

DMG OPEN-FILE REPORT 83-36

**MINERAL LAND CLASSIFICATION OF
THE SUTTER CREEK
15 MINUTE QUADRANGLE,
AMADOR AND CALAVERAS COUNTIES,
CALIFORNIA**

1983



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MINERAL LAND CLASSIFICATION OF THE
SUTTER CREEK 15' QUADRANGLE
AMADOR AND CALAVERAS COUNTIES, CALIFORNIA

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Open-File Report 83-36 SAC
1983

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PREFACE

Open File Report 83-36 SAC is one of a series of mineral-land classification studies in the western Sierra Nevada region being conducted by the California Division of Mines and Geology, under authority of the Surface Mining and Reclamation Act of 1975 (SMARA). The classification information is provided to the State Mining and Geology Board for transmittal to local governments who regulate land use in this region. SMARA was enacted by the State Legislature to assure mineral resource conservation and adequate mined-land reclamation. The undertaking is of importance in economic geology, because it deals with very specific mineral resource conservation issues in areas of intense land-use competition. Results of these studies, therefore, should be of considerable interest to local land-use planners, other responsible government agencies, local property owners, and to the mining industry.

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EXECUTIVE SUMMARY

The California Surface Mining and Reclamation Act of 1975 (SMARA) requires the State Geologist to classify land based upon the presence, absence, or potential occurrence of significant mineral deposits. This service is intended to provide an objective scientifically based assessment of mineral resource availability for consideration in subsequent land use decisions. The primary objective of mineral land classification is to ensure that the mineral potential of land is recognized and considered before land-use decisions, that could irreversibly preclude mining, are made. Commitment of land to uses that are incompatible with mining has been a major contributing factor to the loss of significant mineral resource availability in California in recent years. It is important that land-use and planning decisions be made with the knowledge of underlying deposits and the importance they may hold in supplying the future needs of our society.

Mineral-land classification under SMARA provides local governments, local property owners, and the mining industry with scientific information regarding the nature, occurrence, and distribution of mineral deposits. The information primarily is intended for use by local government in land use planning and by the mineral industries.

At the request of the State Mining and Geology Board, the State Geologist has initiated mineral-land classification studies in the western Sierra Nevada of California. The Sutter Creek 15-minute U.S. Geological Survey topographic quadrangle, which encompasses about 240 square miles of land in the central Sierra Nevada foothills, is one of about 40 quadrangles in the region scheduled to be classified. A geologic map and six mineral-land classification maps for seven types of mineral deposits known to occur in the Sutter Creek quadrangle accompany this report. It is most feasible to classify mineral availability by types of deposits based upon their interpreted modes of origin. This type of categorization can be related to the presence of certain types of rocks necessary for the genesis of each variety of deposit. Assessment of mineral potential then relies, in part, upon the occurrence of the geologic ingredients necessary for the genesis of the deposits. These are deposits of industrial minerals, deposits formed by hydrothermal, volcanogenic, magmatic concentration, and contact metasomatic processes, as well as placer deposits. The nature and distribution of these deposits closely relate to the geologic framework of the region and mineral land classification reflects these relationships.

The mineral-land classification study of the Sutter Creek 15' quadrangle confirms the widespread mineralization in this area. Major findings of the study are:

- o One of the most important high quality clay, specialty sand, and lignite resource areas in California is situated in the western part of the Sutter Creek quadrangle. These deposits, which support several large industries in the region, occur in the Ione Formation (Middle Eocene age). Locally, this formation crops out along an eighteen-mile long, two-mile wide belt situated mainly between the Mokelumne and Cosumnes River areas. Parts of the twelve-mile segment of the belt, extending through the Sutter Creek quadrangle, is classified MRZ-2a. The remainder, including those areas where the formation is overlain by Quaternary alluvial deposits, are classified MRZ-2b. Geologic studies, exploration drilling, and material testing reveal that the economic potential of the Ione Formation, as a whole, is high and that large volumes of commercial clay, sand, and lignite are present along the western margin of Amador County. If protected from land uses that are incompatible with mining, this area can continue to be an important source of these mineral commodities throughout the foreseeable future.

- o A 14-mile segment of the well-known Mother Lode gold belt extends through the Sutter Creek quadrangle. A substantial portion of all the gold produced from the entire Mother Lode belt was mined from this area; but, in modern times, it has not received the attention it deserves for its potential for future production. Consequently, home development, which normally is considered to be incompatible with mining activity, has been permitted to occur. Information obtained during this study and the study of adjacent quadrangles has led to the conclusion that the Mother Lode gold belt is still a significant gold resource area.
- o Several geologic formations, exposed within the Sutter Creek quadrangle, contain base and precious metal deposits of volcanogenic origin. These are polymetallic sulfide deposits associated with the Copper Hill and Gopher Ridge Volcanics (foothill copper-zinc belt). Three areas are classified as containing significant deposits. Similar deposits associated with these rocks are likely to exist elsewhere within the quadrangle. The overall economic potential of local deposits along the foothill copper-zinc belt is considered to be high. This conclusion is based on (1) historic mining production, (2) the fact that gold is commonly associated with these deposits, (3) the fact that the mining industry is showing great interest in these deposits and is conducting exploration work in the Sutter Creek quadrangle at the present time, and (4) the high likelihood that additional deposits are present.
- o Eight separate areas underlain by carbonate rock (an industrial mineral) have been classified as containing rock suitable for use as a marketable product. Although relatively small in areal extent, these lensoidal rock bodies typically extend to considerable depths; therefore, they most likely represent carbonate deposits of significant economic potential.

INTRODUCTION

Background and Purpose

The primary objective of mineral-land classification is to assure that mineral potential and the significance of mineral deposits are recognized and considered as land use decisions, that could preclude mining, are made. The availability of mineral resources is vital to our society. Yet, most types of mineral deposits are rare, isolated occurrences, which are difficult to identify. These circumstances limit the options available for locating mine sites. At the same time, California is faced with growing land-use competition and local planning agencies are faced with increasingly difficult land-use decisions. Many land-use decisions have been made with little, if any, knowledge of underlying mineral deposits and the importance they hold in supplying the needs of our society.

In 1975 the State took a major and innovative step towards resolving the conflict between mining and competing land uses by implementing the Surface Mining and Reclamation Act (SMARA). This law provides for reclaiming mined lands, and for classifying lands within the State according to the presence, absence, or likely occurrence of mineral resources. This information is provided by the State Geologist under the policies of the State Mining and Geology Board and transmitted to local government for use in their general plans.

How To Use This Report

This report is intended to provide information to three basic user groups: local government, property owners, and the mining industry. A discussion of the geologic framework of the region is included in this report to provide the essential scientific basis for classification. The reader can, however, interpret mineral-land classification information correctly without securing an understanding of the geologic framework.

It is important that users of the report gain a clear understanding of the way in which Mineral Resource Zones (MRZ) are categorized and applied to mineral-land classification. This is described in detail in the Mineral Land Classification section of the text. Special attention should be given to: (1) the classification system for mineral resources zones developed by the California Division of Mines and Geology (CDMG) and how this relates to a similar approach employed by the U.S. Bureau of Mines and the U.S. Geological Survey; (2) the graphical representation of the resource classification system (Figure 4); and; (3) associated nomenclature used to communicate information concerning mineral potential of land (see definitions that define terminology used in Figure 4).

APPROACH TO CLASSIFICATION

The western slope of the Sierra Nevada between Mariposa and Lake Almanor is one of several geographic regions of California to be selected for mineral-land classification studies (Figure 1). Other regions of the State subject to classification include major metropolitan centers and the California Desert Conservation Area.

Classification of the Sierra Nevada region is being conducted over areas represented by 15-minute quadrangles, each of which contains about 240 square miles. In all, 40 such quadrangles in the Sierra Nevada are scheduled for study (Figure 2). The Sutter Creek quadrangle was the third of the group to be completed.

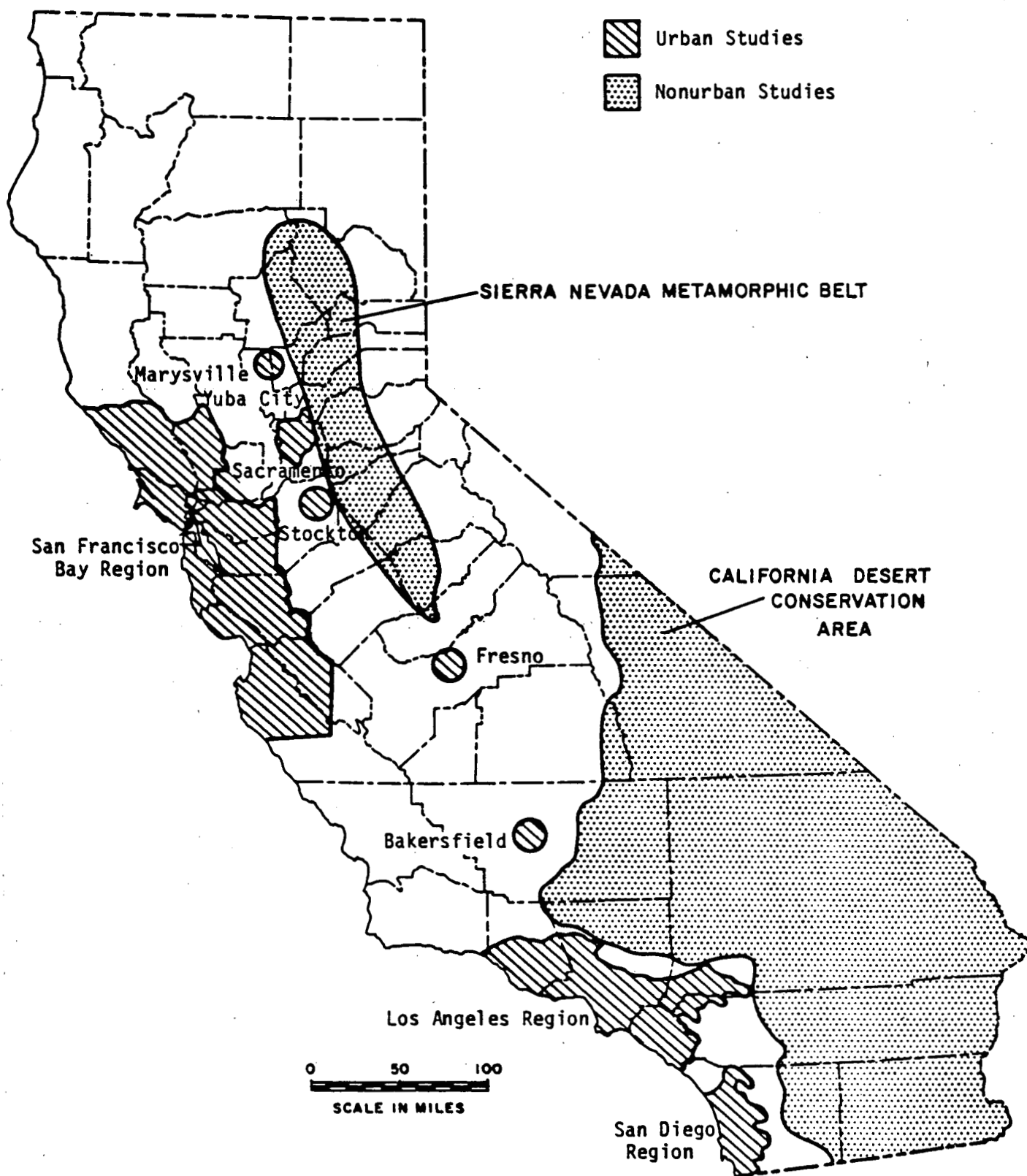


Figure 1. Map of California showing urban and nonurban areas of the State subject to mineral land classification.

The Sutter Creek quadrangle classification study was conducted primarily during the winter and fall months of 1982. The study included research of geologic and mining-related literature, compilation of a geologic map at a scale of 1:48,000, and plotting of reported mines and prospects using information obtained from the U.S. Geological Survey (1979), the U.S. Bureau of Mines (undated), the U.S. Bureau of Land Management (1982), publications of the California Division of Mines and Geology, and data provided by mining companies and property owners. The study included a field work phase in which staff geologists visited selected mine and mineral sites within the study area. Conclusions drawn from field observations, supplemented with literature descriptions, were related to regional geology in an effort to ascertain geologic factors which control or influence mineralization. Follow-up reconnaissance was undertaken in select areas to obtain a clearer understanding of the nature and distribution of the mineral deposits.

The information gathered during the field period was combined and analyzed. Mineral resource zones were then assigned to areas in accordance with mineral-land classification guidelines adopted by the State Mining and Geology Board. A geologic map (scale 1:48,000) and a series of mineral-land classification maps (scale 1:48,000) were prepared, and are included in this report (Plates 1-6). All maps show mine and prospect localities.

GEOGRAPHIC SETTING

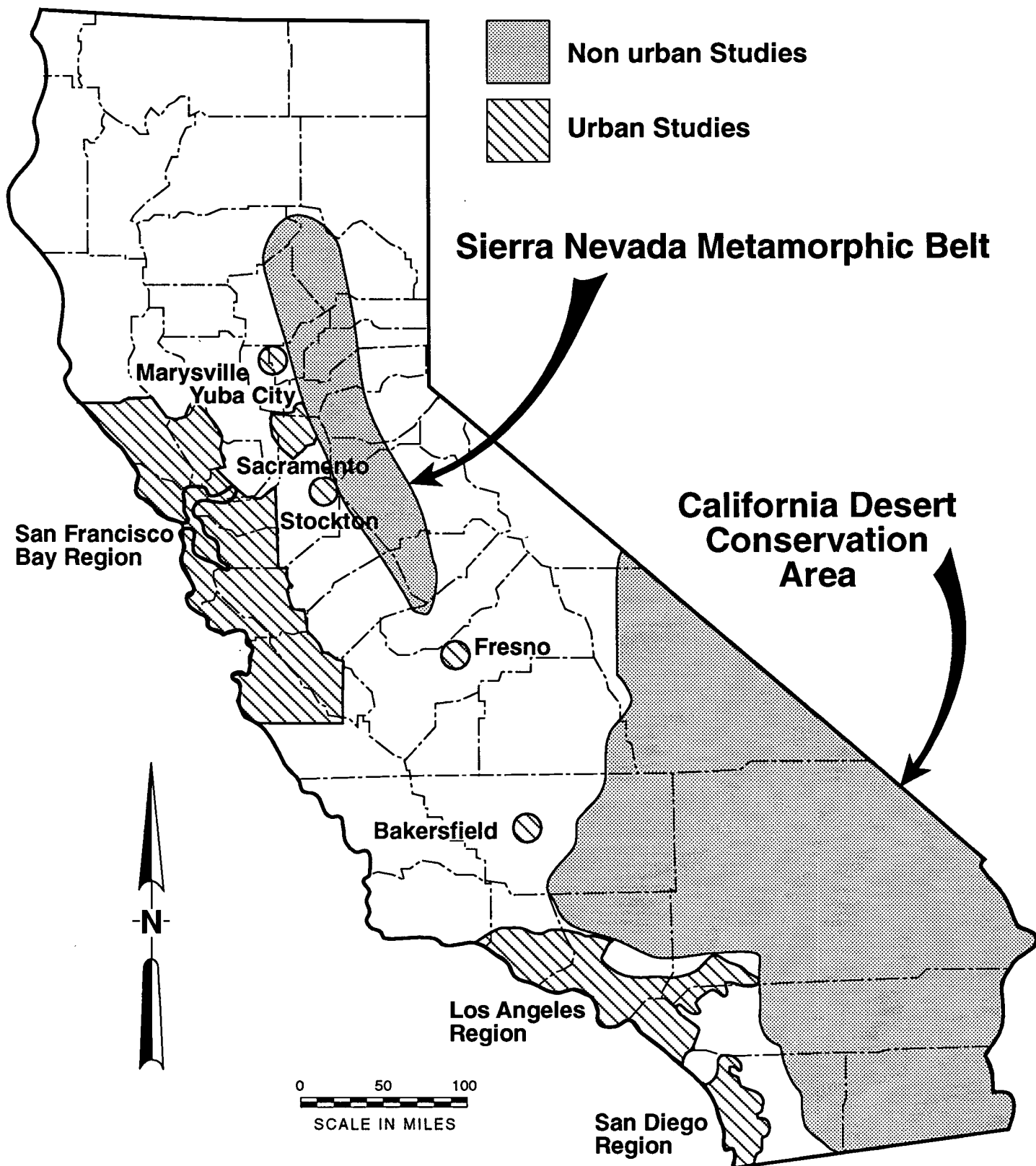
The Sutter Creek quadrangle encompasses about 240 square miles of land lying along the western foothill region of the Sierra Nevada of California. Most of the area lies within Amador County, and a small part of the southeast corner of the quadrangle lies within Calaveras County (Figure 2). Elevations range from approximately 200 feet in the southwestern part of the study area to 2000 feet in the northeastern part. The topography is characterized by northwest-trending ridges and troughs, with relief varying from low to moderately high. The area is drained by a series of generally southwest-trending creeks including Willow, Dry, Ranchiera, Horse, Sutter, and Jackson Creeks. A six mile segment of the Mokelumne River and part of the Pardee Reservoir lies in the southeast part of the quadrangle.

Depending on factors such as elevation, slope exposure, and soil cover, vegetation communities in the study area consist of open grass land, chaparral, oak woodland and mixed coniferous forest land, including pine, cedar, and Douglas fir. Climate within the study area is hot during the summer and mild during the winter. Snowfall in the Sierra Nevada normally occurs at higher elevations than present in the study area. Rainfall normally ranges from approximately 20 inches in the western part of the study area to 40 inches in the eastern part.

Population centers in the study area include the Mother Lode towns of Jackson (County seat), Martell, Sutter Hill, Sutter Creek, Amador City, Dry Town, and Plymouth (Plate 1). Associated with clay, sand, and lignite mining in the western part of the quadrangle is the city of Ione. State Highway 49, 88, 124, and 16, along with numerous county roads, provide good access to most parts of the quadrangle.

GEOLOGIC SUMMARY

It has long been recognized that the distribution of mineral deposits closely relates to the geology of a region. Consequently, a general understanding of the lithologic and structural framework of the region is of considerable value for evaluating mineral



potential. The following discussion is provided herein to familiarize the reader with aspects of the geology that controlled or influenced the formation of mineral deposits in the Sutter Creek quadrangle and elsewhere in the Sierra Nevada metamorphic belt. A glossary of geologic and mining related terms is provided at the back of this report.

Regional

The Sutter Creek quadrangle occupies the central part of a northwest-trending belt of metamorphic rocks which underlies the western slope of the Sierra Nevada between Mariposa and Lake Almanor, California (Figure 3). These rocks are distributed within three major fault-bounded lithologic terranes that extend along the length of the metamorphic belt. The terranes are each composed of thick accumulations of Paleozoic and/or Mesozoic marine sedimentary and volcanic rocks of various lithologies that have been deformed, intruded, and metamorphosed. The rock sequences have been isoclinally folded on a regional scale and faulted to such an extent that true stratigraphic thicknesses rarely can be accurately measured. Bedding, foliation, and major structural features throughout the metamorphic belt normally trend northwest and dip steeply to the east.

Detailed geologic mapping (scale 1:24,000) is lacking over most of the 9,000 square miles that the Sierra Nevada metamorphic belt encompasses. Presently, geologists are interpreting the overall lithologic and structural framework of this metamorphic belt in terms of plate tectonic concepts. There is general agreement that convergent plate tectonism governed the Early Paleozoic to Late Jurassic development of the belt and that the fault-bounded terranes collectively represent a "collage" of tectonically accreted blocks emplaced along the western margin of the North American continent at various intervals during geologic time. Discussions on the geology and geologic history of the Sierra Nevada metamorphic belt are presented in Stewart and others (1977), Howell and McDougal (1978), Ernst (1981), and Saleeby (1982). These and other papers referenced are summarized in the following brief description of the geologic framework of the Sierra Nevada metamorphic belt.

Structural Framework

The structural framework of the Sierra Nevada metamorphic belt is dominated by a series of northwest-trending fault systems that extend through the length of the foothill region (Figure 3). These features are normally identified by long narrow bands of serpentinite, talc-chlorite schist, mariposite, or highly-sheared and foliated country rock. Gold-bearing quartz vein systems and chromite-bearing ultramafic rocks are commonly spatially associated with these structures.

Major fault systems of the Sierra Nevada foothill region are the Calaveras-Shoo Fly thrust (Schweikert, 1981; Schweikert and Bogen, 1983), the Melones fault, and the Bear Mountains fault (Clark, 1964, 1976; Duffield and Sharp, 1975; Behrman, 1977; Wagner and others, 1981; Figure 3). South of Placerville, these faults are generally mapped as continuous, linear features with few structural complexities. From the Placerville area north, however, the Bear Mountains and Melones faults branch out into a network of structurally complex, and as yet, poorly-defined fault systems. Structural interpretation of rock units, herein assigned to the eastern, central, and western tectonic blocks north of Placerville, suggest that the northern and southern extents of the Melones fault zone are parts of two separate systems. The northern extent of the Melones fault zone appears to represent a continuation of the Calaveras-Shoo Fly thrust (Schweikert, 1981, p. 90). The southern extent of the Melones fault, which appears to continue northwest from Placerville through the Grass Valley area along an unnamed and poorly mapped fault, may be continuous with the Camel Peak fault of Hietanen (1981; Figure 3).

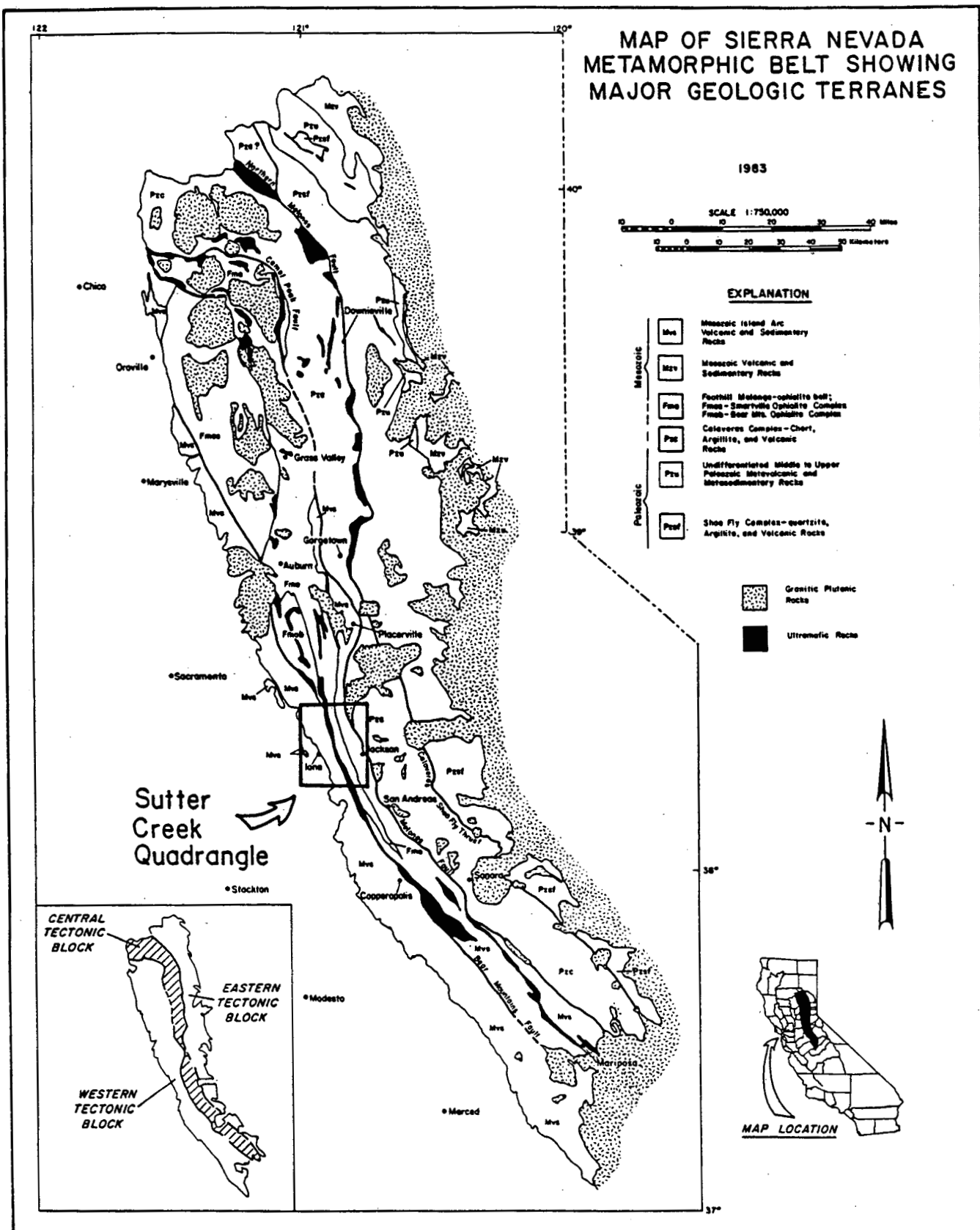


Figure 3. Map of Sierra Nevada metamorphic belt showing major geologic terranes. Compiled from Jennings (1977), Kemp (1982), Hietanen (1981), and Harwood (1983).

Eastern Block

The eastern tectonic block is bounded on the east by an intrusive contact of granitic rocks of the Sierra Nevada batholith and on the west by faults of the Calaveras-Shoo Fly thrust and northern Melones fault system (Figure 3). Most of this tectonic block is underlain by metasedimentary rocks of the Shoo Fly Complex (Early Paleozoic) which is exposed northeast of Quincy, California. The Shoo Fly Complex was named as a formation by Diller (1892) for stratified continental rise and slope deposits composed principally of quartzose sandstone and argillite. Subsequently, McMath (1966), Clark (1976), d'Allura and others (1977), and Schweikert (1981) -- mapped the Shoo Fly Complex, at least as far south as the Merced River, incorporating rocks into the Shoo Fly that were previously assigned to the younger Calaveras Complex. In the northeastern part of the eastern block, the Shoo Fly Complex is unconformably overlain by Middle Paleozoic to Upper Jurassic marine sedimentary and volcanic rocks (Figure 3) which are summarized by d'Allura and others (1977) and Harwood (1983). According to Schweikert and Snyder (1981), accretion of the eastern tectonic block to the North American continent is related to the Middle Paleozoic Antler orogeny and regional tectonic events which followed soon after.

Central Block

The central tectonic block is bounded on the east by the Calaveras-Shoo Fly thrust and northern Melones fault system, and on the west by the southern Melones and, perhaps, the extension of the Camel Peak fault system as mapped by Hietanen (1981; Figure 3). Metamorphic rocks underlying the central block are assigned to the Calaveras Complex, which is composed mainly of semicoherent to chaotic beds of chert and argillite, incorporated with minor volcanic and carbonate rocks. These deposits are thought to have accumulated in deep ocean and marginal basin environments beginning in Middle Paleozoic time (Schweikert and Snyder, 1981; Miller, 1982) and later accreted to the continent during the Sonoma orogeny sometime in Permo-Triassic (?) time (Schweikert and Snyder, 1981).

The term Calaveras Formation was first introduced by Turner (1893a, 1893b) for all Paleozoic metasedimentary and metavolcanic rocks exposed in the Sierra Nevada, except for Lower to Middle Paleozoic rocks mapped north of Quincy by Diller (1892). Subsequent workers have substituted the term Complex for Formation and have reassigned more than half of the original sequence to the Shoo Fly Complex.

Western Block

The western tectonic block is bounded on the east by the southern Melones fault and the possible Camel Peak fault extension. Its western boundary is concealed by unconformably overlapping Cenozoic volcanic and sedimentary deposits (Figure 3). The western block is underlain by several distinctive metamorphic terranes, the most extensive and continuous of these being Upper Jurassic volcanic and sedimentary rocks of volcanic island arc derivation. These deposits are exposed in two subparallel belts extending between the Fresno River and Oroville (Figure 3). In the southern foothills area, the two belts are divided by the Bear Mountains fault zone and in the central and northern regions by melange-ophiolite basement rock. Volcanic rocks in both belts are dominated by thick piles of basaltic to andesitic pyroclastic deposits in which pillow lava and volcanoclastics are common. Alternating with the volcanics are several thick and relatively continuous epiclastic rocks composed mostly of black clay slate and associated graywacke, conglomerate, and tuffaceous beds.

Based on overall stratigraphic and lithologic similarities, Schweikert (1981) suggested that the two belts could represent parts of a single volcanic island arc system that developed in Late Triassic (?) time and persisted into Late Jurassic, at which time they were accreted to the North American continent during plate collision leading to the Nevadan orogeny (Schweickert and Snyder, 1981). Kemp (1982) interprets the thick, dominantly andesitic pyroclastic deposits of the western foothill arc belt as a once-active magmatic core of an island arc chain, and he suggests that dominantly mafic volcanic rocks of the eastern foothill arc belt could represent pyroclastic apron or platform deposits developed in more distal settings of the volcanic island arc system. This interpretation is supported by the presence of abundant intermediate to felsic differentiated volcanic centers and associated volcanogenic sulfide bodies in the western foothill island arc belt that are absent in the more mafic volcanic rocks of the eastern foothill arc belt.

As summarized by Clark (1964, 1976), both belts have been divided into several formations on the basis of alternating volcanic and sedimentary sequences. The belt on the east contains the Penon Blanco Volcanics (Late Triassic ? - Early Jurassic ?), volcanic rocks of the Logtown Ridge Formation (Late Jurassic), and slate, graywacke, conglomerate, and volcanic rocks of the Mariposa Formation (Late Jurassic). The belt on the west contains the Peaslee Creek Volcanics, Merced Falls Slate, Gopher Ridge Volcanics, Salt Springs Slate, and Copper Hill Volcanics, all of which are, or are thought to be, of Late Jurassic age. Age dates have been established mainly by the presence of diagnostic fossils within the sedimentary rocks (Clark, 1964).

Although stratigraphic and structural relationships are unclear, it is believed that the Upper Jurassic volcanic island arc deposits were developed over older melange-ophiolite basement rocks which crop out within the western block (Figure 3). The use of the term melange to describe this complex and often chaotic assemblage of rocks of varying lithologies and ages within the Sierra Nevada foothills, was first applied by Duffield and Sharp (1975). Their work and subsequent mapping by Morgan (1976), Parkison (1976), Behrman (1977, 1978a,b), Behrman and Parkison (1978), Schweikert (1978), Saleeby and others (1978), Xenophontos and Bond (1978), and Saleeby (1981, 1982) show that a belt of chaotic and highly disrupted sedimentary, volcanic, and ophiolitic (oceanic crust and upper mantle) rocks form a continuous span in the Sierra Nevada foothills extending between the Tuolumne River and the North Fork Feather River (Figure 3).

Sutter Creek Quadrangle

Geologic mapping in the Sutter Creek quadrangle was first published by Turner (1894). Various areas of the quadrangle were later mapped in more detail by Taliaferro (1950), Clark (1964), Duffield and Sharp (1975), Parkison (1976), Bartow and Marchand (1979), and Miller (1982). A compilation of their mapping, along with modifications resulting from this study is presented on Plate 1.

Metamorphic Rocks

Most of the rocks exposed in the Sutter Creek quadrangle are included in the western tectonic block. These are rocks of the Upper Jurassic volcanic island arc terrane, which are exposed in two belts separated by rocks of the melange-ophiolite complex (Figure 3; Plate 1). The eastern volcanic island arc belt contains rocks of the Logtown Ridge and Mariposa Formations. The Mariposa Formation is noteworthy in that the gold-bearing quartz vein system of the well-known Mother Lode belt is contained almost entirely within its boundaries. The western volcanic arc belt is underlain by the Copper Hill Volcanics, Salt Springs slate, and Gopher Ridge Volcanics. Both

sequences of andesitic volcanic rocks contain volcanogenic sulfide deposits which form part of the foothill copper-zinc belt.

The melange-ophiolite basement complex exposed within the Sutter Creek quadrangle consists of a chaotic rock assemblage (melange) which is dominated by sedimentary strata composed chiefly of slate, shale, quartzite, conglomerate, graywacke, and carbonate rock (Duffield and Sharp, 1975). Chromite is associated with ultramafic rocks within and bordering the melange. Also exposed within this terrane are several carbonate rock bodies.

Exposed along the eastern margin of the Sutter Creek quadrangle are phyllite, chert, volcanic, and minor carbonate rocks of the central block's Calaveras Complex (Plate 1). Due to a lack of detailed mapping, the rocks are shown on Plate 1 as undifferentiated Calaveras Complex, except for a limestone body located east of Plymouth. In addition to limestone a few isolated lode gold and manganese prospects occur in this terrane.

Intrusive Rocks

Part of a relatively large granitic body crops out in the northeast part of the Sutter Creek quadrangle. The pluton, which is described by Duffield and Sharp (1975), intrudes rocks of the Calaveras Complex and terminates along the Melones fault. Generally, intrusive rocks of the west-central Sierra Nevada foothills have been assigned a Late Jurassic age by previous workers, as summarized in Stern and others (1981). Turner (1894) and Duffield and Sharp (1975) show that a contact metamorphic aureole has developed around parts of this intrusive. North of the study area, along this same contact zone, a number of copper-gold deposits occur, either in the form of skarn or related fracture filling hydrothermal deposits.

Cenozoic Deposits

Overlying the metamorphic rocks, along the western margin of the study area, are interlayered and intermixed beds of quartz sand, kaolin-rich clay, and lignite of the Ione Formation. These economically important deposits are thought to have accumulated in deltaic environments along an inland sea which occupied California's central valley during Eocene time (about 40 million years ago). Locally, the lignite deposits form arcuate-shaped beds ranging in thickness from a few inches to 24 feet. These deposits probably accumulated in lagoonal waters behind off-shore islands, which now crop out as volcanic ridges west of Ione and Jackson Valleys. Maximum thickness of the Ione Formation has been reported to be about 450 feet. The nature and distribution of these deposits are described by Pask and Turner (1952), Carlson and Clark (1954), and Chapman and Bishop (1975).

Remnants of ancient river channel deposits, preserved through time by cappings of younger resistant volcanic rocks, crop out along some ridge tops in the northeast, northwest, and southeast parts of the study area. These deposits represent vestiges of major river systems that drained the Eocene Sierra Nevada landscape during the time the Ione Formation was developing (Lindgren, 1911). The Tertiary river channel deposits exposed in the northwest of the quadrangle area have been worked quite extensively.

Ridge-capping exposures of Mehrten rocks crop out along the apparent courses of two parallel Tertiary streams that flowed west through the central part of the quadrangle. A few exposures of Mehrten and Valley Springs rocks also occur in the northeast and southeast corners of the quadrangle where they overlie ancient river channel deposits. The exposures of Mehrten Formation in the southeast corner of the quadrangle overlie

parts of the extensively mined ancient stream channel deposit of the Mokelumne Hill District. Sediments of the Mehrten and Valley Springs Formations also form broad alluvial fan systems exposed along the southwest part of the quadrangle. The Tertiary deposits, which overlie metamorphic rock with marked angular unconformity throughout the northern and central Sierra Nevada, are described by Bateman and Wahrhaftig (1966), Piper and Gale and others (1939), and Lindgren (1911).

Faults

Two of the major Sierra Nevada fault systems, the Melones and the Bear Mountains, extend through the Sutter Creek quadrangle (Plate 1). Extending through the quadrangle from Jackson to Plymouth and northward, a narrow band (750-2500 feet) of highly sheared, recrystallized metamorphic rock marks the trace of the Melones fault zone. Located a few hundred to a few thousand feet west of the Melones fault zone and oriented parallel to it, is the gold-bearing quartz vein system of the Mother Lode belt. These veins occupy east dipping faults referred to by Clark (1964) as the "Mother Lode fissure system". Knopf (1929) and Zimmerman (1983) have mapped and described the faults and related quartz vein systems making up the Mother Lode gold belt between Jackson and Plymouth.

A nearly continuous narrow band of ultramafic rock, mainly serpentinite, represents the trace of the Bear Mountain fault zone extending northwesterly through the central part of the quadrangle. A number of local chromite prospects, some of which have yielded production in the past years, are located along the fault zone.

MINERAL LAND CLASSIFICATION

Guidelines

Land throughout the Sutter Creek quadrangle was classified into Mineral Resource Zones (MRZs) with respect to the presence, absence, or likely occurrence of mineral deposits according to guidelines adopted by the California State Mining and Geology Board (1979, p. 23). Section I.1a of these guidelines requires that the State Geologist classify land into Mineral Resource Zones (MRZs) as follows:

MRZ-1 Areas where adequate information indicates that no significant mineral deposits are present, or where it is judged that little likelihood exists for their presence. This zone shall be applied where well-developed lines of reasoning, based upon economic geologic principles and adequate data, demonstrate that the likelihood for occurrence of significant mineral deposits is nil or slight.

MRZ-2 Areas where adequate information indicates that significant mineral deposits are present or where it is judged that a high likelihood exists for their presence. This zone shall be applied to known mineral deposits where well-developed lines of reasoning, based upon economic geologic principles and adequate data, demonstrate that the likelihood for occurrence of significant mineral deposits is high.

MRZ-3 Areas containing mineral deposits the significance of which cannot be evaluated from available data.

MRZ-4 Areas where available information is inadequate for assignment to any other MRZ zone.

McKelvey Diagram

The State Geologist, in consultation with the Mining and Geology Board, has adapted the MRZ nomenclature presented in the above guidelines to generally accepted terminology for consideration of mineral resources and reserves commonly known as the McKelvey Diagram (Figure 4).

The McKelvey diagram, which was developed by the U.S. Bureau of Mines and the U.S. Geological Survey (1980), is a graphical representation of what has become a standard reference to present the relationship between the knowledge of mineral deposits and their economic characteristics (grade and size). The nomenclature used with the diagram (see definitions below) is important in communicating mineral potential information in activities such as mineral-land classification, and the terminology has been incorporated into the criteria developed for assigning mineral resource zones. Note that the horizontal axis of the diagram represents degree of knowledge about mineral deposits while the vertical axis represents economic characteristics. The two major divisions on the diagram are "Identified Resources" and "Undiscovered Resources." The division between these two major "knowledge" categories also marks the division between areas classified MRZ-2 and MRZ-3; the distinction between the two is that land areas classified MRZ-2 contain identified mineral resources while land areas classified MRZ-3 are those in which undiscovered mineral resources are likely to be present.

Nomenclature

Following are definitions of the nomenclature associated with the McKelvey diagram. It is important to refer to these definitions when studying the different resource categories shown on Figure 4.

RESOURCE -- A concentration of naturally occurring solid, liquid, or gaseous material in and/or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

RESERVES -- That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative.

Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification.

ORIGINAL RESOURCE -- The amount of a resource before production.

IDENTIFIED RESOURCES -- Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified resources include economic, marginally economic, and subeconomic components. To reflect varying degrees of geologic certainty, these economic divisions can be subdivided into measured, indicated, and inferred.

MEASURED RESERVES -- Quantity is computed from dimensions revealed in outcrops, trenches, workings, or drill holes; grade and (or) quality are computed from the results of detailed sampling. The sites for

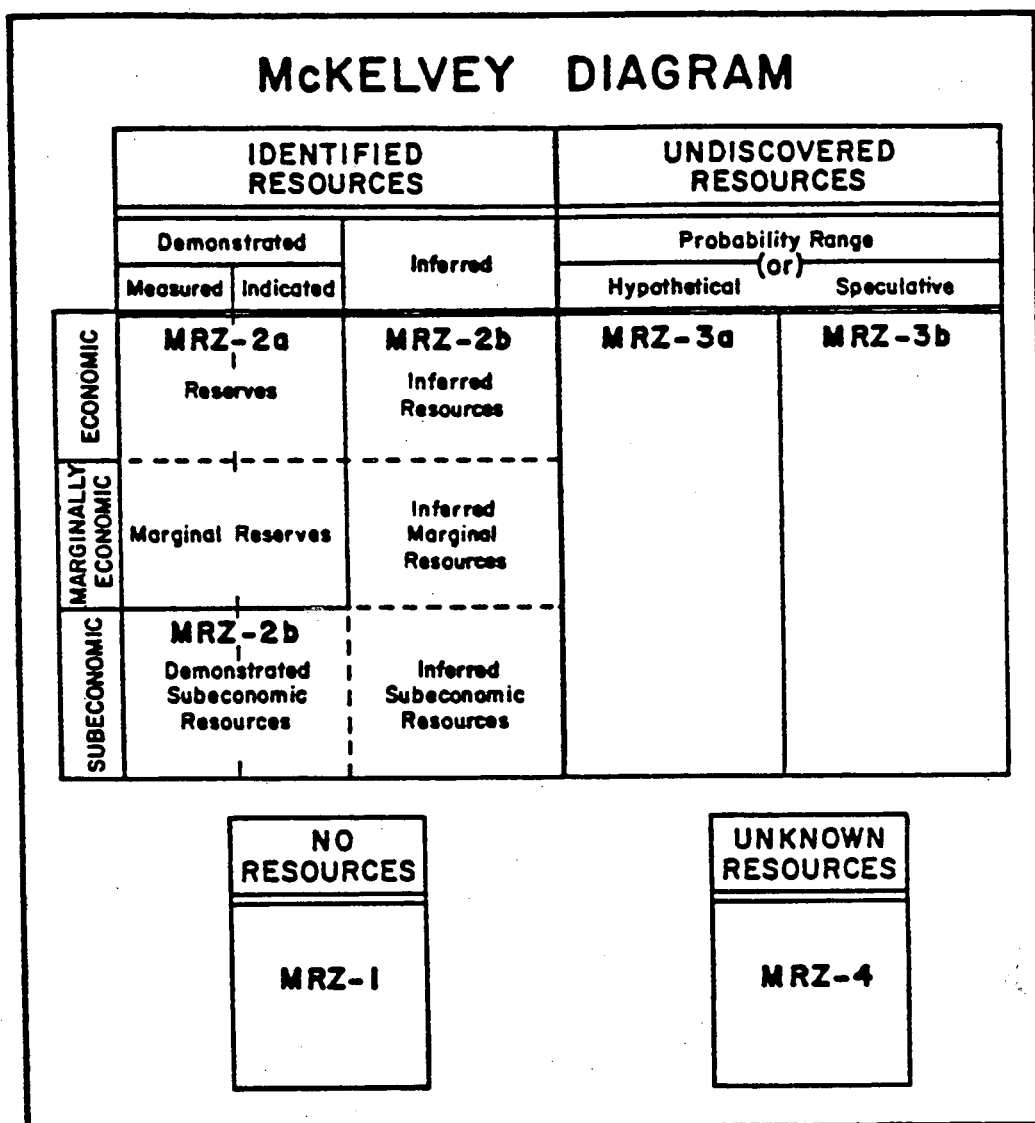


Figure 4. Diagrammatic relationship of mineral resource zone categories to the resource/reserve classification system developed by the U.S. Bureau of Mines and the U. S. Geological Survey. Modified from U.S. Geological Survey (1980).

inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, depth, and mineral content of the resource are well established.

INDICATED RESERVES -- Quantity and grade and (or) quality are computed from information similar to that used for measured resources, but the sites for inspection, sampling, and measurement are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than that for measured resources, is high enough to assume continuity between points of observation.

DEMONSTRATED RESERVES -- A term for the sum of measured plus indicated reserves.

INFERRED RESOURCES -- Estimates are based on an assumed continuity beyond measured and(or) indicated resources, for which there is geologic evidence. Inferred resources may or may not be supported by samples or measurements.

MARGINAL RESERVES -- That part of the reserve base which, at the time of determination, borders on being economically producible. The essential characteristic here is economic uncertainty. Included are resources that would be producible, given postulated changes in economic or technologic factors.

ECONOMIC -- This term implies that profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.

SUBECONOMIC RESOURCES -- The part of identified resources that does not meet the economic criteria of reserves and marginal reserves.

UNDISCOVERED RESOURCES -- Resources, the existence of which are only postulated, comprising deposits that are separate from identified resources. Undiscovered resources may be postulated in deposits of such grade and physical location as to render them economic, marginally economic, or subeconomic. To reflect varying degrees of geologic certainty, undiscovered resources may be divided into two parts:

HYPOTHETICAL RESOURCES -- Undiscovered resources that are similar to known mineral bodies and that may be reasonably expected to exist in the same producing district or region under analogous geologic conditions. If exploration confirms their existence and reveals enough information about their quality, grade, and quantity, they will be reclassified as identified resources.

SPECULATIVE RESOURCES -- Undiscovered resources that may occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential. If exploration confirms their existence and reveals enough information about their quantity, grade, and quality, they will be reclassified as identified resources.

MRZ Categories - Nonurban Studies

In order to communicate mineral potential information for the purposes of classifying land in nonurban areas of the state with respect to metallic and industrial minerals, the classification categories set forth in guidelines of the Mining and Geology Board have been adapted to the McKelvey diagram. These general adaptations are presented below*:

MRZ-1: Areas where available geologic information indicates there is little likelihood for the presence of mineral resources.

MRZ-2a: Areas underlain by demonstrated mineral reserves where geologic data indicate that significant measured or indicated resources are present. As shown on Figure 4, MRZ-2 is divided on the basis of both degree of knowledge and economic factors, and MRZ-3 is divided according to degree of knowledge. Areas classified MRZ-2a contain discovered mineral deposits that represent either measured or indicated reserves as determined by such evidence as drilling records, sample analysis, surface exposure, and mine information.

MRZ-2b: Areas underlain by inferred mineral resources where geologic information indicates that significant inferred resources are present. Areas classified MRZ-2b contain discovered deposits that represent either inferred reserves or deposits that are presently subeconomic as determined by limited sample analysis, exposure, and past mining history. Further exploration work and/or changes in technology or economics could result in upgrading areas classified MRZ-2b to MRZ-2a.

MRZ-3a: Areas underlain by geologic settings within which undiscovered mineral resources similar to known deposits in the same producing district or region may be reasonably expected to exist (hypothetical resources). Land areas classified MRZ-3a are underlain by geologic settings which are favorable environments for the occurrence of specific mineral deposits. In the McKelvey diagram, these are referred to as hypothetical resources. Further exploration work within these areas could result in the reclassification of specific localities into the MRZ-2a or MRZ-2b categories.

MRZ-3b: Areas that may contain undiscovered mineral resources that occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential (speculative resources). Land areas classified MRZ-3b are underlain by geologic settings which appear to be favorable environments for the occurrence of specific mineral deposits. In the McKelvey diagram, these are referred to as speculative resources. Further exploration work could result in the reclassification of all or part of these areas into MRZ-3a category or specific localities into the MRZ-2a or MRZ-2b categories.

MRZ 4: Areas where geologic information does not rule out either the presence or absence of mineral resources.

* Specific MRZ criteria have been developed for each type of mineral deposit.

Areas classified MRZ-1 (areas which are not likely to contain mineral deposits) and MRZ-4 (areas where available data do not preclude the presence or absence of mineral deposits) fall outside the McKelvey diagram (Figure 4). However, both classification categories are important factors in mineral-potential and land-use considerations.

MINERAL DEPOSITS CLASSIFIED

The Sutter Creek quadrangle was evaluated for the presence or likely occurrence of specific metallic and industrial mineral deposits based on past mineral production and modern geologic concepts relating to mineral occurrences. The following types of mineral deposits were identified:

1. Industrial minerals (clay, specialty sand, lignite, carbonate rock, talc and asbestos).
2. Deposits containing gold formed by hydrothermal cavity filling and replacement processes.
3. Deposits containing gold, copper, and zinc formed by volcanogenic processes.
4. Deposits of chromite formed by magmatic concentration.
5. Deposits containing copper and gold formed by contact metasomatism.
6. Placer deposits containing gold.

Mineral resource zones relative to each type of deposit are presented in a series of maps (Plates 2-6) that accompany this report. Descriptions of the nature and occurrence of the deposits and the mineral resource zones follow. The order of the discussion of the types of mineral deposits is according to our evaluation of the relative importance that these types of deposits have to the current and future economy of the area.

The mineral land classification information provided on Plates 2-6 is presented in composite form on Plate 7. This map is intended primarily for use as a land use planning tool and, therefore, emphasis is placed on those areas classified under categories of MRZ-2 and MRZ-3. In addition, mineral resource zones are labeled according to mineral commodities (gold, copper, chromite) rather than mineral deposit type (hydrothermal, volcanogenic, magmatic segregation). Explanation and mine/prospect index listing for Plates 2-7 is presented on Plate 8.

Industrial Minerals (clay, specialty sand, lignite, carbonate rock, talc, asbestos) - Plate 2

Nature and Occurrence

Industrial minerals present in the Sutter Creek quadrangle include clay, specialty sand, lignite, carbonate rock, talc, and asbestos deposits. These are described below.

Clay: Clay is a natural, earthy, fine-grained material which has many important and vital industrial applications in our society. The U.S. Bureau of Mines (1980) lists six basic groups of clay for industrial and commercial use: Kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay and shale; each group having various properties and uses. One of the most important clay resource areas in California is located in the lone area along a twelve-mile long, two-mile wide belt underlying

the western margin of the study area. The clay is mined from the Middle Eocene Ione Formation which locally also contains commercial grade specialty sand and lignite (described below). Most of the clay deposits contained in the Ione Formation are of the kaolinite group (Pask and Turner, 1952). These deposits have been utilized mainly as fire clays since clay was first mined here in the 1840's by John Sutter. Other uses of Ione clay include production of calcined kaolin, filler clays, paper filler clays, bond clays, mortars, roofing and floor tile, clay pipe, and specialty clays for refractories. Also mined from the Ione Formation are pisolitic clay deposits, which, because of their appearance and high iron-aluminum content, are locally referred to as "laterite". These deposits are an important source of iron-aluminum additive material for several cement producers in northern California. Although the Ione Formation has been mined for use in ceramic raw material at a number of localities along the Sierra Nevada foothills, the Ione area is the only place where high grade refractory and relatively pure kaolinitic clays of any extent have been found or mined.

Specialty sand: Specialty sand is sand that is mined and processed for purposes other than aggregate, ballast, or fill uses. Specialty sand deposits are normally characterized by their high quartz content, which is a physically durable and chemically inert mineral. Specialty sand is essential to the manufacturing of glass, the foundry industry, and certain chemical and metallurgical processes. It is also utilized as a basic ingredient in fillers, extenders, abrasives, and filters. The various uses require various grades of sand, with glass and chemical uses normally requiring the highest quartz content. An important source of specialty sand in California is the Ione Formation. Quartz sand and kaolinitic clays in the Ione Formation are commonly intermixed. Both are often mined together and then separated. Once processed, the sand mined from the Ione area is normally used for purposes requiring high purity, most notably glass manufacturing and foundry materials.

Lignite: Lignite is a carbonaceous material that is intermediate in grade between peat and subbituminous coal. It is present in the Ione Formation as discontinuous, arcuate-shaped beds interlayered with clay and sand. Lignite deposits of the Ione area represent the only source of montan wax in the United States and the free world. An extraction product of lignite, montan wax is a hard substance with a high melting point and is used in carbon paper inks, polishes, and lubricants. Lignite is also used in the manufacturing of flue pipe. Currently there is a proposal to construct a 14 megawatt co-generation facility in the Ione area which would use as fuel a mixture of residue lignite, that is generated as a waste product from the production of montan wax, and lignite low in montan wax content.

Carbonate rock deposits: The carbonate rocks, limestone (CaCO_3) and dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$), are widely used by society. The construction, agricultural, metallurgical, chemical, sugar refining, paint and glass manufacturing, and cement producing industries are all very dependent upon their availability. By far the greatest volume of carbonate rock goes into production of cement, which over the past years consistently has been California's leading nonfuel mineral commodity product in dollar value. Limestone deposits form in relatively shallow marine or lake environments, and most deposits of economic importance were derived from seawater, mainly through organic related chemical processes. Although some dolomite deposits are derived similarly from seawater, most are formed as an alteration product of limestone by hypersaline brine solutions.

Carbonate rock deposits of the Sierra Nevada metamorphic belt are generally present as small, isolated, lensoidal bodies measuring less than a few thousand feet in length and a few hundred feet in width. A notable exception is the large carbonate rock mass covering many square miles in the Columbia-Murphys area. The Sierra

Nevada carbonate rock deposits occur in terranes dominated by deep water sedimentary and volcanic rocks, which suggests that the shallow water carbonates are either seamount deposits and/or large rock fragments that slid down the continental slope onto a basin floor as landslide debris (olistostromes). Most of these occur in pre-Jurassic rocks within the Calaveras Complex, the foothill melange belt, and the Shoo Fly Complex. At least eight small deposits of limestone have been identified in the Sutter Creek quadrangle (Plate 1).

Talc: Talc is a magnesium-rich silicate mineral used mainly as a filler-type additive by the paint, paper, ceramic, cosmetic, plastics, roofing, petroleum, rubber, and chemical industries. Talc may form as a hydrothermal alteration product of ultramafic rock or through metamorphism of dolomite or dolomitic limestones.

According to Carlson and Clark (1954), small amounts of talc (soapstone) have been produced intermittently from Amador County since 1911 for use as a roofing filler, soapstone pencils, and other minor industrial purposes. There are no known active talc mines in the study area.

Asbestos: Asbestos is an industrial commodity term applied to several naturally fibrous minerals that are used in manufactured goods because of their fibrous and heat resistant characteristics. The various minerals used which make up asbestos are chrysotile, crocidolite, amosite, anthophyllite, tremolite, and actinolite. Almost all of the asbestos mined in California is made up of either chrysotile ($\text{Mg}_3\text{Si}_2\text{O}_5\text{OH}_4$) or tremolite ($\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}\text{OH}_2$). In the Sierra Nevada, both chrysotile and tremolite asbestos are usually found in or near massive serpentine bodies as veins or veinlets in parallel or net-like patterns. These minerals form in fractures that result from differential expansion during serpentinization.

Most large masses of serpentinized peridotite contain some asbestos, yet few deposits are of sufficient size or grade to warrant production from them. Whether a deposit is economic depends, largely, on such factors as extent, width, and spacing of the fibrous veins. Other important characteristics of asbestos is the length, flexibility, and tensile strength of the fiber. Reported production of asbestos in the Sutter Creek quadrangle amounts to only 12 tons produced in the early 1900s (Carlson and Clark, 1954). However, one of the largest producers of asbestos in the nation, Calaveras Asbestos Ltd. is located about 25 miles southwest of the study area.

Mineral Resource Zones

Mineral-land classification of the Sutter Creek quadrangle with respect to industrial minerals is presented on Plate 2 in composite form. A Mineral Resource Zone assigned to any one area represents the highest order of mineral favorability judged to exist for any industrial mineral deposit. For example, if an area is classified MRZ-2 with respect to carbonate rock but is MRZ-1 with respect to talc, MRZ-2⁽ⁱ⁾ is shown. Areas classified MRZ-2 and MRZ-3 are also labeled according to specific commodity type.

Areas Classified MRZ-1⁽ⁱ⁾: These are areas where geologic information indicates there is little likelihood for the presence of industrial mineral deposits. No areas in the quadrangle are classified MRZ-1⁽ⁱ⁾.

Areas Classified MRZ-2a⁽ⁱ⁾: These are areas underlain by deposits containing industrial minerals where geologic data indicate that significant measured or indicated resources of rock material suitable for use as a marketable product are present.

Much of the land underlain by the Ione Formation is classified MRZ-2a⁽ⁱ⁾. This land represents areas where systematic exploration drilling and material testing by companies operating in the Ione area adequately define measured and indicated reserves of clay, specialty sand, and lignite.

Areas Classified MRZ-2b⁽ⁱ⁾: These are areas underlain by deposits containing industrial minerals where geologic information indicates that significant inferred resources of rock material suitable for use as a marketable product are present.

Areas underlain by the Ione Formation, which have not been adequately drilled and the material tested, are assigned to the MRZ-2b category as compared to MRZ-2a above. Significant clay, sand, and/or lignite deposits are inferred to exist in these areas based on assumed lateral continuity of known economic deposits, similar mineralogy observed in surface exposures, and limited drilling and material testing.

Land classified MRZ-2b also include 8 separate areas underlain by small limestone bodies. Two of these deposits, the Allen limestone and the Dal Porto Marble quarries (localities 108 and 110), have been mined in the past years. Data regarding the quality and dimensions of these deposits (Carlson and Clark, 1954 and Logan, 1947) indicate that significant inferred resources of limestone, suitable for use as marketable products, are present.

Areas Classified MRZ-3a⁽ⁱ⁾: These are areas underlain by rocks within which undiscovered industrial mineral resources, similar to known deposits in the same producing district or region, may be reasonably expected to exist (hypothetical resources). Such areas may include prospects of undetermined significance. In the Sutter Creek quadrangle, known talc and asbestos deposits are restricted to areas underlain by ultramafic rocks. Consequently, all ultramafic bodies are classified MRZ-3a⁽ⁱ⁾.

Areas Classified MRZ-3b⁽ⁱ⁾: These are areas that may contain undiscovered industrial mineral resources that may occur, either, in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential (speculative resources). No areas within the Sutter Creek quadrangle are classified MRZ-3b⁽ⁱ⁾.

Areas Classified MRZ-4⁽ⁱ⁾: These are areas where geologic information does not rule out either the presence or absence of industrial mineral resources. They represent geologic environments in which one or another industrial mineral may be present.

Deposits Formed by Hydrothermal Processes (gold) - Plate 3

Nature and Occurrence

During the waning stages of magmatism, metal enriched fluids are expelled from a cooling magma at elevated temperatures and passed through fractures and other open cavities within the outer margins of a pluton and the surrounding country rock. These fluids may react with the rock that the pluton is in contact with to form contact metasomatic replacement deposits, or travel for a considerable distance where they may commingle with meteoric or connate water, or water derived from metamorphic reactions. The resulting metal-rich fluids may then traverse faults, fracture zones, porous rock or other open cavity spaces. In the course of passage, the fluids can undergo transformation through chemical reaction with the rock they traverse, heat loss, and changes in pressure. The combined effects of these changes can lead to the formation of

hydrothermal ore deposition by precipitation and concentration in open cavities or through metasomatic replacement of favorable rock, or a combination of both. In addition, significant chemical and mineralogical transformations may also occur due to reactions that take place between host rock and ore forming fluids.

Deposits formed by hydrothermal processes represent a major source of metallic mineral resources and to a lesser extent, non-metallic ones. The metallics would include deposits of gold, silver, lead, zinc, copper, mercury, antimony, tin, tungsten, molybdenum, and numerous minor elements. Non-metallic deposits would include kaolin, alunite, barite, various clay minerals, and a host of other substances.

Gold-bearing hydrothermal cavity fillings and replacement deposits are present in the Sutter Creek quadrangle along a 14-mile segment of the well-known Mother Lode belt and in a number of isolated localities elsewhere in the study area. A substantial portion of all the gold produced from the entire Mother Lode belt was mined from the 12-mile segment between Jackson and Plymouth. Detailed descriptions of the geology and mines of the Mother Lode belt located in the study area are given by Knopf (1929), Carlson and Clark (1954), Clark (1970), and Zimmerman (1983).

The Mother Lode belt is composed of a system of gold-bearing quartz veins that occupy fault and fracture openings within, or slightly to the west of, the Melones fault zone. The host rock for these deposits is composed mainly of metamorphosed sedimentary and volcanic rocks of the Mariposa Formation (Late Jurassic). Mineralization occurs in quartz veins mainly as free gold in narrow and nearly vertical ore shoots that often persist to great depth. Locally occurring along the quartz vein system are elongate bodies of highly altered and mineralized rock (referred to as gray ore by Knopf, 1929) composed of varying amounts of quartz, ferroan carbonate, mariposite, talc, and sericitic rock.

Ore genesis of gold deposits in the Mother Lode and elsewhere in the study area is not well understood. However, isotope studies conducted by Taylor (1981) on rock samples collected from deposits along the Mother Lode belt indicate "ore-forming solutions were essentially metamorphic in nature, and contained CO₂ of possible magmatic and metamorphic origin."

Mineral Resource Zones

Mineral-land classification of the Sutter Creek quadrangle with respect to hydrothermal ore deposits is presented on Plate 3. Mineral resource zones for this class of deposits are denoted by the superscript "h" (e.g., MRZ-2a^(h)).

Areas Classified MRZ-1^(h): These are areas where geologic information indicates there is little likelihood that significant hydrothermal ore deposits are present. This would include areas underlain by alluvium in excess of 2,000 meters. The nature and occurrence of hydrothermal ore deposits is such that no area within the Sutter Creek quadrangle can be assigned this category.

Areas Classified MRZ-2a^(h): These are areas containing hydrothermal ore deposits where geologic data indicates that significant measured or indicated resources are present. No areas are presently classified MRZ-2a^(h).

Areas Classified MRZ-2b^(h): These are areas that contain hydrothermal mineral deposits where geological information indicates that significant inferred resources

are present. The 14-mile extent of the Mother Lode belt is assigned to the MRZ-2b(h) category. The Mother Lode belt as a whole, rather than individual mines or veins, was classified MRZ-2b because of the overall continuity of the system and the extensive nature of mineralization throughout the belt as demonstrated by historic mining activity, which is not likely to have depleted gold resources. This reasoning is based on: (1) the high likelihood that blind ore bodies are likely to be present; (2) the knowledge that some subeconomic mineralization is likely to become enriched at depth; (3) the well-known vertical persistence of the veins; (4) the fact that some of the mines were involuntarily closed in World War II; and (5) the fact that current mining and milling technology allow production from low-grade disseminated deposits associated with the belt. Additional information regarding reserves of individual mines within the belt could result in upgrading some localities to MRZ-2a(h) status.

Areas Classified MRZ-3a(h). These are areas characterized by distinct geologic settings within which undiscovered metallic deposits, similar to known hydrothermal ore deposits in the same producing district or region, may be reasonably expected to exist (hypothetical resources). In all cases, it is assumed that the deposits are controlled by local structures along which mineralization occurred. Such areas may include prospects of undetermined significance.

Two areas in the Sutter Creek quadrangle are classified MRZ-3a(h). These areas border both sides of the Mother Lode belt and contain a number of quartz vein gold prospects of undetermined significance.

Areas Classified MRZ-3b(h). These are areas that may contain undiscovered metallic resources of hydrothermal origin that may occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their mineral potential (speculative resources). No areas within the Sutter Creek quadrangle are assigned to this category.

Areas Classified MRZ-4(h). These are areas where available information does not rule out the presence or absence of hydrothermal mineral deposits of significance. Since deposits formed by hydrothermal process could occur anywhere at reasonable depths in the metamorphic and igneous bedrock underlying the Sutter Creek quadrangle, much of the area is assigned to this classification category.

Deposits Formed by Volcanogenic Processes (gold, copper, zinc) - Plate 4

Nature and Occurrence

A segment of the foothill copper-zinc belt of the western Sierra Nevada extends through the western half of the Sutter Creek quadrangle. The belt in total is defined by a widespread group of polymetallic sulfide deposits associated with felsic pyroclastic rock horizons present in the Gopher Ridge and Copper Hill Volcanics, and the associated Smartville Volcano-plutonic complex (Kemp, 1982). The deposits are stratabound, commonly stratiform, accumulations of iron sulfides, mainly pyrite, mixed with varying amounts of chalcopyrite, sphalerite, galena, and precious metals. Mineralization was associated with subaqueous hydrothermal exhalative systems related to island arc volcanism venting mineralizing fluids at the sea water-rock interface. Most of the deposits are similar in mineralogy, morphology, and metal zoning to the Kuroko-type (Zn-Pb-Cu) and Noranda-type (Zn-Cu) volcanogenic deposits (Kemp, 1982). Ore grades within the deposits commonly average 2 to 5 percent copper, 2 to 15 percent zinc, 1 to 2 percent lead, 2 to 5 oz/ton silver, and 0.01 to .05+ oz/ton gold. Some deposits are enriched in precious metals with sulfide ore commonly assaying in excess of 0.10 oz/ton gold and 10 oz/ton silver (Jenkins, 1948).

The foothill copper belt includes about 20 notable mines and a host of smaller ones; together they have produced almost 200 million pounds of copper and 50 million pounds of zinc. Most mining activity in the belt occurred during the Civil War, World War I, and World War II. The mines have not produced since the late 1940s. One of the notable producers was the Newton mine, which is located in the central part of the study area. A number of the most important mines along the copper-zinc belt are described by Jenkins (1948). Kemp (1982) discusses the overall nature and distribution of these deposits.

Mineral Resource Zones

Mineral-land classification of the Sutter Creek quadrangle with respect to volcanogenic mineral deposits is presented on Plate 4. Mineral Resource Zones for this class of deposits are denoted by the superscript "v" (e.g., MRZ-2a^(v)).

Areas Classified MRZ-1^(v): These are areas where geologic information indicates there is little likelihood for the presence of mineral deposits formed by volcanogenic processes. These areas represent geologic terranes within which marine volcanic rocks are not expected to be present at the surface or at reasonable depths. In the Sutter Creek quadrangle, this category is limited to areas underlain by large intrusive bodies.

Areas Classified MRZ-2a^(v): These are areas containing volcanogenic metallic ore deposits where geologic information indicates that significant measured or indicated reserves are present. No areas in the Sutter Creek quadrangle presently meet this criterion.

Areas Classified MRZ-2b^(v): These are areas containing ore deposits of volcanogenic origin, where geologic information indicates that significant inferred reserves are present.

Three areas within the Sutter Creek quadrangle that are located along the foothill copper-zinc belt are classified MRZ-2b: the Newton mine (locality No. 18; Plate 4), the Irish Hill copper mine (locality No. 16 and 15; Plate 4) and the southern extent of the Copper Hill mine prospect group located just north of the study area in the Placerville quadrangle. These areas contain massive sulfide bodies that have yielded copper, zinc, and some gold in the past years and it is likely from surface evidence that additional mineralized zones exist within these areas.

Areas Classified MRZ-3a^(v): These are areas underlain by marine volcanic rock sequences in which undiscovered volcanogenic ore deposits, similar to known deposits in the same producing district or region, may be reasonably expected to exist (hypothetical resources). Such areas may include prospects of undetermined economic significance. Areas underlain by the Gopher Ridge, and Copper Hill volcanics, are assigned to the MRZ-3a^(v) category because they are the host rocks for known volcanogenic deposits of the foothill copper-zinc (Cu-Zn) belt and additional deposits are, therefore, likely to exist. This belief is shared by the mining industry who is actively engaged in exploration work within the study area. Also, using geophysical data published by the U.S. Geological Survey (1969), it was observed in the present study that high magnetic anomalies are often associated with the occurrence of known massive sulfide deposits present within the study area. Similar looking anomalies, which could reflect the existence of additional deposits, were recorded locally in the aeromagnetic survey.

Areas Classified MRZ-3b^(v): These are areas that may contain undiscovered metallic resources of volcanogenic origin that may occur either in known types of deposits in favorable geologic settings where discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential (speculative resources). The area underlain by the parts of the foothill melange belt, the Logtown Ridge Formation and the Brower Creek member of the Mariposa Formation are classified MRZ-3b^(v). These contain volcanic rock units that are favorable geologic settings for the occurrence of volcanogenic deposits, but none are known to exist.

Areas Classified MRZ-4^(v): These are areas where geologic information does not rule out the presence or absence of volcanogenic base and metal deposits. These areas are underlain by formations that, in part, are composed of marine volcanic rocks that could contain ore deposits of volcanogenic origin. In the present study area these include areas underlain by the Mariposa Formation, Salt Springs Slate, part of the foothill melange-ophiolite belt, and the Calaveras Complex.

Deposits Formed by Magmatic Concentration (Chromite) - Plate 5

Nature and Occurrence

Magmatic ore deposits form when crystallization and differentiation of magmatic bodies result in concentration of valuable minerals. The only mineral deposits of this type known to occur in the study area are concentrations of chromite. Chromite ($\text{Cr}_2\text{O}\cdot\text{FeO}$) is the world's only economic source of chromium, an extremely hard, strong metal that is resistant to oxidation, corrosion, abrasion, chemical attack, and high temperature breakdown; chromium is used for alloy (stainless steel), refractory (furnace lining), and chemical purposes. Chromite is a strategic mineral in short supply in the United States. During emergencies such as World War I and II, known deposits, however small, have been mined in California.

Primary deposits of chromite occur as magmatic segregations and disseminations in layered and alpine-type ultramafic intrusive rocks. Ultramafic rocks of the Sierra Nevada metamorphic belt are of the alpine-type. Generally, economic concentrations of chromite in alpine-type ultramafic rocks exist as podiform deposits, enveloped by dunitic masses. The origin of these deposits is not clearly understood. It is, however, generally accepted that ophiolitic terranes in which these deposits occur represent oceanic crust and upper mantle rocks generated at a spreading center and that these rocks and enclosed chromite bodies formed from the same silicate melt. In undisrupted ophiolite complexes, most of the chromite pods are located between 1 or 2 km beneath layered gabbros (Thayer, 1960) and, in general, are randomly distributed in the residual mantle peridotites that include harzburgites and dunites (Lago and others, 1982). However, these relationships are normally obscured in ultramafic rocks because they have normally undergone extensive folding, faulting, and serpentinization.

There is probably no ultramafic belt that does not contain, somewhere along its length, concentrations of chromite of sufficient tonnage and grade to constitute ore (Stanton, 1972). Wells and others (1940), Cater (1948), and Cater and others (1951), and Rynearson (1948) have described numerous chromite deposits that have been prospected or mined along the Sierra Nevada ultramafic belt. Eleven of these are reported to have produced more than 1,000 tons of chromite (Rice, 1957); the most notable of these being the Pilliken area mines in El Dorado County, which produced over 34,000 tons (Cater and others, 1951). None of these mines have been active since the early 1950s.

Chromite deposits within the Sutter Creek quadrangle occur in ultramafic rock marking the trace of the Bear Mountains fault zone (Plate 1); here, eleven of these deposits have been mined or prospected in past years. The deposits worked thus far have been relatively small, irregular lenses (pods) of massive chromite exposed at the surface. Six of these are reported to have produced a combined total of about 720 tons of ore, mostly during 1916 (Cater, 1948), but most of the known chromite deposits are worked out. However, little if any exploration drilling to discover new or related deposits has been carried out since the 1940s.

Mineral Resource Zones

Mineral-land classification of the Sutter Creek quadrangle with respect to magmatic deposits is presented on Plate 5. Mineral resource zones for this class of deposits are denoted by the superscript "m" (e.g., MRZ-3a^(m)).

Areas Classified MRZ-1^(m): These are areas where geologic information indicates there is little likelihood for the occurrence of deposits formed by magmatic concentration. In the Sutter Creek quadrangle, these areas represent geologic terranes within which ultramafic rocks are not expected to be present at the surface or at reasonable depths. These are areas underlain by granitic plutons, Upper Jurassic island arc rocks (Copper Hill, Gopher Ridge, Salt Springs, Logtown Ridge, and Mariposa Formations), and Upper Paleozoic-Triassic (?) sedimentary rocks of the Calaveras Complex. The area along the western margin of the quadrangle, which is underlain by Tertiary deposits measuring up to hundreds of feet thick, also is classified MRZ-1^(m). This is based on the subsurface projection of the Upper Jurassic island arc rocks described above, which are classified MRZ-1^(m).

Areas Classified MRZ-2a^(m): These are areas where geologic data indicate that significant measured or indicated chromite resources are present. There are no areas in the Sutter Creek quadrangle that presently meet this criterion.

Areas Classified MRZ-2b^(m): These are areas containing deposits formed by magmatic concentration, where geologic information indicates that significant inferred resources are present. There are no areas in the Sutter Creek quadrangle that presently meet this criterion.

Areas Classified MRZ-3a^(m): These are areas underlain by intrusive rocks within which undiscovered deposits formed by magmatic concentration similar to known deposits in the same producing district or region may reasonably be expected to exist (hypothetical resources). Such areas may include prospects of undetermined economic significance. Within the Sutter Creek quadrangle, these are areas underlain by ultramafic rock that do or could contain segregations and disseminations of chromite somewhere along their extents.

Areas Classified MRZ-3b^(m): Areas that may contain undiscovered mineral resources formed by magmatic concentration that occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential (speculative resources). No area in the study area has been classified MRZ-3b^(m).

Areas Classified MRZ-4^(m): These are areas where available geologic information does not rule out either the presence or absence of mineral resources formed by magmatic concentration. Two areas within the quadrangle have been assigned to this category (Plate 5). The area on the west represents land underlain by the foothill melange belt (Plate 1) within which the occurrence of ultramafic rocks is

common. The linear strip of land to the east, zoned MRZ-4^(m), represents the trace of the Melones fault zone. Although ultramafic rocks are not mapped along the Melones fault within the study area, they are closely associated with the fault elsewhere in the Sierra Nevada metamorphic belt.

Deposits Formed by Contact Metasomatism (copper, gold) - Plate 3

Nature and Occurrence

Contact metasomatic deposits containing varying amounts of iron, tungsten, tin, copper, lead, zinc, molybdenum, gold, and silver develop where high temperature effects and infiltration of metasomatic fluids and gasses expelled from intruding magma bring about replacement reactions in the surrounding country rock. Although replacement reactions can occur in many different rock types, carbonate rocks are the most susceptible. Consequently, metasomatic deposits are most commonly well-developed in carbonate bodies that are in contact with, or in close proximity to, a stock or batholith. The most important type of these are skarn deposits, which are characterized by a distinctive gangue mineral assemblage of coarse-grained, generally iron-rich, mixture of Ca-Mg-Fe-Al silicates. Ore minerals of these deposits occur as oxides, sulfides, arsenides, and native metals. The deposits are typically irregular-shaped bodies that may show extreme variation in degree of metallization.

Historically, contact metasomatic deposits have not constituted a major source of ore minerals in the Sierra Nevada metamorphic belt. Only a few mines have yielded noteworthy production. This is mainly due to the small amount of carbonate rocks present within the eastern, central, and western tectonic blocks that are in contact with, or in close proximity to, plutonic rock.

Typical representatives of the few known skarn deposits in the Sierra Nevada foothill region are the Pioneer-Lilyama copper mines located 11 miles northwest of Placerville in the southwest quarter of the Georgetown 15-minute quadrangle, which are described by Jenkins (1948). Although no deposits formed by contact metasomatism are known to exist in the Sutter Creek quadrangle, such deposits do exist in the Placerville quadrangle to the north within the contact aureole of the granitic pluton exposed east of Plymouth (Plate 1).

Mineral Resource Zones

Mineral-land classification of the Sutter Creek quadrangle with respect to contact metasomatic deposits is presented on Plate 3 along with deposits formed by hydrothermal processes. Mineral resource zones for this class of deposits are denoted by the superscript "s" for skarn (e.g., MRZ-3a^(s)).

Areas Classified MRZ-1^(s): These are areas where geologic information indicates there is little likelihood for the presence of contact metasomatic deposits. Concealed granitic rocks may be present at relatively shallow depths anywhere in the study area. The configuration of the granitic-metamorphic contact in the subsurface is not known in sufficient detail to warrant the application of the MRZ-1^(s) classification to any part of the Sutter Creek quadrangle.

Areas Classified MRZ-2a^(s): These are areas containing contact metasomatic deposits, where geologic data indicate that significant measured or indicated metallic resources are present. No deposits contained in any area of the quadrangle meet this criterion.

Areas Classified MRZ-2b(s): These are areas containing contact metasomatic deposits, where geologic information indicates that significant inferred resources are present. No areas within the quadrangle presently meet this criterion.

Areas Classified MRZ-3a(s): These are areas that fall within the contact aureole of plutonic rock masses within which undiscovered metallic deposits (hypothetical resources) of contact metasomatic origin similar to known deposits in the same producing district or region may be reasonably expected to exist. Such areas may include prospects of undetermined significance. For the purposes of this report, the contact aureole is represented by a one half-mile-wide zone of influence that extends out into the country rock surrounding the plutonic masses, except where contact aureoles have been faulted out by the Melones fault zone. The area contained within contact aureoles extending along the eastern margin of the granitic rock mass exposed east of Plymouth is classified MRZ-3a(s).

Areas Classified MRZ-3b(s): These are areas that may contain undiscovered metallic resources of contact metasomatic origin that may occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential (speculative resources). No areas in the Sutter Creek quadrangle are classified MRZ-3b(s).

Areas Classified MRZ-4(s): Areas where geologic information does not rule out either the presence or absence of contact metasomatic deposits. These areas represent geologic environments that unmapped or concealed contacts between plutonic and older metamorphic rocks could occur.

In the Sutter Creek quadrangle all areas outside the one half-mile wide zone along metamorphic-plutonic rock contacts are zoned MRZ-4(s) because plutonic rock bodies and associated contact metasomatic deposits could occur at reasonable depths.

Placer Deposits (gold, chromite) - Plate 6

Nature and Occurrence

Placer deposits are concentrations of heavy minerals that form due to wave or current action of water or air. The action of these mediums selectively retain high-density mineral grains and winnow out the lighter grains and finer materials. Minerals likely to be concentrated in a placer deposit are dense and resistant to weathering, solution, and abrasion. They include gold, platinum, group elements, chromite, scheelite, cassiterite, rutile, zircon, niobium-bearing minerals, and diamonds.

The minerals that make up placer deposits may be derived from: (1) economic lode deposits, such as the Mother Lode gold veins of California; (2) noneconomic lode deposits, occurring as small gold quartz stringers or veinlets of cassiterite; (3) sparsely disseminated ore minerals, such as minute grains of platinum group elements disseminated in ultramafic rock; and (4) rock-forming minerals, such as grains of magnetite, ilmenite, monazite, and zircon.

Environments which may produce these concentrations are (1) streams, (2) glacial streams, (3) beaches, (4) eluvial environments, and (5) eolian environments. Any of these environments that might have operated in the past can be preserved by uplift or burial, with their included placer concentrations. Ordinarily, regional uplift causes rapid erosion of unconsolidated materials; however, gravels may be preserved by later resistant

volcanic or sedimentary rock covers, uplifted, and re-exposed by cross-cutting valleys. Regional subsidence, stream overloading, or lava flows have buried placer gravels to depths of tens or hundreds of meters.

Both ancient and modern stream-channel deposits present within the Sutter Creek quadrangle have been mined in the past. Gold has been the only placer mineral known to be mined in the study area.

Mineral Resource Zones

Mineral-land classification of the Sutter Creek quadrangle with respect to placer deposits is presented on Plate 6. Mineral resource zones assigned for placer deposits are denoted by the superscript "p" (e.g., MRZ-2a^(p)).

Areas Classified MRZ-1^(p): These are areas where geologic information indicates there is little likelihood for the presence of placer mineral deposits. Because this quadrangle is transected by the Mother Lode gold belt on the east, and the drainage of the area flows westerly across the gold belt, it is quite possible that any of the alluvial material could contain recoverable gold, and that significant deposits could be present but concealed from view by nearby shallow surficial deposits. Therefore, no areas have been assigned to the MRZ-1^(p) category.

Areas Classified MRZ-2a^(p): These are areas containing placer mineral deposits where geologic information indicates that significant measured or indicated resources are present. There are no known placer mineral properties located in the study area that meet this criterion.

Areas Classified MRZ-2b^(p): These are areas containing placer deposits where geologic information indicates that significant inferred resources are present. Although several gold placer deposits present within the study area, such as the ancient stream deposits capping Irish Hill (located several miles northwest of Lone), have been mined in the past years, none have been assigned to the MRZ-2b category because information regarding gold content is lacking.

Areas Classified MRZ-3a^(p): These are areas underlain by alluvial deposits within which undiscovered placer mineral deposits similar to known placer deposits in the same producing district or region may be reasonably expected to exist (hypothetical resources). Such areas may include prospects of undetermined significance. In the Sutter Creek quadrangle, these include areas underlain by Tertiary to Holocene stream channel deposits.

Areas Classified MRZ-3b^(p): These are areas that may contain undiscovered placer mineral resources that may occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential (speculative resources). No areas within the Sutter Creek quadrangle have been classified MRZ-3b^(p).

Areas Classified MRZ-4^(p): Areas where geologic information does not rule out the presence or absence of placer deposits. This classification category encompasses most of the 240 square miles of land contained in the study area for reasons explained in MRZ-1^(p).

CONCLUDING REMARKS

Results of the Mineral-Land Classification Study of the Sutter Creek 15-minute quadrangle are as follows

- o Overall mineral potential in the Sutter Creek quadrangle is highly favorable, especially in terms of clay, specialty sand, lignite, gold and copper production. Areas of special interest are land underlain by the Ione Formation, the foothill copper-zinc belt, and the Mother Lode belt, which is a world class mineralized zone.
- o Five areas have been classified as containing significant measured or indicated mineral reserves (MRZ-2a). All five are areas underlain by the Ione Formation, which is composed of high quality kaolinite clay, specialty sand, and/or lignite.
- o Seventeen areas have been classified as containing significant inferred mineral reserves (MRZ-2b). These include the Mother Lode gold belt, five areas underlain by clay, sand, and lignite deposits of the Ione Formation, three areas containing polymetallic massive sulfide deposits (Newton, Copper Hill, and Irish Hill Copper mine areas), and eight areas underlain by small carbonate rock deposits.
- o Specific areas have been classified as representing favorable geologic environments (MRZ-3a and MRZ-3b) for the occurrence of the various types of mineral deposits classified in this report. These represent areas underlain by various geologic formations, distinct rock types, and/or specific structural features.
- o Mineral-land classification of the Sutter Creek 15-minute quadrangle provides local government agencies with information regarding the presence or likely occurrence of mineral deposits contained beneath land within their jurisdiction. Future land-use policy decisions made for land within the quadrangle can be made with a better understanding of underlying mineral significance or potential. Results of the study should also be useful to local property owners and to industry by targeting areas favorable for mineral exploration. Thus, the classification effort should result in the development of new mineral deposits, thereby increasing the industrial and economic base of the region, the state, and the nation.

RECOMMENDATIONS

- o Chromite deserves more attention by explorationists and others. Most chromite deposits mined in the past represent small surface exposures of chromite-bearing dunite present along the ultramafic rock belt extending through the quadrangle. Little, if any, exploration work using current technology has been carried out in the region to find economic deposits that might exist at depth.
- o Land-use competition in the area represented by the Sutter Creek 15-minute quadrangle has increased dramatically over the last 10 to 15 years, mainly as a result of widespread home development in isolated locations along the foothill belt. Some home-development sites are located on or adjacent to known mineral deposits that have been mined in the past. This is common along the Mother Lode and foothill copper-zinc belt, where, until recently, mining was thought to be more of historical interest than a modern day reality. As a result, local government is faced with unexpected land-use conflicts between surface uses and extraction of minerals. Mineral information provided in this report could help avert situations similar to those described above. For example, certain areas within the quadrangle

have been classified as areas containing mineral deposits of potentially economic significance (MRZ-2b). Local government should consider the contribution that these deposits could make to the economy and well-being of the region, state, and nation, while weighing mining land uses in comparison to other competing land-use possibilities which preclude ultimate use of these mineral resource potentials.

- o Other areas within the quadrangle have been classified as representing favorable geologic environments for mineral occurrence (MRZ-3a and MRZ-3b). Although the presence or absence of significant mineral deposits at any given locality in areas classified as such, cannot be demonstrated without site-specific evaluations, it should be considered in the land-use planning process that these lands represent target areas for mineral exploration and that major mineral discoveries could be made in the future.
- o Topical investigations should be conducted in areas classified MRZ-4 in order to better define their mineral potential and these lands should be reclassified accordingly. Any information gained by the mining industry and made available to the State Geologist would be of considerable value to the mineral-land classification effort.
- o The Sutter Creek quadrangle should be reevaluated and classification maps updated in about 10 years time in order to take into account possible new mineral discoveries, geologic concepts, technology, and economics.

ACKNOWLEDGMENTS

Much of the data base used in the preparation of this report was obtained from property owners and residences of Amador and Calaveras Counties, as well as from mining and mineral exploration companies and organizations active in the region. Their cooperation, time, and assistance contributed significantly to the completion of this mineral-land classification study.

REFERENCES

- Bartow, J.A., and Marchand, D.E., 1979, Preliminary geologic map of Cenozoic deposits of the Sutter Creek quadrangle, California (scale 1:62,500): U.S. Geological Survey Open-File Report 79-436.
- Bateman, P.C., and Wahrhaftig, C., 1966, Geology of the Sierra Nevada: California Division of Mines and Geology Bulletin 190, p. 107-172.
- Behrman, P.G., 1977, Paleogeography and structural evolution of a middle Mesozoic volcanic arc-continental margin, Sierra Nevada Foothills, California: University of California, Berkeley, unpublished Ph.D. thesis.
- Behrman, P.G., 1978a, Pre-Callovian rocks, west of the Melones fault zone, central Sierra Nevada Foothills: Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 337-348.
- Behrman, P.G. 1978b, Paleogeography and structural evolution of a Middle to Late Jurassic volcanic arc, Sierra Nevada foothills, California: University of California, Berkeley, unpublished Ph.D. dissertation.
- Behrman, P.G., and Parkison, G.A., 1978, Paleogeographic significance of the Callovian to Kimmeridgian strata, central Sierra Nevada foothills, California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 349-360.
- California State Mining Board, 1979, California Surface Mining and Reclamation Policies and Procedures: California Division of Mines and Geology Special Publication 51, 40 p.
- Carlson, D.W., and Clark, W.B., 1954, Mines and mineral resources of Amador County, California, in California Journal of Mines and Geology, v. 50; pp. 149-285.
- Cater, F.W., Jr., 1948, Chromite deposits of Calaveras and Amador counties, California: California Division of Mines and Geology Bulletin 134, Geological investigations of chromite in California, Part III - Sierra Nevada, Chapter 2, p. 33-60.
- Cater, F.W., Jr., Rynearson, G.A., and Dow, D.H., 1951, Chromite deposits of El Dorado County, California, in Geological investigations of chromite in California, Part 3: California Division of Mines and Geology Bulletin 134, p. 107-167.
- Chapman, R.H., and Bishop, C.C., 1975, Geophysical investigations in the Ione A Amador, Sacramento, and Calaveras Counties, California; California Division of Mines and Geology Special Report 117, 27 p.
- Clark, L.D., 1964, Stratigraphy and structure of part of the western Sierra Nevada metamorphic belt, California: U.S. Geological Survey Professional Paper 410, 70 p.
- Clark, L.D., 1976, Stratigraphy of the north half of the western Sierra Nevada metamorphic belt: U.S. Geological Survey Professional Paper 923, 26 p.

- Clark, L.D., Imlay, R.W., McMath, V.E., and Silberling, N.J., 1962, Angular unconformity between Mesozoic and Paleozoic rocks in the northern Sierra Nevada, California: U.S. Geological Survey Professional Paper 450B, Article 6, p. B15-B19.
- Clark, W.B., 1970, Gold Districts of California: California Division of Mines and Geology Bulletin 193, 186 p.
- d'Allura, J.A., Moores, E.M., and Robinson, L., 1977, Paleozoic rocks of the northern Sierra Nevada: Their structural and paleogeographic implications, in Stewart, J.H., Stevens, C.H., and Fritsche, A.E., editors, Paleozoic paleogeography of the western United States Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 1, p. 395-408.
- Diller, J.S., 1892, Geology of the Taylorville region, California: Geological Society of America Bulletin, v. 3, p. 370-394.
- Duffield, W.A., and Sharp, R.V., 1975, Geology of the Sierra Foothills melange and adjacent areas, Amador County, California: U.S. Geological Survey Professional Paper 827, 30 p.
- Ernst, W.G., editor, 1981, The Geotectonic Development of California, Volume 1: Prentice-Hall, Englewood Cliffs, New Jersey, 706 p.
- Harwood, D.S., 1983, Stratigraphy of upper Paleozoic volcanic rocks and regional unconformities in part of the northern Sierra terrane, California: Geological Society of America Bulletin, v. 94, p. 413-422.
- Hietanen, A., 1981, Petrological and structural studies in the northwestern Sierra Nevada, California: U.S. Geological Survey Professional Paper 1226, 59 p., 2 plates.
- Howell, D.G., and McDougall, K.A., editors, 1978, Mesozoic paleogeography of the western United States Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 361-384.
- Jenkins, O.P., editor, 1948, Copper in California: California Division of Mines and Geology Bulletin 144, 429 p., 61 plates.
- Jennings, C.W., 1977, Geologic Map of California: California Division of Mines and Geology Geologic Data Map No. 2, scale 1:750,000.
- Kemp, W.R., 1982, Petrochemical affiliations of volcanogenic massive sulfide deposits of the foothill Cu-Zn belt, Sierra Nevada, California: University of Nevada, Reno, unpublished Ph.D. dissertation, 458 p.
- Knopf, A., 1929, The Mother Lode system of California: U.S. Geological Survey Professional Paper 157, 88 p.
- Lago, B.L., Rabinowicz, M., and Nicolas, A., 1982, Podiform chromite ore bodies: a genetic model: Journal of Petrology, v. 23, Part 1, p. 103-125.

- Lindgren, W., 1911, The Tertiary gravels of the Sierra Nevada of California: U.S. Geological Survey Professional Paper 73, 226 p.
- Lindgren, W., and Turner, H.W., 1894, Placerville, California: U.S. Geological Survey Geologic Atlas, Folio 3, 3 p.
- Logan, C.A., 1947, Limestone in California: California Journal of Mines and Geology, v. 43, n. 3, p. 175-357.
- McMath, V.E., 1966, Geology of the Taylorsville area, northern Sierra Nevada, California: California Division of Mines and Geology Bulletin 190, p. 173-183.
- Miller, J., 1982, Stratigraphy, structure and metamorphism of the Calaveras Complex in part of Amador and Calaveras counties, California: University of California, Santa Cruz, unpublished M.S. thesis, 102 p.
- Morgan, B.A., 1976, Geology of Chinese Camp and Moccasin quadrangles, Tuolumne County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-840, scale 1:24,000.
- Parkison, G.A., 1976, Tectonics and sedimentation along a Late Jurassic (?) active continental margin, western Sierra Nevada Foothills, California: University of California, Berkeley, unpublished M.S. thesis, 160 p.
- Pask, J.A., and Turner, M.D., 1952, Geology and ceramic properties of the Ione Formation, Buena Vista area, Amador County, California: California Division of Mines and Geology Special Report 19, 39 p.
- Piper, A.M., Gale, H.S., and Thomas, H.E., 1939, Geology of the Mokelumne area, California: U.S. Geological Survey Water-Supply Paper 780, p. 14-100.
- Rynearson, G.A., 1948, Chromite deposits of Tulare and eastern Fresno counties, California, in Geological investigations of chromite in California: California Division of Mines and Geology Bulletin 134, Part III - Sierra Nevada, Chapter 3, 103 p.
- Rice, S.J., 1957, Chromite, in Mineral commodities of California: California Division of Mines and Geology Bulletin 176, p. 121-130.
- Saleeby, J., 1982, Polygenic ophiolite belt of the California Sierra Nevada: geochronological and tectonostratigraphic development: Journal of Geophysical Research, v. 87, Number B, p. 1803-1824.
- Saleeby, J., 1981, Ocean floor accretion and volcanoplutonic arc evolution of the Mesozoic Sierra Nevada, in Ernst, W.G., editor, The Geotectonic Development of California, Volume I: Prentice-Hall, Englewood Cliffs, New Jersey; p. 133-181.

- Saleeby, J.B., Goodin, S.E., Sharp, W.D., and others, 1978, Early Mesozoic paleotectonic-paleogeographic reconstruction of the southern Sierra Nevada region, in Howell, D.G., and McDougall, K., editors, Mesozoic paleogeography of the western United States Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 311-336.
- Schweikert, R.A., 1981, Tectonic evolution of the Sierra Nevada Range, in Ernst, W.G., editor, The Geotectonic Development of California, Volume I: Prentice-Hall, Englewood Cliffs, New Jersey; p. 88-131.
- Schweikert, R.A., 1978, Triassic and Jurassic paleogeography of the Sierra Nevada and adjacent regions, California and western Nevada, in Howell, D.G., and McDougall, K.A., editors, Mesozoic paleogeography of the western United States Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 361-384.
- Schweikert, R.A., and Bogen, N.L., 1983, Tectonic transect of Sierran Paleozoic through Jurassic accreted belts Volume and Guidebook, Society of Economic Paleontologists and Mineralogists, Pacific Section, 22p.
- Schweikert, R.A., and Snyder, W.S., 1981, Paleozoic plate tectonics of the Sierra Nevada and adjacent regions, in Ernst, W.G., editor, The Geotectonic Development of California, Volume I: Prentice-Hall, Englewood Cliffs, New Jersey, p. 183-201.
- Stanton, R.L., 1972, Ore Petrology: McGraw Hill, New York, 713 p.
- Stern, T.W., Bateman, P.C., Morgan, B.A., Newell, M.F., and Peck, D.L., 1981, Isotopic U-Pb ages of zircon from the granitoids of the central Sierra Nevada: U.S. Geological Survey Professional Paper 1185, 17 p.
- Stewart, J.H., Stevens, C.H., and Fritsche, A.E., editors, 1977, Paleozoic paleogeography of the western United States Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 1, 502 p.
- Taliaferro, N.L., 1950, Geologic map of the Sutter Creek quadrangle: University of California, Berkeley unpublished map, scale 1:62,500.
- Taylor, B.E., 1981, Hydrothermal fluids in the Mother Lode gold deposits of California: EOS Abstracts, v. 62, Number 45, p. 1059.
- Thayer, T.P., 1960, Some critical differences between Alpine-type and stratiform peridotite-gabbro complexes International Geological Congress, 21st, Copenhagen, 1962, Procedure, v. 13, p. 247-259.
- Turner, H.W., 1893a, Some recent contributions to the geology of California: American Geologist, v. 11, p. 307-324.
- Turner, H.W., 1893b, The rocks of the Sierra Nevada: U.S. Geological Survey 14th Annual Report, Part 2, p. 435-495.
- Turner, H.W., 1894, Jackson, California: U.S. Geological Survey Geological Atlas, Folio 11, 6 p.

- U.S. Bureau of Land Management, 1982, Microfiche listing of unpatented mining claims in California.
- U.S. Bureau of Mines, undated, Mineral Industry Location System (MILS); files for El Dorado and Amador counties.
- 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, 5 p.
- U.S. Geological Survey (1969), Aeromagnetic map of the northern Mother Lode area, California; U.S. Geological Survey Geophysical Investigations Map GP-671.
- U.S. Geological Survey, Branch of Resources Analysis, 1979, Mineral Data System Computerized Resource Information Bank (MDS-CRIB); files for El Dorado and Amador Counties.
- Wagner, D.L., Jennings, C.W., Bedrossian, T.L., and Bortugno, E.J., 1981, Geologic map of the Sacramento quadrangle, California: California Division of Mines and Geology Regional Geologic Map Series, scale 1:250,000.
- Wells, F.G., Page, L.R., and James, H.L., 1940, Chromite deposits of the Pilliken area, El Dorado County, California: U.S. Geological Survey Bulletin 922-0, p. 417-460.
- Xenophontos, C., and Bond, G.C., 1978, Petrology, sedimentation, and paleogeography of the Smartville terrane (Jurassic) - Bearing on the genesis of the Smartville ophiolite: Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 291-302.
- Zimmerman, J.E., 1983, The geology and structural evolution of a portion of the Mother Lode belt, Amador County, California: University of Arizona, unpublished M.S. thesis, 138 p.

GLOSSARY

Accreted Terranes	A plate tectonic model in which blocks or fragments of preexisting oceanic and continental crust are "welded" along a continental margin through convergent plate tectonism.
Alpine-Type Ultramafic Rocks	Intrusive rocks of ultramafic composition that occur within orogenic belts typically as small (few tens of square miles or less in area), elongate masses oriented more or less parallel to the local trend of the belt. Large numbers of these small bodies often occur as components of long, narrow "serpentine" belts.
Andesite	A gray-to-brown, hard, strongly porphyritic, fine- to medium-grained volcanic rock.
Argillite	A compact rock, derived either from mudstone (claystone or siltstone) or shale, that has undergone a somewhat higher degree of induration than mudstone or shale but is less clearly laminated than shale and without its fissility, and that lacks the cleavage distinctive of slate.
Auriferous	Said of a substance that contains gold, especially said of gold-bearing mineral deposits.
Basalt	A general term for dark-colored mafic igneous rocks, commonly extrusive but locally intrusive (e.g. as dikes).
Batholith	A large, generally discordant plutonic mass that has more than 40 square miles (100 km ²) of surface exposure and no known floor.
Bedding	The arrangement of a sedimentary rock in beds or layers of varying thickness and character.
Carbonate Rock	A rock consisting chiefly of carbonate minerals, such as limestone, dolomite, or carbonatite; specifically a sedimentary rock composed of more than 50 percent by weight of carbonate minerals.
Cassiterite	Principal ore of tin.
Cenozoic	An era of geologic time, from the beginning of the Tertiary period to the present. The Cenozoic is considered to have begun about 65 million years ago.
Complex	A large-scale field association or assemblage of different rocks of any age or origin, having structural relations so intricately involved or otherwise complicated that the rocks cannot be readily differentiated in mapping.

Conglomerate	A coarse-grained clastic sedimentary rock, composed of rounded to subangular fragments larger than 2 mm in diameter (granules, pebbles, cobbles, boulders) set in a fine-grained matrix of sand or silt, and commonly cemented by calcium carbonate, iron oxide, silica, or hardened clay.
Connate Water	Water entrapped in the interstices of a sedimentary rock at the time of its deposition.
Contact Aureole	A zone surrounding an igneous intrusion in which the country rock shows the effects of contact metamorphism.
Contact Metasomatic	A mass change in the composition of rocks in contact with an invading magma, from which "fluid" constituents are carried out to combine with some of the country-rock constituents to form a new suite of minerals.
Continental Rise	That part of the continental margin that is between the continental slope and the abyssal plain, except in areas of an oceanic trench. It is a gentle incline with slopes of 1:40 to 1:2000, and generally smooth topography, although it may bear submarine canyons.
Continental Slope	That part of the continental margin that is between the continental shelf and the continental rise (or oceanic trench). It is characterized by its relatively steep slope of 3-6 degrees.
Convergent Plate Tectonism	Tectonic activity along a boundary between two plates that are moving toward each other.
Disseminated Sulfide Deposit	Said of a mineral deposit (especially of metals) in which the desired minerals occur, in association with sulfide minerals, as scattered particles in the rock, but in sufficient quantity to make the deposit an ore.
Dunite	Peridotite in which the mafic mineral is almost entirely olivine, with accessory chromite almost always present.
Epiclastic	Textural term applied to mechanically deposited sediments (gravel, sand, mud) consisting of weathered products of older rocks. Detrital material from preexistent rocks.
Exhalite	A chemical sediment, usually containing oxide, carbonate, or sulfide as anions, and iron, manganese, base metals, and gold as cations, formed by the issuance of volcanically-derived fluids onto the sea floor or into the sea; thus, the product of exhalation.
Fault	A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

Felsic Volcanic Rock	A mnemonic term derived from (fe) for feldspar, and (s) for silica and applied to light-colored rocks containing an abundance of one or all of these constituents.
Fold	A curve or bend of a planar structure, such as rock strata, bedding planes, foliation, or cleavage. A fold is usually a product of deformation, although its definition is descriptive and not genetic and may include primary structures.
Foliation	A general term for a planar arrangement of textural or structural features in any type of rock; especially the planar structure that results from flattening of the constituent grains of a metamorphic rock.
Formation	A persistent body of igneous, sedimentary, or metamorphic rock, having easily recognizable boundaries that can be traced in the field without recourse to detailed paleontologic or petrologic analysis, and large enough to be represented on a geologic map as a practical or convenient unit for mapping and description; the basic cartographic unit in geologic mapping.
Gabbro	A group of dark-colored, basic intrusive igneous rocks composed principally of basic plagioclase (commonly labradorite or bytownite) and clinopyroxene (augite), with or without olivine and orthopyroxene.
Granitic Rock	A term loosely applied to any light-colored coarse-grained plutonic rock containing quartz as an essential component, along with feldspar and mafic minerals.
Graywacke	An old rock name that has been variously defined but is now generally applied to a dark gray firmly indurated coarse-grained sandstone that consists of poorly sorted angular to subangular grains of quartz and feldspar, with a variety of dark rock and mineral fragments embedded in a compact clayey matrix having the general composition of slate and containing an abundance of very fine-grained illite, sericite, and chloritic minerals.
Harzburgite	A peridotite composed chiefly of olivine and orthopyroxene.
Hydrothermal	Of or pertaining to hot water, to the action of hot precipitated water, such as a mineral deposit precipitated from a hot aqueous solution, with or without demonstrable association with igneous processes.
Igneous Rock	Said of a rock or mineral that solidified from molten or partly molten material, i.e. from a magma.

Industrial Minerals	Any rock, mineral, or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gemstones; one of the non-metallics.
Intermediate Volcanic Rock	Said of an igneous rock that is transitional between basic and silicic (or between mafic and felsic), generally having a silica content of 54 to 65 percent; e.g. syenite and diorite.
Island Arc	A chain of islands, e.g. the Aleutians, rising from the deep-sea floor and near to the continents.
Isotope	One of two or more species of the same chemical element, i.e. having the same number of protons in the nucleus, but differing from one another by having a different number of neutrons.
Jurassic	The second period of the Mesozoic era (after the Triassic and before the Cretaceous), thought to have covered the span of time between 190 and 135 million years ago.
Lithologic Terrane	The area or surface over which a particular rock or group of rocks is prevalent.
Mafic	Said of an igneous rock composed chiefly of one or more ferromagnesian, dark-colored minerals in its mode; also, said of those minerals.
Magma	Naturally occurring mobile rock material, generated within the Earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes.
Melange	A mappable body of rock characterized by the inclusion of fragments and blocks of all sizes, both exotic and native, embedded in a fragmented and generally sheared matrix of more tractable material.
Mesozoic	An era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic, or from about 225 to about 65 million years ago.
Metamorphic Rock	Any rock derived from preexisting rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.
Metasedimentary Rock	A sediment or sedimentary rock that shows evidence of having been subjected to metamorphism.
Metavolcanic Rock	Partly metamorphosed volcanic rock.
Meteoric Water	Water of recent atmospheric origin.

Ophiolite	A distinct assemblage of ultramafic rocks, coarse-grained gabbro, coarse-grained diabase, volcanic rocks and radiolarian chert.
Ore Deposit	The naturally occurring material from which a mineral or minerals of economic value can be extracted at a reasonable profit.
Orogeny	The process by which structures within fold-belt mountainous areas were formed, including thrusting, folding, and faulting in the outer and higher layers, and plastic folding, metamorphism, and plutonism in the inner and deeper layers.
Paleozoic	An era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic, or from about 570 to about 225 million years ago.
Peridotite	A general term for a coarse-grained plutonic rock composed chiefly of olivine with or without other mafic minerals such as pyroxenes, amphiboles, or micas, and containing little or no feldspar. Peridotite is commonly altered to serpentine.
Phyllite	A metamorphosed rock, intermediate in grade between slate and mica schist. Minute crystals of sericite and chlorite impart a silky sheen to the surfaces of cleavage (or schistosity).
Plate Tectonics	A theory of global tectonics in which the lithosphere is divided into a number of plates whose pattern of horizontal movement is that of torsionally rigid bodies that interact with one another at their boundaries, causing seismic and tectonic activity along these boundaries.
Pluton	A body of rock resulting from intrusion of magma.
Polymetallic	Said of deposits that contain economically important quantities of three or more metals.
Prospect	An area that is a potential site of mineral deposits, based on preliminary exploration. A prospect is distinct from a mine in that it is nonproducing.
Pyroclastic	Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent.
Pyrometasomatism	The formation of contact-metamorphic mineral deposits at high temperatures by emanations issuing from the intrusive and involving replacement of enclosing rock with addition or subtraction of materials.
Rutile	An ore of titanium.
Scheelite	An ore of tungsten.

Schist	A strongly foliated crystalline rock, formed by dynamic metamorphism, that can be readily split into thin flakes of slabs due to the well-developed parallelism of more than 50 percent of the minerals present, particularly those of lamellar or elongate prismatic habit, e.g. mica or hornblende.
Sedimentary Rock	A rock resulting from the consolidation of loose sediment that has accumulated in layers; e.g. a clastic rock (such as conglomerate or tillite) consisting of mechanically formed fragments of older rock transported from its source and deposited in water or from air or ice; or a chemical rock (such as rock salt or gypsum) formed by precipitation from solution; or an organic rock (such as certain limestones) consisting of the remains or secretions of plants and animals.
Serpentine	A rock consisting almost wholly of serpentine-group minerals, e.g. antigorite and chrysotile or lizardite, derived from the alteration of ferromagnesian silicate minerals such as olivine and pyroxene.
Slate	A compact, fine-grained metamorphic rock that possess slaty cleavage and hence can be split into slabs and thin plates. Most slate was formed from shale.
Stock	An igneous rock intrusion that is less than 40 square miles (100 sq. km.) in surface exposure, is usually, but not always, discordant and resembles a batholith except in size.
Strata-bound	Said of a mineral deposit confined to a single stratigraphic unit. The term can refer to a stratiform deposit, to variously oriented orebodies contained within the unit, or to a deposit containing veinlets and alteration zones that may or may not be strictly conformable with bedding.
Stratiform	Said of a special type of strata-bound deposit in which the desired rock or ore constituents, or is strictly coextensive with, one or more sedimentary, metamorphic, or igneous layers; e.g. beds of salt or iron oxide, or layers rich in chromite or platinum in a layered igneous complex.
Stratigraphy	The science of rock strata. It is concerned not only with the original succession and age relations of rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties - with all characters and attributes of rocks as strata; and their interpretation in terms of environment or mode of origin, and geologic history.
Structure	The general disposition, attitude, arrangement, or relative positions of the rock masses of a region or area; the sum total of the structural features of an area, consequent upon such deformational processes as faulting, folding, and igneous intrusion.

Terrane	The area or surface over which a particular rock or group of rocks is prevalent.
Tertiary	The first period of the Cenozoic era (after the Cretaceous of the Mesozoic era and before the Quaternary), thought to have covered the span of time between 65 and three to two million years ago. It is divided into five epochs: the Paleocene, Eocene, Oligocene, Miocene, and Pliocene.
Tuff	A general term for all consolidated pyroclastic rocks.
Ultramafic Rock	A general name for very mafic plutonic rock including, among others, dunite, peridotite, and pyroxenite.
Volcanic Rock	Finely crystalline or glassy igneous rock resulting from volcanic action at or near the Earth's surface, either ejected explosively or extruded as lava; e.g. basalt.
Volcanogenic	Formed by processes directly connected with volcanism; specifically, said of mineral deposits (massive sulfides, exhalites, banded iron formations) considered to have been produced through volcanic agencies and demonstrably associated with volcanic phenomena. Also spelled: volcanigenic.
Zircon	The chief ore of zirconium and is used as a refractory; when cut and polished, the colorless varieties provide exceptionally brilliant gemstones.

GLOSSARY REFERENCE SOURCES

Bates, R.L. and Jackson, J.A., editors, 1980, Glossary of Geology, 2nd edition: American Geological Institute, 749 p.

American Geological Institute, 1974, Dictionary of Geological Terms: Anchor Press/Doubleday, 545 p.

Note: Definitions of some multiple-word terms presented in GLOSSARY have been modified and combined.