Mineral Resources of the Mecca Hills Wilderness Study Area, Riverside County, California

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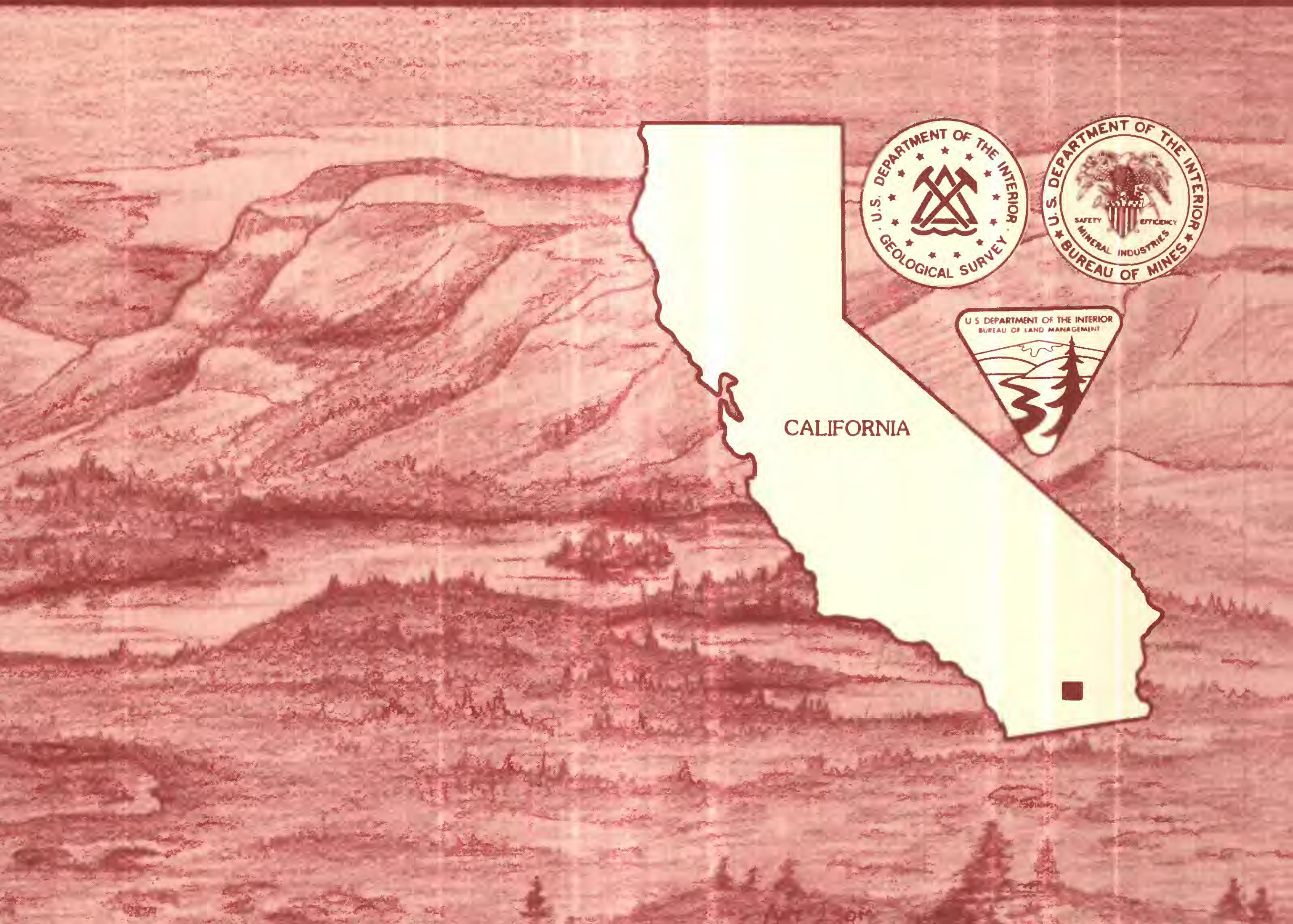

Chapter C

Mineral Resources of the Mecca Hills Wilderness Study Area, Riverside County, California

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U.S. GEOLOGICAL SURVEY BULLETIN 1710

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
SOUTH-CENTRAL CALIFORNIA DESERT CONSERVATION AREA, CALIFORNIA

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of a part of the Mecca Hills Wilderness Study Area (CDCA-343), Riverside County, California.

CONTENTS

FIGURES

Mineral Resources of the Mecca Hills Wilderness Study Area, Riverside County, California

By Douglas M. Morton, James E. Kilburn, *and* Andrew Griscom
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SUMMARY

Abstract

The part of the Mecca Hills Wilderness Study Area (CDCA-343) for which mineral surveys were requested encompasses 9,490 acres in the northeast corner of the Salton Trough in southern California. Field work for this report was conducted in 1983 and 1985 by the U.S. Bureau of Mines and U.S. Geological Survey to assess the identified mineral resources (known) and the mineral resource potential (undiscovered) of the area.

No metallic mineral resources were identified in the study area, nor were any current mining claims found. Oil and gas leases were present in 1983. The Skeleton Canyon mine, in the southwestern part of the study area, yielded clay to seal nearby irrigation canals, but does not currently constitute a resource.

Areas within the San Andreas fault zone extending northwest and southeast from the clay deposit have moderate resource potential for clay. Undiscovered clay resources in this area are likely to be of little economic interest. The area southwest of the San Andreas fault has low potential for oil and gas resources and the entire study area has moderate potential for low-temperature (less than 90°C) geothermal resources. The study area has low potential for barite and strontium resources.

Character and Setting

The Mecca Hills Wilderness Study Area is a badlands area of low but extremely rugged relief located at the north end of the Salton Trough, 13 mi southeast of Indio, Calif. (fig. 1). It is underlain by a basement of Proterozoic (see appendix for geologic time chart) gneiss and related rocks and the Mesozoic Orocopia Schist. The basement rocks are overlain mainly by a deformed sequence of upper Pliocene and Pleistocene nonmarine sedimentary rocks. The San Andreas fault crosses the southwestern part of the study area, where it cuts the Pliocene and Pleistocene Palm Springs Formation.

Identified Resources

All prospects within and near the study area were examined, and eight samples were collected and analyzed. There are no identified mineral resources in the study area.

The only known mine within the study area is the Skeleton Canyon mine, which has a large tonnage of clay that could become a resource if a market were identified. This mine consists of bulldozer cuts from which clay was mined to seal irrigation canals (Crowell and Sylvester, 1979, p. 157). The clay is present as low hills of brick-red fault gouge within the San Andreas fault zone and contains fragments and blocks of siltstone and sandstone. The clay unit strikes N. 60° W. and dips about 30° NE. Exposures of the clay cover about 30 acres of which 20 acres are inside the study area. The clay zone is about 4,900 ft long and 50 to 100 ft thick. It pinches out to the southeast and is buried by alluvium on the northwest.

Mineral Resource Potential

There is no direct evidence that mineralizing events took place within the Mecca Hills Wilderness Study Area. The areas within the San Andreas fault zone northwest and southeast of the clay occurrence at the Skeleton Canyon mine have a moderate potential for clay resources, although undiscovered clay resources are unlikely to be economic. The area southwest of the San Andreas fault has low potential for oil and gas resources and the entire study area has moderate potential for low-temperature (less than 90 °C) geothermal resources. The study area has low potential for barite and strontium resources.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is a joint effort by the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM). An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines

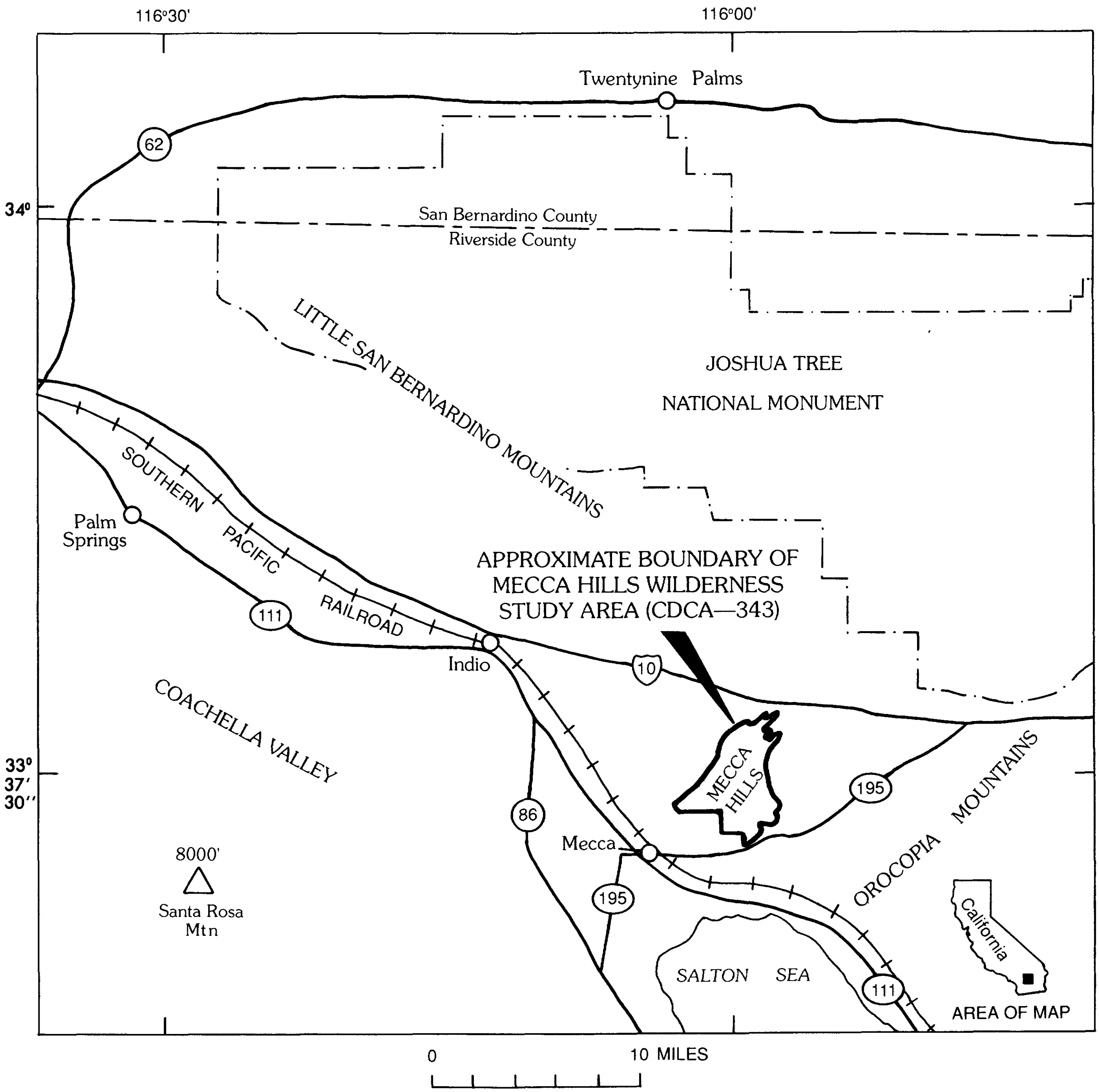

Figure 1. Index map showing the location of the Mecca Hills Wilderness Study Area, Riverside County, California.

evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to the system described by U.S. Bureau of Mines and U.S. Geological Survey (1980). Studies by the U.S. Geological Survey are designed to provide a reasonable scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Mineral assessment methodology and terminology as they apply to these surveys were discussed by Goudarzi (1984). See appendix for the definition of levels of mineral resource potential, certainty of assessment, and classification of identified resources.

Area Description

The part of the Mecca Hills Wilderness Study Area (CDCA-343) for which mineral surveys were requested encompasses 9,490 acres. It is located in southern California, in the northeast side of the Salton Trough, 13 mi southeast of Indio and 4 mi north of the Salton Sea (fig. 1). The study area includes parts of the Thermal Canyon, Mecca, and Mortmar 7.5-minute quadrangles and part of the Cottonwood Spring 15-minute quadrangle. The climate is arid and the vegetation sparse. Access to the study area is by unimproved dirt roads from California Highway 195 and Interstate Highway 10 (fig. 1) and by flat-bottomed sandy washes that can be traveled by off-road vehicles. The Mecca Hills have low relief but are deeply dissected by a labyrinth of narrow, steep-walled canyons forming a spectacular badlands topography. Elevations in the study area range from about 40 to 1,600 feet above sea level.

Previous and Present Investigations

Field work for this report was carried out between 1983 and 1985. Geologic maps, principally by A.G. Sylvester, provided the geologic basis for the mineral resource potential assessment. The general geology of the study area was described by Dibblee (1954), Hays (1957), Ware (1958), Sylvester (1979), and Sylvester and Smith (1975, 1976). Oil and gas potential of the study area was evaluated by Scott (1983).

The U.S. Bureau of Mines (USBM) collected information related to current and past mining activities within and adjacent to the study area. Field work, conducted during 1983, consisted of an examination of all mines and prospects in and near the study area and collecting eight samples for chemical analysis. A scintillometer was carried during the field investigations to detect radioactive minerals. Quantitative amounts of gold and silver were determined by fire assay; quantitative amounts for other elements were determined by atomic-absorption or induction-coupled plasma analysis. The samples were also analyzed by semiquantitative spectrographic methods for 40 elements. In addition, a preliminary ceramic evaluation of one clay sample was done. Complete analytical results are on file at the U.S. Bureau of Mines, Western Field Operations Center, E. 360 Third Ave., Spokane, WA 99202.

The U.S. Geological Survey (USGS) conducted geologic mapping in the study area between 1983 and 1984 to augment existing geologic maps and made a reconnaissance geochemical survey of stream sediments in 1984. Geophysical interpretations were made from gravity and aeromagnetic maps in 1985.

APPRAISAL OF IDENTIFIED RESOURCES

By Harry W. Campbell
U.S. Bureau of Mines

There are no identified mineral resources in the Mecca Hills Wilderness Study Area. Clay, sand, and gravel occurrences are located inside the Mecca Hills Wilderness Study Area.

History and Production

Oil and gas leases covered much of the Mecca Hills Wilderness Study Area in 1983. The folds and faults near the San Andreas fault zone locally form discontinuous, complex structures that make small but favorable structural traps for hydrocarbons (Sylvester and Smith, 1976, p. 2081, 2101). Oil and gas exploration in the Mecca Hills has occurred sporadically since 1921 without positive results. The only mining activity known in the study area was near the mouth of Skeleton Canyon. Clay was extracted there and used to seal nearby irrigation canals. Clay was also mined from the Red Top mine west of the study area. Sand and gravel were produced from an alluvial fan south of the study area and used as aggregate and fill for local construction projects. In 1983 a commercial sand and gravel pit was operating south of Thermal Canyon 4 mi west of the area. A well northwest of the study area reportedly produced hot water (Oesterling and others, 1964, p. 195).

Mineral Occurrences

The Skeleton Canyon mine consists of bulldozer cuts from which clay was mined (Crowell and Sylvester, 1979, p. 157). The clay forms low hills of brick-red fault gouge within the San Andreas fault zone and contains fragments and blocks of siltstone and sandstone. The clay zone strikes N. 60° W. and dips about 30° NE. Exposures of the clay are about 4,900 ft

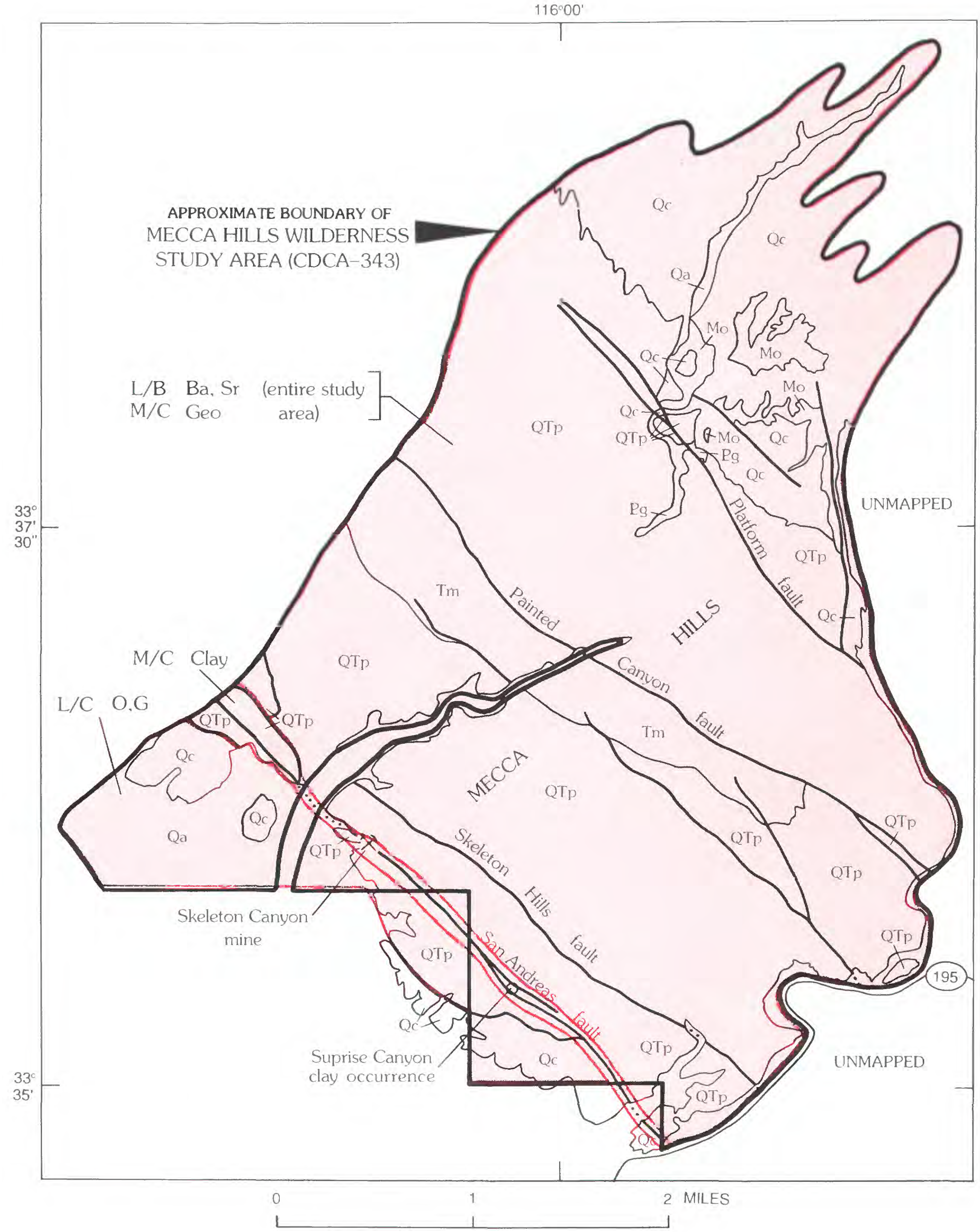

Figure 2. Mineral resource potential and generalized geology of the Mecca Hills Wilderness Study Area, Riverside County, California. Geology from A.G. Sylvester (unpub. data, 1985).

long, 50 to 100 ft thick, and cover about 30 acres of which about 20 acres are inside the study area. The clay zone probably pinches out southeast of the mine and is buried by alluvium to the northwest.

The Skeleton Canyon mine has a large tonnage of bentonitic clay that could be a resource if a market were identified. Small quantities of clay were mined for transitory projects, but local demand is currently insufficient to justify commercial operation of a clay pit. Favorable characteristics of this occurrence are: (1) it is minable by relatively low-cost, openpit methods; (2) more than five million tons have no overburden; (3) the clay unit is 50 to 100 ft thick; and (4) it is accessible from paved roads and is near rail transportation. Unfavorable features of the occurrence are: (1) the clay is impure and requires processing (for example, washing and screening); (2) the complex deformation in this vicinity makes continuity of the clay unpredictable where it is not exposed; (3) water supplies are not readily available; (4) current commercial markets are relatively far away; and (5) other clay deposits are already being mined. A detailed sampling program involving trenching and drilling would be necessary to precisely determine the tonnage and quality of clay that may be present.

Suitability for most uses depends upon the physical properties of bentonite, and specialized tests must be made for each intended use. For this report, one sample was tested for some common physical and chemical properties. As shown by X-ray diffraction analysis, montmorillonite is the major clay mineral, but kaolinite is also present in minor quantities. Impurities include quartz, feldspar, calcite, dolomite, and minor muscovite and gypsum. Preliminary ceramic testing suggests that the clay is unsuitable for structural clay products because it is too soft and has a short firing range (Campbell, 1984, p. 13). A chemical analysis of the clay gave the following weight percent for oxides: 53.1, SiO_2; 14.0, Al_2O_3; 4.5, Fe_2O_3; 0.6, TiO_2; 7.1, CaO; 3.8, MgO; 2.8, Na_2O; 1.7, K_2O; 0.08, MnO; 0.7, SO_3^{-2}; and 0.3, P_2O_5. According to the USBM clay classification system, this clay is a low-swelling calcium bentonite (Ampian, 1979, p. 2, 3). Calcium bentonites have poor colloidal properties and have little value for drilling mud and other uses requiring thixotropic suspensions.

A second clay occurrence in the study area is along the San Andreas fault at Surprise Canyon. This prospect covers approximately 4 acres and is about 2,000 ft long and 50 ft thick. The quality of the clay here appears similar to that at the Skeleton Canyon mine.

Sand and gravel occur in alluvial fans and braided streams throughout the Mecca Hills Wilderness Study Area. A principal source of sand and gravel in southern California is from alluvial fans that have built up along mountain fronts (Goldman, 1968, p. 5). Present production, however, is primarily near rapidly expanding urban areas, where construction and industrial markets exist, and is intermittent in more remote areas where public projects (for example, highways, canals, dams) are being constructed. Because the unit price of sand and gravel is low, and transportation costs are high, it typically must be produced near potential markets; however, existing deposits near urban markets are being depleted, and zoning restriction and urban expansion preclude the development of some deposits. Therefore, it may become necessary to transport sand and gravel from distant deposits that are now uneconomic (Leighton, 1980, p. 168). Large deposits of sand and gravel near rail transportation in the Coachella Valley (fig. 1) make the region around the Mecca Hills a likely source of sand and gravel resources for the Los Angeles Basin, but because there are adequate deposits outside the study area, it is unlikely that the sand and gravel occurrences in the Mecca Hills Wilderness Study Area would be developed.

Chip samples were taken across quartz veins in gneiss and schist and across altered zones adjacent to felsic dikes and stocks. Assay results for these samples showed no significant metal concentrations.

Anorthosite occurs in canyons in the north-central part of the study area. Anorthosite is an igneous rock containing from 26 to 35 percent alumina (aluminum oxide). The USBM is investigating methods to produce aluminum from anorthosite (Eisele and Bauer, 1983). The ultimate domestic aluminum resource is expected to be a low-grade, nonbauxitic material such as anorthosite; however, utilization of these large, low-grade sources of aluminum awaits development of processes that are economically competitive with the Bayer process for

EXPLANATION

Area with moderate and low mineral resource potential

See appendix for definition of levels of resource potential (M, L) and certainty of assessment (B, C)

Commodities

	Clay
Ba	Barium
Sr	Strontium
O, G	Oil and gas
Geo	Geothermal

Geologic map units

Qa	Alluvium (Quaternary)
Qc	Ocotillo Conglomerate (Quaternary)
QTp	Palm Springs Formation (Quaternary and Tertiary)
Tm	Mecca Formation (Tertiary)
Mo	Orocopia Schist (Tertiary)
Pg	Gneiss, migmatite, and intrusive rocks (Proterozoic)
———	Contact
——···	Fault—Dotted where concealed

Figure 2. Continued.

extracting alumina from bauxite. The anorthosite occurrence in the study area is advantageously situated near the Los Angeles metropolitan area and close to a rail and highway network; however, a shortage of water and the overlying sedimentary rocks are unfavorable features of this occurrence and would hinder any future mining. Further work is needed to determine the size and quality of this anorthosite occurrence. The presence of 30 billion tons of anorthosite in the San Gabriel Mountains, about 100 mi northwest of Mecca Hills, makes the mining of anorthosite in the study area unlikely in the foreseeable future.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Douglas M. Morton, James E. Kilburn,
and Andrew Griscom
U.S. Geological Survey

Geology

The Mecca Hills Wilderness Study Area is located in the northeast margin of the Salton Trough, which is the northernmost extension of a major structural zone in North America that includes the Gulf of California. The San Andreas fault is a major strike-slip fault that forms the east boundary of the Salton Trough and crosses the southwest margin of the study area (fig. 2). The Mecca Hills comprise a northeast-oriented elongate dome formed by compression associated with movement along the San Andreas fault.

The study area is underlain by two groups of crystalline rocks that are generally exposed only in canyons that have cut through overlying sedimentary rocks. The older group is Proterozoic gneiss and migmatite that was intruded by Proterozoic anorthosite, felsic dikes, and related rocks. This gneiss-anorthosite complex structurally overlies the younger basement rock group, the Orocopia Schist, a deformed thick sequence of greenschist facies metasedimentary rock and minor metavolcanic rock of probable Late Cretaceous age. The two basement complexes are separated by a major shear zone, which also is probably Late Cretaceous (Sylvester and Smith, 1976) in age. Quartz veins cut both the gneiss and schist.

The oldest sedimentary rock within the study area is the late Pliocene(?) Mecca Formation (Dibblee, 1954), which consists of thick-bedded, reddish-brown, nonmarine arkose, breccia, and conglomerate. These sedimentary rocks are largely derived from the basement upon which they unconformably rest. Overlying and in part interfingering with the Mecca Formation is the late Pliocene and Pleistocene Palm Springs Formation (Dibblee, 1954), which consists largely of nonmarine arkose and conglomerate. These two formations thicken from northeast to southwest (Dibblee, 1954; Sylvester and Smith, 1976).

The Pleistocene Ocotillo Conglomerate overlies and interfingers with the upper part of the Palm Springs Formation (Dibblee, 1954). Unconsolidated young alluvium occurs along canyon bottoms.

The dominant structures in the study area are four major northwest-striking faults. The northeasternmost fault, the Platform fault, forms the southwest boundary of the Orocopia Schist. The basement rocks offset by this fault have only a thin cover of sedimentary rocks of the Mecca and Palm Springs Formations (Sylvester and Smith, 1976). The amount and type of movement on this fault is unknown. The Painted Canyon fault is 1 mi southwest of the Platform fault (fig. 2). Between the Platform and the Painted Canyon faults the Mecca and Palm Springs Formations were deformed into a series of anticlines and synclines (Sylvester and Smith, 1976). One mile southwest of the Painted Canyon fault is the Skeleton Canyon fault, which is part of the San Andreas fault zone (Sylvester and Smith, 1976). It is about 0.25 mi northeast of the San Andreas fault. The San Andreas fault, the master strike-slip fault in California, is located near the southwest margin of the study area and is well marked by scarps and offset drainages (Clark, 1984).

Geochemical Studies

Nonmagnetic heavy-mineral concentrates from stream sediments are the most useful samples in arid parts of the western United States and were thus selected as the sample medium for the reconnaissance geochemical survey. Seventeen stream sediment samples were collected near the margins of the Mecca Hills Wilderness Study Area from drainages ranging from fractions of a mile to several square miles. The samples were analysed by a six-step semiquantitative emission-spectrographic method (Grimes and Marranzino, 1968) for 30 elements. A complete listing of the analytical techniques and results are in Detra and Kilburn (1985).

Samples for the nonmagnetic heavy-mineral concentrates were composited from active alluvium and sieved through a 10-mesh screen and panned to remove most of the less dense material such as quartz, feldspar, clay, and organic material. The resulting sample was further concentrated by a hand magnet and a magnetic separator to remove magnetite and other magnetically susceptible minerals. The remaining nonmagnetic concentrate, which may contain gold, silver, and ore-forming sulfide and oxide minerals, was split into two parts, one for spectrographic analysis and the other for microscopic study.

Microscopic study identified visible amounts of the minerals barite ($BaSO_4$), sphene ($CaTiSiO_5$), zircon ($ZrSiO_4$), and rutile (TiO_2) in all of the samples. Three of the samples contained lead shot. Widespread anomalous concentrations of barium, titanium, and zirconium were found in the geochemical analyses reflecting the presence of barite, sphene, zircon, and rutile. Anomalous concentrations of barium ranged from 5,000 to about 10,000 parts per million (ppm). Anomalous concentrations of titanium were greater than 20,000 ppm. Anomalous concentrations of zirconium were greater than 2,000 ppm. Those samples containing lead shot had anomalous concentrations of lead ranging from 7,000 to 50,000 ppm, and one sample had an anomalous concentration of antimony (500 ppm). Analysis of the lead shot indicated the antimony was in the lead shot.

Three samples contained anomalous concentrations of molybdenum; two samples contained 20 ppm and the third 30 ppm. Three samples contained anomalous concentrations of tin; two samples contained 100 ppm and the third 150 ppm. A single sample contained 10,000 ppm of strontium. Strontium is generally present in association with barium; barite forms a complete solid-solution series with the mineral celestite, ($SrSO_4$). This single anomaly is probably due to strontium within the solid-solution series of barite-celestite.

Barite may be derived from veins within the basement and (or) overlying sedimentary rock. No parent mineral could be determined for the anomalous concentrations of tin and molybdenum. However, their small amounts and isolated occurrences indicate little, if any, mineralization. All of the titanium, zirconium, tin, and molybdenum concentrations found in the samples are to be expected in sedimentary deposits derived from a granitic terrain. None of the anomalous concentrations of elements other than strontium and barium are considered to be significant in relation to undiscovered mineral resources.

Geophysical Studies

An aeromagnetic map (U.S. Geological Survey, 1983) was prepared from an aeromagnetic survey of the Salton Sea region flown in 1981 by a private contractor and includes the Mecca Hills Wilderness Study Area. Comparison of the contoured aeromagnetic map with the geologic map indicates that the study area can be divided into four regions, each with a characteristic magnetic pattern. The central region, which includes about two-thirds of the study area, is characterized by an irregular-shaped magnetic high with maximum amplitudes of 80 to 120 gammas. The source rocks for this high are probably the Proterozoic crystalline rocks, which are exposed in a few canyons and are probably no deeper than a few hundred feet below the exposed sediments. In the north quarter of the study area, a magnetic low is probably caused by the nonmagnetic Orocopia Schist. A northwest-trending curvilinear magnetic gradient between these aeromagnetic features marks the approximate location of the Platform fault separating the schist from the Proterozoic rocks.

The third aeromagnetic region is at the extreme north end of the study area, where a small magnetic high is possibly caused by Proterozoic rocks north of the Orocopia Schist. The concealed contact between these two units probably lies on the high side of the magnetic gradient approximately along the -20 gamma contour.

At the extreme south and southwest limits of the study area, a magnetic low coincides with thick nonmagnetic sediments in the Coachella Valley. On the northeast side of this low, a linear northwest-trending magnetic gradient coincides with the main strand of the San Andreas fault, which truncates the magnetic Proterozoic rocks.

Gravity data that include the study area are available as complete Bouguer anomaly maps (Elders and others, 1972, Biehler and Rotstein, 1982; Oliver and others, 1980) and as residual isostatic gravity maps (Roberts and others, 1981). The area underlain by the Orocopia Schist has a local gravity high of at least 15 milligals. The cause of the gravity high is not evident because the density of the schist is probably about the same or less than that of the surrounding Proterozoic rocks. However, the basement rocks beneath the schist are probably oceanic crust because the schist contains small amounts of metabasalt and ultramafic rocks (Haxel and Dillon, 1978). The gravity high may indicate shallow oceanic crust beneath the schist (Griscom, 1980), but, if so, these presumably magnetic rocks must be too deep to show on the aeromagnetic map. A steep gravity gradient along the San Andreas fault slopes down to the southwest into a prominent low associated with the thick low-density sediments in the Coachella Valley. Analysis of this low (Biehler, 1964) suggests at least 15,500 ft of sediments, the maximum thickness being along the northeast side of the valley near the San Andreas fault.

Mineral and Energy Resources

There is no evidence that mineralizing events took place within the Mecca Hills Wilderness Study Area. The results of geochemical studies yielded no suites of anomalous elements indicative of events that would concentrate metals. Anomalous barite and strontium concentrations indicate chemical processes, but these processes were not sufficient to create a resource. There are no known mineral deposit models that fit the limited data on metals, barite, and strontium in this area. There is low potential, certainty level B for barite and strontium resources in the study area, based primarily on geochemical data. There is moderate potential, certainty level C, for clay resources along the San Andreas fault extending northwest and southeast from a known clay occurrence and the Skeleton Canyon mine. Undiscovered clay would probably be impure, with narrow but deep deposits within the fault zone making development highly unlikely. The entire Mecca Hills Wilderness Study Area is part of a larger Salton Trough region that has "significant lateral extent favorable for discovery and development of local sources of low-temperature (less than 90 °C) geothermal water" (Muffler, 1979, Map 1). A thermal spring having a surface temperature of less than or equal to 50 °C is near or possibly within the study area (Muffler, 1979, map 1). Low-temperature geothermal resources may be used for direct heating or for drying agricultural or manufactured products. The heat source for these geothermal fluids is assumed to be a probable magmatic body at depth that helps heat fluids circulating along the fault zones (Sammel, 1979, p. 106-107). The potential for low-temperature (less than 90 °C) geothermal resources is moderate within the study area, with certainty level of C. Roses are grown in Mecca using direct heat from geothermal wells (W.A. Elders, oral commun., 1987), however water from these wells may be related to geothermal systems south or wouthwest of Mecca, away from Mecca Hills.

An earlier, regional evaluation of the petroleum potential of certain lands in California found the Mecca Hills Wilderness Study Area to have low to zero potential for oil and gas (Scott, 1983). The area lacks marine source rocks, although such rocks may underlie the Coachella Valley west of the study area. One drill hole to 3,792 ft was drilled in R. 7 S., R. 10 E., sec. 25 south of the Mecca Hills Wilderness Study Area in 1923. The driller's well log of the hold, Spindletop Oil Association Well No. 1, reported shows of gas and possibly heavy oil (D. Curtis, oral commun., 1987). There has been no known work in the intervening six decades to confirm this report. Oil and gas may have matured and been driven up along the flanks of the Salton Trough by geothermal processes, however, this is highly speculative. There are no direct indications that oil or gas may be present in the study area; however, the area southwest of the San Andreas fault has low potential for oil and gas resources, with a certainty of C.

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

LOW mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with few or no indications of having been mineralized.

MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

HIGH mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data supports mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

Levels of Certainty

LEVEL OF RESOURCE POTENTIAL →

<table>
<tr><td rowspan="4">U/A
UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td></tr>
</table>

LEVEL OF CERTAINTY →

A. Available information is not adequate for determination of the level of mineral resource potential.
B. Available information suggests the level of mineral resource potential.
C. Available information gives a good indication of the level of mineral resource potential.
D. Available information clearly defines the level of mineral resource potential.

Abstracted with minor modifications from:

Taylor, R. B., and Steven, T. A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268–1270.

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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p. 5.

GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES (in Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	~570[1]
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				(3800?)
pre-Archean[2]					4550

[1]Rocks older than 570 Ma also called Precambrian, a time term without specific rank.

[2]Informal time term without specific rank.

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March 3, 1849