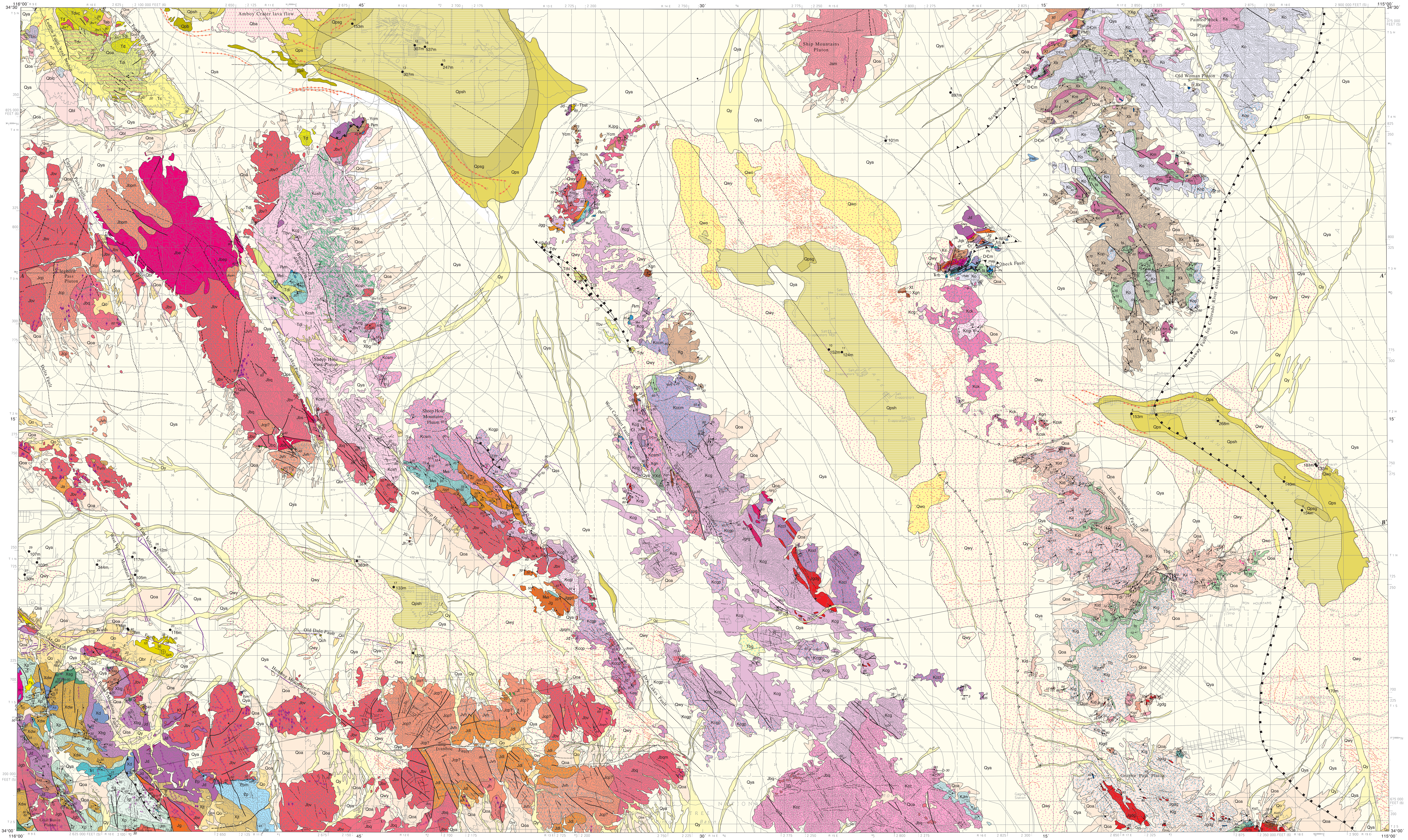

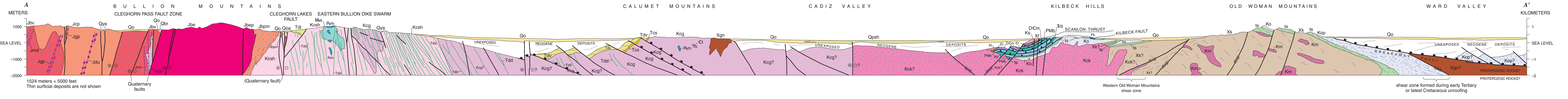

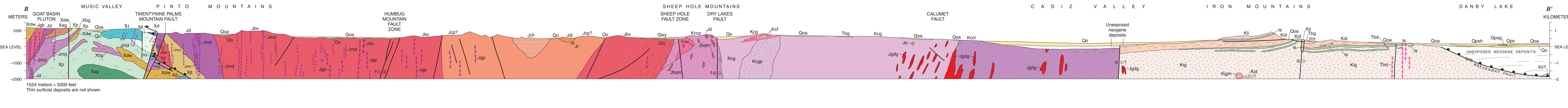

GEOLOGIC MAP OF THE SHEEP HOLE MOUNTAINS 30' x 60' QUADRANGLE, SAN BERNARDINO AND RIVERSIDE COUNTIES, CALIFORNIA

By
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INTRODUCTION

Geologic map units are described briefly on this map, with the expectation that readers seeking detailed descriptions (including contact relations and modal mineral proportions for plutonic units) can consult the source geologic maps listed on the index map (fig. 1). Summary modal diagrams are shown here in Figure 2. Geophysical maps and interpretations are available in Simpson and others (1984), Mariano and others (1986), Frost and Okaya (1986), Mariano and Grauch (1988), and Jachens and Howard (1992). Neumann and Leszcykowski (1993) summarized information on mines and mineral deposits. Discussions and interpretations of the geology are available from the source geologic maps and elsewhere, and are briefly summarized here. The map was prepared in 1994.

NAMES

The map applies new names to structures including the Ivanhoe fault, eastern Bullion dike swarm, Amboy Crater lava flow, Ship Mountains pluton, Cleghorn Pass pluton, Sheep Hole Mountains pluton, and Sheep Hole Pass pluton. I apply pluton names to structural bodies and not necessarily to lithodemes or map units, even though they may largely coincide. For example, the Old Woman pluton is an intrusive body consisting of the formally named Old Woman Mountains Granodiorite. Map units newly named on this map are the Dale Lake Volcanics; Coxcomb Intrusive Suite and its included Sheep Hole Pass Granite, Sheep Hole Mountains Granodiorite, and Clarks Pass Granodiorite; Iron Mountains Intrusive Suite and its included Granite Pass Granite, Danby Lake Granite Gneiss, and Iron Granodiorite Gneiss; Chubbuck Porphyry; Bullion Mountains Intrusive Suite and its included Virginia Dale Quartz Monzonite; and Dog Wash Gneiss. Intrusive suites are proposed on this map in order to group together each of a series of lithodemes that appear to be closely related lithologically, spatially, and temporally. The underlying concept of an intrusive suite is that all the units are in some manner cogenetic and that they are products of a single fusion episode (Bateman, 1992).

GEOLOGIC SUMMARY

The Sheep Hole Mountains quadrangle covers an area of the Mojave Desert characterized by basins and ranges (fig. 3). Alluviated valleys and playas (dry lakes) are as low as 165 m elevation at Cadiz Lake playa (see map of major topographic features). The mountain ranges they separate are as high as 1490 m elevation, for example in the Old Woman Mountains. Rock units are well exposed owing to low rainfall and sparse vegetation.

PROTEROZOIC ROCKS

Proterozoic rocks are found mostly in the eastern and southwestern parts of the quadrangle. They are metamorphosed, and encompass few supracrustal rocks and a variety of plutonic rocks of mostly granitic composition (fig. 2g). Early Proterozoic plutonic and metaplutonic units about 1.7 Ga in age in the Old Woman Mountains and Kilbeck Hills underlie the metamorphosed Cambrian Tapeats Sandstone. Rocks about 1.7 Ga in age are also found in the Pinto Mountains: the Dog Wash Gneiss, which intrudes the unit here called the Pinto Gneiss (part) of Miller (1938), and the granite of Joshua Tree, which nonconformably underlies the quartzite of Pinto Mountain. The quartzite of Pinto Mountain could be as old as Early Proterozoic based on Powell's (1982) suggested correlation with the Pinto Gneiss (part) of Miller (1938), or it could be as young as Late Proterozoic and Early Cambrian if correlative with the Stirling Quartzite. Middle Proterozoic plutonic rocks (approximately 1.4 Ga) are recognized in the Calumet and Old Woman Mountains. The gneiss of Dry lakes valley, of Early or Middle Proterozoic protolithic age, is distinct from other Proterozoic intrusive rocks because it is highly peraluminous.

PALEOZOIC ROCKS

Paleozoic strata metamorphosed to sillimanite grade are found in the northeastern and central parts of the quadrangle. In the Kilbeck Hills and Old Woman Mountains the Paleozoic rocks nonconformably overlie the Fenner Gneiss of Hazzard and Dosch (1937); in the Old Woman Mountains, they probably also overlie the Kilbeck Gneiss although contact relations are obscured by the effects of deformation and metamorphism. The Paleozoic rocks form a distinctive lithologic sequence (Stone and others, 1983) that allows them to be correlated with Cambrian to Permian marine units deposited on the shallow shelf of cratonic North America: the Tapeats Sandstone, Bright Angel Shale, higher Cambrian and Devonian carbonate rocks (including the Bonanza King Formation), Redwall Limestone, Bird Spring Formation, Hermit Shale, Coconino Sandstone, and Kaibab Limestone (Stone and others, 1983).

MESOZOIC ROCKS

Mesozoic rocks consist of scattered metamorphosed supracrustal rocks and large volumes of batholithic rocks. The early Mesozoic Buckskin Formation of Reynolds and Spencer (1989), which is correlative with the Moenkopi Formation, crops out in the Kilbeck Hills where it overlies the Permian Kaibab Limestone. The metasedimentary gneiss of Sheep Hole Mountains is also inferred to represent early Mesozoic strata, but its contact relations are obscure.

The earliest Phanerozoic intrusion in the quadrangle is the Early Triassic quartz monzonite of Twentynine Palms (approximately 240 Ma). This quartz-poor unit (fig. 2f) forms four small bodies in the southwest corner of the quadrangle and is more widepread west of the quadrangle (Rogers, 1961; Dibblee, 1967b, 1968; Trent, 1984). It records the earliest phase of continental arc magmatism related to the newly active western margin of North America. Further intrusive magmatism in Jurassic and Cretaceous time tended to be increasingly more siliceous (fig. 2), and was so voluminous as to displace much pre-existing Proterozoic crust in the quadrangle by Mesozoic batholithic rocks.

Numerous Jurassic plutons were emplaced in the western part of the quadrangle. They embrace a wide range of compositions from gabbro to syenogranite (figs. 2d,e), and also a range of emplacement depths. Rocks in the Goat Basin and Music Valley plutons in the southwest corner of the quadrangle contain euhedral epidote suggestive of crystallization at high pressure, and therefore, deep emplacement. Aluminous hornblende compositions in an unspecified Jurassic dike rock in the Kilbeck Hills also suggest moderately high-pressure emplacement (corresponding to depths of approximately 16 km; Foster and others, 1992). Shallow mesozonal or hypabyssal emplacement is indicated for other plutons such as the Cleghorn Pass pluton and Ship Mountains pluton. The Jurassic Dale Lake Volcanics appear to represent eruptive products associated with the voluminous Bullion Mountains Intrusive Suite. This Jurassic suite (approximately 160 Ma) encompasses rock units most of which contain lavender alkali feldspar; representative modal compositions are indicated in Figure 2d. Swarms of mafic dikes and granite prophyry dikes in the western part of the quadrangle are probably part of the Late Jurassic Independence dike swarm described by Chen and Moore (1979), Karish and others (1987), and James (1989).

Nonmarine deposition in the Jurassic(?) and Cretaceous is represented by the McCoy Mountains Formation of Miller (1944), present in the Coxcomb Mountains in the south-central part of the quadrangle. This unit was intruded and metamorphosed by Late Cretaceous plutons.

Late Cretaceous (approximately 70 Ma) plutonic rocks dominate the eastern two-thirds of the quadrangle, forming parts of two coeval and similar batholiths. The Old Woman-Piute Range batholith (Miller and others, 1990) crops out in the northeast part of the quadrangle and farther north in the Old Woman Mountains and Piute Mountains (fig. 2c). It consists chiefly of metaluminous granodiorite and peraluminous granite described by Miller, Howard, and Hoisch (1982), Miller and others (1990), and Foster and others (1989, 1992). Hornblende compositions suggest that the granodiorite was emplaced at estimated pressures corresponding to depths of approximately 15–19 km (Foster and others, 1992). The Cadiz Valley batholith underlies much of the central part of the quadrangle and areas south of the quadrangle (John, 1981). It encompasses granite and granodiorite here divided into two intrusive suites closely similar in composition and age, the Iron Mountains Intrusive Suite (fig. 2b) and the Coxcomb Intrusive Suite (fig. 2a). By means of geobarometric study, Anderson (1988) concluded that intrusion of rocks in the Iron Mountains Intrusive Suite was shallow, at an estimated pressure corresponding to approximately 6–8 km depth. The Cretaceous rocks have been further discussed by Miller and others (1981), Miller, Howard, and John (1982), Calzia (1982), and Calzia and others (1986).

CENOZOIC ROCKS AND DEPOSITS

Early Miocene basalt, dacite, and clastic units in the western part of the quadrangle form the stratigraphically lowest Tertiary deposits. Regional relations indicate that they are associated with an episode of tectonic extension. Early Miocene dacitic intrusions include a laccolith in the Iron Mountains, a subvolcanic stock intruded into a dacitic volcanic carapace at Lead Mountain, and the eastern Bullion dike swarm.

Younger Neogene deposits include Miocene and (or) Pliocene conglomerate and gravel units in the west part of the quadrangle. Sedimentary breccia of Miocene and (or) Pliocene age occurs in several patches isolated from its source materials and may represent landslides associated with strike-slip faulting. The basalt of Deadman Lake volcanic field in the northwest corner of the quadrangle and rocks of the remainder of the Deadman Lake volcanic field west of the quadrangle are assigned a late Pliocene age based on correlation with basalt at Dish Hill north of the quadrangle, which was dated as 2 Ma (Wilshire and Nielson-Pike, 1986). Two Quaternary basalt flows lie nearby, the basalt of Lead Mountain and the younger basalt of Amboy.

Basin deposits beneath the present valleys have been explored by scores of shallow drill holes and by 29 holes deeper than 100 m (table 1). Smith (1960, 1970) described faunal assemblages characteristic of brackish water, recovered from depth under Cadiz and Danby Lakes, which form a basis for correlating the subsurface sediments containing them with the Bouse Formation. This Pliocene unit is exposed east of the quadrangle and was deposited in lakes and (or) an estuarine proto-gulf of California (Metzger, 1968; Lucchitta, 1979; Spencer and Patchett, 1997). Below Bristol Lake, Rosen (1989) found that cored sediments indicative of persistent playa environments are interbedded with six tephra layers as old as 3.7 Ma. This indicates that playa environments rather than lacustrine environments have prevailed at the sites of the dry lakes since Pliocene time.

Playa deposits occupy the surface of four large dry lakes in the quadrangle, as well as five smaller basins. Evaporite deposits in the larger playas have provided major resources of brine and salt (Ver Plank, 1958; Calzia, 1992; Gundry, 1992). Quaternary alluvial units intervene between the playas and the ranges and include wide expanses of Holocene alluvium. Late Pleistocene faunas were described by Reynolds and Reynolds (1992). Perched or dissected old Pleistocene alluvium and associated sandstone and breccia crop out adjacent to range fronts and along faults; a Rancholabrean vertebrate faunal assemblage (Jefferson, 1992) and an ash bed correlated with the 0.7-Ma Bishop Tuff (Bacheller, 1978) have been described from the southwest corner of the quadrangle. Windblown sand reworked from alluvial and playa deposits forms extensive dune fields and sand sheets in the basins and locally climbs onto the highlands. Windblown sand near Dale Lake has been tentatively dated as 5 to 60 ka in age (Tchakerian, 1992). Many of the dune fields are active.

STRUCTURAL EVOLUTION

The Early Proterozoic Ivanpah orogeny associated with plutonism produced pervasive foliation and mineral assemblages of high amphibolite to granulite facies in nearby regions (Wooden and Miller, 1990; Foster and others, 1992). The details of this orogeny are obscure within the quadrangle, but much of the fabric and mineral assemblages in the exposed Proterozoic rocks likely date from this era. Early Proterozoic events in the San Bernardino Mountains area a few tens of kilometers west of the quadrangle were discussed by Barth and others (2000).

Following Proterozoic erosion, marine Cambrian sandstone and younger Paleozoic strata were deposited unconformably over Proterozoic plutonic and metamorphic rocks. Crustal stability prevailed until the earliest Triassic when plutonism began in the west, followed by pre-Jurassic metamorphism and ductile deformation of the Permian or Triassic intrusions and surrounding rocks in the Pinto Mountains.

Jurassic volcanic rocks and elongate plutons in the western and southern parts of the quadrangle form part of a long NW–SE belt of Jurassic igneous rocks in the southwestern Cordillera. Where the belt narrows just southeast of the quadrangle could be a place to look for disruption related to a Jurassic sinistral Mojave-Sonora megashear postulated by Silver and Anderson (1974). Cretaceous intrusions obscure the critical eastern part of the Jurassic igneous belt.

The N to NNW strike of Jurassic dike swarms that are present in mountain ranges in the southwest part of the quadrangle suggest that they were emplaced during approximately E–W or ENE–WSW extension in the Late Jurassic. Their original orientation is less certain because the ranges in which they occur may have been rotated during Neogene events (Carter and others, 1987).

In the northeastern part of the quadrangle, a regionally developed Mesozoic ductile fault (tectonic slide in the sense of Hutton, 1979), the Scanlon thrust, places an inverted sequence of early Paleozoic strata and their Proterozoic basement over younger Paleozoic and Triassic rocks (Miller, Howard, and Hoisch, 1982; Howard and others, 1987). Present evidence suggests that the upper plate moved west. The lower plate Paleozoic and Triassic rocks in turn are internally sliced and folded (Horringa, 1989) and ductilely faulted down over highly strained tectonic schist derived from Proterozoic protoliths. I use the term "tectonic schist" in the sense of Hutton (1979) to describe highly foliated rocks in a zone of high strain. The lower tectonic slide (ductile fault), here termed the Kilbeck fault, attenuates crustal section and so may be a lag fault. Relative and absolute timing of the two major tectonic slides and associated fabrics remain uncertain, but they are cut by the Old Woman pluton and other Late Cretaceous batholithic rocks.

Tectonic schist also formed at lower structural levels as envelopes that separate subhorizontal tonguelike sheet intrusions of the Old Woman pluton from its Proterozoic host, the Kilbeck Gneiss. The Kilbeck Gneiss shows evidence of ultrametamorphism and partial melting during the Late Cretaceous events (Miller, Howard, and Hoisch, 1982; Howard and others, 1989b).

The Cretaceous Cadiz Valley batholith was intruded as plutons elongated chiefly NW–SE, as were the Jurassic plutons. Intrusion recrystallized and foliated a western aureole approximately 2–3 km wide in older rocks. In the southeast part of the batholith in the Iron Mountains, early-intruded parts of the batholith, together with intervening screens of Proterozoic rocks that became tectonic schist, were mylonitized throughout a thickness exceeding 1.3 km in a subhorizontal roof zone above younger undeformed parts of the batholith (Miller and others, 1981; Miller and Howard, 1985). Sense of shear in mylonitized Cretaceous granite (Danby Lake Granite Gneiss), where measured, is top to the ENE. Miller and others (1981) suggested a possible diapiric model to explain this synplutonic deformation in the Iron Mountains. More locally developed mylonitic rocks exhibiting a similar NE strike of lineation are found to the west in Cadiz Valley, the northern Coxcomb Mountains, and the Sheep Hole Mountains (Howard and others, 1982).

To the north in the Old Woman Mountains, local Late Cretaceous mylonitization immediately followed plutonism and was associated with extensional unroofing and rapid cooling (Foster and others, 1991, 1992). The mylonitic fabrics record shear down to the west off the west flank of the range (Western Old Woman Mountains shear zone of Carl and others (1991) near the northern quadrangle border), and shear down to the ESE off the southeast flank of the range (Howard and others, 1989b).

Aplitic dikes and mineralized joints that cut mylonitized Cretaceous rocks in several ranges are dated as latest Cretaceous or earliest Tertiary in age (Howard and others, 1982; Miller and Howard, 1985). They mostly strike northwest, indicating NE–SW orientation of least principal stress at the end of plutonism.

Following denudation in the early Tertiary, the onset of volcanism in the early Miocene coincided with major tectonic extension in the Mojave Desert. Evidence for this extension is best displayed in areas east and west of the quadrangle (for example, Davis and Lister, 1988; Howard and John, 1987; Dokka, 1989). In the quadrangle, westward downtilting associated with the extension is recorded by steep west stratal dips of early Miocene rocks in the western Calumet Mountains and is suggested also by the moderate NNE dip of the early Miocene East Bullion dike swarm in the eastern Bullion Mountains. Cross section *A–A′* interprets extensional structural style between these localities. Gently east-dipping extensional faults are exposed in the eastern Sheep Hole and Pinto Mountains and imaged seismically below Ward Valley (Frost and Okaya, 1986). In cross section *A–A′*, I infer a style of concealed half grabens under the valleys to be consistent with unmigrated industry seismic reflection profiles (D.A. Okaya, unpub. data).

In late Neogene and Quaternary time, strike-slip faults that are part of the eastern California shear zone displaced rocks in western parts of the quadrangle (Howard and Miller, 1992; Richard, 1993). East-striking faults (in the Pinto Mountains) are sinistral, and NW-striking faults are dextral (Dibblee, 1961, 1967a; Hope, 1966; Jagiello, 1991). Ranges and basins in the quadrangle may owe their forms largely to transpression and transtension between the moving and rotating strike-slip fault blocks (Simpson and others, 1984; Jagiello and others, 1992; Jachens and Howard, 1992; Richard, 1993). Large rotations are expected between the Pinto and Bullion Mountains based on models of bookshelf faulting and regional paleomagnetic studies (Carter and others, 1987; Luyendyk, 1991; Dokka and Travis, 1990; Richard, 1993). However, Jurassic dike swarms in these two ranges have unexpectedly similar strikes, a finding that may accord better with small relative rotation (approximately 20°) predicted by Powell's (1993) palinspastic model.

A slickensided surface was encountered in drilling of probable Quaternary deposits under Cadiz Lake (Bassett and others, 1959; Howard and Miller, 1992). The presence of this concealed fault suggests that other Quaternary faults could be concealed by the widespread Holocene deposits in Bristol Lake, Cadiz, and Danby Lake valleys. Faults exposed in the east and central parts of the quadrangle last moved in the early Pleistocene, whereas the Valley Mountain faults in the southwest part of the quadrangle cut deposits assigned to the Holocene (Howard and Miller, 1992). This concentration of youngest fault activity to the southwest accords with a southwestward increase in seismicity (Goter, 1992).

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