A and B Areas of Critical Environmental Concern (ACECs; outlined in pink). Generalized geology from Stewart and Carlson (1978).

Redwall Limestone, primarily in the Redwall. The Azure Ridge Mine workings we visited are in limestone of the Cambrian Muav Formation, but other workings are in the Temple Butte Formation and Redwall Limestone. We visited and sampled the Tramp, Lincoln, Black Jack, and Azure Ridge Mines.

## Tramp Mine

The orebody at the Tramp Mine is steep to subvertical, cuts across bedding, and appears to be pipelike. The ore consists of brecciated limestone impregnated or cemented with copper-carbonate minerals, chiefly malachite, and iron-oxide minerals. Stringers and irregular pockets of mineralized rock appear to be controlled by fractures, and they occur over a width of 1 to 2 m and a vertical distance of at least 100 m. A nearby minor, steep fault apparently is unrelated to the ore body. In contrast to the Black Jack and Azure Ridge Mines, mineralization at the Tramp Mine has no veinlike aspect, and chalcocite is rare to absent. Hill (1916) described the mineralogy of the deposit (called the Tramp Miner property at that time) as limonitic, with minor cuprite and malachite. A select grab sample that we analyzed contains about 220 ppm silver, 0.96 percent copper, 5.7 percent lead, and 0.96 percent zinc.

## Lincoln Mine

Many of the underground workings at the Lincoln Mine are difficult to locate with certainty, and all are now inaccessible. The dumps and piles of rock at the mine are dominated by three types of material: fine-grained, homogeneous, noncherty limestone; medium-grained, marble-like, recrystallized limestone; and limestone breccia, derived mostly from recrystallized limestone but also in part from fine-grained limestone. Much of the breccia contains malachite, some poorly crystalline and some filmy or powdery. Some pieces of recrystallized limestone and fine-grained limestone have malachite coatings on fractures. Chalcocite ore and derivative gossan are minor constituents of the dump material. Scattered shallow diggings (but no adits or shafts) north of the Lincoln Mine proper are in distinctive, light-yellowish brecciated limestone and fault gouge (or other clayey material), in part gypsum-bearing. Hill (1916), who had access to the underground workings, describes a stratiform ore body in pinkish-gray crystalline limestone below chert-rich gray limestone. He also described chalcocite replacing small amounts of bornite and chalcopyrite.

## Black Jack Mine

The well-exposed chalcocite veins of the Black Jack Mine are subvertical and about 0.5 m to as much as 2 m thick. These veins are at a high angle to the gently dipping beds of the host limestone. Veins typically are bordered by a zone, a few meters wide, of slightly to moderately brecciated limestone, grading outward into unbrecciated limestone. This marginal breccia zone is cut by chalcocite veins and veinlets,

a few tens of centimeters to 1 m thick. Some veins contain minor sphalerite. Weathering of the chalcocite veins has produced gossan. Dump materials include both chalcocite and subordinate copper-carbonate-bearing breccia.

## Azure Ridge Mine

Originally called the Bonella claims (Hill, 1916), the chief workings are at the northern end of Azure Ridge, immediately adjacent to Garden Wash (fig. 22), although other workings exist a kilometer or more south along strike. Hill (1916) described the ore as irregular replacement lenses of limonite in massive limestone. We observed that some of the mineralized rock at the Azure Ridge forms veins and veinlets similar in style and size to those at the Black Jack Mine. These are accompanied by veinlike bodies of chalcocite-bearing breccia, some of which have been altered or weathered to copper-carbonate-bearing breccia. Both chalcocite and mineralized breccia are prominent in the dumps.

During the study of the Million Hills Wilderness Study Area, a detailed sampling program was conducted at the Azure Ridge Mine by Bergquist and others (1994). They reported small pods of mineralized rock along bedding-plane faults over an area 5,000 ft (>1,500 m) long. Along with concentrations in excess of 1 percent for copper, lead, and zinc, they found values of cobalt as high as 471 ppm, gold as high as 3.3 ppm, germanium as high as 150 ppm, and gallium as high as 75 ppm. Although many of these samples were carefully selected and are not representative of average compositions, the high values obtained for cobalt, gold, germanium, and gallium may be significant.

Our samples from the Azure Ridge, Black Jack, Tramp, and Lincoln Mines (Ludington and others, 2005), do not show significantly elevated gallium contents. The highest value obtained was 14 ppm. Our samples do have elevated cobalt (as much as 279 ppm), indium (as much as 39 ppm), and gold (as much as 0.9 ppm). We analyzed only 4 samples for germanium, and two of them contained 22 to 26 ppm, which is anomalous, but not as high as the samples reported by Bergquist and others (1994).

## Mineral Deposit Model

All these mines show similarities in host rock, mineralogy, and geochemistry, although they exhibit a variety of structural styles. From our reconnaissance observations and sketchy previous descriptions, their mode of origin remains unclear, and the relative importance of structure and stratigraphy is indeterminate. We compare the deposits with three well-known types of deposits in nearby northern Arizona and southwestern Utah.

## Solution-collapse breccia pipes of the southern Colorado Plateau

These deposits are subvertical pipelike bodies of breccia formed by collapse of Pennsylvanian and Permian strata into paleokarst cavities in the underlying Mississippian Redwall Limestone (Wenrich, 1985). Several thousand breccia pipes

have been identified in northern Arizona; only a few are mineralized. Primary mineralization has two aspects or phases: (1) younger uraninite mineralization and (2) older Mississippi Valley–like base metal sulfide mineralization, which evidently acted as a reductant that caused later deposition of uranium. Breccia pipe deposits have produced copper, in the late 1800s and early 1900s, and uranium, over the past several decades. In addition, some mineralized breccia pipes also contain anomalous levels of a variable suite of other metals and metalloids, including Ag, As, Au, Ba, Cd, Co, Hg, Mo, Ni, Pb, Sb, Se, Sr, V, W, Zn, and rare earth elements (Wenrich and Silberman, 1984).

Although the breccia in the deposits in the Gold Butte district suggests some affinity to the solution-collapse breccia pipes, the Gold Butte deposits occur in rocks stratigraphically lower than typical breccia pipes of the Colorado Plateau. Chalcocite, the dominant sulfide mineral at the Black Jack and Azure Ridge Mines, is found in some Colorado Plateau breccia pipes.

### Stratabound Copper Deposits in the Kaibab Formation

These small deposits occur in the Harrisburg Member of the Kaibab Formation at several places in the Grand Canyon region (Tainter, 1947; Gibbons, 1952; Keith and others, 1983; Sorauf and Billingsley, 1991). These deposits contain disseminated and fracture-controlled malachite, azurite, and less commonly chalcopyrite and chalcocite in flat-lying sedimentary chert breccias. Mineralized zones are sporadic and generally less than a meter thick. Small-scale mining with hand sorting, conducted intermittently from the early 1900s through the early 1960s, produced some copper, along with minor silver and gold. Genesis of these small copper deposits is unclear. Apparent associations with high-angle fault zones may or may not be important. Possible genetic relations to the solution-collapse breccia pipes have yet to be investigated. Bliss and Pierson (1993) suggest that the presence of gypsum, as a source of sulfur, within the Harrisburg Member of the Kaibab Formation may be an important factor.

The Nevada deposits do have some similarities in lithology and mineralogy to the stratabound copper deposits in the Kaibab Formation in Arizona. However, the Nevada deposits have significant lead and zinc contents, have no evidence of being stratigraphically controlled on scales of meters or ten of meters, and do not have any apparent association with chert or chert breccia. Furthermore, the Black Jack and Azure Ridge Mines contain important steeply inclined veins.

### The Apex Mine, Southwest Utah

This extraordinary mine is located about 90 km to the northeast of Gold Butte, in the Tutsagubet District near St. George, Utah. It was the first mine in the world devoted primarily to production of gallium and germanium (Bernstein, 1986; Petersen and others, 1989). Gallium and germanium are strategic materials with a variety of high-technology applications, particularly in semiconductors (Orton, 2004). Most gal-

lium and germanium demand is met from recycling and from production as byproducts from the processing of aluminum and zinc ores, respectively. The Apex Mine was active from the mid 1980s until 1991. A reserve of about 272,000 short tons averaging 1.9 percent copper, 1.8 percent zinc, 60 ppm silver, 370 ppm gallium, and 1,000 ppm germanium had been delineated just before mining began in 1986 (Petersen and others, 1989). A yearly production goal of 9,000 kg of gallium and 19,000 kg of germanium was set, but we have been unable to determine the actual production figures. The mine apparently closed because of complications in the recovery process. After closure, the property was apparently sold to a partnership of Preussag AG and Teck Cominco Ltd., both major producers of germanium from zinc ores.

Apex Mine ore occurs in breccia, gouge, and fissures in steeply dipping fault zones in Pennsylvanian Callville Limestone. The ore consists of copper and iron oxides, carbonates, arsenates, and sulfates. Principal host minerals for gallium and germanium are, respectively, jarosite and goethite (Dutrizac and others, 1986). Owing to thorough oxidation of the ore, few remnants of primary, sulfide ore have been found. Primary minerals include pyrite, marcasite, galena, chalcopyrite, bornite, sphalerite, anhydrite, quartz, and goyazite ( $\text{SrAl}_3[(\text{O} \text{H})_3](\text{PO}_4)_2] \cdot \text{H}_2\text{O}$ ) (Mahin, 1990). Although jarosite commonly occurs as a secondary mineral, and the fine grain of the Apex material makes textural interpretations difficult, at least part of the gallium-bearing jarosite has been interpreted to be hypogene, not secondary. This jarosite yielded late Miocene K-Ar ages (Bowling, 1988), corresponding to the timing of tectonic extension, both at Apex and in the Gold Butte–Virgin Mountain ACECs.

Because of the high value of germanium and gallium, mineralized rock from these deposits could be more valuable for germanium and (or) gallium than for the base metals. The germanium price has fallen recently, but has typically been in excess of \$1,000/kg since the early 1980s. Gallium prices have hovered near \$500/kg over the same time period.

Wenrich and others (1987) consider the Apex deposit to be a variety of solution-collapse breccia pipe. However the U.S. Geological Survey (Cox and Bernstein, 1986) and the British Columbia Geological Survey (Trueman, 1998) classify Apex as a Kipushi-type carbonate-hosted  $\text{Cu} \pm \text{Pb} \pm \text{Zn}$  deposit. The namesake deposits for the Kipushi type are in the Democratic Republic of the Congo, Africa. The African deposits are distinctly larger but have a similar structural and stratigraphic setting and have produced both gallium and germanium (De Magnée and Francois, 1988). Other examples of this deposit type are found in Canada, Alaska, Ireland, Namibia, Australia, and China (Trueman, 1998; Cox and Bernstein, 1986). The similar (and uncommon) geochemistry suggests that the Apex Mine and the Nevada deposits are genetically similar to the African ones.

The source of sulfur in most genetic models for the Kipushi-type deposits is evaporites at depth. In the Gold Butte district, there is abundant gypsum in the stratigraphic section, but it is all at higher stratigraphic levels than those occupied by the copper deposits. Exposures in the Gold Butte district

are not extensive enough to evaluate the relative importance of stratabound karst breccias versus throughgoing steep structures in localization of the mineralizing process. The Nevada mines are all lower in the regional stratigraphic section than the Apex Mine. Whether or not stratigraphic setting is an essential aspect of the genesis of the Apex deposit is unknown. The primary sulfide minerals recognized at Apex do not include chalcocite, though a little secondary chalcocite is present.

## Other Copper Deposits

In addition to the deposits on Tramp and Azure ridges, Winters (1988) studied several copper prospects (Green Monster and Pink Lady claims, fig. 12) in Permian sandstone and conglomerate (Toroweap Formation?) and another nearby unnamed prospect in limestone of the Permian Kaibab Formation. Samples from the prospects in sandstone and conglomerate are anomalous in copper and silver, but not lead or zinc, and may represent traditional redbed copper deposits. The unnamed prospect in limestone has anomalous lead and zinc concentrations, as well copper and silver, and may represent another Kipushi-like prospect. The claims are no longer current.

Winters (1988) noted two other prospects to the south of the Green Monster and Pink Lady claims. The Red Dot claim and an unnamed prospect about 800 m northeast of the Red Dot also have anomalous copper, silver, lead, and zinc contents, and could be Kipushi-like occurrences. These prospects are apparently mislocated, as their reported coordinates plot in Proterozoic rocks, yet they are described as being in Paleozoic limestone. Examination of aerial photography in the region revealed a likely location for the Red Dot, but no surface disturbance could be seen to the northeast. These possible locations still do not correspond with carbonate bedrock; it is possible that the prospects might be in large blocks of Paleozoic rock in the Tertiary conglomerates.

## Uranium Deposits in Sedimentary Rocks

A low-grade, stratiform uranium deposit (Long Shot deposit, also known as the Blue Chip prospect) is exposed along the west side of a ridge that is in part of the Gold Butte A and Gold Butte B ACECs (fig. 12). The deposit occurs in the Thumb Member of the Tertiary Horse Spring Formation. Anomalously radioactive rock composed predominantly of calcite, with locally abundant dolomite, gypsum, and iron oxide, occurs near the base of a section of resistant limestone with bedding that dips shallowly east. According to Johnson and Glynn (1982), rock with  $U_3O_8$  contents of as much as 240 ppm and local carnotite ( $K_2(UO_2)_2[VO_4]_2 \cdot 3H_2O$ ) on fractures occur in a 1-m-thick body as much as 5,000 m long. Gypsiferous bedding planes are the primary ore control and organic matter is rare, although sparse fossil twig casts were noted by Johnson and Glynn (1982). The radioactive zone was explored by numerous pits, nine drill holes, and an 11-m-long adit, most along a 4-km access road.

Prospects in the area include those known as the Long Shot Mine, Lucky Bart prospect, Atomic prospect, and South Valley No. 2 claim, among others (Johnson and Glynn, 1982; U.S. Geological Survey, undated; fig. 12). In addition to the radioactive zone in this area, we noted carnotite in white dolomitic limestone of the same rock unit in a prospect near Horse Spring at the north end of the ridge containing the Long Shot Mine. We have no information on uranium content of carnotite-bearing rock in the Horse Spring area, but dolomitic limestone collected there contains about 12 ppm U, which is weakly anomalous (sample AP-072A, Ludington and others, 2005). The U.S. Geological Survey's MRDS (Mineral Resource Database System; U.S. Geological Survey, undated) database also lists uranium occurrences at the Atomic prospect 0.8 km south of Horse Spring, the South Valley #2 claim 1.5 km southeast of Horse Spring, and the Blue Chip prospect about 1.5 km north of Horse Spring. We did not examine these locations, which are all in exposures of the Horse Spring Formation.

Our examination of the Long Shot Mine area showed local radioactive areas as high as 16 times background (2,500 counts per second (cps) with a background of 150 cps) and extensive radioactivity at 3 or more times background. The highest radioactivity is generally associated with yellow carnotite on fractures (fig. 23). Interestingly, some of the most radioactive material was not carbonate rock, but clay-altered tuff near a caved adit at the Long Shot Mine (fig. 24). Uranium contents of samples taken here verify those reported by Johnson and Glynn (1982), with a high value of 181 ppm (Ludington and others, 2005). In addition to uranium, our analyses show scattered anomalous amounts of As, Bi, Co, Cu, Li, Mo, Ni, Sb, Sr, Tl, V, and Zn (table 4). With the exception of vanadium and copper, this is not the usual suite of trace element enrichment that accompanies uranium in sedimentary-rock-hosted deposits.



**Figure 23.** Yellow carnotite crusts on fractures in limestone, Long Shot Mine (also called Blue Chip), Gold Butte B Area of Critical Environmental Concern (ACEC).

**Table 4.** Selected element concentrations (in ppm) in samples from Long Shot prospect.

[Complete results are in Ludington and others (2005). nd = not detected; cps = counts per second.]

Element	AP-204	AP-206	AP-207	AP-208	AP-209
U	139	181	128	40	12
Th	6.4	4.0	7.1	0.2	0.9
As	2,100	116	206	22	40
Bi	1.1	0.2	0.2	0.1	<0.1
Co	158	2.3	4.7	0.7	2.8
Cs	40	4.8	26	0.8	4.0
Cu	134	15	14	4.5	3.3
Li	460	86	150	10	nd
Mo	7.4	25	6.8	1.0	1.5
Ni	1,820	28	17	5.6	22
Sb	0.7	2.4	1.1	0.1	0.1
Sr	804	2,230	800	1,200	523
Tl	14	3.6	1.5	0.4	0.3
V	571	172	109	22	9
Zn	178	137	288	38	8
Radioactivity	650 cps	2,500 cps	500 cps	450 cps	150 cps

**Figure 24.** Radioactive clay-altered tuff (in dug-out area) beneath limestone, Long Shot Mine. Scintillometer, about 25 cm long, for scale.

We examined several samples with the scanning electron microscope (SEM), using energy-dispersive analysis (EDX). The only uranium-bearing mineral we identified was carnotite ( $K_2(UO_2)_2V_2O_8 \cdot 3H_2O$ ), which explains the strong correlation between uranium and vanadium seen in table 4. In addition to carnotite, sample AP-204, which is hematite-rich brecciated limestone with high contents of many trace metals (table 4), was found to contain pyrite framboids that are wholly replaced by iron oxide (fig. 25). The framboids mainly occur in the breccia matrix and are only sparsely distributed in limestone clasts. The sample also contains late veinlets of strontianite and tiny crystals of chromian spinel (fig. 25), which may be the source of the anomalously high nickel and cobalt contents.

The limestone-hosted uranium in the Long Shot Mine area in the Horse Spring Formation is unusual. Possible analogue deposits are those in the Grants Uranium Belt of New Mexico, where about 3 million kg of  $U_3O_8$  were mined from small deposits in the Todilto Limestone with 0.2 to 0.5 percent  $U_3O_8$  (McLemore, 2002). The uranium mineral assemblage in the Todilto deposits includes pitchblende ( $UO_2$ ), coffinite ( $(U,Th)[(OH)_{4x}(SiO_4)_{1-x}]$ ), and tyuyaminite ( $Ca(UO_2)_2[VO_4]_2 \cdot 8H_2O$ , the calcium analog of carnotite), along with several vanadium minerals, fluorite, barite, hematite, pyrite, and galena (Berglof and McLemore, 1996). Data on trace elements in the Todilto deposits are not available, but the mineral assemblage does not suggest a trace-element suite similar to that associated with uranium in the Horse Spring deposit. In addition, pyrite framboids have not been reported in the Todilto deposits, which occur in a “marine-influenced salina/playa” setting (Armstrong, 1995).

The mineralogy, chemistry, and geologic setting of the Long Shot Mine are generally similar to those of many highly productive sandstone-hosted uranium deposits in the southwestern United States. These deposits commonly contain carnotite as a secondary uranium mineral, and have anomalously high vanadium, molybdenum, and selenium, with locally high copper and silver (Turner-Peterson and Hodges, 1986). They occur most commonly in continental sedimentary rocks of Mesozoic age.

The uranium in the Horse Spring Formation in the Long Shot Mine area may have been derived from weathering of the Proterozoic rocks to the south, including the Gold Butte granite (Johnson and Glynn, 1982; Dexter and others, 1983), although the latter authors noted that the Gold Butte granite has few characteristics associated with "fertile" uranium-enriched granites. The unusual trace-metal suite in our sample AP-204 may have been derived from detrital material from the Proterozoic rocks. The accumulation of framboids and spinel in that sample may reflect the concentration of residual material during the dissolution of limestone by the fluids that originally transported uranium. Johnson and Glynn (1982) also suggested tuffs within the Horse Spring Formation as a possible source for the uranium. Extraction of uranium from volcanic glass by ground water or hydrothermal fluids is a well-documented process (Zielinski, 1978; George-Aniel and Leroy, 1988).

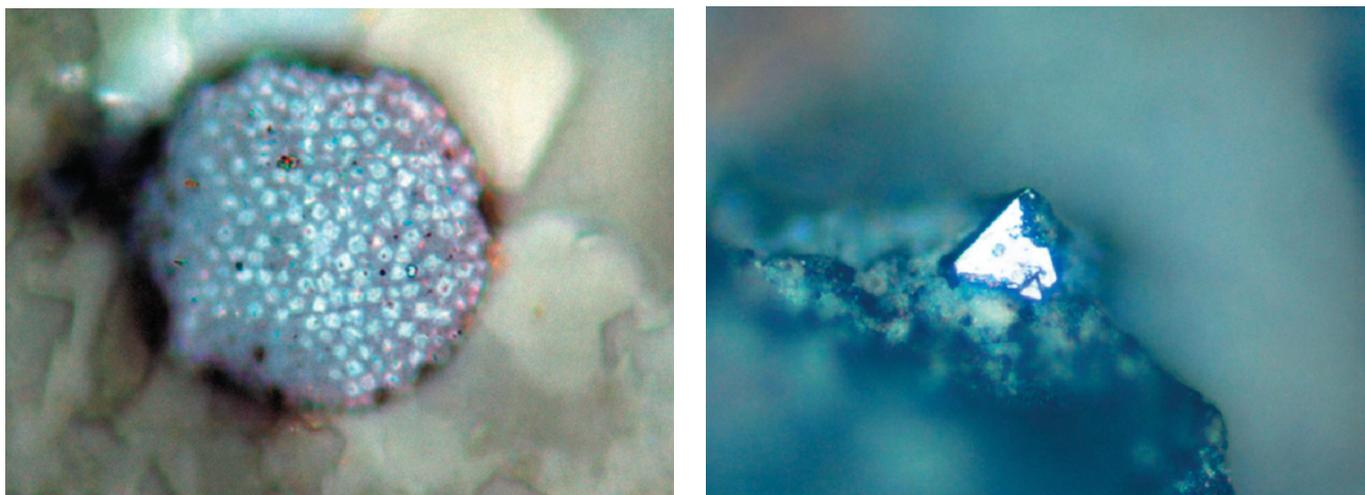
A uranium occurrence has also been described in Mesozoic sedimentary rock near the Bitter Ridge Fault in the Gold Butte A ACEC (fig. 12). It is about 20 km north-northwest of the Long Shot Mine. The occurrence, which has yielded samples with as much as 193 ppm  $U_3O_8$ , was described as ferruginous claystone in a 1-m-thick gouge zone along a high-angle fault (Johnson and Glynn, 1982). The occurrence bears some resemblance in its chemistry to the Long Shot prospect, because samples have anomalously high Cd, Co, Cu, Mo, Ni, Sn, W, V,

and Zn (Johnson and Glynn, 1982). The Bitter Ridge uranium occurrence was not visited during our field reconnaissance, nor were several other uranium prospects shown on figure 12.

### Titanium-Bearing Placer Deposits

Beal (1963) studied titanium-bearing pegmatite and placer deposits in a 25-km<sup>2</sup> area north and west of the Windmill Mine in the south part of the Gold Butte B ACEC. He reported  $TiO_2$  contents as high as 3.5 percent in pegmatite samples and 5.8 percent in placer samples. He also reported that the pegmatites associated with granitic plutons contain ilmenite and Ti-magnetite as plates or blebs, but that the titanium mineral content does not exceed 7 percent in any pegmatite and the pegmatites constitute less than 15 percent of the exposed rock. This would indicate grades of less than 1 percent  $TiO_2$  for any large amounts of rock. Beal stated that the area contains millions of tons of placer material containing 2 to 5 percent  $TiO_2$ . The Ti-bearing minerals in placers in the area reportedly include both Ti-magnetite and ilmenite, but Ti-magnetite was the only mineral noted in samples investigated petrographically (Beal, 1963).

Dexter and others (1983) also discussed titanium placer potential in the Gold Butte area, and they reported  $TiO_2$  contents of stream-sediment samples to be between 0.5 and 6.2 percent and to average about 2 percent. They noted that sphene, Ti-magnetite, ilmenite, and leucoxene occur in Proterozoic rocks in the Gold Butte area. According to Dexter and others, the titanium placers in the area represent a low-grade, subeconomic resource. Nonetheless, they assigned low to moderate potential for titanium placers in major drainages in the northern and western parts of Gold Butte B ACEC. Of 41 stream sediment samples collected by Dexter and others (1983), five were found to have 2 percent or more  $TiO_2$ . The largest area that Dexter and others delineated as having titanium potential is a large area of



**Figure 25.** Photomicrographs in reflected light of minerals in sample AP-204, Long Shot Mine. Left, a hematitized framboid about 30 microns in diameter. Right, a chromian spinel crystal about 50 microns across in a cavity. On the basis of SEM/EDX spectra, the spinel has chromium > iron > aluminum > magnesium.

Quaternary alluvium as much as 1 km wide that extends 5 km southeastward from near the Gold Crown Mine (fig. 12) into Cedar Basin. However, only one stream sediment sample with 1.8 percent  $\text{TiO}_2$  was collected from a tributary to this drainage. All stream sediment samples with 2 percent or more  $\text{TiO}_2$  were taken from relatively small drainages with minor amounts of potential placer reserves.

## Mica Deposits

Mica was mined on a small scale in the Virgin Mountain and Gold Butte B ACECs. During the 1950s, mica schist in the Virgin Mountains was mined in the Mica Notch area, screened nearby (Tingley, 1989), and further processed in a separation plant at Riverside (Beal, 1965). According to Beal, one trial carload of this mica was shipped to Los Angeles in 1959, but transportation cost reportedly prevented further economic development. In addition, book mica was mined from pegmatite in the Gold Butte area in the 1890s and early 1900s and probably from pegmatite at the Taglo Mine. We examined mica occurrences in all three areas during this study.

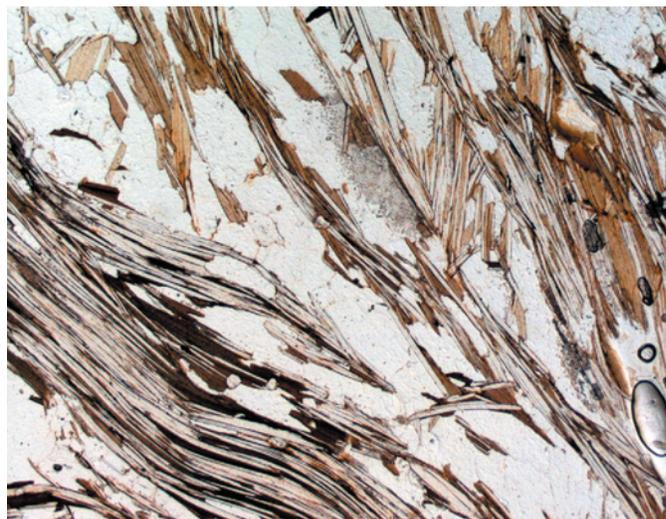
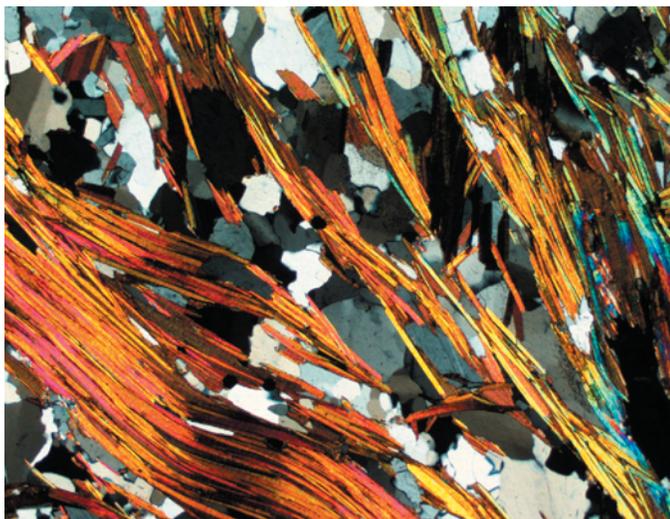
The Mica Notch deposit, which is in the same area as the Mica Notch beryllium deposits, consists of friable to moderately indurated mica schist that contains quartz, feldspar, garnet, muscovite, and biotite. The mica deposit was investigated by the Union Pacific Railroad Company and described in a short report as a band of mica schist “600–800 feet in width throughout a length of 3,000 feet... that appears to consist almost entirely of biotite mica” (Union Pacific Railroad Company Oil Development Department, 1959). However, a map accompanying the report shows a larger area of mica schist about 1,800 m long and as much as 750 m wide. According to a Beryllium Associates company report (Hansen and others, 1961) the best grades are in “an area of 2,000 feet by 4,000 feet and, as exposed in the canyon bottoms, at least 1,000 feet deep.” Beal (1965) reported that

large amounts of clean mica schist could be mined at low cost from the area. Our reconnaissance examination showed that this material occurs in a large, poorly exposed area that also contains pegmatite and amphibolite.

On the basis of thin-section examination of two samples from the Mica Notch area, we found that the rock contains about 40 percent mica by volume. The mica consists of approximately equal amounts of biotite and muscovite (fig. 26). In general it occurs in grains that average about 1 mm across and 0.1 mm thick, but in one sample a significant amount was found to occur as extremely fine grains. Fine-grained quartz and plagioclase make up most of the rest of the rock. As much as 10 percent garnet, in grains about 1 mm across, is also present.

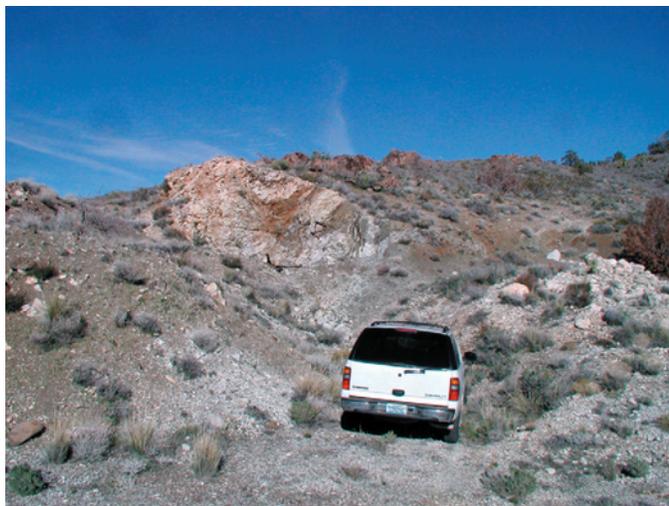
Beryllium Associates evaluated the Mica Notch mica schist deposit in conjunction with work on beryllium deposits in the area. According to G.W. Hansen (written commun., 2006), the mica was concentrated by air tabling methods and a pure muscovite separate was produced from this concentrate by electromagnetic separation. Mr. Hansen further stated that he calculated that the Mica Notch schist contains about 30 percent muscovite that could be processed into paint-grade flake muscovite by wet grinding methods.

Longwell and others (1965) noted that sheet mica was mined from pegmatite in the “South Virgin Mountains” (that is, in the Gold Butte B ACEC) in the 1890s, and 1,800 pounds were reportedly mined at that time (Beal, 1965). The Snowflake Mine, about 2 km north of Mica Peak, is one of two mica localities known in the area. We visited the site in 2005 (fig. 27) and found a small pit and adit driven into an irregular pegmatite mass that contains a few percent mica in surface exposures. Sheets of biotite and muscovite as much as 10 cm in diameter were noted on the Snowflake Mine waste dump. We also found sheet mica in books as much as 5 cm across to be abundant in 1-m-wide border zones in pegma-



**Figure 26.** Photomicrograph of mica schist that contains about 40 percent mica, by volume, from Mica Notch. Left, in cross-polarized light, horizontal field of view about 3 mm. The mica shows bright birefringent colors; white to black grains are quartz and feldspar. Right, same view in plane-polarized light, showing that the mica is a mixture of brown to black biotite and white muscovite.

tite at the Taglo Mine (fig. 17). The Mica Queen prospect is reported near the eastern boundary of the Virgin Mountain ACEC, about 5 km north of Whitney Ranch (fig. 12), but we did not visit this location. The Bachmann mica prospect is northeast of the Taglo Mine in Arizona. Other pegmatite mica prospects that we did not visit include the Nevada Mica and Mica Mountain mines in the Gold Butte B ACEC to the south of Gold Butte (fig. 12). Longwell and others (1965) reported muscovite at the former to be of poor quality and less than 2.5 cm in diameter.



**Figure 27.** Snowflake sheet-mica deposit in pegmatite on Mica Peak.

## Vermiculite Deposits

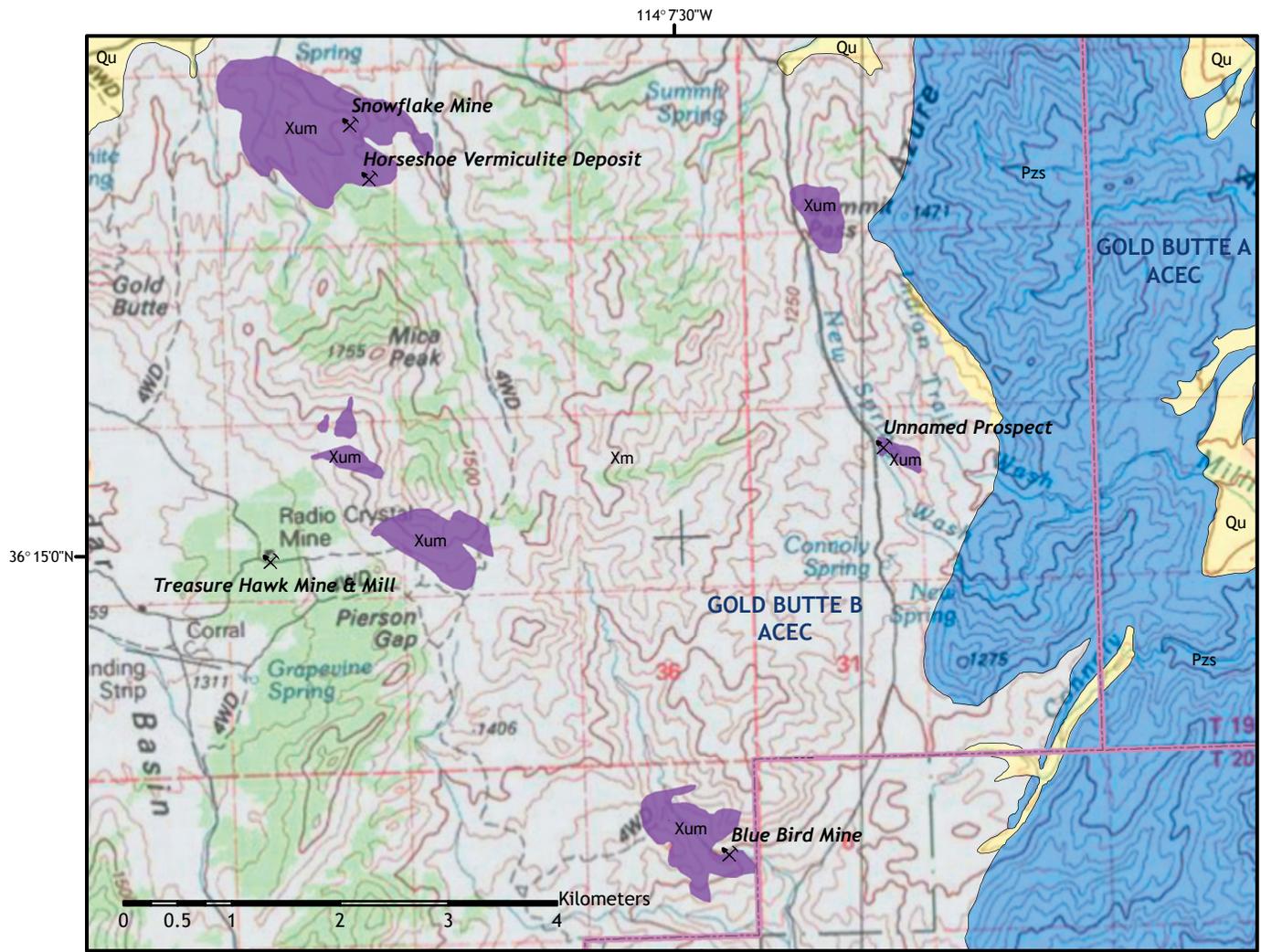
Several vermiculite deposits are in the Gold Butte B ACEC in the vicinity of Mica Peak. The vermiculite occurs in Proterozoic ultramafic rocks that intrude gneisses and schists. The host gneisses are of high metamorphic grade (granulite facies) on the basis of the local presence of hypersthene and sillimanite in quartz- and feldspar-rich rocks with biotite and garnet (Volborth, 1962). The protoliths of the gneisses are thought to have been Early Proterozoic (1.9–1.7 Ga) strata dated elsewhere in the region (Wooden and Miller, 1990). The ultramafic rocks are mainly pyroxenite and amphibolite, but include some peridotite. Volborth (1962) mapped many small (<100 m wide) lenses and five larger bodies of such rocks in the Gold Butte Proterozoic terrain, mostly east and southeast of Gold Butte (fig. 28). The Horseshoe claim (Gold Butte) vermiculite deposits, which are north of Mica Peak, were described by Leighton (1967). The Cascade and Summit deposits, on the south flank of Mica Peak, have not been described in detail in the literature, but current (2005) claim blocks covering these deposits appear to correspond with relatively large ultramafic rock bodies mapped by Volborth (1962).

On the basis of detailed mapping by Leighton (1967), the vermiculite in the deposits on the Horseshoe claims occurs in

an area 300 m by 600 m and in two smaller areas of altered ultramafic rock. These are part of an irregular ultramafic body exposed over an area 1.5 km by as much as 0.75 km. The vermiculitized rock is not resistant and rarely forms good outcrops, but it is exposed in an open pit 100 m by 25 m that is about 3 m deep and in several trenches and road cuts in a low-lying area about 250 m in diameter (fig. 11). The vermiculite occurs in variable amounts in friable pyroxene-rich ultramafic rock, and masses of more resistant vermiculite-poor amphibolite and peridotite are also present. According to Leighton (1967), mixtures of vermiculite and biotite are present in the deposit, including two types that display marked exfoliation on heating—“vermiculite-hydrobiotite” and “biotite-hydrobiotite.” Biotite that does not exfoliate is also present. Chemical analyses reported by Leighton show that both expandable types have  $MgO/(FeO + Fe_2O_3)$  of nearly 3:1 (by weight), indicating highly magnesian compositions that may be termed phlogopite. X-ray diffraction (XRD) analyses indicate that the expandable mica in the Gold Butte deposits is more than one mineral. Leighton (1967) reported basal spacings of 12.48 Å, 10.75 Å, and 10.27 Å, with the last essentially a biotite spacing. Spectra on samples that we collected have XRD peaks at 14.25 Å, 11.8 Å, and 10.1 Å. The first is typical of vermiculite and the last of phlogopite or biotite. The peak at 11.8 Å is unusual but near the 12-Å peak common for commercial vermiculites (Hindman, 2006). Hindman (1995) reported prominent XRD reflections at 14.6 Å, 12.2 Å, and 10.1 Å for vermiculite from Mica Peak and noted that the presence of a 12-Å phase is common in the highest quality exfoliating vermiculites.

Information on the quality of the Gold Butte area vermiculite suggests that it has commercial potential. Leighton (1967) reported expanded specific volumes of Gold Butte vermiculite to be from 11 to 20  $cm^3/g$  for 14-, 8-, and 3-mesh screened samples. For comparison, average volumes for commercial exfoliated vermiculite from Libby, Montana, are 12–16  $cm^3/g$ . Hindman (1995) reported expanded volumes of 10–14  $cm^3/g$  for Mica Peak samples and noted that this compared favorably with published measurements of commercial vermiculite concentrates. According to Leighton (1967), the Gold Butte vermiculite is generally present in small flakes, but it also occurs in books as much as 12 cm across. Hindman (1995) reported that the vermiculite ore in the Mica Peak area contains a significant amount of vermiculite in excess of 2 mm grain size and that concentrates of material as large as grade number 1 (ca. 3–6 mm; Hindman, 2006) could be produced. On the basis of crude propane-torch testing and sieving of four samples that we collected, 49–85 percent of the expanded vermiculite is less than 0.85 mm (–20 mesh Tyler), 15–44 percent is 0.85–1.7 mm (10–20 mesh Tyler), 1–8 percent is 1.7–3.35 mm (6–10 mesh Tyler), and amounts of larger material are negligible (table 5). Vermiculite books as large as 3 by 10 mm were produced from our samples by this testing (fig. 29).

Data on the grade of the deposits is limited. Leighton (1967) reported that the vermiculite content (probably by volume) of altered ultramafic rock was 40 percent but that



**EXPLANATION**

	Qu	Quaternary sediments, undivided	
	Pzs	Paleozoic carbonate and siliclastic rocks	✕ mine or prospect
	Xum	Paleoproterozoic mafic and ultramafic metamorphic rocks	
	Xm	Paleoproterozoic igneous and metamorphic rocks, undivided	

**Figure 28.** Mafic and ultramafic rocks in the Mica Peak area, showing location of mineral deposits. Basic geology generalized from L.S. Beard (written commun., 2005); outlines of ultramafic rock bodies modified from Volborth (1962), and our unpublished mapping. Boundaries of Areas of Critical Environmental Concern (ACECs) in pink.

**Table 5.** Data on vermiculite samples from the Horseshoe claims, Gold Butte ACEC.

[Total weight = sum of expanded and nonexpanded material weights. Expanded weight = weight of material separated by flotation on water subsequent to exfoliation.]

Sample	Total weight (g)	Expanded weight (g)	Calc. % vermiculite	6 mesh (%)	6-10 mesh (%)	10-20 mesh (%)	20 mesh (%)
AP-193	79.3	2.0	2.5	0	5	10	85
AP-194	66.4	11.4	17.2	1	8	43	48
AP-196	83.4	8.7	10.4	0	1	35	64
AP-201	40.0	2.0	5.0	0	5	20	75



**Figure 29.** Coarse expanded vermiculite grains produced from sample AP-194 by heating with a propane torch. Most of the expanded vermiculite from this sample was finer-grained than that shown in the photograph.

vermiculite made up 60 percent of a narrow zone. Hindman (1995) reported that the northern (Horseshoe claim) area generally had 20-25 percent vermiculite, whereas exposures to the south (Summit and Cascade claims) contained 30-35 percent vermiculite. Expandable vermiculite makes up 2.5 to 17.2 percent of the sampled material from the Horseshoe claim block that we tested (table 5).

We have no information on the size of the Gold Butte area vermiculite deposits. Hindman (1995) speculated that no more than a few hundred tons of vermiculite concentrate could have been produced, judging from the size of the old workings. However, the large extent of the surface exposures of potentially exploitable vermiculite-bearing rock suggests that the resource may be significant.

## Borate Mineral Deposits

Colemanite ( $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$ ) has been mined from bedded deposits in the Horse Spring Formation in two areas in the Muddy Mountains west of the Gold Butte–Virgin Moun-

tain ACECs, and it has been speculated that the Horse Spring Formation in the Lime Ridge and Tramp Ridge structural blocks may have potential for such deposits (F. Johnson, oral commun., 2004). In the Muddy Mountains, the colemanite is restricted to the upper part of the Bitter Ridge Limestone Member (Castor, 1993). Geologic maps by Beard (1993) and Beard and Campagna (1991) suggest that Bitter Ridge Limestone is not present in the Gold Butte–Virgin Mountain ACECs. During reconnaissance examination of the Horse Spring Formation section in the Horse Spring and Gardens Spring area in the Gold Butte A ACEC, we found no occurrences of borate minerals. However, we did not collect samples in the area to test for high boron contents or for pathfinder elements, such as lithium and strontium, that might suggest the presence of borate minerals.

## Gypsum Deposits

Four areas in the Gold Butte–Virgin Mountain ACECs have identified gypsum resources, but there is no record of gypsum production from the ACECs. Three of these areas include inholdings of mining claims, presumably for gypsum, within the ACEC boundaries.

Gypsum deposits have been described in the Toroweap Formation along the north flank of the Virgin Mountains. The Hen Spring deposit (fig. 12), described by Papke (1987) as the Bunkerville Ridge deposit, consists of a 15-m-thick lower gypsum unit and a 10-m-thick upper gypsum unit separated by about 5 m of dolomite. The bedding in these units dips 50° to 60° northwest, and outcrops of carbonate rocks to the southwest suggest that the gypsum beds are terminated by a fault in that direction. The gypsum is reportedly white, massive, friable, and relatively pure except for dolomite interbeds. Exploration has been by trenching and one open cut. According to Beal (1965), gypsum deposits as much as 3 m thick are exposed by shallow excavations a short distance to the east.

The Virgin Mountains deposit (fig. 12) is on the south slope of Virgin Peak about 2 km north of Whitney Pocket. Papke (1987) described it as poorly exposed, massive, white, fine-grained gypsum with dolomite in the Pakoon Formation. On the basis of small-scale geologic mapping (Longwell and others, 1965), the deposit is in the Toroweap Forma-

tion. According to Papke, the deposit dips 30° to 40° to the southwest and has a thickness of about 20 m. It contains an unknown proportion of dolomite interbeds.

The St. Thomas Gap deposits, in the Wechech Basin in the Gold Butte A ACEC (fig. 12), which occur in the Thumb Member of the Horse Spring Formation, crop out along north-northeast-trending ridges (fig. 30), and are traceable for a total distance of about 4 km (Papke, 1987). The gypsum occurs in four principal units ranging from 10 to 30 m thick that dip 10° to 45° east according to Papke; however, our reconnaissance in this area disclosed gypsite units ranging from 5 to 10 m thick that dip 15° to 35° to the southeast. The gypsite is impure because of interbedded and intermixed quartz, clay, and carbon-



**Figure 30.** Ridge-forming gypsite in the Wechech Basin at sample site AP-066. Gypsite is as much as 10 m thick here and dips 15° to 35° to the east.

ate (Papke, 1987). Chip samples that we collected from this area contain only 80 to 82 percent gypsum on the basis of chemical analyses (table 6; Ludington and others, 2005), but analysis of a grab sample indicates gypsum content as high as 93 percent (Papke, 1987). There is no evidence of past gypsum mining in this area, but gypsum was mined from the Thumb Member of the Horse Spring Formation in the Rainbow Gardens area, near Las Vegas (Castor, 1989; Castor and others, 2000).

Gypsum occurs in the upper part of the Toroweap Formation in two areas along the west side of Gold Butte Wash, and these areas include three blocks of claims that form inholdings within the Gold Butte A and B ACECs. The northern area (Legion Nos. 1–2 and Leeway Nos. 3–5, fig. 12) contains poorly exposed gypsum-bearing sequences as much as 10 m thick that dip about 30° east beneath yellowish-gray cherty limestone. The gypsum is underlain by pale yellow to white sandstone and cherty limestone that probably belong to the Esplanade Formation. There are no prospects or mine workings, and the gypsum is relatively impure. The deposits in the southern area (Boulder Nos. 1–2, Blue Ridge Nos. 1–2; fig. 12), which are about 4 km northwest of the Gold Butte townsite, appear to be in approximately the same stratigraphic interval.

### Limestone Deposits

Relatively pure limestone suitable for lime or cement has not been reported in the Gold Butte–Virgin Mountain ACECs. The Paleozoic carbonate rocks in the Bunkerville area are mostly described as variably dolomitic, sandy, shaly, or containing abundant chert (Beal, 1965). Devonian limestone, mined for lime production at Apex northeast of Las Vegas and under development as a source of cement limestone in the

**Table 6.** Composition of gypsum samples from the Wechech Basin, Gold Butte A ACEC, compared with high-grade gypsum ore from the Blue Diamond Mine and low-grade gypsum ore from the PABCO Mine.

[All data in weight percent. Gypsum calculated = 2.146 x SO<sub>3</sub>. Data on Wechech Basin grab, Apex, and Blue Diamond samples are from Papke, 1987.]

Sample-----	AP-065	AP-066	AP-064	—	—
Location-----	Wechech Basin	Wechech Basin	Wechech Basin	Apex (PABCO)	Blue Diamond
Unit-----	Horse Spring	Horse Spring	Horse Spring	Muddy Creek	Kaibab
Sample type-----	5-m chip	4.5-m chip	grab	grab	grab
SiO <sub>2</sub>	7.53	5.44	5.35	9.43	0.33
Al <sub>2</sub> O <sub>3</sub>	0.97	0.74	0.63	3.94	0.03
Fe <sub>2</sub> O <sub>3</sub>	0.24	0.26	0.16	0.22	0.01
MgO	0.93	1.39	0.77	5.47	0.03
CaO	26.90	27.91	30.50	27.70	33.40
Na <sub>2</sub> O	0.06	0.05	0.18	0.69	0.02
K <sub>2</sub> O	0.27	0.22	0.45	0.68	0.02
LOI	20.60	21.30	17.77	13.2	18.3
CO <sub>2</sub>	1.06	1.32	0.62	9.20	0.02
SO <sub>3</sub>	37.38	38.15	43.20	29.40	48.10
Gypsum (calc.)	80.21	81.87	92.71	63.09	103.22

Moapa area, is represented in the Virgin Mountain–Gold Butte area by the Muddy Peak Limestone or Temple Butte Limestone. According to McNair (1951), the Muddy Peak Limestone is about 550 ft (170 m) thick and consists of dolomitic limestone with interbedded limestone. Such material would likely not be suitable for high-calcium lime or cement.

Tertiary limestone in the Horse Spring Formation may have potential as cement limestone. A chip sample of rela-

tively pure limestone taken by us from the Thumb Member of the formation in the Garden Spring area contains high  $\text{SiO}_2$ , high  $\text{MgO}$ , and marginally low  $\text{CaCO}_3$  for lime (table 7). The sample is sufficiently high in  $\text{CaO}$  for cement rock, but  $\text{Na}_2\text{O}+\text{K}_2\text{O}$  is marginally excessive. A grab sample of hard, white carbonate from the Kim Ball prospect has less  $\text{Na}_2\text{O}+\text{K}_2\text{O}$  but is from a relatively small mass (10 m by 20 m) of rock.

**Table 7.** Comparison of some major element analyses of carbonate rock samples from the Horse Spring Formation in the Gold Butte A and Gold Butte B ACECs with Portland cement and high-Ca lime ore specifications.

[All figures are weight percents. AP-069 and AP-070 are grab samples from the Kim Ball prospect area; AP-071 is a 5-m chip sample from Horse Spring prospect; AP-072A is a 2-m chip from the Horse Spring prospect; AP-209 is a 10-m chip sample from the Garden Spring area.  $\text{CaCO}_3$  percent calculated using  $\text{CaO} \times 1.78$ ;  $\text{MgCO}_3$  percent using  $\text{MgO} \times 2.09$ . Portland cement specifications from Ames and others (1994). High-Ca lime ore specification from Stanley T. Krukowski (oral commun., 2005).]

Element	AP-069	AP-070	AP-071	AP-072A	AP-209	Portland cement ore specification	High-Ca lime ore specification
$\text{SiO}_2$	5.81	0.50	3.15	8.08	4.96		<1
$\text{Al}_2\text{O}_3$	0.03	0.07	0.39	0.54	0.79		
$\text{Fe}_2\text{O}_3$	0.04	0.12	0.18	0.21	0.35		
$\text{MgO}$	0.23	22.06	20.46	14.31	1.55		<1
$\text{CaO}$	53.22	30.29	29.45	33.40	52.49	ca. 50	
$\text{Na}_2\text{O}+\text{K}_2\text{O}$	0.05	0.09	0.43	0.55	0.57	<0.4	
$\text{P}_2\text{O}_5$	0.02	0.01	0.02	0.01	0.02		
LOI	40.6	46.7	45.8	42.8	39.2		
$\text{CaCO}_3$	94.73	53.92	52.42	59.45	94.43		>95
$\text{MgCO}_3$	0.48	46.11	42.76	29.91	3.23		
Total carbonate	95.21	100.02	95.18	89.36	97.66		

## Magnesite Deposits

Magnesite deposits have been reported in the Horse Spring Formation (Hewett and others, 1936; Longwell and others, 1965). The best-known magnesite deposit in the area, the Bauer prospect, has been reported to be at different locations by different authors. Longwell and others (1965) located it about 11 km northeast of the Gold Butte townsite near Horse Spring (fig. 12). We found carbonate from prospects in that area to be mainly dolomite rather than magnesite (samples AP-071 and AP-072A; table 7; Ludington and others, 2005). Hewett and others (1936) reported the Bauer prospect to consist of two exploratory tunnels about 14 km north of the Gold Butte post office, and gave analytical results of 20.2 to 41.3 percent  $\text{MgO}$  and 3.1 to 23.8 percent  $\text{CaO}$  for samples from the tunnels and surface outcrops. The highest  $\text{MgO}$  content was for a bed of hard white rock only 0.4 ft (12 cm) thick. The samples were described as “lump” samples of relatively resistant rock from the lower 6 m of a shallowly east dipping unit of soft white dolomite, magnesite, and clay as much as 25 m thick. They reported that the unit crops out for more than 1 km along strike and estimated a reserve of about 500,000 short tons, assuming an average thickness of 6 m. We did not examine this location and cannot comment on this size estimate.

Another deposit, the Kim Ball Magnesite deposit, is located about 18 km north-northeast of the Gold Butte townsite (fig. 12). Our reconnaissance in that area disclosed some small masses of white carbonate with chemistry that ranged from nearly pure calcite to dolomite (samples AP-069 and AP-071; table 7; Ludington and others, 2005).

At present, the only magnesite deposit mined in the United States is in the Paradise Range at Gabbs, Nevada, where magnesium minerals have been mined since 1935 (Castor, 2004). By contrast to the Bauer prospect, analyses of typical magnesite ore from Gabbs range from 39.9 to 46.8 percent  $\text{MgO}$  and 1.3 to 8.9 percent  $\text{CaO}$  (Hewett and others, 1936; Dixon, 1961). Reserves are unspecified but said to exceed 50 years at the present mining rate (L. Johnson, oral commun., 2003).

## Silica Deposits

The Aztec Sandstone is exposed in many places in the Gold Butte A ACEC and also in the Whitney Pocket and Red Rock Spring ACECs. Rocks of this unit have been prospected regionally as a source of silica but have not been extensively mined (Longwell and others, 1965). The unit is generally

composed of moderately indurated, reddish-orange to pink, coarsely cross-bedded eolian sandstone that forms cavernous outcrops (figs. 31, 32). In some places the unit contains thick beds of nearly white to pale-yellow sandstone. Hewett and others (1936) reported that a few carloads of Aztec Sandstone were shipped from the Wyatt Mine in the Muddy Mountains to the west of the Virgin Mountain–Gold Butte area. Mur-

phy (1954) reported the Aztec Sandstone to be marginal as a source of silica sand, but he noted that its potential might be enhanced if iron-free beds were found. We analyzed a 20-m chip sample of nearly white Aztec Sandstone from the Whitney Pocket ACEC. The results (sample AP-063, table 8; Ludington and others, 2005) show that the sandstone is unsuitable for container glass.



**Figure 31.** Excavation in pink Aztec Sandstone in the Whitney Pocket ACEC. Partially walled excavation is about 1.5 m high.



**Figure 32.** White to pale-pink Aztec Sandstone just west of Whitney Pocket. Site of sample AP-063.

**Table 8.** Composition of white Aztec Sandstone from the Whitney Pocket ACEC compared with commercial silica sand and container glass specifications.

[All figures are weight percents; Simplot Silica Plant data are from Murphy (1954); container glass data are from Zdunczyk and Linkous (1994).]

Element	AP-063 20-m chip	Simplot Silica Mine	Simplot Silica Plant	Container glass specification
SiO <sub>2</sub>	88.89	97.25	98.93	98.5 min
Al <sub>2</sub> O <sub>3</sub>	2.47	1.38	0.65	0.5 max
Fe <sub>2</sub> O <sub>3</sub>	0.45	0.19	0.03	0.035 max
MgO+CaO	3.93	0.27	0.05	0.2 max
TiO <sub>2</sub>	0.08	0.08	0.03	0.03 max
Cr <sub>2</sub> O <sub>3</sub>	0.025	0.00	nd	0.001 max

## Mineral Exploration and Development

There is no known currently active mineral exploration by large mining companies in any of the ACECs that are the subject of this report. However, the copper-nickel-PGE deposits in the Bunkerville district were the subject of considerable exploration and promotion during the 1980s and late 1990s, and that work extended outside the private inholding at the Key West Mine into the Gold Butte A and Virgin Mountain ACECs.

Coneva Holdings Ltd. LLC, of St. George, Utah, plans to remove and process stockpiles of ore from the Key West Mine, and they have a valid use permit from Clark County that was recently extended until 2010. The company acquired a second use permit to maintain an extraction plant for copper, nickel, and platinum that involves a chemical leaching process at a site 22 miles (35 km) to the northwest of the Key West Mine.

A group of nine locators, including American Gold Corporation, holds four eight-member placer claims on the northwest flank of Bunkerville Ridge in the Gold Butte A

ACEC. The same locators have placer claims in the Virgin River ACEC to the northwest.

The Western Mining Association of Eight holds four eight-member association placer claims north and west of the Key West Mine that have been active for five years. In 2004, both Trend Mining and Mountain Gold Exploration Inc. held claims in the same region, but these were not listed as active in November 2005.

The Leavitt family has held as many as 40 claims for beryllium, mica, and tungsten in the Mica Notch area in the Virgin Mountain ACEC, some of them for over 50 years. In November of 2005, only a single claim, the Blue Bell # 10, was still listed with Don and Eldred Leavitt as locators. Peoples Inc. holds seven claims east of Whitney Pocket in the Virgin Mountain ACEC near the Roadside prospect, described by Tingley (1989) as a copper and silver(?) prospect.

Current claim holdings in the Gold Butte B ACEC are more numerous. At least 100 lode and millsite claims are held jointly by Mark Whitmore and the Whitmore Family Trust in three groups in a northwest-trending swath that covers vermiculite discoveries around Mica Peak. These claims were originally staked from 1993 through 1998, and all were current in 2005. Minor amounts of vermiculite were mined from a deposit north of Mica Peak in the 1940s. This area is within Whitmore's Horseshoe group of claims. Since the 1980s, at least three companies have evaluated the area for vermiculite. Most recently, work has focused on Whitmore's Cascade and Summit groups south of Mica Peak (IBI Corporation, 2004; J. Hindman, oral commun., 2005).

James Harlow holds 10 lode claims in the Gold Butte B ACEC that possibly extend into the Gold Butte Townsite ACEC. The claims were filed in 1991 and 1993 and were probably staked for gold, because the locations are quite near the Gold Butte Mine.

There is one known active mining and milling operation in the Gold Butte B ACEC. This is the small-scale, privately held Treasure Hawk Mine, owned by John Lear. It operated in a sporadic manner until at least 1987 and is again active as of spring 2006. Joanna Dill holds two placer claims near the Treasure Hawk Mine that were originally staked in 1981. Cutthroat Mining Corp. holds two lode claims and a millsite claim in the same area; these were staked in 2004. Rhonda McCauley holds three lode claims near Summit Pass in the east part of the Gold Butte B ACEC that were located in 2003 for unknown commodities.

Two areas that cover parts of the Gold Butte A and Gold Butte B ACECs were the subject of mineral resource assessments by the U.S. Geological Survey and the U.S. Bureau of Mines. They are the Lime Canyon Wilderness, in the northern part of Gold Butte B and the southwestern margin of Gold Butte A (Winters, 1988; Evans and others, 1990), and the Million Hills Wilderness Study Area (Causey, 1988; Moyle and Buehler, 1990) in the southernmost part of Gold Butte A and the eastern margin of Gold Butte B. The studies of both these areas included geochemical analyses of stream-sediment, panned concentrate, and spring and well water samples (Bull-

ock and others, 1990; McHugh and others, 1989; McHugh and Nowlan, 1989).

At one time, parts of the Gold Butte A ACEC were under lease or lease application for oil and gas. Two shallow exploratory wells were drilled there in the 1980s.

## Mineral Resource Potential

### Locatable Minerals in Gold Butte A ACEC

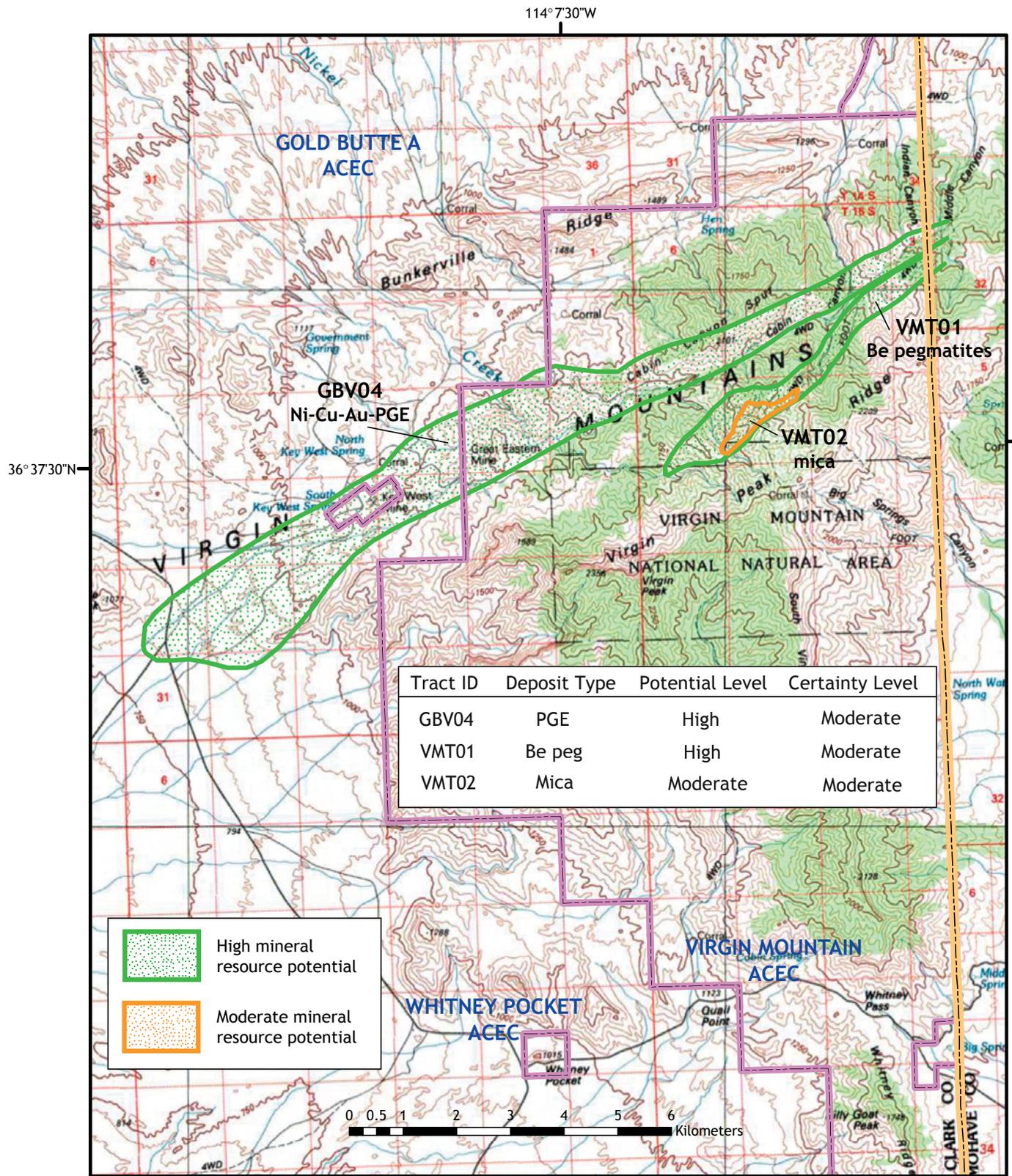
#### Ni-Cu-Au-PGE Deposits

The potential for discovery of additional Ni-Cu-PGE deposits like those studied here (Key West and Great Eastern Mines) is high, with a moderate level of certainty. Any undiscovered deposits would be related to unexposed olivine hornblendite dikes or a larger subsurface intrusion, so the most prospective areas are the regions between the two mines and the extensions of that trend, both to the northeast and to the southwest, where the trend passes under alluvial cover. This area is delineated on figure 33 as tract GBV04. Factors used to delineate this tract include the known deposits, the observed occurrences of olivine hornblendite, the aeromagnetic data of Falconbridge (Theodore A. DeMatties, written commun., 2006), and the aeromagnetic high described by Langenheim and others (2000). Hose and others (1981) also identified this as an area of mineral resource potential. The tract includes some areas covered by a thin layer of alluvium.

Whereas the probability that undiscovered deposits like those at the Key West and Great Eastern Mines exist is high, deposits with either higher grade or larger tonnage would be necessary for further development to be likely. This is not impossible, as commercial deposits related to mafic dikes (Lightfoot and Farrow, 2002) are commonly not exposed at the surface. Deep exploration in the Bunkerville district has been proposed several times in the past, but has never been carried out. A significant Cu-Ni-Au-PGE resource may be present.

#### Kipushi-Type Copper Deposits

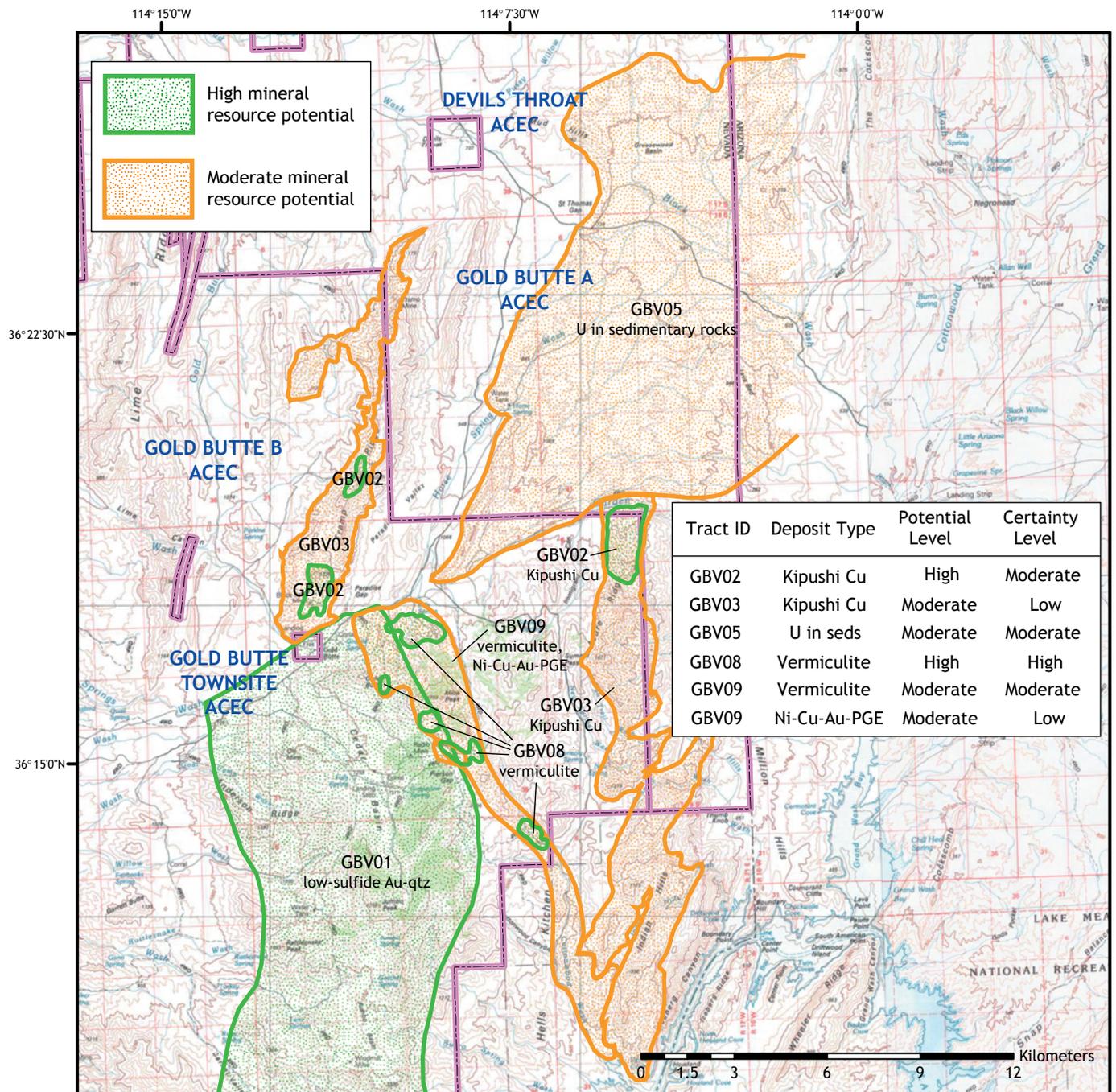
The small base-metal deposits in Paleozoic limestone in the Tramp Ridge and Gold Butte blocks are unlikely to ever be important sources of copper, lead, zinc, or silver. However, they may contain potentially significant concentrations of two unusual high-value metals, gallium and germanium, as well as cobalt. The characteristics of these deposits indicate clearly that they can be considered to be Kipushi-type deposits. The deposits in the ACECs have not been explored seriously for more than 70 years, and no modern methods have been employed. The genesis of this deposit type is not well enough understood to know for certain if the age or detailed stratigraphic variations in lithology of the host rocks are important factors controlling their occurrence, but all the deposits in the Gold Butte A and B ACECs are restricted to the Muav



**Figure 33.** Mineral resource potential tracts for Ni-Cu-Au-PGE deposits, Be-bearing pegmatite deposits, and mica deposits in the Gold Butte A and Virgin Mountain Areas of Critical Environmental Concern (ACECs; outlined in pink).

Formation, Temple Butte Formation, and Redwall Limestone. We have used stratigraphy to outline a tract (GBV03, fig. 34) that has moderate potential for the occurrence of undiscovered deposits, with a low level of certainty. Because exploration of the known deposits could reveal important amounts of germanium and gallium, we designate three small areas (tract GBV02, fig. 34) within tract GBV03 to have high potential,

with a moderate level of certainty. In their study of the Million Hills Wilderness Study Area, Bergquist and others (1994) designated this area to have high potential for Kipushi-type deposits. Technological developments to improve recovery of germanium and gallium could transform these small copper deposits into significant sources of the strategic metals gallium and germanium.



**Figure 34.** Mineral resource potential tracts for Kipushi-type Cu (Ge-Ga) deposits, uranium deposits in sedimentary rocks, vermiculite deposits, and Ni-Cu-Au-PGE deposits in the Gold Butte A and Gold Butte B Areas of Critical Environmental Concern (ACECs; outlined in pink).

## Uranium Deposits in Sedimentary Rocks

A laterally extensive low-grade uranium deposit straddles the boundary of the Gold Butte A and B ACECs, extending north-east from the Long Shot Mine area. The deposit is in limestone of the Horse Spring Formation. According to Johnson and Glynn (1982), an area of 5 km by 17 km underlain by the Horse Spring Formation in the Tramp Ridge block in both ACECs is favorable for uranium. Although surficial uranium contents only range as high as 0.02 percent  $U_3O_8$ , we consider the same approximate area to have moderate potential, with a moderate level of certainty (tract GBV05, fig. 34) for sandstone- or limestone-hosted uranium deposits. We have expanded the potential area of Johnson and Glynn to the east to include Horse Spring Formation rocks that fill the Tertiary basin in the east part of the Tramp Ridge block, including those buried beneath younger deposits. Beard (1996) proposed that this basin was separate from the Wechech Basin to the north, where no uranium occurrences are known, so we do not include the Wechech basin in the tract.

## Borate Mineral Deposits

The Horse Spring Formation contains borate deposits to the west, in the Muddy Mountains. However, in the Gold Butte A ACEC the formation lacks the stratigraphic unit that contains borate minerals, and hence potential for undiscovered deposits is low.

## Gypsum Deposits

Parts of the Gold Butte A ACEC in Wechech Basin have moderate potential for deposits of gypsum in the Horse Spring Formation, with a high certainty level (tract GBV06, fig. 35). Gypsite units as much as 10 m thick in the area contain about 80 percent gypsum, a higher grade than ore at the PABCO Mine. However, the commercial PABCO gypsite is in a thick, flat-lying deposit with little or no overburden, whereas the Wechech Basin gypsite dips shallowly east and extraction of commercial amounts would require removal of overburden. Permian rock units in the ACEC contain gypsum on the north flank of Bunkerville Ridge and in private inholdings in the Lime Canyon Wilderness Area, but these deposits have low commercial potential because they are thin, dip moderately, and would require substantial stripping of resistant Permian carbonate overburden.

## Limestone Deposits

Relatively pure limestone suitable for lime or cement has not been reported in the Gold Butte A ACEC. Paleozoic carbonate rocks in the area are generally impure. Devonian limestone, mined for lime and under development as a source of cement limestone elsewhere in the region, has been described as dolomitic in the ACEC, and such material would likely not be suitable for high-calcium lime or cement. Our chip sample of Tertiary limestone from the Horse Spring Formation in the

Garden Spring area in the Gold Butte B ACEC to the south indicates that this limestone is also chemically unsuitable for lime production. It is sufficiently high in CaO for cement rock, but alkali contents are slightly high. Relatively pure Tertiary limestone is present, but only in small amounts. It is possible that the ACEC contains large unexamined deposits of limestone that are suitable for cement or lime production; however, based on the available information the potential is low.

## Magnesite Deposits

Magnesite occurs in the basal part of the Horse Spring Formation. Hewett and others (1936) reported that magnesite-bearing beds contain a reserve of about 500,000 short tons. We did not examine the deposit and cannot comment on this size estimate. However, the deposit is relatively small and low grade when compared with the magnesite deposits at Gabbs, Nevada; therefore we consider the potential for commercial magnesite in the Gold Butte A ACEC to be low.

## Silica Deposits

The Aztec Sandstone, which is exposed extensively in the Gold Butte A ACEC, has been proposed as a potential source of silica, but the unit typically has a chemical composition that makes it unsuitable for silica sand, and the potential for silica deposits is low.

There is no evidence for other types of metallic mineral deposits in the ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Gold Butte A ACEC

The northern and southern parts of the area are within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). Two shallow exploratory oil wells were drilled within the ACEC (fig. 12). Gold Butte KPS Fed. No. 1 was drilled to a depth of 705 m about 2 km northwest of Horse Spring by Redi Corp. in 1986. There is no information on the rocks encountered, and Garside and others (1988) show it as a dry hole with no oil or gas shows. Thomas Gap Federal No. JP-1 was drilled by Ruby Drilling Co. to a depth of 619 m about 6 km to the north in 1987. Information in the files of the Nevada Bureau of Mines and Geology Information Office indicate that this hole was drilled into Permian rock; it was a dry hole but had a "slight oil show" between depths of 288 m and 326 m. A deep exploratory well, Virgin River U.S.A. No. 1-A was drilled to a depth of nearly 6,000 m on Mormon Mesa about 7 km west of the ACEC. It was a dry hole with no oil shows that was collared in the Muddy Creek Formation, intersected Mesozoic and upper Paleozoic rocks, and bottomed in granitic basement (Garside and others, 1988).

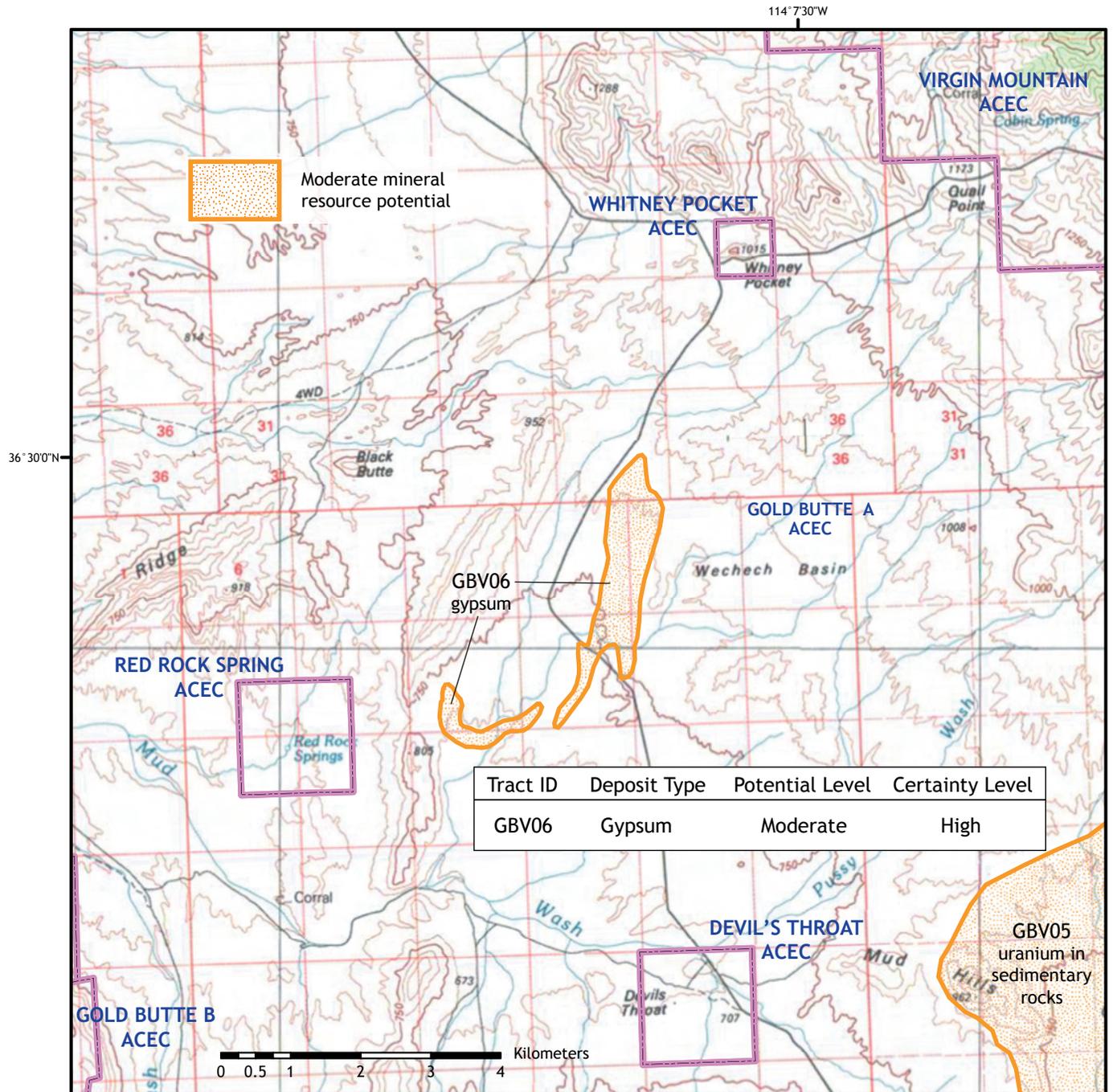
There is no indication of potential for brine or evaporite deposits of sodium or potassium. This ACEC contains no

known deposits of other leasable minerals, and the potential for their occurrence is low.

### Salable Minerals in Gold Butte A ACEC

**Crushed Stone.**—The highest quality stone for crushed-stone aggregate production in the Gold Butte A ACEC is Proterozoic granite, quartz monzonite, and granodiorite gneiss, as mapped by Beal (1965). Other high quality units

include Devonian Muddy Peak Limestone and Cambrian Prospect Mountain Quartzite. The Muddy Peak Limestone is relatively free of chert and thus not subject to alkali-silica reactivity, which can degrade concrete. Together, these lithologic units constitute tract AGBV01 (fig. 36), which has high potential for crushed-stone aggregate deposits. This tract has only a moderate level of certainty, because the distribution of different Proterozoic lithologies has not been mapped in detail throughout this ACEC.



**Figure 35.** Mineral resource potential tract for gypsum deposits in the Gold Butte A Area of Critical Environmental Concern (ACEC; outlined in pink).



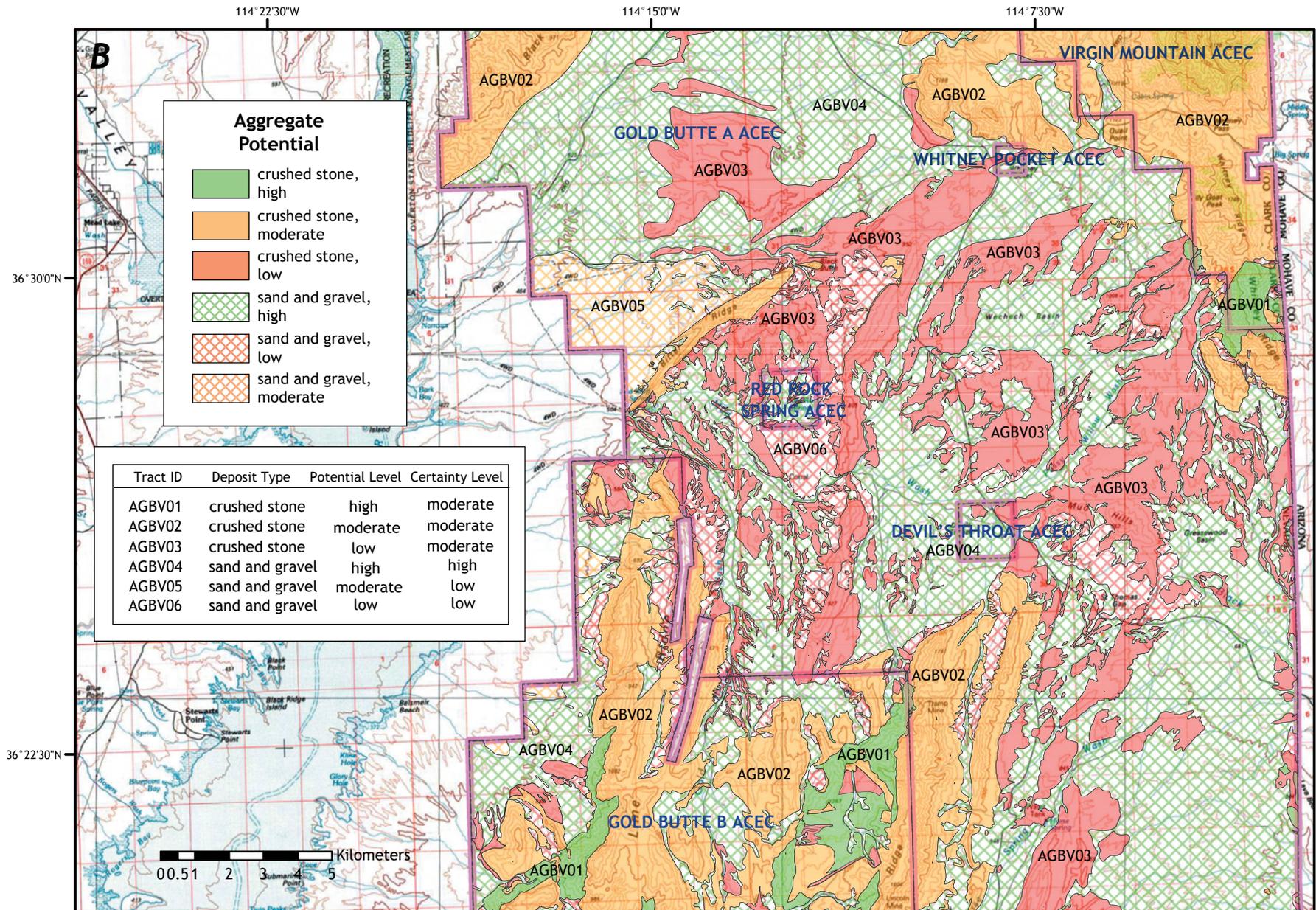


Figure 36.—Continued.

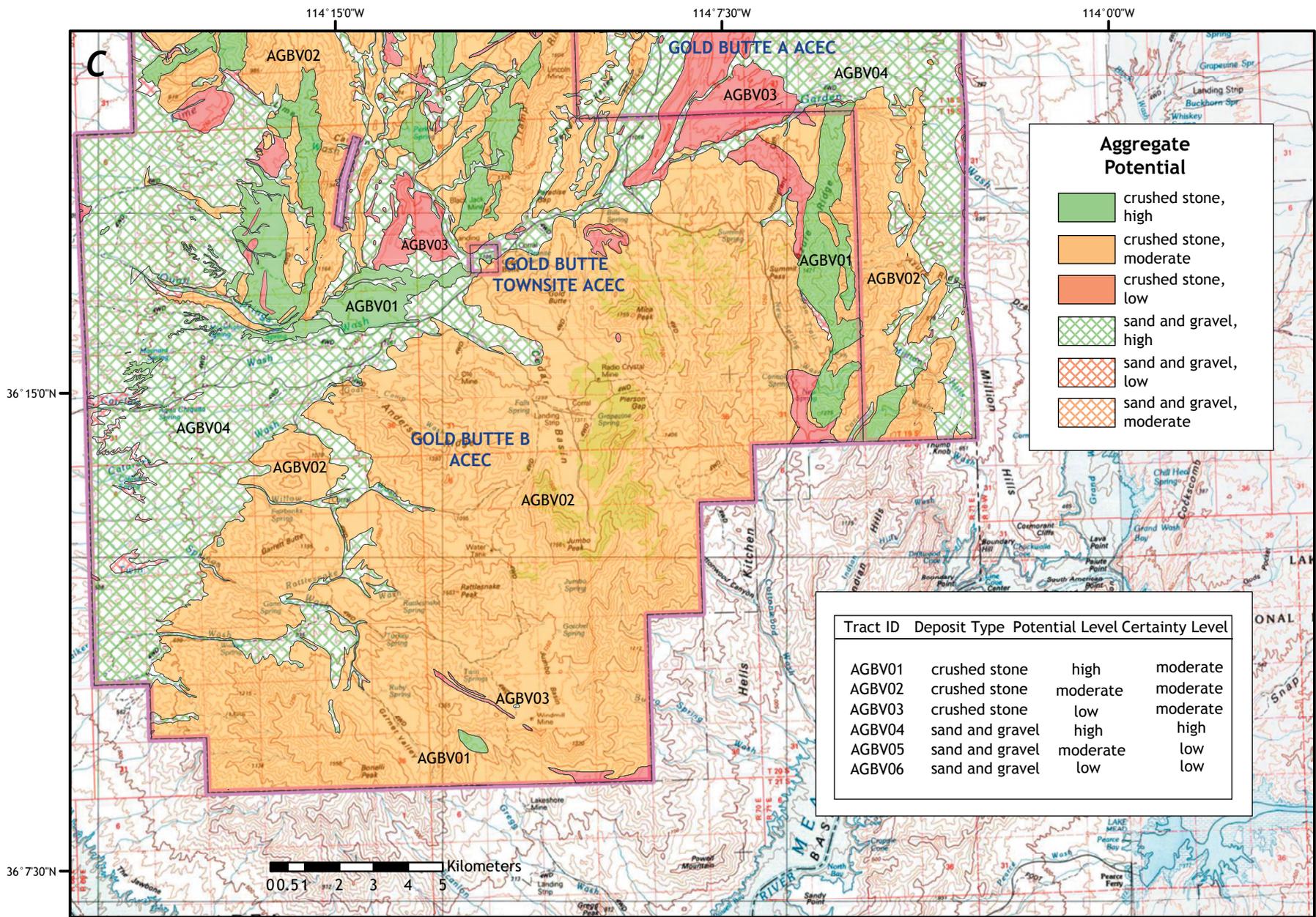


Figure 36.—Continued.

Somewhat lower quality metamorphic rocks, including biotite and biotite-garnet gneiss and schist, make up most of the Proterozoic part of the Bunkerville Ridge block. Chert-bearing limestones make up most of the Paleozoic rocks in the Bunkerville Ridge, Virgin Peak, Lime Ridge, and Tramp Ridge blocks. Together, these two groups of units were used to delineate tract AGBV02 (fig. 36), which has moderate potential for crushed-stone aggregate deposits, with a moderate degree of certainty.

The Triassic sedimentary rocks in the ACEC are composed of shale, sandstone, conglomerate, limestone, and gypsum. Most of the sandstone, including the Jurassic Aztec Sandstone, is friable. The Tertiary sedimentary rocks, Miocene Horse Spring Formation and Miocene-Pliocene Muddy Creek Formation, are made up primarily of friable sandstone, shale, conglomerate, and gypsum. Together with the shales in the Paleozoic section, these units have low potential for crushed-stone aggregate deposits (tract AGBV03, fig. 36), with a moderate degree of certainty.

*Sand and Gravel.*—A large area in the Gold Butte A ACEC is covered with alluvial fan and wash deposits, notably the large alluvial fan on the north flank of the Virgin Mountain and smaller fans in the Overton Basin south of Black Ridge, the Wehech Basin east of Lime Ridge, and to the east of Tramp Ridge. The thickness of these deposits is in general unknown, but they represent a significant aggregate resource. Several small sand and gravel operations exploit the fan deposits west of Bunkerville along the Virgin River. These deposits have high potential for sand and gravel aggregate deposits (tract AGBV04, fig. 36), with a high degree of certainty.

A large area on the west side of the ACEC, northwest of Bitter Ridge, has only moderate potential for sand and gravel aggregate deposits (tract AGBV05, fig. 36), with a moderate certainty level, because it is capped with well-cemented calcrete. Areas that are primarily sand dunes and sand derived from erosion of the Aztec Sandstone have low potential for sand and gravel aggregate deposits (tract AGBV06, fig. 36), with a moderate level of certainty.

## Locatable Minerals in Gold Butte B ACEC

### Low-Sulfide Gold-Quartz Vein Deposits

None of the gold-bearing quartz veins in the Gold Butte block have become important sources of gold, although they have been explored and prospected for more than a hundred years. Nevertheless, they conform to a recognized deposit type, low-sulfide gold-quartz veins (Berger, 1986; Drew, 2003), and sampling during the present study as well as during the studies of Dexter and others (1983) and of Winters (1988) consistently returned values in excess of 3 ppm gold. These concentrations suggest that at least part of most of the quartz veins may contain gold at grades high enough to mine successfully.

Similar deposits have been developed into small, but profitable operations. An example would be the Keystone Mine, near Death Valley in California (Pray, 2001). The gold apparently occurs primarily as free electrum, so efficient concentration methods can be simple and relatively inexpensive. There is no indication of gold disseminated in the wall rocks of these veins, so any operations will be small. Some material could be mined from the surface, but most mining would eventually have to be by underground methods. Veins commonly pinch and swell, both laterally and vertically, and there is a high probability that a number of vein deposits exist that are not exposed at the surface.

The tract (GBV01) that we have outlined (fig. 37) is based on paleodepths estimated using the reconstructions of Fryxell and others (1992), Fitzgerald and others (1991), and Reiners and others (2000) and reflects paleodepths of about 5 to 10 km. The tract has high potential for the occurrence of additional low-sulfide gold-quartz vein deposits like the ones already known, with a high degree of certainty. Dexter and others (1983) designated areas within this tract to have moderate potential for small gold deposits, but low potential for large valuable deposits. Whether any particular vein can be exploited successfully is a function of detailed grade distribution and can only be determined by detailed on-site exploration.

### Kipushi-Type Copper Deposits

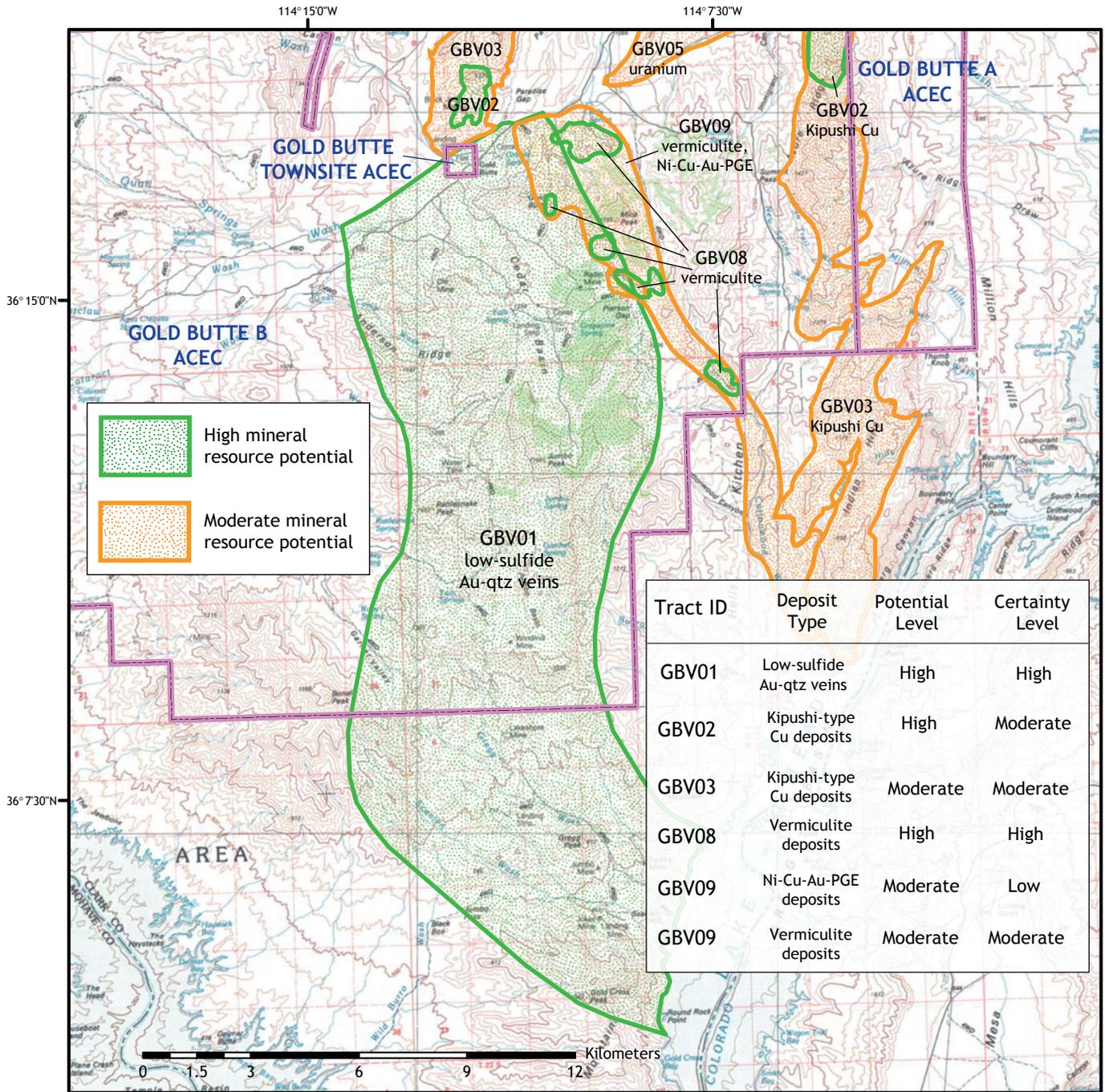
The small base-metal deposits in Paleozoic limestone in the Tramp Ridge and Gold Butte blocks are unlikely to ever be important sources of copper, lead, zinc, or silver. However, they may contain potentially significant concentrations of two unusual high-value metals, gallium and germanium, as well as cobalt. The characteristics of these deposits indicate clearly that they can be considered to be Kipushi-type deposits. The deposits in the ACECs have apparently not been explored for more than 70 years, and no modern methods have been employed. The genesis of this deposit type is not well enough understood to know for certain if the age or detailed stratigraphic variations in lithology of the host rocks are important factors controlling their occurrence, but all the deposits in the Gold Butte A and B ACECs are restricted to the Muav Formation, Temple Butte Formation, and Redwall Limestone. We have used the occurrence of these stratigraphic units to outline a tract (GBV03, fig. 34) that has moderate potential for the occurrence of undiscovered Kipushi-type deposits, with a low level of certainty. Because exploration of the known deposits could reveal important amounts of germanium and gallium, we designate three small areas (tract GBV02, fig. 34) within tract GBV03 to have high potential, with a moderate level of certainty. In their study of the Million Hills Wilderness Study Area, Bergquist and others (1994) designated this area to have high potential for Kipushi-type deposits. Technological developments to improve recovery of germanium and gallium could transform these small copper deposits into significant sources of the strategic metals gallium and germanium.

### Titanium Deposits

Pegmatite and placer deposits that contain as much as 3.5 percent and 5.8 percent TiO<sub>2</sub>, respectively, have been evaluated as sources of titanium in the Gold Butte B ACEC (Beal, 1963; Dexter and others, 1983). Ilmenite and Ti-magnetite occur in the pegmatite deposits, but according to Beal (1963) the pegmatites contain 7 percent or less of combined ilmenite and Ti-magnetite and represent less than 15 percent of the exposed

rock. By contrast, the Tellnes Mine in Norway, a 350-million-ton lode titanium deposit, contains about 40 percent ilmenite, and other lode deposits under evaluation in Brazil contain similarly large reserves with TiO<sub>2</sub> contents of 15 to 20 percent (Garnar and Stanaway, 1994).

Commercial placer titanium deposits can have low bulk TiO<sub>2</sub> contents, but are generally very large. The huge shoreline and dune deposits in Australia, which extend for hundreds of kilometers along the country's east and west coasts are



**Figure 37.** Mineral resource potential tracts for low-sulfide gold-quartz vein deposits, vermiculite deposits, and Ni-Cu-Au-PGE deposits in the Gold Butte A, Gold Butte B, and Gold Butte Townsite Areas of Critical Environmental Concern (ACECs; outlined in pink).

examples (Garnar and Stanaway, 1994). Titanium minerals recovered from such deposits are restricted to ilmenite, rutile, and leucosene, and the deposits often produce zircon as a byproduct (King, 2005). The most valuable titanium placer deposits in the world are probably in Sierra Leone; these deposits have rutile contents of about 1.5 percent (Garnar and Stanaway, 1994). On the basis of samples collected by Beal (1963), titanium in the Gold Butte area placer deposits occurs mostly as Ti-magnetite, which is not a titanium ore mineral.

On the basis of this evidence, the potential for commercial titanium deposits in the Gold Butte area is low. The pegmatite deposits that contain titanium-bearing minerals are too small and low grade, and potential placer deposits are small and likely do not contain significant amounts of titanium ore minerals.

## Uranium Deposits in Sedimentary Rocks

The Long Shot Mine area in the Gold Butte B ACEC is a laterally extensive low-grade uranium deposit in limestone of the Horse Spring Formation. We consider a large area that extends northward into the Gold Butte A ACEC to have moderate potential, with moderate certainty, for sandstone- or limestone-hosted uranium deposits (Tract GBV05, fig. 34). This tract is part of an area that was considered favorable for uranium deposits on the basis of an earlier study (Johnson and Glynn, 1982), although surficial uranium concentrations in this area only range as high as 0.02 percent  $U_3O_8$ .

## Vermiculite Deposits

Bodies of ultramafic rock that contain potentially economic deposits of vermiculite occur in scattered areas in Proterozoic rocks in the Gold Butte B ACEC. Well-delineated areas that include ultramafic rock with known vermiculite as mapped by Volborth (1962) have high potential for vermiculite deposits with a high certainty (tract GBV08, fig. 34). These areas are in blocks of currently valid mining claims held for vermiculite. A larger area of Proterozoic rock that contains mapped bodies of ultramafic rock and may contain others that are poorly exposed has moderate potential for vermiculite deposits with moderate certainty (tract GBV09, fig. 34).

## Ni-Cu-Au-PGE Deposits

The ultramafic rocks in the Gold Butte B ACEC do not occur as dikes, like those in the Bunkerville Ridge block. They have more complex forms and have clearly been subject to regional metamorphism. Nevertheless, numerous samples of this rock, particularly at the Blue Bird Mine and at the Mar-ron Tungsten prospect, outside this ACEC, have anomalous concentrations of copper, gold, and platinum. Some of these samples have relatively high nickel concentrations as well. Although we did not study these rocks extensively, they have geochemical affinities with altered and mineralized rocks in

the Bunkerville District. We designate the same tract (GBV09, fig. 34) that we assigned moderate potential for vermiculite deposits to have moderate potential for Ni-Cu-Au-PGE deposits, with a low level of certainty.

## Limestone Deposits

Relatively pure limestone suitable for lime or cement has not been reported in the Gold Butte B ACEC. Paleozoic carbonate rocks in the area are generally impure. Devonian limestone, mined for lime and under development as a source of cement limestone elsewhere in the region, has been described as dolomitic in the Gold Butte A ACEC to the north, and these rocks, probably present in the Gold Butte B ACEC, would not be suitable for high-calcium lime or cement. Our chip sample of Tertiary limestone from the Horse Spring Formation near Garden Spring indicates that this limestone is also chemically unsuitable for lime production. It is sufficiently high in CaO for cement rock, but alkali contents are slightly high. It is possible that the ACEC contains large unexamined deposits of limestone that are suitable for cement or lime production; however, on the basis of the available information the potential is low. In addition, any such deposits would lie a considerable distance from easy access routes and would probably not be commercial because of high haulage costs.

There is no evidence for other types of metallic mineral deposits in the ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Gold Butte B ACEC

Small areas in the northern part of this ACEC are within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). No exploratory wells have been drilled in the ACEC, although two shallow dry holes were drilled in the Gold Butte A ACEC to the north. Highly metamorphosed Proterozoic rocks underlie most of this ACEC and such rocks generally have no hydrocarbon potential.

There is no indication of potential for brine or evaporite deposits of sodium or potassium. The ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Gold Butte B ACEC

*Crushed Stone.*—The rock units that contain high-quality stone in the ACEC are the Paleozoic carbonate rocks that are relatively free of chert and some of the quartz- and feldspar-rich Proterozoic granitic rocks. These units have high potential for crushed-stone aggregate deposits (tract AGBV01, fig. 36), with a moderate degree of certainty. Most of the Proterozoic metamorphic rocks are either relatively mica- and hornblende-rich gneisses or the coarsely porphyritic Gold Butte Granite (Volborth, 1962). Large parts of this granite weather readily to a gruss, and are not suitable for high-quality crushed stone.

In addition, there are large areas in the Lime Ridge and Tramp Ridge blocks that expose chert-bearing Paleozoic carbonate rocks. These rocks constitute a tract (AGBV02, fig. 36) that has moderate potential for crushed-stone aggregate deposits, with a moderate degree of certainty. The Miocene Horse Spring Formation, as well as areas of Proterozoic rock characterized by easily weathered ultramafic rocks, has low potential for crushed-stone aggregate deposits (tract AGBV03, fig. 36), with a moderate level of certainty.

*Sand and Gravel.*—The alluvial fan deposits in this ACEC contain mostly Proterozoic metamorphic and Paleozoic carbonate rock clasts and help delineate a tract with high potential for sand and gravel aggregate deposits, with a moderate level of certainty (tract AVGB04, fig. 37). These deposits are far from transportation corridors and are unlikely to be developed in the near future. Some areas on the western edge of the ACEC have moderate potential for sand and gravel aggregate deposits (tract AGBV05, fig. 36), with a moderate certainty level, because the alluvium is capped with well-cemented calcrete. Areas with substantial amounts of low-quality Tertiary rocks in the Horse Spring and Muddy Creek Formations, as well as thin deposits of talus on steep slopes, have low potential for sand and gravel aggregate deposits, with a low certainty level (tract AVGB06, fig. 36).

## Locatable Minerals in Virgin Mountain ACEC

### Ni-Cu-Au-PGE Deposits

The potential for discovery of additional Ni-Cu-PGE deposits like those studied here (Key West and Great Eastern Mines) is high, with a moderate level of certainty. Any undiscovered deposits would be related to unexposed olivine hornblende dikes or a larger subsurface intrusion, so the most prospective areas are the regions between the two mines and the extensions of that trend, both to the northeast and to the southwest, where the trend passes under alluvial cover. This area is delineated on figure 33 as tract GBV04. Factors used to delineate this tract include the known deposits, the observed occurrences of olivine hornblende, the aeromagnetic data of Falconbridge (Theodore A. DeMatteis, written commun., 2006), and the aeromagnetic high described by Langenheim and others (2000). Hose and others (1981) also identified this as an area of mineral resource potential. The tract includes some areas covered by a thin layer of alluvium.

Whereas the probability that undiscovered deposits like those at the Key West and Great Eastern Mines exist is high, deposits with either higher grade or larger tonnage would be necessary for further development to be likely. This is not impossible, as commercial deposits related to mafic dikes (Lightfoot and Farrow, 2002) are commonly not exposed at the surface. Deep exploration in the Bunkerville district has been proposed several times in the past, but has never been carried out. A significant Cu-Ni-Au-PGE resource may be present.

### Beryllium-Bearing Pegmatite Deposits

An area in the north part of the Virgin Mountain ACEC is considered to have high potential, with moderate certainty, for deposits of beryllium in pegmatite (tract VMT01, fig. 33). The most abundant beryllium mineral in the Virgin Mountains deposits is chrysoberyl, which has been effectively concentrated using gravity techniques (Holmes, 1964). Work by the U.S. Bureau of Mines in the 1960s indicated weighted average grade at about 0.30 percent BeO for pegmatite deposits in the Mica Notch area in this ACEC. This compares favorably with other pegmatite resources in the world, which have grades ranging between 0.04 percent and 0.20 percent BeO (Sabey, 2006).

The only domestic beryllium deposit that is mined at this time is the Spor Mountain deposit in Utah, which has an average grade of 0.7 percent BeO and a resource estimated at more than 70,000 short tons of BeO (Sabey, 2006). By contrast, the known Mica Notch BeO resource was estimated at 190,000 short tons of rock with 0.35 percent BeO, which constitutes a small resource of 665 short tons of BeO. The exposed beryllium deposits in the Virgin Mountain ACEC, which were explored by minor excavations and shallow drilling, are small and unlikely to be developed at this time. However, the area might contain larger deposits at depth.

### Limestone Deposits

Relatively pure limestone suitable for lime or cement has not been specifically reported in the Virgin Mountain ACEC. Paleozoic carbonate rocks in the area are generally impure. Devonian limestone, mined for lime and under development as a source of cement limestone elsewhere in the region, has been described as dolomitic in this ACEC, and such material would likely not be suitable for high-calcium lime or cement. The potential is low for limestone deposits in the Virgin Mountain ACEC.

### Mica Deposits

Mica was mined on a small scale in the Virgin Mountain ACEC during the 1930s and 1950s. Sheet mica deposits in pegmatite in this ACEC are small, and we consider them to have low potential. Large amounts of mica-rich schist occur in the Mica Notch area, and this area has moderate potential, with moderate certainty, for the occurrence of flake mica deposits (tract VMT02, fig. 33). The schist contains about 40 percent mica by volume, half of which is muscovite. Unpublished work on beneficiation suggests that a muscovite concentrate may be produced from the schist. Muscovite is widely used for industrial applications, but biotite has little commercial application at this time (Tanner, 1994). Further evaluation, beyond the scope of this study, would be needed to determine mica quality and marketability.

There is no evidence for other types of metallic mineral deposits in this ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Virgin Mountain ACEC

A few small areas along the southwest boundary of this ACEC are within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There are no known exploratory wells. There is no indication of potential for brine or evaporite deposits of sodium or potassium. The ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Virgin Mountain ACEC

*Crushed Stone.*—The highest quality stone for crushed-stone aggregate production in the Virgin Mountain ACEC is in Proterozoic granite, quartz monzonite, and granodiorite gneiss, as mapped by Beal (1965). Other high quality units include Devonian Muddy Peak Limestone and Cambrian Prospect Mountain Quartzite. The Muddy Peak is relatively free of chert, and thus not subject to alkali-silica reactivity, which can degrade concrete. Together, these lithologic units were used to delineate tract AGBV01 (fig. 36), which has high potential for crushed-stone aggregate deposits. This tract has only a moderate level of certainty because the distribution of different Proterozoic lithologies has not been mapped in detail throughout this ACEC.

Chert-bearing limestones make up most of the Paleozoic rocks in the Virgin Peak block, and they constitute the major part of tract AGBV02 (fig. 36) in this ACEC. This tract has moderate potential for crushed-stone aggregate deposits, with a moderate degree of certainty.

A large part of the Proterozoic part of the Virgin Peak block, south of the Virgin Mountains shear zone (see fig. 5), is made up of mafic gneisses with a high biotite content, which results in low durability. There are also few equant fragments. Together with the shales in the Paleozoic section, and all Triassic and younger sedimentary rocks, these units have low potential for crushed-stone aggregate deposits (tract AGBV03, fig. 36), with a moderate degree of certainty.

*Sand and Gravel.*—Most of the Virgin Mountain ACEC exposes bedrock; a few valleys contain alluvial material. Most of this alluvial material is of high quality, and these areas have high potential for sand and gravel aggregate deposits (tract AGBV04, fig. 36), with a high level of certainty.

## Locatable Minerals in Whitney Pocket ACEC

### Silica Deposits

The Aztec Sandstone, which makes up much of the bedrock in the Whitney Pocket ACEC, has been proposed as a potential source of silica and was mined in the past in small amounts elsewhere in Clark County. However, chemical analysis of white sandstone from this ACEC indicates that the unit has low potential as a source of silica.

There is no evidence for metallic mineral deposits in this ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Whitney Pocket ACEC

This entire ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983), but there are no known exploratory wells. There is no indication of potential for brine or evaporite deposits of sodium or potassium. The ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Whitney Pocket ACEC

*Crushed Stone.*—There is a small amount of Permian Toroweap Formation in the northeast corner of this ACEC that consists of sandstone, limestone, siltstone, and interbedded gypsum. This area has moderate potential for crushed-stone aggregate deposits, with a moderate degree of certainty (tract AGBV02, fig. 36). The rest of the bedrock in the ACEC is either Triassic Moenkopi Formation or Jurassic Aztec Sandstone and has low potential for crushed-stone aggregate deposits, with a moderate degree of certainty (tract AGBV03, fig. 36).

*Sand and Gravel.*—The alluvial deposits surrounding the outcrops of Aztec Sandstone in this ACEC contain mostly clasts of durable carbonate rocks from the mountains to the north and so have high potential for sand and gravel aggregate deposits, with a high level of certainty (tract AGBV04, fig. 36).

## Locatable Minerals in Red Rock Spring ACEC

### Silica Deposits

The Aztec Sandstone, which makes up all of the bedrock in the Red Rock Spring ACEC, has been proposed as a potential source of silica and was mined in small amounts in the past elsewhere in Clark County. However, chemical analysis of white sandstone from the nearby Whitney Pocket ACEC indicates that the unit has low potential as a source of silica.

There is no evidence for metallic mineral deposits in this ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Red Rock Spring ACEC

This entire ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983), but there are no known exploratory wells. There is no indication of potential for brine or evaporite deposits of sodium or potassium. The ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Red Rock Spring ACEC

*Crushed Stone.*—The outcrops within the Red Rock Spring ACEC are all friable Aztec Sandstone and thus have low potential for crushed-stone aggregate deposits, with a moderate level of certainty (tract AGBV03, fig. 36).

*Sand and Gravel.*—Much of the alluvial material in this ACEC is primarily fine sand derived from the Aztec Sandstone, with few clasts present, and has low potential for sand and gravel aggregate deposits, with a moderate level of certainty (tract AGBV06, fig. 37). Some other, slightly older terrace deposits contain carbonate clasts and have high potential for sand and gravel aggregate deposits (tract AGBV04, fig. 36), with a high level of certainty.

## Locatable Minerals in Devil's Throat ACEC

### Gypsum Deposits

The Devil's Throat ACEC has low potential for commercial gypsum deposits, although it contains a sinkhole that may have been caused by solution collapse of subsurface gypsum beds. This gypsum would lie at depths in excess of 20 m, and mining would entail expensive removal of overburden.

There is no evidence for metallic mineral deposits in this ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Devil's Throat ACEC

This entire ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). No exploratory drilling has been done within the ACEC, but two shallow dry holes were drilled nearby in the Gold Butte A ACEC. Thomas Gap Federal No. JP-1, which reportedly intersected an oil show (Garside and others, 1988), was about 1.5 km to the southeast of the ACEC.

There is no indication of potential for brine or evaporite deposits of sodium or potassium. This ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Devil's Throat ACEC

*Crushed Stone.*—The only bedrock exposed in the ACEC is Miocene Horse Spring Formation, which consists of fine-grained clastic sedimentary rocks and gypsum. This material has low potential for crushed-stone aggregate deposits, with a moderate level of certainty (tract AGBV03, fig. 36).

*Sand and Gravel.*—The alluvial fan deposits in this ACEC contain mostly carbonate rock clasts, with only minor chert, and have high potential for sand and gravel aggregate deposits, with a high degree of certainty (tract AGBV04, fig. 36). The Devil's Throat sinkhole suggests a natural hazard that could

affect exploitation of these resources. Studies of this and other sinkholes in the area (McLaurin and others, 2005) indicate that dissolution of gypsum beds beneath the alluvium is responsible for the karstlike features. Their study used seismic profiling to suggest that the alluvial deposits here are about 50 m thick.

## Locatable Minerals in Gold Butte Townsite ACEC

### Low-Sulfide Gold-Quartz Vein Deposits

The Gold Butte Townsite ACEC does not contain any known mineral prospects. However, currently valid lode claims, possibly for gold, were staked in 1991 and 1993 in the Gold Butte B ACEC just to the south and may extend into the Gold Butte Townsite ACEC. Quartz vein samples from the Golden claim group in this area contain as much as 14.2 ppm gold (Dexter and others, 1983). Almost the entire ACEC has high potential for low-sulfide gold-quartz vein deposits like the ones already known, with a high degree of certainty (tract GBV01, fig. 37). Whether any individual vein can be exploited successfully is a function of detailed grade distribution and can only be determined by detailed on-site exploration.

A very small part of the northwest corner of the ACEC has moderate potential for the occurrence of undiscovered Kipushi-type copper deposits, with a low level of certainty (tract GBT03, fig. 34).

There is no evidence for other types of metallic mineral deposits in the ACEC, and the potential for other types of locatable mineral deposits is low.

## Leasable Minerals in Gold Butte Townsite ACEC

The area is not within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983), nor is it within the region considered by the BLM to be prospectively valuable for sodium and potassium (Wayland and others, 1980).

There is no indication of potential for brine or evaporite deposits of sodium or potassium. This ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Gold Butte Townsite ACEC

*Crushed Stone.*—Bedrock exposures in the Gold Butte Townsite ACEC are either coarsely porphyritic Gold Butte granite or chert-bearing Paleozoic limestone. Both these units have moderate potential for crushed-stone aggregate deposits (tract AGBV02, fig. 36), with a moderate level of certainty.

*Sand and Gravel.*—The alluvial fan deposits in the ACEC, although probably quite thin, contain mostly high-quality clasts, and have high potential for sand and gravel aggregate deposits, with a moderate level of certainty (tract

AGBV04, fig. 36). However, like those in the Gold Butte B ACEC, they are distant from transportation corridors and unlikely to be developed soon.

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# Chapter D. Mineral Resource Potential of the Mormon Mesa Tortoise, Arrow Canyon, and Coyote Springs Tortoise Areas of Critical Environmental Concern, Clark County, Nevada

By Kathryn S. Flynn, Stephen B. Castor, Steve Ludington, and Brett T. McLaurin

## Summary and Conclusions

The Mormon Mesa Tortoise Area of Critical Environmental Concern (ACEC) contains areas with high potential for limestone deposits and areas with moderate potential for stone and silica deposits. The potential for undiscovered deposits of other locatable and leasable minerals is low. The Mormon Mesa Tortoise ACEC has areas with high, moderate, and low potential for crushed-stone aggregate deposits and areas with high and moderate potential for sand and gravel aggregate deposits.

The Arrow Canyon ACEC has no known mineral deposits, and the potential for undiscovered deposits of locatable and leasable minerals is low. Arrow Canyon ACEC has areas with high and moderate potential for crushed-stone aggregate and moderate potential for sand and gravel aggregate.

The Coyote Springs Tortoise ACEC contains known deposits of stone and silica, and a part of it has moderate potential for additional silica deposits. The ACEC also has areas with high potential for limestone deposits. The potential for undiscovered deposits of other locatable and leasable minerals is low. The Coyote Springs Tortoise ACEC has areas with high, moderate, and low potential for crushed-stone aggregate deposits and high and low potential for sand and gravel aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Mormon Mesa Tortoise, Arrow Canyon, and Coyote Springs Tortoise ACECs were studied in the field to con-

firm descriptions of the geology that were gleaned from the geologic literature. Samples were collected and analyzed, and known mineral deposits were visited and examined wherever possible. Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

The Arrow Canyon, Coyote Springs Tortoise, and Mormon Mesa Tortoise Areas of Critical Environmental Concern (ACECs) are contiguous, and they are located northeast of Las Vegas on the northwest side of Interstate 15 (fig. 1). A legal description of these lands is included in appendix 2.

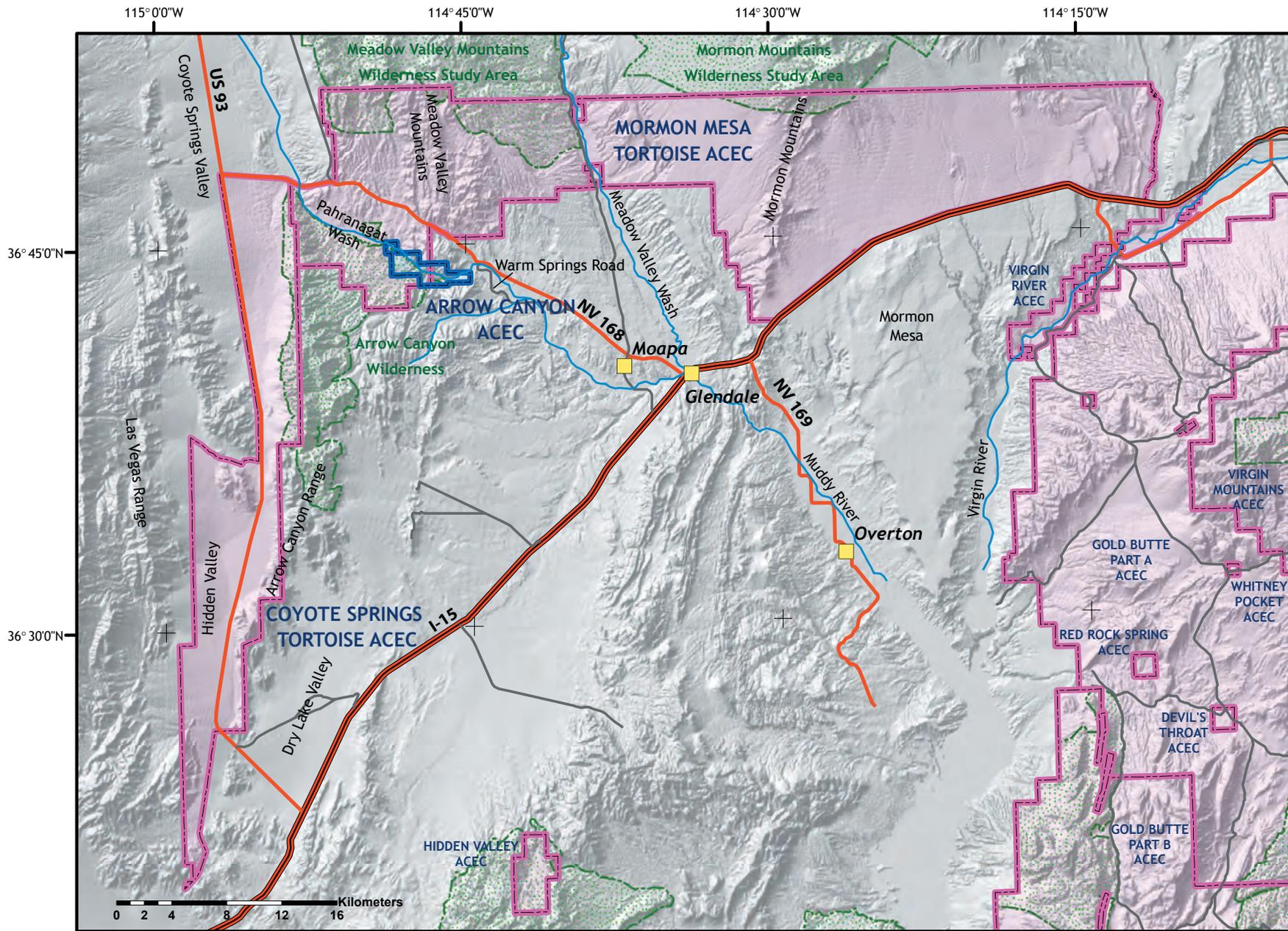
The Mormon Mesa Tortoise ACEC is located northwest of the Virgin River and adjoins the north border of Clark County, about 90 km northeast of Las Vegas (fig. 1). Interstate 15 forms the south boundary of the ACEC for about 30 km and provides access to the area. The ACEC includes part of the Arrow Canyon Wilderness. It also overlaps part of the Arrow Canyon ACEC, that is, some lands are included within both ACECs (fig. 1).

The Arrow Canyon ACEC straddles Pahrangat Wash (fig. 1). The western part of the area is also included in the Mormon Mesa Tortoise ACEC and partially overlaps the Arrow Canyon Wilderness. Nevada State Highway 168 and Warm Springs Road both cross Pahrangat Wash to the east of the ACEC.

The Coyote Springs Tortoise ACEC adjoins the Mormon Mesa Tortoise ACEC on the west (fig. 1). It measures about 52 km north to south and is 2 to 6 km wide. The south tip of the ACEC is about 10 km northeast of the edge of Las Vegas. The ACEC encompasses the southern part of Coyote Springs Valley and also Hidden Valley to the southwest. U.S. Highway 93 bisects the ACEC from north to south.

## Physiographic Description

Mormon Mesa forms a triangular highland between the Muddy and Virgin Rivers. The Mesa stands about 200 m



**Figure 1.** Index map of Mormon Mesa Tortoise, Arrow Canyon, and Coyote Springs Tortoise Areas of Critical Environmental Concern (ACEC; outlined in pink), showing towns and roads, wilderness areas, and wilderness study areas. Arrow Canyon ACEC boundary is shown in contrasting color (blue) to clarify the boundary overlap with the Mormon Mesa Tortoise ACEC.

above the riverbeds. From the Meadow Valley Mountains in the west, the Mormon Mesa Tortoise ACEC extends 60 km east across the mesa to the Virgin River Valley. The Meadow Valley Mountains have the most relief in the ACEC, reaching elevations of 1,500 m. The Mormon Mountains, in the central part of the ACEC, are lower in elevation. Much of the ACEC is a flat pediment at an elevation of about 750 m, with no streams or gullies and an average topographic gradient of less than 50 feet (18 m) per mile (Gardner, 1972).

Arrow Canyon is a narrow gorge that cuts through the northern Arrow Canyon Range for several miles. The Arrow Canyon ACEC contains part of the Arrow Canyon gorge (fig. 2) and the mouth of the Pahrnagat Wash, which flows south-east (see also fig. 14). The canyon walls are about 120 m high in the gorge (Page and Dixon, 1997). Elevations in the ACEC range from about 570 m to about 840 m.

The Coyote Springs Tortoise ACEC contains most of southern Coyote Springs Valley and also part of Hidden Valley (fig. 1) to the south. The area is bounded by the Las Vegas Range on the west and the Arrow Canyon Range on the east. Perennial streams in the northern part of the ACEC flow northward into Coyote Springs Valley, where they join Pahrnagat Wash at the north tip of the Arrow Canyon Range and flow east toward Arrow Canyon. The central part of the ACEC drains into the Hidden Valley alkali flat, and drainages in the south part of the ACEC drain eastward into Dry Lake Valley (fig. 1). The ACEC has little relief in the valleys (fig. 3) but it does include the western flank of the Arrow Canyon Range (up to 1,530 m elevation).

## Geologic Setting

The three ACECs are located on the eastern edge of the Basin and Range Physiographic Province. The Colorado Plateaus Province lies to the east. The mountain ranges in all three



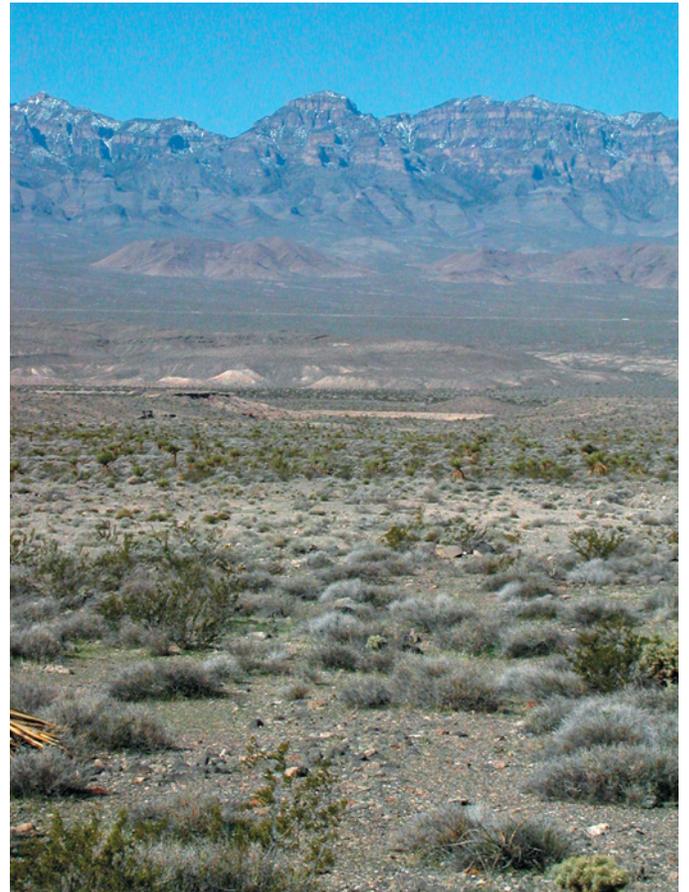
**Figure 2.** Cliffs of Paleozoic limestone at the mouth of Arrow Canyon.

ACECs are composed of Paleozoic sedimentary rocks (predominantly carbonates). These rocks underwent folding and thrust faulting during the late Cretaceous Sevier orogeny, followed by extensional basin and range faulting in the late Cenozoic. Large parts of the region are underlain by sedimentary deposits that blanketed low-lying areas during the late Miocene and filled intermontane valleys during the Quaternary. Figure 4 is a generalized geologic map of the three ACECs.

## Geology

### Mormon Mesa Tortoise ACEC

Mormon Mesa is mostly covered by Quaternary alluvium but also has large exposures of Tertiary sedimentary rocks and smaller outcrops of Paleozoic sedimentary rocks (fig. 4). The Tertiary rocks include relatively minor exposures of the Oligocene to middle Miocene Horse Spring Formation and extensive exposures of the late Miocene Muddy Creek Formation. The Meadow Valley Mountains and Mormon Mountains within the area are composed primarily of Paleozoic carbonate



**Figure 3.** Starvation Flat, at the north end of the Coyote Springs Tortoise Area of Critical Environmental Concern (ACEC). Looking west, beyond the ACEC to the Las Vegas Range.

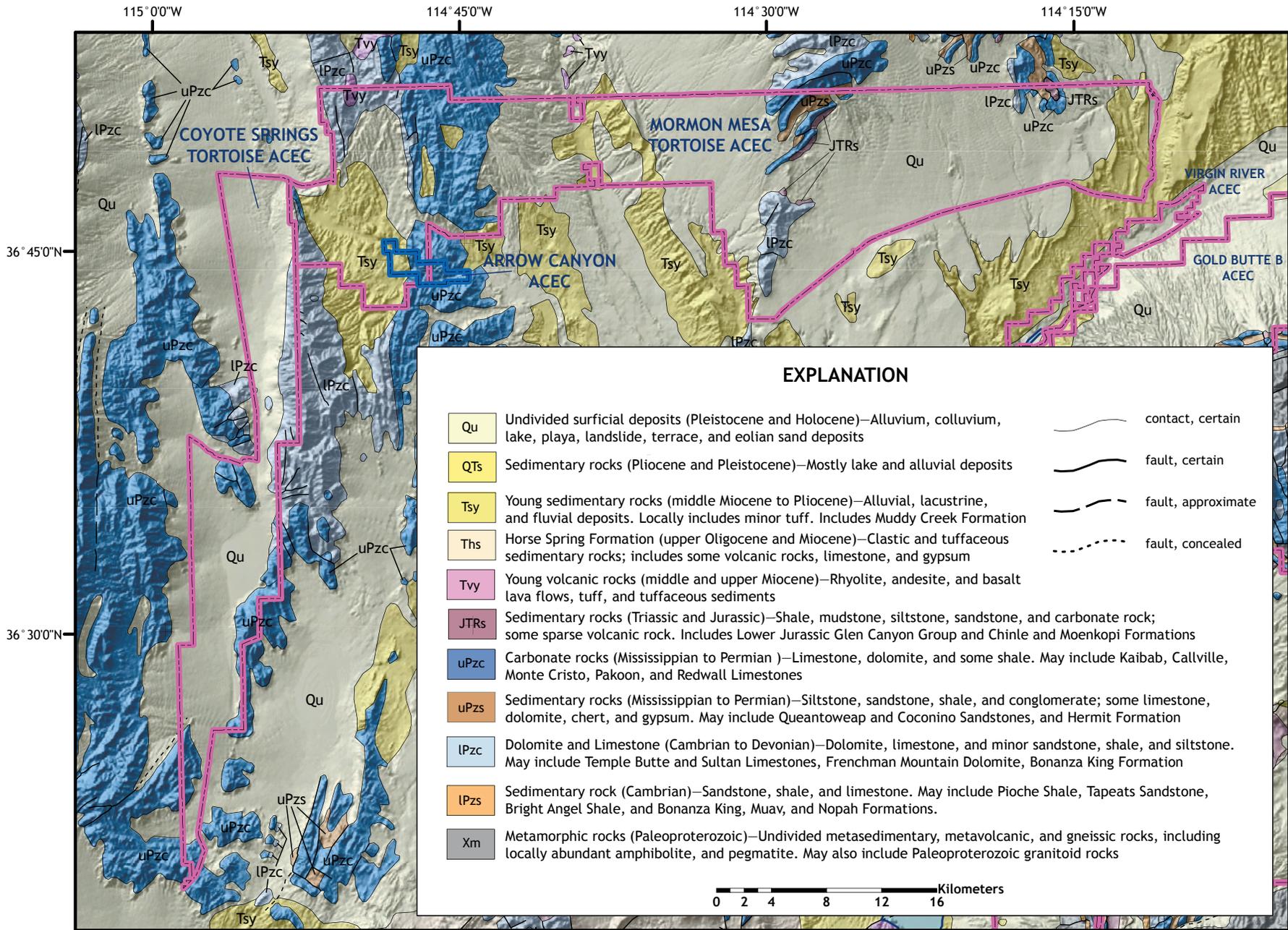


Figure 4. Generalized geology of the Mormon Mesa Tortoise, Coyote Springs Tortoise, and Arrow Canyon ACECs. Geology modified from Stewart and Carlson (1978).

rocks, but some Mesozoic siliciclastic rocks are also exposed, including the Triassic Moenkopi Formation and the Jurassic Aztec Sandstone (Page and Pampeyan, 1996; Schmidt, 1994; Schmidt and others, 1996). These units are cut by thrust faults associated with the Sevier orogeny and high-angle normal faults related to Cenozoic extension.

The young basin that underlies the eastern part of Mormon Mesa and areas to the east is known as the Virgin River Depression. Geophysical data (Langenheim and others, 2001) indicate that the basin is 5 to 10 km deep and filled with Tertiary and Quaternary sediments. A few Quaternary faults strike generally north in the central part of the basin (Langenheim and others, 2000).

The surface of Mormon Mesa (fig. 5) is a pediment cut on the Muddy Creek Formation and its reworked alluvial deposits (Gardner, 1972). Bedrock in the area is locally covered by caliche, an indurated layer of calcium carbonate that formed in the arid climate under aggrading conditions. The soil profile consists of a few meters of caliche, which transitions downward into the clastic parent material. This caliche is at least 890,000 years old, and it may be as old as 3 million years (Gardner, 1972).

## Arrow Canyon ACEC

The walls of Arrow Canyon expose Mississippian, Pennsylvanian, and Permian strata. These carbonate rocks are especially well exposed and accessible in Arrow Canyon, giving it a reputation as one of the best-studied Paleozoic sections in the eastern Great Basin (Page and Dixon, 1997). Bedrock in the eastern part of the ACEC is the Permian Bird Spring Formation, which includes abundant marine fossils and a distinctive reddish marker bed near the top of the unit (Page and Dixon, 1997). The western part of the ACEC is composed of the Bird Spring Formation, the Indian Springs Formation, the Battleship Wash Formation, and the Monte Cristo Group (Page, 1992). These units are mostly limestone



Figure 5. Mormon Mesa pediment, as seen from Meadow Valley Wash. Moapa Peak, just north of the ACEC, in background.

with beds of chert, except for the Bullion Dolomite member of the Monte Cristo Group (Page and Dixon, 1997). Continuous and extensive stratigraphic exposure has made Arrow Canyon a popular place to study stratigraphy. Conodont fossils from the Indian Springs Formation were used to define the boundary between the Mississippian and Pennsylvanian Periods (Brenckle and others, 1997).

## Coyote Springs Tortoise ACEC

Paleozoic carbonate rocks form the bedrock of the Coyote Springs Tortoise ACEC (fig. 4), but much of it consists of wide valleys filled with younger sediments (Eakin, 1964). Ordovician, Silurian, and Devonian carbonate rocks form the northern part of the Arrow Canyon Range that is exposed in the ACEC (Page, 1998). The Las Vegas Range on the west and the southern part of the Arrow Canyon Range expose the same Permian and Mississippian rock units as Arrow Canyon. Coyote Springs Valley contains Quaternary deposits of alluvium and playa sediments.

Numerous large and small folds in these Paleozoic rocks are evidence of regional compression during the Sevier orogeny. The Battleship Wash Syncline is an open fold whose axis crosses Arrow Canyon in the study area, and it is visible along the east side of the Arrow Canyon Range (Page and Dixon, 1997). Another major syncline is concealed by alluvium in Coyote Springs Valley (Page, 1992). The rocks are cut by thrust faults associated with the Sevier orogeny and high-angle normal faults related to Cenozoic extension.

## Mining History

The only recorded mining activity within the boundaries of these three ACECs was at the Quartzite quarry (fig. 6) in the central part of Coyote Springs Tortoise ACEC. We found no information about dates or amounts of production at that quarry. The quartzite may have been mined as a source of silica or for building stone.

Quartzite was reportedly mined for several years from the Tiffany Minerals Co. quarry (fig. 6), which is about 2 km east of the Coyote Springs Tortoise ACEC (Murphy, 1954). No figures are available for total production, but in 1954 production was reported to be less than 2,000 short tons of quartzite per year. The quartzite was trucked to a mill on the Union Pacific Railroad, but the operation was abandoned because the abrasiveness of the rock caused high milling costs. In addition, building stone was mined about 10 km east of the Coyote Springs Tortoise ACEC.

The Apex limestone quarries and plant of Chemical Lime Inc. form the largest mining operation in the vicinity of the three ACECs. The limestone was drilled and evaluated in the 1930s (Hewett and others, 1936), and limestone was mined and shipped from the area by U.S. Lime Products Corp. and processed elsewhere. In the early 1950s, annual production

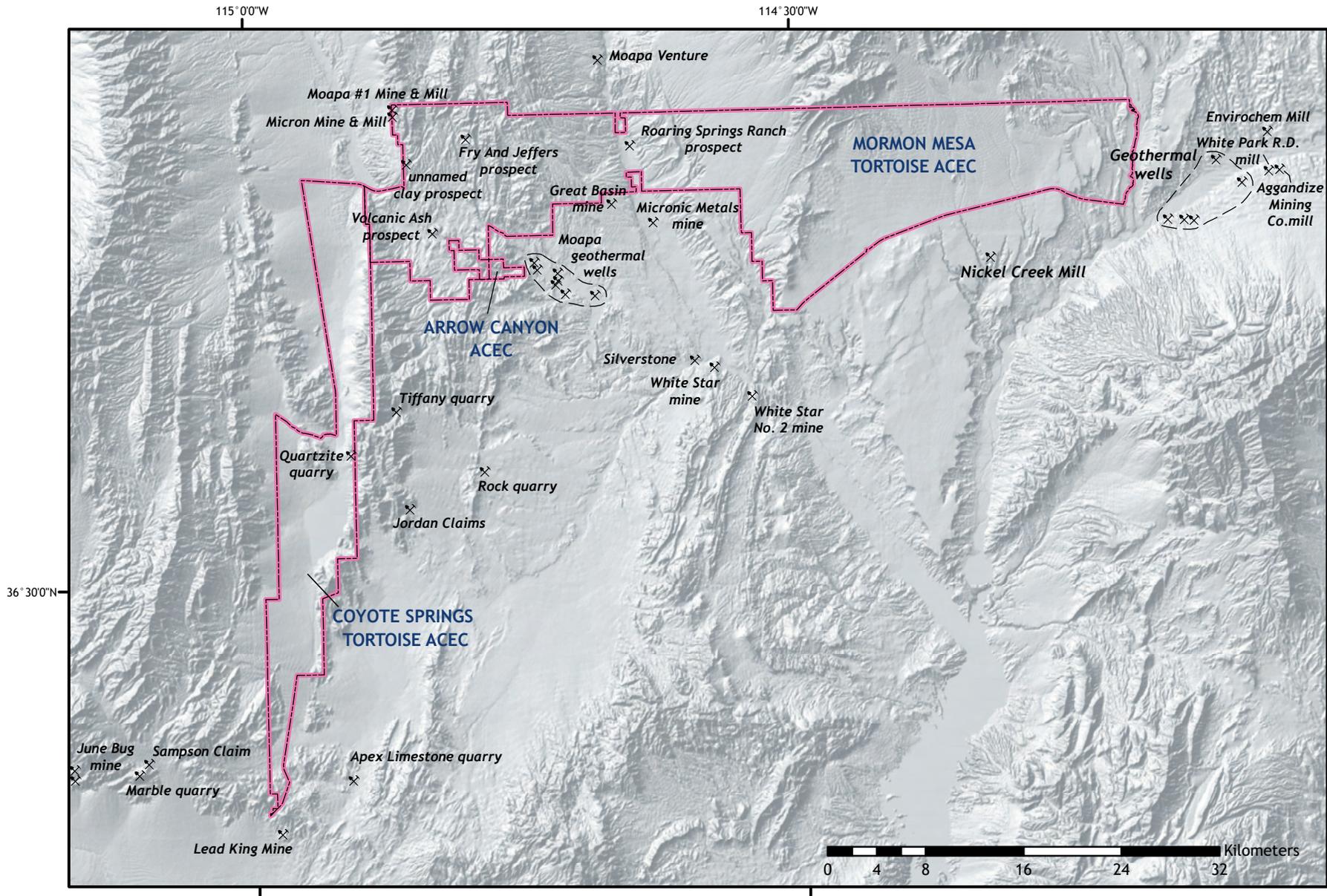


Figure 6. Mines and prospects in and near the Mormon Mesa Tortoise, Arrow Canyon, and Coyote Springs Tortoise Areas of Critical Environmental Concern (ACEC; outlined in pink).

was given by the U.S. Bureau of Mines at more than 500,000 short tons. In 1958, after acquisition of the operation by the Flintkote Co., a lime plant was constructed. In 1980 the operation was acquired by Genstar Lime and Cement Inc., which was succeeded by Chemstar Lime Inc. in 1986 and by Chemical Lime Inc. in 1994. The most recent production figure for the operation is 195,000 short tons of quicklime in 1990 (Nevada Department of Minerals and Nevada Bureau of Mines and Geology, 1991).

Although we found no direct evidence of placer gold, it is possible that there has been some placer gold mining along Meadow Valley Wash, which bisects the Mormon Mesa Tortoise ACEC. There has been no other known mining within the boundaries of the three ACECs, although moderately extensive mining of silica and dimension stone has taken place a few kilometers east of Coyote Springs Tortoise ACEC. In addition, exploration drilling for geothermal energy has taken place immediately east of the Arrow Canyon ACEC and southeast of the Mormon Mesa ACEC, along the Virgin River (fig. 6).

## Mineral Deposits

### Mormon Mesa Tortoise ACEC

The mines database of the Nevada Department of Environmental Protection locates the Roaring Springs Ranch gold prospect within the Mormon Mesa Tortoise ACEC, on Meadow Valley Wash (fig. 6), but provides no further information. A field visit to the indicated site revealed no evidence of exploration or mining aside from a primitive road off the Meadow Valley Wash road (fig. 7). Another source (Nevada Department of Industrial Relations, 1987) indicates that the Moapa #1 mine and mill was under construction in 1986 by the Roaring Springs Ranch Company, but that the site of this mine and mill was 20 km to the west, in section 6 of T13S, R64E. There are no other references to these developments.

In the far northwestern corner of the area, the Moapa #1 mine and mill (gold) and the Micron mine and mill (gold) were reportedly in operation in the mid 1980s (Nevada Department of Industrial Relations, 1987, 1988). Given the geologic



**Figure 7.** Purported site of Roaring Springs Ranch gold prospect.

context, these could have exploited polymetallic vein or replacement deposits in Paleozoic limestone. They are located at the south end of the Meadow Valley Mountains district (Tingley, 1989). Two visits to this area (fig. 6) yielded no evidence of gold mining activity (fig. 8). A shallow gravel pit was noted in the area, as well as some possible claim markers (fig. 9).

Clay deposits occur in the Muddy Creek Formation in the western part of the Mormon Mesa Tortoise ACEC. According



**Figure 8.** Purported site of the Micron Mine and mill; Paleozoic carbonate rocks in hills on right. Looking north along former U.S. Highway 93.



**Figure 9.** Possible old claim marker in the vicinity of the Moapa #1 and Micron sites, Mormon Mesa ACEC.

to Vandenberg (1937), a bed of white bentonite about 3 feet (1 m) thick is exposed for about 2 km in a bluff at the Volcanic Ash prospect (figs. 6, 10).

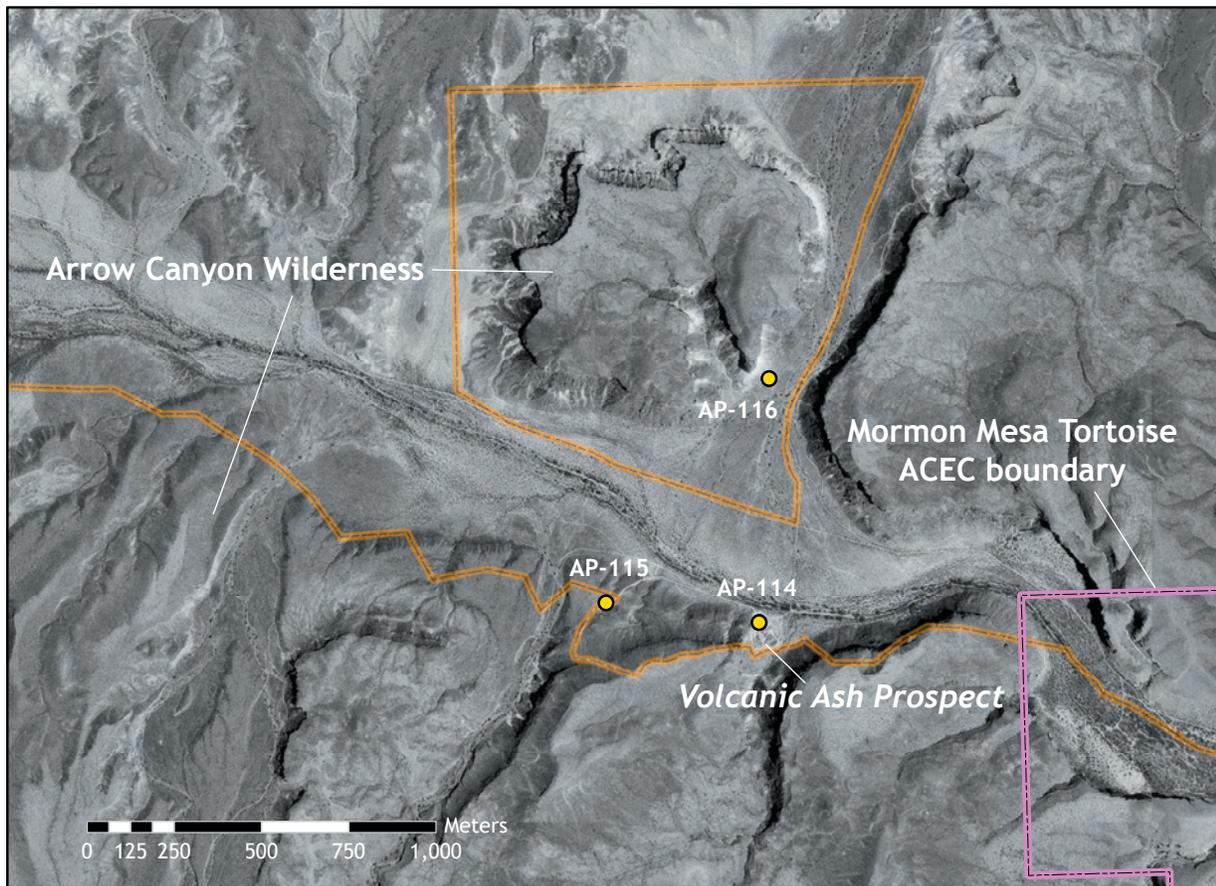
During field reconnaissance in this area, which is along Pahranaagat Wash, we sampled a 1.1-m-thick, nearly flat lying bed of white to pale olive green expansive clay from a small prospect (fig. 11) along the south side of the wash (sample site AP-114). XRD analysis of this sample indicates the presence of smectite clay, possibly the sodium-rich clay beidellite, along with significant amounts of dolomite and minor quartz and feldspar. However, a chemical analysis of the sample (Ludington and others, 2005) suggests the presence of a magnesian smectite such as saponite, because MgO/CaO is higher than can be accounted for by dolomite contamination. In a road cut about 500 m to the west is a poor exposure of low-quality clay mixed with calcite and glassy shard tuff at about the same stratigraphic level (sample AP-115). This clay occurs in a sequence of sandstone, gypsum, and 5.6-Ma tuff capped by limestone that is probably part of the Muddy Creek Formation.

A second clay prospect, about 65 m long and 10 m wide (fig. 12), is about 6 km north-northwest of the Volcanic Ash prospect (sample site AP-038). At this prospect, a bed of pale-olive-green to pale-brown clay occurs in shallowly west

dipping redbeds of the Muddy Creek Formation. On the basis of XRD analysis, this clay is considered to be of low quality because it contains large amounts of impurities, mainly calcite and quartz with minor feldspar and dolomite. The clay mineral could not be determined by XRD analysis; the clay differs considerably from the Volcanic Ash prospect clay on the basis of chemical analysis (Ludington and others, 2005).

The Fry and Jeffers prospect (fig. 6) was reportedly explored for uranium in lower Paleozoic limestone in the western part of the Mormon Mesa Tortoise ACEC (Campbell, 1987). Radioactivity at the site was about 1.6 times background, and soil samples from the area reportedly contained as much as 110 ppm  $U_3O_8$  (Nelson, 1954). This occurrence is in shallowly northeast dipping black Paleozoic limestone with no veins or structures and no visible uranium minerals. Later reconnaissance of the area showed only weakly anomalous radioactivity, and the occurrence was judged to be of no interest (Campbell, 1987). Examination of aerial photography of the region reveals no evidence of any significant surface disturbance.

Near Meadow Valley Wash, but outside the ACEC, four other gold prospects have been reported (fig. 6): the Moapa Venture prospect, about 5 km north of the ACEC bound-



**Figure 10.** Aerial view of Volcanic Ash clay prospect in the Mormon Mesa ACEC, showing wilderness (orange) and ACEC (pink) boundaries, and location of samples.

ary (Nevada Department of Industrial Relations, 1983); the Great Basin prospect, about 1 km south of the ACEC boundary (Nevada Department of Industrial Relations, 1987); the Micronic Metals mine, about 2 km south of the ACEC boundary (Nevada Department of Industrial Relations, 1981); and Silverstone, about 7 km southwest of the south tip of the ACEC (Nevada Department of Industrial Relations, 1983). These sites were reportedly in operation in the 1980s, but we were unable to find any further information about these locations or locate them in the field.

The Gourd Springs mining district is in the East Mormon Mountains of Lincoln County, 12 to 15 km north of the Mormon Mesa Tortoise ACEC. Reported lode deposits are either associated with Precambrian pegmatites or consist of manganese enrichments in Cambrian limestone (Tschanz and Pampeyan, 1970). Manganese ore was reportedly produced in 1929 from this district, but Tingley (1984) was unable to locate these workings.

The Mormon Mountains district contains the Whitmore Mine, which is about 10 km north of the ACEC. It consists of several adits, shallow shafts, and prospect pits along a moderately northwest-dipping detachment fault. Unmineralized Paleozoic limestone is in the hanging wall, and altered and veined granitic rock is in the footwall. Quartz, pyrite, chalcopyrite, and bornite occur in the veins, and a select vein sample contains more than 2 percent copper and 50 ppm silver (Tingley, 1989). In 1908, 19 short tons of ore were produced containing 4 troy ounces of silver and 2,621 pounds of copper.

Near the town of Mesquite, about 10 km east of the ACEC, three small mills reportedly operated intermittently in the 1980s (fig. 6): Envirochem (Nevada Department of Industrial Relations, 1982); White Park R.D (Nevada Department of Industrial Relations, 1991); and Aggandize Mining Co. (Nevada Department of Industrial Relations, 1991). None of these is known to be operating at present.

The White Star bedded gypsum deposit is located about 7 km southwest of the south tip of the ACEC, near the town of Glendale, Nevada (figs 1, 6). The deposit, a flat-lying gyp-

site bed about 7 m thick in the Muddy Creek Formation, was mined by the White Star Plaster Co. from 1919 to 1920 to supply a nearby mill (Papke, 1987). The White Star No. 2 deposit, about 4 km to the southeast, was mined underground from 1921 to 1923 to feed the same mill. The latter deposit consists of a shallowly west dipping gypsum unit about 8 m thick in the Kaibab Formation (Papke, 1987).

Federated Commercial Industries Co. is currently exploring a large area of gypsum in the upper part of the Muddy Creek Formation in Lincoln County, about 4 km north of the Mormon Mesa ACEC. Published information on gypsum in this area describes the Snowwhite deposit as flat-lying, near-surface gypsite about 2 m thick in an area of about 7 km<sup>2</sup> (Papke, 1987). The current exploration personnel of Federal Commercial Industries report that it covers a much larger area (G. W. Hansen, written commun., 2005).

## Arrow Canyon ACEC

No mineral deposits are known in or near the Arrow Canyon ACEC. However, several wells were drilled to explore for geothermal energy in the Muddy Springs area about 1 to 6 km east of the east end of the Arrow Canyon ACEC.

## Coyote Springs Tortoise ACEC

The Lead King mine, in the Dike mining district, exploited a polymetallic deposit in a shear zone in upper Paleozoic carbonate rocks. It is less than 2 km south of the south tip of the Coyote Springs Tortoise ACEC (fig. 6). It reportedly produced 2 carloads of lead ore sometime before the 1950s (Longwell and others, 1965). This deposit may be a Mississippi-Valley-type deposit of Paleozoic age.

Small quantities of ore have been produced from mines in the Gass Peak mining district, which is about 10 to 15 km west of the south end of the Coyote Springs Tortoise ACEC (fig. 6). The bedrock in this district is Monte Cristo Limestone that



**Figure 11.** White to pale-olive-green clay in a small prospect on the south side of Pahrnat Wash. Sample site AP-114.



**Figure 12.** Clay bed in redbeds of the Muddy Creek Formation. Unnamed clay prospect, sample site AP-038.

has been replaced with lead and zinc minerals (now oxidized) adjacent to shear zones. The June Bug Mine produced about 1,000 short tons of ore in 1916-1917 (Longwell and others, 1965). The Sampson claim has no recorded production. Some of the deposits in the Gass Peak district may be Mississippi-Valley-type replacement deposits.

A once-active quarry in the Ordovician Eureka Quartzite is in the central part of the Coyote Springs Tortoise ACEC (fig. 6). This quarry is about 150 m long, 30 m wide, and 20 m deep (fig. 13). It is visible from Highway 93 near the western base of the Arrow Canyon Range. The quartzite is white, very hard, firmly cemented, and partially recrystallized. It may have been mined as a source of stone rather than of silica. A chip sample of quartzite that represents about 10 m of bedded thickness (sample AP-036; Ludington and others, 2005) contains more than 99 percent  $\text{SiO}_2$ . Except for slightly elevated  $\text{Fe}_2\text{O}_3$ , it is suitable for the production of container glass (table 1). The thickness of the Eureka Quartzite in the area is given at 40 to 50 m (Page, 1998). Reserves available at economic min-



**Figure 13.** Quartzite quarry on the Coyote Springs Tortoise ACEC at the west base of the Arrow Canyon Range. Sample site AP-036.

ing costs may be low because the bedding dips shallowly westward under increasingly thick cover. Mapping by Page (1992, 1998) shows that the Eureka Quartzite crops out extensively in the Arrow Canyon Range. In the Coyote Springs ACEC it is mainly high on the steep western face of the range and within the Arrow Canyon Wilderness Area.

The quarry described above is west of the Arrow Canyon Range mining district as defined by Tingley (1992). This district reportedly contains several deposits of silica and building stone within about 10 km of the east boundary of the Coyote Springs Tortoise ACEC. The locations of some of these are in doubt because of discrepancies among published sources (Murphy, 1954; Tingley, 1989; Hess, 2001). The Tiffany Minerals Co. quarry is the only other mined deposit located by us or by Tingley (1989) with certainty. The Eureka Quartzite was mined at a rate of about 2,000 short tons per year from this site (Murphy, 1954), which is about 1 km east of the Coyote Springs Tortoise ACEC. The quarry is about 75 m long, 40 m wide, and 12 m deep in a dip slope on beds that dip at a low angle to the east (Tingley, 1989). On the basis of an analysis reported in Murphy (1954), the chemistry of Tiffany mine quartzite has very high  $\text{SiO}_2$  and is similar to that of our sample AP-036. We have no information about reserves at the Tiffany deposit.

The Chemical Lime Corporation mines high-calcium limestone from the Crystal Pass Limestone Member of the Devonian Sultan Formation at Apex about 5 km east of the south end of the ACEC (fig. 6). In addition, the company mines dolomite from the Bullion Dolomite Member of the Monte Cristo Formation in the same area. Both rocks are used to make lime in an adjacent plant. Relatively minor amounts of magnesium are considered to be deleterious in high-calcium lime, and kiln feed that contains more than 1 percent  $\text{MgCO}_3$  (about 0.5 percent  $\text{MgO}$ ) is unsuitable (S. Krukowski, personal commun., 2006). In addition, kiln feed with more than 1 percent  $\text{SiO}_2$  is generally considered unacceptable. In southern Nevada, Cambrian through Middle Devonian rocks, which are predominantly dolomite and dolomitic limestone, generally

**Table 1.** Comparison of major element composition of Nevada silica deposits.

[AP-036 = quartzite quarry, Coyote Springs ACEC; AP-117 = American Cement and Aggregate Corp. plant, Mercury, Nevada; AP-006C = Arden Quarries, Nevada. Tiffany Mine and Simplot Silica data are from Murphy (1954); container glass specification data are from Zdunczyk and Linkous (1994). na = data not available.]

Element	AP-036	AP-117	AP-006C	Tiffany Mine	Simplot Silica ore	Simplot Silica product	Container glass specification
$\text{SiO}_2$	99.42	98.53	95.56	99.52	97.25	98.93	98.5 min
$\text{Al}_2\text{O}_3$	0.17	0.33	0.77	0.27	1.38	0.65	0.5 max
$\text{Fe}_2\text{O}_3$	0.16	0.25	0.4	0.01	0.19	0.03	0.035 max
$\text{MgO} + \text{CaO}$	0.07	0.06	1.22	0.02	0.27	0.05	0.2 max
$\text{TiO}_2$	0.01	0.02	0.02	0.01	0.08	0.03	0.03 max
$\text{Cr}_2\text{O}_3$	0.036	0.04	0.031	na	0.00	na	0.001 max

**Table 2.** Comparison of some major element analyses of 3-m chip sample AP-324 and 25-m chip sample AP-328 from the Coyote Springs Tortoise ACEC with a grab sample from the Apex quarry, with Portland cement specifications, and with high-Ca lime specifications.

[CaCO<sub>3</sub> % calculated using CaO x 1.78; MgCO<sub>3</sub> % calculated using MgO x 2.09. Apex Limestone Quarry data from Tingley and others (1992). Portland cement specifications from Ames and others (1994). High-Ca lime ore specification from Stanley T. Krukowski (oral commun., 2005).]

Element	AP-324	AP-328	Apex Limestone Quarry	Portland cement ore specification	High-Ca lime ore specification
SiO <sub>2</sub>	1.86	2.00	0.80		<1
Al <sub>2</sub> O <sub>3</sub>	0.20	0.16	0.16		
Fe <sub>2</sub> O <sub>3</sub>	0.11	0.08	0.12		
MgO	0.54	0.26	0.34		<0.5
CaO	54.32	56.23	54.94	ca. 50	
Na <sub>2</sub> O+K <sub>2</sub> O	0.12	0.08	0.05	<0.4	
P <sub>2</sub> O <sub>5</sub>	0.08	0.01	0.04		
LOI	42.8	41.10	43.20		
CaCO <sub>3</sub>	96.69	100.09	97.79		>95
MgCO <sub>3</sub>	1.13	0.54	0.71		
Total carbonate	97.82	100.63	98.50		

contain too much MgO and (or) other impurities (such as silica in the form of chert) to meet specifications. However, some Upper Devonian and Mississippian limestone units in southern Nevada generally have sufficiently low MgO contents for lime production. The Crystal Pass Limestone at Apex is chemically suitable (table 2), and it is especially attractive because its very fine grain size is desirable for the production of high-quality lump lime. More coarsely crystalline limestone decrepitates during calcination, producing fine-grained lime.

## Mineral Exploration and Development

There are a number of current placer claims in and adjacent to the Mormon Mesa Tortoise ACEC. American Gold Corp. holds four current association placer claims on the surface of Mormon Mesa, along the south boundary of the Mormon Mesa Tortoise ACEC, near its east end. These are part of the same block of claims described in the Virgin River ACEC report (Chapter G of this report). A group of eight individuals hold five association placer claims in the central part of the Mormon Mesa Tortoise ACEC, near the northern boundary, along Meadow Valley Wash. These claims include the Roaring Springs Ranch prospect mentioned above. A different group of eight people holds two other placer claims further south along Meadow Valley Wash, just within the Mormon Mesa Tortoise ACEC. The Fire Corporation holds seven association placer claims along the south boundary of the ACEC, about 3 to 8 km west of Meadow Valley Wash, and a third group of eight people holds two claims in that same vicinity. John P. Simons

holds five placer claims in the western part of the ACEC, just south of the Fry and Jeffers uranium prospect.

American Cement and Aggregate Corp. holds eight claims near the center of the Coyote Springs Tortoise ACEC in the vicinity of the quartzite quarry described above. The company produces silica sand from the Eureka Quartzite near Mercury, Nevada. Nevada Aggregates Holding LLC holds a single claim near the south tip of the Coyote Springs Tortoise ACEC.

None of the claims listed above shows any signs of current exploration activity. We are not aware of any other current exploration activity in the three ACECs.

## Geothermal Sites and Exploration

Wells drilled near the Mormon Mesa Tortoise and Arrow Canyon ACECs intersected thermal water (fig. 6). Warm springs and wells in the Muddy Springs area are within 1 km of the Arrow Canyon ACEC and 2 km of the Mormon Mesa Tortoise ACEC. On the basis of data in Garside (1994) and Shevenell and Garside (2005), well CSV-3, which is near U.S. Highway 93 along the west border of the Coyote Springs Tortoise ACEC, intersected hot water (41°C), and other wells and springs in the area produce warm water (31-36°C). Warm Spring, which is in the Muddy Springs geothermal area, produces one of the highest flows of thermal water in Nevada (Garside, 1994).

Despite the presence of thermal wells and springs in the area, the likelihood for a geothermal system with sufficiently high temperature (150°C) for electrical generation in the area

is considered to fall in the “permissive” to “marginally favorable” classes in most of the three ACECs (Coolbaugh and others, 2005). These classes constitute the two lowest geothermal favorability classifications for the Great Basin. Relatively small areas in the central and northern part of the Coyote Springs Tortoise ACEC and the northwestern part of the Mormon Mesa Tortoise ACEC are shown by Coolbaugh and others as “favorable,” which is equivalent to only moderate potential in their classification scheme. However, potential for direct use applications, such as residential or aquacultural heating, is high in the Muddy Springs area.

## Mineral Resource Potential

### Locatable Minerals in Mormon Mesa Tortoise ACEC

*Precious and Base Metals.*—Although there are hydrothermal precious- and base-metal deposits in nearby areas, the geologic environments that host these deposits do not occur inside this ACEC, and the potential for their presence is low.

*Uranium.*—The Fry and Jeffers uranium prospect is not in an area that exhibits significant or widespread effects of mineralizing processes, and radioactivity in the area is not much above background levels. On the basis of this and the regional geology, we do not consider the ACEC to have potential for uranium deposits.

*Clay.*—There are clay occurrences within this ACEC, but the clay is of poor quality and unlikely to be present in large amounts. The potential for clay deposits is low.

*Stone and Silica.*—At least two deposits have produced silica and/or stone near this ACEC. However, there are no continuous outcrops of Eureka quartzite within the ACEC, and the mineral resource potential is low.

*Limestone.*—At Apex (fig. 6), high-calcium limestone is mined from the Crystal Pass Member, the uppermost unit in the Devonian Sultan Limestone, and this unit is known to contain high-calcium limestone elsewhere in southern Nevada. An equivalent limestone unit is included in the upper part of the Guilmette Formation, which crops out in the western part of the Mormon Mesa Tortoise ACEC (Page, 1992, 1998). Although we have demonstrated that the Sultan (or upper Guilmette) contains high-calcium limestone at one site in the Coyote Springs Tortoise ACEC, the potential for economic deposits cannot be demonstrated at the highest certainty level without more careful sampling. Two large areas mapped as Sultan Formation (Longwell and others, 1965) and upper Guilmette Formation (Page, 1992, 1998) are considered to have high potential, with moderate certainty, for limestone deposits (tract MMT01, fig. 14).

*Gypsum.*—There are two abandoned gypsum mines near the south tip of this ACEC, but the appropriate depositional environments are not found inside the ACEC, and the potential for gypsum deposits there is low.

### Leasable Minerals in Mormon Mesa Tortoise ACEC

The entire Mormon Mesa Tortoise ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Mormon Mesa Tortoise ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

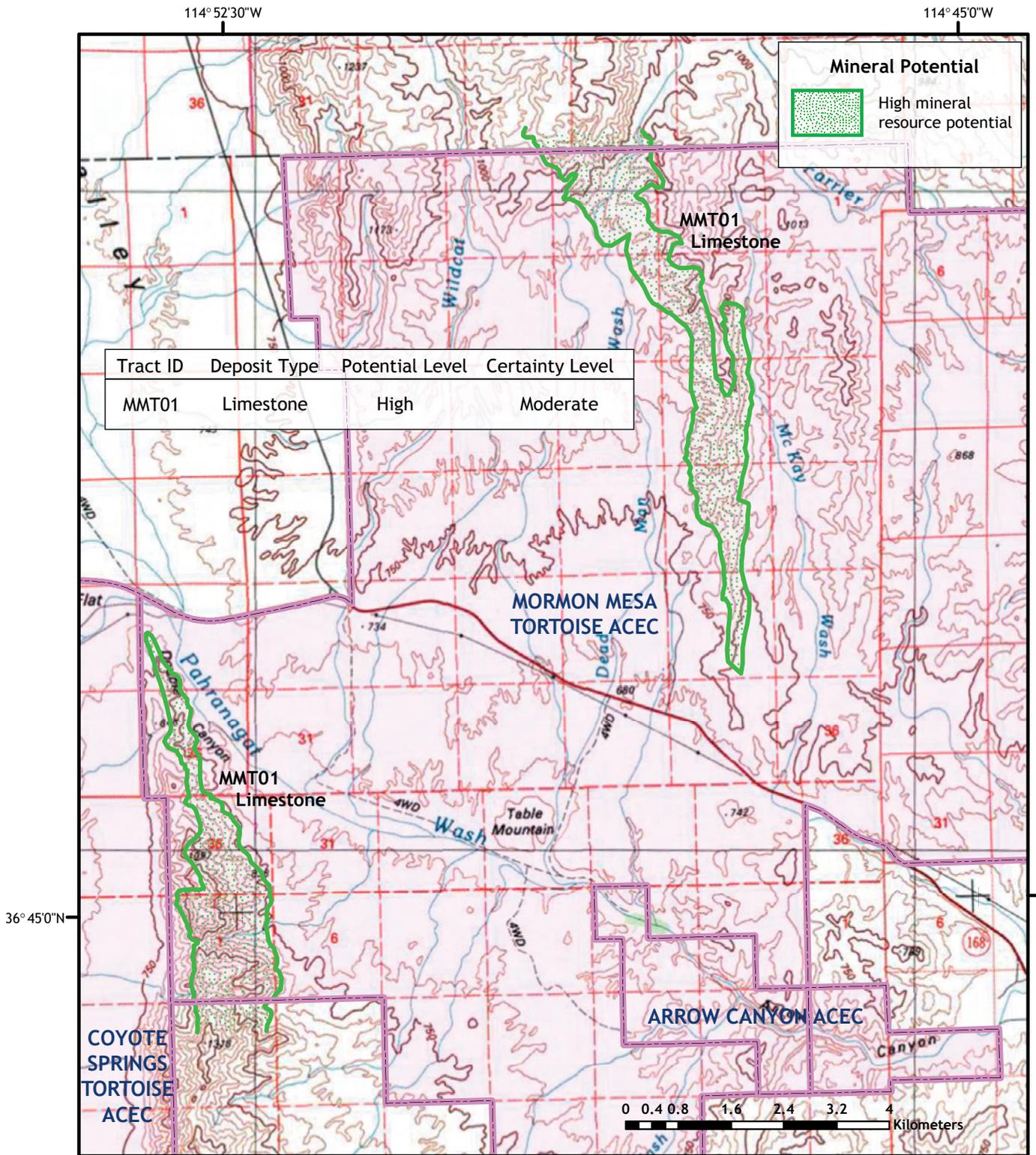
### Salable Minerals in Mormon Mesa Tortoise ACEC

*Crushed Stone.*—The highest potential areas for crushed-stone aggregate are located in the western part of this ACEC, where Paleozoic carbonate rocks form north-trending ridges. The highest quality lithologies are found in the Highland Peak Formation, the Nopah Formation, Eureka Quartzite, Laketown Dolomite, Simonson Dolomite, the Guilmette Formation, the Crystal Pass Limestone, Battleship Wash Formation, and various members of the Bird Springs Formation. Geologic mapping by Page (1992) indicates that the carbonate rocks in these units are limestone, dolomitic limestone, and dolomite and are relatively chert-free compared to other Paleozoic carbonate units. Areas underlain by these rocks constitute tract AMAC03 (fig. 15), and have high potential for crushed-stone aggregate, with a high degree of certainty. High-potential areas in the tract are also present in the south-central part of the ACEC along the southern extension of the Mormon Mountains.

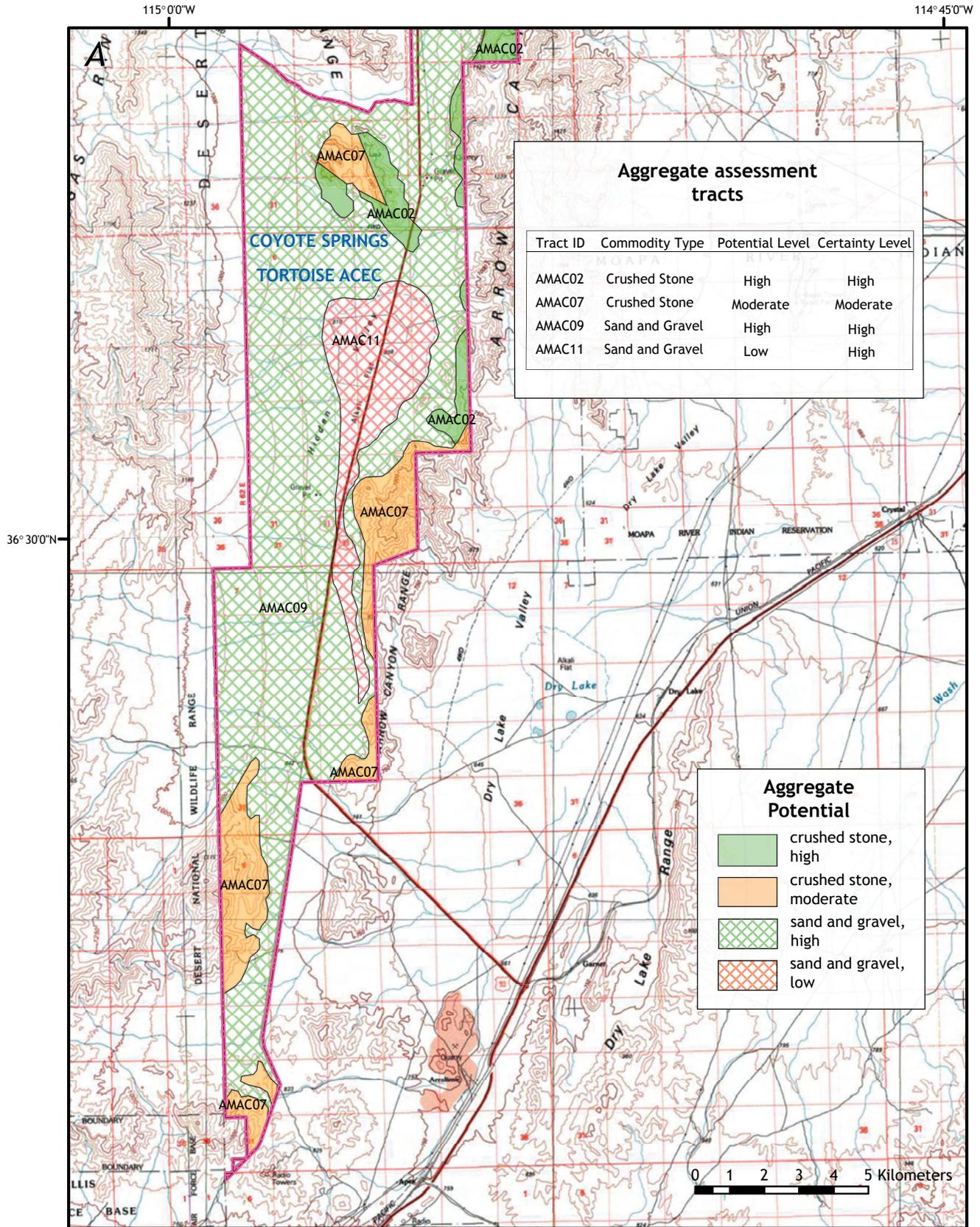
Siliceous beds in other carbonate units are composed of discontinuous chert layers that can be in intervals of as much as 7 m thick. Units that have shale interbeds and/or significant chert content were designated to have moderate potential for crushed-stone aggregate, with a moderate level of certainty (tract AMAC08, fig. 15).

Low potential units include the Muddy Creek Formation, which is a friable sandstone-shale sequence with conglomeratic units. The distribution of Muddy Creek Formation was used to designate tract AMAC05 (fig. 15), which has low potential for crushed-stone aggregate, with a high level of certainty. Some areas of Muddy Creek Formation are covered with varying thicknesses of Quaternary alluvial deposits; these areas were evaluated for sand and gravel aggregate deposits.

*Sand and Gravel.*—Extensive sand and gravel units occur across Mormon Mesa. These deposits are characterized by carbonate clasts from the Arrow Canyon Range and the Mormon Mountains. They constitute good-quality aggregate and are assigned a high potential for sand and gravel aggregate deposits, with a high level of certainty (tract AMAC10, fig. 15). On the mesa itself, alluvial fan deposits lie atop the Mormon Mesa caliche horizon, which in turn is underlain by the Muddy Creek Formation. In areas south of the Mormon Mountains, the alluvial deposits are thinner and expose the caliche horizon and the underlying Muddy Creek Formation.



**Figure 14.** Mineral resource potential tracts for limestone deposits in the Mormon Mesa Tortoise Area of Critical Environmental Concern (ACEC).



**Figure 15.** Mineral resource potential tracts for aggregate resources in the Mormon Mesa Tortoise (B, C, D), Arrow Canyon (B), and Coyote Springs Tortoise (A, B) Areas of Critical Environmental Concern (ACEC).

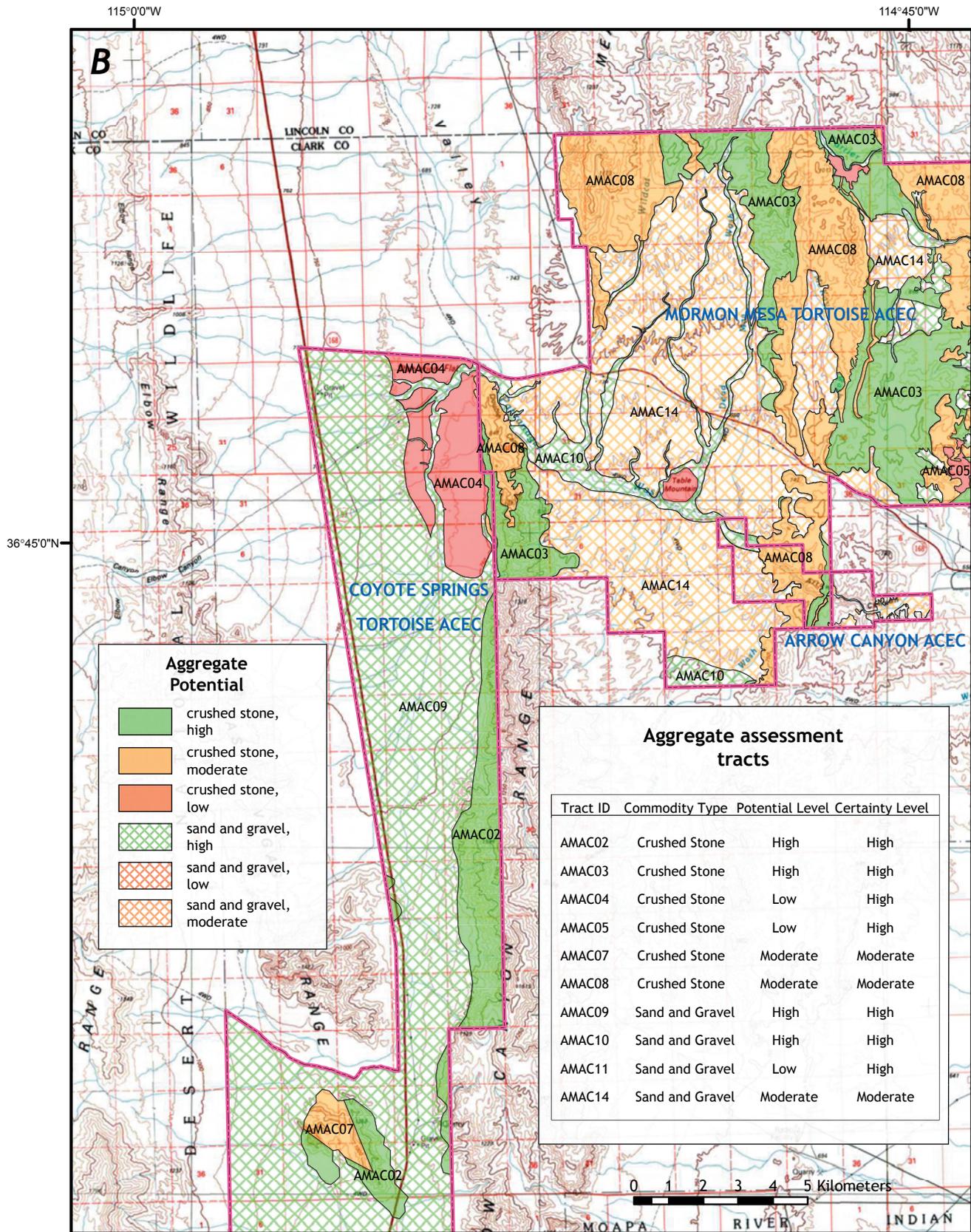


Figure 15.—Continued.

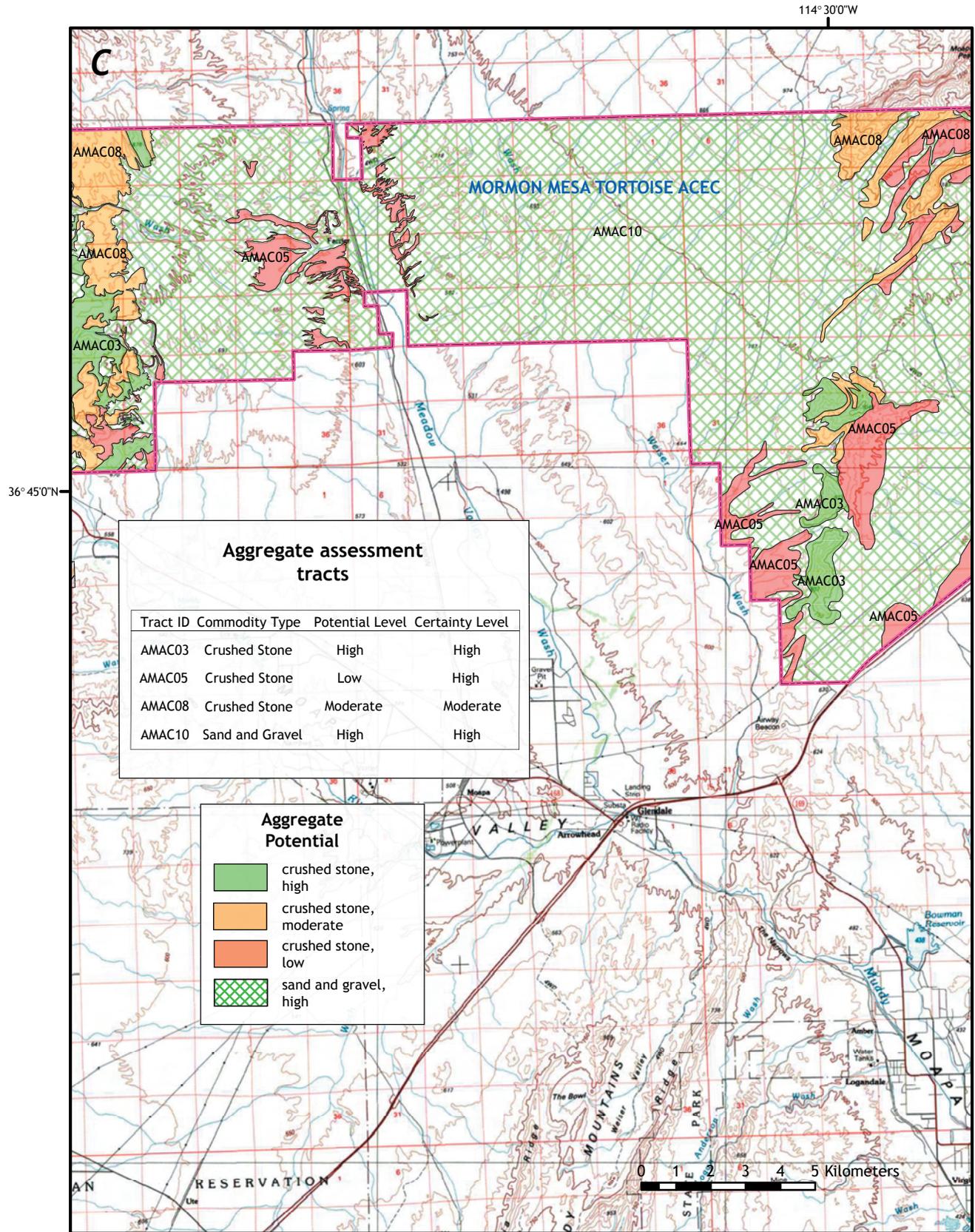


Figure 15.—Continued.

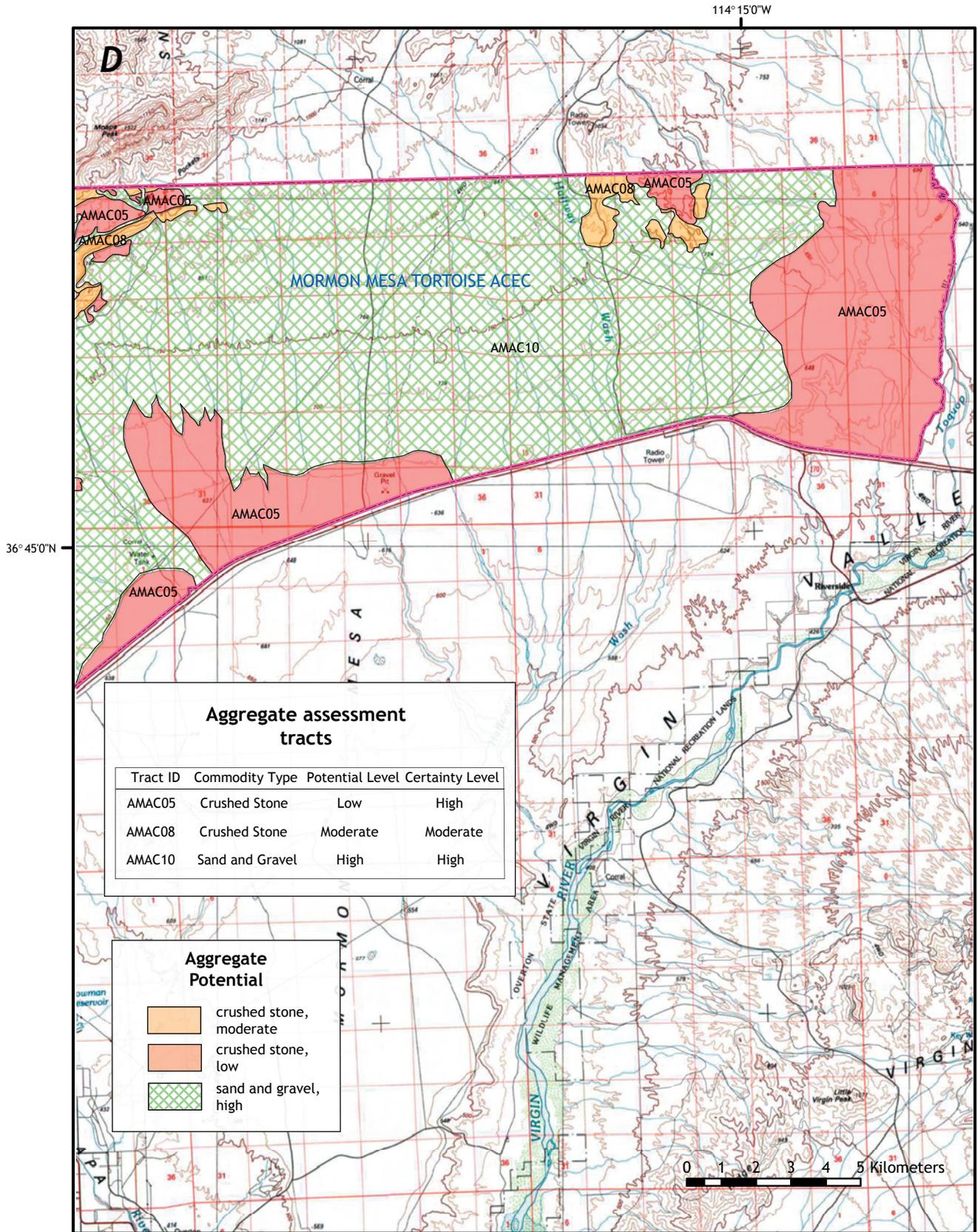


Figure 15.—Continued.

Farther west, a thin veneer of alluvial deposits overlies the Muddy Creek Formation, making separating the two difficult. Together, the Muddy Creek Formation and these alluvial deposits were used to delineate a tract (tract AMAC14, fig. 15) that has moderate potential for sand and gravel aggregate deposits, with a moderate level of certainty. Three small areas (tract AMAC12, fig. 15) have low sand and gravel potential, with a low certainty level.

### Locatable Minerals in Arrow Canyon ACEC

*Clay.*—There are clay occurrences near the Arrow Canyon ACEC, but the clay is of poor quality and unlikely to be present inside the ACEC. The potential for clay deposits is low.

*Stone and Silica.*—At least two deposits have produced stone and (or) silica near this ACEC. However, there are no outcrops of the Eureka Quartzite inside the ACEC, and there is no potential for the occurrence of sand and (or) silica deposits.

The Arrow Canyon ACEC contains no known deposits of other locatable minerals.

### Leasable Minerals in Arrow Canyon ACEC

The entire Arrow Canyon ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Arrow Canyon ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

### Salable Minerals in Arrow Canyon ACEC

*Crushed Stone.*—High quality stone in Paleozoic carbonate rocks was used to define tract AMAC01 (fig. 15) in the eastern part of the Arrow Canyon ACEC. This tract has high potential for crushed-stone aggregate with a high certainty level. The western part of the ACEC is characterized by the lower quality stone in tract AMAC06 (fig. 15), which has moderate potential for crushed-stone aggregate deposits, with a moderate level of certainty.

*Sand and Gravel.*—Alluvial deposits and the Muddy Creek Formation constitute tract AMAC13, in the southwest and easternmost parts of this ACEC, which has moderate potential for sand and gravel aggregate deposits, with a moderate certainty level (fig. 15). The area of Pahranaagat Wash that is upstream from Arrow Canyon gorge is alluvial gravels and has high potential for sand and gravel aggregate deposits, with a high certainty level (tract AMAC10, fig. 15).

### Locatable Minerals in Coyote Springs Tortoise ACEC

*Precious and Base Metals.*—Although there are hydrothermal precious- and base-metal deposits in nearby areas, the

geologic environments that host these deposits do not occur inside this ACEC, and the potential for their presence is low.

*Silica and Stone.*—At least two mines produced silica-rich quartzite in and near this ACEC. Both metallurgical-grade silica and stone were probably produced. Small tracts that include outcrop areas of the Eureka Quartzite have been designated to have moderate potential for silica deposits with a high level of certainty. The potential for commercial silica deposits is not high in these tracts because the Eureka Quartzite dips shallowly west under large thicknesses of carbonate rock; therefore, development of these deposits appears unlikely. The potential for production of building stone from such deposits is considered to be low because the stone is neither unique nor particularly attractive. These areas (tract CST01, fig. 16) are all near the eastern boundary of the ACEC and near the western base of the Arrow Canyon Range. Part of one of the areas is in the Arrow Canyon Wilderness and thus closed to mineral entry.

*Limestone.*—Three small areas of Devonian limestone in the Coyote Springs Tortoise ACEC have been designated as high potential, with moderate certainty, for commercial high-calcium limestone. This designation is supported by a sample of high-calcium limestone in one of these areas, although our sample of this rock has unacceptably high SiO<sub>2</sub> (table 2). Further sampling and analysis would be required to raise the certainty level. These areas (tract CST02, fig. 16) are along the eastern boundary of the ACEC in the Arrow Canyon Range and along the western boundary in the Las Vegas Range.

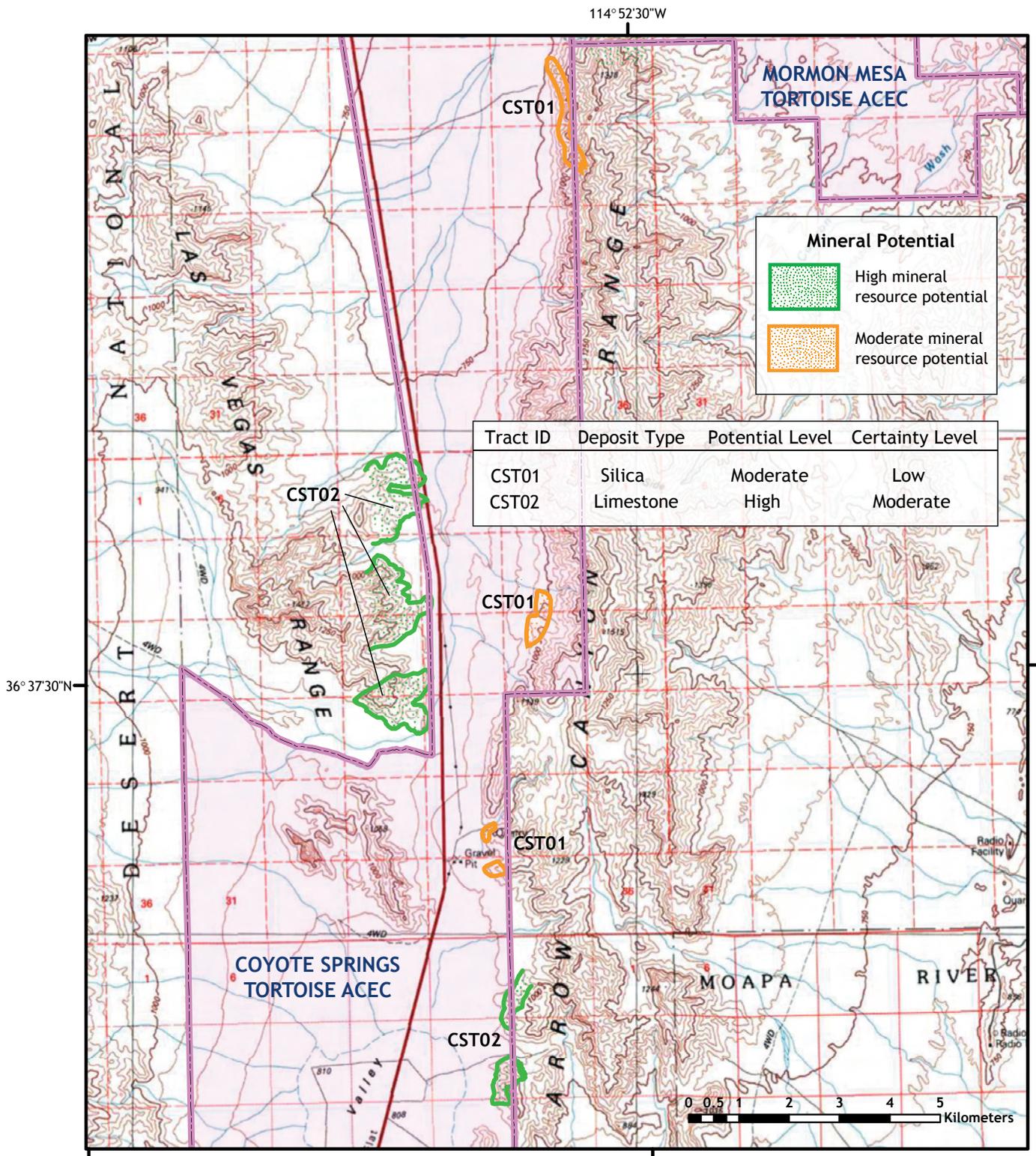
### Leasable Minerals in Coyote Springs Tortoise ACEC

The entire Coyote Springs Tortoise ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Coyote Springs Tortoise ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

### Salable Minerals in Coyote Springs Tortoise ACEC

*Crushed Stone.*—The areas with the highest potential for crushed-stone aggregate in the Coyote Springs Tortoise ACEC are in the northern half of the ACEC, at the base of the Arrow Canyon Range. Here, the rocks include the Nopah Formation, Ordovician dolomites and quartzites, and the Silurian Laketown Dolomite. Monte Cristo Limestone is found in the southern part of the ACEC in the Las Vegas Range. These rock units were used to delineate tract AMAC02 (fig. 15), which has high potential for crushed-stone aggregate, with a high certainty level.

The presence of significant amounts of chert in some parts of the Bird Springs Formation leads to designation of



**Figure 16.** Mineral resource potential tracts for silica and limestone deposits in the Coyote Springs Tortoise Area of Critical Environmental Concern (ACEC).

the areas underlain by this rock unit to have only moderate potential for crushed-stone aggregate, with a moderate level of certainty. This tract (AMAC07, fig. 15) is mostly in the southern part of the ACEC.

In the far northeastern part of the ACEC, just west of the Arrow Canyon Range, some areas of Muddy Creek Formation that are moderately well lithified constitute tract AMAC04 (fig. 15), which has low potential for crushed-stone aggregate, with a high level of certainty.

*Sand and Gravel.*—Most of Coyote Springs Valley is underlain by alluvial deposits containing primarily clasts of carbonate rocks from the Las Vegas and Arrow Canyon Ranges. These areas constitute tract AMAC09 (fig. 15), which has high potential for sand and gravel aggregate deposits, with a high level of certainty.

In the southern part of this ACEC, playa deposits extend some 11 km along the axis of the valley. The playa deposits are fine-grained silt and clay, and they constitute tract AMAC11 (fig. 15), which has low potential for sand and gravel aggregate deposits, with a high level of certainty.

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# Chapter E. Mineral Resource Potential of the Arden, Bird Spring, and Sloan Rock Art Areas of Critical Environmental Concern, Clark County, Nevada

By Stephen B. Castor, Brett T. McLaurin, Kathryn S. Flynn, and Steve Ludington

## Summary and Conclusions

The Arden Area of Critical Environmental Concern (ACEC) contains known deposits of silica that were mined in the past. These deposits help define an area in the ACEC that has high potential for the occurrence of silica deposits. The Arden ACEC contains a gypsum deposit that was mined in the past, but the potential for the occurrence of undiscovered gypsum deposits in this area is low. Two small uranium prospects are near the Arden ACEC, but these imply only low potential for the occurrence of uranium deposits. There is no potential for the occurrence of other deposits of locatable or leasable minerals.

The Arden ACEC contains areas with both low and moderate potential for the occurrence of crushed-stone aggregate deposits. The ACEC also contains tracts with high potential for the occurrence of sand and gravel aggregate deposits.

The Bird Spring ACEC contains no known mineral deposits. There is no potential for the occurrence of other deposits of locatable or leasable minerals. The ACEC has areas of both moderate and low potential for the occurrence of crushed-stone aggregate deposits, and a tract with high potential for the occurrence of sand and gravel aggregate deposits.

The Sloan Rock Art ACEC contains no known mineral deposits. There is no potential for the occurrence of other deposits of locatable or leasable minerals. The ACEC has moderate potential for the occurrence of crushed-stone aggregate deposits; sand and gravel aggregate does not occur.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval

of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Arden, Bird Spring, and Sloan Rock Art Areas of Critical Environmental Concern (ACECs) were studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature. Samples were collected and analyzed, and representatives of the companies with mining operations in and near the areas were contacted.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

The Arden ACEC, Bird Spring ACEC, and the Sloan Rock Art ACEC are described together in this report because they are in close proximity. The areas are south of Las Vegas near Interstate 15 (fig. 1). Arden and Bird Spring can be accessed by various primitive roads that extend west from the Sloan exit on Interstate 15 or south from the Blue Diamond Road (Nevada Highway 160), although some access roads from the Blue Diamond Road are partially blocked by new housing developments. Sloan Rock Art ACEC is within both the Sloan Canyon National Conservation Area and the North McCullough Wilderness. It is accessed from a primitive road that extends east from Las Vegas Boulevard near the Sloan exit off I-15. A legal description of these lands is included in appendix 2.

## Physiographic Description

The Arden ACEC consists primarily of hills that reach elevations of more than 1,300 m; Longwell and others (1965) referred to them as "hills near Sloan." They are drained by alluvial fans that range between 800 and 900 m in elevation along north- to northeast-draining valleys. The Bird Spring ACEC ranges in elevation from 1,250 to 1,450 m on the

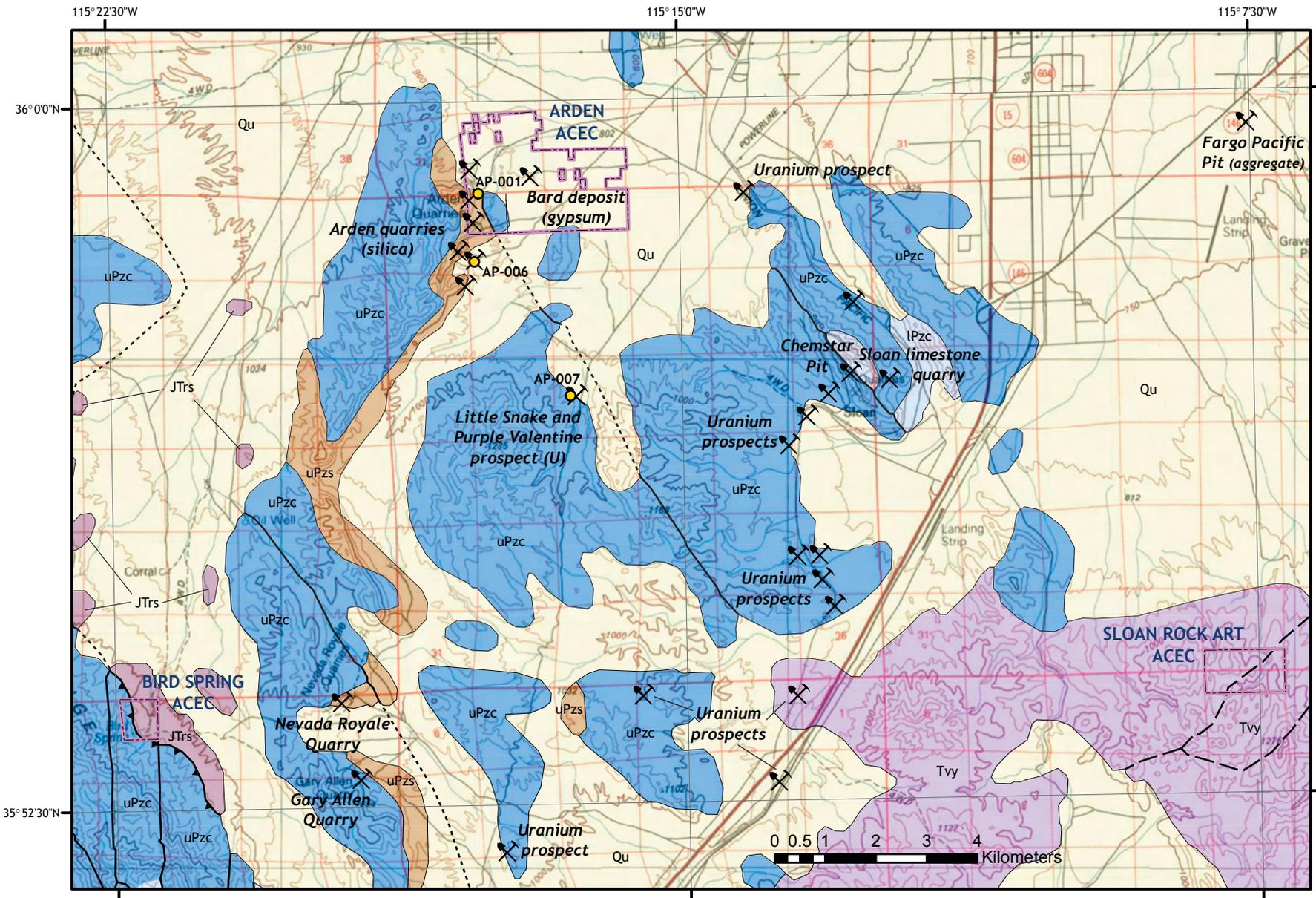


Figure 1. Generalized geology of the Arden, Bird Spring, and Sloan Rock Art Areas of Critical Environmental Concern (ACECs; outlined in pink). See explanation on page E3.

**EXPLANATION**



Figure 1.—Continued.

northeast slope of the Bird Spring Range. The Sloan Rock Art ACEC is an area of small hills with a valley that drains north on the east side of the ACEC. The area ranges in elevation from 900 to 1,150 m, and is on the west flank of the McCullough Range.

**Geologic Setting**

The area is part of the Basin and Range Physiographic Province, characterized by north trending mountain ranges and intervening valleys. The Arden and Bird Spring ACECs are in the southern part of the Spring Mountain structural block, an area mainly characterized by west- to north-dipping Paleozoic and Mesozoic sedimentary rocks that are cut by major Mesozoic thrust faults and Cenozoic normal faults (Burchfiel and others, 1974). The Sloan Canyon ACEC is in the northern part of the McCullough Range structural block, an area that is mainly underlain by west-dipping Miocene volcanic rocks.

**Geology**

Bedrock in the Arden ACEC consists of, from oldest to youngest: cherty carbonate rocks of the Pennsylvanian-Permian Bird Spring Formation; Permian redbeds; and Permian cherty carbonate strata of the Kaibab and Toroweap Formations. The Permian redbeds were originally correlated with the Supai Formation (Hewett, 1931) but later correlated with the Hermit Shale and placed in the Hermit Formation (Longwell and others, 1965). Strata in these units mostly dip gently westward; however, Longwell and others (1965) mapped northeast-trending folds south of the ACEC, and they described the overall structure in the hills near Sloan as an elongate dome. They noted that all the Paleozoic strata in the area have dips of less than 10°. Northwest-striking Cenozoic normal faults cut the bedrock.

The Bird Spring ACEC is notable for exposures of the Bird Spring thrust fault, which dips about 25° west. It separates the Pennsylvanian-Permian Bird Spring Formation in the upper plate from Mesozoic rocks (mostly Chinle and Moenkopi Formations) in the lower plate.

Rocks of the Sloan Rock Art ACEC consist of Miocene basalt and andesite flows. Some details of the volcanic geology of the area were studied by Bridwell (1991).

**Mining History**

At least seven inactive silica and gypsum open-pit mines are in and near the Arden ACEC, mostly in the Arden Quarries area (fig. 1). In addition, there are some inactive underground mines and several prospects. Within 10 km of the area, gypsum, dolomite, limestone, silica, stone, and construction aggregate have all been mined.

The mining of limestone in the Sloan area, about 5 km southeast of the Arden ACEC, began in 1910 (Longwell and others, 1965), and dolomite mining was initiated in the same area in 1928 and continued until 1997. Both limestone and dolomite were used to produce lime at a plant in Henderson. Carbonate rock mining at Sloan has resumed, but the rock is now used in construction aggregate.

Gypsum mining in the Arden area, about 3 km north of the Arden ACEC, began in 1909 and continued until 1931. Mining in the Bard area within the Arden ACEC (fig. 1) took place at about the same time (Papke, 1987). In 1925, mining began at the Blue Diamond gypsum deposit, about 10 km northwest of the Arden ACEC. This operation, which was scheduled to cease in 2005 to make way for housing development, has likely produced more gypsum than any other deposit in Nevada.

Silica mining began in 1930 at a locality about 5 km north of the Arden ACEC (described by Murphy [1954] as the Arden operation). Foundry sand and glass sand were reportedly produced there. Steel-molding sand was shipped in 1934 from the Bard operation, which mined silica from sites in the Arden ACEC and nearby areas. Building stone may also have been produced from these sites. Silica was also reportedly shipped as glass sand from a deposit near Jean, about 12 km south of the Arden ACEC, although this production may actually have come from the Nevada Royale and Gary Allen Quarries, which are further north, closer to the Arden and Bird Spring ACECs.

There are no known mines or prospects in the Bird Spring ACEC. Significant amounts of base and precious metals were mined in the Goodsprings district, about 20 km to the southwest. Stone and aggregate are presently mined at the Las Vegas Rock Quarry 7 km to the west. Minor amounts of silica and stone were mined in the past, about 5 km to the east at the Nevada Royale and Gary Allen Quarries.

The Sloan Rock Art ACEC has no history of mining. Sand and gravel have been mined from alluvial fans about 8 km to the north. Limestone, dolomite, and crushed stone have been mined at Sloan, about 10 km to the northwest of the ACEC. An abandoned mineshaft is about 2 km to the southwest, but no mineral deposit has been described from the area.

## Mineral Deposits

### Arden Quarries

Silica-rich sandstone is exposed in several quarries and underground excavations (figs. 2 and 3), now closed, along the west edge of the Arden ACEC. These deposits occur in a relatively resistant unit of white to light-pink, cross-bedded quartz arenite about 50 m thick that is likely correlative with the Coconino sandstone (fig. 4). The northernmost quarry, in the Arden ACEC, is a narrow pit, about 300 m long and 15 m

wide. Chip samples from exposures just south of this quarry that represent about 40 m of section contain 93.19 percent to 94.39 percent SiO<sub>2</sub> (Ludington and others, 2005). X-ray diffraction (XRD) analysis and petrographic examination show that the major impurities are K-feldspar, calcite, and dolomite. To the south is a 250-m-long and 10-m-wide open cut that has a series of portals to room-and-pillar workings cut into its west wall. A sample of representative rock from the open cut contains 95.6 percent SiO<sub>2</sub> (Ludington and others, 2005).

The chemical analyses of the sandstone samples from the Arden Quarries suggest that the material will not meet specifications for glass sand (table 1; Ludington and others, 2005). In comparison with analyses of the Baseline Sandstone from the Simplot Silica operation at Overton, Nevada, which is used as glass sand, sandstone from the Arden Quarries area contains too little silica and too many impurities for glass sand, which requires at least 98.5 percent silica (table 1). It is possible that the quality can be upgraded by simple processing; however, examination of a thin section of the best material that we collected from the Arden Quarries showed that carbonate occurs as small rhombs intergrown with quartz at grain boundaries (fig. 5), and it is unlikely that glass sand can be produced from it by inexpensive processing.

### Bard Gypsum Deposit

The Bard gypsum deposit is in the Arden ACEC (fig. 1), where it is exposed in an abandoned open pit that is 75 m x 15 m. The gypsum has a maximum exposed thickness of 5 m in a bed that is nearly horizontal. The gypsum is of only fair quality because of interbeds of clayey and silty material. X-ray diffraction of a sample showed small amounts of quartz, montmorillonite, and illite (Papke, 1987). The gypsum is overlain by about 5 m of reddish-brown sandstone and about 15 m of gray limestone. This sequence is capped by cherty limestone of the Kaibab Formation.



**Figure 2.** Narrow open cut at the North Arden Silica Quarry.

**Table 1. Composition of sandstones from Arden Quarries.**

[Simplot Silica Plant data are from Murphy (1954); container glass specifications are from Zdunczyk and Linkous (1994).]

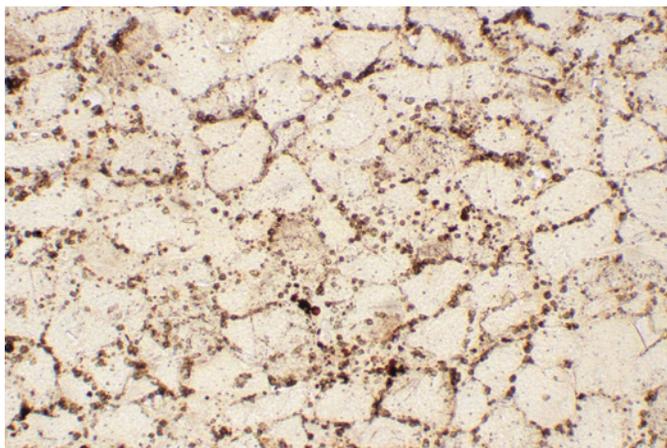
Element	AP-001M	AP-001T	AP-006C	Simplot Silica mine	Simplot Silica Plant	Container glass specification
SiO <sub>2</sub>	94.39	93.19	95.56	97.25	98.93	98.5 min
Al <sub>2</sub> O <sub>3</sub>	1.51	1.65	0.77	1.38	0.65	0.5 max
Fe <sub>2</sub> O <sub>3</sub>	0.31	0.37	0.4	0.19	0.03	0.035 max
MgO + CaO	1.62	2.03	1.22	0.27	0.05	0.2 max
TiO <sub>2</sub>	0.05	0.08	0.02	0.08	0.03	0.03 max
Cr <sub>2</sub> O <sub>3</sub>	0.027	0.024	0.031	0.00	nd	0.001 max



**Figure 3.** Concrete-barricaded portals in Coconino Sandstone at the South Arden Quarry site.



**Figure 4.** Relatively resistant cliffs of Coconino Sandstone (red rocks in lower part of face), Arden Quarries area.



**Figure 5.** Photomicrograph, in plane-polarized light, of silica-rich sandstone from the South Arden Quarry (sample AP-006) showing tiny dolomite rhombs along grain borders and within sand grains. Horizontal field of view is 1.25 mm.

## Uranium Prospects

Two uranium prospects are about 5 km southeast of the Arden ACEC. One, called the Little Snake and Purple Valentine prospect (fig. 1), was visited during this study. In a small pit there (fig. 6), yellow and greenish-yellow fracture coatings are present in the most radioactive part of an exposed shear zone, where maximum radioactivity is about 20 times background. A grab sample (sample AP-007, fig. 1) of the most radioactive rock contains 384 ppm U along with elevated Sr and V (Ludington and other, 2005). The occurrence does not correspond with any commercial uranium deposit models, although Johnson (1982) and Johnson and Glynn (1982) compared carnotite occurrences in the area with the potentially commercial Yeelirie calcrete carnotite deposit in western Australia. However, the Yeelirie deposit is a 6-km-long, 3-km-wide, and 8-m-thick deposit in calcrete that was deposited in a broad valley, which is unlike the occurrence examined.



**Figure 6.** Hematitic radioactive shear zone in uranium prospect, hammer for scale.

## Mineral Exploration and Development

The Arden, Bird Spring, and Sloan Rock Art ACECs contain no active mining claims, and there is no current exploration activity.

## Mineral Resource Potential

### Locatable Minerals in Arden ACEC

A part of the Arden ACEC is considered to have high potential for deposits of silica, with a moderate certainty level (tract ABS03, fig. 7). The samples that we took indicate that the sand is probably not pure enough for the production of glass,

although it was reportedly used for that purpose in the past. It may be suitable for commodities with less rigorous specifications, such as foundry sand, for which it was used in the past. The amount of silica-rich sandstone in the area is large, and we estimate that about 20 million short tons of resource could be mined by open-cut methods without removal of overlying rock in the area of the Arden quarries. The certainty level for this determination is moderate because it is unclear whether or not the silica product that could be produced from the sandstone is of sufficient quality for commercial use.

A small part of the Arden ACEC has low potential, with a moderate certainty level, for sedimentary gypsum deposits (tract ABS02, fig. 7). The potential area surrounds the Bard gypsum mine, where the exposed gypsum is thin and of relatively poor quality. The potential area extends beneath Quaternary alluvium in this area, where removal of overburden would be necessary. Potential for economically viable gypsum deposits is low here because mining of thin, low-grade gypsum deposits under cover is too expensive. The gypsum undoubtedly extends under the Kaibab Formation to the west; however, successful commercial extraction of such material is highly unlikely.

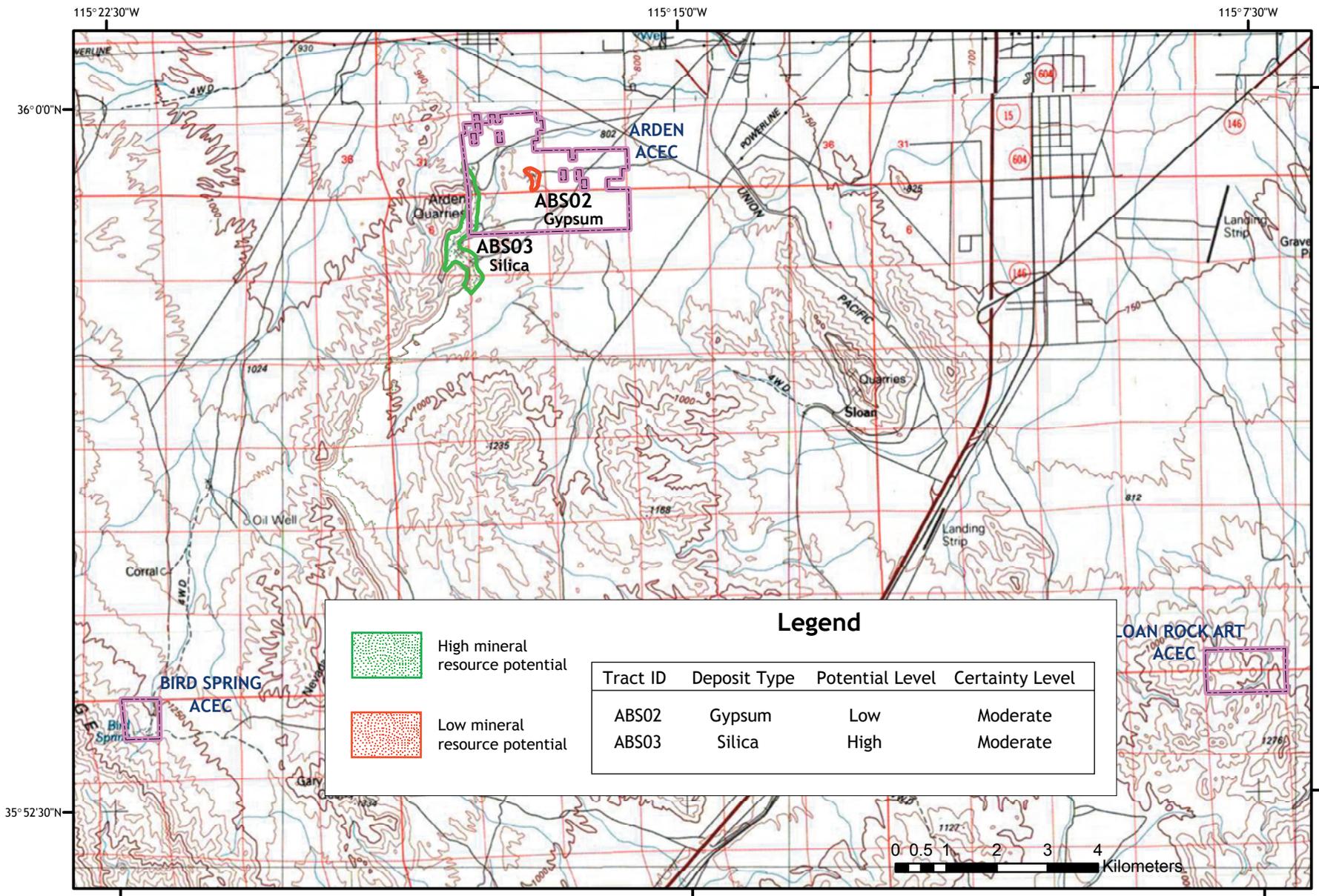
In the past, gypsum mining in the Arden area was by underground methods, which are not now competitive. Modern gypsum mining in Nevada is by surface mining methods in areas with little overburden. At the BPB operation at Blue Diamond, high-grade gypsum (>92 percent gypsum) was mined until recently from erosional remnants of gypsum that cap resistant limestone of the Kaibab Formation. At the PABCO and Pioneer Mines, low-grade (70-85 percent gypsum) ore is mined from very large deposits (Castor, 2003; Papke, 1987). The PABCO ore is easily beneficiated by washing to a purity of 92-95 percent gypsum, which is suitable for wallboard and plaster. At both mines, mining and beneficiation costs are low. The Pioneer Mine produces low-cost gypsum for agricultural uses only.

There is no evidence for deposits of other locatable minerals.

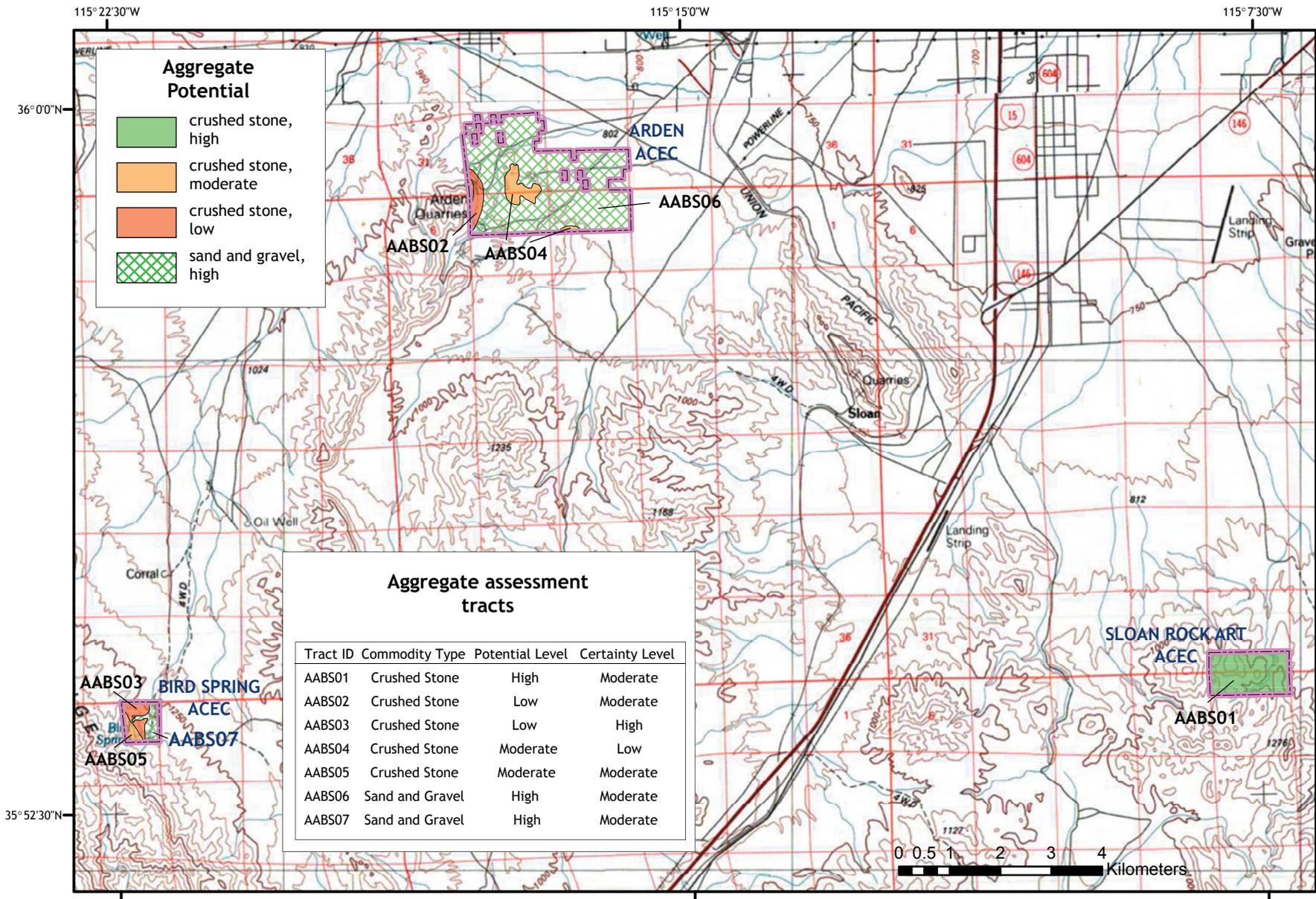
### Leasable Minerals in Arden ACEC

The area is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). The Arden Dome, a structure that lies mostly to the north and northeast of the area, was the site of oil exploration drilling between 1929 and 1944. Six wells were drilled to test the structure, one more than 1,100 m deep. Two of six wells in the area had hydrocarbon showings (Lintz, 1957). Miller (1945) suggested that the dome was formed during nearby intrusive activity rather than by compressive tectonism and that the chance of finding carbon dioxide exceeded that of finding hydrocarbons.

There is no indication of potential for brine or evaporite deposits of sodium and potassium. The ACEC contains no known deposits of leasable minerals, and the potential for their occurrence is low.



**Figure 7.** Mineral resource potential tracts for gypsum and silica deposits in the Arden, Bird Spring, and Sloan Rock Art Areas of Critical Environmental Concern (ACECs; outlined in pink).



**Figure 8.** Mineral resource potential tracts for aggregate resources in the Arden, Bird Spring, and Sloan Rock Art Areas of Critical Environmental Concern (ACECs; outlined in pink).

## Salable Minerals in Arden ACEC

*Crushed Stone.*—West-dipping Coconino Sandstone, Toroweap Formation, and Kaibab Limestone characterize the western side of this ACEC. The Coconino Sandstone has been quarried for stone, but the friable nature of most of the unit means it will not make high-quality aggregate. The Coconino does have zones that are more strongly lithified, but overall the material is not suitable for high-quality aggregate. Areas where Coconino Sandstone crops out are assigned a low potential for crushed-stone aggregate deposits, with a moderate certainty level (tract AABS02, fig. 8). Cherty zones in the Bird Spring and Toroweap formations and the Kaibab Limestone lead to assignment of a moderate potential for crushed-stone aggregate deposits, with a low certainty level (tract AABS04, fig. 8) in areas where these units are exposed.

*Sand and Gravel.*—Although friable clasts of Permian sandstone occur in alluvial deposits, carbonate clasts derived from adjacent highlands means that much of the available aggregate material is of high quality. Carbonate clast sources include the Bird Spring Formation, the Toroweap Formation, and the Kaibab Limestone. Most of the area that is underlain by alluvium has high potential for sand and gravel aggregate, with a moderate certainty level (tract AABS06, fig. 8).

## Locatable Minerals in Bird Spring ACEC

The Bird Spring ACEC contains no known deposits of locatable minerals, and there is no potential for their occurrence.

## Leasable Minerals in Bird Spring ACEC

There is no indication of potential for brine or evaporite deposits of sodium and potassium in the Bird Spring ACEC. The area contains no known deposits of leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Bird Spring ACEC

*Crushed Stone.*—This ACEC is along the south end of the Bird Spring thrust fault, where Paleozoic carbonate rocks overlie siltstone and sandstone of the Triassic Moenkopi Formation. Carbonate rocks in the hanging wall that are interbedded with chert define a tract with moderate potential for crushed-stone aggregate deposits, with a moderate certainty level (tract AABS05, fig. 8). The Moenkopi Formation is a slope former, dominated by shale and some sandstone. This unit has low potential for crushed-stone aggregate deposits, with a high certainty level (tract AABS03, fig. 8).

*Sand and Gravel.*—Alluvial deposits with mostly carbonate clasts occur on the eastern side of this ACEC, covering the lower slopes and filling in the northward-draining wash. This area has high potential for sand and gravel aggregate deposits, with a moderate certainty level (tract AABS07, fig. 8).

## Locatable Minerals in Sloan Rock Art ACEC

The Sloan Rock Art ACEC contains no known deposits of locatable minerals, and there is no potential for their occurrence.

## Leasable Minerals in Sloan Rock Art ACEC

There is no indication of potential for brine or evaporite deposits of sodium and potassium in the Sloan Rock Art ACEC. The area contains no known deposits of leasable minerals, and the potential for their occurrence is low.

## Salable Minerals in Sloan Rock Art ACEC

*Crushed Stone.*—The rocks of this ACEC are faulted and fractured basaltic andesites and basalt. They define an area of high potential for crushed-stone aggregate deposits, with a moderate certainty level (tract AABS01, fig. 8).

*Sand and Gravel.*—A canyon drains this ACEC, and the wash contains clasts of volcanic rocks. However, the alluvial deposits are too small to be significant, and the area has no potential for sand and gravel aggregate deposits.

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## E10 Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada

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# Chapter F. Mineral Resource Potential of the Ash Meadows and Amargosa Mesquite Trees Areas of Critical Environmental Concern, Nye County, Nevada

By Stephen B. Castor, Brett T. McLaurin, Steve Ludington, and Kathryn S. Flynn

## Summary and Conclusions

The Ash Meadows Area of Critical Environmental Concern (ACEC) contains known deposits of montmorillonite clay and zeolite that have been mined in the past. Two areas in the southern part of the ACEC have high potential for the occurrence of zeolite deposits on the basis of field evaluation and samples collected during this study. Extensive areas in the northern and western parts of this ACEC have high potential for the occurrence of montmorillonite clay deposits. Important deposits of sepiolite and saponite clay are mined by IMV Nevada in a 4-km-wide corridor between the Ash Meadows and Amargosa Mesquite Trees ACECs. Three areas that include parts of both ACECs have high potential for the occurrence of such clay deposits, although IMV Nevada has dropped most of the claims within the ACECs.

There is no potential for the occurrence of other deposits of locatable or leasable minerals in either ACEC.

The Ash Meadows ACEC has areas with high, moderate, and low potential for the occurrence of crushed-stone aggregate deposits. There are areas of both high and low potential for the occurrence of sand and gravel aggregate deposits.

The Amargosa Mesquite Trees ACEC has no potential for the occurrence of crushed-stone deposits. There are areas of both high and low potential for the occurrence of sand and gravel aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Ash Meadows and Amargosa Mesquite Trees ACECs were studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature. Samples were collected and analyzed, and representatives of the companies with mining operations in and near the areas were contacted.

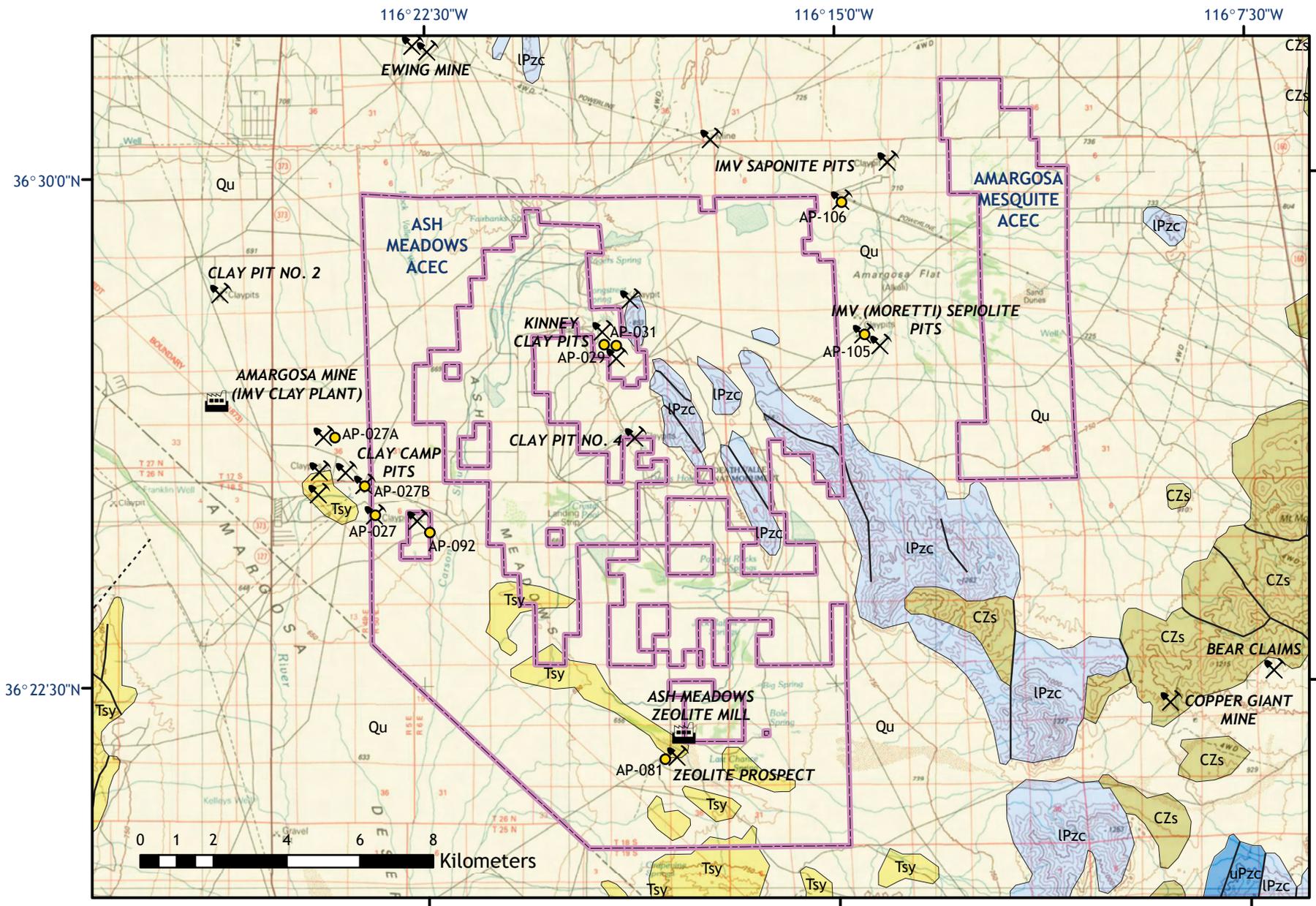
Definitions of mineral resource potential and certainty levels are given in appendix 1 and are similar to those outlined by Goudarzi (1984).

## Lands Involved

The Ash Meadows ACEC and the Amargosa Mesquite Trees ACEC were combined in this chapter because they have similar geology and mineral resource potential and they are in close proximity. The ACECs are in Nye County, southwest of Highway 95 and east of Nevada State Highway 373 and the community of Amargosa Valley. The Ash Meadows ACEC surrounds the Ash Meadows National Wildlife Refuge, and its southwest edge lies along the Nevada-California border. A mineral report was prepared before the withdrawal of the wildlife refuge from mineral entry (Wallace, 1999). Ash Meadows ACEC also surrounds the Devils Hole area, a small satellite of Death Valley National Park. The ACECs can be accessed by various secondary and primitive roads that extend eastward from Highway 373. A legal description of these lands is included in appendix 2.

## Physiographic Description

The Ash Meadows ACEC consists mainly of Ash Meadows, a low-lying, spring-fed wetland area that ranges between about 640 m and 700 m in elevation. The wetlands lie in the Amargosa Desert, a broad intermontane basin that drains southward, via the Carson Slough, into the Amargosa River and eventually into Death Valley. The Ash Meadows wetland area flanks hills that reach elevations of as much as 960 m within the ACEC. The Amargosa Mesquite Trees ACEC is at elevations of 730 m to 780 m in a transitional bajada-playa environment along the east side of Amargosa Flat, an alkali



**Figure 1.** Generalized geology of the Amargosa Mesquite Trees and Ash Meadows Areas of Critical Environmental Concern (ACEC), showing mines, prospects, and location of analyzed samples. Geology modified from Stewart and Carlson (1978). See explanation on page F3.

**EXPLANATION**

- Qu
**Undivided surficial deposits (Pleistocene and Holocene)**—Alluvium, colluvium, lake, playa, landslide, terrace, and eolian sand deposits
  - Tsy
**Young sedimentary rocks (middle Miocene to Pliocene)**—Alluvial, lacustrine, and fluvial deposits. Locally includes minor amounts of tuff. Includes Panaca, Bouse, and Muddy Creek Formations
  - uPzc
**Carbonate rocks (Mississippian to Permian)**—Limestone, dolomite, and some shale. May include Kaibab, Callville, Ely, Tippipah, Temple Butte, Rogers Spring, Monte Cristo, and Redwall Limestones, Toroweap Formation, Coconino Sandstone, and Bird Spring Formation
  - lPzc
**Dolomite and Limestone (Cambrian to Devonian)**—Dolomite, limestone, and minor amounts of sandstone, shale, and siltstone. May include Sevy, Simonson, Laketown, Lone Mountain, Ely Springs Dolomites, Devils Gate and Muav Limestone, and Guilmette, Nevada, Carrara, Bonanza King, and Nopah Formations, Dunderberg and Pioche Shales, Pogonip Group, and Eureka Quartzite
  - CZs
**Sedimentary rocks (Neoproterozoic and Cambrian)**—Quartzite, siltstone, and phyllite, with lesser amounts of conglomerate, limestone, and dolomite. May include Stirling, Zabriskie, and Prospect Mountain Quartzites, Wood Canyon, Deep Spring, Campito, Poleta, Harkless, Saline Valley, Wyman, and Johnnie Formations, and Reed Dolomite
- 
- Contact, certain
  - Fault, certain
  - Fault, approximate
  - Fault, concealed
  - Thrust fault
  - Mineral processing plant
  - Mine or prospect
  - AP-001 Sample site, with sample number

playa. The Amargosa Flat playa drains westward into the north part of the Ash Meadows wetlands.

**Geologic Setting**

The Ash Meadows and Amargosa Mesquite Trees ACECs are in the Amargosa Desert, a northwest-trending structural basin in the Basin and Range Physiographic Province. The Amargosa Desert occupies an area between the north-trending basin and range structures to the northeast, and northwest-trending structures of the Walker Lane belt to the southwest. The Walker Lane belt is a zone of diverse topography and strike-slip faulting caused mostly by late Tertiary to modern extension (Stewart, 1992). Miocene to modern extensional tectonism created northwest-trending ranges and valleys in the Death Valley region to the southwest.

**Geology**

Lower Paleozoic (Cambrian) rocks underlie the hills in and near the Ash Meadows and Amargosa Mesquite ACECs (fig. 1). The oldest rocks are in the Bonanza King Formation, which is mostly dolomite with some limestone. Parts of the unit contain silty to sandy layers (Cornwall, 1972). Shale and carbonate rocks of the Nopah Formation overlie the Bonanza King Formation at the north end of the hills.

Rhyolitic tuffs and sedimentary rocks of Miocene and Pliocene age crop out in the southern part of the Ash Meadows ACEC. These rocks may be part of 16- to 10-Ma volcanic deposits of the southwestern Nevada volcanic field (Sawyer and others, 1994), and may also include younger rocks. They are widely zeolitized, and the zeolitized tuffs are overlain by siltstones, limestones, and tuffs, similar to the 7- to 5-Ma Furnace Creek Formation (Fleck, 1970).

Most of the Ash Meadows ACEC is underlain by Pliocene lacustrine and spring silt, clay, and carbonate deposits, which are covered by thin Quaternary deposits. Tuffs in the Pliocene strata have K-Ar and fission track ages of 3.2 to 2.1 Ma (Hay and others, 1986).

In the Amargosa Mesquite Trees ACEC, Quaternary deposits are the only geologic units exposed, but drilling there by IMV Nevada has shown that Pliocene clay and carbonate deposits are present at shallow depth.

**Mining History**

The mining history in the area of the Ash Meadows and Amargosa Mesquite Trees ACECs primarily involves clay mining in the Ash Meadows mining district. A large part of Nevada’s industrial clay has come from this district, and we estimate total clay production from the district at more than 1

Figure 1.—Continued.

million short tons. Clay was discovered in the district in 1917, and mining began in 1918 (Kral, 1951). Early clay production in the district was mainly of fuller's earth used to decolorize and filter oils, but it also included some bentonite used in drilling mud (Papke, 1970). Most of the mining was in the Clay Camp area just west of the Ash Meadows ACEC (fig. 1), where the clay was mined by dragline excavation. It was dried, crushed, sized, and sacked at Clay Camp and shipped by rail. Recorded production through 1949 was about 180,000 short tons; however, this total is probably low because more than 34,000 short tons were produced in 1929 alone (Kral, 1951). U.S. Bureau of Mines (USBM) records indicate that clay production ceased in 1954, which probably marked the end of clay mining in the Clay Camp area.

In the 1970s, Industrial Minerals Ventures (IMV) began clay mining again in the Ash Meadows district. Clay produced by this operation in the 1970s and 1980s was listed as fuller's earth and bentonite by the USBM. Dragline trenching of sepiolite at the Moretti deposit (fig. 1) in the Amargosa Flat area was noted by Papke (1972), and both bentonite and sepiolite were being mined by 1980 (Papke, 1981). Saponite clay production began in the 1990s from deposits a few kilometers north of the sepiolite operation. In the 1990s, Rio Tinto PLC acquired IMV, and in 1997, the current owner, Mud Camp Mining Co. LLC, acquired IMV from Rio Tinto. In 2002, about 30,000 short tons of sepiolite, saponite, and bentonite were produced by IMV at a processing plant in Amargosa Valley (Castor, 2003). Production in 2003 and 2004 was about 33,200 and 32,600 short tons, respectively (Driesner and Coyner, 2004, 2005). The company exports a variety of clay products worldwide and is the only producer of sepiolite and saponite in the United States.

In addition to clay mining, small amounts of zeolite have been produced from the Ash Meadows ACEC. A Union Carbide geologist discovered zeolite in 1960, and in 1973 a similar deposit was discovered a few kilometers to the south in California. Anaconda Minerals Co. acquired both deposits in the 1970s, and they were subsequently leased to Zeolite International Inc., who began mining in the 1980s. A processing plant (fig. 1) on private land that is surrounded by the Ash Meadows ACEC has been shipping zeolite, mostly mined from the California deposit, since the 1980s. The current operator, Ash Meadows Zeolite LLC, a subsidiary of Badger Mining Corp., ships 1,000 to 2,000 short tons annually of zeolite used in water filtration, odor control, and nuclear clean-up (Castor, 2003).

## Mineral Deposits

### Clay Deposits

Clay deposits occur in and around the Ash Meadows ACEC and adjacent to the Amargosa Mesquite Trees ACEC. These deposits may be subdivided into montmorillonite, saponite, and sepiolite deposits on the basis of the main clay

mineral commodity; however, more than one type of clay may be found in some of the deposits. Montmorillonite is sodium and (or) calcium smectite. Sodium-rich montmorillonite is typically a high-swelling clay that is used in drilling mud, scoopable cat litter, and in other applications that require high swelling capacities. Calcium-rich montmorillonite is generally used where swelling capacities are less important, as in foundry bonding clay. Saponite is magnesium-rich smectite. It is related to the more common montmorillonite, but is chemically and structurally distinct. Sepiolite is a rare fibrous clay that is used in salt-water and geothermal drilling muds, cat litter, and absorbent products. It is commonly included with palygorskite (attapulgitite) in the hormite group of clay minerals (Heivilin and Murray, 1994). About 80 percent of the clay mined by IMV Nevada is sepiolite.

### Clay Camp Deposits

Ash Meadows mining operations that produced clay between 1918 and 1954 mainly exploited deposits directly west of the Ash Meadows ACEC and north of the Clay Camp ruins (fig. 1). According to Kral (1951), these deposits were as much as 100 feet (30 m) in diameter, and were mined to a depth of 24 feet (7 m); a high water table in this area precluded deeper extraction. Exposures in a number of places indicate that about 2 m of carbonate-rich overburden overlies the useable clay. Excellent quality white montmorillonite is reportedly still present in one pit as a lens-shaped body 30 feet (9 m) long and 1.5 feet (45 cm) thick that is underlain by an unknown thickness of fair-quality clay (Papke, 1970). Kral (1951) described the clay mineral from these deposits as montmorillonite and reported that the clay was used for both fuller's earth and in drilling mud. However, on the basis of analyses by Papke (1970), clay sampled from this area swelled only slightly and the dominant clay mineral is saponite. Small pits and prospects extend east from the Clay Camp area into the Ash Meadows ACEC. A sample (AP-027) from a 2-m-thick clay bed in a small pit (fig. 2) inside the ACEC and about 150 m from its western border contains saponite clay with feldspar, dolomite, and quartz as impurities on the basis of X-ray diffraction (XRD) analysis. Chemical analysis of this sample (Ludington and others, 2005) yields MgO/CaO of 3.7, indicating that this is a magnesium-rich clay because this ratio exceeds the MgO/CaO for dolomite. A sample of pale-brown nonswelling clay from a small pit 1.5 km within the Ash Meadows ACEC on a private inholding was found to contain saponite clay with quartz, feldspar, and illite impurities. This sample (AP-092) has extreme MgO/CaO (Ludington and others, 2005) and no dolomite, indicating that it contains relatively large amounts of saponite.

### Saponite Pits

Smectite clay is currently mined by IMV Nevada from pits that lie just northeast of the Ash Meadows ACEC and just west of the Amargosa Mesquite Trees ACEC (fig. 1). The pits are shallow (fig. 3) and exploit clay-rich beds that range from

a few centimeters to 6 m thick, occur over a wide area, and appear to be nearly continuous (Wahl and Papke, 2004). The average thickness is about 5 feet (1.5 m), and the average overburden thickness is about 7 feet (2 m). According to Wahl and Papke, the dominant clay mineral here is saponite. Khoury and others (1982) and Hay and others (1986) reported mixtures of stevensite (a magnesian clay mineral) and kerolite (a talc variety) from this area. However, their samples were not taken from the pits from which clay is currently mined and marketed as saponite. XRD analysis of samples that we collected from an active clay pit in this area shows significant amounts of dolomite and a little halite as impurities in the clay. Although nonglycolated XRD analysis of our samples indicates the presence of sepiolite and possible saponite, glycolated patterns give a strong response for an expansive smectite clay such as saponite (glycolation causes distinctive expansion of the mineral lattice in some clay minerals that is measurable by XRD; in sepiolite there is no lattice change, but glycolation of a smectite clay such as saponite causes a distinctive peak shift).



**Figure 2.** Location of clay channel sample AP-027 in small pit east of Clay Camp.



**Figure 3.** Shallow saponite pit 0.5 km northwest of the Ash Meadows ACEC.

Chemical analyses (samples AP-106 and AP-106HG; Ludington and others, 2005) show MgO/CaO of 1.1 to 1.7, indicating that the clay is magnesium-rich. It is beyond the scope of this study to make a definitive mineralogic determination, but the clay has been marketed as saponite for many years and most of our data support the saponite identification.

## Sepiolite Pits

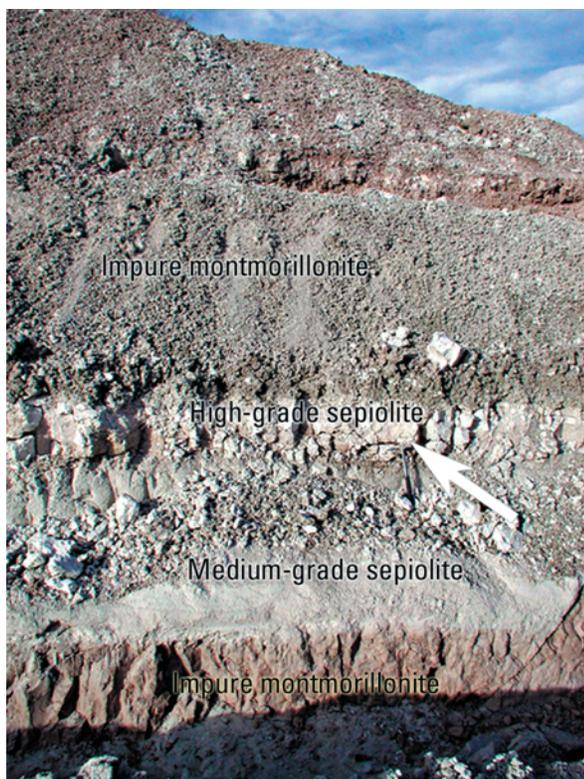
The only source of commercial sepiolite in the United States is on Amargosa Flat in a 2.5-mile-wide corridor between the Ash Meadows and Amargosa Mesquite Trees ACECs. Here sepiolite occurs in a nearly continuous and essentially horizontal bed as much as 20 feet (6 m) thick, with an average thickness of 6 feet (2 m). It lies below 10-25 feet (3-8 m) of overburden (Wahl and Papke, 2004). The sepiolite bed occurs within the saponite-bearing sequence described above. Impurities in the sepiolite clay include dolomite, calcite, quartz, feldspar, volcanic glass, and traces of other clays (Wahl and Papke, 2004). We took two samples of sepiolite from an operating pit (figs. 4 and 5). One, a 30-cm channel sample from a 30- to 60-cm-thick high-grade bed, was nearly pure sepiolite with a trace of dolomite (sample AP-105). Another was a grab sample of medium-grade sepiolite from below the high-grade bed (sample AP-105A). Samples of clay-rich beds from above and below the sepiolite (AP-105B and AP-105C, respectively) contain minor amounts of montmorillonite clay, as does a nearby surface sample near the boundary of the Ash Meadows ACEC.

## Kinney Mine

Clay has been mined from two pits and one underground operation in the Kinney Mine area (fig. 1), which is within the Ash Meadows ACEC. The clay occurs in a gently westward sloping bench that is capped by limestone. The two pits, a western pit (fig. 6) and an eastern pit (fig. 7), are each about 200 m in diameter and expose a 2- to 3-m-thick bed of clay



**Figure 4.** Belly dump mining of overburden in an IMV Nevada sepiolite pit; overburden in this area is about 5 m thick.



**Figure 5.** Pale pinkish-gray high-grade sepiolite bed (above and behind hammer head, see white arrow) about 30 cm thick (sample AP-105), lying above light-gray medium-grade sepiolite about 1 m thick (sample AP-105A). Greenish-gray bed (sample AP-105B) above sepiolite and light brownish-gray bed (sample AP-105C) below it are impure montmorillonite clay. IMV Nevada sepiolite pit.

that is overlain in most places by 1–4 m of bedded limestone. Samples of clay from these pits contain variable amounts of quartz, potassium feldspar, and calcite as impurities. Chemical analysis (Ludington and others, 2005) suggests that the clays are magnesium-rich (AP-029 and AP-031). The best identification for an unexpanded sample by XRD analysis is montmorillonite; however, the chemical analysis suggests that it is saponite. XRD analysis following glycolation shows expansion to 17 Å, which is appropriate for smectite. Papke (1970) described clay in this area, which he referred to as East Ash Meadows, as similar to clay from the Main Ash Meadows (Clay Camp) district. He reported that white montmorillonite from approximately the same location as our sample AP-031 (fig. 8), unlike the saponite at Clay Camp, had good swelling ability and high plastic viscosity. Melhase (1926) described underground clay mining in this area, but production was probably small (Papke, 1970).

## Ewing Mine

Montmorillonite clay has been mined by IMV Nevada from pits in the Ewing Mine area (fig. 1), which is about 4 km north of the Ash Meadows ACEC. Papke (1970) called



**Figure 6.** West Kinney Pit looking east. Sample AP-029 is from the southwest corner of the pit.



**Figure 7.** East Kinney Pit looking northeast. Sample AP-031 was taken from the east wall of the pit.

this property the K-B deposit and described the clay as 4 feet (1.2 m) of white clay, overlain by 2.5 feet (0.8 m) of very pale orange impure clay, capped by as much as 8 feet (2.4 m) of vuggy limestone (fig. 9). According to Papke, the white clay has moderate swelling ability and low viscosity, whereas the overlying clay has lower swelling capacity and higher viscosity. Although Papke (1970) reported that the clay in this area contains abundant gypsum, a sample of the white clay taken for this study (AP-108) was found to consist of nearly pure Ca bentonite on the basis of XRD and chemical analysis (sample AP-108; Ludington and others, 2005).

## Zeolite Deposits

Nearly pure deposits of the zeolite mineral clinoptilolite occur in the southwestern part of the Ash Meadows ACEC. Pale-yellow to white clinoptilolite occurs in a large deposit



**Figure 8.** Site of sample AP-031 in the East Kinney Pit, a channel sample representing about 1.2 m of the 2-m thick clay bed.



**Figure 9.** White Ca-bentonite bed at least 1 m thick in the bottom of a pit wall in the Ewing Mine.

about 3 km south of the ACEC in California, where it is mined (fig. 10). The deposit reportedly extends into Nevada (Santini and Shapiro, 1982), where green clinoptilolite was mined in the past (fig. 11). The zeolite occurs in rocks that were mapped as a unit of Miocene or Pliocene sandstone and claystone (Denny and Drewes, 1965). According to Shep-



**Figure 10.** White clinoptilolite in an active pit in California south of the Ash Meadows ACEC. Pit walls are 15–30 m high.



**Figure 11.** Pale-green zeolitized tuff exposure in the Ash Meadows ACEC. Sample AP-081 was taken from the relatively resistant outcrop in the left foreground. The Ash Meadows Zeolite LLC processing plant is in the right background.

pard (1986), the clinoptilolite occurs in vitric, nonwelded, ash-flow tuff that dips 15°–30° eastward and ranges from 46 to 122 m thick. On the basis of XRD analysis, zeolitized tuffs from both the California mine site and exposures in Nevada are mineralogically identical and remarkably pure. The zeolitized rock is almost wholly composed of clinoptilolite (figs. 12 and 13), verifying Sheppard's report that the rock contains more than 80 percent clinoptilolite. Impurities are smectite clay, opal, and crystal and lithic fragments (Sheppard, 1986). Chemical analysis indicates that the green zeolite from Nevada (AP-081) is nearly identical in silica content to the California zeolite (AP-078), but has slightly higher amounts of potassium and lower amounts of sodium and calcium (table 1; Ludington and others, 2005). The zeolitized rock from both localities has considerably lower silica than nonzeolitized tuff collected nearby (AP-104G).

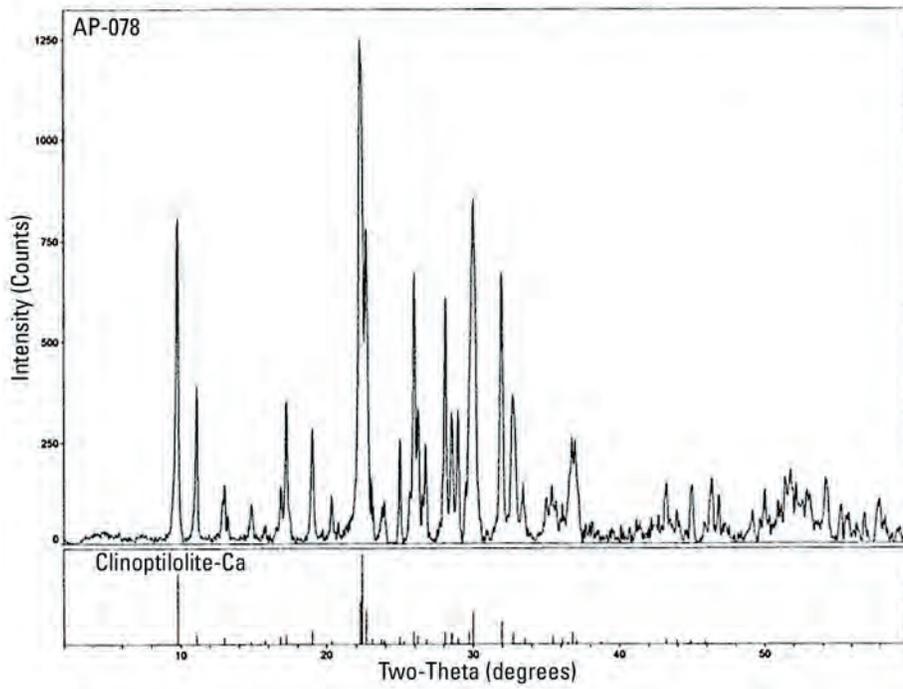


Figure 12. XRD analysis of sample AP-078, zeolite ore from Ash Meadows Zeolite pit in California.

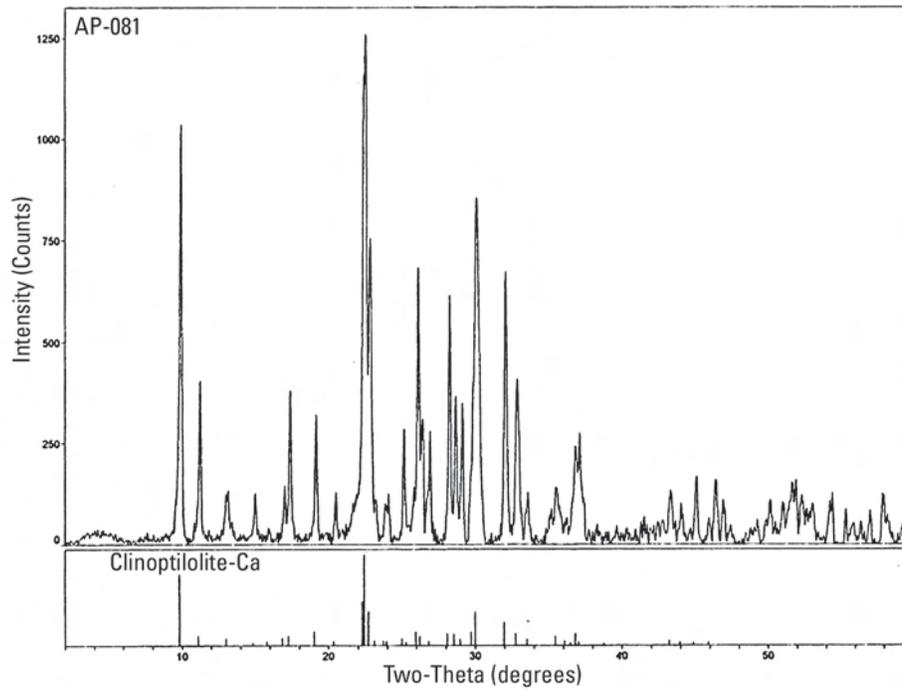


Figure 13. XRD analysis of sample AP-081, zeolitized tuff from Nevada.

**Table 1.** Comparison of chemical analyses of zeolite ore from the Ash Meadows Zeolite (AMZ) mine in California and a prospect in Nevada with unaltered tuff.

Sample-----	AP 078	AP 081	AP 104G
Location-----	Ash Meadows Zeolite mine, CA	Ash Meadows Zeolite prospect, NV	SW of AMZ claims, NV
Description-----	White zeolitized tuff	Green zeolitized tuff	White glass shard tuff
SiO <sub>2</sub> (wt. %)	65.59	66.36	71.34
Al <sub>2</sub> O <sub>3</sub> (wt. %)	10.96	10.82	10.76
Fe <sub>2</sub> O <sub>3</sub> (wt. %)	0.79	0.68	0.85
MgO (wt. %)	0.24	0.16	0.30
CaO (wt. %)	1.41	0.99	1.27
Na <sub>2</sub> O (wt. %)	3.96	2.79	3.73
K <sub>2</sub> O (wt. %)	3.73	5.64	3.31
TiO <sub>2</sub> (wt. %)	0.09	0.09	0.09
P <sub>2</sub> O <sub>5</sub> (wt. %)	0.01	0.02	0.02
MnO (wt. %)	0.04	0.01	0.03
Loss on ignition	13.1	12.3	8.3
Sum	99.92	99.86	100.00

## Mineral Exploration and Development

The Ash Meadows and Amargosa Mesquite Trees ACECs have been the site of significant exploration drilling in the past. An extensive shallow drilling program was undertaken in the 1990s by Rio Tinto PLC in the area of sepiolite and saponite mining in the northeast part of the Ash Meadows ACEC and in the west part of the Amargosa Mesquite Trees ACEC. On the basis of this drilling, a large area of claims was staked in the Amargosa Flat area, including claims in the Ash Meadows and Amargosa Mesquite Trees ACEC.

Anaconda Minerals Co. drilled for zeolite in the southeast part of the Ash Meadows ACEC in the 1970s. On the basis of data acquired during this drilling, a block of claims was staked in the ACEC and in an adjacent area in Nevada and California.

We found many small pits and prospects in the Ash Meadows ACEC. Most of these were probably dug during clay exploration; however, they are generally poorly preserved shallow excavations that do not contain good exposures of clay-bearing strata. A few small prospects, probably exploring for zeolite, are in the south part of the Ash Meadows ACEC.

There are 60 active mining claims in or near the Ash Meadows and Amargosa Mesquite Trees ACECs. The largest claim block is the 31-claim “GA” group of Ash Meadows Zeolite LLC in the southwestern part of the Ash Meadows ACEC. These claims, with 2005 as the last assessment year of record, are southwest of the company’s Ash Meadows Ranch processing plant and extend in a southwesterly direction to the California border. Mud Camp Mining LLC holds five “CAT” claims in the Ash Meadows ACEC, three claims that are about 1 mile (1.5 km) south of the Kinney mine clay pits in Sec. 26, T. 17 S., R. 50 E., and two claims in the northeast part of ACEC the near its clay mines. In addition, the company holds 10 CAT claims in the west part of the

Amargosa Mesquite Trees ACEC near its clay mines. A 12-claim block of “BOB” claims is held by individual locators near the south edge of the Ash Meadows ACEC. Individuals hold two claims, the Tyco and Broken Pick Mine claims in the northeast part of the Amargosa Mesquite Trees ACEC. This site includes a water well and a sign proclaiming the presence of the Buck Mining Company.

## Mineral Resource Potential

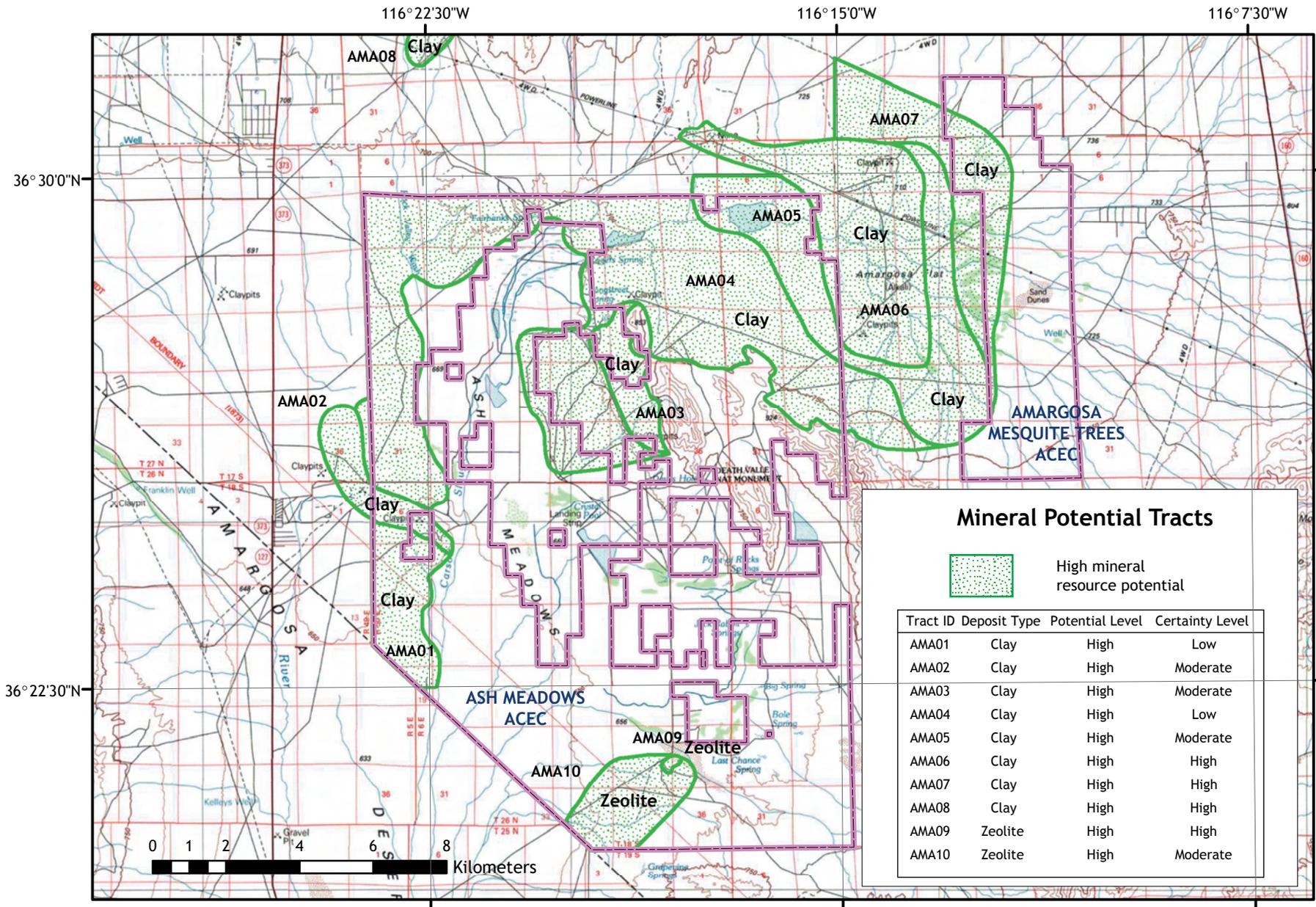
### Locatable Minerals in Ash Meadows ACEC

*Metals.*— There is no evidence for metallic mineral resource potential in the Ash Meadows ACEC.

*Clay.*— Areas with high potential for clay deposits with a high level of certainty (tracts AMA06 and AMA08, fig. 14) contain active IMV Nevada clay mines, are directly adjacent to the mines, or are currently held under claim by IMV Nevada. For the most part, these areas are outside the ACECs, but tract AMA06 covers a small part of the Ash Meadows ACEC along its northwest boundary.

Areas with high potential for clay deposits with a moderate certainty level (tracts AMA02, AMA03, and AMA05, fig. 14) contain inactive clay mines that yielded samples with high clay contents. All these tracts cover part of the Ash Meadows ACEC and include areas near the Clay Camp pits and the Kinney Mine (fig. 1).

Areas with high potential for clay deposits with a low certainty level (tracts AMA01, AMA04, and AMA07, fig. 14) are defined by scattered occurrences of clay noted in Hay and others (1986) and (or) by favorable strata of probable Pliocene age. Tracts AMA01 and AMA04 cover large parts of the Ash Meadows ACEC.



**Figure 14.** Mineral resource potential tracts for locatable and leasable minerals in the Amargosa Mesquite Trees and Ash Meadows Areas of Critical Environmental Concern (ACEC).

*Zeolite.*— In the southern part of the Ash Meadows ACEC, two areas are considered to have high potential for zeolite deposits (fig. 14). Tract AMA09 is a small area with high potential with a high certainty level, and is defined by exposures of strongly zeolitized tuff that are currently under claim by Ash Meadows Zeolite LLC. The larger tract AMA10 has high potential with a moderate certainty level, and is covered by overburden; it is currently under claim by Ash Meadows LLC.

### Leasable Minerals in Ash Meadows ACEC

The southwestern half of the Ash Meadows ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). The north-eastern half, and the entire Amargosa Mesquite Trees ACEC, are not within this region.

There is no indication of potential for brine or evaporite deposits of sodium or potassium.

The Ash Meadows ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is judged to be low.

### Salable Minerals in Ash Meadows ACEC

*Crushed Stone.*— A few areas underlain by Cambrian carbonate rocks in the eastern part of the ACEC (tract AAMA03, fig. 15) are designated to have moderate potential for crushed-stone aggregate, with a low level of certainty. The northernmost exposures of bedrock are mapped as Nopah Formation. The low chert content within this unit means that this area (tract AAMA01, fig. 15) has high potential, with a low level of certainty. In the southern part of the area, outcrops of the younger sediments and volcanic rocks (tract AAMA02, fig. 15) are soft and friable and unsuitable for crushed stone and are designated to have low potential, with a moderate certainty level.

*Sand and Gravel.*— A large part of the Ash Meadows ACEC has low potential for sand and gravel aggregate, with a moderate level of certainty (tract AAMA07, fig. 15); the materials exposed are primarily soft and fine-grained sedimentary material. High-potential sand and gravel deposits with a moderate certainty level occur adjacent to carbonate outcrops in the Devils Hole area and around the southern and western parts of the area (tract AAMA05, fig. 15).

### Locatable Minerals in Amargosa Mesquite Trees ACEC

*Metals.*— There is no evidence for metallic mineral resource potential in the Amargosa Mesquite Trees ACEC.

*Clay.*— Areas with high potential for clay deposits with a moderate level of certainty (tracts AMA02, AMA03, and AMA05; fig. 15) contain inactive clay mines that yielded

samples with high clay contents. Only tract AMA05 impinges on the Amargosa Mesquite Trees ACEC, including small areas along its western boundary.

Areas with high potential for clay deposits with a low certainty level (tracts AMA01, AMA04, and AMA07, fig. 15) are areas defined by scattered occurrences of clay noted in Hay and others (1986) and (or) by favorable strata of probable Pliocene age. Tract AMA07 includes a substantial part of the northwestern part of the Amargosa Mesquite Trees ACEC.

### Leasable Minerals in Amargosa Mesquite Trees ACEC

The entire Amargosa Mesquite Trees ACEC is outside the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983).

There is no indication of potential for brine or evaporite deposits of sodium or potassium.

The Amargosa Mesquite Trees ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is judged to be low.

### Salable Minerals in Amargosa Mesquite Trees ACEC

*Crushed Stone* – There are no rock outcrops, and thus there is no potential for crushed-stone aggregate in the Amargosa Mesquite Trees ACEC.

*Sand and Gravel* - The northern part of the Amargosa Mesquite Trees ACEC has low potential for sand and gravel aggregate, with a high level of certainty (tract AAMA06, fig. 15). This area consists of soft and fine-grained sedimentary material. In the southern part of the area quartzite and carbonate clasts derived from the highlands to the southeast indicate an area with high potential for sand and gravel aggregate, with a low certainty level (tract AAMA04, fig. 15).

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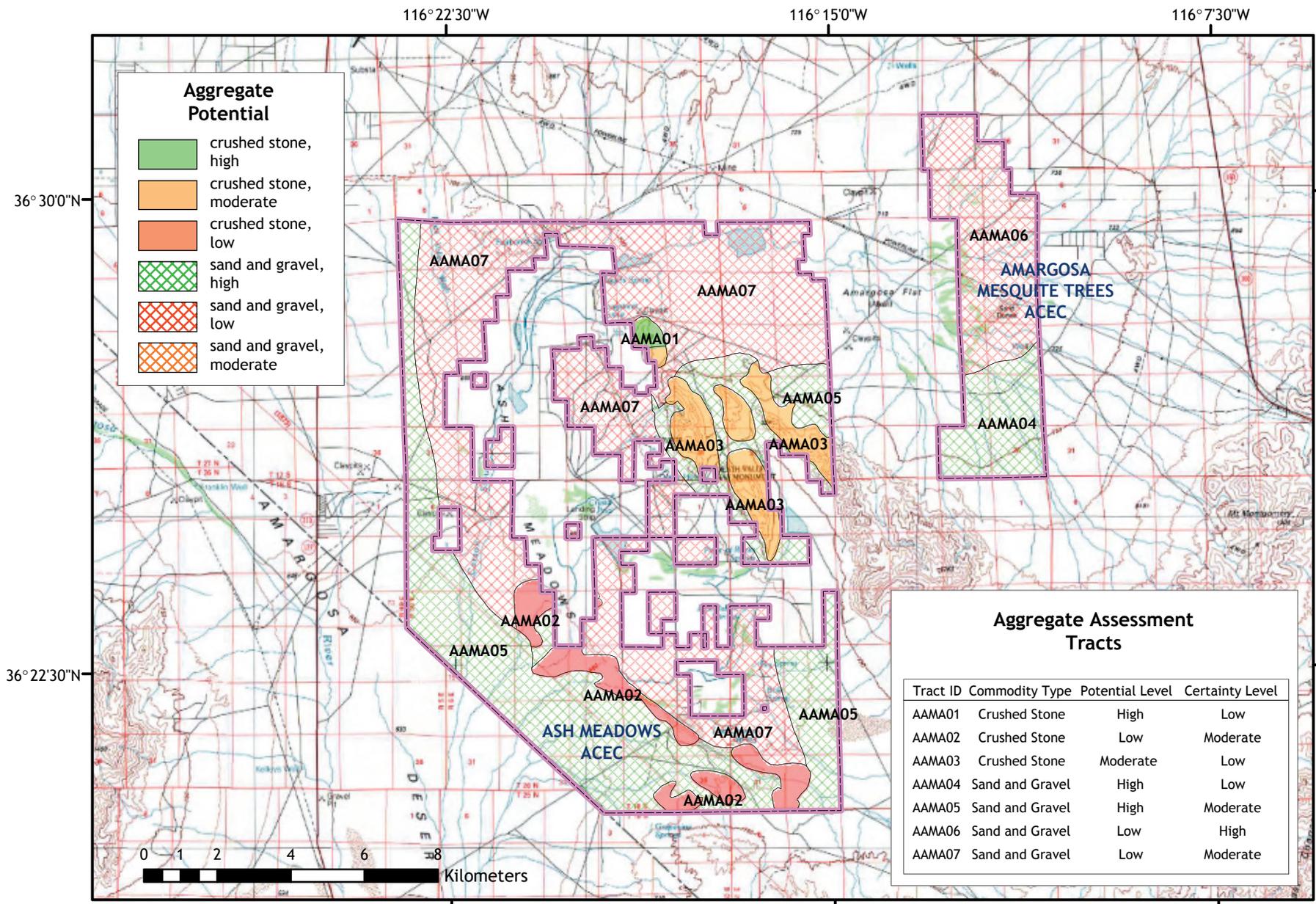


Figure 15. Mineral resource potential tracts for aggregate resources in the Amargosa Mesquite Trees and Ash Meadows Areas of Critical Environmental Concern (ACEC).

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# Chapter G. Mineral Resource Potential of the Virgin River Area of Critical Environmental Concern, Clark County, Nevada

By Brett T. McLaurin, Steve Ludington, Stephen B. Castor, and Kathryn S. Flynn

## Summary and Conclusions

There are 27 current placer claims in or adjacent to the Virgin River Area of Critical Environmental Concern (ACEC), but there is insufficient information available to evaluate placer deposits of precious metals in the area, and the potential for the occurrence of gold placer deposits is unknown. There is no potential for the occurrence of other deposits of locatable or leasable minerals.

The Virgin River ACEC has potential for the occurrence of deposits of sand and gravel aggregate that are similar to currently active sand and gravel operations nearby. Two tracts have high potential for sand and gravel aggregate deposits and two have low potential. Potential for the occurrence of crushed-stone aggregate deposits in the area is low.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Virgin River ACEC was studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature. No samples were collected.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

The Virgin River ACEC is about 9 km southwest of Mesquite, Nevada, and lies just south of Interstate 15 along

the Virgin River (fig. 1). Access to the area is by Nevada State Highway 170 (Riverside exit off I-15). The area includes the Virgin River, its floodplain and adjacent riverbanks. A legal description of these lands is included in appendix 2.

## Physiographic Description

The Virgin River ACEC consists primarily of the floodplain of the Virgin River (fig. 2), much of which may be inundated during rare storm events. Elevations along the river range from 455 m at the upstream end to 407 m at the downstream end, and the highest elevations along the riverbank are about 500 m.

## Geologic Setting

The Virgin River ACEC lies along the eastern margin of the central part of the Basin and Range Province, which adjoins the Grand Canyon region of the Colorado Plateaus on the east. The Virgin River flows along the axis of the Virgin River depression, a deep structural basin that marks the northern border of the South Virgin Mountains.

## Geology

The central part of the area was mapped by Williams and others (1997) at a scale of 1:24,000 (Riverside Quadrangle), and they provide detailed descriptions of the rock units in the area. The north bank and a small portion of the south bank of the Virgin River expose the Pliocene and upper Miocene Muddy Creek Formation. All other deposits in the ACEC are Quaternary in age.

The area is on the divide between the Mesquite Basin and the Mormon Basin, which together form the Virgin River depression. The depth to basement in the ACEC is about 2 to 3 km, although the depression is considerably deeper both upstream and downstream (Langenheim and others, 2000).

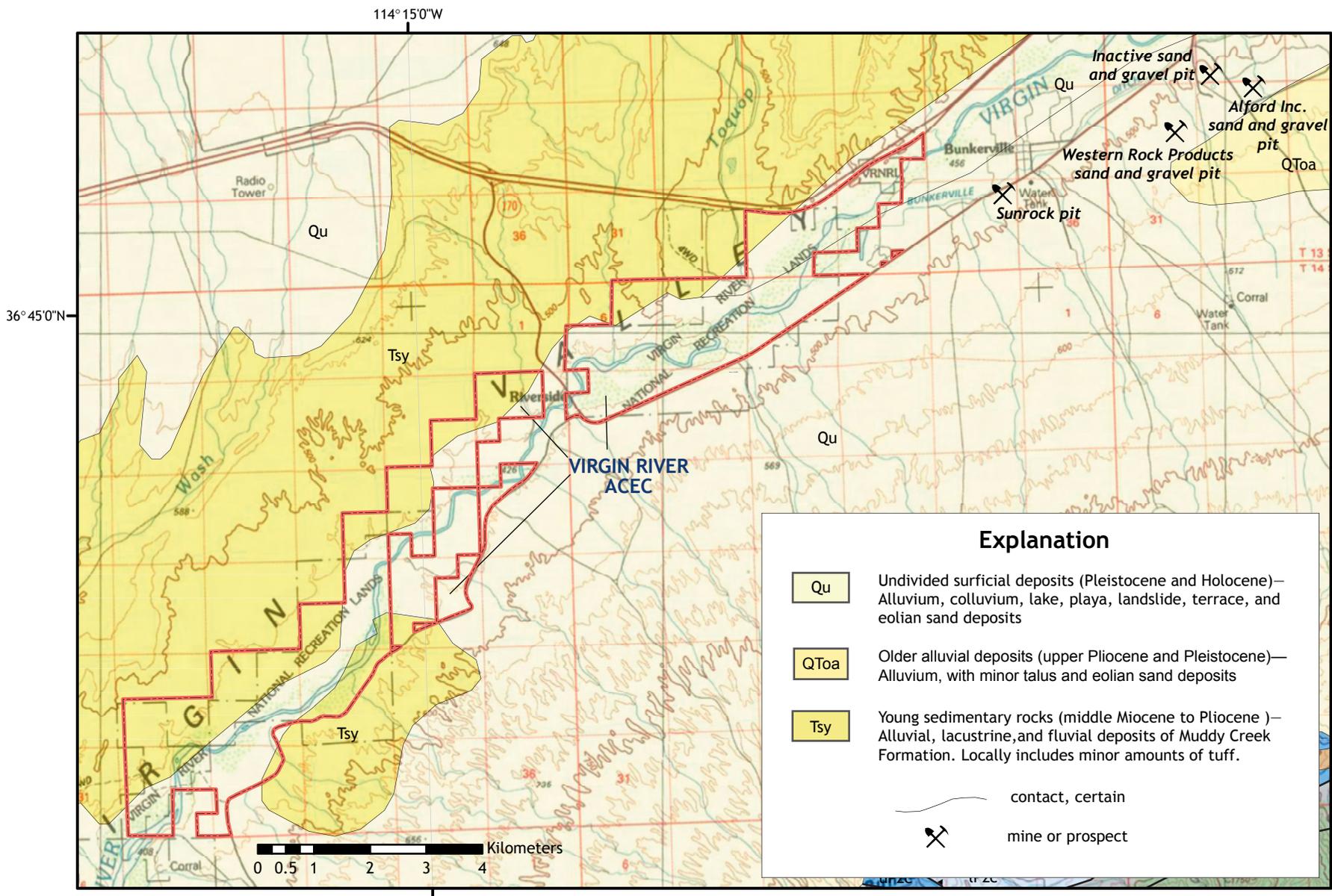


Figure 1. Generalized geology of the Virgin River Area of Critical Environmental Concern (ACEC; outlined in pink). Geology modified from Stewart and Carlson (1978).

## Muddy Creek Formation

The Muddy Creek Formation in the ACEC is mostly sandstone and siltstone, but it also includes some evaporite deposits (mostly gypsum), as well as limestone, conglomerate, and breccia. A fluvial facies of the Muddy Creek Formation that consists primarily of sandstone with minor conglomerate was deposited by an ancestral Virgin River before more recent incision.

## Quaternary Deposits

Quaternary deposits in the ACEC were mostly deposited in floodplain, stream terrace, and alluvial fan settings. The floodplain and stream terrace sediments were deposited by the Virgin River. The alluvial fan deposits were derived from areas to the south and east, including Black Ridge and the South Virgin Mountains. All of the stream terrace and alluvial fan deposits may be capped by caliche horizons (as much as 2 m thick) in various stages of development.

## Floodplain and Channel Deposits

These deposits are the topographically lowest in the area, and are the result of activity of the present day Virgin River. Williams and others (1997) mapped two units in the main channel area. An approximately 2-m-thick unit of fine to medium sand with lesser amounts of silt and gravel is characterized as bar deposits, active channel fill, and abandoned channel fill. The floodplain deposits are also approximately 2 m thick and consist primarily of sand, with some gravel. The floodplain deposits are volumetrically the most abundant in the lower areas of the Virgin River Valley.

## Terrace Deposits

The terrace deposits are found at higher elevations above the floodplain. The terraces include sediments deposited by both the present-day and ancestral Virgin Rivers. Terrace deposits closest to the modern floodplain are predominantly



**Figure 2.** Floodplain of the Virgin River.

sand with lesser amounts of gravel, silt, and clay. Higher elevation terrace deposits are primarily gravel and can be as much as 50 m thick. Clast composition is variable. Deposits originally derived from the Virgin Mountains and Black Ridge may contain limestone, dolomite, gneiss, granite, pegmatite, quartzite, and chert, and they are found on the southeast side of the river. Sediments originally derived from the Mormon Mountains have mostly carbonate clasts and lack the igneous and metamorphic clasts. Terrace deposits with Mormon Mountain lithologies lie on the northwest side of the river.

## Alluvial Fan and Pediment Deposits

These sediments are part of a large alluvial fan complex that slopes to the northwest from the flanks of the Virgin Mountains and Black Ridge. The distributary channels of the fan are upwards of 100 m wide and contain gravelly braided stream deposits. The depth of incision is between about 15 m and 30 m. The interchannel areas of the alluvial fan complex also contain abundant gravel and may be greater than 35 m thick. Clast composition of the alluvial fan deposits is consistent with their derivation from the Virgin Mountains.

## Mining History

There are several active sand and gravel mining operations on the south bank of the Virgin River, near the townsite of Bunkerville, outside of the ACEC. No other present-day or historic mining operations are known.

## Mineral Deposits

The sand and gravel deposits near Bunkerville are the only known mineral deposits of any kind within the ACEC. Other known mineral deposits are about 10 km to the southeast, on the northern flank of the Virgin Mountains. These include the Key West and Great Eastern nickel-platinum deposits and the Hodges-Wharton tungsten prospect.

A sand and gravel aggregate operation, operated by Sunroc Corporation, is located about 2 km east of the ACEC, and several other small sand and gravel pits are 2 to 3 km farther upstream (fig. 1).

## Mineral Exploration and Development

There are 27 current placer claims within and adjacent to the Virgin River ACEC. All were located in 2003 and 2004 by American Gold Corporation. We have no additional information about these claims, but presume they are for placer gold exploration. We noted no evidence of recent disturbances in the area.

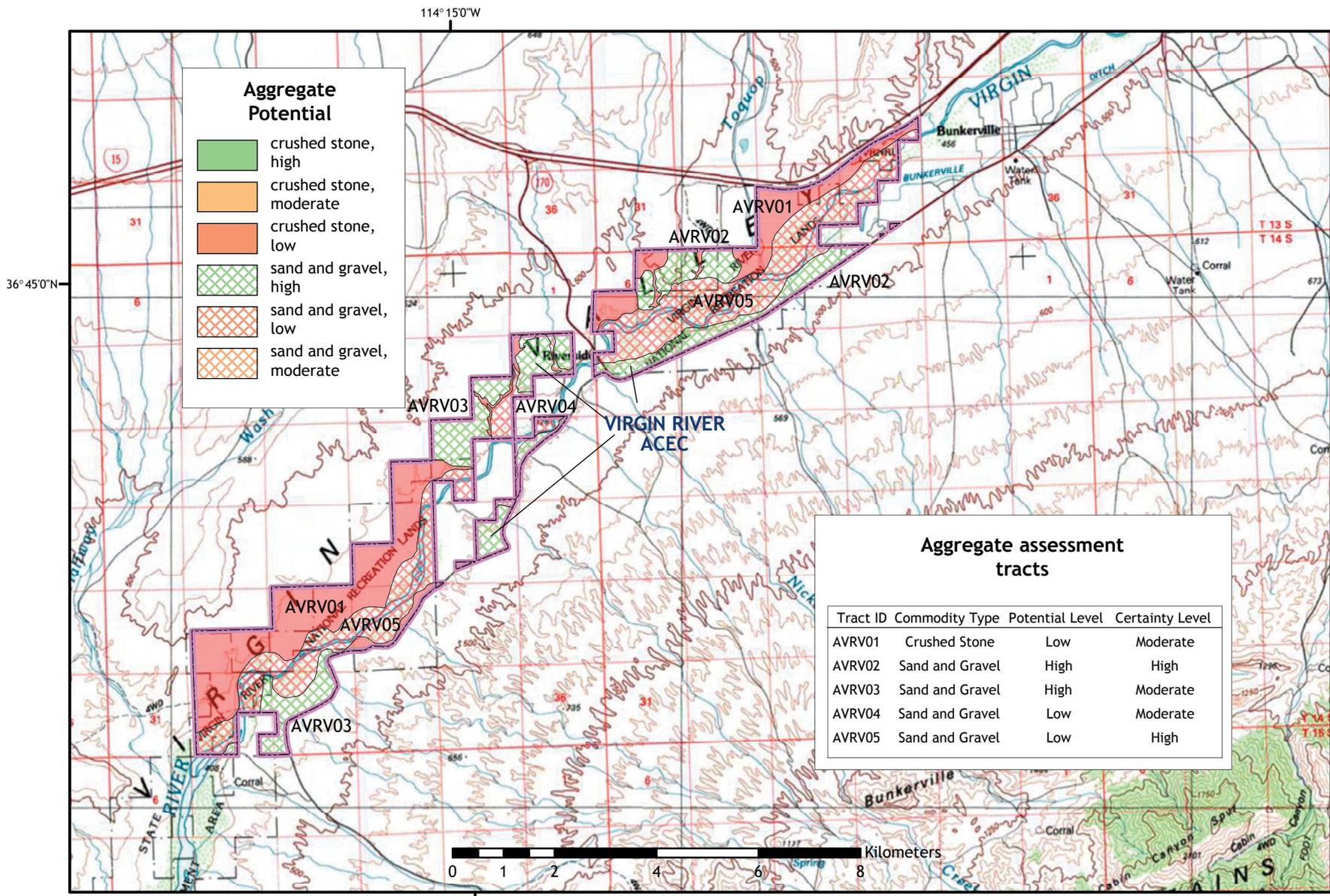


Figure 3. Mineral resource potential tracts for aggregate resources in the Virgin River Area of Critical Environmental Concern (ACEC).

## Mineral Resource Potential

### Locatable Minerals

There are no known lode mineral deposits in the Virgin River ACEC. Because there is no appropriate bedrock, there is no potential for the existence of undiscovered deposits. The potential for placer gold deposits is unknown, but there are no known important sources of gold upstream from the ACEC.

### Leasable Minerals

The entire Virgin River ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). An exploratory oil well, Virgin River U.S.A. No. 1-A, was drilled by Mobil Oil Corp. to a depth of 5,964 m about 10 km southwest of the ACEC on Mormon Mesa. The well, Nevada's deepest as of 1986, was collared in the Muddy Creek Formation and bottomed in granitic rock. It was a dry hole (Garside and others, 1988).

There is no indication of potential for brine or evaporite deposits of sodium or potassium. Evaporite deposits in the Muddy Creek Formation contain primarily gypsum.

The Virgin River ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

### Salable Minerals

The Virgin River ACEC is favorably located for the development of aggregate resources. It is in close proximity to both I-15 and the Mesquite-Bunkerville road, which provide ideal transportation routes to Mesquite and to metropolitan Las Vegas. Figure 3 illustrates the aggregate potential for various areas of the ACEC.

*Crushed Stone.*—Most of the exposed material in the ACEC is alluvium. Some partially consolidated beds in the Muddy Creek Formation, primarily along the northwest side of the river, can be considered to be rock, but their friable nature makes them unsuitable for crushed stone. These areas are assigned low potential for crushed-stone aggregate deposits, with a moderate level of certainty (tract AVR01, fig. 3).

*Sand and Gravel.*—Within this ACEC, the highest potential for the development of sand and gravel resources is on the northwest side of the river in the vicinity of Riverside, Nevada. This assessment is based on the apparent quality and quantity of the material as well as proximity to transportation routes. Two tracts have been designated to have high potential for sand and gravel aggregate, AVR02, with a high level of certainty, and AVR03, with a moderate certainty level (fig. 3).

Terrace gravels of the ancestral Virgin River are the primary aggregate resource in this area. Estimated thickness of the gravels is between 10 and 50 m. Sandy terrace sediments that are as much as 10 m thick cap these terrace gravels. Clast composition in the terrace gravels varies between the deposits

west and east of Riverside. Deposits east of Riverside in tract AVR02 contain carbonate clasts derived from the Mormon Mountains and thus have fewer chert and metamorphic clasts (Williams and others, 1997). These constitute a higher-quality aggregate resource, since the lack of silica-rich clasts can decrease the potential for alkali-silica reactivity (ASR) in concrete applications. Alluvial fan deposits south of the river, between the floodplain and Riverside Road, are also within this tract. They are about 30 m thick. Although it has high potential, the area between the road and the floodplain is narrow, no more than 400 m wide, and the space available for a possible mining operation could be problematic. These alluvial fan deposits are similar to those mined by Sunroc Sand and Gravel outside the eastern edge of the ACEC.

The other tract with high potential, AVR03, is primarily west of Riverside. The alluvial fan deposits there are somewhat thinner than those in tract AVR02, and they are not as accessible to I-15.

The areas within the floodplain (tract AVR05, fig. 3) of the Virgin River have low potential for sand and gravel aggregate deposits, with a high level of certainty. This is because the aggregate material that is in the floodplain and channel bar deposits is of lower quality, and is subject to periodic flooding.

Areas that encompass sandy terrace deposits and the Muddy Creek Formation also have low potential for sand and gravel aggregate deposits, with a moderate level of certainty (tract AVR04, fig. 3). The Muddy Creek Formation in the ACEC is poorly consolidated and sand-rich, with some conglomerate layers of limited thickness and lateral extent. Although this material could be utilized as a sand resource, the nearby terrace and alluvial fan gravels are of higher quality.

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# Chapter H. Mineral Resource Potential of the Hidden Valley Area of Critical Environmental Concern, Clark County, Nevada

By Steve Ludington, Stephen B. Castor, Brett T. McLaurin, and Kathryn S. Flynn

## Summary and Conclusions

The Hidden Valley Area of Critical Environmental Concern (ACEC) contains deposits of building stone that were mined in the past. However, the stone is of low quality, and the potential for the occurrence of locatable stone or silica sand deposits is low. There is no potential for the occurrence of other deposits of locatable or leasable minerals.

The Hidden Valley ACEC contains areas with both moderate and low potential for the occurrence of crushed stone aggregate deposits, as well as a tract with low potential for the occurrence of sand and gravel aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Hidden Valley ACEC was visited briefly to confirm descriptions of the geology that were gleaned from the scientific literature. Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

**Figure 1.** Panoramic photograph of Hidden Valley, showing floor of Aztec Sandstone (pink) and surrounding hills of Paleozoic carbonate rocks (dark grey).



## Lands Involved

The Hidden Valley ACEC is about 40 km northeast of the city of Las Vegas. It is about 15 km south of the townsite of Crystal (exit 75 on Interstate 15), and is reached by secondary roads from there. A legal description of these lands is included in appendix 2.

## Physiographic Description

The Hidden Valley ACEC consists primarily of a flat valley at an elevation of about 1,000 m, surrounded by hills and mountains that reach elevations of more than 1,600 m. The area is drained to the north by a tributary of California Wash.

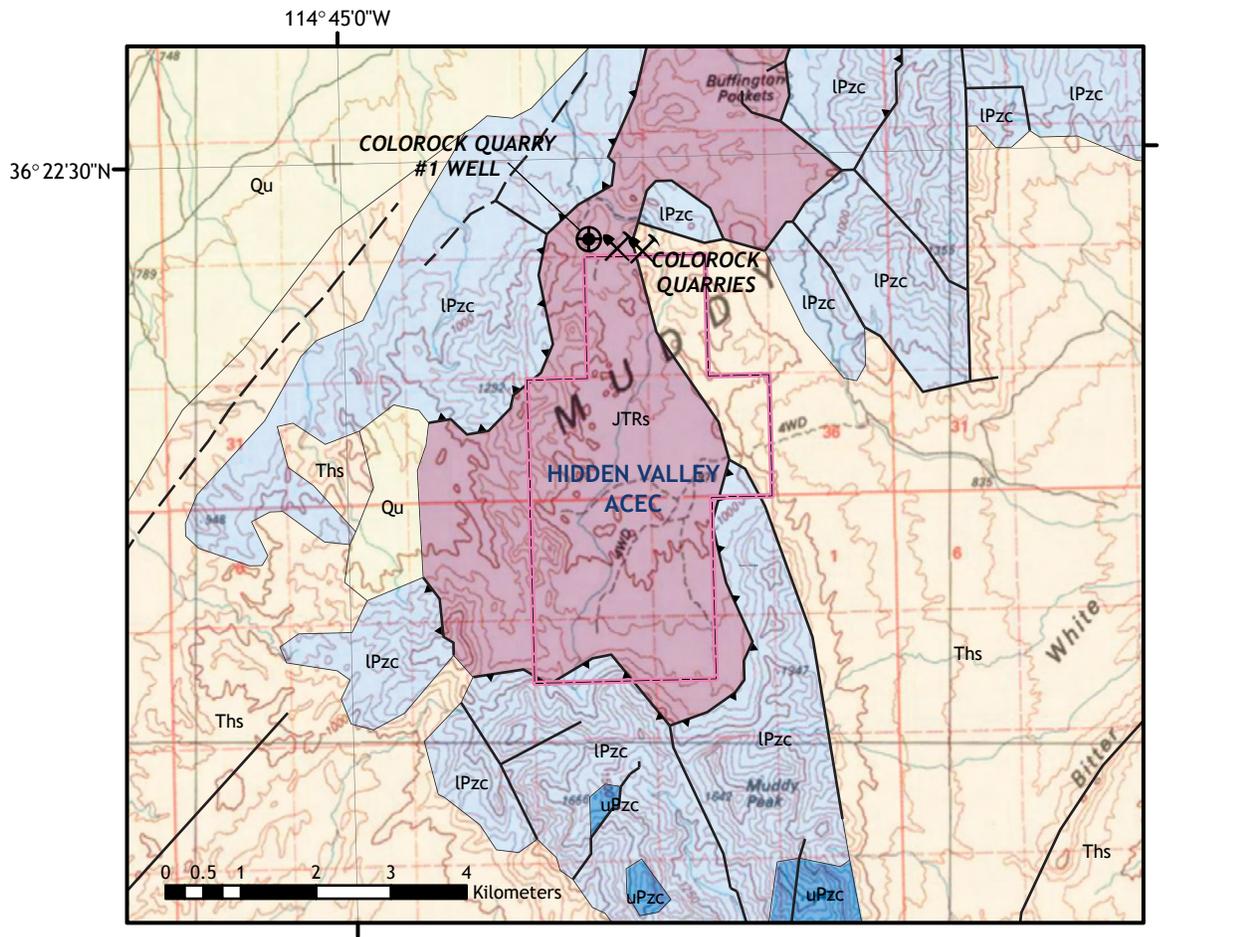
## Geologic Setting

The Hidden Valley ACEC is in the Basin and Range Physiographic Province, an area characterized by late Cenozoic tectonic extension, including numerous thrust faults. It lies on the western margin of the Grand Canyon region of the Colorado Plateaus Province. Proterozoic gneiss and schist are exposed in the Virgin Mountains, less than 40 km to the east. On the west, nonextended Pennsylvanian and Permian limestone and dolomite are exposed less than 10 km away.

## Geology

The valley floor of Hidden Valley and part of its flanks are composed of Jurassic Aztec Sandstone (fig. 1). The Aztec Sandstone consists of brick-red to pink, fine- to medium-

H2 Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada



EXPLANATION

- |   |  |
|---|--|
| <p><b>Qu</b> Undivided surficial deposits (Pleistocene and Holocene)—alluvium, colluvium, lake, playa, landslide, terrace, and eolian sand deposits</p> <p><b>Ths</b> Horse Spring Formation (Upper Oligocene and Miocene)—tuffaceous sedimentary rocks; includes some volcanic rocks, sandstone, limestone, and gypsum</p> <p><b>JTRs</b> Sedimentary rocks (Triassic and Jurassic)—mostly sandstone and shale. Includes Lower Jurassic Aztec Sandstone and Chinle and Moenkopi Formations</p> <p><b>uPzc</b> Carbonate rocks (Mississippian to Permian)—limestone, dolomite, and some shale. May include Kaibab, Callville, Temple Butte, Monte Cristo, and Redwall Limestones, Toroweap Formation, Coconino Sandstone, and Bird Spring Formation</p> <p><b>lPzc</b> Dolomite and Limestone (Cambrian to Devonian)—dolomite, limestone, and minor amounts of sandstone, shale, and siltstone. May include Temple Butte, Muddy Peak, and Guilmette Limestone; Nopah, Muav, and Bonanza King Formations; Pioche Shale; and Eureka Quartzite</p> | <p> contact, certain</p> <p> fault, certain</p> <p> fault, approximate</p> <p> fault, concealed</p> <p> thrust fault</p> <p> mine or prospect</p> <p> oil exploration drill hole</p> |
|---|--|

Figure 2. Generalized geology of the Hidden Valley Area of Critical Environmental Concern (ACEC; outlined in pink). Geology modified from Stewart and Carlson (1978)

grained, well-sorted, quartz-rich sandstone. It is characterized by large cross beds generally considered to be of eolian (wind-blown) origin (Stewart, 1980) and typically weathers to form high cliffs and distinctive knobby outcrops. The Aztec Sandstone is correlative with the Navajo Sandstone of the Colorado Plateaus, and it is the formation that forms distinctive red cliffs at Valley of Fire State Park and Red Rock Canyon in Nevada and at Zion National Park in Utah.

The hills and valleys surrounding Hidden Valley consist of Cambrian and Ordovician carbonate rocks. These rocks are massive to well bedded, light- to dark-gray dolomite and limestone that represent a variety of different marine carbonate depositional environments (Longwell and others, 1965).

These carbonate rocks were thrust westward over the Aztec Sandstone on the North Buffington back-thrust fault system related to the Sevier orogeny in Late Cretaceous time (Carpenter and Carpenter, 1994). This fault was later deformed and, in places, overturned by the eastward-moving Muddy Mountains thrust system in earliest Tertiary time (Bohannon, 1983). Fine-grained lacustrine and fluvial deposits of the Miocene Horse Springs Formation crop out in the eastern part of the area. Figure 2 is a geologic map of the ACEC and surrounding area. No igneous rocks occur in or near the area.

## Mining History

Two stone quarries were developed at the northern edge of the Hidden Valley ACEC at an unknown date. Longwell and others (1965) reported that the Colorock Quarry in this area had small recorded production. During our reconnaissance of the area, two other small quarries were found about 200 m out-

side of the northern boundary of the ACEC. Both sites showed some evidence of drilling and stone splitting. Other activity within 20 km of the area has been restricted to small-scale mining of industrial minerals (silica, clay, and borates).

## Mineral Deposits

The Hidden Valley ACEC contains outcrops of Aztec Sandstone that is variegated pale red, pale orange-pink, and light reddish-brown to white (fig. 3). Quarries in this rock have furnished small amounts of building stone. The largest quarry in the area is a cut about 30 m long, 10 m wide, and 2 to 3 m deep (fig. 4). It and two other quarries are within about 200 m of the northern boundary of the ACEC. The Wyatt silica mine, located about 2 km northeast of the ACEC, produced three or four carloads of silica sand from the Aztec Sandstone.

Other nearby mineral deposits and prospects are: the Vanderbilt bedded clay deposit, 10 km southwest; the Anniversary lacustrine borate deposit, 11 km south; the Ore Car Mine (gem beryl), 11 km south; the Bauer-Dollery and Virgin River manganese deposits, 25 km southeast; the White Basin lacustrine borate deposit, 10 km east; and the Overton bedded magnesite deposit, 25 km northeast.

## Mineral Exploration and Development

There has been no known modern mineral exploration or development in this ACEC. Past development activity was restricted to limited quarrying of building stone at two sites



**Figure 3.** Banded pale-red and white Aztec Sandstone from a quarry near the northern boundary of the Hidden Valley ACEC. GPS instrument (15 cm long) for scale.



**Figure 4.** Aztec Sandstone at a small quarry near the Hidden Valley ACEC. Note the drill hole to the left of the rock hammer.

near the north edge of the ACEC, including the Colorock Quarry. A small stone building in the area was likely constructed at that time.

In the past, there has been a small amount of petroleum exploration activity in Clark County, particularly in the 1950s and 1980s, and a number of deep wells have been drilled. However, no discoveries of exploitable petroleum have resulted. In 1983, Colorock Quarry # 1 well was drilled in the Colorock Quarry area by Chevron U.S.A. Inc. and Michel T. Halbouty Energy Co. (Garside and others, 1988). Another oil well, Frank #1, was drilled by Hall Co. in the area, but its exact location is not available (Garside and others, 1988).

## Mineral Resource Potential

### Locatable Minerals

The Hidden Valley ACEC has only low potential for the development of low-quality stone deposits. The Aztec Sandstone in the ACEC has been the source of a limited amount of stone production that was likely sold in the Las Vegas area as rough-hewn flagstone and ashlar. In the judgment of the authors, the Hidden Valley stone is of relatively poor quality and the area is difficult to access. The stone is too friable for the production of cut dimension stone. Existing producers of rough-hewn stone in the Las Vegas area exploit less friable parts of the Aztec Sandstone and other units, and there are large reserves of such material outside the ACEC. On the basis of analyses of Aztec Sandstone from other deposits in Clark County (Ludington and others, 2005), the Hidden Valley ACEC is not considered to be a good source of high-quality industrial sand.

There are no other known deposits of locatable minerals in the ACEC.

### Leasable Minerals

The entire Hidden Valley ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). No oil or gas shows were reported by Garside and others (1988) in the Colorock Quarry # 1 well, which was collared about 125 m north of the ACEC. It was drilled to a depth of 10,030 feet (3,058 m) through the Aztec Sandstone and underlying Mesozoic rock units. On the basis of the lithologic log (Nevada Bureau of Mines and Geology Information Office file), it probably also penetrated the Permian Kaibab and Toroweap Formations, and bottomed in red Permian sandstone. No data are available for the vaguely located Frank #1 well, other than a total depth of 1,005 feet (306 m).

There is no indication of potential for brine or evaporite deposits of sodium or potassium.

The Hidden Valley ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

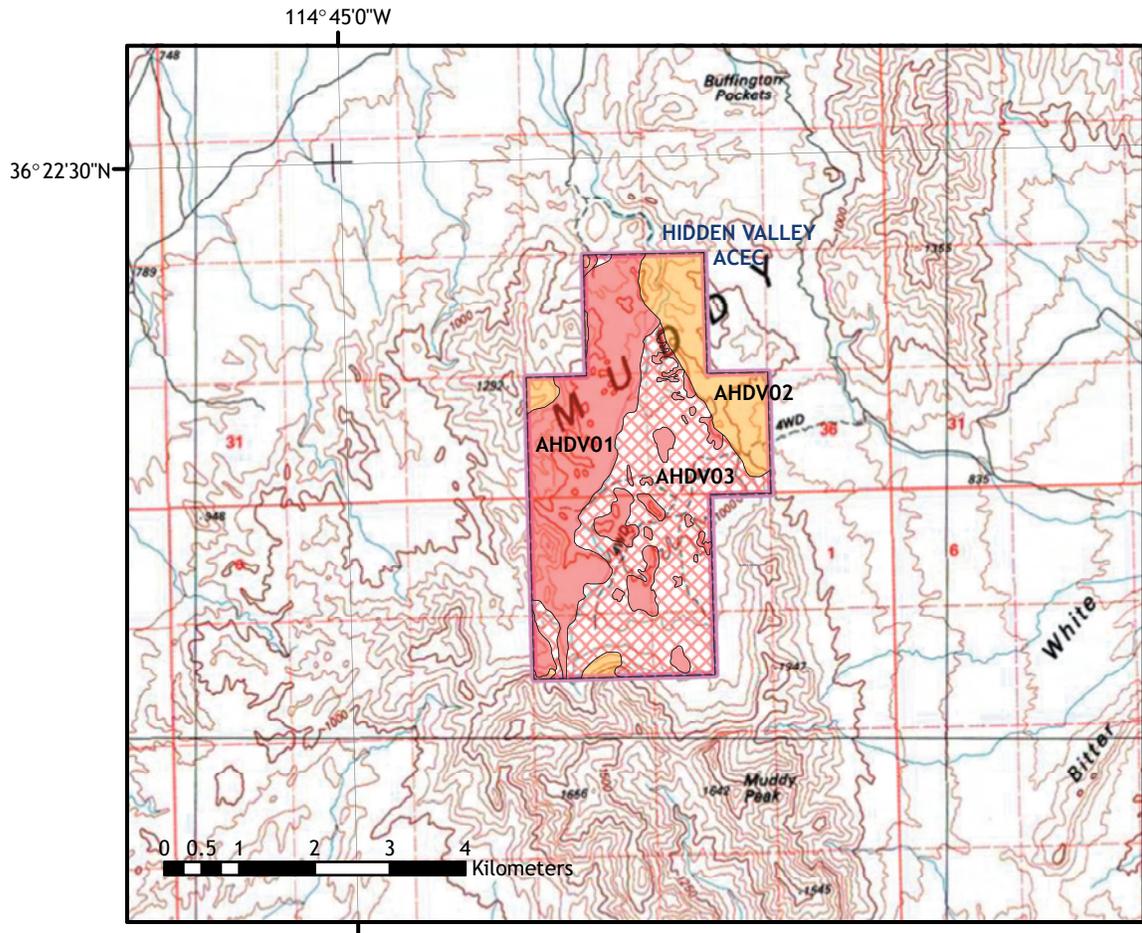
### Salable Minerals

*Crushed Stone.*—Because they contain moderate amounts of chert, the carbonate rocks above the thrust fault are judged to have moderate potential for crushed-stone aggregate deposits, with a low certainty level (tract AHDV01, fig. 5). The areas underlain by friable Aztec Sandstone have low crushed-stone aggregate potential, with a moderate level of certainty (tract AHDV02, fig. 5).

*Sand and Gravel.*—Alluvial deposits fill the valley east of the Aztec Sandstone outcrop area and are primarily fine-grained sand. Although some coarse material from the carbonate rocks is present, the sand and gravel potential in this area is low, with a moderate level of certainty (tract AHDV03, fig. 5).

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**EXPLANATION**

- Moderate potential for crushed stone aggregate
- Low potential for crushed stone aggregate
- Low potential for sand and gravel aggregate

**Aggregate Assessment Tracts**

Tract ID	Commodity Type	Potential Level	Certainty Level
AHDV01	Crushed Stone	Low	Moderate
AHDV02	Crushed Stone	Moderate	Low
AHDV03	Sand and gravel	Low	Moderate

Figure 5. Mineral resource potential tracts for aggregate resources in the Hidden Valley Area of Critical Environmental Concern (ACEC; outlined in pink).

# Chapter I. Mineral Resource Potential of the Rainbow Gardens Area of Critical Environmental Concern, Clark County, Nevada

By Stephen B. Castor, Steve Ludington, Brett T. McLaurin, and Kathryn S. Flynn

## Summary and Conclusions

The Rainbow Gardens Area of Critical Environmental Concern (ACEC) contains known deposits of gypsum, as well as prospects for limestone, silica, lithium, copper, uranium, and sand and gravel aggregate. Only gypsum has been mined in significant quantities, and the PABCO (Apex) gypsum mine, immediately adjacent to the ACEC, is a major gypsum source, producing more than 1,000,000 short tons of gypsum annually.

The ACEC contains areas of high mineral resource potential for gypsum deposits in the Tertiary Muddy Creek Formation and areas of moderate mineral resource potential for gypsum in the Mesozoic Moenkopi Formation. Areas with high potential for limestone deposits are found in the northern part of the ACEC. There is an area with moderate potential for lithium (hectorite clay) deposits. The potential for undiscovered deposits of silica, uranium, and metals is low.

The ACEC has areas with high, moderate, and low potential for crushed-stone aggregate deposits. Unconsolidated material in the ACEC has high potential for sand and gravel aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential of these lands.

The Rainbow Gardens ACEC was studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature. Samples were collected and analyzed,

and representatives of companies with mining operations in and near the areas were contacted.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

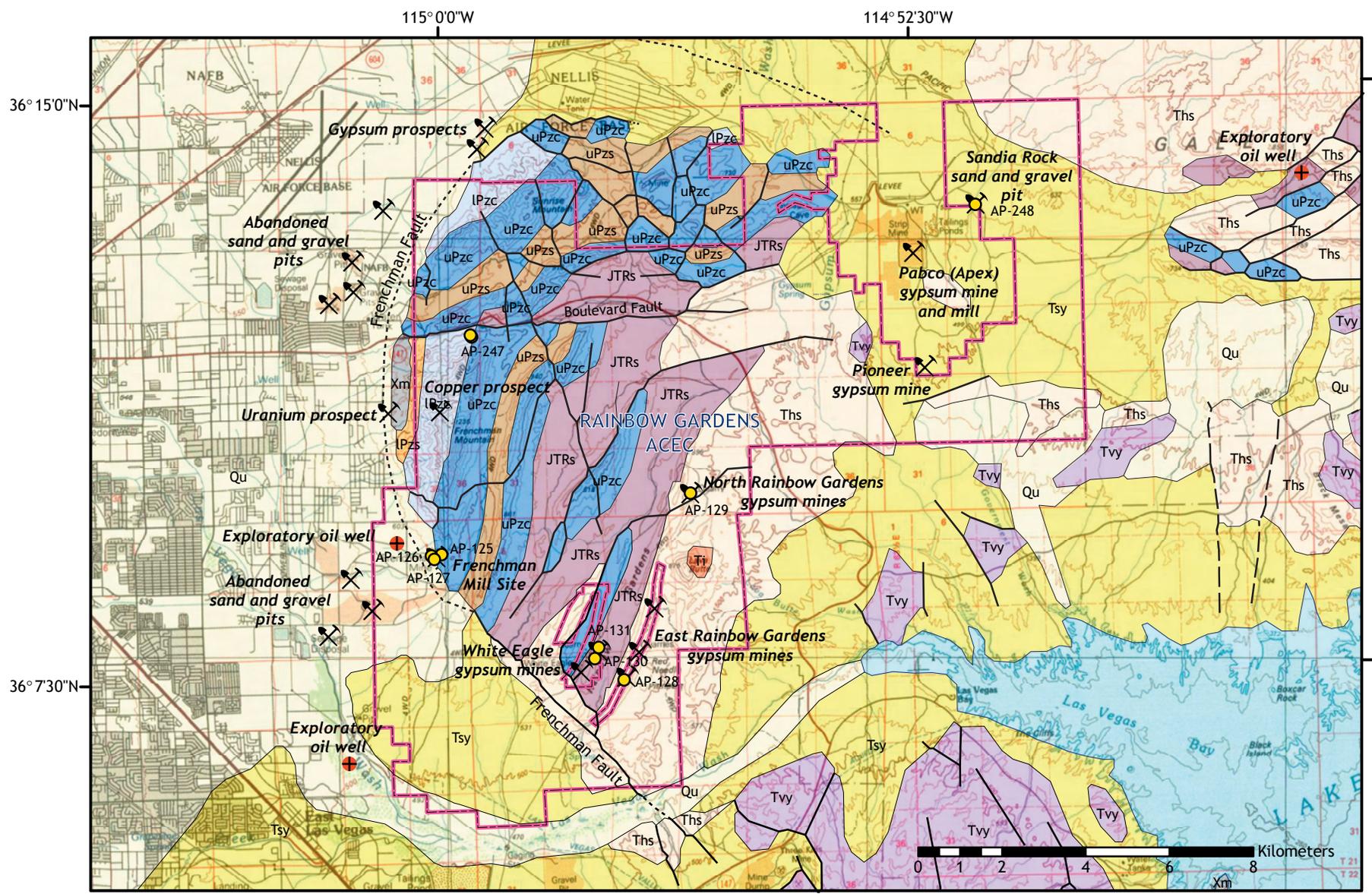
The Rainbow Gardens ACEC is east of Las Vegas and southeast of Interstate 15 (fig. 1). The ACEC is bounded on the southeast and east by the Lake Mead National Recreation Area and on the north by Nellis Air Force Base. It is accessed most easily from Nevada State Highway 143 (Lake Mead Boulevard) and by several secondary and primitive roads that branch off of this highway. It may also be accessed from Hollywood Boulevard in southeast Las Vegas and by primitive roads in that area. A legal description of these lands is included in appendix 2.

## Physiographic Description

The Rainbow Gardens ACEC is named for an area of colorful rock strata near its southeastern boundary. Near its western boundary, it includes Frenchman Mountain, a rugged ridge that forms the eastern backdrop for Las Vegas and reaches elevations of more than 1,200 m. The northwest part of the ACEC includes Sunrise Mountain, which is more than 1,000 m in height. The lowest part of the ACEC is at an elevation of about 440 m along its southern boundary in Las Vegas Wash, which drains into Lake Mead to the east. Streams and washes in the Rainbow Gardens ACEC drain westward into Las Vegas basin and eastward into Lake Mead.

## Geologic Setting

The Rainbow Gardens ACEC is in the Basin and Range Physiographic Province, which is characterized by north-



**Figure 1.** Generalized geology of the Rainbow Gardens Area of Critical Environmental Concern, showing mines, prospects, and locations of analyzed samples. Geology modified from Stewart and Carlson (1978).

**EXPLANATION**

Qu	Undivided surficial deposits (Pleistocene and Holocene)—Alluvial, colluvial, lake, playa, landslide, terrace, and eolian sand deposits
QTs	Sedimentary rocks (Pliocene and Pleistocene)—Mostly lake and alluvial deposits
Tsy	Young sedimentary rocks (middle Miocene to Pliocene)—Alluvial, lacustrine, and fluvial deposits. Locally includes minor amounts of tuff. Includes Muddy Creek Formation
Ths	Horse Spring Formation (upper Oligocene and Miocene)—Clastic and tuffaceous sedimentary rocks; includes some volcanic rocks, limestone, and gypsum
Tvy	Young volcanic rocks (middle and upper Miocene)—Rhyolite, andesite, and basalt lava flows, tuff, and tuffaceous sediments
Ti	Intrusive rocks (Oligocene and Miocene)—Aphanitic, porphyritic, and coarsely crystalline rocks ranging in composition from gabbro to granite
JTRs	Sedimentary rocks (Triassic and Jurassic)—Shale, mudstone, siltstone, sandstone, and carbonate rock; some sparse volcanic rock. Includes Lower Jurassic Glen Canyon Group (Kayenta and Moenave Formations, Aztec Sandstone) and Chinle and Moenkopi Formations
uPzc	Carbonate rocks (Mississippian to Permian)—Limestone, dolomite, and some shale. May include Kaibab, Callville, Monte Cristo, and Redwall Limestones, Toroweap Formation, and Bird Spring Formation
uPzs	Sedimentary rocks (uppermost Devonian to Permian)—Siltstone, sandstone, shale, and conglomerate; some limestone, dolomite, chert, and gypsum. May include Queantoweap Sandstone, Hermit Formation, Coconino Sandstone, Supai Group, and Pakoon Formation
lPzc	Dolomite and Limestone (Cambrian to Devonian)—Dolomite, limestone, and minor amounts of sandstone, shale, and siltstone. May include Muav Limestone, Frenchman Mountain Dolomite, and Bonanza King ? and Nopah and Sultan Formations
lPzs	Sedimentary rock (Cambrian)—Sandstone, shale, and limestone. May include Pioche Shale, Lyndon Limestone, and Chisholm Shale
Xm	Metamorphic rocks (Paleoproterozoic)—Undivided metasedimentary, metavolcanic, and gneissic rocks, including locally abundant amphibolite and pegmatite. May also include Paleoproterozoic granitoid rocks
	contact, certain
	fault, certain
	fault, approximate
	fault, concealed
	thrust fault
	mine or prospect
AP-001 	sample site, with sample number
	exploratory oil well

Figure 1.—Continued.

trending mountain ranges and intervening valleys. However, the ACEC lies near the border of this province with the Colorado Plateaus Province and exposes Paleozoic and Mesozoic strata that are similar to those of the Colorado Plateaus. The geology of the region is characterized by rocks ranging in age from Proterozoic through Miocene that are cut by a complex of late Cenozoic extensional faults. Important regional structural features include the Lake Mead Fault system, the Las Vegas Valley shear zone, and steep to moderately dipping normal faults. The Las Vegas Valley shear zone is a major west-northwest-striking right-lateral fault zone that extends across much of southern Nevada. It has accommodated as much as 65 km of dextral displacement to the northwest of the ACEC (Longwell, 1974; Wernicke and others, 1988; Deubendorfer and Black, 1992) and is associated with large-magnitude clockwise rotation of adjacent rocks. The Lake Mead Fault system is a major east-northeast-striking left-lateral fault zone (Anderson, 1973) that appears to merge with the right-lateral Las Vegas Valley shear zone.

**Geology**

The Rainbow Gardens ACEC has been completely mapped geologically at 1:24,000 scale (Bingler, 1977; Bell and Smith, 1980; Matti and others, 1993; Castor and others, 2000; Deubendorfer, 2003). Rock units range in age from Proterozoic through late Miocene. Proterozoic schist and gneiss, exposed along the western base of Frenchman Mountain (Matti and others, 1993), is overlain by relatively thin lower Cambrian sandstone and shale units and then by a thick sequence of carbonate-dominated Cambrian, Devonian, and Mississippian to Permian rocks. Mesozoic rocks, mainly composed of shallow marine to nonmarine Triassic and Jurassic redbeds, with some carbonate and gypsum beds, are capped by eolian sandstone. Rocks of the uppermost Oligocene to middle Miocene Horse Spring Formation and a red sandstone unit described by Bohannon (1984) are mainly composed of nonmarine red sandstone, with some carbonate rocks and tuff. The Muddy Creek Formation, which is mostly composed of poorly indurated sandstone and siltstone with local gypsum, limestone, and conglomerate units, filled late Miocene basins. The Paleozoic and Mesozoic strata are conformable, but the break between the youngest Mesozoic unit (Jurassic Aztec Sandstone) and the oldest Tertiary unit (basal part of the Horse Spring Formation) is marked by a low-angle unconformity.

The Rainbow Gardens ACEC contains six major structural elements: the Frenchman Mountain block, Sunrise Mountain block, Boulder Basin, Nellis Basin, Gale Hills block, and Las Vegas Valley. The Frenchman Mountain block is bounded by the Frenchman Fault and Las Vegas Valley on the west, the Sunrise Mountain block on the north, and the Boulder Basin on the east. The east-trending, left-lateral Boulevard Fault Zone separates the Frenchman Mountain block from the Sunrise Mountain block (Castor and others, 2000). The Frenchman Mountain block is dominated by east-tilted

Paleozoic, Mesozoic, and Miocene strata and widely spaced, generally northwest-dipping normal faults that have produced three major stratigraphic repetitions.

In contrast to the Frenchman Mountain block, the Sunrise Mountain block is composed of many small blocks. East-northeast-striking, moderately southeast-dipping Paleozoic and Mesozoic strata are cut by closely spaced normal, oblique, and strike-slip faults that fragment the Sunrise Mountain block. The structural complexity in the Sunrise Mountain block increases northward toward the Munitions Fault, a major east-striking fault zone that dips moderately northward and bounds the Sunrise Mountain block on the north.

The Frenchman Fault forms the west side of the Sunrise Mountain and Frenchman Mountain blocks, and has a northwest-striking southern strand partly within the southwest part of the Rainbow Gardens ACEC that accommodated normal dextral (Castor and others, 2000) and reverse dextral motion (R.E. Anderson, oral commun., 1998). This strand merges northward with the central north-striking part of the Frenchman Fault, which surfaces west of the ACEC (Matti and others, 1993) and extends into the northwest part of the ACEC.

The Boulder Basin is east of the Frenchman Mountain block and consists primarily of Miocene sedimentary strata that are tilted gently to moderately eastward. The northern part of the Boulder Basin is complicated by an east- to north-east-trending fold belt that extends beyond the east border of the ACEC (Deubendorfer, 2003), suggesting that the basin, once a half graben or series of half grabens, was significantly modified by north-south shortening. The late Miocene Muddy Creek Formation is locally deformed in this area.

The Nellis Basin, a small late Tertiary basin north of the Munitions Fault, extends southeast into the ACEC. A limestone member of the late Miocene Muddy Creek Formation is apparently confined to this basin. The basin may have developed in a right step or pull-apart along the Las Vegas Valley shear zone.

Within the Rainbow Gardens ACEC, bedrock exposed in the Gale Hills block, which bounds the Boulder Basin on the northeast, is almost all middle Miocene sedimentary rock. However, east of the ACEC, the Gale Hills block includes the southeast extension of the Las Vegas Valley shear zone, along which Paleozoic and Mesozoic strata are exposed (Deubendorfer, 2003).

## Mining History

There are seven inactive open-pit gypsum mines in the Rainbow Gardens ACEC; most are in or near the Rainbow Gardens area (fig. 2). The best known is the White Eagle mine, where gypsum was mined from a series of narrow pits (fig. 3) between 1938 and 1956 by Pabco Products, Inc. (Papke, 1987) and later by Fibreboard Paper Products. According to Papke, the nearby East Rainbow Gardens pits (figs. 4, 5) were the source of gypsum for Pabco Products, Inc., in the late 1950s after mining ceased in the White Eagle area; however, U.S. Bureau of Mines records show the operator as Fibreboard Paper Products at this time.

Gypsum mining at the North Rainbow Gardens mine (fig. 6), about 5 km northeast of the White Eagle mine, began in the late 1950s (Papke, 1987). Fibreboard Paper Products was the operator at this mine (referred to by the U.S. Bureau of Mines as the “Henderson” operation). In 1959, the company switched its mining operations from the Rainbow Gardens area to the PABCO mine about 7 km to the northeast (see below). The North Rainbow Gardens mine was mostly idle until the late 1980s, when it was again operated by Nevada Gypsum and Mining and Nevada Gypsum, Inc. The last mining activity recorded at the property was in 1993 (Castor, 1994).



**Figure 2.** View looking northeast at part of the Rainbow Gardens Area of Critical Environmental Concern showing the abandoned East Rainbow Gardens pits in white gypsum beds in the Horse Spring Formation (center) and the access road in the foreground. Lava Butte is immediately behind. The abandoned Rainbow Gardens pits, including the White Eagle mine, are in the left center along Rainbow Gardens Road. The light-colored plateau beyond Lava Butte is capped by gypsite that is currently being mined by PABCO and Pioneer Gypsum.



**Figure 3.** White Eagle mine, Rainbow Gardens, looking north. Gypsum is in moderately east-dipping red sandstone in the lower part of the Moenkopi Formation. Sample AP-130 was taken north of the white vehicle in the distance.



**Figure 4.** East Rainbow Gardens gypsum mine, looking south. Dark, resistant conglomerate of Thumb Member of Horse Spring Formation caps the gypsum and forms skyline. Sample AP-128 is from outcrop behind vehicle.



**Figure 5.** East Rainbow Gardens gypsum mine, looking north. Lava Butte is in background.

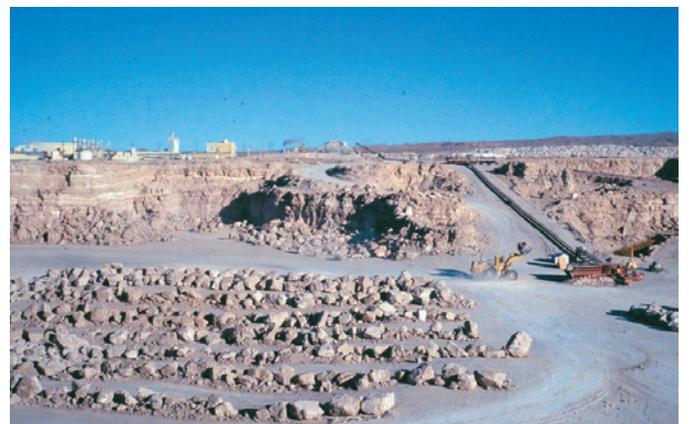


**Figure 6.** North Rainbow Gardens gypsum mine. The open pit was reclaimed in the middle 1990s after mining ceased in 1993.

The PABCO Gypsum Mine, also called the Apex Mine (fig. 7), is located in a large inlier of private land in the Rainbow Gardens ACEC (fig. 1). It is one of five active gypsum mines in Nevada and has been the site of continuous mining since 1959. U.S. Bureau of Mines records show that it was operated by Fibreboard Paper Products in 1959 and by Johns Manville Products Corp. between 1968 and 1976. In 1976 the operation was purchased by Pacific Coast Building Products, Inc., which currently owns the property as part of its PABCO Gypsum subsidiary. Production from the mine has been more than 1,000,000 short tons annually since 2001; however, the ore contains 70 to 80 percent gypsum, and production figures for beneficiated gypsum (92 percent or more gypsum by weight) must be adjusted downward to account for this factor.

The Pioneer Gypsum Mine, a subsidiary of D.L. Denman Construction of Las Vegas, began mining gypsum for cement manufacture and agricultural uses in 2001. The mine is located adjacent to the ACEC within the same inholding as the PABCO Gypsum mine. Production figures have not been published for this operation.

Although gypsum has been the main focus of mining in the Rainbow Gardens ACEC, the earliest mining operation was probably at the Frenchman mine, which produced minor amounts of copper in 1917 and 1918 (Longwell and others, 1965). Paul Watelet, a Belgian miner who managed Pacific Coast Gypsum and South Nevada Gold Mining, was purported to be the “Frenchman,” and these companies reported discoveries of gypsum and gold east of Las Vegas between 1905 and 1912. Clippings in the Nevada Bureau of Mines and Geology Las Vegas district file from 1912 to 1914 indicate that the South Nevada Gold Mining Co. operated the Frenchman mine and report that the mill included a 300-ton-per-day cyanide plant and that a shipment of metal to an assay office was made. The ruins of a mill stand on the site shown on topographic maps as the Frenchman mine, but no ore was noted there or nearby.



**Figure 7.** PABCO (Apex) Mine. Gypsite ore is conveyed to be washed, calcined, and made into wallboard and plaster at the plant in the background.

## Mineral Deposits

### Gypsum

Open-pit operations at the PABCO Gypsum mine (Apex mine) are within 1 km of the Rainbow Gardens ACEC in a large inholding in the ACEC. The gypsum forms a thick, relatively resistant cap on a gently south-dipping plateau. It is underlain by sandy redbeds of the Muddy Creek Formation. Drilling indicates that the thickness of the gypsum exceeds 35 m in the vicinity of the mine (L. Ordway, PABCO mine manager, oral commun., 1997). The gypsum is generally covered by less than 2 m of sandy overburden and occurs in an area of 13 km<sup>2</sup> (Papke, 1987). Mineable reserves in this area are quite large, probably more than 400 million short tons. The gypsum ore mined by PABCO is transported from the open pit by conveyor belt and upgraded to gypsum suitable for plaster and wallboard production at a simple washing plant.

The ore mined by PABCO is generally friable and porous gypsite that consists of fine intergrown gypsum crystals with various amounts of admixed silt and sand. The gypsite is white to grayish orange or light greenish gray. Locally, it contains layers of fine-grained, sugary, compact gypsum. In places, relatively large selenite crystals or masses of crystals are present (Papke, 1987), and crystals as much as 20 cm long have been noted (Castor and others, 2000). Steeply dipping northwest-striking faults that probably have only minor amounts of offset are exposed in the pit.

The Pioneer Gypsum mine, also within 1 km of the ACEC boundary, exploits the same gypsum-bearing unit as the PABCO operation, and the gypsum appears to be of similar grade. The ore is shipped without processing for use in cement manufacture and agricultural applications.

Gypsum has been mined and prospected for at several sites within the Rainbow Gardens ACEC in the past, and gypsum prospect pits are common. The Permian-Pennsylvanian Pakoon Formation is the oldest unit that has been explored for gypsum. Other units that contain beds of relatively pure gypsum are the Toroweap, Kaibab, Moenkopi, and Horse Spring Formations. At the White Eagle mine, where the gypsum is in the lower redbed unit of the Moenkopi Formation, it is white to pale greenish yellow, as much as 35 m thick, and contains some silty interbeds. It was mined over a strike length of about 1,200 m from three pits, the largest of which is about 370 m long and 60 m wide. Papke (1987) reported 78 percent gypsum in a sample from the White Eagle mine; however, a select sample taken for this study from the White Eagle mine contains nearly 88 percent gypsum (sample AP-131, table 1).

Gypsum was also mined from the Thumb Member of the Miocene Horse Spring Formation about 1 km east and 5 km northeast of the White Eagle mine at the East Rainbow Gardens and North Rainbow Gardens areas (fig. 1). In the East Rainbow Gardens area, gypsum was mined from four pits over a strike length of about 1,500 m. The largest pit is about 550 m long and 30 m wide. A 25-m-long chip sample taken along the

south end of the largest pit contains about 83 percent gypsum on the basis of chemical analysis (Sample AP-128, table 1; Ludington and others, 2005). In the North Rainbow Gardens area, site of the most recent gypsum mining within the ACEC, the gypsum-rich sequence is about 150 m wide and is apparently repeated by faulting and folding (Castor and others, 2000). Gypsum mined from the North Rainbow Gardens area in the 1980s and 1990s was shipped crude (generally 87 to 92 percent gypsum) for agricultural use or for use in cement. A select grab sample of gypsum taken from the North Rainbow Gardens mine for this study contains about 91 percent gypsum on the basis of chemical analysis (Sample AP-129, table 1; Ludington and others, 2005).

Mineral Resource Data System (MRDS) data (U.S. Geological Survey, undated) indicate that gypsum prospects occur in the Muddy Creek Formation to the north of the Rainbow Gardens ACEC and in the Kaibab Formation near Gypsum Cave. In addition, mining claim inholdings in the ACEC north of Gypsum Cave include gypsum prospects in the upper part of the Toroweap Formation. On the basis of our observations, the gypsum in the Toroweap occurs as relatively narrow, steeply south-dipping bodies, and only minor amounts of gypsum occur at Gypsum Cave.

Gypsum is abundant in the middle part of the Pakoon Formation, but this unit has only been the site of minor gypsum prospecting. Other gypsum-rich units in the area include the upper part of the Toroweap Formation, where resistant limestone is overlain by 10 to 30 m of gypsum, and the Harrisburg Member of the Kaibab Formation, which includes a gypsiferous sequence as much as 20 m thick (Castor and others, 2000). Harrisburg Member gypsum has been mined for many years at the Blue Diamond mine, about 30 km southwest of the Rainbow Gardens ACEC. In addition to gypsum in the lower redbed unit of the Moenkopi Formation, as at the White Eagle mine, abundant gypsum is also present in the Schnabkaib Member and upper redbed unit of the Moenkopi Formation.

### Limestone

Relatively pure limestone suitable for use in Portland cement and possibly high-calcium lime occurs in the Rainbow Gardens ACEC but has not been mined. At Apex, about 9 km north of the ACEC, large amounts of high-calcium lime are produced annually from pure micritic limestone in the upper part of the Crystal Pass Member of the Sultan Formation. The fine-grained texture of this limestone is important, because more coarsely crystalline limestone decrepitates during calcination, making the production of lump lime impossible. Micritic carbonate is present in the unit in the Frenchman Mountain Quadrangle, but X-ray diffraction (XRD) analysis of a chip sample from this unit shows that it is dolomitic. No pure Paleozoic limestone is known to occur in the ACEC; the Paleozoic carbonate rocks there are either dolomitic, or contain interbeds of dolomite, sandy detritus, or minor to abundant chert (Castor and others, 2000).

**Table 1.** Composition of gypsum samples from the Rainbow Gardens ACEC compared with high-grade gypsum ore from the Blue Diamond mine and low-grade gypsum ore from the PABCO mine.[All data in weight percent. Gypsum = 2.146 x SO<sub>3</sub>. Data on White Eagle grab, Apex, and Blue Diamond samples are from Papke, 1987.]

Sample-----	AP-128	AP-129	AP-131	—	—	—
Location-----	Rainbow Gardens E	Rainbow Gardens N	White Eagle	White Eagle	Apex (PABCO)	Blue Diamond
Unit-----	Horse Spring	Horse Spring	Moenkopi	Moenkopi	Muddy Creek	Kaibab
Sample type---	chip	select grab	select grab	grab	grab	grab
SiO <sub>2</sub>	5.89	0.86	0.24	1.53	9.43	0.33
Al <sub>2</sub> O <sub>3</sub>	0.89	0.11	0.05	0.15	3.94	0.03
Fe <sub>2</sub> O <sub>3</sub>	0.28	0.05	0.04	0.08	0.22	0.01
MgO	1.52	0.32	0.23	4.92	5.47	0.03
CaO	31.33	34.67	33.61	31.60	27.70	33.40
Na <sub>2</sub> O	0.07	0.01	0.01	0.05	0.69	0.02
K <sub>2</sub> O	0.39	0.04	0.04	0.15	0.68	0.02
LOI	21.2	21.2	20.4	14.8	13.2	18.3
CO <sub>2</sub>	1.46	0.22	0.62	10.40	9.20	0.02
SO <sub>3</sub>	38.48	42.23	40.98	36.50	29.40	48.10
Gypsum	82.57	90.61	87.93	78.33	63.09	103.22

**Table 2.** Comparison of some major element analyses of 35-m chip sample AP 320 and grab sample AP-324 (Rainbow Gardens ACEC) with Portland cement and high-Ca lime ore specifications.[CaCO<sub>3</sub> % calculated using CaO x 1.78; MgCO<sub>3</sub> % calculated using MgO x 2.09. Portland cement specifications from Ames and others (1994). High-Ca lime ore specification from Stanley T. Krukowski (oral commun., 2005).]

Element	AP-320	AP-324	Portland cement ore specification	High-Ca lime ore specification
SiO <sub>2</sub>	4.04	1.86		<1
Al <sub>2</sub> O <sub>3</sub>	0.54	0.20		
Fe <sub>2</sub> O <sub>3</sub>	0.26	0.11		
MgO	0.92	0.54		<1
CaO	52.40	54.32	ca. 50	
Na <sub>2</sub> O+K <sub>2</sub> O	0.22	0.12	<0.4	
P <sub>2</sub> O <sub>5</sub>	0.14	0.08		
LOI	41.5	42.8		
CaCO <sub>3</sub>	93.27	96.69		>95
MgCO <sub>3</sub>	1.92	1.13		
total carbonate	95.19	97.82		

The Bitter Ridge Limestone Member of the Horse Creek Formation may locally have potential for use as cement or high-calcium limestone. Regionally this unit contains large thicknesses of nearly pure high-calcium limestone. However, in the Rainbow Gardens ACEC, it is commonly interbedded with tuff, volcanic breccia, and sandstone (Castor and others, 2000), and is not as economically desirable as in other locations.

Lacustrine algal limestone in the Nellis basin in the northern part of the ACEC may be more desirable because it is relatively pure and could be easily mined. This limestone

unit, mapped as part of the Muddy Creek Formation (unit Tml, Castor and others, 2000) is as much as 50 m thick in places, is nearly flat-lying, and is exposed over about 1.5 km<sup>2</sup> in the ACEC. XRD analyses of this limestone indicate that it is nearly pure calcite, and the chemistry of a 35-m chip sample and a grab sample (samples AP-320 and AP-324, respectively, table 2) indicates that it is suitable for Portland cement. However, its chemistry and the fact that it is relatively coarse grained, indicate that it is not suitable for high-calcium lime production. The limestone is also exposed extensively to the north of the ACEC.

## Lithium

A rise in lithium demand and consumption during the 1970s, driven by new uses coupled with concern about future availability for the production of deuterium, prompted significant lithium exploration by the U. S. Geological Survey. Exploration was mainly focused on modern playa deposits in Nevada and California, but deposits of older lithium-rich lacustrine sedimentary rocks were also studied. The upper part of the Lovell Wash Member of the Horse Spring Formation in the Frenchman Mountain quadrangle was found to contain a 40-m-thick section with average lithium content of 1,000 ppm (Brenner-Tourtelot and Glanzman, 1978; Brenner-Tourtelot, 1979). The presence of hectorite ( $\text{Na}_{0.3}(\text{Mg},\text{Li})_3\text{Si}_4\text{O}_{10}(\text{F},\text{OH})_2$ ), a trioctahedral lithium-rich clay mineral, was suspected.

Samples collected from the Lovell Wash Member in both the Frenchman Mountain and Henderson quadrangles were found to have lithium contents as high as 900 ppm on the basis of atomic absorption analyses at the Nevada Bureau of Mines and Geology Analytical Laboratory (Castor and others, 2000). In addition, XRD analysis indicates that clay separates from one of these samples contains trioctahedral clay, and we concur that hectorite is probably present.

## Sand and Gravel

The Sandia Aggregate sand and gravel pit (fig. 8) is in the northeastern part of the ACEC. It is about 2 km east of the PABCO Gypsum mine and is also operated by Pacific Coast Building Products, Inc. The pit is about 100 m by 800 m in area and 30 m deep. The material mined is Quaternary alluvium that is mostly composed of pebble- to boulder-sized clasts of Paleozoic carbonate rock.



**Figure 8.** Sandia Aggregates sand and gravel pit in the Rainbow Gardens Area of Environmental Concern. Pit is about 110 m wide and 800 m long.

## Silica

According to Longwell and others (1965), the Sunrise Mountain silica deposit, which is probably in the Aztec Sandstone, lies in or near the Rainbow Gardens ACEC. No production has been recorded from this deposit and its location is poorly known. The Sunrise Mountain silica deposits may be on Nellis Air Force Base to the north of the ACEC. No evidence of mining in Aztec Sandstone exposures were found during detailed mapping in the area (Castor and others, 2000). Analyses given in Hewett and others (1936) for Aztec Sandstone from a silica prospect in the Muddy Mountains indicate that the silica content, about 94 percent, is too low to meet specifications for glass sand. White Aztec Sandstone from Whitney Pocket in the Gold Butte area contains only about 89 percent silica.

The silica-rich Coconino Sandstone occurs in places in the Rainbow Gardens ACEC; however, it is generally thin and occurs on steep slopes beneath thick Permian carbonate (Castor and others, 2000). One area in the ACEC contains Coconino Sandstone exposures as much as 70 m thick and 300 m wide over a distance of 2 km.

## Metal Mines and Prospects

*Frenchman Mine.*—The Frenchman Mine, the site of an old mill (fig. 9) at the western base of Frenchman Mountain near the western border of the ACEC, was credited with small production of oxidized copper ore in 1917 and 1918 (Longwell and others, 1965). No copper minerals were found when the site was visited for this study, and samples taken from waste piles and a limonitic breccia outcrop to the south contain less than 20 ppm Cu, along with low Ag, Pb, and Zn contents (Samples AP-126 and AP-127, Ludington and others, 2005).



**Figure 9.** Remains of a mill at the reported site of the Frenchman Mine. No sign of mining was noted here; ore was probably transported from a mine site to the north.

About 3 km north of the Frenchman Mine is a group of adits that follow a north-striking, steeply east-dipping breccia zone as much as 12 m wide that is cemented by carbonate, hematite, and copper minerals. This is the only occurrence of copper minerals noted during detailed mapping of the Frenchman Mountain quadrangle (Castor and others, 2000). Access to the adits is by pack trail from the valley floor to the west, and the authors suspect that these adits were the source of ore processed at the Frenchman mill site described above. The breccia zone locally forms a contact between vuggy pale orange dolomite and brown dolomite of the Nopah Formation. Examination of samples of this breccia by reflected light microscopy and scanning electron microscope (SEM) with energy-dispersive X-ray analysis (EDX) shows that the copper minerals include primary chalcopyrite, along with secondary chalcocite, covellite, cuprite, and malachite (figs. 10 and 11). Tiny grains of a silver-bearing sulfide mineral are locally intergrown with the covellite and chalcocite. Samples from this site contain 0.7 percent to more than 1 percent copper and as much as 95 ppm silver, along with anomalously high Sb, As, Au, Hg, Mo, Ni, and Se (samples AP-345 and AP-345A, Ludington and others, 2005).

## Uranium

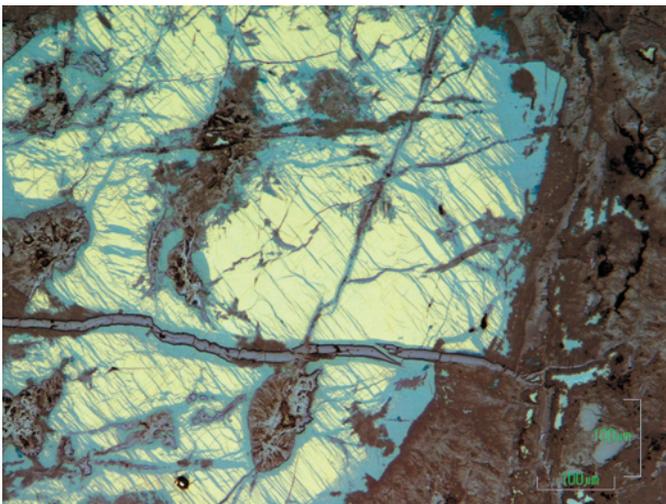
A uranium prospect, the Little Hal, Steve Nos. 1 and 11 claims, is reported near the west edge of the Rainbow Gardens ACEC. Garside (1973) describes the prospect as occurrences of anomalous radioactivity (six times background) associated with pegmatite dikes in Precambrian metamorphic rocks. The location in Precambrian host rocks puts it west of the ACEC. During detailed mapping (Castor and others, 2000), radioactivity as high as three times background was noted in similar rocks in the same general area. Interestingly, uranium contents

as high as 139 ppm occur in copper-rich rock (sample AP-345A, Ludington and others, 2005) from the adits described above, which are in the same general area. Uranium is associated with copper and base-metal deposits in carbonate rocks in the Goodsprings district about 50 km to the southwest; however, except for a shipment of five short tons of uranium ore from one mine, uranium occurrences there are very low grade (Garside, 1973).

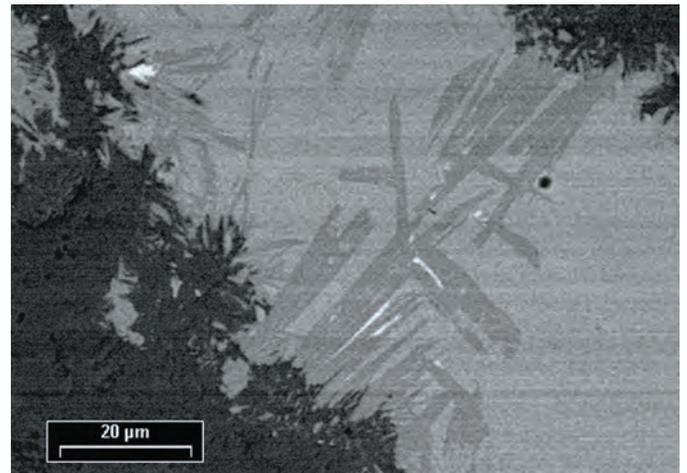
## Mineral Exploration and Development

The Rainbow Gardens ACEC contains 72 mining claims that are current as of 2005. Pacific Coast Building Products, Inc., holds 56 placer claims in sections 1, 12, and 13 of T20S, R63E, just to the west of the company's PABCO (Apex) mine. Bedded deposits of nonmetallic minerals, such as gypsum, are staked using placer claims. Several areas of claims that were presumably staked for gypsum are in the ACEC west of the PABCO mining area and claims. A group of four individuals holds three placer claims in section 14 of T20S, R63E, southeast of the PABCO claims near Gypsum Spring. Bingham's Pride holds four placer claims in sections 15 and 16 of T20S, R63E, west of Gypsum Spring. The Lima brothers hold seven placer claims in section 16 of T20S, R63E about 2 km west of Gypsum Spring. In addition, the Lima brothers hold eight claims in section 34 of T20S, R63E about 4 km to the south in the area of the north Rainbow Gardens gypsum pit.

Other small holdings within the ACEC include a single millsite claim held by Robert Dawson in section 2 of T20S, R63E, and a single claim held by J.L. Block in section 2 of T21S, R62E, in the east part of the ACEC near an abandoned sand and gravel pit.



**Figure 10.** Photomicrograph of chalcopyrite (pale yellow) partly replaced by chalcocite (bluish gray) surrounded by iron oxide, cuprite, and malachite. Cross-polarized light. Sample AP-345A.



**Figure 11.** Back-scattered scanning electron microscope image of sample AP-345A, showing silver-bearing sulfide (bright) in chalcocite (gray) with blades of covellite (darker gray). Surrounding dark areas are cuprite and iron oxide.

## Mineral Resource Potential

### Locatable Minerals

*Gypsum.*—Parts of the Rainbow Gardens ACEC have high potential for gypsum deposits, with a high certainty level (tract RBG01, fig. 12). This tract contains extensions of the gypsum unit in the Muddy Creek Formation that is currently being mined at the PABCO and Pioneer Gypsum Mines. On the basis of present and past production and the existence of remaining gypsum resources, part of the Middle Miocene Thumb Member of the Horse Springs Formation has high potential, with moderate certainty (tract RBG02). Potential areas in this tract are a gypsum-rich unit mapped in the Thumb Member by Castor and others (2000). On the basis of past production and the presence of gypsum-rich beds (upper part of the Kaibab Formation and rocks in the lower part of the Moenkopi Formation), tract RBG03 has moderate potential with a moderate certainty level (fig. 12). The gypsum beds in tract RBG03 are generally lower in quality than those in tract RBG02, owing to the presence of silty interbeds. With the exception of the area including the North Rainbow Gardens mine (fig. 1), gypsum in tracts RBG02 and RBG03 occurs in relatively thin, moderately dipping deposits, and large volumes cannot be mined without extensive overburden removal. In parts of the Sunrise Mountain structural block north of the Boulevard Fault (fig. 1), the rock units are segmented by abundant faults into small blocks that render commercial gypsum mining unlikely.

Other units that have been explored, but not mined for gypsum in the ACEC, are the late Paleozoic Pakoon, Kaibab, and Toroweap Formations. In most of the ACEC, these Mesozoic and Paleozoic units are moderately dipping and the gypsum deposits, which are as much as 30 m thick, have been explored with narrow pits. More extensive mining would require removal of significant amounts of overburden, rendering the relatively low-value gypsum noncommercial. For instance, the upper part of the Toroweap Formation contains gypsum beds as much as 30 m thick. However, this gypsum is typically sandwiched between thick resistant carbonates of the Toroweap and the overlying Kaibab Formation, and thus only small amounts of gypsum could be mined by open pit methods without prohibitively expensive overburden removal. The three active gypsum mines in the Las Vegas area—PABCO (Apex), Blue Diamond, and Pioneer—exploit relatively flat-lying gypsum deposits that require removal of little or no overburden. Presumably, Fibreboard Paper Products moved its gypsum mining operations from the Rainbow Gardens area to the PABCO (Apex) location to reduce mining costs and to ensure long-term reserves.

*Limestone.*—An area underlain by limestone in the north part of the ACEC is considered to have high potential for the limestone deposits for cement production, with a moderate level of certainty (tract RBG04, fig. 12). Although the chemical composition of this limestone has not been directly deter-

mined, XRD analyses indicate that it is nearly pure calcium carbonate. Similar lacustrine limestone is mined by Nevada Cement Company for cement production in northern Nevada (Hardy and others, 2004). Other limestone units in the area are considered to have low potential because they are dolomitic or contain other impurities.

*Lithium Clay.*—An area underlain by lithium-rich sedimentary rocks in the Lovell Wash Formation is judged to have moderate potential as a source of lithium clay (hectorite), with a low certainty level (tract RBG05, fig. 12). The presence of such clay in the area has been established, but the size and purity of possible deposits are unknown. The potential for the production of lithium chemicals is considered to be low. Modern lithium production comes almost exclusively from brines pumped from beneath playas (Kunasz, 2005). Lithium extraction from such brine deposits is very inexpensive, and it is unlikely that other sources will be developed in the near future.

*Silica.*—An area in the north part of the Rainbow Mountains ACEC contains large exposures of Coconino Sandstone as much as 70 m thick; elsewhere in the area the unit is thinner (Castor and others, 2000). The sandstone is similar to that in the Arden ACEC; however, Coconino Sandstone deposits in the Rainbow Gardens ACEC constitute a much smaller resource and commercial potential is low. On the basis of analyses from other areas, potential for commercial silica deposits in the Aztec Sandstone in the Rainbow Gardens ACEC is also low.

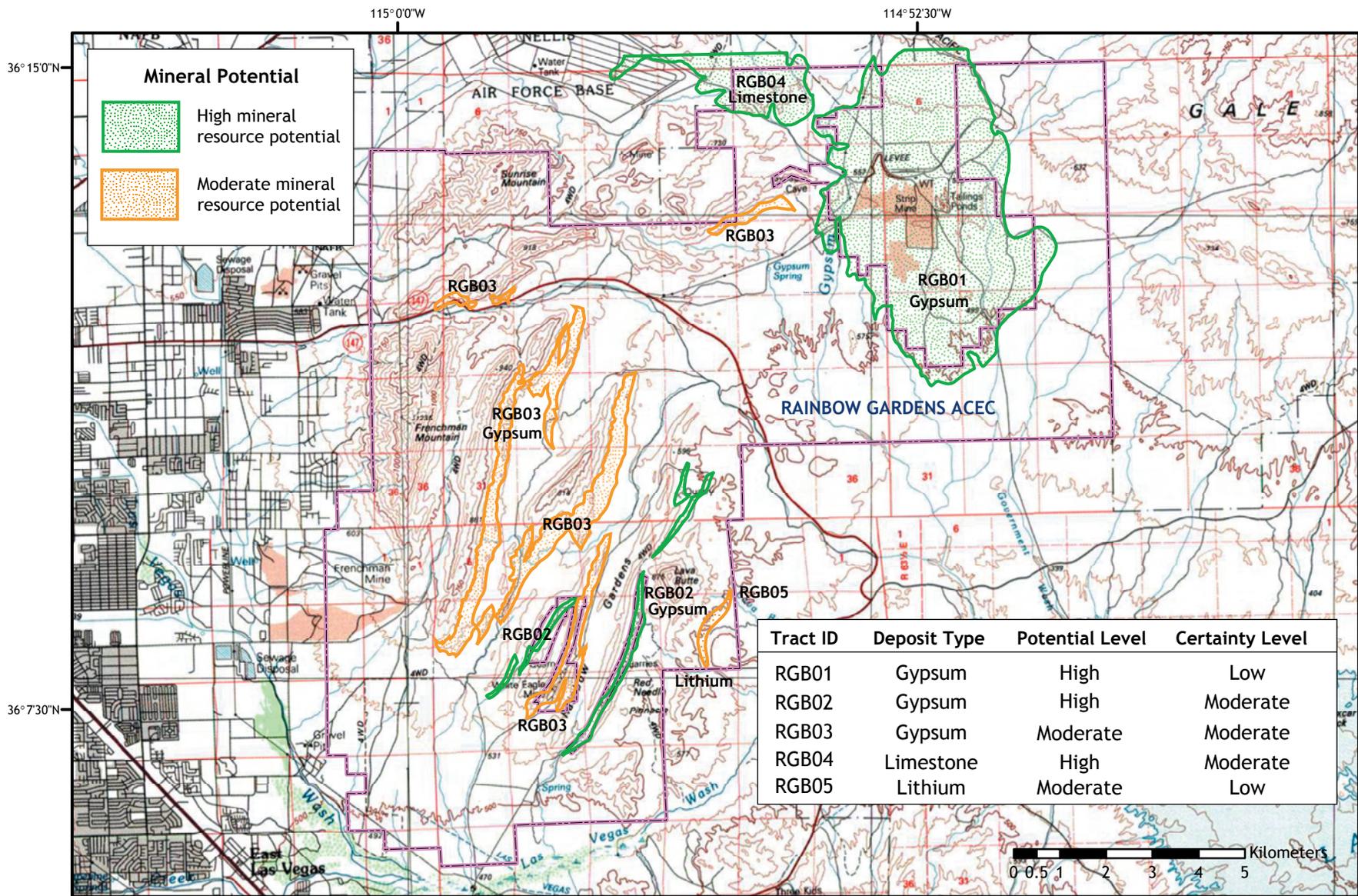
*Metals.*—Although copper and silver minerals occur in a breccia zone on the west flank of Frenchman Mountain, the potential for hydrothermal base- or precious-metal deposits in the ACEC is low.

Detailed geologic mapping in the area did not reveal other occurrences of mineralized rock, and there is nothing distinctive about the geologic environment of the single occurrence that would suggest the presence of undiscovered deposits.

Although anomalous radioactivity was noted in Precambrian rocks west of the Rainbow Gardens ACEC, and anomalously high uranium occurs with copper minerals near the west edge of the ACEC, the area is considered to have low potential for uranium deposits.

### Leasable Minerals

The area is not within the regions considered by the BLM to be prospectively valuable for oil and gas (Smith and Gere, 1983). A single oil exploration hole, McAuley Associates No. 2, was drilled in 1953 to 691 m inside the ACEC near its western border (fig. 1). No geologic data are available, and it was reported as a dry hole by Garside and others (1988). Another dry hole, was drilled to 915 m about 1 km west of the ACEC. Muddy Dome No. 1 was drilled by Rosen Oil Co. in 1965 to a depth of 1,662 m about 5 km east of the ACEC. This hole targeted the Gale anticline, a feature mapped in the Gale Hills block by Longwell and others (1965). The hole was col-



**Figure 12.** Mineral resource potential tracts for gypsum, limestone, and lithium resources in the Rainbow Gardens Area of Critical Environmental Concern (ACEC; outlined in pink).

lared in Jurassic sandstone and bottomed in the Permian Supai Formation. No oil and gas shows were reported, but fresh- and salt-water zones were noted at depth.

There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Rainbow Gardens ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

## Salable Minerals

**Crushed Stone.**—High quality stone is confined to the Cambrian Nopah Formation, the Devonian Crystal Pass Member of the Sultan Formation, and the Permian Pakoon Limestone. These units contain less chert than other Paleozoic carbonate rocks. Together, they constitute tract ARBG01 (fig. 13), which has high potential for deposits of crushed-stone aggregate, with a moderate level of certainty.

Lower quality stone is characterized by chert-bearing carbonate rocks, and including the Cambrian Muav Limestone, Cambrian Frenchman Mountains Dolomite, Mississippian Redwall Limestone, and Permian Kaibab Formation. Portions of the Horse Spring Formation that are composed of conglomerate, sandstone, limestone, and volcanic rocks can also be considered in this category. These rocks constitute tract ARBG03 (fig. 13), which has moderate potential for deposits of crushed-stone aggregate, with a moderate level of certainty.

Triassic sedimentary rocks, Tertiary rocks of the Muddy Creek Formation, and gypsiferous and brecciated units of the Thumb Member of the Miocene Horse Spring Formation represent the lowest quality material, due to their friable nature, lack of thick sandstone and conglomerate units, and the presence of gypsum. These rocks constitute tract ARBG02 (fig. 13), which has low potential for deposits of crushed-stone aggregate, with a low level of certainty.

**Sand and Gravel.**—All the unconsolidated material in the Rainbow Gardens ACEC has high potential for sand and gravel aggregate deposits, with a high degree of certainty (tract ARBG04, fig. 13). Clasts in the most extensive and highest quality sand and gravel deposits are mainly carbonate rocks, and are in the southern and eastern part of the ACEC. The southern deposits are alluvial fans and are ideally situated to provide aggregate materials to the growing Las Vegas Valley. These materials are mostly carbonate rocks. The sand and gravel in the eastern part of the ACEC is mostly eroded from Miocene and Triassic deposits and may not perform as well in construction applications as aggregate supplied from the fans in the south.

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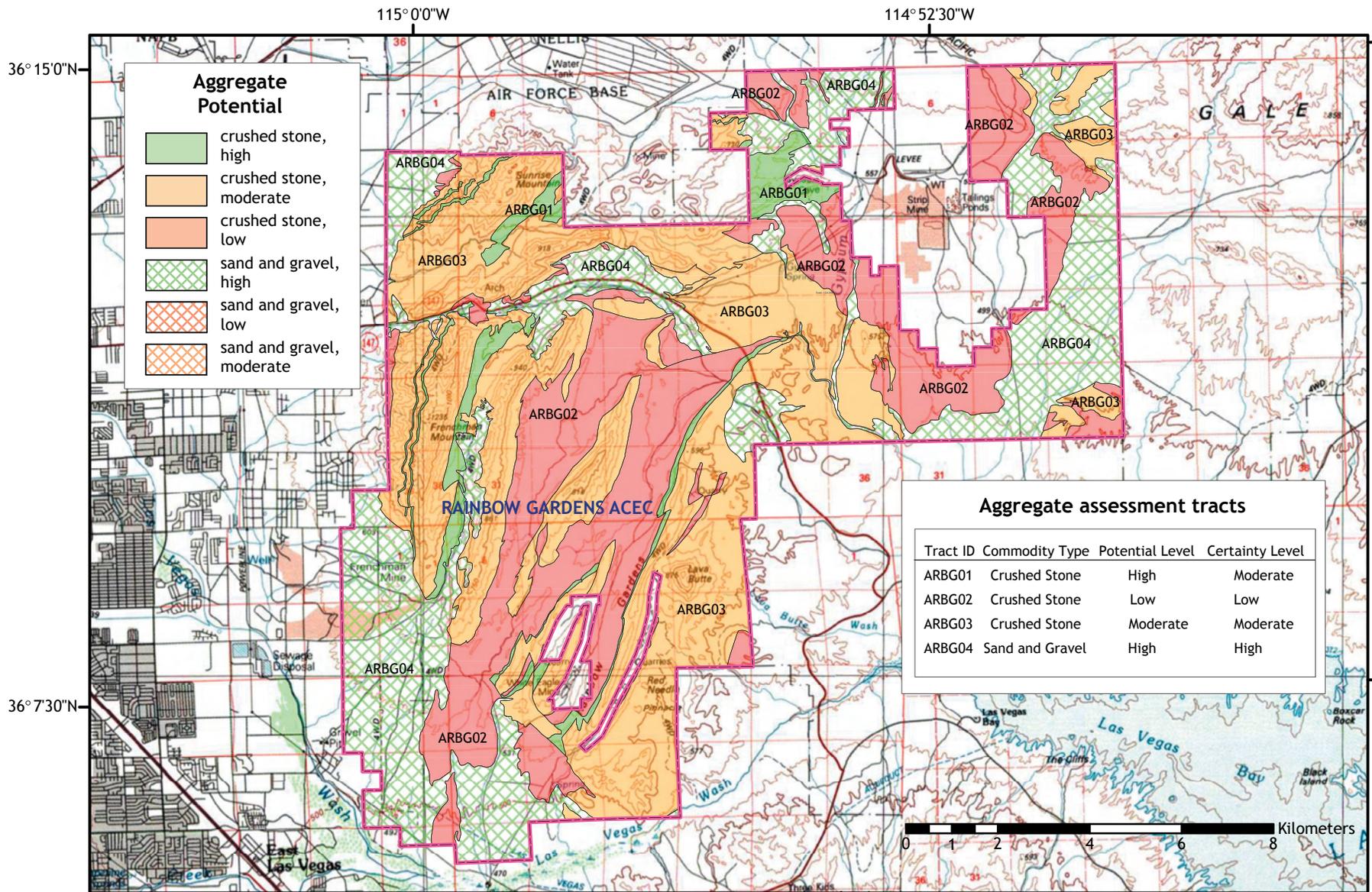


Figure 13. Mineral resource potential tracts for aggregate resources in the Rainbow Gardens Area of Critical Environmental Concern (ACEC; outlined in pink).

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# Chapter J. Mineral Resource Potential of the River Mountains Area of Critical Environmental Concern, Clark County, Nevada

By Steve Ludington, Stephen B. Castor, Brett T. McLaurin, and Kathryn S. Flynn

## Summary and Conclusions

The River Mountains Area of Critical Environmental Concern (ACEC) contains occurrences of altered and mineralized volcanic rocks that are similar to epithermal precious-metal deposits. An area in the southern part of the ACEC, near Railroad Pass and Boulder City, Nevada, has moderate potential for the occurrence of undiscovered epithermal precious-metal deposits. The results of historical exploration and geochemical studies made for this report indicate that the exposed occurrences do not have high enough precious-metal concentrations to encourage development.

Until the 1960s, there was extensive mining of manganese at the north end of the ACEC. These deposits are not now viable, and there is only low potential for the occurrence of undiscovered sedimentary manganese deposits.

Potentially commercial perlite occurs in the northeast part of the ACEC. There are current mining claims staked for perlite, and a small area has high potential for the occurrence of perlite deposits.

There is no potential for the occurrence of other deposits of locatable or leasable minerals.

The River Mountains ACEC has areas of high, moderate, and low potential for the occurrence of crushed-stone aggregate deposits, and areas of high and low potential for the occurrence of sand and gravel aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential of these lands.

The River Mountains ACEC was studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature. Numerous samples were collected and analyzed.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

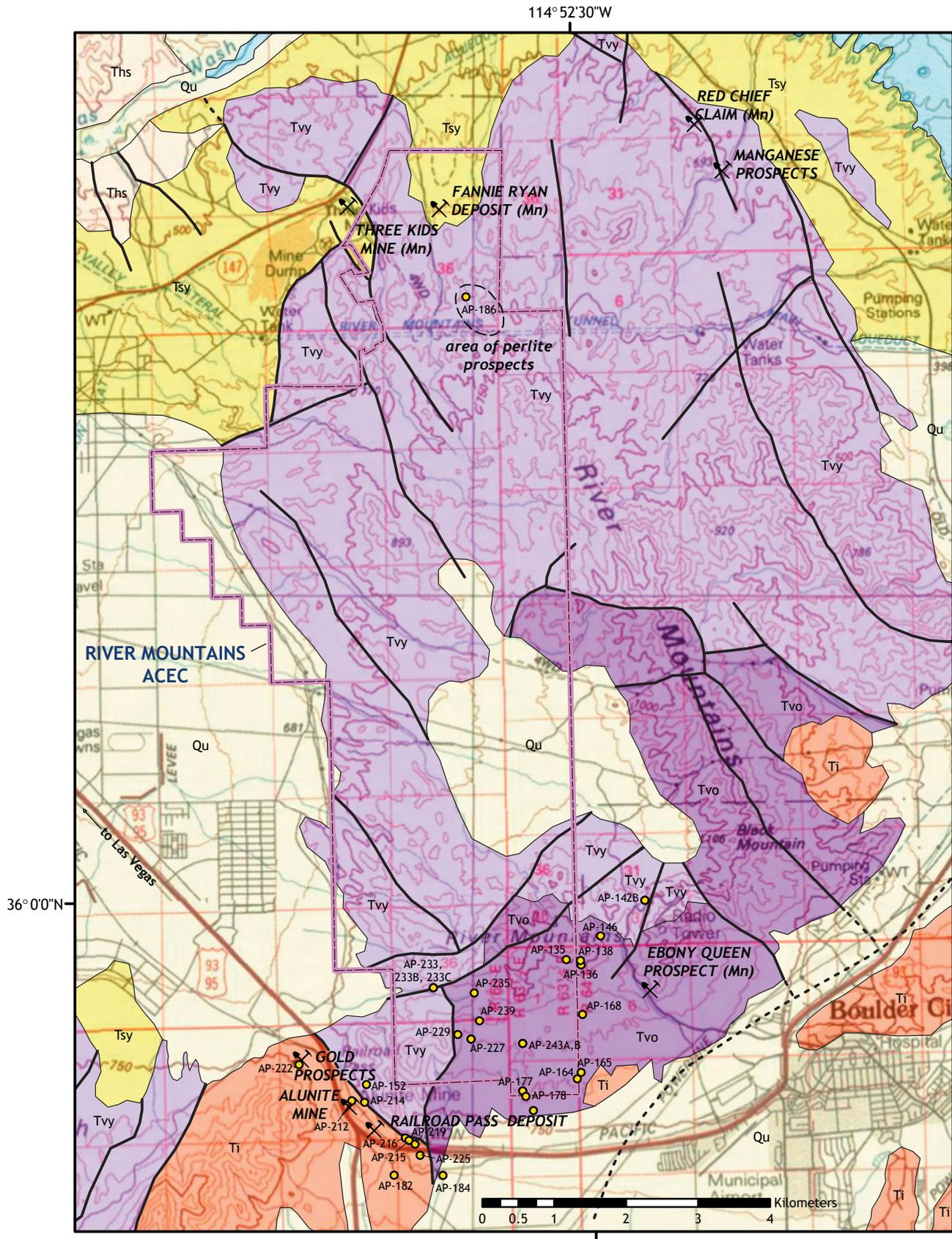
The River Mountains ACEC is southeast of Las Vegas, directly east of the city of Henderson and northwest of Boulder City. It is reached from city streets and paved roads that surround it, as well as by hiking and bicycle trails that enter the area from the Bootleg Canyon road, at the southeast corner of the ACEC. A loop trail, under development, will skirt the south and west sides of the ACEC (<http://www.rivermountainstrail.com>). A legal description of these lands is included in appendix 2.

## Physiographic Description

The River Mountains consist of a series of low mountains whose ridgelines trend north-northwest, parallel to normal faults in the area. Elevations range from about 750 m at the foot of the mountains to a little more than 1,100 m on the highest peaks.

## Geologic Setting

The River Mountains are in the central Basin and Range Physiographic Province, generally characterized by north-trending mountain ranges and intervening valleys, and lie between the Sevier orogenic belt and the Colorado Plateaus. The area underwent large-magnitude extension in the middle to late Miocene, and it lies directly north of the Colorado River extensional corridor (Deubendorfer and others, 1998). The rocks exposed in the River Mountains form part of an



**Figure 1.** Generalized geology of the River Mountains Area of Critical Environmental Concern (ACEC), showing mines, prospects, and locations of analyzed samples. Geology modified from Stewart and Carlson (1978), Anderson (1977), Bell and Smith, (1980), and Smith (1984). See explanation on page 3.

extensive group of middle Tertiary volcanic rocks that extend west into the Mojave Desert of California and south into western Arizona (Smith, 1982, 1986a, b).

## Geology

The rocks in the River Mountains consist of a series of primarily intermediate-composition volcanic and intrusive rocks. These rocks are portrayed on a series of three geologic maps (Anderson, 1977; Bell and Smith, 1980; Smith, 1984)

that were used to help compile the simplified geologic map presented in figure 1.

The oldest group of rocks has been termed the volcanic rocks of River Mountains by Smith (1986a). This group consists of a central intrusion and a sequence of andesites that form the flanks of the volcano. The age of the central pluton is between 13.4 and 12.8 Ma. West of the main outcrop area of this River Mountains volcano is an area underlain by strongly altered and oxidized rocks. The original composition of many of these rocks is uncertain, but they were probably primarily dacites. These rocks, termed the volcanic rocks of Red Mountain by Bell and Smith (1980) and Smith (1984), may be the strongly altered distal equivalents of the rocks of the River Mountains volcano.

A second episode of volcanism produced the volcanic rocks of Bootleg Wash (undated), which are found only in a small outcrop area in the southern part of the River Mountains and consist primarily of andesite and dacite. Succeeding these rocks is a widespread sequence of dacite and andesite domes and flows termed the volcanic rocks of Powerline Road (also undated). Capping the sequence are rhyolites and alkali basalts dated at 12.1 Ma. Each of these four groups of rocks appears to be fault bounded (Smith, 1986a).

Smith and others (1990) and Metcalf and others (1993) studied the petrology of these volcanic rocks and found the andesites and dacites to contain between about 54 and 67 percent silica. They proposed that the rocks formed by mixing of mantle- and crustal-derived magmas, aided by crystal fractionation. They are fundamentally calc-alkaline, although some show elevated potassium contents that are believed to be the result of potassium metasomatism. Several of the rock units commonly contain abundant basaltic inclusions.

All these volcanic rocks are cut by an extensive series of north-northwest-trending normal faults that dip primarily to the east. In detail, the dips of the volcanic rocks are variable, and many of the rocks show no clear bedding features. This structure is thought to be the result of transport and extension related to the west-dipping Saddle Island detachment fault that underlies the River Mountains and McCullough Range (Weber and Smith, 1987). This fault is part of the Lake Mead Fault Zone, and the original position of the River Mountains was apparently tens of kilometers to the east-northeast (Deubendorfer and others, 1998).

The volcanic rocks of Red Mountain are very distinctive on satellite images. This is a result of hydrothermal alteration that has added silica, potassium, and sulfate to the rocks. X-ray diffraction studies of samples from this region show that many of the rocks have been altered to mixtures of quartz, sericite/illite, and alunite.

At the northern end of the ACEC, in the vicinity of the Three Kids Mine, a limited amount of tuffaceous sedimentary rock belonging to the Horse Spring Formation is found above and interlayered with the Miocene volcanic rocks.

All these rocks are overlain by younger sedimentary rocks of the Muddy Creek Formation, and by Quaternary deposits.

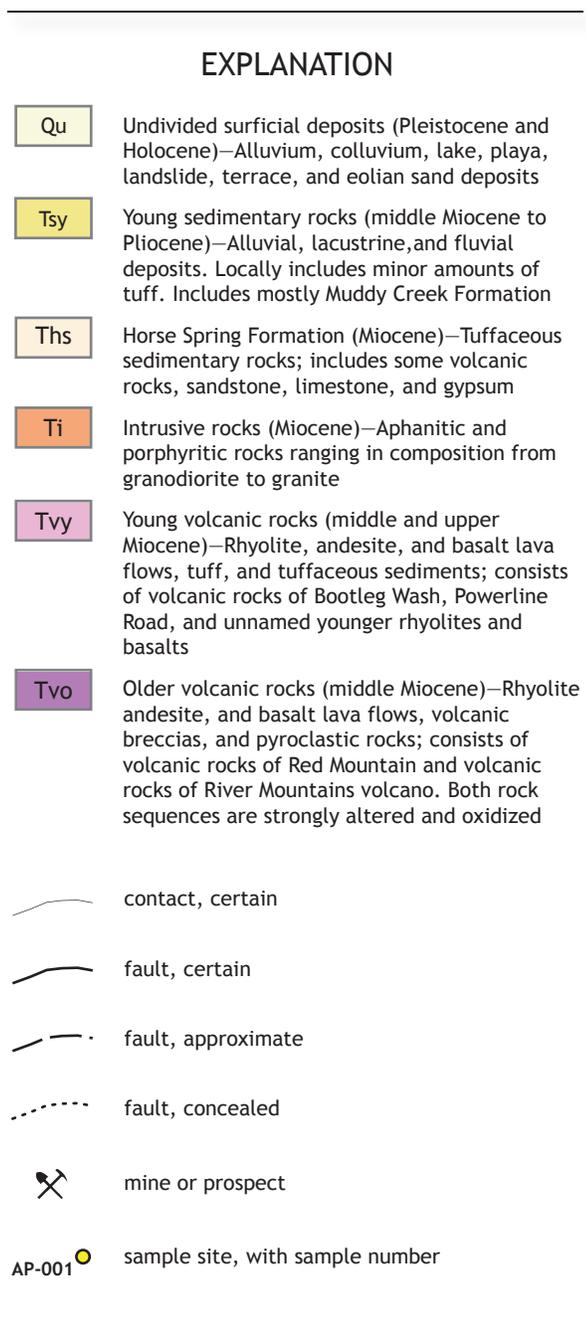


Figure 1. Continued.

## Mining History

Gold and alunite were discovered by R.T. Hill at the southern end of the River Mountains in 1908. The hydrothermal alteration was recognized to be similar to that in the Goldfield district, and initial expectations were high for the discovery of important gold deposits. However, exploration failed to discover high-grade gold ore. Sporadic attempts to mine deposits here, in what became known as the Alunite (or Railroad Pass) district occurred into the 1930s, but the total production of gold was probably not much more than 1,000 ounces, and attempts to recover alunite also proved unsuccessful. The principal mine, known as the Quo Vadis, is about 9 km southwest of the ACEC. However, other deposits, including the Alunite Mine and the Railroad Pass deposit, are located within 2 km of the ACEC, just north of U.S. highways 93 and 95, at Railroad Pass (fig. 1). Information about the history of the Alunite district is from Vanderburg (1937) and Longwell and others (1965).

Several manganese deposits were discovered in Clark County during World War I, when there was a rush of prospecting caused by wartime needs for manganese. The Three Kids Mine, which is located at the north end of the River Mountains ACEC (fig. 1), was active intermittently from 1917 until 1952. Low-grade manganese ore was also produced from unnamed deposits immediately west of the Three Kids Mine, and total production until the end of mining in 1961 exceeded 2,000,000 short tons of ore that yielded about 300,000 short tons of manganese. Most of the ore was mined and sold under contract to the U.S. General Services Administration at a price substantially above the world market price. The Ebony Queen prospect is about 1 km east of the ACEC, about 3 km west of Boulder City. This deposit is a vein, a few hundred meters long, and about 1 to 3 m in width. It was initially explored about 1925, but no manganese was produced. Other manganese occurrences in and near the River Mountains and south of Boulder City have been explored, but ore was not found. Information about the history of the manganese deposits is from Vanderburg (1937) and Longwell and others (1965).

Advanced Mining LLC submitted a plan of operations to the BLM for the Dawson perlite claims located east of Henderson in the northern part of the River Mountains ACEC (fig. 1) in September 2000. The plan called for taking bulk samples for testing, and mining at 50,000 short tons per year was planned if test results were positive (Castor, 2001). More recent information on the project has not been received, and no sign of mining or prospecting activity was noted when the area was visited in early 2005. The claims were active as of November 2005.

## Mineral Deposits

Two important types of metallic mineral deposit occur in and near the River Mountains ACEC. They are the gold deposits related to quartz-alunite alteration in the Alunite (Rail-

road Pass) district, and the manganese deposits that occur in sedimentary rocks of the Horse Spring Formation and volcanic rocks of the River Mountains. Perlite of possible commercial value also occurs in the volcanic rocks of the River Mountains.

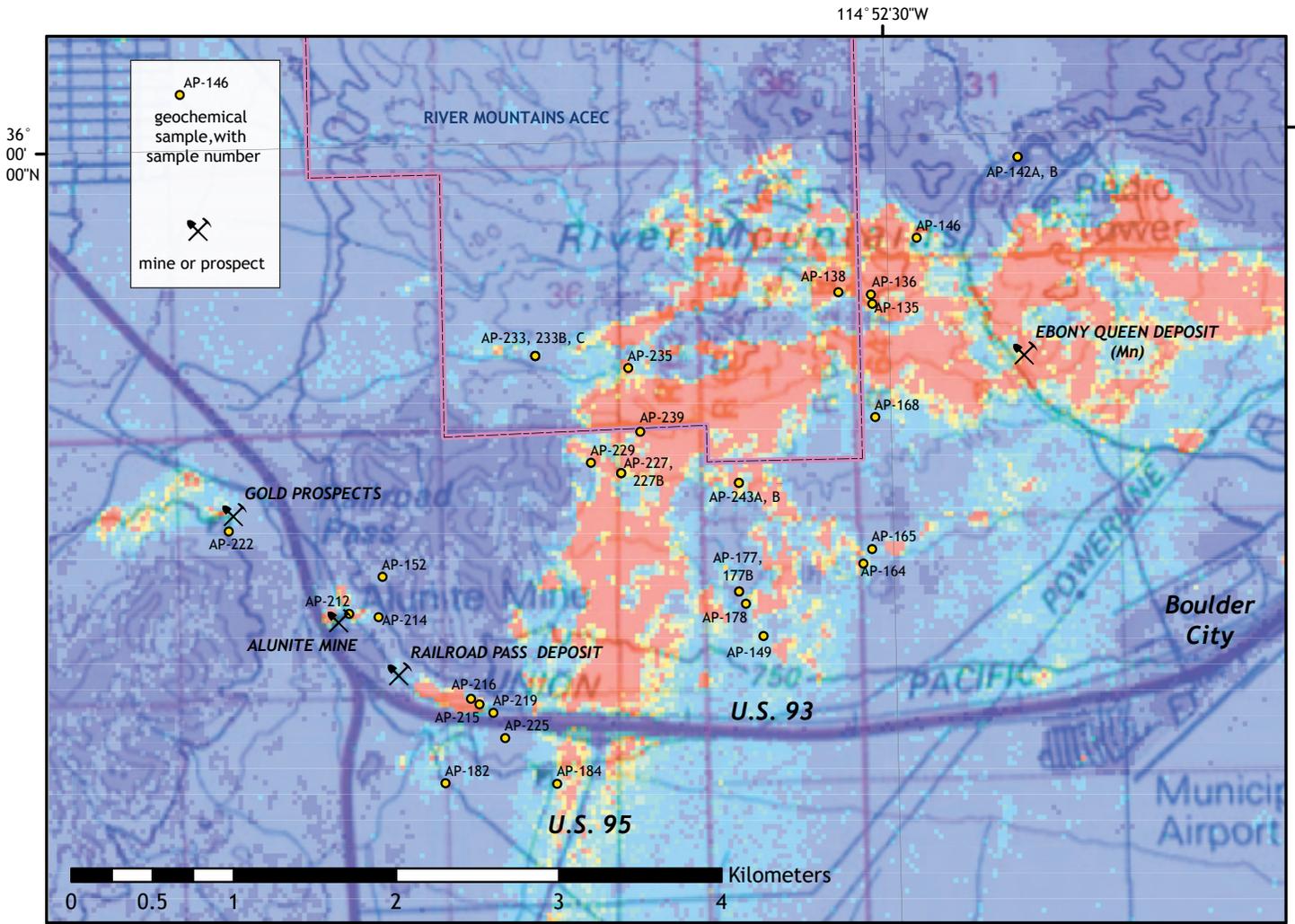
## Epithermal Gold Deposits

The old workings at Railroad Pass are on the southwestern margin of a large area of altered volcanic rock that extends east and north from Railroad Pass. These rocks crop out prominently in the southeastern corner of the River Mountains ACEC (fig. 2). The combination of scattered high precious-metal values, locally anomalous amounts of Bi, Te, and Sn, and widespread altered quartz-alunite rock suggests that this area can be best classified as a high-sulfidation epithermal precious-metal deposit.

The color patterns in figure 2 were generated using Advanced Spaceborne Thermal Emission and Reflection (ASTER), which is a 14-band multispectral satellite imaging system (Rowan and others, 2003). The composite color image uses the ratio of ASTER bands 7 (2.235–2.285  $\mu\text{m}$ ) and 6 (2.185–2.225  $\mu\text{m}$ ). Ground-truth comparisons of the areas colored intense pink in the image, both here in the southern River Mountains and farther south, in the Searchlight district, suggest that this color commonly indicates pervasive quartz-alunite alteration.

The altered rocks, which appear in visible light as various shades of red, yellow, and orange because of fine-grained iron-oxide minerals (fig. 3), correspond closely with rocks mapped by Anderson (1977), Bell and Smith (1980) and Smith (1984) as intensely altered and oxidized volcanic rocks. The altered rocks may be part of a hydrothermal system related to the River Mountains volcano of Smith (1982) or to the Boulder City pluton, dated by Anderson and others (1972) at 13.8 Ma. Of 34 samples analyzed using X-ray diffraction (XRD), 12 were found to contain sericite/illite, 10 alunite (fig. 4), two kaolinite/dickite, and one pyrophyllite. In places, the altered rock contains barite±gypsum veins (sample AP-182, fig. 3; fig. 5) and breccia cemented by gypsum+pyrite. Green copper oxide minerals occur locally. The strongest alteration generally occurs along faults (fig. 6) or resistant silica ledges (fig. 7).

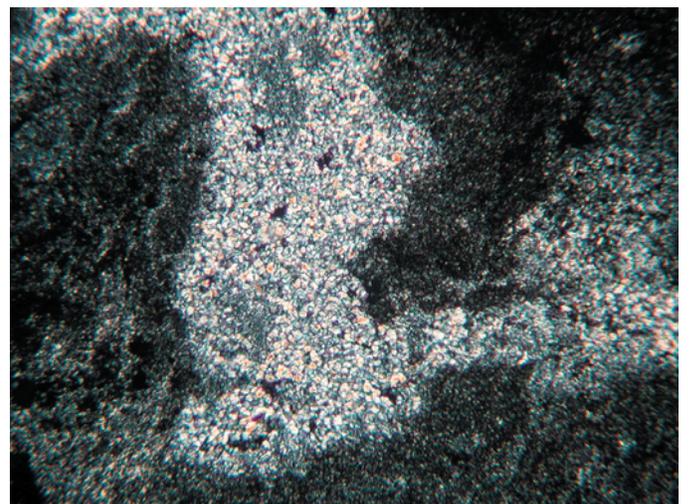
Figures 1 and 2 show the location of rock samples collected during this study that were geochemically analyzed for a variety of elements related to hydrothermal mineralization (Ludington and others, 2005). Of 33 samples analyzed, all but 2 show evidence of sulfur enrichment. Twenty of the 33 samples are at least moderately anomalous in Ag, As, Bi, Cd, Cu, Mo, Pb, Sb, Sn, Te, Tl, W, or Zn. Five samples are highly anomalous: AP-184 (Ag, Bi, Cu, Mo, Zn), AP-233B (Cu, Zn), AP-182 (Mo, Pb), AP-275 (Ag, Pb), and AP-282 (Cu). Only three samples have been analyzed for gold, and they yielded background values (1–7 parts per billion, ppb). One sample reported by Smith and Tingley (1983) from dumps at the Alunite Mine (fig. 1) contains 0.1 parts per million (ppm) Au and <0.5 ppm Ag, and their sample 1327 (fig. 1) contains 0.5 ppm Au and 1 ppm Ag. None of these anomalous samples contain



**Figure 2.** ASTER image (ratio of bands 7/6) of southern part of the River Mountains Area of Critical Environmental Concern (ACEC; outlined in pink). Red color indicates quartz-alunite alteration. See text for details.



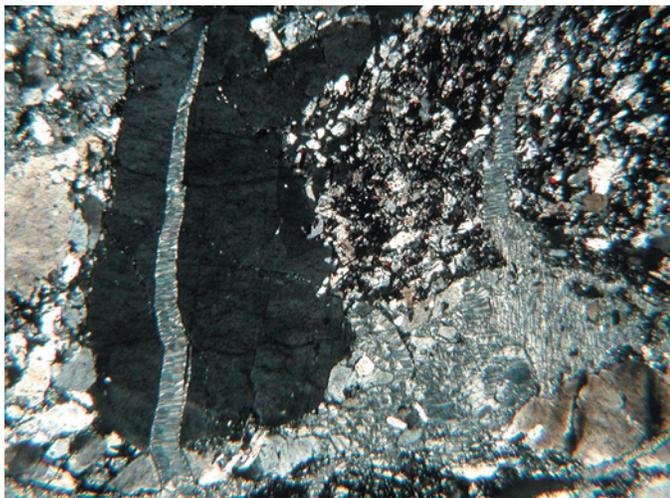
**Figure 3.** Altered and mineralized rocks within the River Mountains ACEC in foreground. Cascata golf course is below, and Boulder City is in the distance.



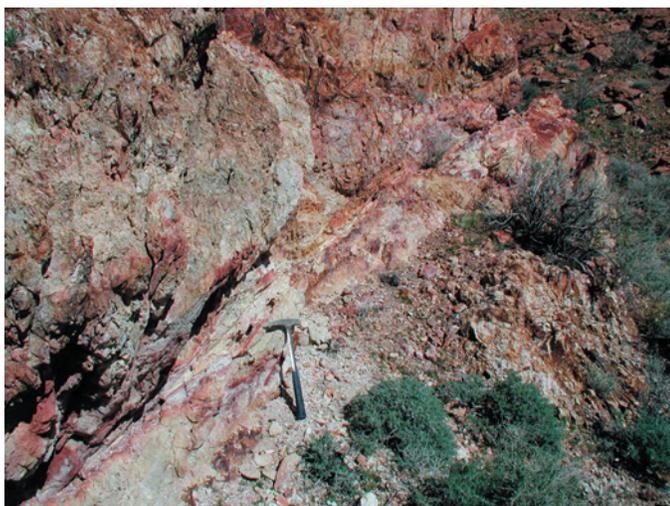
**Figure 4.** Nearly pure alunite in quartz-alunite rock (sample AP-216), 1.6 km south of the River Mountains ACEC. Horizontal field 1.3 mm. Cross-polarized light.

values indicative of commercially viable precious-metal ore; however sample AP-184 contains nearly 7 percent copper.

The area that is strongly altered and mineralized has an extent of more than 10 km<sup>2</sup>, about a third of which is within the River Mountains ACEC (fig. 2). Most of the highly anomalous samples come from an area between US Highway 93 and the ACEC boundary, in and near Boulder City. Alteration and mineralization produced alunite-rich rock that is well exposed in an abandoned railroad cut, as well as at scattered prospects and adits. These workings expose barite+hematite+gypsum veins and, locally, copper oxide minerals. This area along U.S. 93 seems to be the most prospective for precious-metal depos-



**Figure 5.** Barite + hematite vein cut by fibrous gypsum (sample AP-182) from a prospect 2 km south of the River Mountains ACEC. Horizontal field about 2.5 mm. Cross-polarized light.



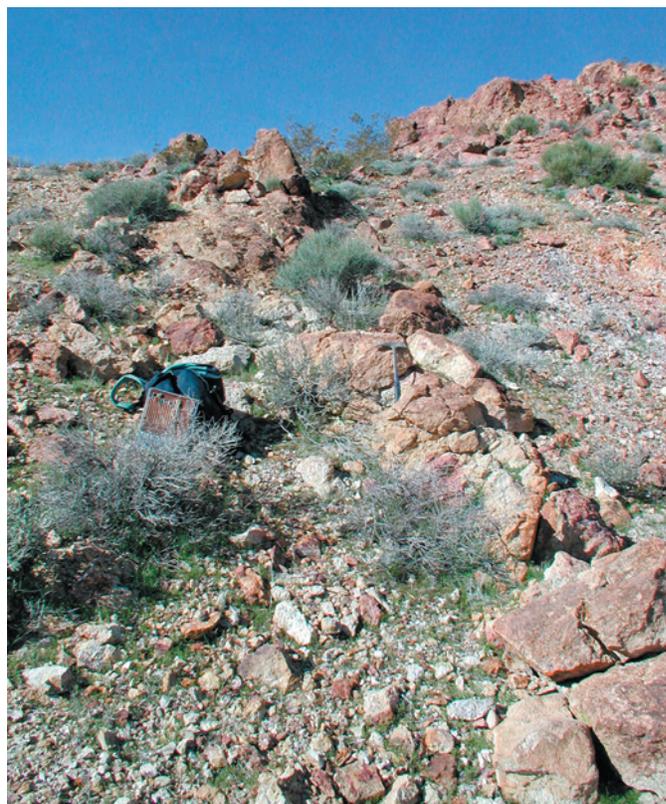
**Figure 6.** Mineralized northeast-striking, northwest-dipping fault within the River Mountains ACEC near sample site AP-138. Altered rock in this area contains quartz, pyrite or limonite, feldspar, and minor alunite.

its. However, the hydrothermally altered area extends northward into the ACEC, and rock with anomalous metal contents (sample AP-233A, fig. 1, fig. 8) occurs there in association with barite veins; silicified, limonitized, and locally alunite-bearing structures; and a few prospect pits.

### Sedimentary Manganese Deposits

The manganese deposits at the Three Kids Mine and nearby unnamed deposits (fig. 1) consist of local accumulations of manganese oxides in tuffaceous siltstone, sandstone, conglomerate, and tuff of the Miocene Horse Spring Formation. According to Longwell and others (1965), the manganese occurs primarily as wad (hydrous manganese oxides), but psilomelane, pyrolusite, and manganite ( $Mn^{3+}O(OH)$ ) are also reported. In places, the wad is opalized. The manganese minerals occur mixed with clastic grains and tuffaceous and gypsiferous material. These accumulations form lenticular pods that vary in size and grade and occur in a syncline that has been deepened by graben faulting at the north end of the River Mountains, adjacent to underlying (but structurally higher) volcanic rocks (Hewett and Weber, 1931).

More modern studies have shown that the mineralized rock consists of transported clasts of colloform manganese



**Figure 7.** Resistant west-trending ledge of altered rock at location AP-132, about 0.5 km east of the River Mountains ACEC. The resistant rock consists mostly of quartz, with lesser feldspar and jarosite.

oxide (todorokite  $[(\text{Mn}, \text{Mg}, \text{Ca}, \text{Ba}, \text{K}, \text{Na})_2 \text{Mn}_3 \text{O}_{12} \cdot 3\text{H}_2\text{O}]$  and coronadite  $[\text{Pb}(\text{Mn}^{4+}, \text{Mn}^{2+})_8 \text{O}_{16}]$ ), manganese-oxide cement (pyrolusite), and manganese-oxide cavity infillings (cryptomelane  $[\text{K}(\text{Mn}^{4+}, \text{Mn}^{2+})_8 \text{O}_{16}]$  and coronadite) (Koski and others, 1988).

In addition to manganese, the rocks in the deposit contain trace amounts of iron, lead, copper, silver, and gold, some of which were occasionally recovered during ore processing (Longwell and others, 1965).

The characteristics of the deposits suggest that manganese minerals were deposited from oxidized, low-temperature fluids in contact with unconsolidated clastic sediment on and below the floor of stratified saline lakes. Strontium isotopic ratios of evaporite and limestone that are interbedded with the manganese deposits are consistent with a lacustrine depositional environment (Koski and others, 1988). Radiometric ages of interbedded tuff units range from about 14 Ma to 12.4 Ma, about the same age as the volcanic flow rocks adjacent to the south (Koski and others, 1990) and as Horse Spring Formation rocks in the Frenchman Mountain area to the north (Castor and others, 2000). The deposits are thus of syngenetic origin, and their ultimate source was probably hot springs related to local volcanic activity (Hewett and Weber, 1931; Hewett, 1933).

## Perlite Deposits

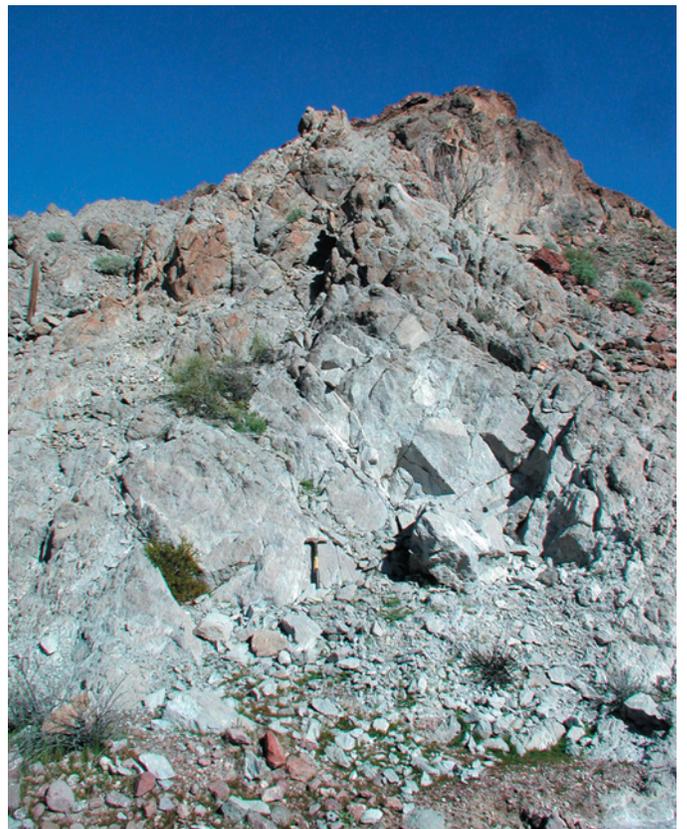
Perlite occurs in a moderately to steeply northwest-dipping tabular body about 20 m wide in the northeastern part of the River Mountains ACEC (fig. 1). This perlite is probably part of the deposit that has been staked as the Dawson perlite claims. It contains minor amounts of feldspar, quartz, and biotite phenocrysts, and the upper part of the body contains as much as 20 percent devitrified rhyolite in the form of



**Figure 8.** Altered and mineralized rocks at the south end of the River Mountains. In the background, the right half of the photograph shows rocks within the River Mountains ACEC.

spherulites. The perlite is light gray (fig. 9) and is of rhyolitic composition with more than 70 percent  $\text{SiO}_2$  (sample AP-186, Ludington and others, 2005). It is contained within devitrified to glassy pumiceous rhyolitic flow rock, which is overlain to the northwest by basaltic andesite flows and debris flows. The perlite is mapped within the dacitic volcanic rocks of Powerline Road. Bell and Smith (1980) reported spherulitic and perlitic dacite in the area of the Dawson perlite claims.

Properties of a select grab sample of the perlite were measured by the New Mexico Bureau of Geology and Mineral Resources. The results of these tests indicate that the perlite sample has relatively high furnace yield, moderate expanded density, and on expansion yields a moderate amount of sinks (sample AP-186, table 1). The expanded perlite has relatively low brightness and large particle size. The test results indicate that it compares favorably with perlite from the Mackie Mine, which is an active operation in Lincoln County, Nevada, that produces expanded perlite mostly sold in horticultural markets. On the basis of the testing, perlite from the River Mountains is less suitable for many markets than perlite from the highly productive No Agua, New Mexico deposits. However, the testing procedure is specifically designed for optimum performance of the No Agua perlite, and better results might be obtained for perlite from the River Mountains using different temperature and feed particle size.



**Figure 9.** Perlite outcrop in the northeastern part of the River Mountains ACEC. Sample AP-186 was taken from this outcrop.

**J8 Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada**

**Table 1.** Test data for perlite expanded at 1300 degrees F. without preheat using material sieved to between 50 and 100 mesh.

[Sieve analyses of expanded perlite reported as percent of sample retained on each sieve at each mesh size. Testing by New Mexico Bureau of Geology and Mineral Resources.]

Sample	Furnace Yield %	Expanded Density lbs/ft3	Average Brightness %	Sinks %	Percent Expanded Retained (Tyler Mesh)							
					20	30	50	70	100	140	Pan	Sum
AP-010A	77	1.94	52.1	22.2	1.0	9.4	30.5	14.2	10.8	11.4	22.7	100.0
AP-010B	88	2.27	55.5	9.6	1.9	17.9	41.1	10.5	7.4	6.8	12.4	100.0
AP-045	68	1.97	60.1	8.4	0.6	6.0	29.9	17.2	12.5	13.0	20.8	100.0
AP-119	92	2.06	52.5	4.8	20.1	34.0	33.7	5.6	2.5	1.3	2.8	100.0
AP-120	96	2.05	50.8	9.0	1.0	8.4	33.1	16.8	12.0	10.3	18.4	100.0
AP-121	86	2.04	52.8	12.0	2.4	16.7	34.5	16.1	9.8	2.1	17.4	99.0
AP-122	85	2.52	57.2	7.0	16.2	27.4	38.7	7.5	35.0	1.9	4.8	100.0
AP-124	96	3.05	42.4	0.6	8.1	42.1	42.9	3.2	1.1	5.0	2.1	100.0
<b>AP-186</b>	<b>95</b>	<b>2.26</b>	<b>57.2</b>	<b>10.2</b>	<b>16.8</b>	<b>33.3</b>	<b>36.0</b>	<b>8.4</b>	<b>3.3</b>	<b>2.1</b>	<b>3.1</b>	<b>100.0</b>
AP-301	84	3.03	56.0	26.2	1.0	12.1	35.9	16.5	11.7	7.7	15.1	100.0
AP-302	90	2.80	59.2	11.4	2.8	12.5	35.1	16.5	10.3	9.5	13.3	100.0
AP-303	90	3.79	62.3	14.2	1.6	21.8	52.0	11.4	4.0	3.0	6.2	100.0
Standard	99	1.87	72.4	6.8	9.9	41.0	37.4	2.9	2.1	4.0	2.7	100.0
Standard	99	1.54	70.6	2.4	19.4	42.5	30.7	3.2	1.9	1.5	0.8	100.0

- AP-010A Grab of fibrous perlite, Nu-Lite Mine, Clark Co., Nevada
- AP-010B 5-m chip of fibrous perlite, Nu-Lite Mine, Clark Co., Nevada
- AP-045 Select grab of granular perlite with phenocrysts, NW of Searchlight Perlite Mine, Clark Co., Nevada
- AP-119 Grab of granular perlite, Pahrock Pit, Mackie Mine, Lincoln Co., Nevada
- AP-120 Select grab of onion skin perlite, Mackie Mine underground, Lincoln Co., Nevada
- AP-121 Grab of granular perlite, main pit, Hollinger Mine, Lincoln Co., Nevada
- AP-122 Grab of granular perlite, east pit, Hollinger Mine, Lincoln Co., Nevada
- AP-124 Grab of granular perlite with obsidian cores, Lovelock perlite pit, Pershing Co., Nevada
- AP-186 Select grab of granular perlite with phenocrysts, River Mountains, Clark Co., Nevada**
- AP-301 Grab of granular perlite, main pit, Searchlight Perlite Mine, Clark Co., Nevada
- AP-302 Grab of granular perlite, northeast pit, Searchlight Perlite Mine, Clark Co., Nevada
- AP-303 Grab of granular perlite, outcrop east of main pit, Searchlight Perlite Mine, Clark Co., Nevada
- Standard Dicaperl granular perlite, No Agua, New Mexico



**Figure 10.** The Bootleg Canyon aggregate pit, a sand and gravel mining operation about 2 km southwest of the River Mountains ACEC.

## Sand and Gravel Operations

A currently active sand and gravel aggregate mine is about 2 km east of the southern part of the ACEC, just west of Boulder City, at the mouth of Bootleg Canyon. It is called the Bootleg Canyon Pit, and is operated by Boulder Sand and Gravel (see figs. 10, 12). Three other similar operations are a few kilometers south of the ACEC along U.S. 95, the Eldorado Pit, the Gornowich Plant, and the Goldstrike Mine.

## Mineral Exploration and Development

There is apparently no current exploration activity for precious metals in or near the River Mountains ACEC. However, there are three active placer claims in sections 25 and 36 of T22S, R63E. In addition, there are 5 active lode claims for perlite in section 36 of T21S, R63E, south of the Fannie Ryan manganese deposit.

## Mineral Resource Potential

### Locatable Minerals

The southeastern part of the River Mountains ACEC appears to have been affected by a robust hydrothermal system that altered most of the rocks to mineral assemblages containing quartz, sericite/illite, and limonite. Alunite occurs in this altered rock locally, along with rare kaolinite and pyrophyllite. These minerals are characteristic of high-sulfidation epithermal precious-metal deposits. However, on the basis of our sampling, the hydrothermal system appears to have been relatively deficient in precious and base metals, and we have designated this area (tract RVM01, fig. 11) to have moderate potential for high-sulfidation epithermal precious-metal deposits, with a moderate level of certainty. The discovery of significant amounts of mineralized rock with significantly higher metal contents could raise this potential estimate. This would probably require drilling to test the hydrothermal system at depth.

Although several small manganese deposits, similar to those exploited at the Three Kids Mine exist within and near the River Mountains ACEC, these deposits appear to be too small and too low grade to be commercially viable. Outcropping manganese deposits are relatively easy to detect, and we assign only a low potential for the occurrence of undiscovered sedimentary manganese deposits. A dramatic rise in the price of manganese could change this, but the large size of manganese deposits typically exploited throughout the world makes development of manganese deposits in the River Mountains a highly unlikely event in the foreseeable future.

Perlite of possible commercial quality occurs in the northeastern part of the River Mountains ACEC. It is not clear if the deposits can be mined economically; the perlite body that we examined is steeply dipping and would have to be mined in

narrow pits or underground. However, more extensive deposits may be present in the immediate area. We assign high potential for perlite, with a moderate level of certainty, to a small area that includes the Dawson perlite claims and our sample site (tract RVM02, fig. 11). There is no indication from our work, previous prospecting, or detailed geologic mapping (Bell and Smith, 1980) that there are more perlite deposits in the area.

### Leasable Minerals

No part of the River Mountains ACEC is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There is no indication of potential for brine or evaporite deposits of sodium or potassium. The ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is judged to be low.

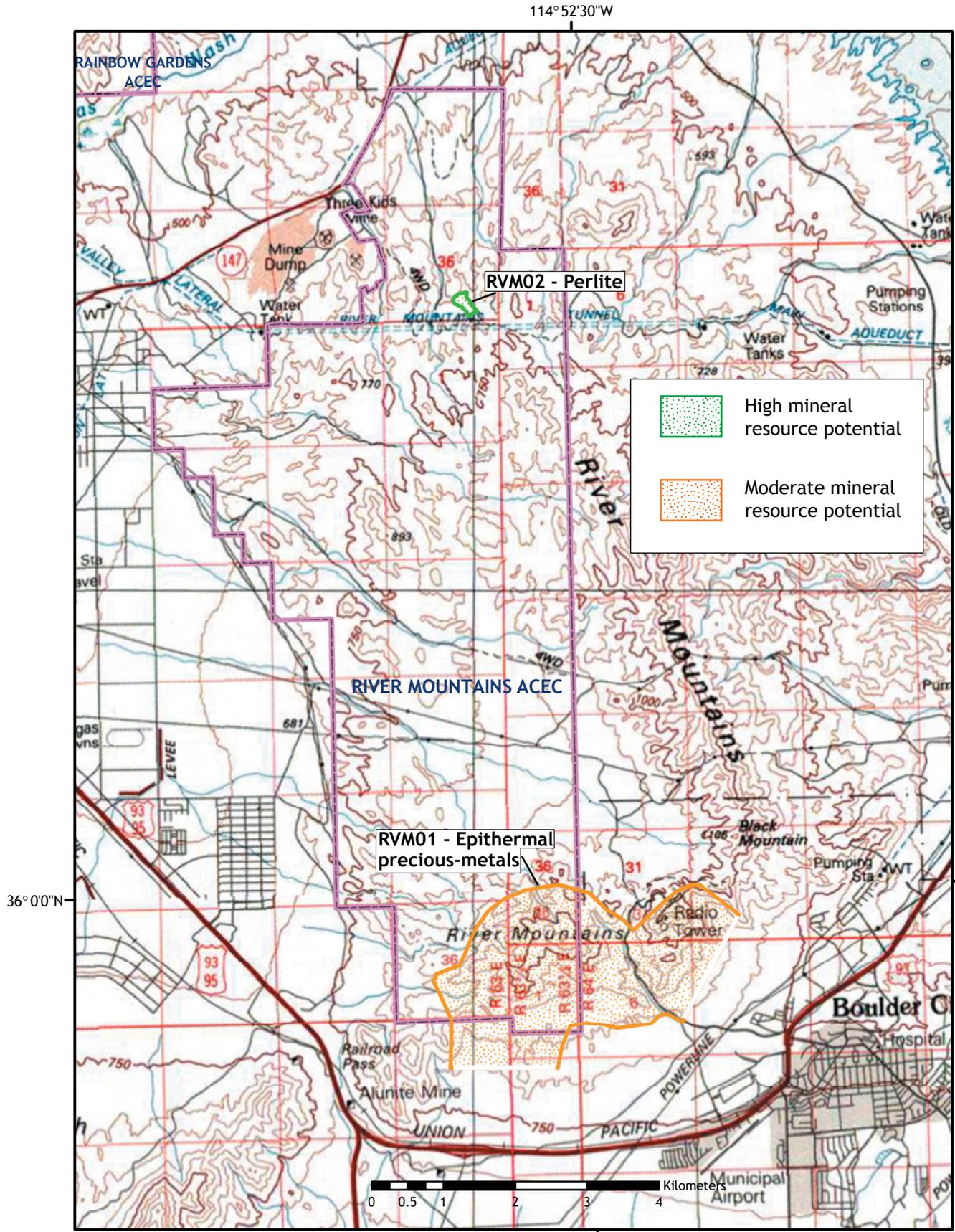
### Salable Minerals

*Crushed Stone.*—We consider the fanglomerates that are exposed in the interior valley in the southern part of the ACEC to have high potential for crushed-stone aggregate, with a moderate certainty level (tract ARVM01, fig. 12). The clasts in these fanglomerates are primarily dacitic volcanic rocks that have been sorted for durability by abrasion during Pliocene fan formation. Most of the outcrop areas of volcanic rock are judged to have moderate potential, with a moderate certainty level (tract ARVM03, fig. 12). The presence of glass and microcrystalline quartz in these fine-grained volcanic rocks makes them susceptible to alkali-silica reactivity (ASR), which can cause rapid deterioration of concrete and reduces the suitability of such rocks for concrete applications. The material might be suitable as base rock or asphalt aggregate. Areas underlain by volcanic breccia and mudflow units and by fine-grained parts of the Muddy Creek Formation are assigned low crushed-stone aggregate potential, with a high level of certainty (tract ARVM02, fig. 12).

*Sand and Gravel.*—Alluvial sand and gravel deposits are found at the north end and in the interior valley in the southern part of the ACEC. The intermittent streams that deposited this alluvium drain northwest and empty onto alluvial fans east of the city of Henderson. Together, these areas have been designated to have high potential, with a high level of certainty (tract ARVM04, fig. 12). There are also low-potential sand and gravel deposits that have been backfilled into pits associated with the manganese mining at the Three Kids Mine site (tract ARVM05, fig. 12).

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**Figure 11.** Mineral resource potential tracts for locatable and leasable minerals in the River Mountains Area of Critical Environmental Concern (ACEC; outlined in pink).

114° 52'30"W

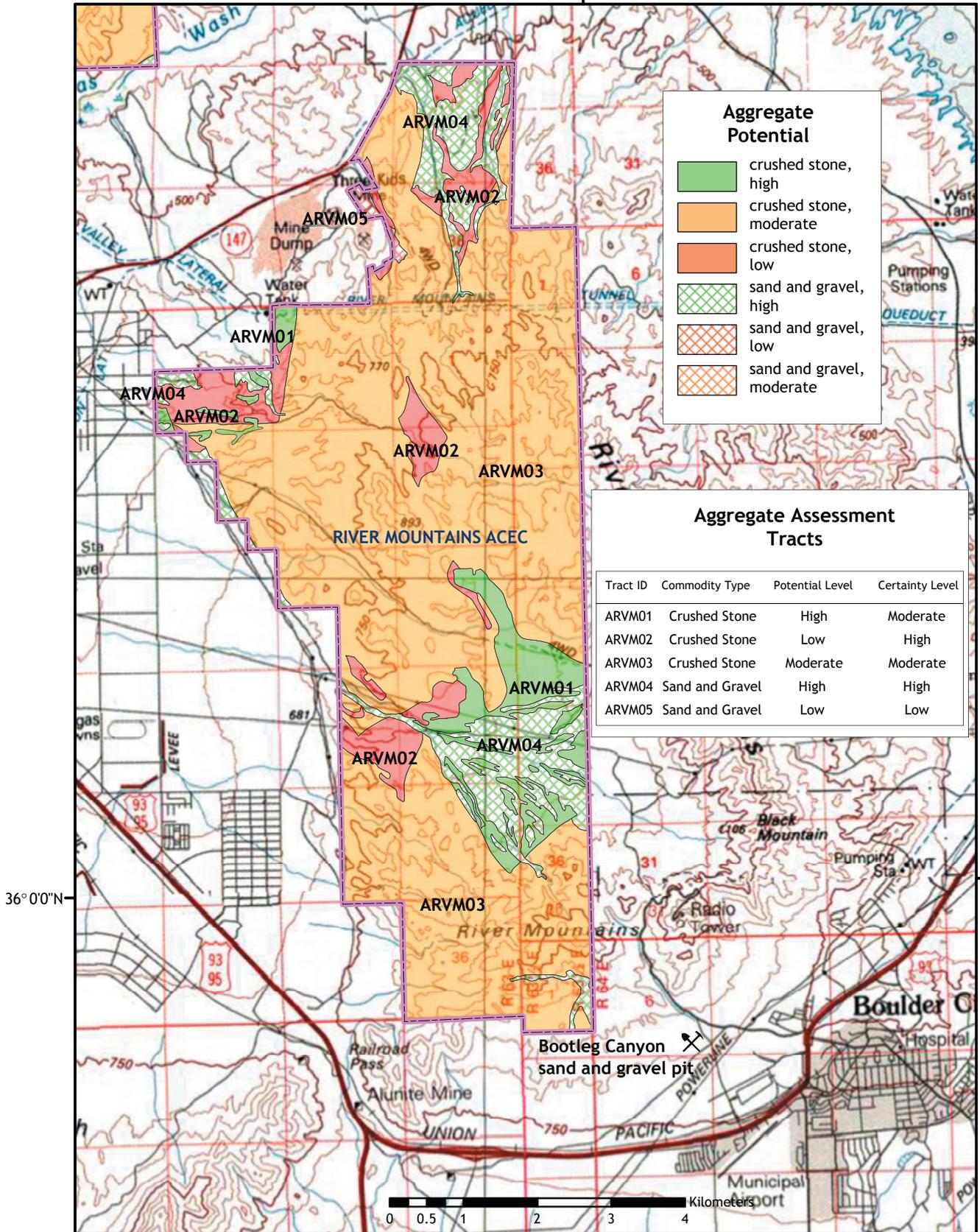


Figure 12. Mineral resource potential tracts for aggregate resources in the River Mountains Area of Critical Environmental Concern (ACEC; outlined in pink).

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# Chapter K. Mineral Resource Potential of the Stump Spring Area of Critical Environmental Concern, Clark County, Nevada

By Kathryn S. Flynn, Steve Ludington, Brett T. McLaurin, and Stephen B. Castor

## Summary and Conclusions

The Stump Spring Area of Critical Environmental Concern (ACEC) exposes only unconsolidated Quaternary sediments. There are no known mineral deposits in the ACEC and no potential for the occurrence of deposits of locatable or leasable minerals.

Because there is no bedrock outcrop in the ACEC, there is no potential for the occurrence of crushed-stone aggregate deposits. The potential for the occurrence of sand and gravel aggregate deposits is low.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Stump Spring ACEC was studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

The Stump Spring Area of Critical Environmental Concern (ACEC) is located approximately 2 km northeast of the Nevada-California border in the Pahrump Valley. It is about 50 km west of Las Vegas and about 30 km southeast of the town of Pahrump. The ACEC is accessible by unimproved roads

from the Old Spanish Trail Highway. A legal description of these lands is included in appendix 2.

## Physiographic Description

The Stump Spring ACEC is in Pahrump Valley, which is separated by the Spring Mountains from Las Vegas Valley to the east. The west boundary of the Pahrump Valley is formed by the Nopah and Kingston Ranges. The valley is relatively flat and as much as 25 km wide. The ACEC ranges from about 780 to 850 meters in elevation and contains a small intermittent stream that drains southwest. The ACEC is named for Stump Spring, which was used by early travelers through the area.

## Geologic Setting

Pahrump Valley is on the southwest margin of the Basin and Range Physiographic Province. The region has experienced multiple periods of deformation, including Mesozoic compression followed by extension that began in Miocene time. The State Line Fault Zone, a zone of strike-slip faulting that strikes almost parallel to the Nevada-California border in the center of the valley, is within the Walker Lane belt, a major northwest zone of right-lateral faulting caused by late Tertiary to modern extension (Stewart, 1992). Analysis of gravity data indicates that the valley could have formed as a pull-apart, transtensional structure along the State Line Fault Zone (Blakely and others, 1998).

The mountains bordering the Pahrump Valley are mostly composed of Late Proterozoic and Paleozoic carbonate and siliciclastic rocks, which probably also underlie the valley. The subsurface bedrock of Pahrump Valley is deformed and topographically complex (Blakely and others, 1998); it is covered by sedimentary deposits that are Oligocene and younger in age. These include Quaternary playa deposits and large alluvial fans on the northeast side of the valley (Sweet-kind and others, 2003).

## Geology

The Stump Spring ACEC is located in an area of Quaternary sediments (fig. 1). Channel gravels become finer-grained upward, becoming mudstone near the top of the sequence. The mudstones are overlain by silt and thin gravel beds (Quade, 2000). These deposits, as well as fossils found in the area, record a change from an environment of fluvial and lacustrine conditions during the most recent glacial cycle to the arid conditions found today.

## Mining History

There has been no known mining within the study area.

## Mineral Deposits

There are no known mineral deposits within the study area. The Beck mine, an iron skarn deposit, is about 10 km southwest of the ACEC in California, and some outlying mines of the Goodsprings polymetallic district are about 20-30 km east-southeast of Stump Spring.

## Mineral Exploration and Development

There are no active mining claims in or near the area, and no known mineral exploration activity.

## Mineral Resource Potential

### Locatable Minerals

On the basis of gravity data, the basin fill beneath the Stump Spring ACEC is about 1,000 m thick (Jachens and others, 1996). There is no known metal-mineralized rock or indication of other locatable mineral deposits, and there is no potential for locatable minerals.

### Leasable Minerals

The area is within the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). The closest exploration well, Miskell-Gov't No. 1, was drilled in 1959 along the west flank of the Spring Mountains about 18 km northeast of the ACEC. It was a dry hole, with minor oil shows, drilled entirely in the Permian Bird Spring Formation to a depth of 793 m (Garside and others, 1988).

There is no indication of potential for brine or evaporite deposits of sodium or potassium. The Stump Spring ACEC

contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

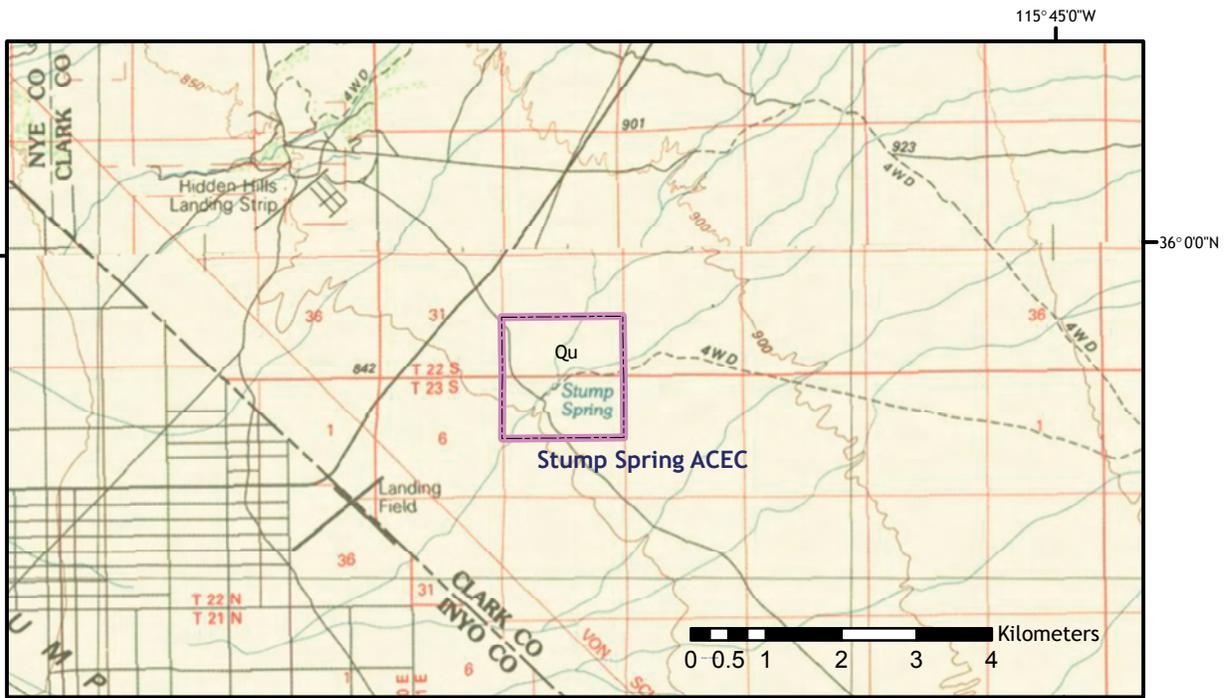
### Salable Minerals

*Crushed Stone.*—There is no bedrock outcrop in the ACEC, and no potential for crushed-stone aggregate deposits.

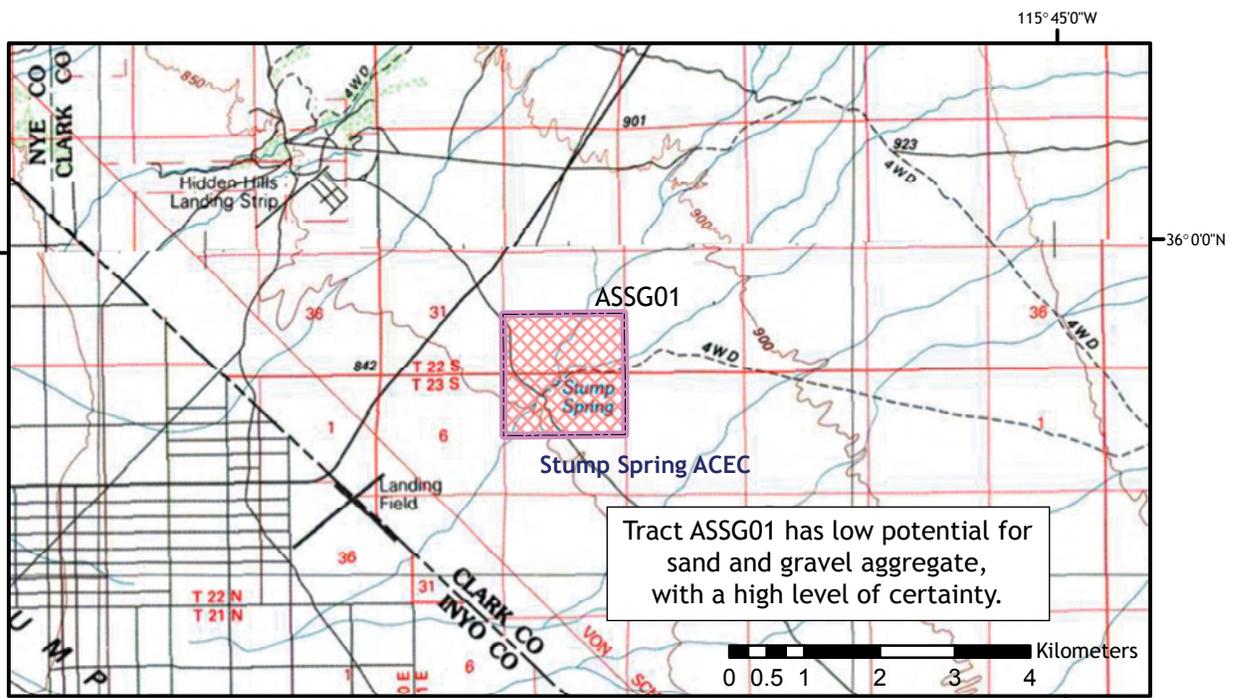
*Sand and Gravel.*—The surface of the ACEC is dominated by small sand dunes stabilized by sparse vegetation. Cobbles of limestone, chert, and sandstone are present, but not in enough quantity to be considered high-quality aggregate. The area has low potential for sand and gravel aggregate deposits, with a high certainty level (fig. 2).

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**Figure 1.** Generalized geology of the Stump Spring Area of Critical Environmental Concern. All materials are unconsolidated Quaternary deposits, including alluvium, colluvium, and playa deposits.



**Figure 2.** Mineral resource potential tracts for sand and gravel aggregate deposits in the Stump Spring Area of Critical Environmental Concern (ACEC; outlined in pink).

# Chapter L. Mineral Resource Potential of the Big Dune Area of Critical Environmental Concern, Nye County, Nevada

By Stephen B. Castor, Brett T. McLaurin, Steve Ludington, and Kathryn S. Flynn

## Summary and Conclusions

The Big Dune Area of Critical Environmental Concern (ACEC) is mostly underlain by Quaternary eolian sand. The sand is unsuitable as a silica source, and the sandy area has low potential for the occurrence of silica sand deposits. There is no potential for the occurrence of other deposits of locatable or leasable minerals.

The ACEC contains areas with both moderate and low potential for the occurrence of sand and gravel aggregate deposits, but there is no potential for the occurrence of crushed-stone aggregate deposits.

## Introduction

This report was prepared for the U.S. Bureau of Land Management (BLM) to provide information for land planning and management, and, specifically, to determine mineral resource potential in accordance with regulations at 43 CFR 2310, which governs the withdrawal of public lands. The Clark County Conservation of Public Land and Natural Resources Act of 2002 temporarily withdraws the lands described herein from mineral entry, pending final approval of an application for permanent withdrawal by the BLM. This report provides information about mineral resource potential on these lands.

The Big Dune ACEC was studied in the field to confirm descriptions of the geology that were gleaned from the scientific literature. One sample was collected and analyzed.

Definitions of mineral resource potential and certainty levels are given in appendix 1, and are similar to those outlined by Goudarzi (1984).

## Lands Involved

The Big Dune ACEC is about 15 km west of the town of Amargosa Valley and about 3 km southwest of US Highway 95 (fig. 1). It can be accessed most easily using unimproved roads from the east (U.S. 95) and south. A legal description of these lands is included in appendix 2.

## Physiographic Description

The southwest part of the Big Dune ACEC consists of a cluster of shifting longitudinal and barchan dunes (fig. 2) that reach elevations of as much as 835 m. The dunes lie on a southward draining alluvial fan surface, which comprises the east and northeast part of the ACEC. The lowest point in the ACEC is at the southeastern corner at an elevation of about 750 m on the alluvial fan surface.

## Geologic Setting

The Big Dune ACEC is in the Amargosa Desert, a northwest-trending structural basin in the Basin and Range Physiographic Province. The Amargosa Desert occupies an area between the north-trending Basin and Range structures to the northeast and northwest-trending structures to the southwest. It lies along the possible southeastern continuation of the Walker Lane Belt, a major northwest-trending zone of right-lateral faulting caused by late Tertiary to modern extension (Stewart, 1992).

## Geology

The Big Dune ACEC is covered by Quaternary eolian sand and fanglomerate. A simplified geologic map is presented in figure 1. The source of the sand is mostly Precambrian (Neoproterozoic) rocks that lie 2 to 10 km to the southwest. The alluvium mainly contains Precambrian metamorphic, Paleozoic carbonate, and Cenozoic volcanic detritus.

## Mining History

There has been no known mining in the Big Dune area. Claims were staked on the sand dunes for silica, aluminum, iron, gold, and titanium (records 6461 and 14977, Nevada Bureau of Mines and Geology, 2001), but these claims have lapsed and there are now (2006) no active claims in the ACEC.

## Mineral Deposits

There are no known mineral deposits in the Big Dune ACEC. Chemical analysis of a sample (AP-110) of eolian sand from Big Dune (Ludington and others, 2005) shows that the sand contains about 73 percent  $\text{SiO}_2$  and thus is not suitable as a source of silica. In addition, the sand contains no significant metal concentrations.

The closest mineral occurrences are gold-bearing quartz veins in Proterozoic rocks and limonitically altered Paleozoic carbonate rocks. These occurrences are in the Lee mining district, about 7 km southwest of Big Dune (Ball, 1907). No gold production has been reported from the district (Cornwall, 1972).

## Mineral Exploration and Development

There is no current exploration activity for minerals in or near the Big Dune ACEC. There are no active claims in the Big Dunes ACEC.

## Mineral Resource Potential

### Locatable Minerals

The Big Dunes ACEC has no potential for locatable mineral deposits.

### Leasable Minerals

Because the chemical composition is not suitable, the dune area in the ACEC cannot be considered a viable silica sand deposit. The potential for silica sand is low.

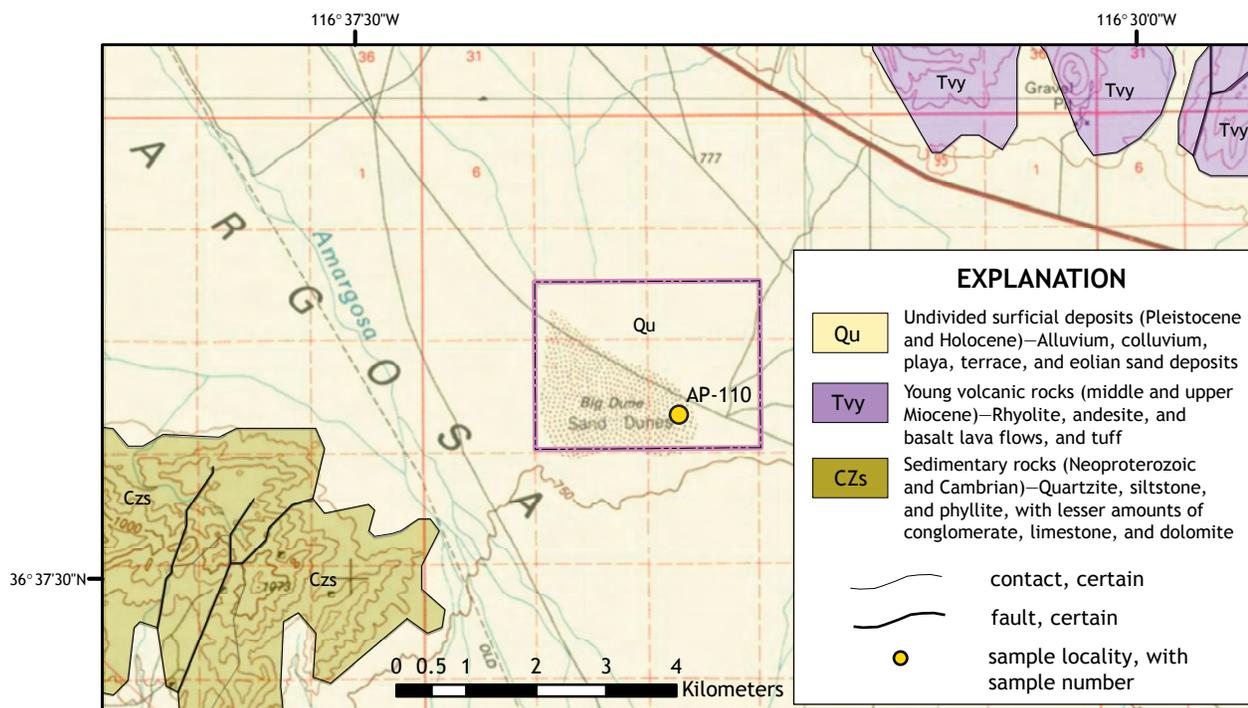
Most of the Big Dune ACEC is within the area the region considered by the BLM to be moderately favorable for oil and gas (Smith and Gere, 1983). There are no exploration wells reported in Nevada within 80 km of the ACEC (Garside and others, 1988).

There is no indication of potential for brine or evaporite deposits of sodium or potassium. The ACEC contains no known deposits of other leasable minerals, and the potential for their occurrence is low.

### Salable Minerals

*Crushed Stone.*—Because no rock crops out, there is no potential for crushed stone aggregate in the ACEC.

*Sand and Gravel.*—The southwest half of the ACEC is covered by fine-grained sand, as sheets and dunes as much as 80 m thick (Swadley and Carr, 1987). The portion of the ACEC that is beneath sand has low potential for sand and gravel aggregate, with a high certainty level (tract ABGD03, fig. 3). However, clastic sediment underlies the dune; it is primarily exposed in the northeast half of the ACEC. This sediment consists of alluvial fan deposits that contain pebble- to boulder-sized clasts of Proterozoic quartzite, Paleozoic carbonate rocks, and Cenozoic volcanic rocks. This area has moderate potential for sand and gravel aggregate, with a moderate certainty level (tract ABGD02, fig. 3).



**Figure 1.** Big Dune Area of Critical Environmental Concern (ACEC; outlined in pink), showing generalized geology and location of analyzed sample. Geology modified from Stewart and Carlson (1978).

Some of the silica-rich clasts may reduce the quality of this aggregate due to alkali-silica reactivity (ASR). There are very large amounts of similar material in the immediate surroundings of the Big Dune ACEC, as it constitutes much of the sediment that fills the Amargosa Valley.

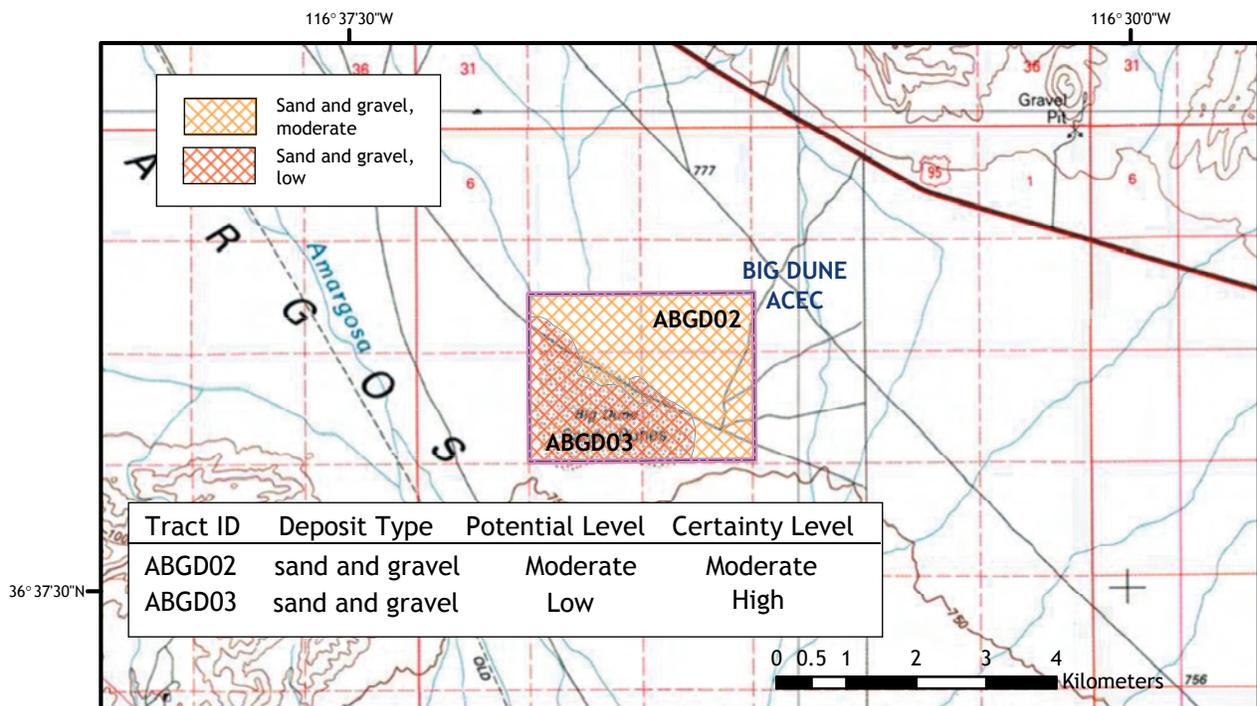


**Figure 2.** Sand dunes in the Big Dune Area of Critical Environmental Concern. Photo taken toward the northwest. Note all-terrain vehicle tracks in the foreground.

## References

Ball, S.H., 1907, A geologic reconnaissance in southwestern Nevada and eastern California: U.S. Geological Survey Bulletin 283, 308 p.  
 Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77, 49 p.

Garside, L.J., Hess, R.H., Fleming, K.L., and Weimer, B.S., 1988, Oil and gas developments in Nevada: Nevada Bureau of Mines and Geology Bulletin 104, 136 p.  
 Goudarzi, G.H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84-0787, 41 p.  
 Ludington, Steve, Castor, S.B., Budahn, J.R., and Flynn, K.S., 2005, Geochemical analyses of geologic materials from areas of critical environmental concern, Clark and Nye Counties, Nevada: U.S. Geological Survey Open-File Report 05-1450 [http://pubs.usgs.gov/of/2005/1450/].  
 Nevada Bureau of Mines and Geology, 2001, Nevada Abandoned Mines Database Compilation Update: Nevada Bureau of Mines and Geology Bulletin Open-File Report 01-03.  
 Smith, M.B., and Gere, W.C., 1983, Lands valuable for oil and gas, Nevada: U.S. Bureau of Land Management, prepared by the U.S. Geological Survey, Conservation Division, Western Region, map, scale 1:500,000.  
 Stewart, J.H., 1992, Walker Lane belt, Nevada and California: An overview, in Craig, S.D., ed., Structure, tectonics and mineralization of the Walker Lane: Geological Society of Nevada Walker Lane Symposium Proceedings Volume, p. 1–16.  
 Stewart, J.H., and Carlson, J.E., 1978, Geologic map of Nevada: U. S. Geological Survey, scale 1:500,000.  
 Swadley, W.C., and Carr, W.J., 1987, Geologic map of the Quaternary and Tertiary deposits of the Big Dune Quadrangle, Nye County, Nevada, and Inyo County, California: U.S. Geological Survey Miscellaneous Investigations Map I-1767, scale 1:48,000.



**Figure 3.** Mineral resource potential tracts for aggregate resources in the Big Dune Area of Critical Environmental Concern (ACEC; outlined in pink).

## Appendix 1. Definitions of Levels of Mineral Resource Potential and Certainty of Assessment

### Definitions of Mineral Resource Potential

**HIGH mineral resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

**MODERATE mineral resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

**LOW mineral resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with few or no indications of having been mineralized.

**UNKNOWN mineral resource potential** is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

**NO mineral resource potential** is a category reserved for a specific type of resource in a well-defined area.

### Definitions of Levels of Certainty

**LOW certainty level** means that available information suggests the level of mineral resource potential.

**MODERATE certainty level** means that available information gives a good indication of the level of mineral resource potential.

**HIGH certainty level** means that available information clearly defines the level of mineral resource potential.

These definitions are adapted from those published in: Goudarzi, G.H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84-0787.

## **Appendix 2. Legal Descriptions of Selected Areas of Critical Environmental Concern in Clark and Nye Counties, Nevada.**

The chapter to which the legal descriptions apply is indicated by capital letters; for example, appendix 2E gives legal descriptions for the areas discussed in chapter E. There is no legal description for the introductory chapter (chapter A).

## Appendix 2B. Legal Descriptions of Piute-Eldorado Tortoise, Crescent Townsite, and Keyhole Canyon Areas of Critical Environmental Concern, Clark County, Nevada

### Piute-Eldorado Tortoise

	Legal Description	Part	
Approx. Total Acreage = 325,271.50 (Clark County) (NVN 076881)	<u>T. 28 S., R. 60 E.,</u>		
	sec. 2,	All;	
	sec. 3,	All;	
	sec. 10,	All;	
	sec. 11,	All;	
	sec. 13,	W½;	
	secs. 14 to 17, inclusive;		
	secs. 21 to 23, inclusive;		
	sec. 24,	All, Except Mineral Entry Patents;	
	sec. 25,	N½, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 26,	lots 2-7, inclusive, 9, partial lots 8, 10, 11, SW¼NE¼, SE¼NW¼, NW¼SE¼, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 27,	All.	
		<u>T. 26 S., R. 61 E.,</u>	
		sec. 1,	All;
		sec. 2,	All;
		secs. 11 to 14, inclusive;	
		sec. 24,	All;
	sec. 25,	All;	
	sec. 36,	All.	
	<u>T. 27 S., R. 61 E.,</u>		
	sec. 1,	All;	
	sec. 12,	All;	
	sec. 13,	All;	
	secs. 23 to 26, inclusive;		
	sec. 35,	All;	
	sec. 36,	All.	
	<u>T. 28 S., R. 61 E.,</u>		
	sec. 1,	All;	
	sec. 2,	All;	
	secs. 10 to 12, inclusive;		
	sec. 13,	N½N½N½, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 14,	N½N½N½, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 15,	N½NE¼, SW¼NE¼, NW¼, W½SW¼, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 16,	All;	
	sec. 19,	lots 3, 4, partial lots 1, 2, NE¼, E½NW¼, E½SW¼, SE¼, All, Except Mineral Entry Patents;	
	sec. 20,	N½, N½S½, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline and Excluding Mineral Survey 4916A Patent;	
	sec. 21,	All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 22,	All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	
	sec. 29,	All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;	

sec. 30, lot 1, partial lot 2, NE $\frac{1}{4}$ NW $\frac{1}{4}$ , All , North of Right-of-Way Nev058548 (NV Hwy 164) Centerline.

T. 29 S., R. 61 E.,

sec. 36, All.

T. 26 S., R. 62 E.,

secs. 3 to 10, inclusive;  
 secs. 15 to 20, inclusive;  
 sec. 22, E $\frac{1}{2}$ , N $\frac{1}{2}$ NW $\frac{1}{4}$ ;  
 secs. 23 to 26, inclusive;  
 sec. 27, NE $\frac{1}{4}$ ;  
 secs. 29 to 32, inclusive;  
 sec. 35, All;  
 sec. 36, All.

T. 27 S., R. 62 E.,

sec. 1, All;  
 secs. 5 to 8, inclusive;  
 sec. 12, All;  
 sec. 13, E $\frac{1}{2}$ ;  
 secs. 17 to 20, inclusive;  
 sec. 24, E $\frac{1}{2}$ ;  
 sec. 25, E $\frac{1}{2}$ ;  
 secs. 29 to 36, inclusive.

T. 28 S., R. 62 E.,

secs. 1 to 17, inclusive;  
 sec. 18, partial lots 5, 6, All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;  
 sec. 20, All;  
 sec. 21, All;  
 sec. 22, N $\frac{1}{2}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;  
 secs. 23 to 26, inclusive;  
 sec. 27, NE $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ ;  
 sec. 28, All;  
 sec. 29, All;  
 sec. 31, lot 15, partial lots 14, N $\frac{1}{2}$ SE $\frac{1}{4}$ , Excluding MS 2518 Patent;  
 secs. 32 to 36, inclusive.

T. 29 S., R. 62 E.,

secs. 1 to 5, inclusive;  
 sec. 6, E $\frac{1}{2}$ ;  
 secs. 7 to 32, inclusive;  
 sec. 33, NE $\frac{1}{4}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ NW $\frac{1}{4}$ ;  
 secs. 34 to 36, inclusive.

T. 30 S., R. 62 E.,

sec. 1, All;  
 sec. 2, All;  
 secs. 11 to 14, inclusive.

T. 27 S., R. 62 $\frac{1}{2}$  E.,

sec. 1, All, unsurveyed;  
 sec. 12, All, unsurveyed;  
 sec. 13, All, unsurveyed;  
 sec. 24, All, unsurveyed;

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sec. 25, All, unsurveyed;  
sec. 36, All, unsurveyed.

### T. 26 S., R. 63 E.,

sec. 19, All;  
sec. 20, W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, West of Right-of-Way CC020733 (Interstate-95) Centerline and South of Powerline Right-of-Way N869 Centerline;  
sec. 21, S $\frac{1}{2}$ S $\frac{1}{2}$ , All, South of Powerline Right-of-Way N869 Centerline;  
sec. 22, S $\frac{1}{2}$ S $\frac{1}{2}$ S $\frac{1}{2}$ , All, South of Powerline Right-of-Way N869 Centerline;  
sec. 23, All, South of Powerline Right-of-Way N869 Centerline;  
sec. 24, All, South of Powerline Right-of-Way N869 Centerline;  
sec. 25, S $\frac{1}{2}$ N $\frac{1}{2}$ NE $\frac{1}{4}$ NE, W $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , SE $\frac{1}{4}$ , All, South of Powerline Right-of-Way N869 Centerline;  
secs. 26 to 36, inclusive.

### T. 27 S., R. 63 E.,

secs. 1 to 36, inclusive.

### T. 28 S., R. 63 E.,

secs. 1 to 8, inclusive;  
sec. 9, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;  
sec. 10, All;  
sec. 11, All;  
sec. 12, lots 1 to 8, inclusive, N $\frac{1}{2}$ ;  
sec. 13, lots 1 to 3, inclusive, NW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;  
sec. 14, lots 1,2, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ ;  
sec. 15, lots 1, 2, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , All, Except Mineral Entry Patents;  
secs. 16 to 20, inclusive;  
sec. 29, NE $\frac{1}{4}$ , N $\frac{1}{2}$ NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , All, North of Right-of-Way Nev058548 (NV Hwy 164) Centerline;  
sec. 30, lots 1 to 4, inclusive, N $\frac{1}{2}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, Except SENE that is South of Right-of-Way Nev058548 (NV Hwy 164) Centerline and Except the E $\frac{1}{2}$ SE $\frac{1}{4}$ ;  
sec. 31, All;  
sec. 32, W $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ .

### T. 29 S., R. 63 E.,

secs. 5 to 10, inclusive;  
secs. 15 to 22, inclusive;  
sec. 23, W $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , SE $\frac{1}{4}$ , All, West of Right-of-Way CC020845 (Interstate-95) Centerline; sec. 24, All, West of Right-of-Way CC020845 (Interstate-95) Centerline;  
sec. 25, W $\frac{1}{2}$ W $\frac{1}{2}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ , All, West of Right-of-Way CC020845 (Interstate-95) Centerline;  
secs. 26 to 36, inclusive.

### T. 30 S., R. 63 E.,

secs. 1 to 24, inclusive;  
sec. 25, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;  
secs. 26 to 29, inclusive;  
secs. 32 to 35, inclusive;  
sec. 36, S $\frac{1}{2}$ N $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , SE $\frac{1}{4}$ ;

### T. 31 S., R. 63 E.,

secs. 1 to 5, inclusive;  
secs. 8 to 16, inclusive;  
secs. 22 to 26, inclusive;

sec. 36, All.

T. 26 S., R. 64 E.,

sec. 29, S $\frac{1}{2}$ N $\frac{1}{2}$ , S $\frac{1}{2}$ , All, South of Powerline Right-of-Way N869 Centerline;  
 sec. 30, lots 2, 3, 4, partial lot 1, S $\frac{1}{2}$ N $\frac{1}{2}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ N $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ,  
 All, South of Powerline Right-of-Way N869 Centerline;  
 secs. 31 to 33, inclusive.

T. 27 S., R. 64 E.,

secs. 4 to 9, inclusive;  
 secs. 16 to 23, inclusive;  
 sec. 25, All, Except Mineral Survey 4071 Patent;  
 sec. 26, All;  
 sec. 27, All;  
 sec. 28, All, Except Mineral Survey 3541 Patent;  
 sec. 29, All, Except Mineral Survey 3541 Patent;  
 sec. 30, All;  
 sec. 31, All;  
 sec. 32, All, Except Mineral Survey 3541 Patent;  
 sec. 33, All, Except Mineral Survey 3541 Patent;  
 secs. 34 to 36, inclusive.

T. 28 S., R. 64 E.,

secs. 1 to 6, inclusive;  
 sec. 7, lot 1, partial lots 2, 3, 4, NE $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, Except Mineral Survey and Mineral Entry Patents;  
 sec. 8, All, Except Mineral Survey 3788 Patent;  
 secs. 9 to 16, inclusive;  
 sec. 17, All, Except Mineral Surveys 3755 and 3788 Patents;  
 sec. 18, lots 2, 4, partial lot 1, W $\frac{1}{2}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ , All, Except Mineral Survey and Mineral Entry Patents;  
 secs. 21 to 26, inclusive;  
 sec. 35, All;  
 sec. 36, All.

T. 29 S., R. 64 E.,

secs. 1 to 3, inclusive;  
 secs. 9 to 16, inclusive;  
 secs. 21 to 28, inclusive;  
 secs. 31 to 36, inclusive.

T. 30 S., R. 64 E.,

secs. 1 to 29, inclusive;  
 sec. 31, lots 3, 4, 13 to 68, inclusive, E $\frac{1}{2}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;  
 secs. 32 to 36, inclusive.

T. 31 S., R. 64 E.,

secs. 1 to 31, inclusive;  
 sec. 32, N $\frac{1}{2}$ , SW $\frac{1}{4}$ ;  
 secs. 33 to 36, inclusive.

T. 32 S., R. 64 E.,

secs. 1 to 3, inclusive;  
 sec. 4, lots 1, 2, 5 to 24, inclusive, 34 to 47, inclusive, 59 to 82, inclusive, 84 to 128, inclusive, S $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ , SW $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;  
 sec. 5, lots 6 to 9, inclusive, 12, 13, 15 to 22, inclusive, 25 to 29, inclusive, 32 to 37, inclusive, 40

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to 45, inclusive, 47 to 78, inclusive, SW<sup>1</sup>/<sub>4</sub>NE<sup>1</sup>/<sub>4</sub>, SE<sup>1</sup>/<sub>4</sub>NW<sup>1</sup>/<sub>4</sub>, NW<sup>1</sup>/<sub>4</sub>SE<sup>1</sup>/<sub>4</sub>;  
 sec. 6, All;  
 sec. 8, All;  
 sec. 9, lots 1, 2, 7, 8, 10 to 21, inclusive, 27 to 30, inclusive, 38 to 41, inclusive, 48, 49, 56, 63, 75  
 to 77, inclusive, 79 to 84, inclusive, SW<sup>1</sup>/<sub>4</sub>NE<sup>1</sup>/<sub>4</sub>, NW<sup>1</sup>/<sub>4</sub>SE<sup>1</sup>/<sub>4</sub>;  
 secs. 10 to 16, inclusive;  
 sec. 22 to 26, inclusive;  
 sec. 36, All.

T. 30 S., R. 65 E.,

secs. 4 to 6, inclusive, unsurveyed;  
 sec. 7, All, Except Mineral Survey 3942 Patent, unsurveyed;  
 sec. 8, All, Except Mineral Survey 3936 and 3942 Patents, unsurveyed;  
 sec. 9, All, Except Mineral Survey 3936 Patent, unsurveyed;  
 sec. 16, All, unsurveyed;  
 sec. 17, All, Except Mineral Survey 3942 Patent, unsurveyed;  
 sec. 18, All, Except Mineral Survey 3942 Patent, unsurveyed;  
 secs. 19 to 21, inclusive, unsurveyed;  
 sec. 30, All, unsurveyed;  
 sec. 31, All, unsurveyed.

T. 31 S., R. 65 E.,

sec. 6, All, unsurveyed;  
 secs. 28 to 33, inclusive, unsurveyed.

T. 32 S., R. 65 E.,

secs. 2 to 8, inclusive;  
 sec. 9, N<sup>1</sup>/<sub>2</sub>, All, North of Right-of-Way CC022416 (NV Hwy 163) Centerline;  
 sec. 10, N<sup>1</sup>/<sub>2</sub>, All, North of Right-of-Way CC022416 (NV Hwy 163) Centerline;  
 sec. 11, N<sup>1</sup>/<sub>2</sub>, N<sup>1</sup>/<sub>2</sub>N<sup>1</sup>/<sub>2</sub>SW<sup>1</sup>/<sub>4</sub>, N<sup>1</sup>/<sub>2</sub>SE<sup>1</sup>/<sub>4</sub>, All, North of Right-of-Way CC022416 (NV Hwy 163)  
 Centerline;  
 sec. 12, NW<sup>1</sup>/<sub>4</sub>, N<sup>1</sup>/<sub>2</sub>SW<sup>1</sup>/<sub>4</sub>, All, North and West of Right-of-Way CC022416 (NV Hwy 163)  
 Centerline;  
 secs. 17 to 20, inclusive;  
 secs. 29 to 32, inclusive.

T. 33 S., R. 65 E.,

sec. 5, All.

**Crescent Townsite**

	<b>Legal Description</b>	<b>Part</b>
Approx. Total Acreage = 420.00 (Clark County) (NVN 076872)	<u>T. 28 S., R. 61 E.,</u>	
	sec. 29,	SW <sup>1</sup> / <sub>4</sub> , W <sup>1</sup> / <sub>2</sub> SE <sup>1</sup> / <sub>4</sub> , Except Mineral Entry Patents;
	sec. 30,	E <sup>1</sup> / <sub>2</sub> SE <sup>1</sup> / <sub>4</sub> ;
	sec. 32,	W <sup>1</sup> / <sub>2</sub> NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> .

**Keyhole Canyon**

	<b>Legal Description</b>	<b>Part</b>
Total Acreage = 240.53 (Clark County) (NVN 076879)	<u>T. 26 S., R. 63 E.,</u>	
	sec. 3,	lots 6 to 8, inclusive, SW <sup>1</sup> / <sub>4</sub> NE <sup>1</sup> / <sub>4</sub> , S <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> .

## Appendix 2C. Legal Descriptions of Gold Butte A, Gold Butte B, Virgin Mountain (Gold Butte C), Whitney Pocket, Red Rock Spring, Devil's Throat, and Gold Butte Townsite Areas of Critical Environmental Concern

### Gold Butte, Part A

	Legal Description	Part
Approx. Total Acreage = 185,670.52 (Clark County) (NVN 076875)	<u>T. 14 S., R. 69 E.,</u>	
	secs. 24 to 26, inclusive;	
	secs. 34 to 36, inclusive.	
	<u>T. 15 S., R. 69 E.,</u>	
	secs. 1 to 3, inclusive,	
	sec. 9,	All;
	sec. 10,	All;
	sec. 11,	N $\frac{1}{2}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , SW $\frac{1}{4}$ SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 12,	All;
	sec. 13,	All;
	sec. 14,	NE $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ ;
	sec. 15,	All;
	sec. 16,	All;
	secs. 21 to 28, inclusive;	
	secs. 33 to 36, inclusive.	
<u>T. 16 S., R. 69 E.,</u>		
secs. 1 to 5, inclusive;		
secs. 8 to 17, inclusive;		
sec. 18,	SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;	
sec. 19,	E $\frac{1}{2}$ ;	
secs. 20 to 28, inclusive;		
secs. 33 to 36, inclusive.		
<u>T. 17 S., R. 69 E.,</u>		
secs. 1 to 3, inclusive;		
secs. 11 to 14, inclusive;		
sec. 24,	All;	
sec. 25,	All, Except Mineral Survey 4709 Patent;	
sec. 36,	All, Except Mineral Surveys 4709 and 4710 Patents;	
<u>T. 18 S., R. 69 E.,</u>		
sec. 1,	lots, 1,2, partial lots 3, 4, S $\frac{1}{2}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ , Except Mineral Survey 4710 Patent.	
<u>T. 14 S., R. 70 E.,</u>		
sec. 1,	All;	
secs. 10 to 36, inclusive.		
<u>T. 15 S., R. 70 E.,</u>		
secs. 2 to 11, inclusive;		
secs. 15 to 20, inclusive;		
sec. 21,	All, Except Mineral Survey 1988 Patent;	
sec. 22,	All, Except Mineral Survey 1988 Patent;	
secs. 28 to 33, inclusive.		
<u>T. 16 S., R. 70 E.,</u>		
secs. 4 to 11, inclusive;		

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secs. 13 to 36, inclusive.

T. 17 S., R. 70 E.,

secs. 1 to 36, inclusive.

T. 18 S., R. 70 E.,

secs. 1 to 6, inclusive, unsurveyed;

secs. 10 to 15, inclusive, unsurveyed;

secs. 22 to 27, inclusive, unsurveyed;

secs. 34 to 36, inclusive, unsurveyed.

T. 13 S., R. 71 E.,

sec. 32, All;

sec. 33, W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, West of Range Improvement (Fence) 0101.

T. 14 S., R. 71 E.,

sec. 4, lots 2, 3, 4, partial lot 1, SW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, West of Range Improvement (Fence) 0101;

secs. 5 to 8, inclusive;

sec. 9, W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, West of Range Improvement (Fence) 0101;

sec. 10, W $\frac{1}{2}$ W $\frac{1}{2}$ , All, West of Range Improvement (Fence) 0101;

sec. 15, W $\frac{1}{2}$ , All, West of Range Improvement (Fence) 0101;

secs. 16 to 20, inclusive;

sec. 21, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ , All, West of Range Improvement (Fence) 0101 (and CC 022455 Pipeline);

sec. 22, W $\frac{1}{2}$ W $\frac{1}{2}$ , All, West of Range Improvement (Fence) 0101;

sec. 28, W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , All, West of Range Improvement (Fence) 0101 (and CC 022455 Pipeline);

secs. 29 to 31, inclusive.

T. 16 S., R. 71 E.,

sec. 19, All;

secs. 29 to 32, inclusive.

T. 17 S., R. 71 E.,

secs. 4 to 10, inclusive, unsurveyed;

secs. 15 to 22, inclusive, unsurveyed;

secs. 27 to 34, inclusive, unsurveyed.

T. 18 S., R. 71 E.,

secs. 3 to 10, inclusive, unsurveyed;

secs. 15 to 22, inclusive, unsurveyed;

secs. 27 to 34, inclusive, unsurveyed.

T. 19 S., R. 71 E.,

sec. 3, All, unsurveyed;

sec. 4, All, unsurveyed;

sec. 9, All, unsurveyed;

sec. 10, All, unsurveyed;

sec. 15, All, unsurveyed;

sec. 16, All, unsurveyed;

sec. 21, All, unsurveyed;

sec. 22, All, unsurveyed;

sec. 27, All, unsurveyed;

sec. 28, All, unsurveyed;

sec. 33, All, unsurveyed;

sec. 34, All, unsurveyed.

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**Gold Butte, Part B**

	<b>Legal Description</b>	<b>Part</b>
Approx. Total Acreage = 122,270.42 (Clark County) (NVN 076876)	<u>T. 17 S., R. 69E.,</u>	
	sec. 22,	All;
	sec. 23,	All;
	sec. 26,	All, Except Mineral Survey 4709 Patent;
	sec. 27,	All;
	sec. 34,	All;
	sec. 35,	All, Except Mineral Survey 4709 Patent.
	<u>T. 18 S., R. 69E.,</u>	
	sec. 2,	lots 1 to 4, inclusive, All, Except Mineral Survey 4709 Patent;
	sec. 3,	All;
	sec. 9,	All;
	sec. 10,	All;
	sec. 11,	All, Except Mineral Survey 4710 Patent;
	sec. 12,	All, Except Mineral Survey 4710 Patent;
	sec. 13,	All;
	sec. 14,	All, except MS 4710 patent;
	secs. 15 to 17, inclusive;	
	secs. 20 to 29, inclusive;	
	secs. 32 to 36, inclusive.	
	<u>T.19 S., R. 69 E.,</u>	
	sec. 1,	lots 1 to 4, inclusive, All, Except Mineral Survey 4707 Patent;
	sec. 2,	lots 1 to 4, inclusive, All, Except Mineral Survey 4707 Patent;
	secs. 3 to 10, inclusive;	
	sec. 11,	All, Except Mineral Survey 4707 Patent;
	secs. 12 to 36, inclusive.	
	<u>T. 20 S., R. 69 E.,</u>	
	secs. 1 to 29, inclusive;	
	secs. 33 to 36, inclusive.	
	<u>T. 18 S., R. 70 E.,</u>	
	secs. 7 to 9, inclusive, unsurveyed;	
	secs. 16 to 21, inclusive, unsurveyed;	
	secs. 28 to 33, inclusive, unsurveyed.	
	<u>T. 19 S., R. 70 E.,</u>	
	secs. 1 to 36, inclusive, unsurveyed.	
	<u>T. 20 S., R. 70 E.,</u>	
	secs. 1 to 11, inclusive, unsurveyed;	
	secs. 14 to 22, inclusive, unsurveyed;	
	secs. 27 to 34, inclusive, unsurveyed.	
	<u>T. 19 S., R. 71 E.,</u>	
	secs. 5 to 8, inclusive, unsurveyed;	
	secs. 17 to 20, inclusive, unsurveyed;	
	secs. 29 to 32, inclusive unsurveyed.	

**Virgin Mountains (Gold Butte C)**

	<b>Legal Description</b>	<b>Part</b>
Total Acreage = 37,090.18	<u>T. 15 S., R. 70 E.,</u>	
	sec. 1,	All;

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(Clark County)	secs. 12 to 14, inclusive;
(NVN 076887)	secs. 23 to 27, inclusive;
	secs. 34 to 36, inclusive.
	<u>T. 16 S., 70 E.</u>
	secs. 1 to 3, inclusive;
	sec. 12, All.
	<u>T. 14 S., 71 E.</u>
	secs. 32 to 34, inclusive.
	<u>T. 15 S., 71 E.</u>
	secs. 3 to 10, inclusive, unsurveyed;
	secs. 15 to 22, inclusive, unsurveyed;
	secs. 27 to 34, inclusive, unsurveyed.
	<u>T. 16 S., 71 E.</u>
	secs. 3 to 10, inclusive;
	secs. 15 to 18, inclusive;
	sec. 20, All;
	sec. 21, All;
	sec. 22, lots 1,2, E $\frac{1}{2}$ NW $\frac{1}{4}$ , NE $\frac{1}{4}$ SW $\frac{1}{4}$ ;
	sec. 27, lots 2, 3, 4, SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ ;
	sec. 28, All;
	sec. 33, All;
	sec. 34, All.
	<u>T. 17 S., 71 E.</u>
	sec. 3, All, unsurveyed.

### Whitney Pocket

	Legal Description	Part
	<u>T. 16 S., R. 70 E.,</u>	
Total Acreage = 160.00	sec. 23,	SE $\frac{1}{4}$ .
(Clark County)		
(NVN 076889)		

### Red Rock Spring

	Legal Description	Part
	<u>T. 17 S., R. 70 E.,</u>	
Total Acreage = 640.00	sec. 7,	SE $\frac{1}{4}$ ;
(Clark County)	sec. 8,	SW $\frac{1}{4}$ ;
(NVN 076883)	sec. 17,	NW $\frac{1}{4}$ ;
	sec. 18,	NE $\frac{1}{4}$ ;

### Devil's Throat

	Legal Description	Part
	<u>T. 17 S., R. 70 E.,</u>	
Total Acreage = 640.00	sec. 26,	All.
(Clark County)		
(NVN 076874)		

**Gold Butte Townsite**

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	<b>Legal Description</b>	<b>Part</b>
Total Acreage = 160.00 (Clark County) (NVN 076877)	T. 19 S., R. 70 E., sec. 17,	S $\frac{1}{2}$ NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , unsurveyed.

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## Appendix 2D. Legal Descriptions of Mormon Mesa Tortoise, Arrow Canyon, and Coyote Springs Tortoise Areas of Critical Environmental Concern, Clark County, Nevada

### Mormon Mesa Tortoise

	Legal Description	Part
Approx. Total Acreage = 146,702.28 (Clark County) (NVN 076880)	<u>T. 13 S., R. 63 E.,</u> sec. 25,	SW $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ , All, South of Right-of-Way Nev065186 (NV Hwy 168) Centerline;
	sec. 36,	All.
	<u>T. 13<math>\frac{1}{2}</math> S., R. 63 E.,</u> sec. 36,	All, unsurveyed.
	<u>T. 14 S., R. 63 E.,</u> sec. 1,	All, unsurveyed.
	<u>T. 13 S., R. 64 E.,</u> secs. 1 to 5, inclusive, unsurveyed; sec. 6,	E $\frac{1}{2}$ , unsurveyed;
	sec. 7,	NE $\frac{1}{4}$ , E $\frac{1}{2}$ SE $\frac{1}{4}$ , unsurveyed;
	secs. 8 to 17, inclusive, unsurveyed;	
	secs. 20 to 29, inclusive, unsurveyed;	
	sec. 30,	S $\frac{1}{2}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ , All, South of Right-of-Way Nev065015 (NV Hwy 168) Centerline, unsurveyed;
	secs. 31 to 36, inclusive, unsurveyed.	
	<u>T. 13<math>\frac{1}{2}</math> S., R. 64 E.,</u> secs. 31 to 35, inclusive, unsurveyed;	
	sec. 36,	W $\frac{1}{2}$ NE $\frac{1}{4}$ , NE $\frac{1}{4}$ NW $\frac{1}{4}$ , N $\frac{1}{2}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ , All, North of Right-of-Way Nev060130 (NV Hwy 168), Centerline, unsurveyed.
	<u>T. 14 S., R. 64 E.,</u> secs. 2 to 6, inclusive, unsurveyed;	
	secs. 8 to 11, inclusive, unsurveyed;	
	sec. 15,	All, unsurveyed;
	sec. 16,	All, unsurveyed.
	<u>T. 13 S., R. 65 E.,</u> sec. 1,	lots 2 to 4, inclusive, SW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	secs. 2 to 24, inclusive;	
	sec. 26,	N $\frac{1}{2}$ ;
	sec. 27,	N $\frac{1}{2}$ ;
	sec. 28,	N $\frac{1}{2}$ , SW $\frac{1}{4}$ ;
	sec. 29,	All;
	sec. 30,	All;
	sec. 31,	lots 1 to 3, inclusive, partial lot 4, NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ , All, North of Right-of-Way Nev060130 (NV Hwy 168) Centerline;
	sec. 32,	All;
	sec. 33,	W $\frac{1}{2}$ .
	<u>T. 13 S., R. 66 E.,</u> secs. 1 to 5, inclusive;	
	sec. 6,	lots 1 to 4, inclusive, S $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;

sec. 7 to 18, inclusive;  
 sec. 19, lots 1 to 4, inclusive, SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ ;  
 secs. 20 to 24, inclusive.

T. 13 S., R. 67 E.,

secs. 1 to 36, inclusive.

T. 14 S., R. 67 E.,

secs. 1 to 5, inclusive;  
 sec. 6, lots 1, 2, S $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ ;  
 sec. 7, NE $\frac{1}{4}$ ;  
 secs. 8 to 11, inclusive;  
 sec. 12, N $\frac{1}{2}$ NE $\frac{1}{4}$ , SW $\frac{1}{4}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , SW $\frac{1}{4}$ SW $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 13, All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 14, NW $\frac{1}{4}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 15, All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 16, All;  
 sec. 17, N $\frac{1}{2}$ , SE $\frac{1}{4}$ ;  
 sec. 20, E $\frac{1}{2}$ ;  
 sec. 21, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 22, NW $\frac{1}{4}$ NW $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline.

T. 13 S., R. 68 E.,

secs. 1 to 32, inclusive;  
 sec. 33, N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 34, N $\frac{1}{2}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , All, North of Right-of-Way Nev 06475 (Interstate-15) Centerline;  
 sec. 35, N $\frac{1}{2}$ N $\frac{1}{2}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 36, All, North of Right-of-Way Nev06475 (Interstate-15) Centerline.

T. 14 S., R. 68 E.,

sec. 4, partial lots 2, 3, 4, All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 5, lots 1 to 4, inclusive, SW $\frac{1}{4}$ NW $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 6, lots 1 to 7, inclusive, S $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate-15) Centerline;  
 sec. 7, partial lots 1, 2, All, North of Right-of-Way Nev06475 (Interstate 15) Centerline.

T. 13 S., R. 69 E.,

secs. 1 to 24, inclusive;  
 sec. 25, lots 1, 3, 12, 15, partial lots 4, 6, 8, 11, 14, N $\frac{1}{2}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;  
 sec. 26, lots 1, 5, 8, 10, 11, 14, partial lots 2, 4, 7, 9, 12, 15, 17, N $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ , NE $\frac{1}{4}$ NW $\frac{1}{4}$  All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;  
 sec. 27, lots 1, 3, 5, 7, 9, partial lots 2, 4, 6, 10, 12, 16, All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;  
 sec. 28, lots 1, 3, 5, 8, partial lots 2, 4, 6, 9, 14, 16, N $\frac{1}{2}$ N $\frac{1}{2}$ , All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;  
 sec. 29, lots 1, 5, 8, 11, 13, partial lots 2, 4, 7, 10, 12, 14, N $\frac{1}{2}$ NE $\frac{1}{4}$ , SW $\frac{1}{4}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;  
 sec. 30, lots 5 to 10, inclusive, 12 to 16, inclusive, 18, 20, 23, 26, partial lots 11, 17, 19, 21, 24, 27, NE $\frac{1}{4}$ , NW $\frac{1}{4}$ SE $\frac{1}{4}$ , All, North of Right-of-Way Nev06475

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	(Interstate 15) Centerline;
sec. 31,	partial lots 8, 10, All, North of Right-of-Way Nev06475 (Interstate 15) Centerline.
<u>T. 13 S., R. 70 E.,</u>	
sec. 4,	SW $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ , All, West of Boundary Line;
sec. 5,	lots 7, 8, 9, 10, partial lots 5, 6, 11, 12, S $\frac{1}{2}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ , All, West of Boundary Line;
sec. 6,	All;
sec. 7,	All;
sec. 8,	All, West of Boundary Line;
sec. 9,	NW $\frac{1}{4}$ NW $\frac{1}{4}$ , NW $\frac{1}{4}$ , SW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$ , All, West of Boundary Line;
sec. 17,	W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, West of Boundary Line;
sec. 18	All;
sec. 19,	All;
sec. 20,	W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ , All, West of Boundary Line;
sec. 29,	NW $\frac{1}{4}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ , All West of Boundary Line;
sec. 30,	lots 5, 6, 7, 9, 12, 14, 15, 16, 17, partial lots 10, 13, NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , NE $\frac{1}{4}$ SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;
sec. 31,	partial lots 9, 11, All, North of Right-of-Way Nev06475 (Interstate 15) Centerline;
sec. 32,	lots 6, 9, partial lots 3, 4, 7, 10, All North of Right-of-Way Nev06475 (Interstate 15) Centerline and Boundary Line.

Note: The “Boundary Line” as denoted in the above legal descriptions for the Mormon Mesa ACEC refers to the Eastern Boundary line of the ACEC, which follows closely the edge of the Mesa and Toquop Wash. However, the line is NOT the Mesa edge, nor Toquop Wash, but follows closely between the two. The “Boundary Line” denoted for the eastern boundary edge of the ACEC is shown on the 7.5” U.S. Geological Survey Flat Top Mesa Topographic Map. This map is in the casefile.

### Arrow Canyon

	<b>Legal Description</b>	<b>Part</b>
	<u>T. 14 S., R. 64 E.,</u>	
Total Acreage = 2,083.68 (Clark County) (NVN 076867)	sec. 3,	NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ , unsurveyed;
	sec. 2,	SW $\frac{1}{4}$ , unsurveyed;
	sec. 12,	All, unsurveyed;
	sec. 11,	N $\frac{1}{2}$ , SE $\frac{1}{4}$ , unsurveyed;
	sec. 10,	NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , unsurveyed.
	<u>T. 14 S., R. 65 E.,</u>	
	sec. 7,	lots 3, 4, E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ .

### Coyote Springs Tortoise

	<b>Legal Description</b>	<b>Part</b>
	<u>T. 13 S., R. 63 E.,</u>	
Approx. Total Acreage = 50,824.18 (Clark County) (NVN 076871)	sec. 5,	700 Feet West of Right-of-Way Nev060729 (Hwy 93) Centerline to Fish & Wildlife (F&W) Management Boundary;
	sec. 8,	700 Feet West of Right-of-Way Nev060729 (Hwy 93) Centerline to F&W Management Boundary;
	sec. 17,	700 Feet West of Right-of-Way Nev060729 (Hwy 93) Centerline to F&W Management Boundary;
	sec. 20,	700 Feet West of Right-of-Way Nev060729 (Hwy 93) Centerline and All South of Right-of-Way Nev065185 (Hwy 168) Centerline;
	sec. 21,	All, South of Right-of-Way Nev065185 (NV Hwy 168) Centerline;
	sec. 22,	All, South of Right-of-Way Nev065185 (NV Hwy 168) Centerline;
	sec. 23,	All, South of Right-of-Way Nev065185 (NV Hwy 168) Centerline;

sec. 26,	NW <sup>1</sup> / <sub>4</sub> NE <sup>1</sup> / <sub>4</sub> , S <sup>1</sup> / <sub>2</sub> NE <sup>1</sup> / <sub>4</sub> , W <sup>1</sup> / <sub>2</sub> , SE <sup>1</sup> / <sub>4</sub> , All, South of Right-of-Way Nev065185 (NV Hwy 168) Centerline;
sec. 27,	All;
sec. 28,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary;
sec. 29,	All, East of F&W Management Boundary;
sec. 33,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary;
sec. 34,	All;
sec. 35,	All.
<u>T. 13<sup>1</sup>/<sub>2</sub> S., R. 63 E.,</u>	
sec. 33,	NE <sup>1</sup> / <sub>4</sub> , NE <sup>1</sup> / <sub>4</sub> NW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> NW <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 34,	All, unsurveyed;
sec. 35,	All, unsurveyed.
<u>T. 14 S., R. 63.,</u>	
sec. 2,	All, unsurveyed;
sec. 3,	All, unsurveyed;
sec. 4,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 9,	E <sup>1</sup> / <sub>2</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 10,	All, unsurveyed;
sec. 11,	All, unsurveyed;
sec. 14,	All, unsurveyed;
sec. 15,	All, unsurveyed;
sec. 16,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 21,	E <sup>1</sup> / <sub>2</sub> E <sup>1</sup> / <sub>2</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 22,	All, unsurveyed;
sec. 23,	All, unsurveyed;
sec. 26,	All, unsurveyed;
sec. 27,	All, unsurveyed;
sec. 28,	E <sup>1</sup> / <sub>2</sub> NE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 33,	E <sup>1</sup> / <sub>2</sub> E <sup>1</sup> / <sub>2</sub> NE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 34,	All, unsurveyed;
sec. 35,	All, unsurveyed.
<u>T. 15 S., R. 63 E.,</u>	
sec. 2,	All, unsurveyed;
sec. 3,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 4,	All, East of F&W Management Boundary;
sec. 10,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 11,	All, unsurveyed;
sec. 14,	All, unsurveyed;
sec. 15,	NE <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> NW <sup>1</sup> / <sub>4</sub> , E <sup>1</sup> / <sub>2</sub> SW <sup>1</sup> / <sub>4</sub> , SE <sup>1</sup> / <sub>4</sub> , All, East of F&W Management Boundary, unsurveyed;
sec. 18,	SW <sup>1</sup> / <sub>4</sub> SW <sup>1</sup> / <sub>4</sub> , All, South of F&W Management Boundary, unsurveyed;
sec. 19,	NW <sup>1</sup> / <sub>4</sub> , S <sup>1</sup> / <sub>2</sub> , All, South of F&W Management Boundary, unsurveyed;
sec. 20,	S <sup>1</sup> / <sub>2</sub> S <sup>1</sup> / <sub>2</sub> , All, South of F&W Management Boundary, unsurveyed;

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sec. 21, S½SE¼, All, South of F&W Management Boundary, unsurveyed;  
sec. 22, NE¼, E½NW¼, NE¼SW¼, SW¼SW¼, SE¼, All, East and South of F&W Management Boundary, unsurveyed.  
secs. 27 to 34, inclusive, unsurveyed.

### T. 16 S., R. 63 E.,

secs. 3 to 10, inclusive;  
secs. 15 to 22, inclusive;  
secs. 28 to 33, inclusive.

### T. 17 S., R. 63 E.,

secs. 7 to 9, inclusive;  
secs. 16 to 21, inclusive;  
secs. 28 to 31, inclusive;  
sec. 32, lots 1, 8, 9, 14, 15, 16, NW¼, NW¼SW¼, All, West of Powerline Right-of-Way N53399 Centerline.

### T. 18 S., R. 63 E.,

sec. 5, lots 4, 8, 9, 16, 17, SW¼NW¼, W½SW¼, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 6, All;  
sec. 7, All;  
sec. 8, lots 3, 5, 6, 13, 14, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 17, lots 4, 5, 12, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 18, lots 1 to 4, inclusive, 6, 7, NE¼, E½NW¼, E½SW¼, W½SE¼, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 19, lots 1 to 4, inclusive, 6, 7, 10, 11, W½NE¼, E½NW¼, E½SW¼, W½SE¼, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 29, lots 4, 22, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 30, lots 1 to 4, inclusive, 6 to 8, inclusive, W½NE¼, E½NW¼, E½SW¼, W½SE¼, All, West of Powerline Right-of-Way N53399 Centerline;  
sec. 31, lots 7, 8, 9, 15, 18, NW¼NE¼, All, West of Powerline Right-of-Way N53399 Centerline.

### T. 19 S., R. 63 E.,

sec. 6, lots 9, All, West of Powerline Right-of-Way N53399 Centerline.

Note: The U.S. Fish and Wildlife Service Management Boundary that parallels Right-of-Way Nev060729 (Hwy 93) is 500 feet west of the right-of-way boundary, or 700 feet from centerline. This land was transferred to the U.S. Fish and Wildlife Service under P.L. 107-282.

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## Appendix 2E. Legal Descriptions of Arden, Bird Spring, and Sloan Rock Art Areas of Critical Environmental Concern

### Arden

	Legal Description	Part
Total Acreage = 1,480.10 (Clark County) (NVN 076866)	<u>T. 22 S., R. 60 E.,</u>	
	sec. 32,	W $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ ;
	sec. 33,	NE $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ , NW $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ , E $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ , NW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ .
<u>T. 23 S., R. 60 E.,</u>		
	sec. 4,	lots 1 to 4, inclusive, S $\frac{1}{2}$ N $\frac{1}{2}$ ;
	sec. 5,	lots 1 to 4, inclusive, S $\frac{1}{2}$ N $\frac{1}{2}$ .

### Bird Spring

	Legal Description	Part
Total Acreage = 160.77 (Clark County) (NVN 076870)	<u>T. 24 S., R. 59 E.,</u>	
	sec. 4,	lots 1, 2, S $\frac{1}{2}$ NE $\frac{1}{4}$ .

### Sloan Rock Art

	Legal Description	Part
Total Acreage = 319.88 (Clark County) (NVN 076885)	<u>T. 23 S., R. 61 E.,</u>	
	sec. 35,	S $\frac{1}{2}$ S $\frac{1}{2}$ .
	<u>T. 24 S., R. 61 E.,</u>	
	sec. 2,	lots 1, 2, 3, 4.

## Appendix 2F. Legal Descriptions of Ash Meadows and Amargosa Mesquite Trees Areas of Critical Environmental Concern

### Ash Meadows

	Legal Description	Part
	<u>T. 17 S., R. 50 E.,</u>	
Total Acreage = 36,904.532	sec. 7,	All;
(Nye County)	sec. 8,	All;
(NVN 076868)	sec. 9,	lots 1 to 12, inclusive;
	sec. 10,	lots 1 to 8, inclusive, 12;
	sec. 11,	All;
	sec. 12,	lots 1 to 15, inclusive;
	sec. 13,	All;
	sec. 14,	All;
	sec. 15,	lots 1 to 4, inclusive;
	sec. 17,	N $\frac{1}{2}$ , SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	sec. 18,	All;
	sec. 19,	All;
	sec. 20,	NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ ;
	sec. 21,	lots 5, 6;
	sec. 22,	lots 1 to 5, inclusive, W $\frac{1}{2}$ SE $\frac{1}{4}$ , S $\frac{1}{2}$ N $\frac{1}{2}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ , S $\frac{1}{2}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 23,	lots 1 to 6, inclusive, N $\frac{1}{2}$ SE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 24,	All;
	sec. 25,	All;
	sec. 26,	NE $\frac{1}{4}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ , SW $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ ;
	sec. 27,	All;
	sec. 28,	E $\frac{1}{2}$ NE $\frac{1}{4}$ ;
	sec. 29,	NE $\frac{1}{4}$ NW $\frac{1}{4}$
	sec. 30,	lots 3 to 10, inclusive, E $\frac{1}{2}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	sec. 31,	All;
	sec. 32,	NE $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ W $\frac{1}{2}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	sec. 34,	NE $\frac{1}{4}$ ;
	sec. 35,	N $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ , NE $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ W $\frac{1}{2}$ , N $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ , NW $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 36,	NE $\frac{1}{4}$ , W $\frac{1}{2}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ .
	<u>T. 18 S., R. 50 E.,</u>	
	sec. 1,	lots 1 to 4, inclusive;
	sec. 2,	lots 1, 2, S $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ ;
	sec. 3,	SW $\frac{1}{4}$ SW $\frac{1}{4}$ ;
	sec. 5,	All;
	sec. 6,	lots 1, 2, 8 to 12, inclusive, S $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ W $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	sec. 7,	lots 4 to 10, inclusive, S $\frac{1}{2}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , NE $\frac{1}{4}$ SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE; sec. 8,
All;	sec. 9,	W $\frac{1}{2}$ NW $\frac{1}{4}$ , SW $\frac{1}{4}$ ;
	sec. 10,	E $\frac{1}{2}$ ;
	sec. 11,	N $\frac{1}{2}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ ;
	sec. 12,	W $\frac{1}{2}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ ;
	sec. 13,	SW $\frac{1}{4}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ , NW $\frac{1}{4}$ SE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ , E $\frac{1}{2}$ W $\frac{1}{2}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 14,	NE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;
	sec. 15,	NE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;
	sec. 16,	lot 2, W $\frac{1}{2}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	secs. 17 to 23, inclusive;	
	sec. 24,	N $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ , N $\frac{1}{2}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ ;
	sec. 25,	S $\frac{1}{2}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NW $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ ;
	secs. 26 to 29, inclusive;	

secs. 33 to 36, inclusive.

T. 17 S., R. 51 E.,

sec. 7, All;  
 sec. 8, NW $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , W $\frac{1}{2}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ ;  
 sec. 17, S $\frac{1}{2}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ , SE $\frac{1}{4}$ ;  
 secs. 18 to 20, inclusive;  
 sec. 29, All;  
 sec. 30, All;  
 sec. 31, lots 1 to 4, inclusive, NE $\frac{1}{4}$ NE $\frac{1}{4}$ , W $\frac{1}{2}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ ;  
 sec. 32, lots 1 to 4, inclusive, N $\frac{1}{2}$ .

T. 18 S., R. 51 E.,

sec. 5, lot 1;  
 sec. 6, lots 2 to 6, inclusive, SW $\frac{1}{4}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , NE $\frac{1}{4}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;  
 sec. 7, NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ ;  
 sec. 8, NW $\frac{1}{4}$ ;  
 sec. 17, E $\frac{1}{2}$ E $\frac{1}{2}$ ;  
 sec. 18, lots 2, 3, 4, SW $\frac{1}{4}$ NE $\frac{1}{4}$ , SE $\frac{1}{4}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ ;  
 sec. 19, lots 1, 2, NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;  
 sec. 20, All;  
 sec. 29, All;  
 sec. 30, lots 2 to 4, inclusive, NE $\frac{1}{4}$ NE $\frac{1}{4}$ , N $\frac{1}{2}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ , N $\frac{1}{2}$ S $\frac{1}{2}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ ,  
 NW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ , SW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ N $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ ,  
 E $\frac{1}{2}$ NW $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ , Excluding Patent 27-70-0091;  
 sec. 31, All;  
 sec. 32, All.

## Amargosa Mesquite Trees

	Legal Description	Part
	<u>T. 16 S., R. 51 E.,</u>	
Total Acreage = 6,890.97	sec. 35,	All;
(Nye County)	sec. 36,	SW $\frac{1}{4}$ .
(NVN 076865)		
	<u>T. 17 S., R. 51 E.,</u>	
	sec. 1,	lots 3, 4, S $\frac{1}{2}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ ;
	sec. 2,	All;
	sec. 11,	E $\frac{1}{2}$ ;
	sec. 12,	All;
	sec. 13,	All;
	sec. 14,	E $\frac{1}{2}$ ;
	sec. 23,	E $\frac{1}{2}$ ;
	sec. 24,	All;
	sec. 25,	All;
	sec. 26,	E $\frac{1}{2}$ ;
	sec. 35,	All;
	sec. 36,	All.

## Appendix 2G. Legal Description of Virgin River Area of Critical Environmental Concern, Clark County, Nevada

### Virgin River

	Legal Description	Part
	<u>T. 14 S., R. 69 E.,</u>	
Approx. Total Acreage = 6,312.82 (Clark County) (NVN 076888)	sec. 11,	SE $\frac{1}{4}$ ;
	sec. 12,	W $\frac{1}{2}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , NW $\frac{1}{4}$ SW $\frac{1}{4}$ ;
	sec. 13,	All Federal Land North of Gold Butte Back Country Byway Road;
	sec. 14,	N $\frac{1}{2}$ NE $\frac{1}{4}$ , NW $\frac{1}{4}$ , N $\frac{1}{2}$ SW $\frac{1}{2}$ , SE $\frac{1}{4}$ SW $\frac{1}{4}$ ;
	sec. 15,	SE $\frac{1}{4}$ ;
	sec. 22,	NE $\frac{1}{4}$ , S $\frac{1}{2}$ ;
	sec. 23,	All Federal Land North of Gold Butte Back Country Byway Road;
	sec. 26,	All Federal Land North of Gold Butte Back Country Byway Road;
	sec. 27,	All Federal Land North of Gold Butte Back Country Byway Road;
	sec. 28,	N $\frac{1}{2}$ , SW $\frac{1}{4}$ , S $\frac{1}{2}$ SE $\frac{1}{4}$ , All Federal Land North of Gold Butte Back Country Byway Road
	sec. 29,	S $\frac{1}{2}$ ;
	sec. 32,	N $\frac{1}{2}$ , SW $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 33,	All Federal Land North of Gold Butte Back Country Byway Road.
	<u>T. 13 S., R. 70 E.,</u>	
Right-of-Way Nev065014 (Interstate 15) Centerline;	sec. 27,	lots 8, 10, 17, 19, 20, 21, partial lots 7, 9, 11, 13, 16, 18, All, South of
	sec. 33,	lots 1, 11, 13, 15, 16, 17, partial lots 2, 4, 6, 8, 10, 12, 14, SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ , All, South of Right-of-Way Nev065014 (Interstate 15) Centerline;
	sec. 34,	lots 1 to 4, inclusive, 6, 11, NW $\frac{1}{4}$ NW $\frac{1}{4}$ , All Federal Land South of Right-of-Way Nev065014 (Interstate-15) Centerline and North of Right-of-Way Nev07490 (NV Hwy 170) Centerline.
	<u>T. 14 S., R. 70 E.,</u>	
	sec. 3,	partial lot 4, All, North of Right-of-Way Nev07490 (NV Hwy 170) Centerline;
	sec. 4,	lots 2, 3, 4, partial lot 1, S $\frac{1}{2}$ NW $\frac{1}{4}$ , All, North of Right-of-Way Nev07490 (NV Hwy 170) Centerline;
	sec. 5,	lots 1 to 4, inclusive, S $\frac{1}{2}$ NE $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , All, North of Right-of-Way Nev07490 (NV Hwy 170) Centerline;
	sec. 6,	lots, 1, 2, 6, 7, S $\frac{1}{2}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;
	sec. 7,	partial lot 2, 3, N $\frac{1}{2}$ NE $\frac{1}{4}$ , NE $\frac{1}{4}$ NW $\frac{1}{4}$ , All Federal Land North of Right-of-Way Nev07490 (NV Hwy 170) Centerline and North of Gold Butte Back Country Byway Road;
	sec. 8,	All, North of Right-of-Way Nev07490 (NV Hwy 170) Centerline.

Note: The Gold Butte Back Country Byway is an RS2477 road authorization.

## Appendix 2H. Legal Description of Hidden Valley Area of Critical Environmental Concern

### Hidden Valley

	Legal Description	Part
Total Acreage = 3,360.00 (Clark County) (NVN 076878)	<u>T. 18 S., R. 65 E.,</u>	
	sec. 26,	W½, unsurveyed;
	sec. 27,	E½, unsurveyed;
	sec. 34,	All, unsurveyed;
	sec. 35,	All, unsurveyed.
	<u>T. 19 S., R. 65 E.,</u>	
	sec. 2,	W½, unsurveyed;
	sec. 3,	All, unsurveyed;
	sec. 10,	N½, unsurveyed;
	sec. 11,	NW¼, unsurveyed.

## Appendix 2I. Legal Description of Rainbow Gardens Area of Critical Environmental Concern, Clark County, Nevada

### Rainbow Gardens

	Legal Description	Part
Approx. Total Acreage = 38,172.03 (Clark County) (NVN 076882)	<u>T. 20 S., R. 62 E.,</u>	
	sec. 12,	All;
	sec. 13,	All;
	sec. 24,	All;
	sec. 25,	All;
	sec. 35,	lots 1 to 4, inclusive;
	sec. 36,	All.
	<u>T. 21 S., R. 62 E.,</u>	
	sec. 1,	All;
	sec. 2,	lots 5, 6, 9 to 12, inclusive, 17, 18;
	sec. 11,	lots 1 to 6, inclusive, 11, 12;
	sec. 12,	All;
	sec. 13,	All;
	sec. 14,	E $\frac{1}{2}$ ;
	sec. 23,	NE $\frac{1}{4}$ NE $\frac{1}{4}$ , E $\frac{1}{2}$ SE $\frac{1}{4}$ ;
	sec. 24,	All;
	sec. 25,	N $\frac{1}{2}$ NE $\frac{1}{4}$ , NE $\frac{1}{4}$ NW $\frac{1}{4}$ .
	<u>T. 20 S., R. 63 E.,</u>	
	sec. 1,	N $\frac{1}{2}$ , NW $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ , N $\frac{1}{2}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$ , SW $\frac{1}{4}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$ , SW $\frac{1}{4}$ SW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ , unsurveyed;
	sec. 2,	All, unsurveyed;
	sec. 3,	SE $\frac{1}{4}$ , unsurveyed;
	sec. 7,	All, unsurveyed;
	sec. 8,	W $\frac{1}{2}$ , unsurveyed;
	sec. 11,	All, Except Mineral Entry Patents, unsurveyed;
	sec. 12,	NW $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SW $\frac{1}{4}$ , unsurveyed;
	sec. 13,	W $\frac{1}{2}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ NW $\frac{1}{4}$ , W $\frac{1}{2}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ , SW $\frac{1}{4}$ , S $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ , W $\frac{1}{2}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ , S $\frac{1}{2}$ SE $\frac{1}{4}$ , unsurveyed;
	secs. 14 to 34, inclusive,	unsurveyed.
	<u>T. 21 S., R. 63 E.,</u>	
	sec. 3,	All;
	sec. 4,	All, Except Mineral Entry Patents;
	secs. 5 to 7, inclusive;	
	sec. 8,	All, Except Mineral Entry Patents;
	sec. 9,	All, Except Mineral Entry Patents;
	sec. 10,	All;
	sec. 16,	All, Except Mineral Entry Patents;
	sec. 17,	All, Except Mineral Entry Patents;
	sec. 18,	All;
	sec. 19,	All;
	sec. 20,	All, Except Mineral Entry Patents;
	sec. 21,	N $\frac{1}{2}$ , SW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SW $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	sec. 30,	lots 1, 2, NE $\frac{1}{4}$ , E $\frac{1}{2}$ NW $\frac{1}{4}$ .
	<u>T. 20 S., R. 64 E.,</u>	
	sec. 4,	All;
	sec. 5,	All;

sec. 8,	N $\frac{1}{2}$ , SE $\frac{1}{2}$ ;
sec. 9,	All;
sec. 16,	All;
sec. 19,	lots 7, 8, SE $\frac{1}{4}$ SW $\frac{1}{4}$ ;
sec. 20,	S $\frac{1}{2}$ NE $\frac{1}{4}$ , NE $\frac{1}{4}$ SW $\frac{1}{4}$ , S $\frac{1}{2}$ SW $\frac{1}{4}$ , SE $\frac{1}{4}$ ;
sec. 21	All;
secs. 28 to 30, inclusive.	

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## Appendix 2J. Legal Description of River Mountains Area of Critical Environmental Concern, Clark County, Nevada

### River Mountains

	<b>Legal Description</b>	<b>Part</b>
Approx. Total Acreage = 10,963.31 (Clark County) (NVN 076884)	<u>T. 21 S., R. 63 E.,</u>	
	sec. 25,	NE $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ NW $\frac{1}{4}$ , S $\frac{1}{2}$ , All, South of NV Hwy 147
	(Lake Mead Drive) Centerline;	
	sec. 26,	partial lots 5, 14, 15, 17, 24, 25, South of NV Hwy 147 (Lake Mead
	Drive) Centerline;	sec. 35,
	sec. 36,	All.
		lots 1, 6, 7, SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	<u>T. 22 S., R. 63 E.,</u>	
	sec. 1,	All;
	sec. 2,	All;
	sec. 3,	S $\frac{1}{2}$ ;
	sec. 10,	NE $\frac{1}{4}$ , NE $\frac{1}{4}$ NW $\frac{1}{4}$ , N $\frac{1}{2}$ SE $\frac{1}{4}$ , SE $\frac{1}{4}$ SE $\frac{1}{4}$ ;
	secs. 11 to 13, inclusive;	
	sec. 14,	N $\frac{1}{2}$ , SE $\frac{1}{4}$ ;
	sec. 23,	E $\frac{1}{2}$ ;
	sec. 24,	All;
	sec. 25,	All;
	sec. 26,	E $\frac{1}{2}$ ;
	sec. 36,	All.
	<u>T. 22 S., R. 63<math>\frac{1}{2}</math> E.,</u>	
	sec. 1,	All;
	sec. 12,	All;
	sec. 13,	All;
	sec. 24,	All;
	sec. 25,	All;
	sec. 36,	All;
	<u>T. 23 S., R. 63<math>\frac{1}{2}</math> E.,</u>	
	sec. 1,	lots 1 to 7, inclusive, S $\frac{1}{2}$ NE $\frac{1}{4}$ .

## Appendix 2K. Legal Description of Stump Spring Area of Critical Environmental Concern, Clark County, Nevada

### Stump Spring

	Legal Description	Part
Total Acreage = 641.32 (Clark County) (NVN 076886)	T. 22 S., R. 55 E., sec. 32, S½;	
	T. 23 S., R. 55 E., sec. 5,	lots 1 to 4, inclusive, S½N½.

## Appendix 2L. Legal Description of Big Dune Area of Critical Environmental Concern, Nye County, Nevada

### Big Dune

	Legal Description	Part
	T. 15 S., R. 48 E.,	
Total Acreage = 1,920.00	sec. 8,	S½, unsurveyed;
(Nye County)	sec. 9,	S½, unsurveyed;
(NVN 076869)	sec. 16,	All, unsurveyed;
	sec. 17,	All, unsurveyed.