Mineral Resource Assessment of Selected Areas in Clark and Nye Counties, Nevada, Edited by Steve Ludington
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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

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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^2 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^2) and Gold Butte B (493 km^2) 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^2) 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^2 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^2, 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^2, 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^2 and is apparently meant to include the remains of the town of Gold Butte, which thrived briefly in the early part of the 20th 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

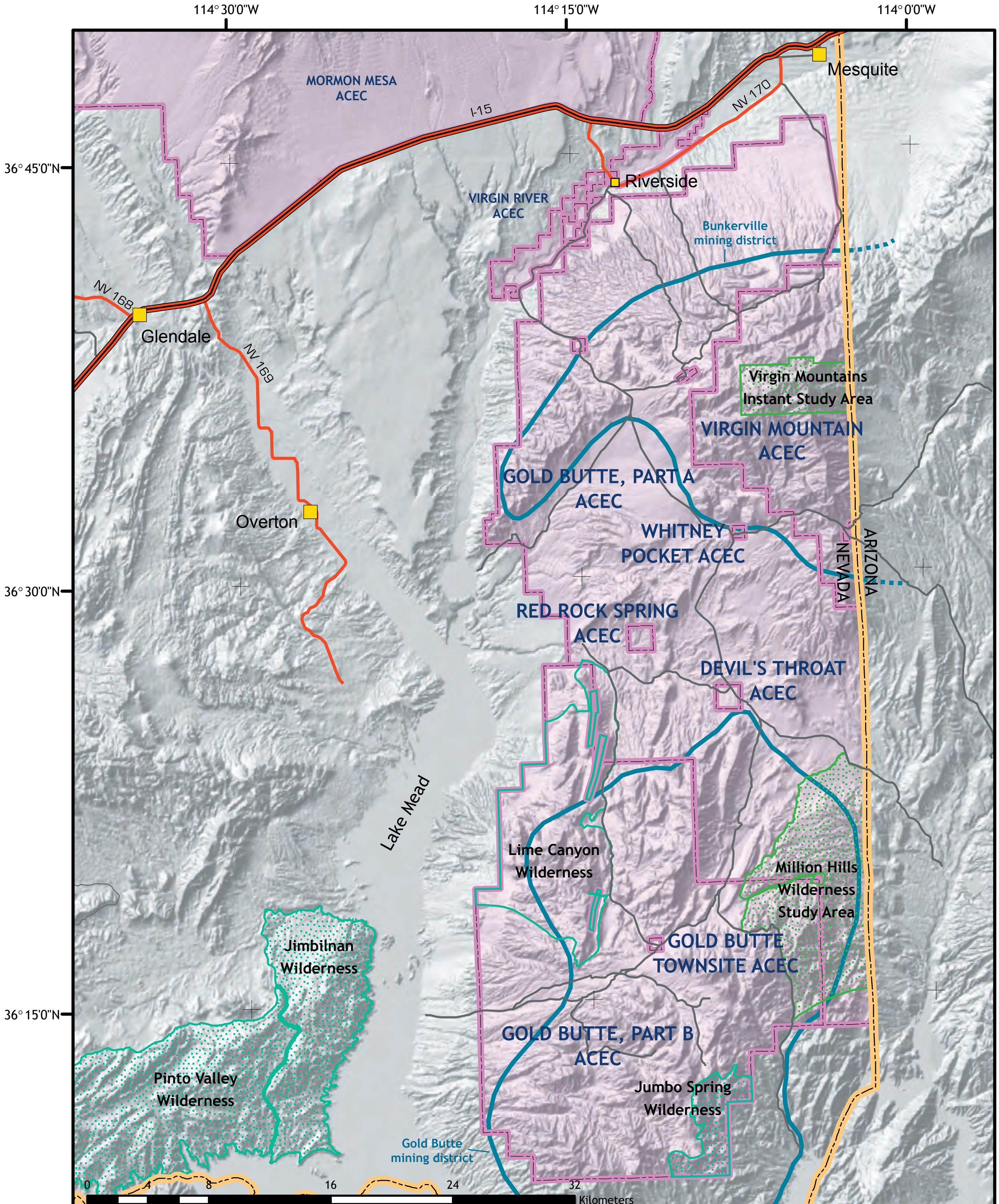


Figure 1. Index map, showing boundaries of Areas of Critical Environmental Concern (ACECs; outlined in pink), wilderness areas (blue-green), wilderness study areas (yellow-green), and mining districts (teal).

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.

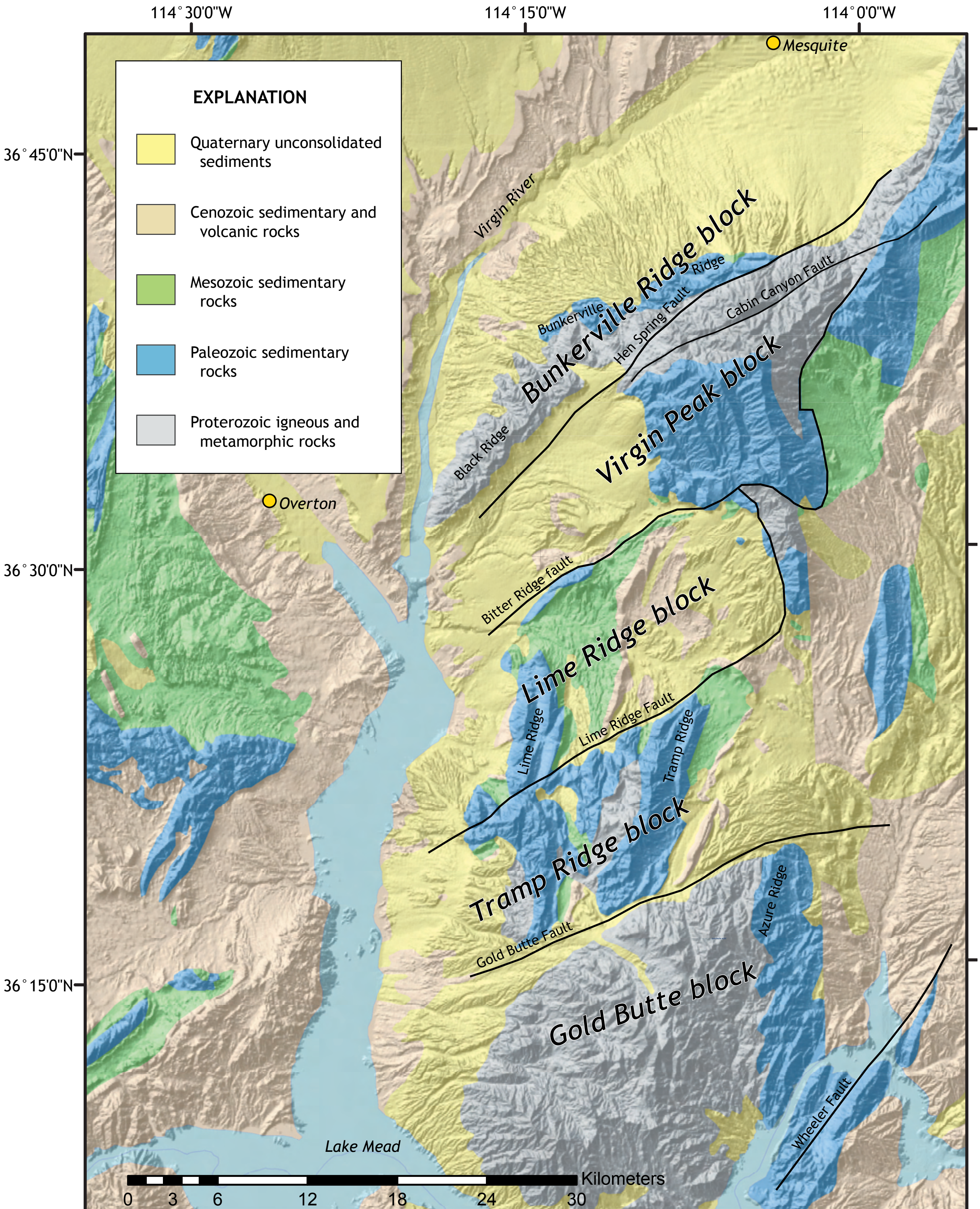


Figure 4. Structural blocks of the Virgin Mountains and areas to the south, southeastern Nevada and northwestern Arizona. Geology modified from Stewart and Carlson (1978) after Beard (1996).

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.

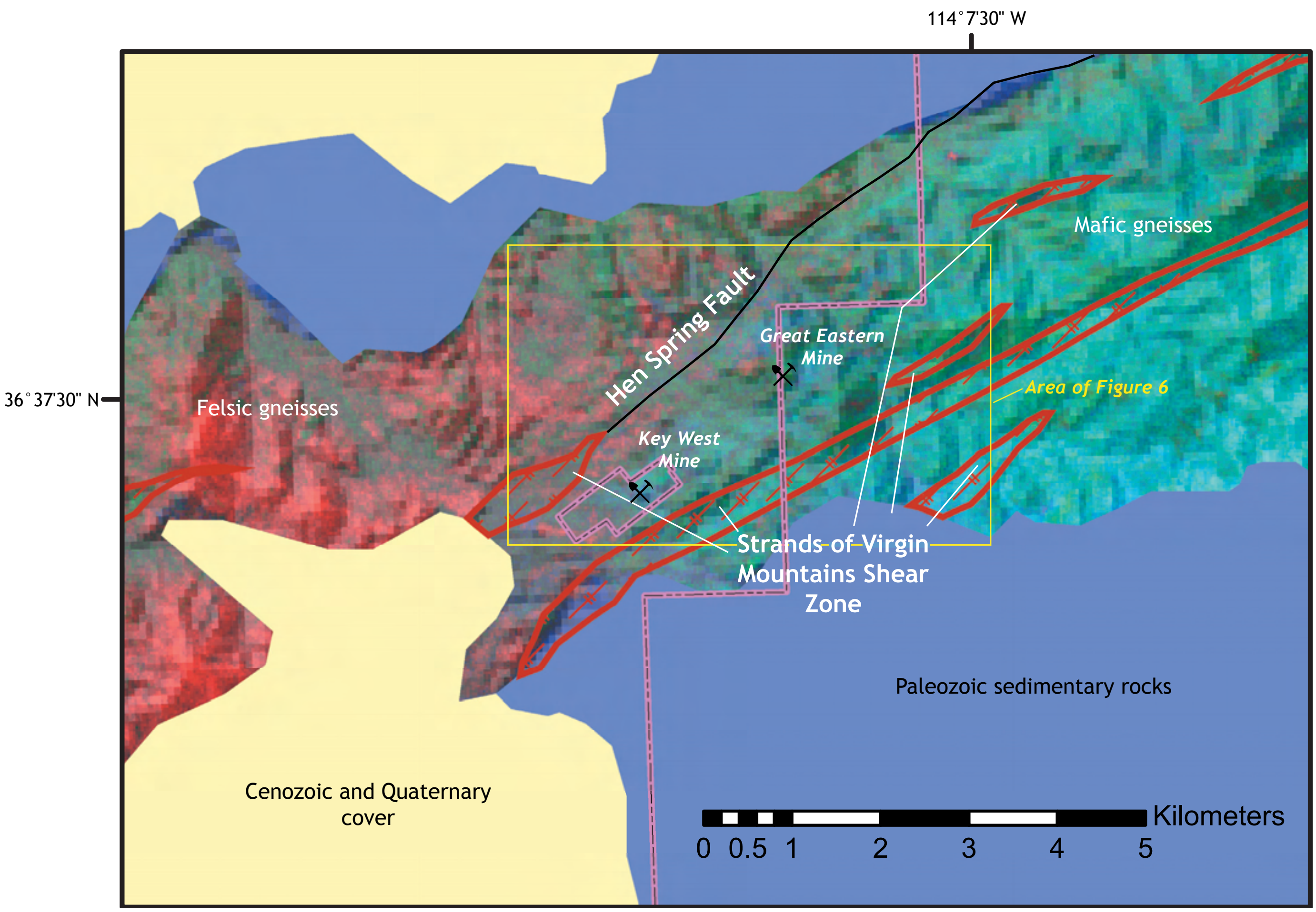


Figure 5. Geologic relations in part of the Virgin Peak and Bunkerville Ridge blocks, showing relations between mafic and felsic gneisses, Hen Spring Fault, and Virgin Mountains shear zone. Proterozoic rocks are portrayed with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery (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 hornblende. 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_2, 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.

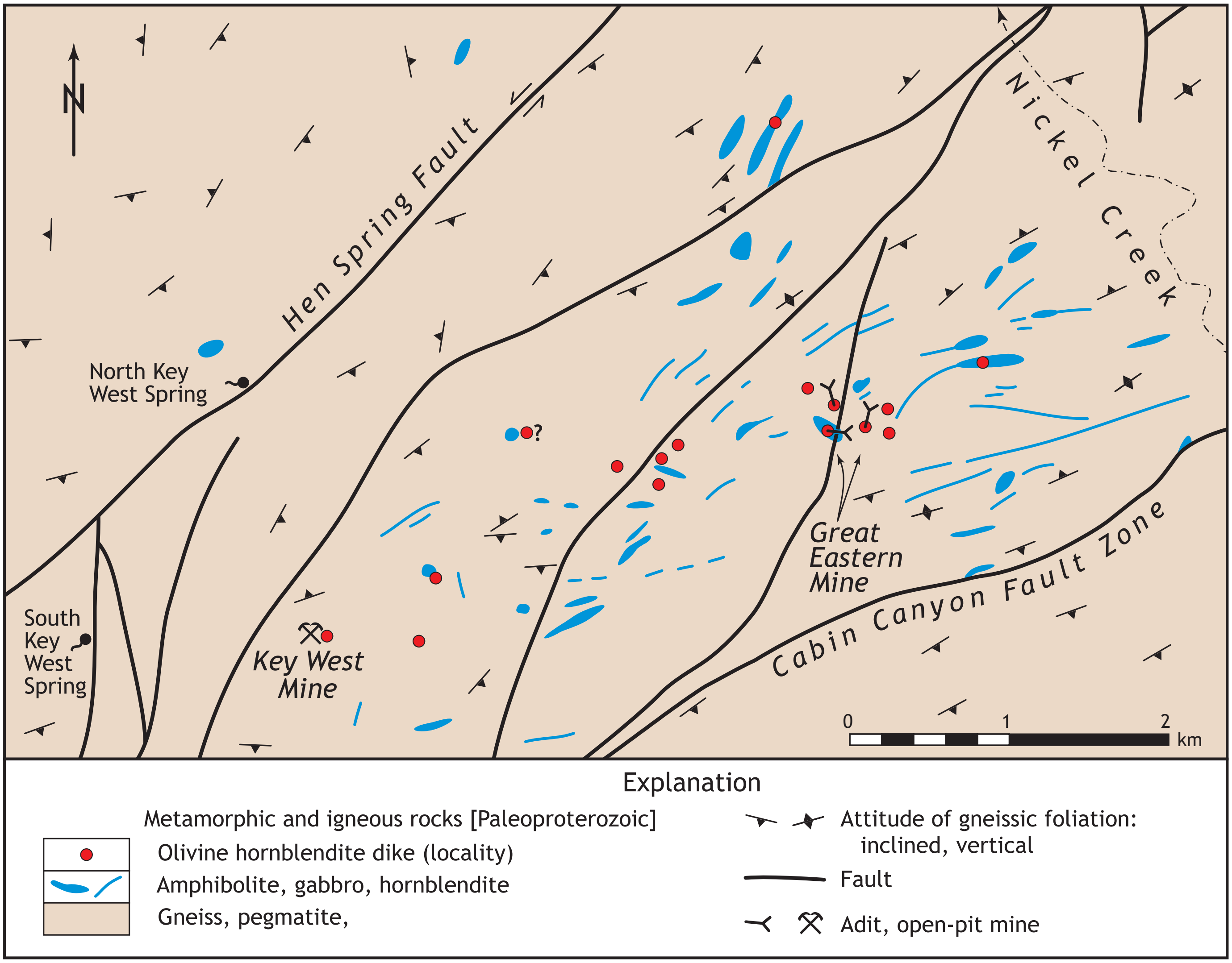


Figure 6. Geologic sketch map of part of the Bunkerville district in the Virgin Mountains (see figure 5 for location). Olivine hornblendite dikes, typically only a few meters wide, are too small to map at this scale; localities are indicated by red dots. The dikes and other intrusions mapped in blue 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 hornblendite.]

	Ni (ppm)	Pd (ppb)	Pt (ppb)	(Pd/Ni)×10	Pt/Pd	References
Bunkerville district, medians						
Gabbro and related hornblendite (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	
Mafic and ultramafic rocks, global averages						Crockett, 2002; Mungall, 2005
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, tholeitic	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
Continental crust						Rudnick and Gao, 2004
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

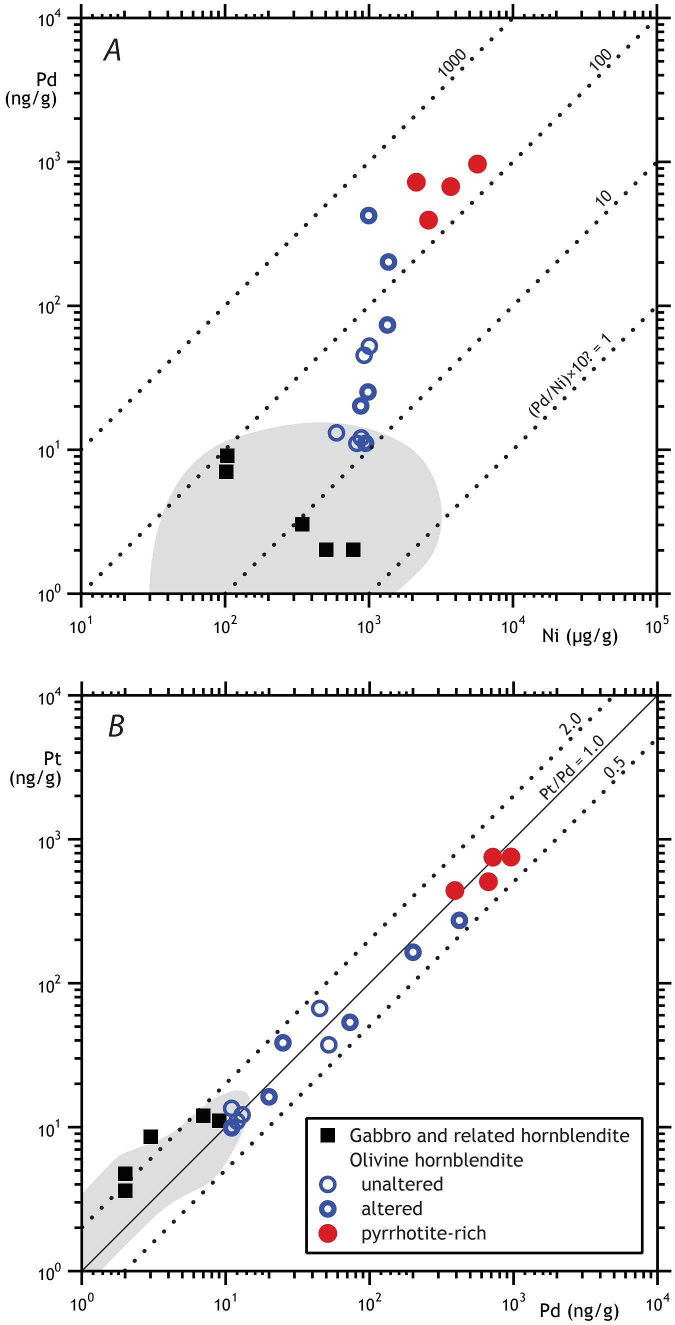


Figure 7. Covariation of nickel with palladium (*A*) and platinum (*B*) in Neoproterozoic gabbroic and olivine hornblendite (OHB) dikes in the Bunkerville district. Light gray indicates the approximate composition fields of common ultramafic, mafic and intermediate igneous rock types, based upon the 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.

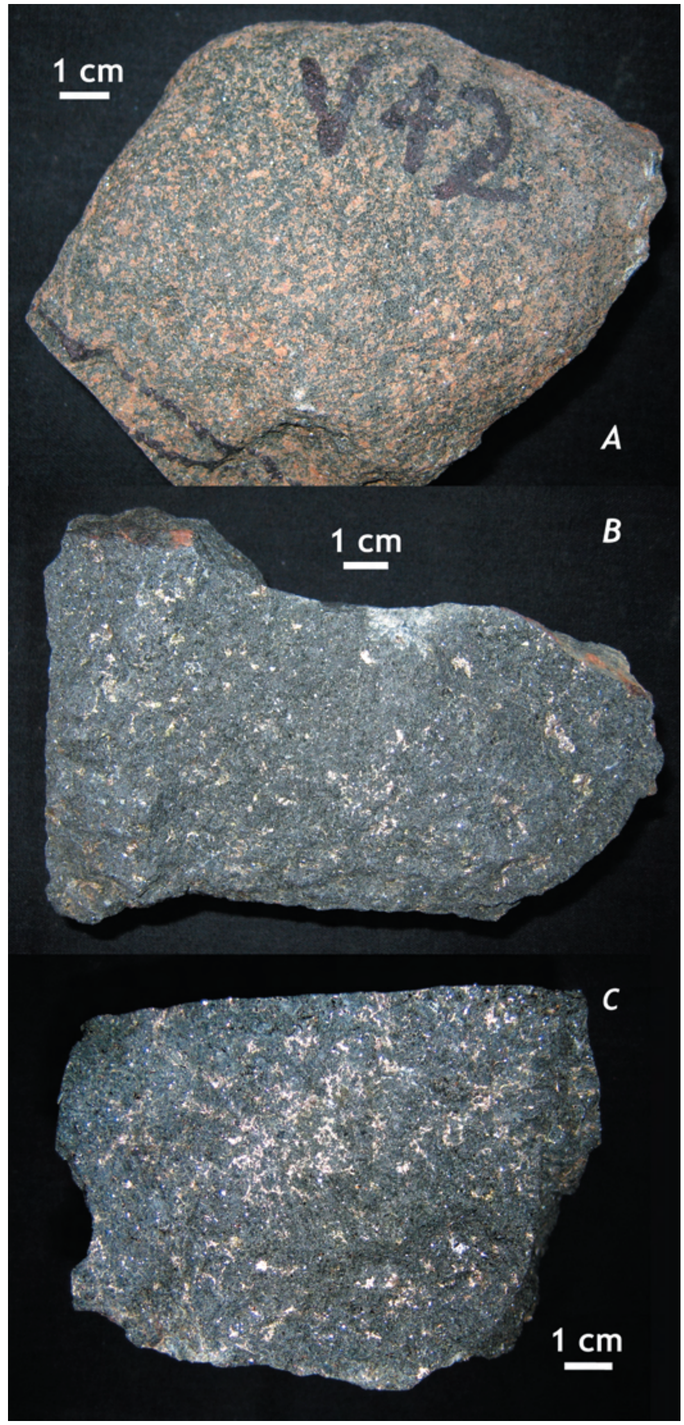


Figure 8. Hand specimens of olivine hornblendite (OHB) from the Bunkerville district. *A*, Weathered surface of typical fine-grained OHB, from a prospect near the Key West Mine (sample V42). Darker, slightly raised areas are chiefly hornblende; lighter colored, slightly depressed areas are partially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

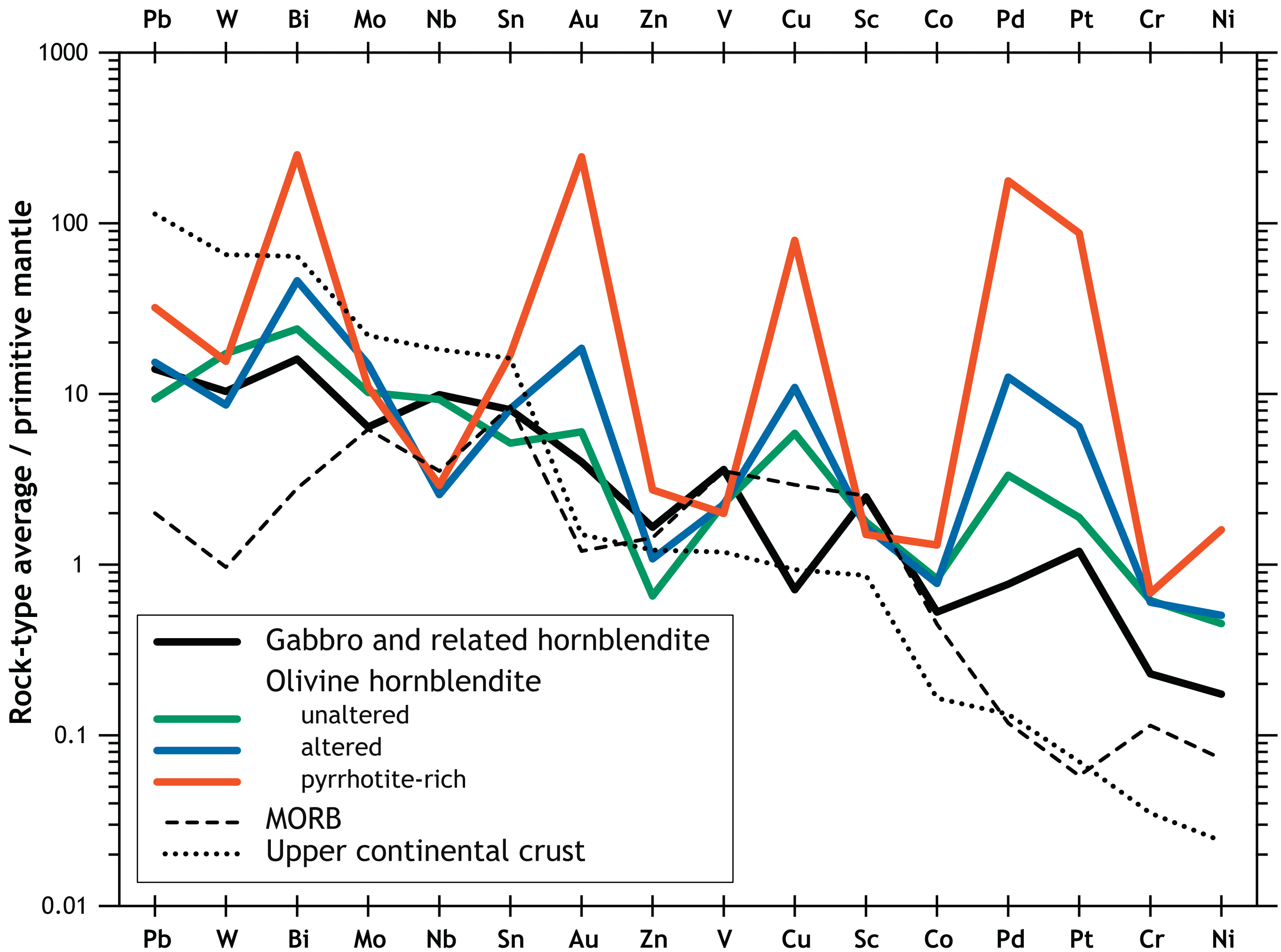


Figure 9. Median abundances of 16 metals in gabbroic dikes and olivine hornblendite (OHB) dikes in the Bunkerville district, compared with average mid-ocean ridge basalt (MORB) (Sun and McDonough, 1989) and average upper continental crust (McLennan, 2001). Concentrations are normalized to those in Earth's 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 continental 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-

Table 2. Stratigraphic correlation chart for Paleozoic and Mesozoic sedimentary rocks in the Gold Butte–Virgin Mountain ACECs.

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

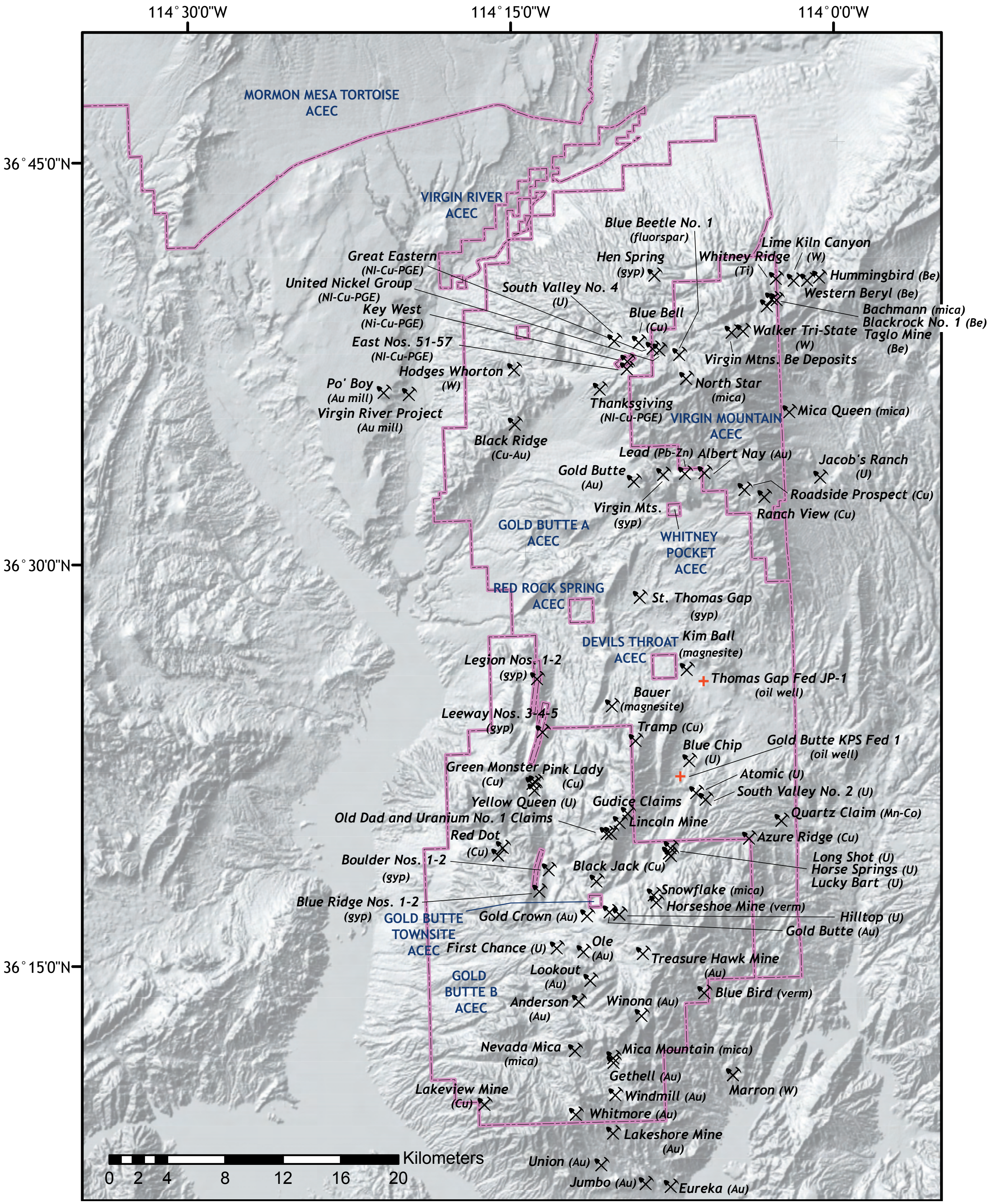


Figure 12. Locations of mines and prospects in Gold Butte–Virgin Mountain Areas of Critical Environmental Concern (ACECs; boundaries in pink). Commodity sought or mined is in parentheses under each name (gyp=gypsum, verm=vermiculite). Red crosses are exploratory oil wells.

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 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).

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

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. 14*A*). In another revealing exposure, a small pegmatite dike intruding OHB is surrounded by a sheath of phlogopitite (a rock com-

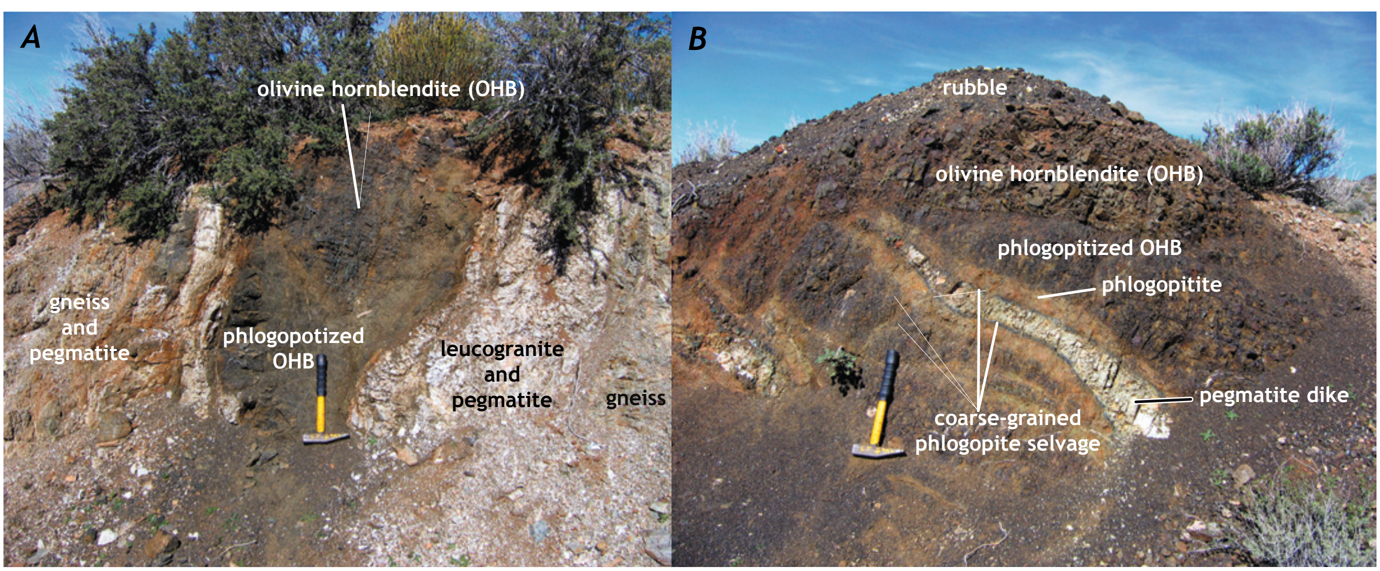


Figure 14. Phlogopotized olivine hornblendite (OHB) dikes in a prospect pit about 0.6 km southwest of the Great Eastern Mine. Hammer for scale is 35 cm long. *A*, OHB dike intruding gneiss, gneissic leucogranite and pegmatite. The dike consists of an outer zone of strongly phlogopitized OHB and a core 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 14*B*). 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 14*B*). 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 [hornblendite] 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 hornblendite (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.

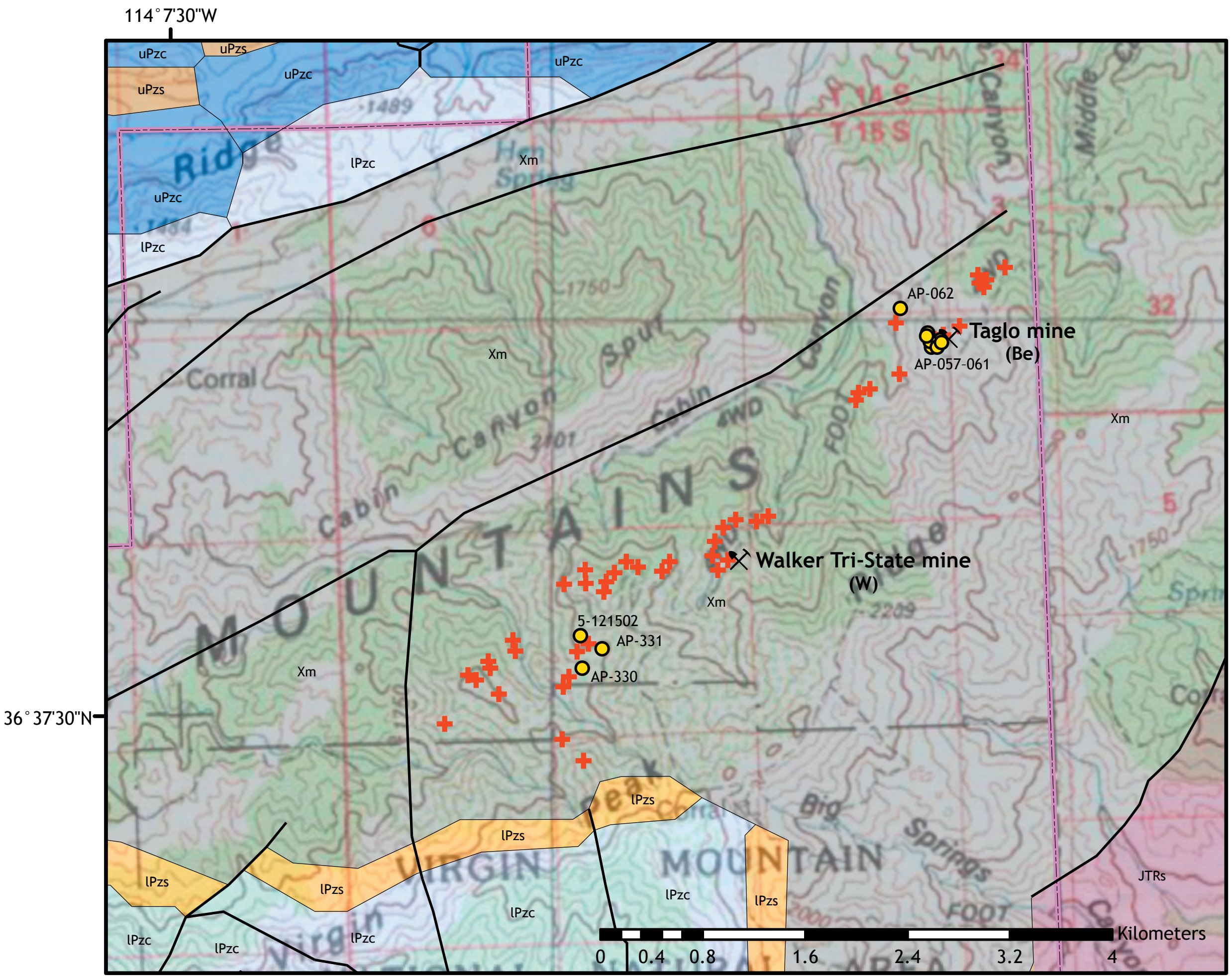
The distribution of OHB, shown on figure 6, appears to form an east-northeast-trending belt that passes through the Key West and Great Eastern Mines. The dikes are conspicuous and weather to a distinctive dark soil, so it is reasonable to expect that we have identified all the surface expressions. However, 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 hornblendite 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 hornblendite 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

AP-001 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 x (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.

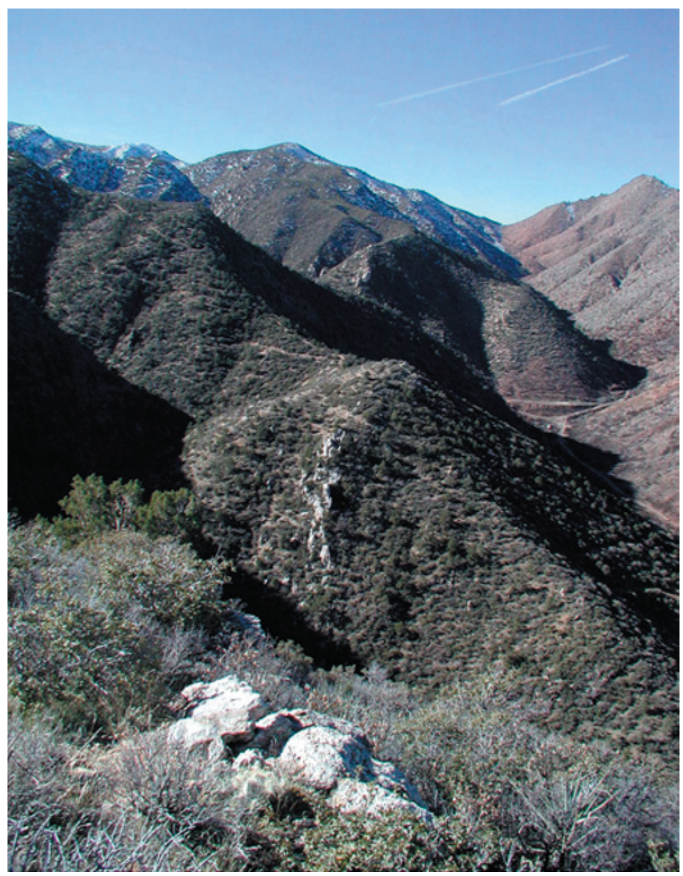


Figure 17. View looking southwest from the Taglo Mine area. The main pegmatite is in the immediate foreground, and a possible extension of this steeply dipping pegmatite is on the next hill to the southwest. The Mica Notch pegmatite area is on the vegetated ridge behind this that extends to the skyline.

+ 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-Condie 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 footwall 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

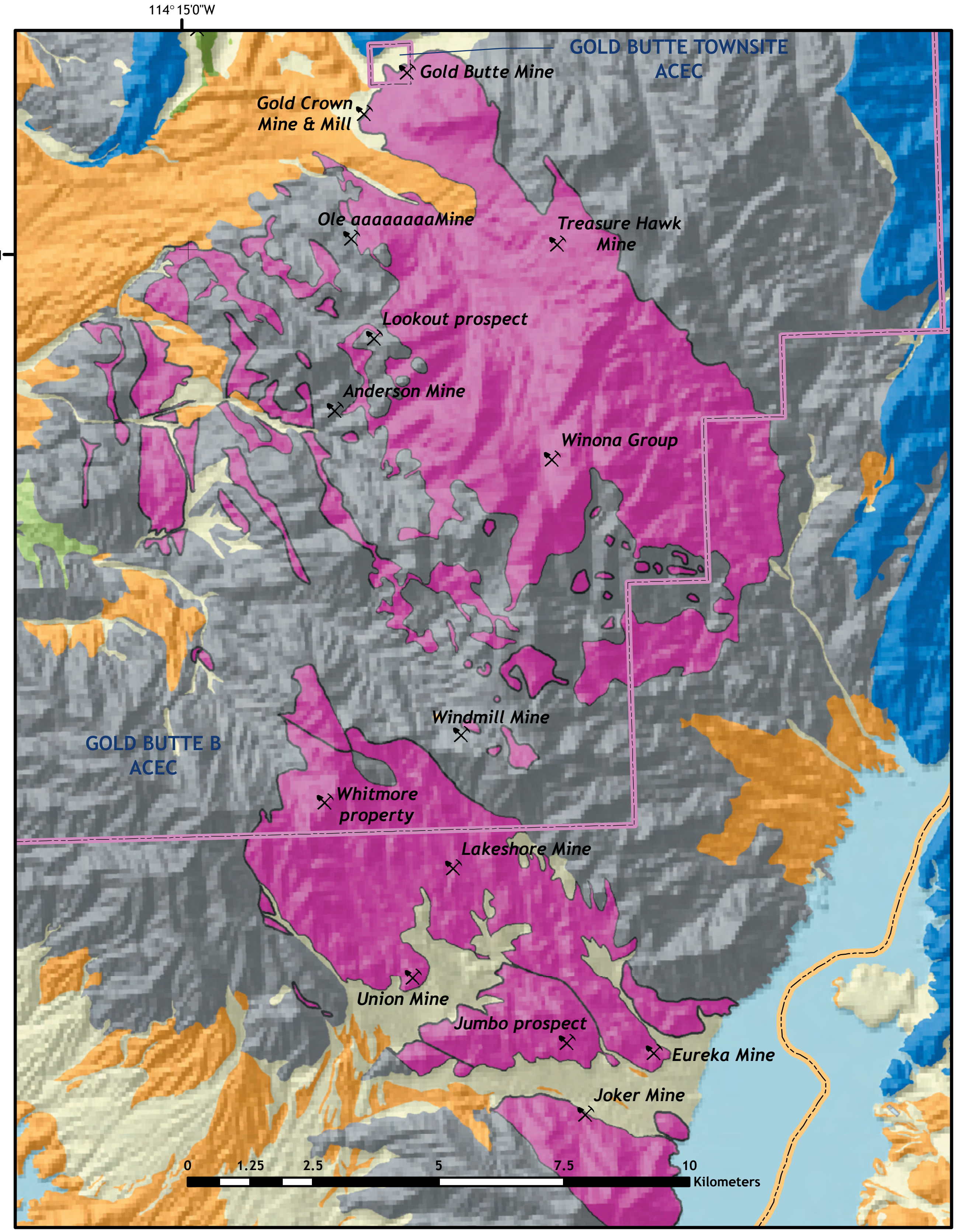


Figure 20. Mines and prospects on gold-bearing quartz veins in the Gold Butte block. Pre-Gold Butte granite metamorphic rocks are shown in gray, Gold Butte granite is dark pink, Paleozoic carbonate rocks are blue, Tertiary sedimentary rocks are gold, and Quaternary alluvium is pale yellow.

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 ($ZnCO_3$), aurichalcite ($(Zn,Cu)_5[(OH)_3|CO_3]_2$), and cerussite ($PbCO_3$). 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

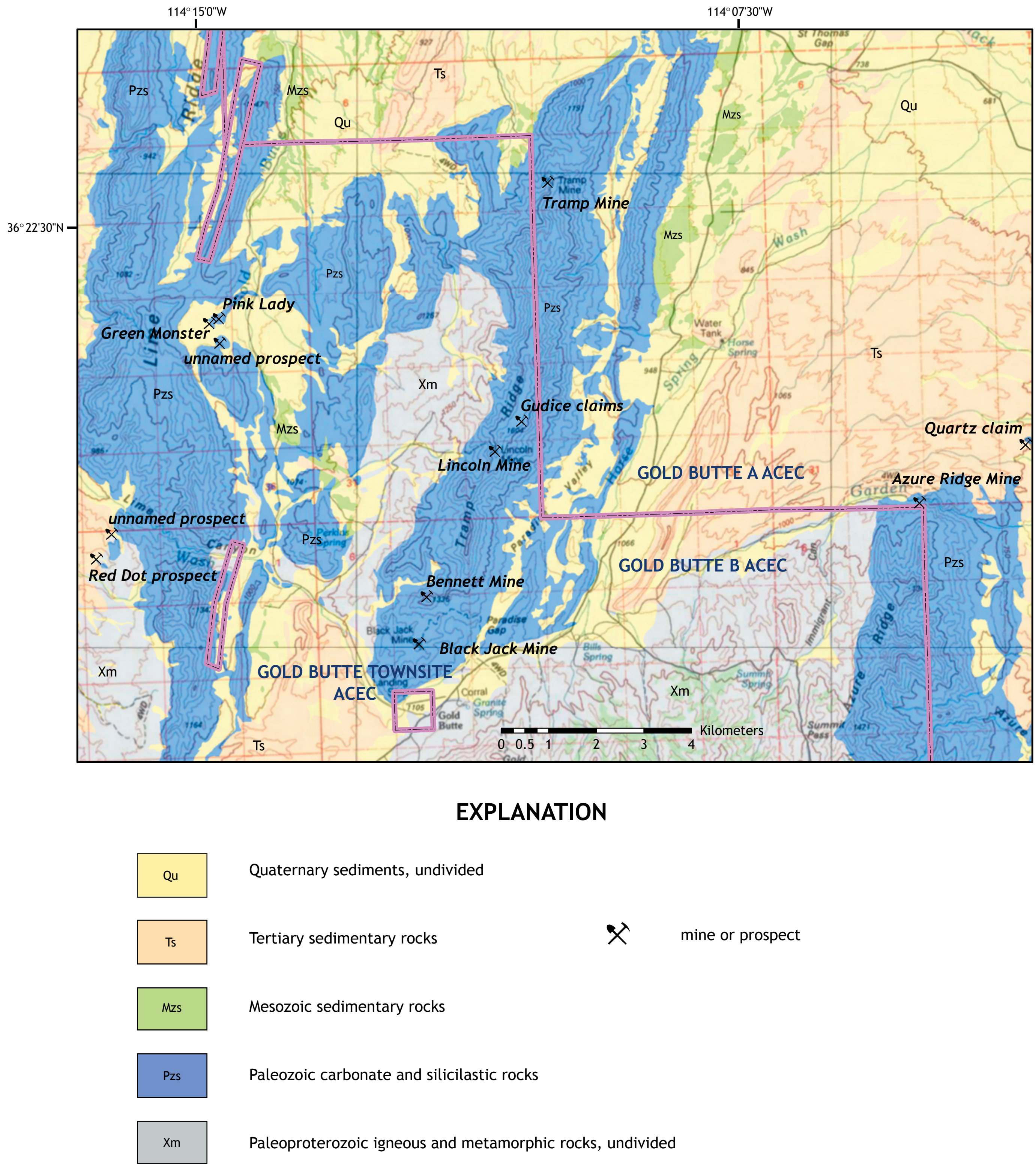


Figure 22. Locations of copper deposits in Gold Butte A and B Areas of Critical Environmental Concern (ACECs; outlined in pink). Generalized geology from Stewart and Carlson (1978).

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 gallium 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 ($SrAl_3[(OH)_5|(PO_4)_2]\bullet H_2O$) (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 Cu±Pb±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 ($Ca(UO_2)_2[VO_4]_2{\bullet}8H_2O$, 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^2 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

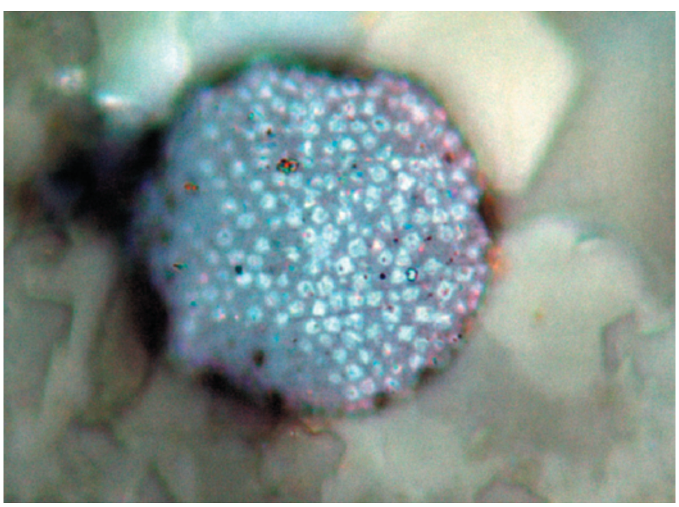
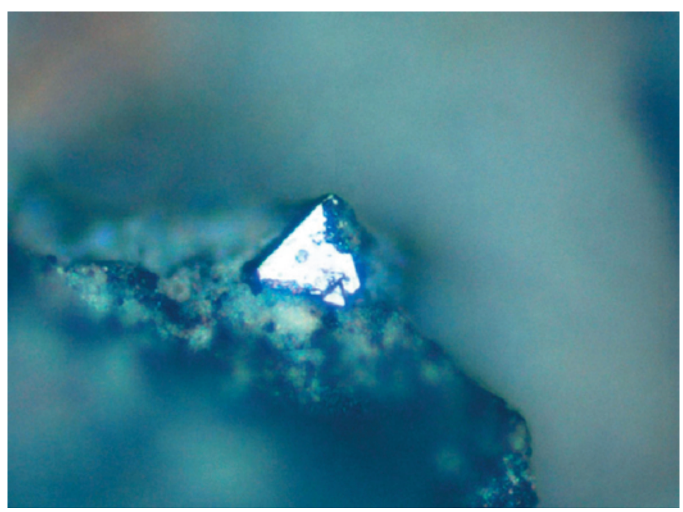



Figure 25. Photomicrographs in reflected light of minerals in sample AP-204, Long Shot Mine. Left, a hematitized framboid about 30 microns in diameter. Right, a chromian spinel crystal about 50 microns across in a cavity. On the basis of SEM/EDX spectra, the spinel has chromium>iron>aluminum>magnesium.

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 TiO_2 was collected from a tributary to this drainage. All stream sediment samples with 2 percent or more 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-

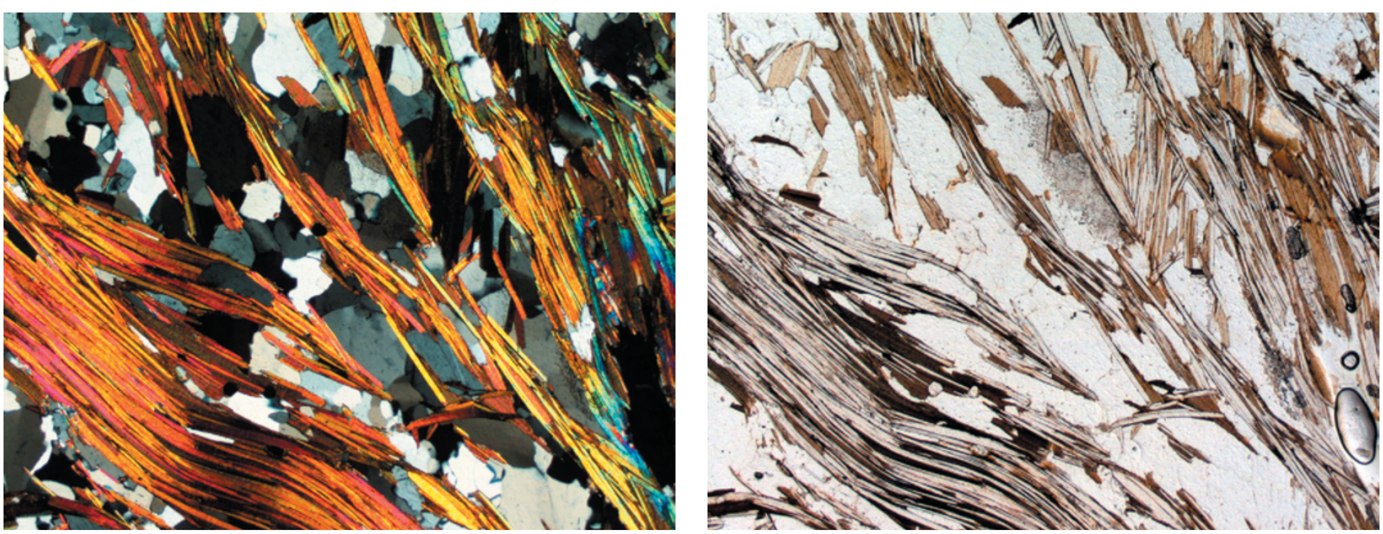


Figure 26. Photomicrograph of mica schist that contains about 40 percent mica, by volume, from Mica Notch. Left, in cross-polarized light, horizontal field of view about 3 mm. The mica shows bright birefringent colors; white to black grains are quartz and feldspar. Right, same view in plane-polarized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

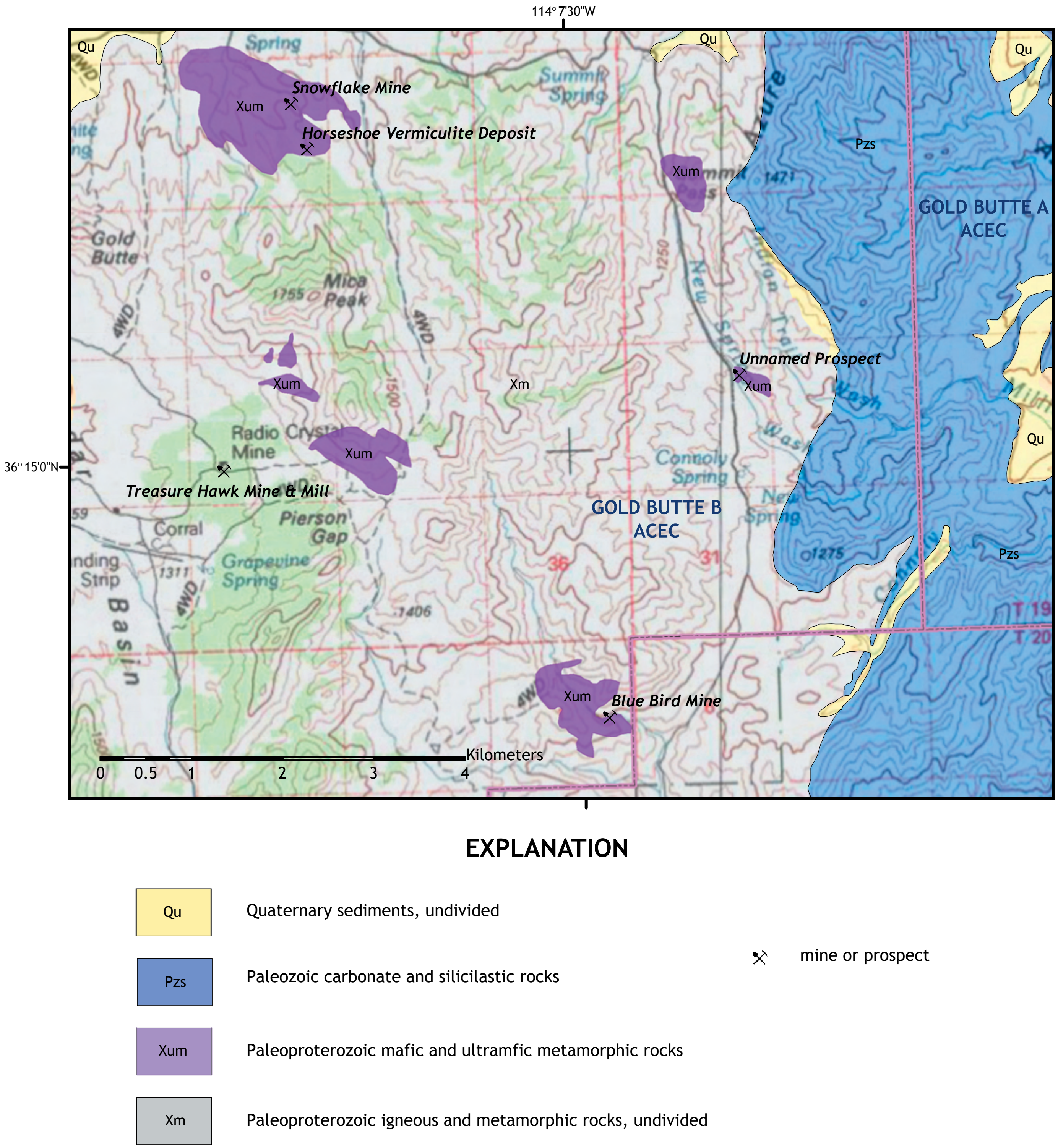


Figure 28. Mafic and ultramafic rocks in the Mica Peak area, showing location of mineral deposits. Basic geology generalized from L.S. Beard (written commun., 2005); outlines of ultramafic rock bodies modified from Volborth (1962), and our unpublished mapping. Boundaries of Areas of Critical Environmental 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 ($Ca_2B_6O_{11}•5H_2O$) has been mined from bedded deposits in the Horse Spring Formation in two areas in the Muddy Mountains west of the Gold Butte–Virgin Mountain 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 Formation. 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 carbonate (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).

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.

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_3. 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_2	7.53	5.44	5.35	9.43	0.33
Al_2O_3	0.97	0.74	0.63	3.94	0.03
Fe_2O_3	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_2O	0.06	0.05	0.18	0.69	0.02
K_2O	0.27	0.22	0.45	0.68	0.02
LOI	20.60	21.30	17.77	13.2	18.3
CO_2	1.06	1.32	0.62	9.20	0.02
SO_3	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 relatively pure limestone taken by us from the Thumb Member of the formation in the Garden Spring area contains high SiO_2, high MgO, and marginally low $CaCO_3$ for lime (table 7). The sample is sufficiently high in CaO for cement rock, but Na_2O+K_2O is marginally excessive. A grab sample of hard, white carbonate from the Kim Ball prospect has less Na_2O+K_2O 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. $CaCO_3$ percent calculated using CaO x 1.78; $MgCO_3$ percent 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-069	AP-070	AP-071	AP-072A	AP-209	Portland cement ore specification	High-Ca lime ore specification
SiO_2	5.81	0.50	3.15	8.08	4.96		<1
Al_2O_3	0.03	0.07	0.39	0.54	0.79		
Fe_2O_3	0.04	0.12	0.18	0.21	0.35		
MgO	0.23	22.06	20.46	14.31	1.55		<1
CaO	53.22	30.29	29.45	33.40	52.49	ca. 50	
Na_2O+K_2O	0.05	0.09	0.43	0.55	0.57	<0.4	
P_2O_5	0.02	0.01	0.02	0.01	0.02		
LOI	40.6	46.7	45.8	42.8	39.2		
$CaCO_3$	94.73	53.92	52.42	59.45	94.43		>95
$MgCO_3$	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 MgO and 3.1 to 23.8 percent CaO for samples from the tunnels and surface outcrops. The highest 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 MgO and 1.3 to 8.9 percent 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. Murphy (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_2	88.89	97.25	98.93	98.5 min
Al_2O_3	2.47	1.38	0.65	0.5 max
Fe_2O_3	0.45	0.19	0.03	0.035 max
MgO+CaO	3.93	0.27	0.05	0.2 max
TiO_2	0.08	0.08	0.03	0.03 max
Cr_2O_3	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. Peeples 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 (Bullock 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

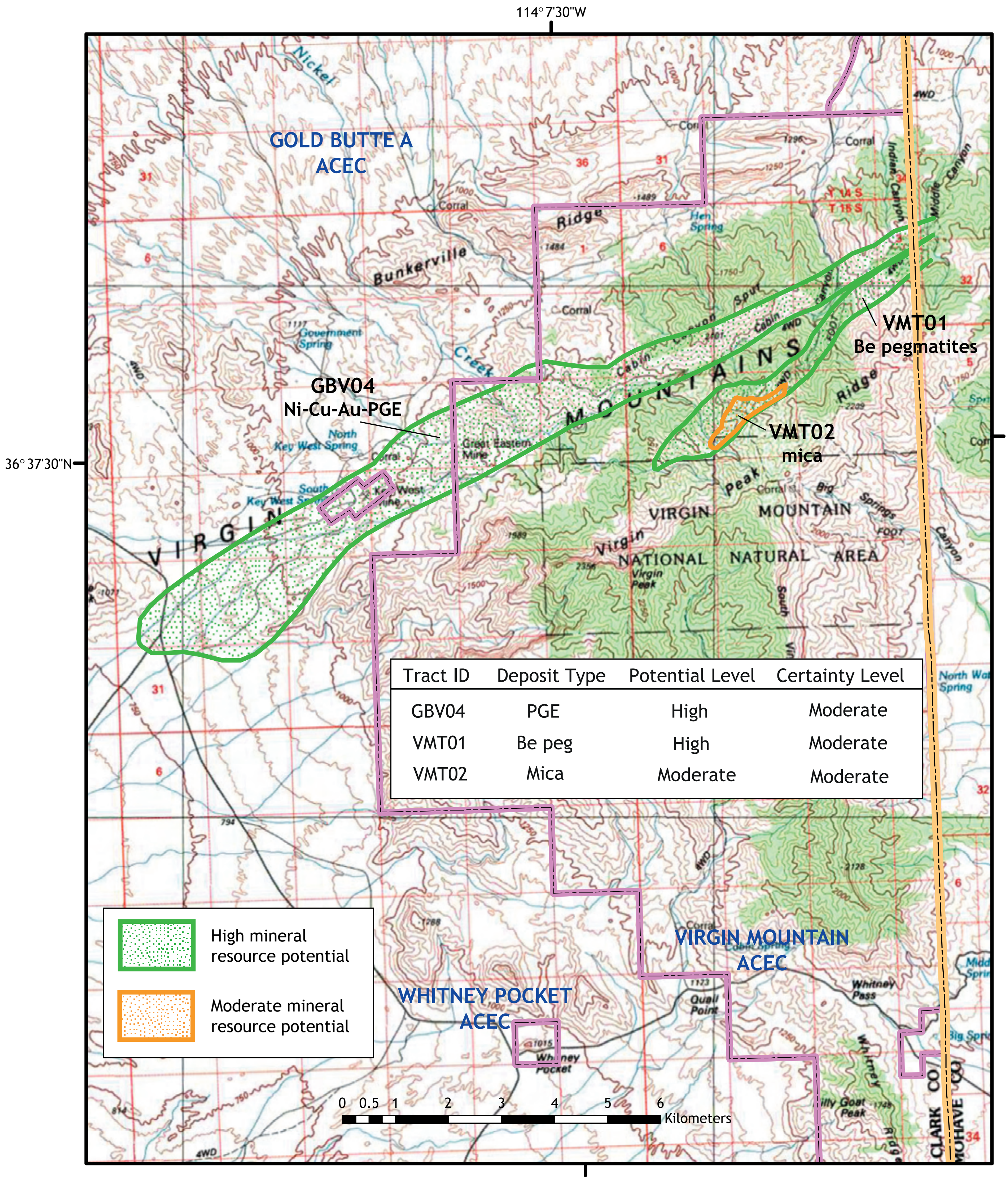
Ni-Cu-Au-PGE Deposits

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

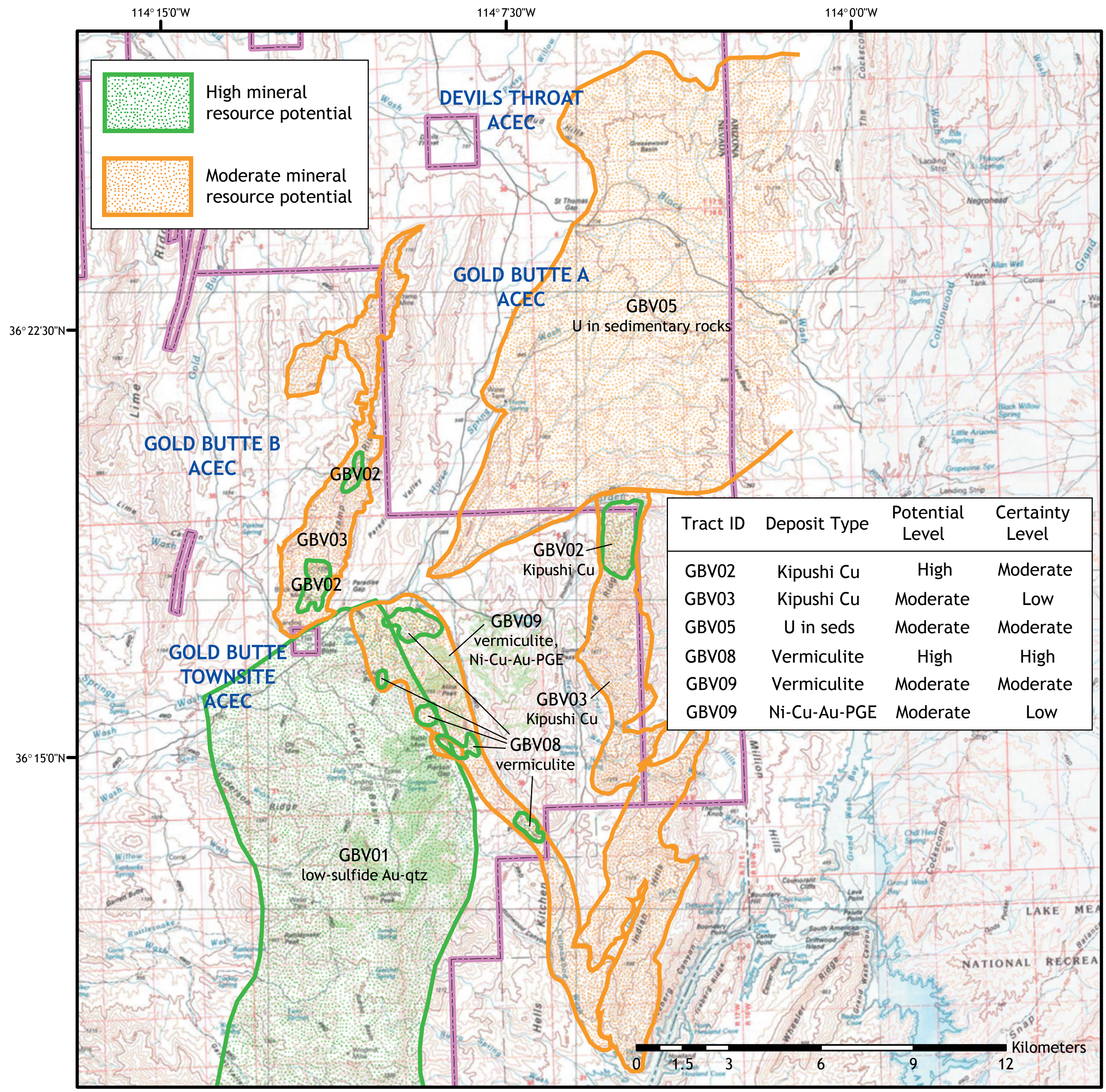
The small base-metal deposits in Paleozoic limestone in the Tramp Ridge and Gold Butte blocks are unlikely to ever be important sources of copper, lead, zinc, or silver. However, they may contain potentially significant concentrations of two unusual high-value metals, gallium and germanium, as well as 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



Tract ID	Deposit Type	Potential Level	Certainty Level
GBV04	PGE	High	Moderate
VMT01	Be peg	High	Moderate
VMT02	Mica	Moderate	Moderate

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.



Tract ID	Deposit Type	Potential Level	Certainty Level
GBV02	Kipushi Cu	High	Moderate
GBV03	Kipushi Cu	Moderate	Low
GBV05	U in seds	Moderate	Moderate
GBV08	Vermiculite	High	High
GBV09	Vermiculite	Moderate	Moderate
GBV09	Ni-Cu-Au-PGE	Moderate	Low

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 northeast 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 litho-logic 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.

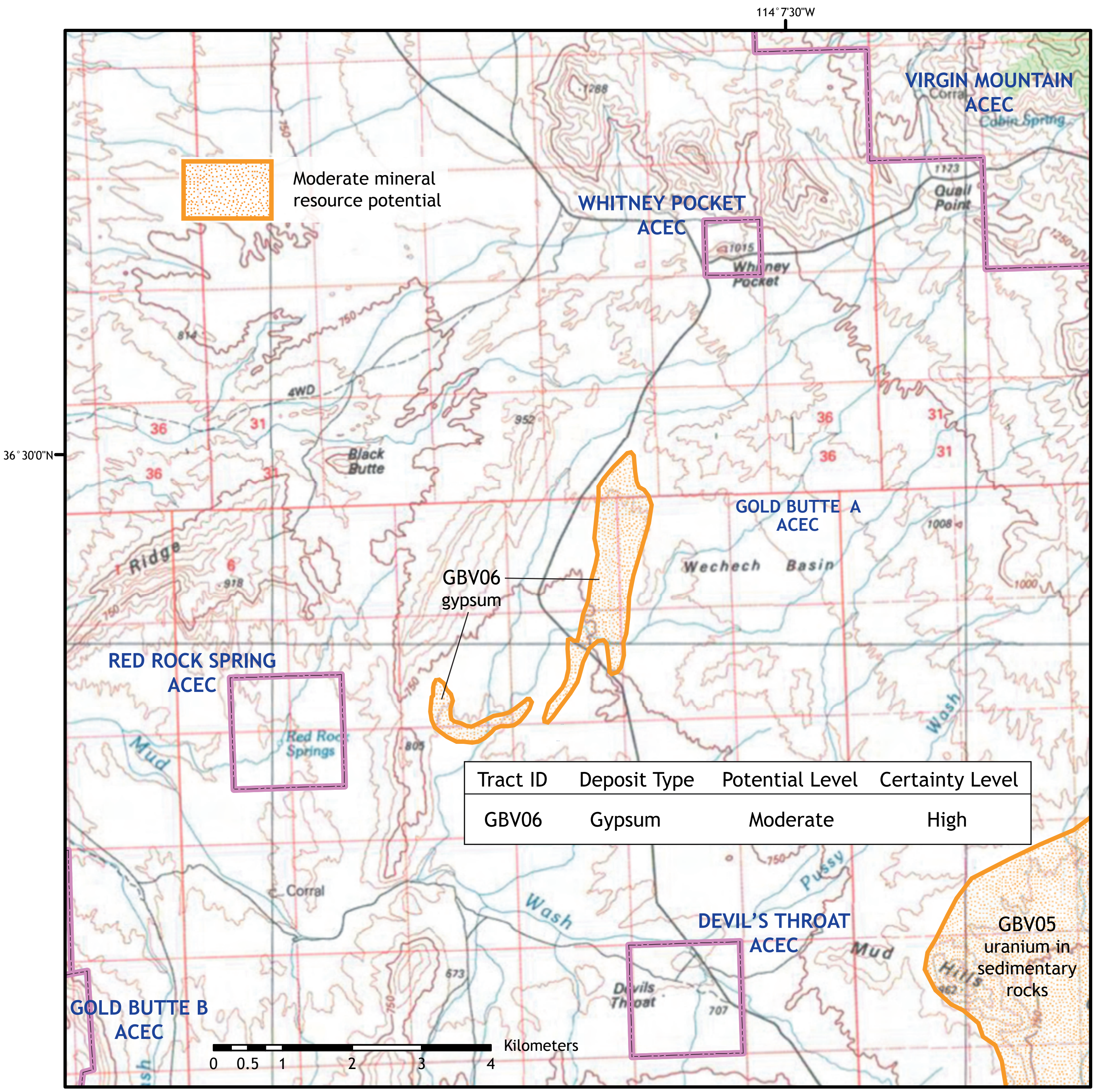


Figure 35. Mineral resource potential tract for gypsum deposits in the Gold Butte A Area of Critical Environmental Concern (ACEC; outlined in pink).

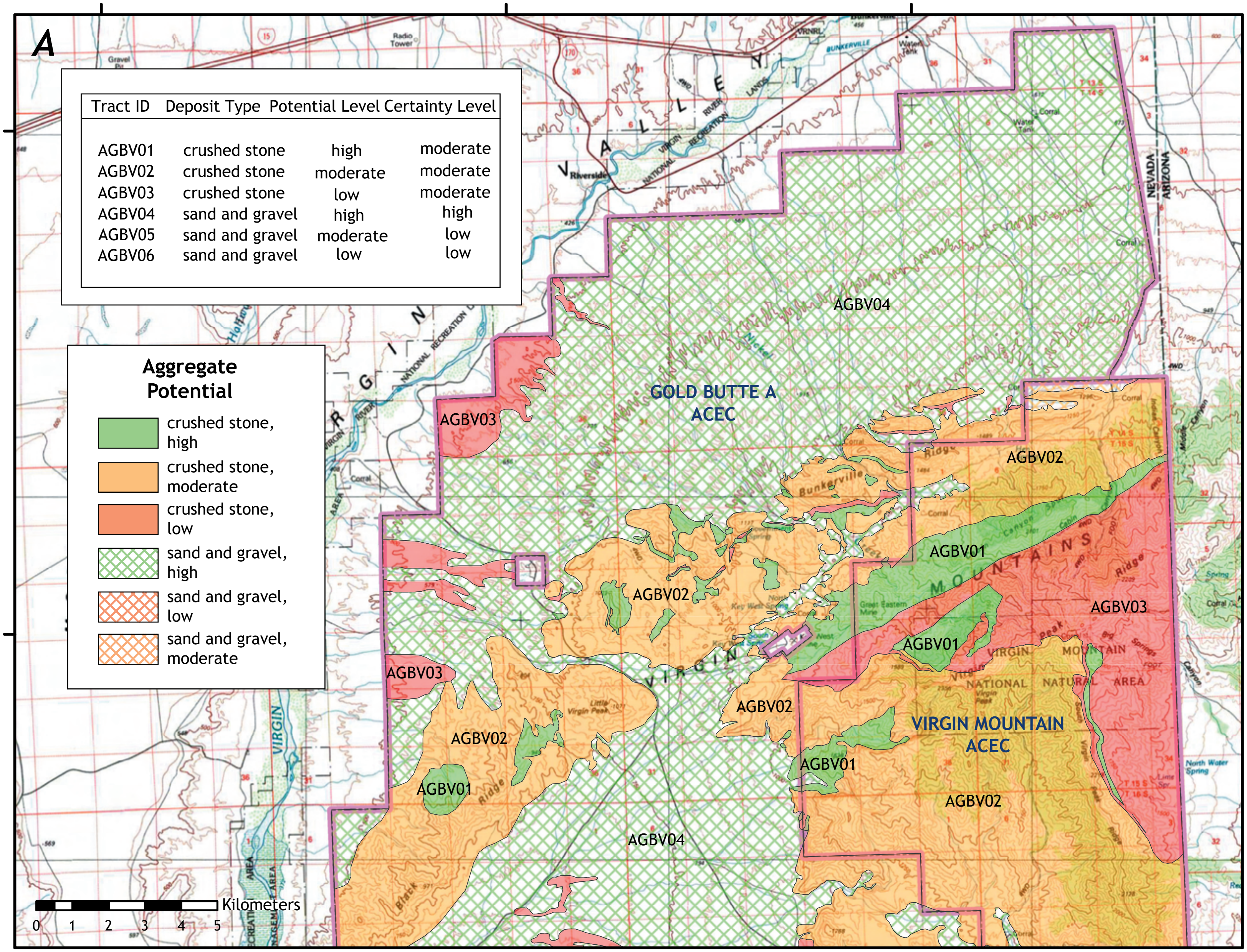
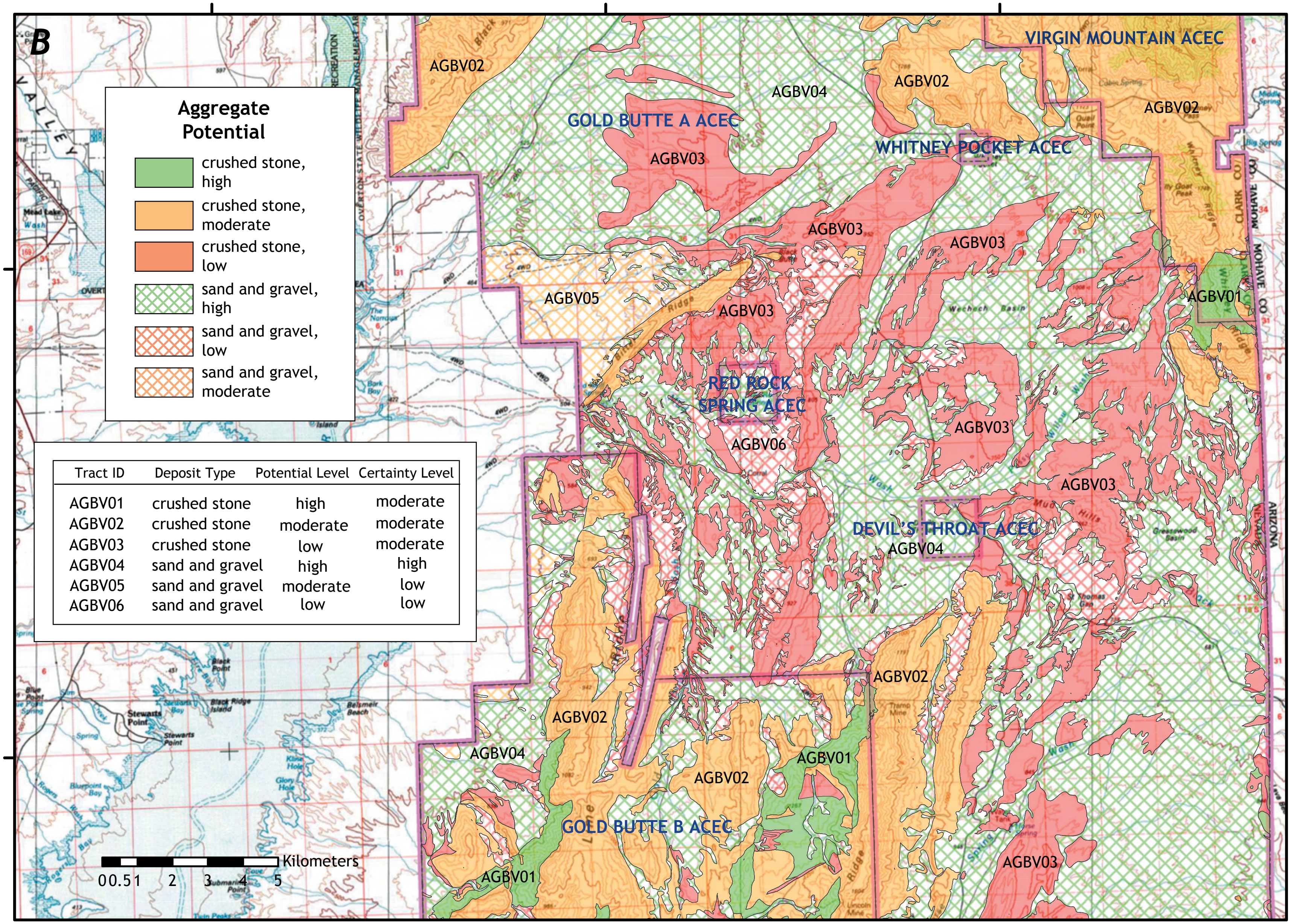
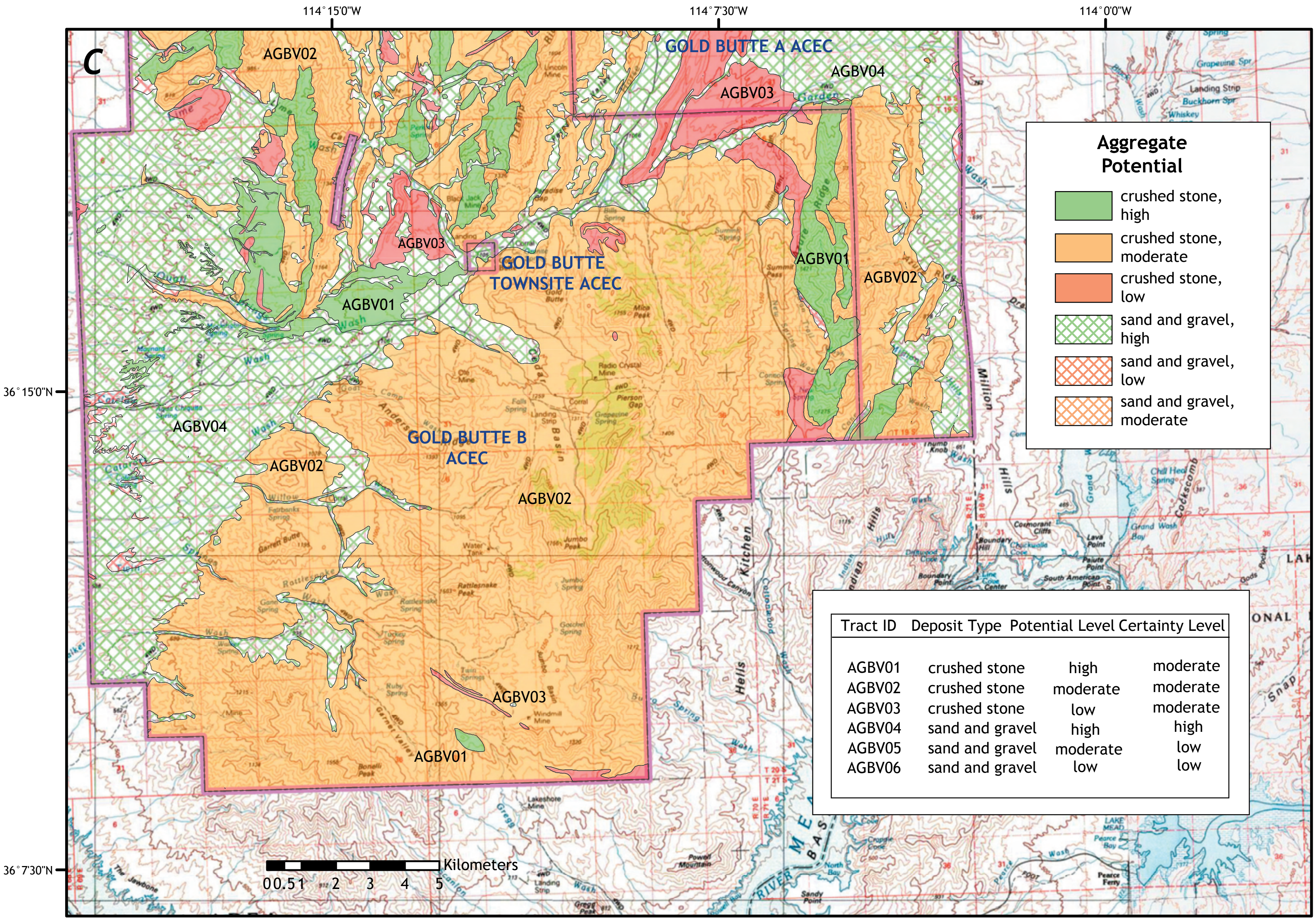


Figure 36. Mineral resource potential tracts for aggregate resources in the Gold Butte A (*A,B,C*), Gold Butte B (*B,C*), Virgin Mountain (*A,B*), Whitney Pocket (*B*), Red Rock Spring (*B*), Devil's Throat (*B*), and Gold Butte Townsite (*C*) Areas of Critical Environmental Concern (ACECs; outlined in pink).



Tract ID	Deposit Type	Potential Level	Certainty Level
AGBV01	crushed stone	high	moderate
AGBV02	crushed stone	moderate	moderate
AGBV03	crushed stone	low	moderate
AGBV04	sand and gravel	high	high
AGBV05	sand and gravel	moderate	low
AGBV06	sand and gravel	low	low

Figure 36.—Continued.



Tract ID	Deposit Type	Potential Level	Certainty Level
AGBV01	crushed stone	high	moderate
AGBV02	crushed stone	moderate	moderate
AGBV03	crushed stone	low	moderate
AGBV04	sand and gravel	high	high
AGBV05	sand and gravel	moderate	low
AGBV06	sand and gravel	low	low

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 Wechech 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.

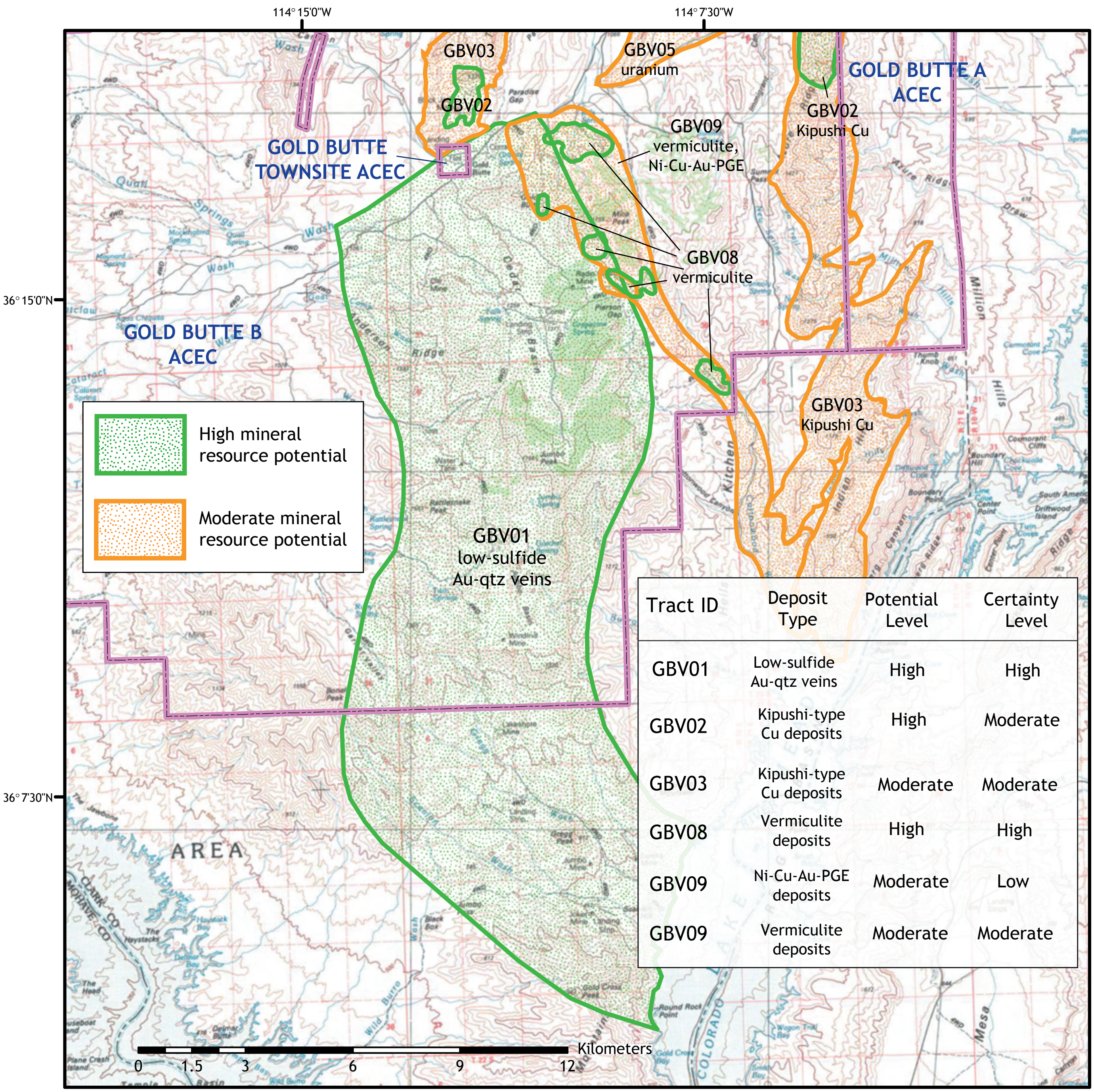
Kipushi-Type Copper Deposits

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_2, 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_2 contents of 15 to 20 percent (Garnar and Stanaway, 1994).

Commercial placer titanium deposits can have low bulk TiO_2 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



Tract ID	Deposit Type	Potential Level	Certainty Level
GBV01	Low-sulfide Au-qtz veins	High	High
GBV02	Kipushi-type Cu deposits	High	Moderate
GBV03	Kipushi-type Cu deposits	Moderate	Moderate
GBV08	Vermiculite deposits	High	High
GBV09	Ni-Cu-Au-PGE deposits	Moderate	Low
GBV09	Vermiculite deposits	Moderate	Moderate

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 leucoxene, 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 Marron 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 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.

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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