CHAPTER 4

PRE-TERTIARY GEOLOGY OF NEVADA

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INTRODUCTION

Much of the mineral wealth of Nevada is hosted in pre-Tertiary rocks. These rocks are three times more extensive in the subsurface at depths of less than 1 km than they are in surface outcrops (chapter 2). Because of this, a combined portrayal of the exposed and concealed rocks is crucial to an analysis of Nevada's mineral resources. Plate 4-1 depicts the pre-Tertiary rocks of Nevada in a way specifically designed to support this analysis. The map shows outcrops (dark colors), as well as the inferred distribution (pastel colors) of Precambrian, Paleozoic and Mesozoic rocks, divided into 13 assemblages, beneath Tertiary volcanic and sedimentary rocks, sediments, and alluvium, and Quaternary alluvium and basin fill. The primary source of information for the map is the Geologic Map of Nevada (Stewart and Carlson, 1978), and most contacts within outcrops are taken from it. In some places, new contacts have been drawn, based on more recent studies.

Methods

This map and accompanying text is not a stratigraphic or sedimentologic summary, nor is it a geologic history of Nevada. The map portrays the known and inferred subsurface distribution of certain lithologic assemblages that are permissive for the occurrence of certain types of metallic mineral deposits. Due to assumptions about the depth at which mineral deposits may be successfully exploited, and to limitations in the various geophysical methods used to interpret concealed rocks, one kilometer below the surface was chosen to be the limit of extrapolation for this map.

The primary method used to extrapolate rock units under cover was the law of superposition, modified by structural information and common sense. Maps showing the distribution of individual units, palinspastic maps, and facies distribution maps in Stewart (1980) served as sources of information, as well as other sources referred to in the text.

Several geophysical studies were used to aid in the subsurface extrapolation. Gravity studies (Jachens and Moring, 1990, chapter 2 of this report) were used primarily to identify areas where low-density cover rocks exceed 1 km in thickness, and thus no pre-Tertiary rocks are inferred to exist at shallow depths. These basins are shown in gray on plate 4-1.

In addition to areas shown by gravity modeling to contain no dense basement rocks within 1 km of the surface, areas believed to be calderas (see chapter 5) are shown by red outlines and a red stippled pattern over the gray tint. Although some calderas may contain less than 1 km of Tertiary volcanic rocks because of tilting or other deformation, all are assumed to be filled with at least 1 km of volcanic deposits, unless there is specific information to the contrary.

UNITS

The map units depicted on plate 4-1 are termed assemblages. Because the purpose of the map is to delineate tracts permissive for the occurrence of specific types of mineral deposits, the division of rock units into assemblages is based primarily on lithology. In addition to stratiform rock units, Mesozoic holocrystalline plutonic rocks are also depicted.

The types of rocks that are particularly important for the occurrence of mineral deposits in Nevada are discussed below. The presence or absence of these lithologic types is the most important factor in dividing the rocks of Nevada into assemblages. Map unit designations refer to the Geologic Map of Nevada (Stewart and Carlson, 1978), hereafter referred to as the State map.

- Limestone and calcareous shale - Areas underlain by carbonate rock and calcareous shale are permissive for several deposit types, including polymetallic replacement deposits, skarns of all varieties, and sediment-hosted gold deposits. Detailed examination of the stratigraphic column of Nevada reveals few extensive stratigraphic intervals that do not contain significant calcareous rocks, and such rocks are believed to be present in the subsurface throughout most of the state.

- Submarine volcanic and metavolcanic rocks - For this group, the criteria were the presence of submarine volcanic or metavolcanic rocks. Examples of units containing such rocks are the Ordovician Valmy Formation (Osv) and the Permian Havallah sequence (PMh).

- Black, organic-rich shales - Organic-rich shales were deposited at several intervals during the geologic history of Nevada in environments where anoxic zones within ocean basins coincided with the sedimentation surface. Prominent among organic-rich formations are the Cambrian Preble Formation (Ct), the Ordovician Vinini Formation (Os), the Devonian Woodruff Formation (Ds), and the Devonian and Mississippian Pilot Shale and Chainman Shale (MDs). Studies by Meissner and others (1984), and Poole and Claypool (1984) were instrumental in understanding the relationship between organic-rich shales and many types of mineral deposits.

- Evaporites - Evaporitic chemical sediments, usually found interbedded with redbed clastic rocks, can serve as an important source of salts for the formation of hydrothermal brines. Evaporates, commonly signaled by gypsum deposits, are found in Nevada in two general stratigraphic environments. In northern Nevada, they are found in Lower and Middle Jurassic rocks, and in the south, in the vicinity of Las Vegas, they are found in Permian, Triassic, and Miocene rocks (Papke, 1987).

Selection of assemblages for delineation under cover is complicated by several additional factors. Most formations are not uniform in lithology. Thus, a stratigraphic unit that includes permissive rocks does not necessarily contain those rocks everywhere the unit is depicted. Also, stratigraphic designations have not been uniformly applied throughout the state. Because of the complexity of Nevada's geology, some units were combined on the State map in such a way as to preclude knowing details of the lithologic composition of the unit throughout the state. In some areas, more detailed knowledge of the stratigraphy and Iithology allowed the application of more detailed criteria to the delineation.

In delineating permissive areas, there is a general bias toward inclusion rather than exclusion. That is, if it is possible that a map unit contains permissive rocks, it has been depicted as permissive, in the absence of any special information to the contrary. This means that some areas have been delineated as permissive where mineral deposits may not exist. The method, however, purposefully minimizes the possibility of failure to delineate areas as permissive that actually are.

Terranes and Lithology

In western North America, terranes have been defined by Silberand others (1987) to be parts of the crust that are fault bounded, and distinguished from neighboring terranes by a distinctive geologic record, expressed by stratigraphy, as well as igneous and metamorphic history. This concept has proven useful in understanding the geologic development of North America and other continents. The <u>rock assemblages</u> depicted on plate 4-1 are defined to be parts of the crust that have similar lithoogy, regardless of history, and that are permissive for similar types of mineral deposits. The resulting map units are generally similar to the terranes defined by Silberling and others (1987) and Silberling (1991), but differ in detail because of the emphasis on lithology.

Some of the assemblages are subsets of the terranes outlined by Silberling and others (1987) and Silberling (1991). For example, several sedimentary assemblages are combined with the Precambrian crystalline assemblage to make up the North American terrane. Mesozoic carbonate and elastic rocks that are tectonically part of the Paradise terrane (or allochthon) (Silberling, 1991), are depicted separately in western Nevada in this analysis. Other assemblages, however, may include rocks that are included in separate terranes. For example, metavolanic and metasedimentary rocks assigned to the Sand Springs terrane by Oldow (1984) and Silberling (1991) are combined with similar lithologic groups in the Paradise volcanic assemblage in this analysis. Rocks of the Gold Range terrane are combined with those of the Golconda terrane to make up the Golconda assemblage of this report.

The descriptions of assemblges that follow are grouped according to their relationship to the terrane designations of Silberling (1991). Figure 4-1 shows the general relationship of the assemblages to each other along an idealized east-west cross section; table 4-1 shows this relationship in tabular form.

Table 4-1. Relationship of Iithologic assemblages used in this report to terranes delimited by Silberling and others (1987). Right hand column lists the assemblages that occur within the lithotectonic terraes in the left hand column.

Silberling (1991)	This report
North America	Precambrian crystalline assemblage Basal elastic assemblage lower Paleozoic carbonate assemblage upper Paleozoic carbonate assemblage part of Mesozoic elastic assemblage part of Mesozoic volcanic assemblage
Roberts Terrane	Roberts Mountains assemblage
Golconda Terrane	Golconda assemblage Mesozoic elastic assemblage Mesozoic carbonate assemblage Koipato volcanic assemblage
Gold Range Terrane	Golconda assemblage
Pine Nut Terrane	Pine Nut assemblage
Paradise Terrae	Paradise volcanic assemblage Mesozoic elastic assemblage Mesozoic carbonate assemblage part of Mesozoic volcanic assemblage
Jungo Terrane	Jungo assemblage
Black Rock Terrane	Black Rock assemblage

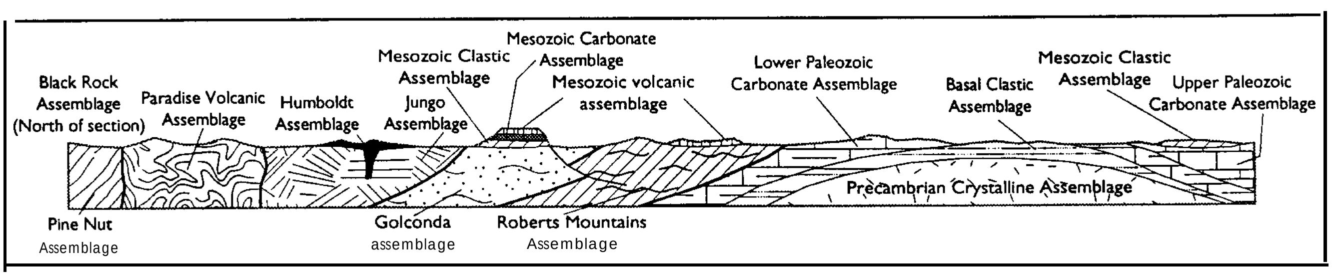

Figure 4-1. Schematic cross section across Nevada, showing the spatial relationships of assemblages to each other.

PRECAMBRIAN CRYSTALLINE ASSEMBLAGE (NORTH AMERICA)

Precambrian crystalline rocks are exposed primarily in the southern part of Nevada, in Clark County and southernmost Lincoln County. The rocks are generally similar to the Precambrian assemblage exposed throughout much of southwestern North America, consisting primarily of medium- to high-grade metasedimentary rocks that were intruded and metamorphosed at about 1,700 Ma, and then intruded by a suite of anorogenic granites with ages near 1450 Ma (Anderson, 1983).

Two enigmatic outcrops of metamorphic rock in the Bullfrog Hills and Trappman Hills in Nye County may be Precambrian in age, and are so designated on plate 4-1, following the State map. However, both show some similarities to metamorphic rocks elsewhere in Nevada that have now been shown to be of late Precambrian and Paleozoic age. These two areas, along with some rocks assigned to the late Precambrian Wyman Formation (Basal clastic assemblage; Mineral Ridge in Esmeralda County), have yielded problematic Miocene K-Ar ages, and may be parts of core complexes (McKee, 1983).

Other types of Precambrian crust may underlie other parts of Nevada. It has been proposed that the southeastern part of the state, south of 40.5°N latitude, is underlain by Proterozoic crust, and the northeastern part by Archean crust (Bryant, 1988). Very few mineral deposits of Proterozoic age are hosted in the Proterozoic rocks where they are exposed in southern Nevada, and, presumably they are also a poor host where not exposed. The western edge of the Precambrian continent during Paleozoic and Mesozoic time, was, however, very important in localizing deposition of several younger rock assemblages, and hence, important in localizing certain types of mineral deposits. Measurements of initial strontium isotope ratios for Mesozoic and younger igneous rocks indicate indirectly the approximate position of the western margin of Precambrian continental crust, and a line based on an initial ratio of $^{87}Sr/^{86}Sr = 0.705$ (Robinson, 1994) is shown on plate 4-1.

BASAL CLASTIC ASSEMBLAGE (NORTH AMERICA)

During latest Precambrian and Early Cambrian time, a transgressive sequence of mostly quartz-rich clastic sedimentary rocks was deposited throughout most of Nevada, forming a wedge that thickens from a few hundreds of meters near the Utah border to as much as 6 km further west. Rocks included in the Basal clastic assemblage on plate 4-1 include the map units Zqs, CZq, and Css on the state map. Stratigraphic units include the Johnnie Formation, the McCoy Creek Group, Sterling Quartzite, Wood Canyon Formation, Zabriskie, Prospect Mountain, and Osgood Mountain Quartzites, Wyman Formation, and the Tapeats Sandstone. This clastic sedimentation marks the submergence of the western margin of North America, following a rifting event that created what remained the passive continental margin into Triassic time (Speed and others, 1988).

In the eastern part of the state, this assemblage is almost entirely quartzose in nature; in the west, the assemblage includes varying proportions of carbonate rocks, particularly in the stratigraphically lower portions of the assemblage. The unit is delineated separately to help define large structures on the map, and to emphasize that carbonates make up only a small part of these rocks. Mica schists that belong to this assemblage host gold-quartz veins of probable Cretaceous age in the Silver Peak district; the epithermal precious-metal deposits at Delamar, and some gold-quartz veins in the Johnnie district are hosted in quartzites of this assemblage.

Lower Paleozoic Carbonate Assemblage (North America)

In middle Cambrian time, the mostly terrigenous, coarse, quartzose, detrital sedimentation on the western margin of North America changed to predominantly the deposition of limestone, dolomite, and fine-grained terrigenous material, and remained so throughout most of the rest of Paleozoic time. Many rock units have been grouped in the lower Paleozoic carbonate assemblage, which includes all of the primarily carbonate units from middle Cambrian through Late Devonian. The assemblage includes the State map units Ꞓt, OꞒt, Ꞓc, OꞒc, Ot, Oc, St, Sc, SOc, Dt, and Dc. The formations included are too numerous to list, but may be found on the explanation of the State map.

The total stratigraphic thickness of this assemblage is as much as 3 km or more. The proportion of shale increases to the west. The depositional environment was a shallow platform, and local emergent areas were probably common; local unconformities are prevalent throughout the section (Matti and McKee, 1977).

These carbonate rocks are host to many of Nevada's most important mineral deposits, including polymetallic replacement deposits, such as those at Pioche and Eureka, tungsten skarn deposits in the Potosi district, zinc-lead skarns in the Ward district, and sediment-hosted gold deposits at Getchell (Preble Formation).

Upper Paleozoic Carbonate Assemblage (North America)

During Mississippian, Pennsylvanian, and Permian time, after the Antler Orogeny, the eastern part of Nevada continued to be a shallow-water platform. Many formations, mostly consisting of carbonate rocks with lesser amounts of shale, are grouped as the Upper Paleozoic carbonate assemblage. Coarse clastic rocks, mostly cherts and pebble conglomerates, filled a foreland trough east of the Roberts Mountains allochthon, while carbonate rocks were deposited farther offshore, to the east. The conglomeratic rocks in the trough have been termed Antler flysch and molasse, to emphasize their association with the tectonic events of the Antler orogeny (Stewart, 1980). State map units included in this assemblage include Mc, PℙPc, Psc, Pc, ℙc, PMc, PℙPcd, and ℙcd. The clastic rocks are represented by MDs on the State map, but are not depicted separately on plate 4-1.

The aggregate thickness of the upper Paleozoic platform sequence is in excess of 3,000 m, and thickens to the east (Stewart, 1980). In general, the depositional environment was similar to that for the lower Paleozoic carbonate assemblage, a broad, shallow, marine shelf.

These carbonate rocks host important polymetallic replacement deposits, such as those in the Goodsprings district. Also, gold and copper skarn deposits in the Robinson and Battle Mountain districts are hosted by rocks of this assemblage.

In addition, some of the fine-grained clastic rocks in the western part of the outcrop area of this assemblage may be favorable for the occurrence of sediment-hosted gold deposits, because of their reduced nature and carbon content. Calcareous shales, siltstones, and mudstones in the Pilot Shale contain up to 3% organic carbon, and intertongue with turbidite, flysch, and shallow marine carbonate rocks (Meissner and others, 1984), whereas rocks of the Chainman Shale commonly contain up to 8% organic carbon, particularly in the "starved basin" of Poole and Claypool (1984). Both units are known as potential petroleum source rocks in the Great Basin.

ROBERTS MOUNTAINS ASSEMBLAGE (ROBERTS TERRANE)

The group of rocks portrayed on plate 4-1 as Roberts Mountains assemblage is a complex collection of rocks including both deep oceanic deposits, consisting of chert, argillite and greenstone, and continental margin deposits, consisting of arkosic and subarkosic turbidites. It is identical with the group of rocks termed Roberts Terrane by Silberling and others (1987) and Silberling (1991). Formations included in this assemblage in north-central Nevada are the Cambrian Schwin and Harmony Formations, the Ordovician Valmy and Vinini Formations, the Silurian Elder Sandstone and Fourmile Canyon Formation, and the Devonian Slaven Chert, and Scott Canyon and Woodruff Formations, as well as the volumetrically minor Mississippian to Permian clastic rocks of the overlap assemblage (Roberts and others, 1958; McKee, 1976). In addition, farther south and west, the unit includes the Palmetto, Diablo and Candelaria Formations (Stewart, 1980; Silberling and others, 1987). State map units include Ꞓsc, Ꞓh, Osv, Os, Se, Ss, Ds, Dsl, and DꞒsv.

As originally interpreted by Merriam and Anderson (1942), and by Roberts (1949), the lower Paleozoic rocks of this unit are largely allochthonous, and were thrust eastward to approximately their present position in the Antler Orogeny, during Late Devonian and Early Mississippian time. In general, the unit consists of a stack of thrust nappes, primarily older over younger. Transport distances are at least 75 km, and may have been twice that distance for some upper thrust slices (Madrid, 1987). Although there may be parts of this lithologic unit that are autochthonous (Stewart, 1980), all similar lithologies are considered part of this assemblage.

For the purposes of this resource analysis, the chief interest in the Roberts Mountains assemblage is in the volcanic rocks, now greenstones, because they are permissive for the occurrence of Besshi-type volcanogenic massive sulfide deposits, and in the organic carbon-rich black shales and bedded barite, which may be indicative of sedimentary exhalative lead-zinc and bedded barite deposits. Nelson (1991) and Maher and others (1993) suggested that the dark, carbonaceous sedimentary rocks of this assemblage are also rich in a variety of trace metals, including gold, arsenic, antimony, and mercury, and may have been the source for some of these metals found in some of the large gold deposits in north-central Nevada. Rocks from the Vinini Formation and Slaven Chert commonly contain more than 10% organic carbon (Poole and Claypool, 1984). Volcanic rocks, which are primarily alkalic basalts, with lesser amounts of tholeiite (Madrid, 1987), are most common in the Valmy Formation, and organic-rich shales and barite are most common farther east, in rocks assigned to the Vinini Formation and to the Slaven Chert.

Parts of many of the large sediment-hosted gold deposits of the Carlin trend are hosted in rocks of this assemblage, as is the Besshi-type volcanogenic massive sulfide deposit at Mountain City.

GOLCONDA ASSEMBLAGE (GOLCONDA TERRANE)

The group of rocks shown on plate 4-1 as the Golconda assemblage consists mostly of rocks called the Havallah sequence (Silberling and Roberts, 1962), and includes deep-water, upper Paleozoic siliceous and volcanic rocks. During the Sonoma Orogeny (Late Permian to Early Triassic), these rocks were thrust tens of kilometers eastward on the Golconda thrust fault to a position on top of, or adjacent to, the Roberts Mountains and lower Paleozoic carbonate assemblages. The upper plate rocks are highly deformed, consisting, in many places, of a series of structurally interleaved thrust slices and, in other places, forming a thick sequence of nappes.

Rocks of the Golconda assemblage include mostly argillite, with abundant chert, greenstone, sandstone, shale, conglomerate, and small amounts of carbonaceous limestone, most of which indicate an oceanic depositional environment (Jones and Jones, 1991). Stratigraphic units include the Havallah (PMh) and Pumpernickel Formations of the older literature, the Inskip Formation in the East Range of Pershing County (Msv), and rocks originally considered parts of the Pablo and Excelsior Formations in Nye and Esmeralda Counties (TRpd) by Ferguson and Muller (1949).

The assemblage is important to this analysis because at least one Cyprus-type massive sulfide deposit, Big Mike, (chapter 10) occurs within these rocks. In addition, calcareous parts of the sedimentary rocks in the assemblage may serve as hosts to skarn and replacement deposits, and reduced facies of the rocks may play a part in the control of the distribution of sediment-hosted gold deposits.

PINE NUT ASSEMBLAGE (PINE NUT TERRANE)

Rocks shown as the Pine Nut assemblage can be divided into four stratigraphic groups (Schweickert and others, 1996). From oldest to youngest, they are: Lower to Upper Triassic lava flows, breccias, and ash-flow tuffs, both subaerial and submarine; Upper Triassic marine carbonate rocks, with some argillites; Upper Triassic to Middle Jurassic siltstone, argillite, and limestone; and Middle Jurassic (and possibly younger) subaerial ash-flow tuff and lava flows. The volcanic rocks are high-K calc-alkaline, and appear to represent a typical magmatic arc at a continental margin. Middle Jurassic plutonic rocks are widespread, and minor plutonism accompanied the earlier Triassic volcanic episode. Some rocks are included in the Pine Nut assemblage that are possible to distinguish as Mesozoic carbonate and Mesozoic clastic assemblage further to the east. Rocks of this assemblage are shown primarily as unit JTRsv on the State map.

At least the lower three groups of rock in the Pine Nut assemblage were deformed and metamorphosed in Middle Jurassic time. The rocks of this assemblage are probably not in their original depositional site, which is not known. It is speculated by some that this site was far to the south, in the Mojave Desert (Schweickert and Lahren, 1990); others favor a site far to the northwest (Oldow, 1984). In either case, rocks of this assemblage reached their present position and were attached to North America sometime before the early Late Cretaceous. Rocks of the assemblage are separated from the Paradise volcanic assemblage on the east by the Pine Nut fault, a strike-slip structure of presumed Jurassic—Early Cretaceous age that separates the moderately deformed rocks of the Pine Nut assemblage from those in the Paradise volcanic assemblage, that have a similar age and stratigraphy, but which have been compressed and thickened during Late Jurassic or Cretaceous southeast-directed thrusting (Luning-Fencemaker fold and thrust belt).

The most important mineral deposits hosted by these rocks are the copper skarn deposits in the Yerington district.

PARADISE VOLCANIC ASSEMBLAGE (PARADISE TERRANE)

The rocks of this assemblage are very similar to those in the Pine Nut assemblage, and consist of Middle Triassic to Middle Jurassic lava flows, breccias, ash-flow tuffs, marine carbonate rocks, argillites, and siltstones. Because the State map delineates the Triassic Luning limestone (TRc) and Jurassic Dunlap Formation (Jd), these formations are shown separately as Mesozoic carbonate and Mesozoic clastic assemblage on this map, and the rocks depicted as Paradise volcanic assemblage contain relatively little sedimentary rock. The volcanic rocks appear to belong to a typical continental arc assemblage, and consist of silicic ash-flow tuffs, and andesite and rhyolite flows (John and others, 1994).

The Paradise volcanic assemblage was complexly deformed during the Middle Jurassic to early Late Cretaceous. The similarities in lithology between the Paradise and Pine Nut suggest that they originated in the same structural and volcanic province, along the same continental margin. The slight differences in lithology suggest to some that tectonic dislocations of as much as hundreds of kilometers are possible between the Paradise and Pine Nut structural blocks (e.g., Oldow, 1984). Various possibilities for the original paleogeography of the region are presented in Stewart and Schweickert (1996).

Characteristic mineral deposits found in this assemblage are almost all pluton-related. The tungsten skarn deposits in the Fairview district are representative examples.

JUNGO ASSEMBLAGE (JUNGO TERRANE)

During Triassic and Early Jurassic time, a shallow marine basin developed in northwestern Nevada, off the margin of Mesozoic North America. The rocks that fill this basin have been called the Jungo Terrane by Silberling and others (1987) and Silberling (1991). The rocks consist primarily of a sequence of pelitic shales as much as 7 km thick, with some sandstone and minor, thin beds of limestone (Speed and Jones, 1969). The rocks of this assemblage are represented primarily by the unit designated JTRs on the State map. All the rocks designated JTRs belong to the Auld Lang Syne group as defined by Burke and Silberling (1973), but only the basinal facies of Speed (1978) have been included in the Jungo assemblage in this report. The shelfal facies rocks, including the Grass Valley, Osobb, Dun Glen and Winnemucca Formations are included in the Mesozoic clastic assemblage. At the top of the Jungo assemblage, Speed (1974, 1975) described a sequence of marine carbonates and evaporites that mark the transition between open marine basinal conditions and an emergent terrane.

Characteristic mineral deposits found in this assemblage are almost all pluton-related. Prominent examples are the productive tungsten skarn deposits at Mill City, which formed in thin limestone beds of the Jungo assemblage. A large gypsum deposit at Empire occurs in the uppermost carbonate-evaporite facies.

HUMBOLDT ASSEMBLAGE (JUNGO TERRANE)

A singular group of rocks, designated the Humboldt assemblage in this report, is found stratigraphically above the Jungo assemblage, in Churchill and Pershing Counties. Here, a sequence of quartz-rich sandstones called the Boyer Ranch Formation lies, in part unconformably, on Upper Triassic siltstones, and primarily in fault contact over Jurassic and Triassic shales of the Jungo assemblage (Speed and Jones, 1969; Speed, 1976). These sandstones are intruded by a complex gabbroic pluton of Middle Jurassic age. Associated rocks include coeval basaltic lava, tuff, and volcanic sandstone. Rocks of this assemblage are designated Jgb on the State map. The only significant mineral deposits in rocks of this assemblage are phosphate-rich iron endoskarn deposits, exemplified by the Buena Vista deposit.

BLACK ROCK ASSEMBLAGE (BLACK ROCK TERRANE)

This assemblage consists of upper Paleozoic to Upper Jurassic oceanic-basin and island-arc rocks in the Pine Forest Range, Jackson Mountains, and other areas north and west of the rocks of the Jungo assemblage. These rocks are locally metamorphosed, and appear to be similar to rocks in the eastern Klamath Mountains in northern California. Rocks of this assemblage are designated JTRs and TRPvs on the State map. The most important mineral deposits in this assemblage are small volcanic-hosted magnetite deposits and possible kuroko massive sulfide deposits.

MESOZOIC CARBONATE ASSEMBLAGE (GOLCONDA TERRANE, PARADISE TERRANE)

In northern Nevada, two groups of pre-Tertiary rocks lie stratigraphically above the Triassic Koipato Group and rest only on rocks of the Golconda assemblage. The lower one, the Star Peak Group (Nichols and Silberling, 1977; State map unit TRc), is predominantly composed of shelf carbonate rocks. The overlying Auld Lang Syne Group (Burke and

Silberling, 1973; State map unit JŦs), consists almost entirely of quartzose clastic rocks of continental provenance. Because of the relative scarcity of carbonate rocks, the Auld Lang Syne Group rocks are delineated separately and included with the Mesozoic clastic assemblage. Farther to the south, the Middle Triassic Grantsville and Upper Triassic Luning Formations and other unnamed rocks are included in the Mesozoic carbonate assemblage, which in this area, corresponds closely to the unit Ŧc on the State map. Carbonate rocks in this assemblage are primarily platform deposits, with some supratidal dolomite (Stewart, 1980), and are not greatly different lithologically from the Lower and Upper Paleozoic carbonate assemblages in central and eastern Nevada.

The Mesozoic carbonate assemblage is delineated separately because of the high proportion of carbonate rocks which makes it permissive for several types of carbonate-hosted mineral deposits. Prominent examples include the McCoy gold-rich skarn and the nearby Cove distal disseminated silver deposit, as well as many small base-metal skarn and replacement deposits in the Luning Formation.

MESOZOIC CLASTIC ASSEMBLAGE (NORTH AMERICA, GOLCONDA TERRANE, PARADISE TERRANE)

Rocks included in this map unit are the Moenkopi and Thaynes Formations (Ŧmt) and related rocks, found primarily in northeastern and southeastern corners of the state, the Chinle Formation and associated rocks (JŦch), found primarily in the southeast, the Aztec Sandstone (JŦa), found in the northeastern and southeastern corners, the Auld Lang Syne Group (JŦs), found in north-central Nevada, and the Dunlap Formation (Jd), found in western Nevada. These rocks are primarily sandstone, shale, and conglomerate. All are continental in origin, except parts of the Moenkopi, which contains some thin carbonate strata. A depositional hiatus and, in many places, an unconformity, separates these rocks from older ones.

In western Nevada, the Dunlap Formation, although lithologically similar to the sandstones in the eastern part of the state, includes features such as coarse, poorly sorted detritus and local heterogeneity of rock types, including volcanic rocks, and evaporite deposits. The Dunlap records deposition in a tectonically active, extensional basin.

The Mesozoic clastic assemblage is delineated separately because it is one of the few assemblages in Nevada that is almost devoid of platform carbonate rocks, and because it hosts few mineral deposits.

MESOZOIC VOLCANIC ASSEMBLAGE (NORTH AMERICA, PARADISE TERRANE)

A variety of volcanic rocks were erupted in Nevada during Mesozoic time. Most of them have since been removed by erosion, but the ones that remain may host some distinctive mineral deposits. A majority of the volume of Mesozoic volcanic rocks are those included here with the Paradise volcanic and Pine Nut assemblages. Available information does not permit the separate delineation of these rocks. The Mesozoic volcanic assemblage consists of all Mesozoic volcanic rocks that can be depicted separately, and includes the Triassic Koipato Group (Ferguson and others, 1951; map unit Ŧk), the Jurassic Pony Trail Group (Muffler, 1964; map unit Jv), the Cretaceous(?) Excelsior volcanics (Speed and Kistler, 1980), and the Cretaceous(?) Darrough Felsite (Brem and others, 1991). Most of them have not been highly deformed.

The Koipato Group (Ferguson and others, 1951) is exposed in north-central Nevada between Lovelock and Winnemucca. It consists of the Limerick Greenstone (andesite flows, tuffs, and breccias), the Rochester Rhyolite (rhyolite flows and ash-flow tuffs, some possibly submarine), the Weaver Rhyolite (submarine? ash-flow tuff, tuffaceous sandstone and conglomerate), and the China Mountain Formation (tuffaceous mudstone and sandstone). This assemblage of volcanic rocks was deposited immediately after, or during the waning stages of, emplacement of the Golconda thrust; locally the lowest rocks of this assemblage are in angular unconformable contact with rocks of the Golconda assemblage, although, in most places, the base is not exposed. The Koipato is considered to be Early Triassic in age, as confirmed by both fossils and radiometric dating of zircons (McKee and Burke, 1972). The most important mineral deposit known in Koipato rocks is the large silver deposit at Rochester, which may be a Triassic epithermal vein deposit. The Limerick Greenstone may also host massive sulfide deposits.

The Pony Trail Group (Muffler, 1964; Smith, 1974) in Eureka County consists of a sequence of Jurassic volcanic and volcaniclastic rocks that apparently rests on eroded upper Paleozoic carbonate and Roberts Mountains assemblage rocks. These volcanic rocks, which are intruded by coeval Jurassic hypabyssal intrusive rocks, host the Modarelli and other volcanic-hosted magnetite deposits.

The volcanic rocks in the Excelsior Mountains are silicic and appear to have been emplaced at or near their present site (Speed and Kistler, 1980). They host no important mineral deposits.

The Darrough Felsite, a sequence of silicic ash-flow tuffs and volcaniclastic sedimentary rocks, was previously thought to be Tertiary in age (Speed and McKee, 1976). Brem and others (1991) infer it to be Late Cretaceous or older, because it is intruded by an 89-Ma pluton. No significant mineral deposits are hosted in the Darrough Felsite.

DEFORMATION, METAMORPHISM, AND PLUTONISM

In addition to the Antler and Sonoma orogenies, described in the sections concerning the Roberts Mountains and Golconda assemblages, metamorphism and deformation affected the rocks described above at four distinct times, each accompanied by significant igneous activity (Barton and others, 1988; Miller and others, 1988).

During Triassic time, low-pressure metamorphism affected rocks in western Nevada. This is best documented in Koipato group rocks and related intrusions in the Humboldt Range, and near a few Triassic plutons farther south. It is not known how far to the east this event was active, but there is no direct evidence for Triassic metamorphism in eastern Nevada. Relatively little deformation accompanied this event. Triassic plutons other than those that form part of the Koipato Group are uncommon. The large polymetallic replacement deposits in the Goodsprings district are associated with Triassic plutons (Carr and others, in revision); however, other contemporaneous mineral deposits are more problematical. John and others (1994) found no mineralization associated with Late Triassic plutonism in western Nevada. Wallace (1977) describes Triassic epithermal deposits in the East Range, but Vikre and McKee (1985) postulate Cretaceous ages for deposits emplaced in Triassic rocks in the Humboldt Range.

In the Jurassic, widespread metamorphism peaked near 160 Ma and was accompanied by the development of foliation at intermediate crustal depths. This has been documented in east-central Nevada by Miller and others (1988), and in northeast Nevada by Snoke and Miller (1988). Mid-crustal metamorphism of unknown but probable Jurassic age is widespread in western Nevada, and is locally exhibited in all of the major assemblages there. In contrast to both the earlier Triassic intrusions, and the later Cretaceous ones, Jurassic intrusive rocks have a high proportion of quartz diorites and other more mafic rocks (Barton and others, 1988). The most important ore deposits associated with the Jurassic plutonic-metamorphic event are the porphyry copper deposits at Yerington. Other Jurassic deposits in western Nevada include iron and copper-iron skarns, and copper-bearing polymetallic veins (John and others, 1994). In addition, possible kuroko volcanogenic massive sulfide deposits occur in Jurassic volcanic rocks in the Jackson Mountains.

The Cretaceous was a time of widespread metamorphism, deformation, and plutonism. In east-central Nevada, a west-dipping cleavage was developed that represents the root zone of the Sevier thrust belt (Miller and others, 1988). Plutonic activity was widespread, and many Cretaceous intrusions are emplaced in regionally metamorphosed rocks. Tonalite and quartz diorite are common before 100 Ma; thereafter, metaluminous granodiorite and quartz monzonite are more common (Barton and others, 1988). Near the end of the Cretaceous, peraluminous granites became widespread (Miller and Bradfish, 1980; Barton and others, 1988).

Mineral deposits associated with this event are numerous, although generally of less economic importance than younger deposits. Important exceptions are the porphyry copper deposits at Ruth (Ely), in the Robinson district and the polymetallic replacement deposits at Eureka. Most of the low-F porphyry molybdenum deposits (Buckingham, Hall) are related to Late Cretaceous plutons, as are the important tungsten skarn deposits at Mill City and Potosi. Peraluminous granitic rocks of Late Cretaceous age are associated with tungsten vein deposits, and, at Mineral Ridge, in the Silver Peak district, with gold-bearing quartz veins.

In the middle Tertiary, beginning after 40 Ma and perhaps continuing to the present day, Nevada has been affected by extensive metamorphism and extensional deformation. The best documented area is in east-central Nevada, where Miller and others (1988) document an Oligocene event that reached amphibolite grade. This event is characterized by extreme ductile extension at deep levels and high-angle normal faulting higher in the crust. Similar deformation is occurring today in the Death Valley, California region (Hamilton, 1988). Nevertheless, a statewide change in tectonic style can be noted in the Miocene (McKee and others, 1970; McKee, 1971). Appearance of high-angle normal faults in the style of those active throughout Nevada today signaled a change in style of volcanism. The eruption of primarily intermediate- to silicic ash-flow tuffs that show evidence of extensive crustal involvement in their genesis was replaced by the production of voluminous bimodal basalt and rhyolite lava flows with more direct mantle affinities (McKee and Noble, 1986).

Most of the important mineral deposits of Nevada are Tertiary in age. Many of the largest sediment-hosted gold deposits, including those of the Carlin trend, although hosted in pre-Tertiary rocks, seem to have been formed during the earlier Oligocene episode. An important group of gold- and copper-rich skarn deposits in the Battle Mountain district are related to Oligocene intrusions of intermediate composition. Most of the important volcanic-hosted epithermal deposits, including those at Comstock, Tonopah, and Goldfield, are Miocene in age.

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