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INDUSTRIAL MINERAL RESOURCE POTENTIAL OF TERTIARY PLAYA DEPOSITS OF THE FORT IRWIN AREA, SAN BERNARDINO COUNTY, CALIFORNIA

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INDUSTRIAL MINERAL RESOURCE POTENTIAL OF TERTIARY PLAYA DEPOSITS OF THE FORT IRWIN AREA, SAN BERNARDINO COUNTY, CALIFORNIA

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ABSTRACT

This report is based on existing reports and recently gathered field data. It discusses mineral resource potential of Tertiary playas in the Fort Irwin region. An estimated 1.3 million tons of measured salt "reserves", and 20 million tons of indicated salt resources, have been identified north of the Fort. Other indicated resources include 300,000 tons of celestite, 800,000 tons of gypsum, and 10 million tons of selenite. Zeolitic tuff was mined south of Fort Irwin from 1978 to 1984, and unexplored occurrences are widespread. Calcium-bentonite is mined near Barstow, and more may exist, including valuable sodium- and lithium-based bentonites.

INTRODUCTION

Open pit mines of the Mojave Desert annually produce hundreds of millions of dollars worth of industrial mineral products from Tertiary playa sediments. The Kramer borate deposit and the lithium-rich bentonite deposits of Hector are among the most familiar to industrial mineral specialists. The Mojave Desert has dozens of lesser known clay, zeolite, gypsum, celestite, strontianite, borate, and saline deposits. Federal land-use decisions are being made that preclude mineral resource development of this region. The authors, and their respective State and federal agencies, undertook the investigation of mines and mineral resource potential of the Fort Irwin region to develop geologic and mineral information where very little published information exists.

Fort Irwin National Training Center is located in the central Mojave Desert, approximately 65 kilometers north of Barstow (see Figure 1). Fort Irwin employs approximately 5,800 persons (1987, unpublished U.S. Government source documents). The southern boundary of Death Valley National Monument is less than 5 kilometers north of the Fort, and the National Aeronautic and Space Administration (NASA) Goldstone satellite tracking facility is contiguous to the west.

The Fort Irwin region has undeveloped industrial mineral deposits, most of which are concealed beneath broad desert playas. Tertiary sedimentary and volcanic formations north and south of the Fort have been relatively well described, but due to limited public access, similar rock formations within the Fort have not been thoroughly studied.

The terrain is barren and rocky, with rugged mountains, playas and broad alluvial fans. Cacti, desert shrubs, and grasses grow abundantly near the isolated springs of the region. Gently sloping bajadas sustain sparse vegetation and the broad playas are completely barren. Pale brown dune sand collects on leeward slopes of sharp ridges and ravines. Strong desert winds winnow elevated alluvial terraces, leaving a mosaic of reddish-brown rock clasts called "desert pavement".

REGIONAL GEOLOGY

The oldest rocks in the Fort Irwin region are of the Precambrian basement complex. Lithologies of the basement complex vary, but most of the oldest rock appears to be quartz-feldspar-biotite gneiss. Troxel and Butler (1979) report the presence of late Precambrian Noonday Dolomite, Johnnie Formation, Stirling Quartzite and Wood Canyon Formation in the Avawatz Mountains. Muehlberger (1954) mapped Precambrian quartzite, phyllite, dolomite, mica schist, and units of meta-andesite north of Leach Lake. Roof pendants of Paleozoic meta-sedimentary rocks are exposed throughout the Fort Irwin region. Identification and correlation of the Paleozoic carbonate units are based upon the presence of Pennsylvanian and Permian fusilinids.

MESOZOIC ROCKS

Mesozoic meta-volcanic rocks crop out in the southeastern, central, and northern parts of Fort Irwin. In the Soda Mountains, the Mesozoic meta-volcanic series was named the Soda Mountains Formation by Grose (1959). Abbott (1972) later measured 1,120 meters of Soda Mountains rhyolite, latite, dacite, and andesite flows. Broad exposures of similar, reddish-brown, Mesozoic meta-volcanic rock crop out in the Red Pass Hills just north of the Soda Mountains (Lindsay, 1991).

Mesozoic quartz monzonite and other varieties of granitic rock crop out in the Quail and Owlshead mountains, the Avawatz Mountains, Granite Mountains, Tiefort Mountains, Alvord Mountains, Lane Mountain, and other areas of the Fort Irwin region. Mineralogic and textural variation of these granitic rocks is pronounced. Weighted-average radiometric dates obtained in the Goldstone area by Miller and Sutter (1982) range from 74 to 148 m.y. Many of the age dates are clustered at about 80 million years. Similarly, radiometric age dates obtained by Wagner and Hsu (1987) in the area northwest of Fort Irwin ranged from 65 to 135 m.y. Pre-Cretaceous granitic plutons of the Fort Irwin region appear to have been emplaced sporadically over a relatively long period of geologic time. The "isotopic clocks" of some of the older granitic plutons may have been reset dur-

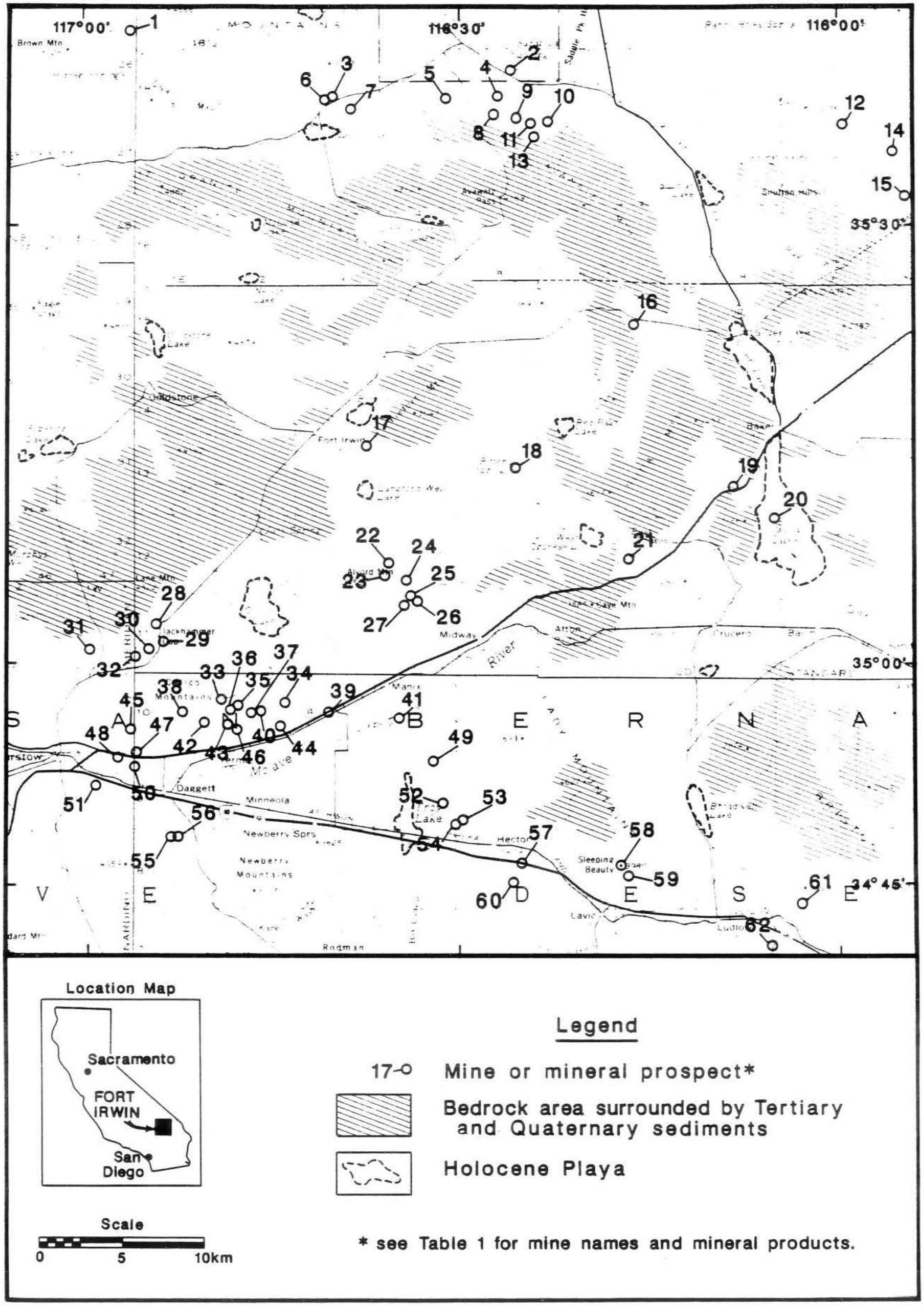

Figure 1. Mines and mineral prospects associated with Tertiary playa deposits of the Fort Irwin region.

Table 1. Mines and mineral Prospects Associated with Tertiary Playa Deposits of the Fort Irwin Region

1	American Magnesium Mine	Magnesium Compounds
2	Saratoga Saline Prospect	Saline Compounds
3	Owls Head Celestite Prospect	Celestite
4	King Salt Prospect	Saline Compounds
5	West End Gypsum Prospect	Gypsum
6	Unnamed Clay Prospect	Clay (Bentonite)
7	Owl Hole Gypsum Prospect Group	Gypsum
8	Boston/Valley Salt Prospect	Saline Compounds
9	Salt Basin Prospect	Saline Compounds
10	Avawatz Gypsum Prospect Group	Gypsum
11	Unnamed Gypsum Prospect	Gypsum
12	Kingston Wash Mine	Clay (Bentonite)
13	Jumbo Salt Prospect	Saline Compounds
14	Red Canyon Gypsum Prospect	Gypsum
15	White Clay Mine	Clay (Bentonite)
16	Silver Lake Clay Group	Clay (Bentonite)
17	Barber Bentonite Mine	Clay (Bentonite)
18	Bitter Spring Clay Prospect	Clay (Bentonite)
19	Pink Lady Mine (Soda Mtns)	Clay (Bentonite)
20	Soda Lake Prospect	Saline Compounds
21	Cronese Mud Mine	Clay (Montmorillonite)
22	Alvord Zeolite Prospect	Zeolites
23	Alvin Zeolite Prospect No.26	Zeolites
24	Alvin Zeolite Prospect No.76	Zeolites
25	Alvin Zeolite Prospect No.62	Zeolites
26	Alvin Zeolite Prospect No.41	Zeolites
27	Alvin Zeolite Prospect No.54	Zeolites
28	Jackhammer Zeolite Prospect	Zeolites
29	Peanut Zeolite Prospect	Zeolites
30	Ross Mine	Celestite
31	Mud Hills Mine	Zeolites
32	Unnamed Clay Prospect	Clay (Bentonite)
33	Pacific Mine	Borates
34	Bentonite Prospect	Clay (Bentonite)
35	Bomber Moon Clay Prospect	Clay (Bentonite)
36	Union Mine	Borates
37	Gunn Mine	Clay (Bentonite)
38	Western Borate Prospect	Borates
39	Unnamed Clay Prospect	Clay (Bentonite)
40	Unnamed Clay Prospect	Clay (Bentonite)
41	Stacsite Mine	Clay (Bentonite)
42	Unnamed Borate Prospect	Borates
43	Centennial Mine	Borates
44	Bentonite Mine	Clay (Bentonite)
45	American Borax Mine	Borates
46	Palm Borate Mine	Borates
47	Barstow Bentonite Mine	Clay (Bentonite)
48	Grottoes Clay Prospect	Clay (Bentonite)
49	Unnamed Clay Prospect	Clay (Bentonite)
50	Monarch Minerals Clay Mine	Clay (Bentonite)
51	Potter Bentonite Prospect	Clay (Bentonite)
52	Henz Bentonite Prospect	Clay (Bentonite)
53	Hector Tuff Clay Prospect	Clay (Hectorite)
54	California Talc Clay Pit	Clay (Bentonite)
55	Unnamed Borate Prospect	Borates
56	Columbus Mine	Borates
57	Fort Cady Borate Prospect	Borates
58	Unnamed Strontianite Prospect	Strontianite
59	Dupont Strontianite Group	Strontianite
60	Newberry Hectorite Mine	Clay (Hectorite)
61	Siberia Clay Prospect	Clay (Bentonite)
62	Unnamed Clay Prospect Group	Clay (Bentonite)

* Traces of zeolite minerals and authigenic feldspar are commonly present in playa clay deposits. Similarly, traces of strontianite, celestite and other sulfate minerals may be present in playa gypsum deposits. Halite is the most abundant saline mineral in the playa beds, but other sodium and potassium salts are generally present. Assessment of the relative abundance of these Tertiary playa minerals in unexplored areas will require systematic drilling and chemical analysis.

ing an especially intense period of intrusive activity that occurred at about 80 m.y.

Mesozoic sedimentary rocks have been mapped in various parts of the Mojave Desert, but little work has been done within the Fort. Walker and Wardlaw (1989) propose the name Silver Lake Formation for a sequence of metamorphosed early Triassic siltstone beds, limestone, and cherty limestone in the Soda Mountains. The Silver Lake Formation rests unconformably on similar Permian metacarbonate beds.

CENOZOIC ROCKS

Tertiary sedimentary and volcanic rocks are widely distributed about Fort Irwin. Volcanic lithologies include thin-bedded airfall tuff, ashflow tuff, massive lahars, and flows. Andesite and dacite are the most abundant volcanic lithologies, although rhyolite and basalt units are present. Tertiary sedimentary rocks include conglomerate, sandstone, siltstone, and evaporite deposits. Late Cenozoic sediments and colluvium exposed in the region are derived largely from Tertiary volcanic rocks.

The Tertiary stratigraphic section, both north and south of Fort Irwin, is characterized by rapid lateral changes in lithology and thickness. Among other things, that suggests that the stratigraphic section accumulated primarily during episodes of tectonic activity (Dibblee, 1967, p. 5).

GEOLOGY SOUTH OF FORT IRWIN

In the Calico Mountains area, between Barstow and the southern boundary of Fort Irwin, felsic volcanic tuff of the Miocene Jackhammer and Pickhandle formations rests unconformably upon Mesozoic intermediate volcanic rocks, granitic plutons, and Paleozoic roof pendants.

In the northwestern part of the Alvord quadrangle, the Pliocene (?) Lane Mountain andesite contains about 100 meters of tuffaceous bedded sediments (Byers, 1960, p. 39-41). This unit unconformably rests on the Miocene Barstow Formation (Dibblee, 1968, p. 91). The middle and upper Miocene Barstow Formation is up to 1360 meters thick and consists of conglomerate, algal limestone, sandstone, tuff and shale. The Barstow Formation is exposed from just southeast of Cuddeback Dry Lake to Bitter Spring. In lower Black Canyon and elsewhere, it disconformably overlies the Pickhandle Formation. East of Calico, the Barstow Formation conformably overlies the Spanish Canyon Formation, which consists of nearly 100 meters of sandstone, conglomerate, tuff, and vesicular basalt (Byers, 1960, p. 22).

The Pickhandle Formation consists largely of ashflows, airfall tuff, and volcanic breccia. It is almost 850 meters thick in places and exposed from Cuddeback Dry Lake to the Calico Mountains. In the Mud Hills, west of the Calico Mountains, the Pickhandle Formation conformably overlies the Jackhammer Formation. The Jackhammer Formation consists of nearly 50 meters of arkosic sandstone, siltstone, limestone and conglomerate.

GEOLOGY NORTH OF FORT IRWIN

The basal part of the Tertiary section in the northern Avawatz Mountains and southernmost Death Valley region consists of thin-bedded, laterally continuous, lacustrine sediments, evaporites, and volcanic tuff. The overlying Tertiary section has hundreds of meters of clastic lacustrine sediments, evaporites and thin-bedded tuff. Incised terraces of Tertiary fanglomerate and colluvium conceal parts of the older playa deposits. Deformation and erosion of the Tertiary playa deposits has been intense in the northern Avawatz Mountains.

INDUSTRIAL MINERAL DEPOSITS

CLAYS

There are numerous occurrences of calcium-rich bentonite within the Barstow Formation (Silva and Eyde, 1991). Hydrogeologic conditions exist in some parts of the Fort Irwin that may be favorable for the formation of valuable sodium and lithium-based clays. The Newberry-Hectorite deposit is located 50 kilometers south of Fort Irwin. Pervasive hydrothermal alteration associated with Tertiary volcanism has converted rhyolite airfall tuff to hectorite.

Gunn mine - The Gunn bentonite mine is located 5 kilometers northeast of Yermo. The minerals sepiolite and hectorite have been observed within a narrow fault zone in the main pit. The presence of these special clay minerals strongly implies that in situ tuffaceous sediments have been altered by low-temperature geothermal activity in the pit area (Regis, 1978, p. 6; Norton, 1965, p. 165). Southwest of the Gunn mine, bentonite is associated with 1 to 4 meter thick magnesite beds. In addition to authigenic clay minerals, nearly all of the clay specimens sampled in this region were found to contain zeolites (Sheppard and Gude, 1969, p. 114; Stinson, 1988).

A 2 meter thick bed, consisting of 90 percent authigenic potassium feldspar, crops out in the eastern Mud Hills. Authigenic potassium feldspar commonly forms when bentonite-bearing and zeolite-bearing tuffaceous sediments are confined in a highly alkaline aqueous environment.

Barber Bentonite Prospect - The Barber Bentonite prospect was probably discovered around the turn of the century. Attempts were made to develop the deposit prior to 1930, and the last known owner was A.M. Barber of Los Angeles. Older CDMG reports give a location that is about 1.5 kilometers south of Bicycle Lake and 3 kilometers northeast of Garlic Spring. The deposit is located within Fort Irwin in an area where tuffaceous sediments are capped with basalt and exposed along the perimeters of small playas. CDMG archive photographs show that the gently dipping bentonite deposit is nearly 10 meters thick. Early literature references state that it is exposed for nearly a kilometer.

Several attempts to verify the location of the old Barber mine site were unsuccessful. However, just west of Bicycle Lake, Kunkel and Riley (1959, p. 239) describe a volcanic unit with a 15 to 30 meter thick bed of tuff, tuffaceous sand and agglomerate at the base. Prior to the establishment of Fort Irwin, mining claims were located west of Bicycle Lake by Bentonite Clay Syndicate and Pomona Tile Company.

Bitter Spring Clay Deposit - The Bitter Spring saline clay deposit is 9 kilometers southwest of Red Pass lake, where unconsolidated alluvium, wind-blown sand, and U.S. Army barbed wire severely limit vehicular movement. Bitter Spring is the most important wildlife refuge in the Fort Irwin region. Several years of concerted U.S. Army effort to restrict vehicular and foot access to Bitter Spring has resulted in remarkable enhancement of desert vegetation and wildlife at the spring. The pale brownish-gray bentonitic beds exposed at Bitter Spring, although representative of Miocene clay deposits of the region, have not been mined. They contain halite, thenardite, authigenic feldspar, and minor illite, gypsum, calcite, and analcime. The mineralization is indicative of authigenic alteration of tuffaceous sediments.

The Bitter Spring clay deposit is in an area underlain by Cenozoic volcanic rocks and sediments derived from volcanic rocks. Basalt, rhyolite, and dacite flows are exposed throughout the region, as are airfall tuff and ashflows. Late Tertiary and Quaternary lacustrine sediments in the region consist largely of reworked airfall tuff. The fine-grained, well-sorted, lake bed sediments of Bitter Spring are brownish-gray, strike N20W, dip 20NE, and have the appearance of leached "salt clay". Similar sediments are exposed in the area north of the Avawatz Mountains. The saline clay beds and overlying dacite ashflow tuff units are displaced by a Quaternary (N20W) fault passing through Bitter Spring. Minor vertical offset has caused ground water to surface at the spring.

Silver Lake Clay Mine - The Silver Lake clay (and gypsum) mine is located in the rugged southern Avawatz Mountains, 4 kilometers east of the Fort Irwin boundary. Thirteen meters of altered, north-dipping, tuffaceous sediments are exposed in the open pit. Pale greenish-gray clay and gypsum beds crop out at an elevation of about 533 meters. The Silver lake deposit, as with other bentonitic deposits of the central Mojave Desert, appears to have been discovered around the turn of the Century. Prospect pits are scattered about the area. Several hundred tons of material have been mined from a larger clay pit.

The Silver Lake clay pit is located midway between broad Cenozoic playas to the west and east. The playas of Fort Irwin (to the west) contain Barstow Formation tuffaceous sediments, and field evidence suggests that Miocene tuffaceous sediments equivalent to the Barstow Formation also underlie Silver Lake (to the east). The uplifted sedimentary exposures of Silver Lake Pass and Red Lake Pass appear to be outliers of a system of interconnected Tertiary lakes.

The lacustrine sediments at Silver Lake Pass are overlain by poorly sorted fanglomerate beds. The sequence at the mine strikes N70W and dips 60 degrees northeast. The beds are folded, uplifted, and truncated to the south by a late Cenozoic fault. Rocks south of the fault are uplifted with respect to rocks on the north.

ZEOLITES

Mud Hills Mine - The Mud Hills zeolite mine is located about 15 kilometers north of Barstow, two kilometers west of Copper City Road, and is accessible by an unpaved road. It lies in an area of gentle hills at about 900 meters elevation. The Mud Hills zeolite deposit was probably discovered before zeolites became economic minerals. Occidental Minerals Corporation began developing this desert property in 1978 and delivered several thousand tons of zeolite product (clinoptilolite) to British Nuclear Fuels, Ltd. (BNFL) in 1981. BNFL used Mud Hills zeolite product to absorb nuclear waste spillage. According to Skillings' Mining Review (1988), Oak Ridge National Laboratory scientists determined that clinoptilolite from the Mud Hills mine out performed 14 other commercially available natural and synthetic zeolites in removing radioactive isotopes from nuclear waste materials. The BNFL contract amount was reported to have been $4,000,000 for a 20-year supply.

Phelps-Dodge Zeolites purchased the mine in late 1982 and continued the contract operation with BNFL. The last shipments were probably made in 1984. The mine was purchased by Steelhead Resources, Ltd. in 1988. Several thousand tons of clinoptilolite-bearing material is neatly stored at the mine in bulk product bags. The Mud Hills zeolite deposit occurs within gently folded tuffaceous sediments of the Miocene Barstow Formation. The main zeolite-bearing unit is a 3 to 6 meters thick, laterally continuous, air fall rhyolite tuff that strikes east-west and dips about 15 degrees to the south. Erosion and topography limit the surface exposure of the beds. Zeolite reserves and resources at the Mud Hills mine are also limited by the depth of zeolitic alteration.

The Mud Hills deposit is a closed-basin, volcanogenic, zeolite deposit (Sheppard and Gude, 1969). The principal zeolite mineral at the Mud Hills mine is clinoptilolite, a potassium-rich variety of heulandite. Clinoptilolite content of pit-run material ranges from 70 to 90 percent within the deposit (Stinson, 1988). The cell spacing and physical character of clinoptilolite is well-suited to absorb cesium-137 and strontium-90, two important nuclear waste isotopes.

GYPSUM, CELESTITE, AND STRONTIANITE

Owlshead Mountains Evaporite Deposits - Celestite and gypsum beds crop out in the area south of the Owlshead Mountains. The Owlshead beds are generally found with brown salt clay, tan smectite clays, and other thin-bedded saline lacustrine deposits. These beds are folded, truncated, displaced by late Cenozoic faults, and overlain by a thick blanket of Plio-Pleistocene fanglomerate. Structural complexity of the area makes stratigraphy and lateral extent of individual beds difficult to measure and document.

Celestite is present as a discontinuous meter-thick bed, thinner beds, and as concretions within the narrow celestite zones. We did not estimate in situ tonnage, but the Owlshead/Avawatz prospects undoubtedly have many thousands of tons of gypsum and associated celestite. A meter thick gypsum bed, brown salt clay, and other lacustrine sediments strike east-northeast and dip northward under fanglomerate at a road cut 500 meters south of Owl Hole Spring. Nodules of celestite were observed in gypsum beds just east of this outcrop. About 150 meters north of the gypsum exposure, the gypsum-saline beds reappear, but strike northwest and dip to the south.

Gypsum, celestite, and salt deposits of the Avawatz and Owlshead mountains are easily recognized in the field and aerial photographs by sharply contrasting dark brown, beige, and white bedding. Strontianite ($SrCO_3$) was not observed in the Owlshead/Avawatz area. However, it has been mined from units of the Barstow Formation in the Mud Hills.

BORATES

Miocene lacustrine deposits underlie much of the Fort Irwin region, and similar beds in the western Mojave Desert have produced borates. Several billion dollars worth of borates have been mined from the Miocene Tropico Group at Kramer, which is located 70 kilometers southwest of Fort Irwin. USBM records indicate that more than $9,000,000 worth of borates have been produced from mines in the eastern Calico Mountains area. Small borate deposits also occur in the Mud Hills, and possible traces of colemanite have been reported within units of the Lane Mountain Andesite (Byers, 1960, p. 41, 65). A late Tertiary or early Quaternary gravel bed is exposed near the southwest corner of the Alvord Mountain quadrangle. The unit consists largely of andesite detritus, but also contains a 300 cm thick bed of bentonitic silt with colemanite, gypsum and celestite (Byers, 1960, p. 42, 65).

Borates and nitrates have been reported in the area north of the Avawatz Mountains. Due to the scope of this project and a limited amount of time available for mineralogical field work, we were able to identify only the more common evaporite minerals: gypsum, celestite, halite, and trona. Regardless, historical accounts of the saline mineral potential of the area may have been somewhat exaggerated. Bailey (1902, p. 63, 176) states that "Borax in considerable quantities has been found in the niter fields...along the flank of the Avawatz range...". He also reports colemanite associated with niter in the area south of Owl Hole Spring. After extensive sampling, Noble (1931, p. 24) could not confirm Bailey's borate occurrences. Contemporary workers have also failed to confirm the existence of borates in the Owlshead area. A sediment sample collected by the Bureau of Land Management from Pipe Line Wash yielded an anomalous boron value.

SALINE COMPOUNDS

Avawatz Mountains Evaporite Deposits - Several important salt prospects have been identified along the northern flank of the Avawatz Mountains. This remote area is accessible by unpaved desert roads from Highway 127, south of Death Valley. The Boston/Valley salt prospect is located in the northern foothills of the Avawatz Mountains, a few hundred meters south of Cave Spring Road, 6.5 kilometers north of Fort Irwin. The Jumbo prospect is 4 kilometers west of Sheep Creek Spring. The King prospect is 4 kilometers southwest of Saratoga Spring. The Salt Basin prospect is located 6 kilometers northwest of Denning Spring. The West End deposit is exposed at a prominent hill at the southern boundary of Death Valley National Monument.

A narrow depositional basin formed along the Garlock fault during the Tertiary Period, and sediments mapped by Muehlberger (1954) 10 miles west of Leach Lake are similar to those exposed on the north flank of the Avawatz Mountains. Brady (1986) also mapped tuffaceous and saline deposits in the Denning Spring area. The Avawatz Formation occurs on the west side of the Avawatz Mountains and extends southward into the Soda Mountains (Henshaw, 1939; Grose, 1959, p. 1534). The upper unit of this formation consists of tuff and coarse-grained sandstone. On the west side of the Avawatz Range, southeast of Cave Springs, Bailey (1902) noted the occurrence of ulexite with sodium carbonates and sulphates.

The region was first systematically explored in 1911 by A.I. Oliver, L.D. Rasor, and geologist J.O. Lewis for the Avawatz Salt and Gypsum Company. In 1941 and 1942, Union Pacific Railroad Company and Basic Magnesium, Inc. jointly mapped and drilled the Boston/Valley deposit. Some exploratory workings were developed. In 1942, a development summary report was prepared by H.C. Lee and L.F. Bayer. Another summary report was prepared by H.S. Gale in 1947 based on field work done by Gale and L.F. Noble in 1942. No systematic exploration, development, or salt mining has taken place since 1942. Saline mineral reserves and resources are summarized in Table 2.

The Boston/Valley salt beds, and all the other prospects, crop out in a desert region noted for intense tectonism and harsh climate. The Boston/Valley beds are truncated and displaced by slivers of the Death Valley fault zone. Miocene and Pliocene salt beds are underlain by basal conglomerate and breccia, and overlain by Plio-Pleistocene fanglomerate. Tertiary volcanic flows, lacustrine clastic sediments, and altered tuff exist throughout the stratigraphic section.

The brown clayey salt beds contain layers of salt and gypsum, and nodules of celestite. Basic Magnesium, Inc. drill cores demonstrate that salt beds extend to a depth of at least 83 meters. Assays of samples from 27 drill holes indicate that the Boston/Valley salt beds contain about 90 percent halite, 8 percent brown clay, some gypsum, and traces of other saline minerals (Gale, CDMG file report, 1947). Noble and others (1922) examined the Avawatz area for the presence of nitrates. They concluded that the nitrate-bearing caliche was uneconomic due to the small size of the area (1,200 acres), and low concentration (1.73 to 2.12 percent).

MINERAL RESOURCE POTENTIAL

The Fort Irwin region has good potential for the development of clays, zeolites, borates, gypsum, celestite, and saline minerals. Potential mineral products associated with Tertiary playa deposits include bentonitic clays and zeolites derived from diagenesis of felsic tuffaceous sediments. Most of the clays appear to be calcium-rich bentonite, and the more valuable sodium- and lithium-based bentonites appear to be rare (Silva and Eyde, 1991).

In areas where bedded lacustrine deposits have not been exposed by tectonic uplift and erosion, economic development can only be accomplished by systematic exploration drilling. Thus, about 90 percent of the desert playas of the Fort Irwin region have not been systematically explored.

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Table 2. Saline mineral reserves and resources of the Avawatz-Owlshead Mountains.

Resource Area	Measured Reserves and Resources (tons	Indicated Reserves and Resources (tons)	
Boston/Valley[1]	Salt: 1,300,000	Salt:	15,000,000
Salt Basin[1]		Salt:	3,960,000
Jumbo[1]		Salt:	1,485,000
King[1]		Salt:	99,000
Owl Hole Spring[2]		Gypsum	800,000
Owl Hole Spring[2]		Selenite	10,000,000
Jumbo, Salt Basin, Celestite Hills, Cave Spring Wash[3]		Celestite	300,000

[1] Calzia and others (1979)
[2] Koch and others (1984)
[3] Durrell (1953)

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