Abstract

The rocks of the East Mojave National Scenic Area (EMNSA) record a history of dynamic geologic events that span more than 1,800 million years (m.y.). These geologic events contributed significantly to development of the spectacular vistas and panoramas present in the area today. The oldest rocks underlie much of the northern part of the EMNSA. These rocks were subjected to extreme pressures and temperatures deep in the Earth's crust about 1,700 million years ago (Ma). They were subsequently intruded by granitic magmas from about 1,695 to 1,650 Ma, by additional granitic magmas at about 1,400 Ma and, later, at about 1,100 Ma, by iron-rich magmas that crystallized to form dark igneous rocks termed diabase. Unusual potassium- and magnesium-rich rocks, emplaced at about 1,400 Ma, crop out in a few places within and near the EMNSA. Their distinctive composition owes to very small degrees of partial melting of mantle peridotite that was highly enriched in incompatible trace elements. At Mountain Pass, just outside the northeast boundary of the EMNSA, the potassium- and magnesium-rich rocks are accompanied by a rare type of carbonatite, an igneous rock composed of carbonate minerals, that contains high-grade rare earth element mineralization.

Subsequent to these igneous-dominated events, sedimentary strata began to be deposited at about 1,000 Ma; mostly sandstone and shale were deposited initially in marine and, less commonly, in continental environments along the west edge of the core of the North American continent. Sedimentation eventually culminated in the widespread deposition of thick marine limestones from about 400 to about 245 Ma. These limestones represent a continental-shelf environment where shallow-water limestone formed to the east and deeper water limestone formed to the west. The end of the formation of these sedimentary deposits probably was caused by uplift of the shelf, which marked the beginning of a long period of tectonic upheaval.

At about 170 Ma, widespread emplacement of coarse-grained granitic magmas began again in the region; some of these magmas also erupted as volcanic rocks. Additional episodes of magmatism took place at about 100 Ma and at 75 Ma. Most of the metallic-mineral occurrences in the EMNSA are associated with the igneous rocks that range in age from 170 to 75 Ma. During each of these magmatic events, the previously deposited sedimentary strata were buckled and broken as the entire region, part of a continental-scale fold and thrust belt, underwent crustal shortening and compression.

A period of tectonic quiescence characterized the region from about 65 Ma to about 20 Ma. The quiet period ended abruptly with widespread volcanism along the southern and eastern parts of the EMNSA. The major gold deposits in the Castle Mountains are associated with this episode of volcanism. During this volcanic outburst, the crust extended laterally in several areas that border the EMNSA: along the lower Colorado River 65 km to the east, in the Kingston Range 20 km to the north, and in the central Mojave Desert 75 km to the southwest. This extensional deformation is characterized by the superposition of upper-crustal rocks over midcrustal rocks along large flat-lying faults, several of which project underneath rocks now exposed at the surface in the EMNSA. The near-surface rocks of the EMNSA, however, apparently escaped much of this intense extensional deformation. High-angle faults, which cut several of the mountain ranges, possibly have undergone several periods of movement, which date back to approximately 70 to 100 Ma. Some faults are of local importance to the physiographic development of the mountain ranges and intervening basins, and, in places, the faults seem to have localized various kinds of ore bodies and mineral occurrences.

Volcanism and extensional deformation waned from 14 to 11 Ma. By approximately 10 Ma, widespread erosion had produced broad erosional dome-shaped mountains in the northwestern part of the EMNSA; study of these classic examples has led to many of the modern concepts of desert erosion. Basaltic volcanism accompanied further development of these dome-shaped mountains over the last 10 m.y.

Large areas of the EMNSA contain indications of various types of metallic mineralization at the ground surface. These metallic indications can be classified into approximately 20 specific types of metallic occurrences that are known to show extremely wide ranging concentrations of metals in variably sized accumulations. Among the metallic occurrences recognized are lead-zinc-silver-gold polymetallic vein; low-sulfide gold-quartz vein; lead-zinc-silver polymetallic replacement; gold breccia pipe; gold-silver quartz-pyrite vein; copper-lead-zinc-silver polymetallic fault and skarn; copper, zinc-lead, tungsten, tin-tungsten, and iron skarn; porphyry molybdenum-copper; and low-temperature quartz-adularia (alunite) gold. Of the 20 types of

mineral occurrence, only ten provide enough geologic information to make highly qualified estimates as to the number of additional mineral deposits that remain to be discovered in the EMNSA. Nonetheless, economically significant concentrations of some metals may well remain to be discovered in the EMNSA, and some known occurrences may become economic in the future. Most of the approximately 700 known individual mineral occurrences have been extensively prospected for more than a century, and at least 15 percent of them have been credited with some production, mostly of minor quantities of metals. In recent years, gold ore bodies at three relatively large mineralized systems in the EMNSA (Castle Mountain, Colosseum, and Morning Star) have been brought into production, and, at another occurrence (Golden Quail), additional resources have been discovered. Each of the former three is present in a different geologic environment and thus is assigned to a specific mineral-occurrence model. The Golden Quail deposit is similar to the Morning Star. The gold production from these four deposits since 1985, combined with the gold reserves remaining in them as of 1993, is much greater than that of all preceding gold discoveries in the EMNSA, partly owing to the present availability of low-cost heap-leaching extraction methods.

The Providence Mountains, the Clark Mountain Range, the Ivanpah Mountains, and the New York Mountains have large numbers of metallic occurrences and show geochemical anomalies in various types of samples. In addition, although the general area of Hackberry Mountain lacks abundant metallic-mineral occurrences, we have included it in a tract of land judged to be favorable for the discovery of additional gold deposits similar to those in the Castle Mountains because the geology of Hackberry Mountain is similar to that of the Castle Mountains. These five mountainous regions make up a broad, roughly north-south-trending region in the central part of the EMNSA. Much less endowed with known occurrences of all types of deposits considered above are the Granite Mountains, the central parts of the Piute Range, the Fenner Valley area, the general area of Cima Dome, Old Dad Mountain and areas west to Soda Lake, and the Cima volcanic field. These areas lie in the eastern and western parts of the EMNSA.

We have made some judgments as to the geology underlying the gravel-covered areas in the EMNSA, which include the extent of shallow bedrock apparently covered only by thin veneers of gravel. These areas are prime targets for exploration because many known ores that were exposed at one time in the mountain ranges have been found during earlier periods of exploration, but few data are available to us for most of these covered areas. The presence of mineralized rocks, the type of mineral occurrence, and the extent and intensity of mineralization in the covered areas are essentially unknown. Most covered mineral deposits do not respond to the standard aeromagnetic geophysical methods evaluated in this study, particularly at the broad spacing of our data-collection flight lines.

The restriction of estimates of undiscovered metal resources in the EMNSA to only currently known types of occurrences would, at reasonable levels of probability, yield small estimates for volumes of many metals, particularly base and ferrous metals, that might be exploited at some future date. However, this statement is true only if the size of most previously discovered deposits in the EMNSA is indicative of the size of deposits still to be discovered there. In our opinion, metals from any newly discovered copper, lead, and zinc deposit of the types presently known in the EMNSA probably would be insignificant from the standpoint of national needs.

Some parts of the EMNSA appear to represent geologic settings capable of hosting significant undiscovered gold and silver resources, primarily on the basis of geologic environments of recently discovered large deposits of gold in the EMNSA. In addition, the widespread distribution in many parts of the EMNSA of geochemically anomalous samples and numerous mineral occurrences, many of which are associated with introduction of igneous rock, indicates the presence of metal-bearing environments in those parts of the EMNSA that may be sites of additional future discoveries of new types of mineral deposits.

The study of the EMNSA by the U.S. Geological Survey has involved a team of more than 15 scientists who have expertise in geology, geochemistry, geophysics, mineral deposits, and resource analysis. Some main points of this report regarding mineralization are the following:

1. Large areas of the EMNSA contain abundant direct and indirect indications of metallic mineralization.
2. Only partial estimates of the entire undiscovered metallic mineral endowment of the EMNSA are possible. Of the approximately 20 metallic-occurrence types known to be present in the EMNSA,

estimates are possible only for those ten types for which adequate geologic information is available, including knowledge of size and metal concentrations of similar occurrences elsewhere.

3. Of the ten specific mineral-deposit types that can be estimated, lead-zinc-silver-gold polymetallic vein and copper skarn are the most common deposits and therefore are the most likely to be discovered in the future.

4. Of the metal commodities estimated, those with the most important economic potential in 1993 appear to be gold, and, to considerably lesser degrees, copper, zinc, and lead.

5. The Mountain Pass deposit, just outside the northeast boundary of the EMNSA, is a world-class source of rare earth elements such as lanthanum, cerium, neodymium, samarium, europium, and gadolinium.

6. It was not possible to make numerical estimates for any of the nonmetallic industrial minerals. Nonetheless, vast resources of limestone and dolomite appear to be present in many of the mountain ranges in the EMNSA, some of which are composed almost entirely of limestone and dolomite.

7. Much of the EMNSA is covered by geologically young unconsolidated deposits of sand and gravel in broad valleys between the mountain ranges. These deposits of sand and gravel are younger than the age of introduction of metals into the rocks of the EMNSA. Although some potential for presence of undiscovered metal deposits of various types in these covered areas exists, it is essentially unknown because of a lack of data.