Preliminary Geologic Map of the Oakdale 30’ × 60’ Quadrangle, California

Scale 1:100,000

By

Chris J. Wills, Matt D. O’Neal, Peter J. Holland, Benjamin M. Parrish, Erica L. Key and Marc P. Delattre

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California
Department of Conservation
California Geological Survey

Preliminary Geologic Map 22-09

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Table of Contents

Plate

Preliminary Geologic Map of the Oakdale 30' × 60' Quadrangle, California

List of Figures

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Introduction

The Oakdale 30’ x 60’ Quadrangle covers 4,892 km² (1,889 mi²) of San Joaquin, Stanislaus, Calaveras, Tuolumne, Mariposa, and Merced Counties, California (Fig. 1). The map area extends 88 km (55 mi) east-west and 55 km (34 mi) north-south. Elevations range from 9 m (30 ft) where the Tuolumne River drains west out of the quadrangle through Modesto, to as high as 1,779 m (5,835 ft) in the Sierra Nevada east of Sonora. Physiographic features of the Oakdale 30’x 60’ Quadrangle include relatively flat agricultural land in the San Joaquin Valley, rolling grasslands in the lower foothills of the Sierra Nevada, and deep canyons and rugged slopes in the western Sierra. Early settlement of California was driven in part by gold found within the Mother Lode belt, which crosses the map area. Other geologic resource studies have focused on limestone and other carbonate rocks and sources of construction aggregate.

Geologic hazards in the area include landslides in some of the weaker rock units and steeper slopes, potential seismic hazards associated with the Foothills fault system, and naturally occurring asbestos and potential sources of radon gas in some of the rock units. This geologic map is intended to illustrate the distribution of the rocks and surficial deposits of the area and their structural and stratigraphic relations to one another. It provides a regional geologic framework as an aid to support evaluations of the potential for geologic resources and hazards. As a compilation product, it includes some areas mapped in greater detail than others. No part of it, however, is sufficiently detailed to serve as a basis for site-specific evaluations but may serve as the basis for more detailed characterizations.

Development of Geologic Map Database

The map has been compiled from many scientific studies in different parts of the quadrangle and represents the work of many geologists. Compilation of the Oakdale 30’ x 60’ Quadrangle builds on a compilation by Higgins (1997) for mineral resources evaluation, and a digital compilation of bedrock mapping covering National Forest lands in California by the U.S. Forest Service (Pacific Southwest Region Bedrock GIS Compilation Mapping).

For those compilations, paper copies of existing geologic maps were scanned and converted into digital lines and polygons using Geographic Information System (GIS) software. The most detailed and accurate maps of a particular area were digitized. One problem encountered in creating this seamless geologic map was that geologic interpretations did not always match from areas mapped by different authors. Reasons for the discrepancies include differences in mapping styles and emphasis on different geological hazards, resources, or features. Some geologists have been focused on mapping a particular aspect of the geology – crystalline bedrock for example – with less detail or concern for mapping other units. Other inconsistencies included different terminology in naming geologic units and faults, drafting errors, and accuracy issues. Although the source maps have been accurately digitized, mapping errors by the original authors still exist. These typical compilation issues are compounded in the Sierra Nevada foothills by evolving tectonic concepts. Older maps of bedrock areas in the foothills were prepared before

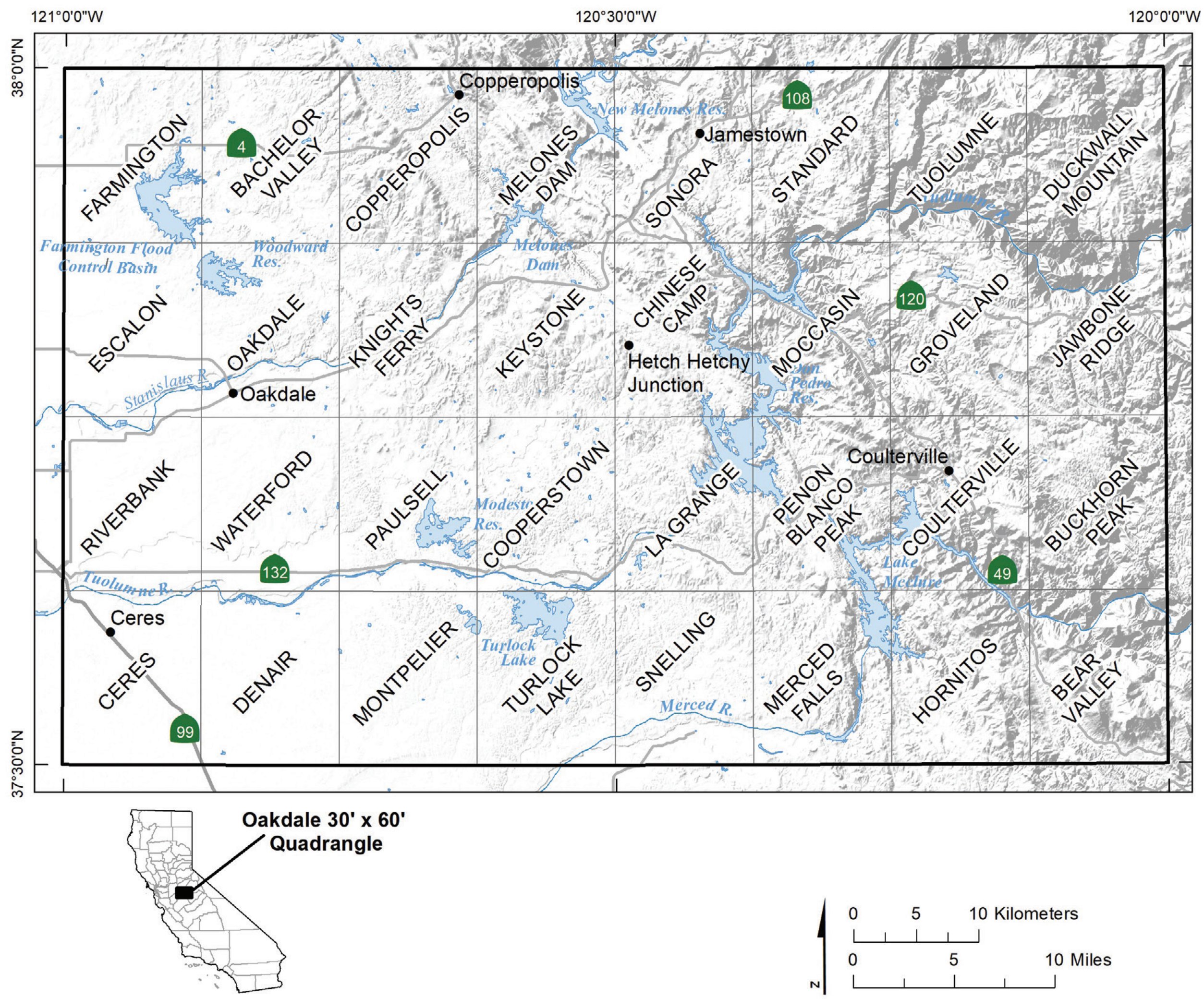

Figure 1. Map showing the location of the study area, and index of 7.5’ quadrangles within the Oakdale 30’x60’ Quadrangle. DEM from U.S. Geological Survey

the development of plate tectonics and the concept of exotic terranes. Mélange, a very common rock type formed in subduction zones and found in areas of intense shearing, was not recognized when some maps used in this compilation were prepared.

Geologic unit names and descriptions used in this compilation attempt to reflect current tectonic concepts as well as the rock descriptions from older mapping. Mapping of Quaternary units in the western part of the Oakdale 30’ x 60’ Quadrangle initially followed the mapping and methodology developed by Denis Marchand and co-workers at USGS (Marchand and Allwardt 1981, and specific maps listed below), and was later revised with the aid of lidar and fieldwork.

Compiled geologic mapping was assimilated, and boundary discrepancies were resolved to create seamless digital geologic map layers in GIS. Compiled mapping was checked and revised primarily using lidar-based topographic data and field-based observations. Where discrepancies were found between the compiled mapping and lidar topography / geomorphology or field observations, lidar and field-based interpretations were favored. These revisions were constrained in part by limitations to land access (and thus field observations) and lidar quality and coverage. This Preliminary Geologic Map was prepared as a GeMS Level 3 compliant geodatabase according to the U.S. Geological Survey's requirements. Generalization processes were performed to combine geologic contacts and features below the minimum map unit size for 1:100,000 scale and include merging / generalization of map sub-units.

Sources of Geologic Mapping

The major sources of geologic mapping used in this compilation are listed below by 7.5' quadrangle (Fig. 1):

Bachelor Valley: Marchand and others, 1981b (1:24,000).

Bear Valley: Bowen, 1969 (1:62,500); Herzig and Sharp, 1992 (approximately 1:10,000).

Buckhorn Peak: Bowen, 1969 (1:62,500); Herzig and Sharp, 1992 (approximately 1:10,000).

Ceres: Marchand, 1980 (1:24,000).

Chinese Camp: Morgan, 1976 (1:24,000); Woodward-Clyde Consultants, 1978 (scale undetermined).

Cooperstown: Woodward-Clyde Consultants, 1978 (scale undetermined); Marchand and others, 1981a (1:62,500).

Copperopolis: Taliaferro and Solari, 1948 (1:62,500); Bartow and others, 1981 (1:62,500); Woodward-Clyde Consultants, 1978 (scale undetermined).

Coulterville: Bowen, 1969 (1:62,500); Evans and Bowen, 1977 (1:24,000); Bogen, 1983 (1:24,000).

Denair: Marchand, 1980 (1:24,000).

Duckwall Mountain: Merguerian, 1981 (1:24,000).

Escalon: Arkley, 1964 (scale undetermined); McElhiney, 1992 (scale undetermined); Rule, 2007 (scale undetermined).

Farmington: Marchand and others, 1981b (1:24,000).

Groveland: Evans and Bowen, 1977 (1:24,000); Merguerian, 1981 (1:24,000).

Hornitos: Bowen, 1969 (1:62,500); Bogen, 1983 (1:24,000).

Jawbone Ridge: Merguerian, 1981 (1:24,000).

Keystone: Taliaferro and Solari, 1948 (1:62,500); Woodward-Clyde Consultants, 1978 (scale undetermined); Bartow and others, 1981 (1:62,500).

Knights Ferry: Taliaferro and Solari, 1948 (1:62,500); Woodward-Clyde Consultants, 1978 (scale undetermined); Bartow and others, 1981 (1:62,500).

La Grange: Mannion, 1960 (1:24,000); Woodward-Clyde Consultants, 1978 (scale undetermined): Marchand and others, 1981a (1:24,000).

Melones Dam: Taliaferro and Solari, 1948 (1:62,500); Bartow and others, 1981 (1:62,500); Woodward-Clyde Consultants, 1978 (scale undetermined).

Merced Falls: Marchand, 1981 (1:24,000); Barry, 1993 (1:24,000).

Moccasin: Morgan, 1976 (1:24,000); Evans and Bowen, 1977 (1:24,000); Woodward-Clyde Consultants, 1978 (scale undetermined); Bogen, 1983 (1:24,000).

Montpelier: Marchand, 1980 (1:24,000).

Oakdale: Arkley, 1964 (scale undetermined); Rule, 2007 (scale undetermined).

Paulsell: Arkley, 1964 (scale undetermined).

Peñon Blanco Peak: Woodward-Clyde Consultants, 1978 (scale undetermined); Bogen, 1983 (1:24,000); Barry, 1993 (1:24,000); Higgins, 1997 (1:110,000).

Riverbank: Arkley, 1964 (scale undetermined).
Snelling: Marchand, 1981 (1:24,000).
Sonora: Eric and others, 1955 (1:24,000); Woodward-Clyde Consultants, 1978 (scale undetermined).
Standard: Hart, 1959 (1:24,000); Higgins, 1997 (1:110,000).
Tuolumne: Merguerian, 1981 (1:24,000), Higgins, 1997 (1:110,000).
Turlock Lake: Marchand and Wagner, 1980 (1:24,000).
Waterford: Arkley, 1964 (scale undetermined).

Regional Geology

The Oakdale 30’x 60’ Quadrangle (Fig. 2 and Plate 1) spans the boundary between the Great Valley and Sierra Nevada physiographic provinces (Jenkins, 1938; Norris and Webb, 1990, CGS, 2002). In a regional tectonic context, the map area is within the Sierra Nevada microplate. This is an area of relative seismic quiescence compared to the Coast Ranges to the west and the Basin and Range to the east. Differential slip between the Pacific and North American plates is accommodated mostly by the San Andreas Fault system to the west (Le Pourhiet and Saleeby, 2013). Within the quadrangle, the Great Valley province is underlain by gently dipping sedimentary rocks and surficial deposits ranging in age from Eocene to Quaternary, which overlie Mesozoic metamorphic and plutonic basement rocks at depth. The Sierra Nevada province within the quadrangle is dominated by Mesozoic and Paleozoic metamorphic and plutonic basement rocks, with a discontinuous cover of Cenozoic sedimentary and volcanic rocks. The Cenozoic rocks consist largely of erosional remnants of once-continuous volcanic flows, lahars, and fluvial sediments deposited in paleo-river channels that once flowed across the range with an approximate east to west course, and now form inverted topography as resistant caps on hills and ridges. Quaternary surficial deposits of alluvium along modern streams, alluvial fans, and landslides are present locally, but are sometimes too small to be shown at map scale.

Basement rocks in the quadrangle record assembly of California at the western edge of the North American continent from late Paleozoic through Jurassic time. The oldest rocks may represent sedimentation on the continental slope, but later units represent subduction zones, island arcs, slivers of continental rock, and fragments of oceanic crust and mantle that were accreted to North America in Mesozoic time. Some structural blocks may represent distinct terranes (exotic terranes) that formed far from North America and from each other and are now separated by major faults. There is not a complete understanding, or consensus among workers on the locations of various terranes or their boundaries, but the locations and ages of geologic units and faults are well enough known that they can be described from oldest to youngest. Geologic descriptions of major units in the following section are modified from Higgins (1997) and other sources as listed.

Shoo Fly Complex

The Shoo Fly Complex is composed dominantly of quartzite, quartz-mica schist, phyllite, calc-silicate rock, marble, and amphibolite, all of Paleozoic age (Sharp, 1984; Merguerian, 1985a, 1985b; Bhattacharyya, 1986; Girty and others, 1996, Schweickert, 2015). The Shoo Fly locally may include gneissic plutonic rock of Paleozoic age and has been intruded by Mesozoic plutonic rock of the Sierra Nevada Batholith (Merguerian and Schweickert, 1987). The highly metamorphosed rocks represent clastic sediments derived, at least in part, from continental material and deposited in a continental slope or trench setting, mainly by density currents (Girty and others, 1996).

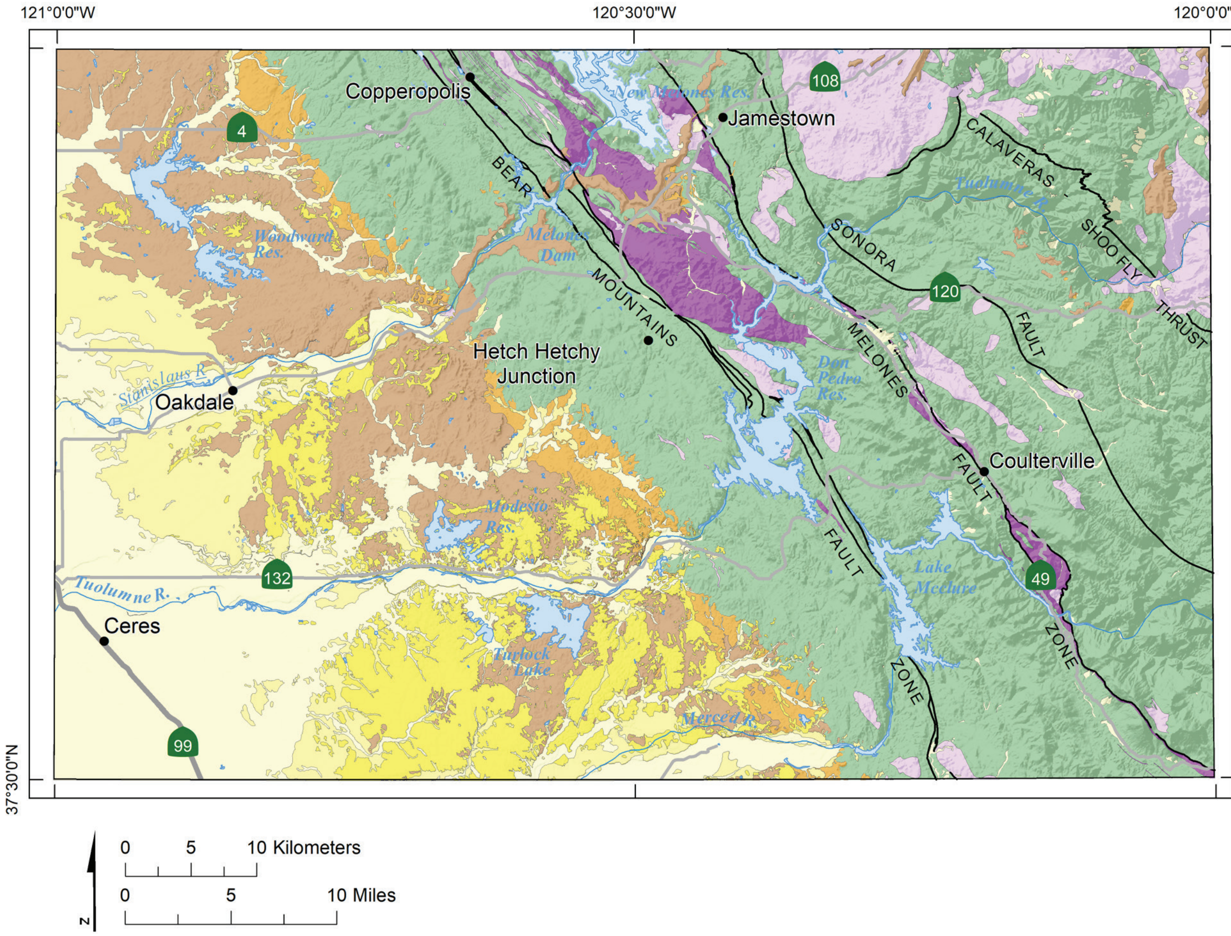

Figure 2. Generalized geologic setting of the Oakdale 30’ x 60’ Quadrangle. Major faults are labelled. Geologic units are colored as follows: purple = ultramafic rocks; green = metasedimentary and metavolcanic rocks; pink = plutonic rocks; orange = Eocene-early Miocene rocks; brown = Miocene-Pliocene deposits; yellow = mid-later Pleistocene deposits; light tan = latest Pleistocene-Holocene deposits; light-yellow = Holocene alluvial sediments; blue = water.

Calaveras Complex

The Calaveras Complex consists of argillite, phyllite, fine-grained schist, and metachert, with local exposures of marble and amphibolite. The protoliths of these metamorphic lithologies largely originated as deep ocean basin deposits (Sharp, 1984). The marble may represent limestone originally formed on seamounts, while the amphibolite is thought to represent metamorphosed volcanic rocks from seamounts (Sharp, 1984). The current mixture is described as a mélange (Bhattacharyya, 1986) with the intense deformation and lack of internal stratigraphy representing soft sediment deformation and submarine landsliding as the unit was deposited, and further disruption as the unit was deformed during subduction and accretion. Fossils from blocks within the assemblage indicate a Paleozoic to Triassic age for the protoliths, but the complex itself was formed in Triassic to Jurassic time.

Ultramafic Rock and Rocks Originally Deposited on Oceanic Crust

West of Chinese Camp, a large body of ultramafic rock, known as the Tuolumne ultramafic complex, underlies the Red Hills and surrounding areas (Morgan, 1976). The Tuolumne ultramafic complex probably represents a fragment of the mantle from the oceanic plate below the ancestral Pacific basin. It includes large areas of relatively unaltered dunite as well as blocks of wehrlite and harzburgite (Figure 2), all partly altered to and surrounded by sheared and altered serpentinite. Serpentinite, with some blocks of harzburgite, are also distributed along the Melones and Bear Mountains fault zones northwest and southeast from the Tuolumne ultramafic complex. Landefeld (1990) considered many of these masses to be serpentinite matrix mélange, which encloses blocks of exotic rock, and formed as tectonic discontinuities within an accretionary prism. Others (Woodward-Clyde Consultants, 1978) interpreted at least some of them as chaotic assemblages deposited by submarine landslides. In either case, serpentinite represents rocks originally formed in the mantle, in which the original fabric has been destroyed by later alteration and shearing.

Overlying the Tuolumne ultramafic complex and probably representing the oceanic crust and sediments deposited in the deep ocean is the Jasper Point Formation, consisting of basalt overlain by radiolarian chert (Bogen, 1983). The Jasper Point Formation is overlain by island arc volcanic rocks of the Peñon Blanco Formation. The Jasper Point and Peñon Blanco Formations form a large, relatively intact stratigraphic sequence that is folded around the Cotton Creek anticline, which forms the distinctive pattern of outcrops southeast of Don Pedro Reservoir and east of Lake McClure.

Sullivan Creek Terrane / Don Pedro Terrane

Between the western edge of the Melones Fault Zone and the Calaveras Complex to the east, bedrock units have been designated as the Sullivan Creek Terrane by Sharp (1984, 1988) and as the Don Pedro Terrane by Schweickert (2015). Sharp (1984) describes the metavolcanic rocks here as including pillow structures, breccia, and poorly sorted thick beds of tuff and tuff breccia. Sharp (1984) and Herzig and Sharp (1992) describe the metasedimentary rocks of the Sullivan Creek Terrane as argillite with coarse siltstone and fine sandstone with blocks of limestone and greenstone, representing sedimentation on oceanic crust with much of the sediment derived from an island arc. The original sediments and tectonic setting of these rocks is very similar to the Calaveras Complex, and different geologists have developed different interpretations of their origin and correlation. Schweickert shows the western contact of the Calaveras Complex as a major terrane-bounding thrust fault: the Sonora fault. Herzig and Sharp (1992) consider the western part of the belt of metasedimentary rocks mapped by Schweickert as the Calaveras Complex to be part of the Sullivan Creek Terrane and the Sonora fault to be a lithological contact within that terrane. In this compilation, we have attempted to preserve as much as possible of both interpretations, to allow later geologists to evaluate the evidence for either. To show this, the eastern Sullivan Creek Terrane (where it could also be the western Calaveras Complex) is shown as queried and the Sonora fault is shown as inferred.

The Sullivan Creek terrane as mapped by Herzig and Sharp (1992) also includes metavolcanic rocks representing fragments of a volcanic arc. These have been named the Bullion Mountain sequence and include metasedimentary rocks similar to other Sullivan Creek Terrane metasedimentary rocks. These metavolcanic rocks were previously mapped as the Peñon Blanco volcanics by Bowen (1969) and described as similar to the Logtown Ridge Formation by Herzig and Sharp (1992).

Middle to Late Jurassic Metasedimentary and Metavolcanic Rocks

Overlying the Peñon Blanco Formation and Sullivan Creek Terrane are metasedimentary and metavolcanic rocks of middle to late Jurassic age. This sequence has metavolcanic rocks at its base, overlain by metasedimentary rocks, and further overlain locally by another unit of metavolcanic rocks. The basal metavolcanic rocks represent a volcanic arc or arcs. These are called the Logtown Ridge Formation east of the Bear Mountains Fault Zone and the Gopher Ridge Volcanics to the west (Clark, 1964). The overlying metasedimentary rocks are similarly called the Mariposa Formation east of the Bear Mountains Fault Zone and the Salt Springs Slate to the west. The Copper Hill Volcanics overlie the Salt Springs Slate.

The metasedimentary rocks represent sand, silt and clay deposited in a deep ocean basin, with the coarser sediments derived from turbidity currents. The metavolcanic rocks represent island arc deposits. The differing names for these stratigraphically similar units were applied to distinguish subtle differences in lithology, including more felsic volcanic rocks within the Gopher Ridge volcanics than in the Logtown Ridge volcanics and more greywacke and conglomerate in the Mariposa than the Salt Springs Slate, as described by Clark (1964). The continuing use of these two sets of unit names allows for the possibility that the rocks separated by the Bear Mountains Fault Zone may have formed independently and have been juxtaposed by later fault movement. One endmember of such an interpretation is advanced by Schweickert and others (2015), who interpret the Logtown Ridge Formation as being derived from a different island arc from the Gopher Ridge and Copper Hill Volcanics.

Plutonic Rocks

The plutonic rocks that occur in the quadrangle have one of two general origins. There are plutonic rocks which represent the intrusive components of the island arcs and accreted terranes (such as the Chinese Camp pluton (Saleeby, 1982)) and there are plutonic rocks associated with the Sierra Nevada batholith (Saleeby and Sharp (1980) and Bateman (1992). Several of the plutons in the area were emplaced in the Late Jurassic (ca 150 Ma), the same time that the Bear Mountains Fault Zone was active (Paterson and Sharp, 1991). Later plutons mapped farther south were emplaced ca 120 Ma, and are undeformed, indicating that accretion and deformation of the metamorphic belts was essentially complete by that time. Where numerical ages are reported for plutonic and metamorphic rocks we have included the uncertainties as reported by the authors, and where no uncertainties were reported, none are included here.

Quartz-Vein Systems and Hydrothermally Altered Rock

Zones of quartz veins and hydrothermally altered rock with associated lode gold deposits spurred the California Gold Rush era settlement and development of this region. Because of their small size, only a few quartz veins are shown on the map. They represent the loci of gold-bearing hydrothermal systems, which were active at different times and intensities during the Mesozoic. They are most common in the area that includes the Melones Fault Zone, Sullivan Creek terrane, Calaveras Complex, Standard Pluton, and part of the Shoo Fly Complex. See the following Economic Geology section for more information.

Paleogene to Neogene Sedimentary and Volcanic Rocks

Paleogene to Neogene sedimentary and volcanic rocks were deposited in ancient river channels cut into and flowing over the igneous and metamorphic bedrock of the map area (described above). These rocks are now exposed as erosional remnants of the ancient channel deposits, with younger (Quaternary river systems incising below the elevation of the Tertiary channels. In the higher elevations of the map area, these rocks are present as isolated remnants which approximately trace the course of these ancient river channels. In the lower elevations, at the foothills-valley transition, these deposits outcrop somewhat more extensively and are onlapped by the younger Pliocene to Quaternary deposits (described in the next section). Three rock units, distinct in age and composition, were deposited in these river channels.

The oldest Cenozoic units in this area are the Eocene gravels and the Ione Formation. Sediments of the Ione Formation were deposited in a fluvial-deltaic-estuarine environment during the Eocene, and the distribution of Ione Formation outcrops approximately represents the shoreline at this time. The Ione Formation has been an important source of kaolin clay, especially north of the quadrangle in Amador County. The coarser-grained gravels deposited upstream of the Ione Formation sediments, in higher-energy river channels, may represent a longer period of deposition spanning from the early Eocene to the earliest Oligocene. These sediments, here referred to as Eocene gravels, have also been somewhat loosely referred to by earlier workers as Tertiary gravels, pre-volcanic gravels, and auriferous gravels. They are distinct from the Ione Formation in being generally coarser grained and having a broader compositional range (including some materials with lower compositional maturity than that of the Ione) and are distinct from the younger Tertiary deposits (described below) in containing no Cenozoic volcanic material. Among the Cenozoic deposits, these sediments host the highest concentrations of placer gold and were the primary target of historic hydraulic and drift mining in the Sierra Nevada.

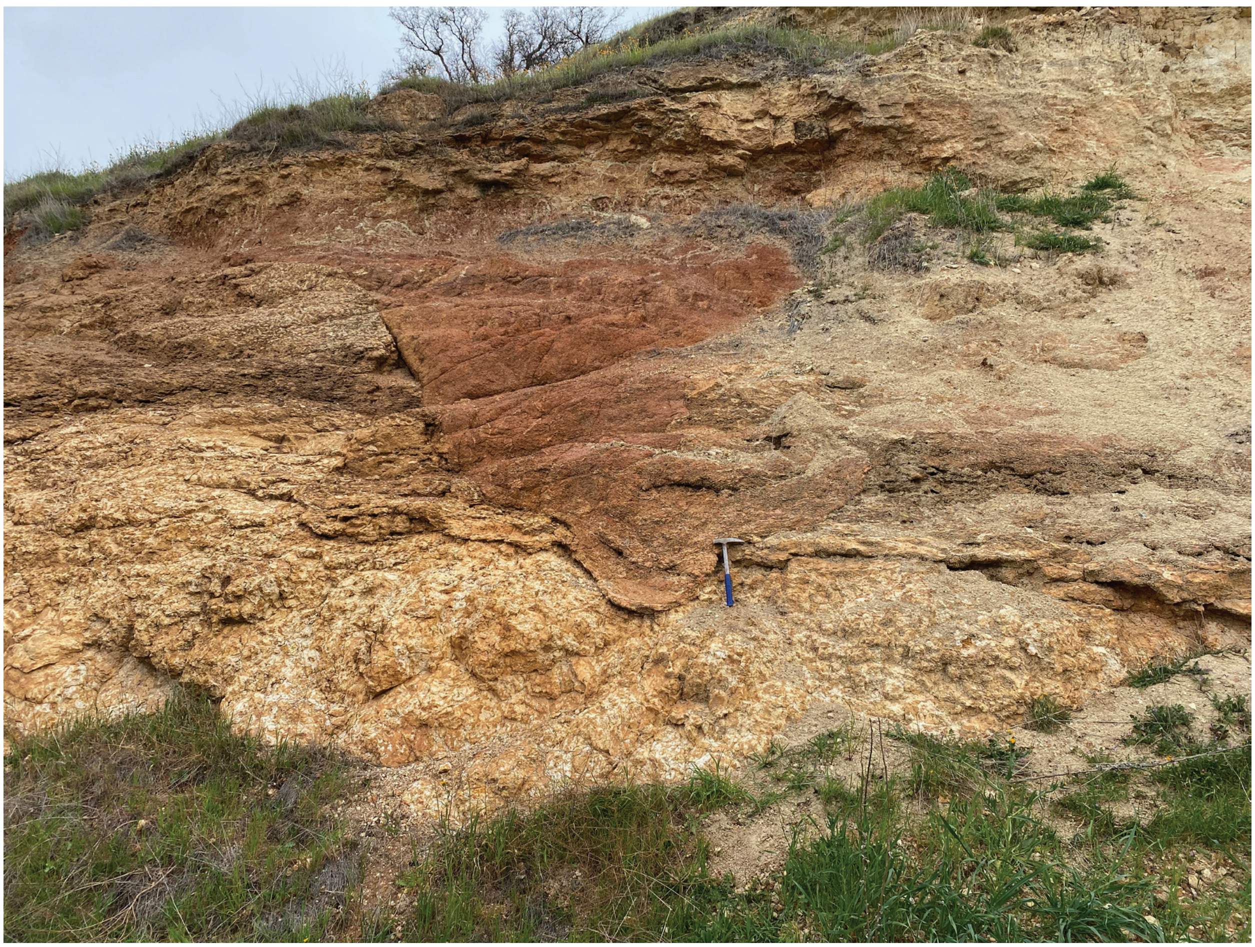

Figure 3. Contact between red (oxidized) Ione sandstone and altered (kaolinitized) bedrock. Rock hammer spans the contact, which is a buttress unconformity. Younger Valley Springs Fm. sediments cap both Ione sandstone and bedrock.

Overlying the above-described sediments is the Valley Springs Formation, consisting of sandstone, siltstone and conglomerate interbedded with altered volcanic ash-flow tuffs. These Oligocene-Miocene sedimentary and volcanic deposits represent sediment deposition in river systems, and intermittent deposition of channelized volcanic ash flows (pyroclastic density currents) within the same channel network. These river channels extended far to the east, with their headwaters in what is now central Nevada, and drained a high elevation plateau (termed the Nevadaplano, e.g. DeCelles, 2004). The ash-flow tuffs erupted from a belt of supervolcanoes in Nevada during the mid-Cenozoic Ignimbrite Flareup (e.g., Henry and others, 2012).

The Valley Springs Formation is overlain by the Miocene-Pliocene Mehrten Formation consisting predominantly of debris flow deposits (commonly interpreted as lahars), and fluvial sediments (conglomerates, lithic sandstones, and siltstones), deposited in river channels which flowed westward across the range. Minor ash-flow tuffs and lava flows are also present within the Formation, though no ash-flow tuffs were observed within our map area. This unit is compositionally distinct and comprised chiefly of volcanic material of intermediate composition (mostly andesite and lesser dacite). The voluminous volcanic material was erupted from a chain of volcanoes running approximately along the modern Sierran Crest, which represents subduction arc magmatism of the Ancestral Cascade Arc. Within the map area, this Formation consists almost wholly of secondary (or fluvially-reworked) volcanic material, but further to the east, nearer to the eruptive sources, many primary volcanic deposits (including both lava flows and pyroclastic flow deposits of varying compositions) cumulatively up to several thousand feet in thickness are present. Nearer to the source area, these materials are divided into several units (e.g. the Relief Peak Formation, Stanislaus Group, etc.) by age and volcanic center affinity. However, such delineation is typically not possible in the more distal and reworked materials (such as in the present map area). The Table Mountain latite, a potassium-rich lava flow within the Mehrten Formation, flowed down a river channel (the Cataract Channel of Bateman and Wahrhaftig, 1966) when it erupted about 10 Ma. The relative resistance to erosion between the flow and surrounding debris flow deposits has formed Tuolumne Table Mountain, one of the most spectacular examples of inverted topography in California. This Formation also hosts a notable assemblage of Pliocene vertebrate fossils.

Pliocene to Quaternary Sedimentary Deposits

The western portion of the Oakdale 30’x60’ Quadrangle is underlain by Quaternary (and lesser Pliocene) sedimentary deposits. Most of these deposits are composed of sediments eroded from the central Sierra Nevada and deposited in stream channels and alluvial fans in the San Joaquin Valley. Some amount of local reworking (and thus local derivation) has also occurred, especially within smaller drainages with local (not Sierran) catchments. As described by Marchand and Allwardt (1981), these deposits comprise four different formations: the Laguna, Turlock Lake, Riverbank, and Modesto Formations. Each formation can be correlated with the end of a glacial period in the Sierra Nevada that produced an abundant supply of sediment. Because sedimentation was episodic and the Sierra Nevada was rising and tilting to the west throughout Quaternary time, the Formations are tilted at different angles. The Modesto Formation is very close to its original angle of deposition and each successively older formation is tilted at a slightly steeper angle. The most recent deposits are found in the lowest, western part of the valley west of the Oakdale 30’x 60’ Quadrangle and along river valleys eroded into the Modesto Formation surface and older surfaces. Similarly, the Modesto Formation forms an extensive depositional surface, east of and slightly upslope from the lowest part of the valley and terraces along channels eroded into older surfaces (Fig. 4). Minor alluvial and debris-flow fans and landslide deposits are also present within the areas of higher elevation and greater topographic relief, though some are too small to show at map scale. Artificial fill, including engineered fill for dams and other structures, and deposits of

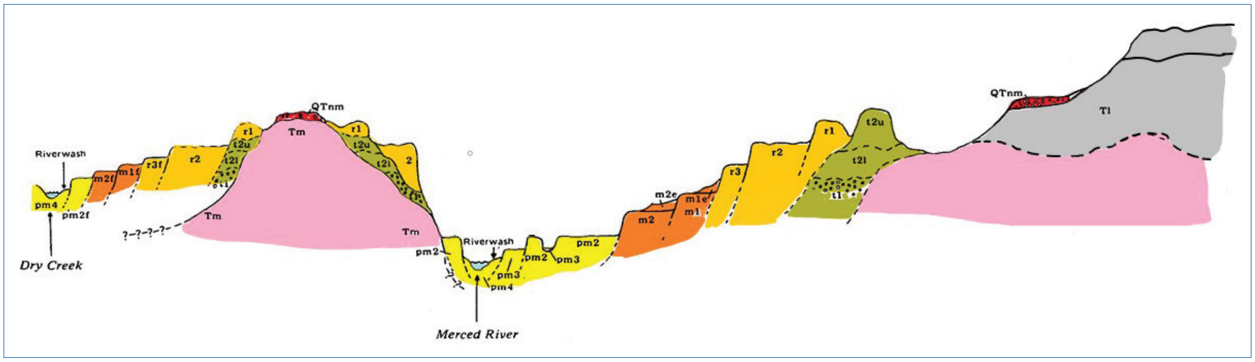

Figure 4. Schematic cross-section of Miocene to Holocene deposits, adapted from Marchand and Allwardt (1981) which shows how the younger units are set into and lower than the older units.

tailings from mining operations are shown locally, but most fills and tailings deposits are not large enough to show on a map of this scale.

Fault Zones

The major faults crossing the Oakdale 30’x60’ Quadrangle are strands of the Foothills fault system defined by Clark (1964). These structures (Fig. 2, and Plate 1) largely represent boundaries of tectonic terranes and/or significant displacement within the terranes accreted to western North America in the Jurassic. While reactivation of a strand of the Foothills fault system caused the 1975 Oroville earthquake (Hart and Rapp, 1975), which led to reexamination of many strands of the fault system for potential Quaternary activity. Major fault zones are described below from west to east.

Bear Mountains Fault Zone

The Bear Mountains Fault Zone is the westernmost of the major faults of the Foothills fault system described by Clark (1964) and was predominantly active during the Late Jurassic to Early Cretaceous (Miller and Paterson, 1991). Although several discrete fault zones are mapped, much of the deformation has occurred in diffuse zones within and along the western margin of a belt of mélange (Miller and Paterson, 1991). Structures within the steeply east-dipping fault zone and related mélange record predominantly reverse slip, with the east side of the fault over the west. A component of left-lateral strike-slip can also be inferred, but the amount of strike-slip displacement is not known (Miller and Paterson, 1991).

Melones Fault Zone

The Melones Fault Zone is also a wide zone of faults and related mélange, including prominent pods and lenses of serpentinite. This fault zone hosts significant gold mineralization of the Mother Lode gold belt (see Economic Geology section below). It generally dips steeply to the east and places Sullivan Creek Terrane over the less-deformed sequence to the west (Clark, 1964) and was active during the Jurassic and Cretaceous (Schweickert, 2015). The fault zone truncates geologic units and structures on the east and is generally parallel to units and structures to the west (Clark, 1964). Paleomagnetic and structural data (Bogen, 1985; Paterson and Wainger, 1991) suggest that the fault originated as a thrust fault and has been rotated to steeper dips by later deformation. The Melones Fault Zone appears to have had significant east-side-up dip-slip displacement, but not significant strike-slip displacement (Paterson and Wainger, 1991; Schweickert, 2015). There has been reactivation of some strands of the fault in the

Quaternary, resulting in offset of the Table Mountain latite (Woodward-Clyde Consultants, 1978).

Higgins (1997) describes the hydrothermal mineralization along the Melones Fault Zone as generally consisting of quartz and calcite veins intimately associated with thick zones of hydrothermally altered wall rock up to hundreds of feet wide. Alteration is mainly to ankerite and lesser amounts of sericite, talc, and mariposite (chrome-bearing mica). This mineralization occurred when hot fluids ascended the many fractures that compose the fault zone. The age of the hydrothermal mineralization is still not well established, but radiometric dating of various rock units indicates that mineralization along the Melones Fault Zone likely occurred episodically between 150 and 110 Ma (Evans and Bowen, 1977; Kistler and others, 1983; Weir and Kerrick, 1987; Landefeld, 1990).

Sonora Fault

The Sonora Fault is interpreted by Schweickert (2015), and other workers as a major thrust fault separating the Calaveras Complex from the Sullivan Creek Terrane/Don Pedro Terrane. Schweickert (2015) reports that the fault was active during late Jurassic time. As discussed previously, others have interpreted this boundary as a lithologic contact within the intensely deformed subduction complex. This feature is shown as an approximately located fault contact in the current map.

Calaveras–Shoo Fly Thrust

The east-dipping Calaveras – Shoo Fly Thrust was mapped by Merguerian (1981, 1985a, 1985b) as the major structure placing Paleozoic metasedimentary rocks of the Shoo Fly Complex over the Mesozoic mélange of the Calaveras Complex. The thrust formed between early Permian and middle Jurassic time, probably during the Permo-Triassic Sonoma orogeny (Merguerian, 1981).

Economic Geology

Significant mining in the Sierra Nevada foothills began after the discovery of gold at Sutter's Mill in 1848. Historically mined commodities within the Oakdale 30' x 60' Quadrangle include placer and lode gold, copper-zinc-lead, and carbonate rock. Other commodities have been mined in lesser quantities (Higgins, 1997).

Gold mining in the quadrangle began with small-scale gold placer mining of river channel and terrace deposits in the mid-1800s. Mining of Tertiary gravels was not as widespread or productive as in counties to the north (such as Sacramento and Yuba). As placer deposits were depleted and vein-hosted gold deposits discovered, underground hard-rock mining dominated gold production until World War II. Later, major mines were operated as open pits as well as dredge operations near Snelling in Merced County (Higgins, 1997).

Discovery of copper-zinc-lead deposits in California followed the Gold Rush in 1848. Production in the Foothill Copper Belt began with mining of gold and silver from the intensely oxidized upper and exposed part of copper-lead-zinc deposits (also known as "gossans") in the mid-1800s. Peak production of copper, zinc, and lead in California occurred during World War I and World War II (Kinkel and Kinkel Jr., 1966).

Lode Gold

Principal lode gold districts of the area include Big Oak Flat (placer, some lode; >$25M produced), Jamestown (lode; $30M produced), Soulsbyville (lode; $20M produced), (Clark, 2005). Reported production values here and in all descriptions that follow, are based on historical set spot prices of gold ($35/troy ounce in 1935). Based on current gold prices, historical production would have been valued much higher.

Clark (2005) divided the famous Mother Lode region, known for its prolific gold production, into three distinct belts (described below): the Mother Lode Gold Belt, the West Gold Belt, and the East Gold Belt. Various deposits are hosted by the Melones Fault Zone, Sullivan Creek terrane, Calaveras Complex, Standard Pluton, and part of the Shoo Fly Complex.

Mother Lode Gold Belt

The Jamestown district was the primary gold producing district in this portion of the Mother Lode gold belt. The district is located near Jamestown and includes the App-Heslep ($6.5M), Dutch-Sweeney ($3M), Harvard ($2M - $3M), Jumper ($5M), Rawhide ($6M), and Santa Ysabel ($1.5M) lode gold mines. About $3 million of placer gold production also came from the Jamestown district (Clark, 2005).

In the northern area of the Jamestown district deposits are found along a northwest-striking contact between serpentinite to the southwest and phyllite, slate, and metaconglomerate to the northeast (Clark, 2005). Deposits in the central and southern portions of the Jamestown district occur along the north-south trending contact between greenstone and slate to the west and chlorite amphibolite schist to the east. Gold occurs as native gold and electrum (naturally occurring gold-silver alloy) and is locally associated with disseminated pyrite in quartz veins often greater than 10 feet wide. Gold-bearing quartz veins also occur with ankerite-quartz-mariposite mineralized schist bodies and parallel quartz stringer veins (Clark, 2005). Gold mineralization is dated at approximately 130 Ma (Marsh and others, 2008; Snow and others, 2008).

East Gold Belt

The Soulsbyville district, near Twain Harte in Tuolumne County, was the one of the most productive districts in the East Gold Belt, producing at least $20 million of gold from the 1850s through the 1930s. Mines include the Black Oak ($3.5M), Gilson ($1.25M), Soulsby ($5.5M), South United ($1.7M) and many other smaller producers.

Gold-quartz veins occur in metamorphic rocks of the Calaveras Complex and granites. Diorite and aplite dikes are spatially associated with gold-quartz veins. Ore mineralization occurs as native gold and electrum (gold with significant silver) in quartz veins typically less than 5 feet thick. Mineralized quartz veins often contained with abundant sulfide minerals, primarily galena (lead sulfide, PbS). Average reported concentration of ore from mills in the region ranged from 0.5 to 1 ounce per ton (Clark, 2005).

Also east of the Mother Lode Gold Belt is the "Pocket belt." This is loosely defined as the immediate area surrounding Columbia and Sonora including Bald Mountain and the Jackass Hill area around Tuttletown. Deposits occur as small but incredibly rich gold-bearing quartz-vein systems. Notable among the deposits of this belt is the presence of gold telluride mineralization (Higgins, 1997).

West Gold Belt

The Royal mine (also known as the Royal-Mountain King mine) in the Hodson district hosted a 120-stamp mill, one of the largest in California, from the 1890s to the early 1940s. Copper ore from Copperopolis (deposits explained in more detail in the following text) was treated at the mill during World War II (Clark, 2005).

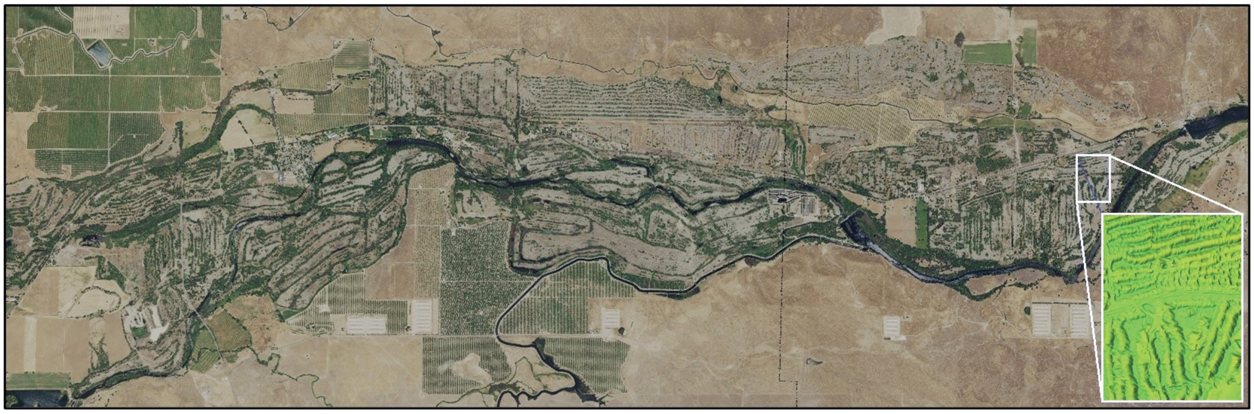

Figure 5. Aerial photo of a portion of the Snelling dredge field, on the Merced River. Arcuate pattern of tailing windrows (visible in photo inset) is produced by the dredge stacker oscillating back and forth ejecting coarse sediments (gravel and boulders) as the dredge moves forward. Finer material is ejected back into the dredge pond separately. (Main image from 2020 NAIP; inset from lidar-derived shaded relief image).

Placer Gold

The Snelling dredge field (Fig. 5) on the Merced River was one of the largest gold dredge fields in California. Records show that small quantities of gold were recovered at Snelling as early as 1880 but significant gold dredging began late in 1907 and continued until the early 1950s. The dredged area at Snelling is about nine miles long and 0.5 to 1.5 miles wide. The recent Merced River gravel deposits targeted by the dredges are loose with very little clay and range from 20 to 35 feet in depth. Small amounts of platinum and silver were recovered as a byproduct of the gold dredging process (Clark, 2005).

Most rivers and streams sourced from the Sierra Nevada contain some gold. The Big Oak Flat district, along with the Deer Flat district, produced approximately $25 million in gold from placers. The La Grange district on the Tuolumne River produced approximately $17 million of gold from 1907 to the late 1940s. The stream sediments in and adjacent to the present Tuolumne River are medium- to coarse gravel, are poorly consolidated, average 30 to 35 feet in thickness and are underlain by tuff. Minor amounts of platinum were also recovered from these gravels (Clark, 2005). One of the bucket dredges was abandoned after mining ceased and can still be found located approximately 2 miles southwest of the town of La Grange, adjacent to the La Grange OHV Park.

Copper, Zinc, and Lead

The copper, zinc, and lead deposits of the Foothill Copper Belt are volcanogenic massive sulfide deposits occurring in Middle to early Late Jurassic marine terranes of the Sierra Nevada foothills (Barton, 2011; Martin, 1988). The Copperopolis mines were among the significant producers of copper in California with a total production of about 72 million pounds of copper. The mines include the North Keystone mine, second largest copper producer in the state during World War II, and the Keystone-Union mine. Copper mineralization is localized in the Bear Mountains Fault Zone and related structures and occurs primarily as chalcopyrite. Copper ore grade strongly correlates with pyrite abundance. Fine-grained magnetite also occurs in the fault zones of the mineralized areas (Heyl, 1948).

At the Blue Moon zinc mine 4 miles north of Hornitos, approximately 13.7 million pounds of zinc, 533,000 pounds of lead, and 406,000 pounds of copper were produced from 1943 through 1945 (Eric and Cox, 1948). The Blue Moon deposit is hosted in the basal sequence of basalts and andesites overlain by rhyolite of the Upper Jurassic Gopher Ridge Formation. Ore occurs as an oxidized gossan 40 to 70 feet thick and lenticular, sheeted sulfide zones parallel to foliation of the host rocks and localized along faults and shear zones. Primary ore minerals in order of abundance are dark-brown sphalerite, pyrite, tetrahedrite, galena, and chalcopyrite. Sulfides occur as massive aggregates, lens-shaped grains, and fine dissemination. Gangue minerals include sericite, quartz, barite, and calcite (Eric and Cox, 1948). The Blue Moon mine is currently being explored for zinc and silver by the Blue Moon Metals company.

Asbestos

Serpentinite, the host rock of chrysotile deposits, is both abundant and widely distributed in California. The first serious attempt to develop a chrysotile asbestos deposit in California was made at the Voorhees mine, approximately 7 miles southeast of Copperopolis. Attempts to develop this deposit were made as early as 1904 and continued intermittently through 1927. In 1954, the property was purchased by the American Asbestos Mining Corporation (Rice, 1957).

The chrysotile at the Voorhees deposit occurs as stockwork cross fiber veins in massive pale green serpentinite. The ore body is approximately 1,700 feet long and ranges from 300 to 600 feet wide (Rice, 1957).

Carbonates

Significant mining of marble, limestone, and dolomite has taken place in the Columbia region, north of the study area. Carbonate rocks extend to the south through the Sonora area. Marble is locally dominant in areas of the Calaveras Complex, and to a lesser extent in Jurassic mélange to the west and Shoo Fly Complex to the east. Precambrian-Cambrian roof pendants in eastern Tuolumne County host minor carbonate rock. Within the Calaveras Complex, carbonate rock occurs as belts that are narrow, elongate, and extend vertically in some cases for at least hundreds of feet (Higgins, 1997).

Clay

The Ione Formation (as described previously) occurs in the southwestern portion of the map area and has been mined further to the north as “ball” clay, an organic-bearing kaolinite, for use in ceramics.

Decorative Rock

Rock has been mined from all bedrock units for ornamental purposes throughout the study area. Quartz-ankerite-mariposite rock of the Mother Lode belt, volcanic rock from the Table Mountain latite, slate-phyllite of the metasedimentary units, and carbonate rock of the Calaveras Complex have all been utilized as decorative rock. Serpentinized portions of ultramafic complexes were previously marketed but concerns about asbestos have shifted demand to “greenstone” metavolcanic rock of the Jurassic island-arc units (Higgins, 1997).

Geologic Sites of Interest

Mariposite Exposure Along Melones Fault

Excellent Mariposite exposures are located along Highway 132, just southwest of Coulterville, near the intersection with Old Highway 49. This white-blue-gray-green rock is composed of mariposite (a chrome-rich mica), quartz, and ankerite (a Calcium-Iron-Magnesium-Manganese carbonate) and is commonly associated with Motherlode gold. Both the Motherlode gold deposits, and the mariposite-bearing rock formed from the same hydrothermal fluid system. Evans and Bowen (1977) show locations of other mariposite exposures on their map.

Serpentinite of the Tuolumne River Ultramafics in the Red Hills

The Red Hills are accessible along Red Hill Road which runs from La Grange Road on the west to Highway 49 on the east. These hills are underlain by ultramafic rocks (rich in magnesium and iron) of various lithologies, especially serpentinite, dunite, and lesser wehrlite and harzburgite. Together, they represent upper mantle material that was variably metamorphosed. Because of the composition of the ultramafic rocks, the soils derived from these rocks are relatively rich in magnesium and iron and deficient in some other elements (such as potassium and sodium) and host a rare assemblage of plant species that produce spectacular wildflower displays.

The Tuolumne Table Mountain Latite

These rocks are accessible from many places, including the Table Mountain Trail accessible from a trailhead at the end of Shell Road near Jamestown. These gray-black volcanic rocks represent lavas that flowed generally westward, down an ancient river channel (the Cataract Channel of Bateman and Wahrhaftig, 1966), about 10 million years ago. Because they are relatively resistant to erosion, these channel-filling lavas have been preserved, while the surrounding rocks that composed the walls of the ancient river canyon have been eroded, resulting in a spectacular example of inverted topography, as shown in Figure 6.

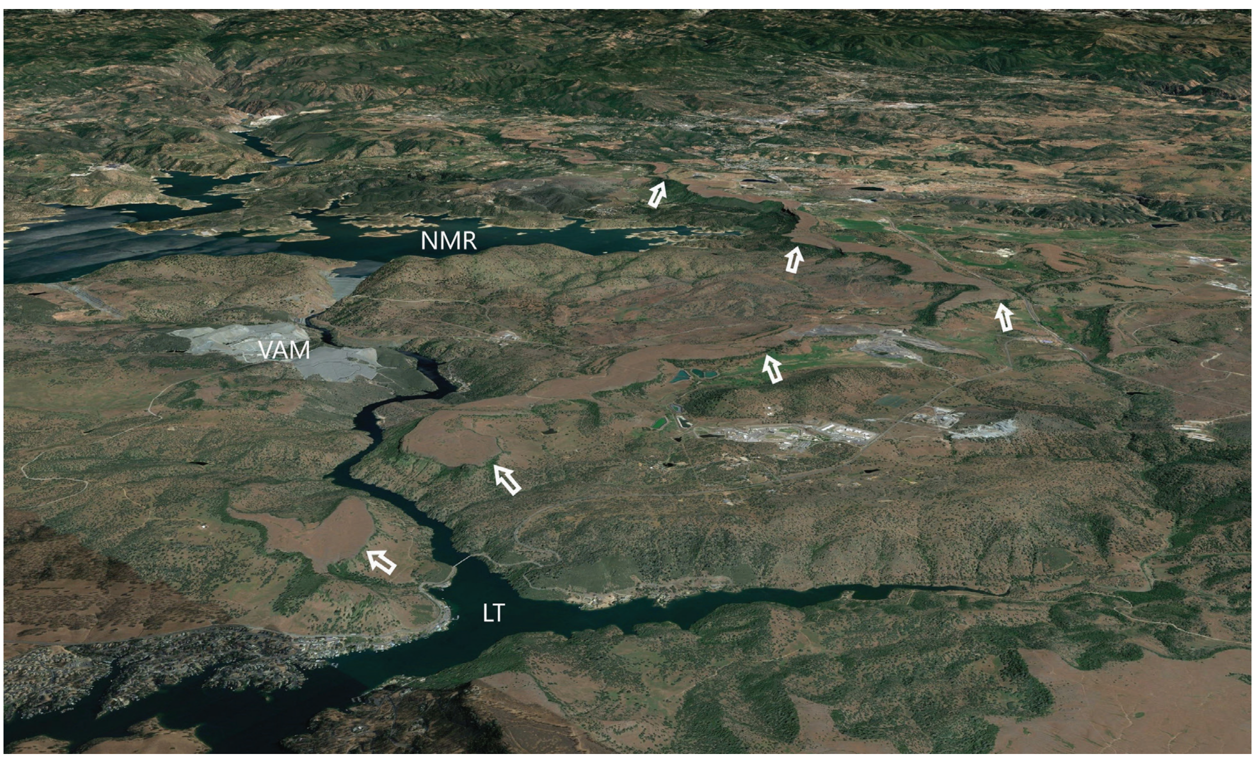

Figure 6. Tuolumne Table Mountain Latite exhibiting inverted topography (brown, flat-lying areas indicated with white arrows); distribution traces paleochannel path (Google Earth oblique photo looking northeast). White text labels: NMR = New Melones Reservoir; VAM = Vorhees Asbestos Mine (defunct); LT = Lake Tulloch.

The La Grange Dredge field

This dredge field is accessible by La Grange Road, just south of Dawson Lake. A plaque by the roadside describes the dredge field, and from this site, remains of a gold dredge may be visible. This field, which is part of the Snelling Gold District, was created by continuous-bucket gold dredges that scooped up the Quaternary age sediments, sorted them on the dredge, and extracted the placer gold. Finer waste material was returned to the lake, while the coarser cobbles were discharged via a conveyor belt (stacker) which oscillated back and forth, depositing the distinctive piles of dredge tailings (called windrows). Dredging was active intermittently from 1907 to 1952, and $17M gold was recovered.

Description of Map Units

The arrangement of map unit descriptions below roughly illustrates the correlation of map units among different tectonic blocks. Similarities and differences among rock units are incompletely reflected in the nomenclature and labeling of the rock units, which evolved from many geologic investigations over the past century. The majority of the units on this map have been adopted from the source maps used in this compilation. Named Formations of sedimentary strata are made up of multiple episodes of individual depositional events and each event need not be distributed over exactly the same area. This can lead to significant differences in the age range of a rock stratigraphic (lithostratigraphic) unit from one area to another.

Map labels are abbreviations that indicate age and origin of surficial deposits, or age and formally recognized names of formations and members. Where stratigraphic assignment is tentative, a query (?) is added to the label in the database. Quaternary units are divided based on distinctive geomorphic features such as fans, floodplains, and terraces, and further subdivided by relative age based on topographic position, degree of erosional dissection, and/or soil development. Some compiled mapping, especially of Quaternary deposits, was generalized for display at the 1:100,000 map scale.

Quaternary to Pliocene Surficial Deposits

af **Artificial fill (late Holocene)—**Deposits of sand, silt and gravel resulting from human construction, mining, or quarrying activities; includes engineered compacted fill and nonengineered fill. Some larger fills are shown on the compilation, but most are too small to be displayed at map scale.

t **Dredge tailings (late Holocene)—**Deposits of gravelly debris from placer mining.

Qha **Young alluvium (Holocene)—**Unconsolidated gravel, sand and silt in active or recently active floodplains, locally including related alluvial fans and streambeds where those are not mapped separately; chiefly streamflow deposited, however also includes some debris-flow deposits. Deposits are near or in the locus of recent sedimentation. Surfaces are generally not uplifted or dissected and show poorly-developed pedogenic soils. Includes areas generally mapped as Grangeville, Hanford, Foster, Tujunga, and Honcut soils. Some of the source maps such as Marchand (1981) and Marchand and Wagner (1980) have divided this unit into four subunits based on relative position to modern stream channels.

Qhl **Lacustrine deposits (Holocene)—**Silt and clay deposited in local lakes, swamps and marshes.

Qa **Alluvium (Holocene to Pleistocene)—**Alluvium deposited in fan, terrace, or fluvial environments. Typically consists of poorly to moderately sorted sand, silt, and gravel.

Occurs in the upper elevations of the map area, and may include deposits of Turlock Lake, Riverbank, or Modesto age.

Qf **Alluvial fan deposits (Holocene to Pleistocene)—**Unconsolidated deposits of sand, silt and locally-derived rock clasts ranging from fine- to coarse gravel to cobble, generally deposited at the mouth of drainages with fan-shaped morphology. Locally these areas contain debris fan lobes.

Qls **Landslide Deposits (Holocene to Pleistocene?)—**Deposits from displaced bedrock and/or surficial materials, broken in varying degrees from relatively coherent large blocks to disaggregated small fragments, deposited by landslide processes. Includes complexes of multiple slides, grouped and mapped as a single feature.

Modesto Formation (Late Pleistocene)—Arkosic sand, silt, and gravel. Many of the large scale (1:24,000) source maps (for example Marchand and Wagner (1980) and Marchand (1981)) have divided the Modesto formation into over 20 mappable units based on relative age and depositional environment. To accommodate our 1:100,000 scale map we have grouped these units into the following:

Qmu **Modesto Formation, upper member, undifferentiated (Late Pleistocene)—**Arkosic alluvial sand and silt not differentiated by terrace level; represents glacial outwash from core of Sierra Nevada and lesser local (not Sierran) sediment sources. May also include minor local arkosic eolian sand. Generally associated with Hanford, Dinuba, Meikle, Wyman, Paulsell and Anderson soils.

Qmu3-4 **Modesto Formation, upper member, 3rd and 4th terrace (Late Pleistocene)—** The two youngest of the four terrace levels that can generally be distinguished geomorphically. Consists predominantly of sand and silt. Generally correlated to Hanford soils.

Qmu1-2 **Modesto Formation, upper member, 1st and 2nd terrace (Late Pleistocene)—** The two oldest of the four terrace levels that can generally be distinguished geomorphically. Consists predominantly of sand, silt and gravel. Generally correlated to Hanford and Meikle soils.

Qmub **Modesto Formation, upper member, basin deposits (Late Pleistocene)—**Arkosic fine sand and silt deposited between the fan distributary channels and in flood basins, commonly stratified. Generally correlated to Dinuba soils.

Qmul **Modesto Formation, upper member, lake and marsh deposits (Late Pleistocene)—**Arkosic silt and clay deposited in local lakes, swamps, and marshes formed at the mouths of small drainages tributary to the Tuolumne River rapid main stem late Modesto aggradation. Generally correlated to Meikle soils.

Qml **Modesto Formation, lower member, undifferentiated (Late Pleistocene)—**Arkosic alluvial sand associated with terraces at or slightly above the highest topographic level associated with upper member. Represents glacial outwash from core of Sierra Nevada and lesser local (not Sierran) sediment sources. Generally associated with Greenfield, Ryer, and Dinuba soils.

Qmlb **Modesto Formation, lower member, alluvial basin deposits (Late Pleistocene)—** Arkosic alluvial fine sand and silt associated with terraces at or slightly above the highest level associated with the upper member level associated with the upper member. Represents glacial outwash from core of Sierra Nevada and lesser local (not

Sierran) sediment sources, deposited between fan distributary channels and in flood basins. Generally correlated to Dinuba soil.

Qme **Modesto Formation, eolian deposits (Late Pleistocene)—**Arkosic eolian fine sand associated with terraces at or slightly above the highest level associated with upper member. Represents glacial outwash from core of Sierra Nevada re-deposited by wind. Generally associated with Greenfield soils.

Qr **Riverbank Formation, undifferentiated (Late Pleistocene)—**Arkosic sand forming terraces topographically at or above Modesto Formation level. Represents glacial outwash from core of Sierra Nevada and lesser locally-sourced sediments. May be composed of one or all of the three sub-units described below:

Qru **Riverbank Formation, upper member (Late Pleistocene)—**Arkosic sand forming terraces topographically at or above Modesto Formation level. Represents glacial outwash from core of Sierra Nevada and lesser locally-sourced (not Sierran) sediments. Generally associated with San Joaquin, Madera, Bear Creek, Yokohl, Redding and Reyes soils.

Qrm **Riverbank Formation, middle member (Late Pleistocene)—**Arkosic sand forming terraces topographically above the Riverbank Formation upper member along the Stanislaus River. Contains alluvial gravel, glacial outwash from core of Sierra Nevada, and locally (foothills) derived alluvial silt and sand with abundant volcanic and metamorphic detritus. Generally associated with Yokohl, Redding, Snelling and San Joaquin soils.

Qrl **Riverbank Formation, lower member (Late Pleistocene)—**Arkosic glacial outwash and lesser locally-sourced sediments forming terrace remnants topographically above middle member levels. Generally associated with Cometa soil.

Turlock Lake Formation (Late Pleistocene)

Qtu **Turlock Lake Formation, upper member (Late Pleistocene)—**Arkosic coarse sand and gravel forming upper part of the formation; represents coarse glacial outwash and lesser locally-sourced sediments. Generally associated with Montpelier soils.

Qtl **Turlock Lake Formation, lower member (Late Pleistocene)—**Arkosic glacial outwash and lesser locally-sourced sand, silt, and pebble gravel; exposed only in valleys or on lower hillslopes where it underlies the upper units. Generally associated with Montpelier, Rocklin, and Whitney soils.

Qnm **North Merced Gravel (Pleistocene)—**Thin locally derived gravel veneer overlying a pediment surface cut across Tertiary strata. The gravels typically consist of well-rounded gravel and cobbles in a reddish-brown sandy matrix. Generally associated with Redding and Keyes soils.

Ᵽl **Laguna Formation (Pliocene)—**Thick gravel with subordinate sand and silt; derived from mixed metamorphic, volcanic, and granitic sources. Compared with younger alluvial units, this unit shows higher clast weathering stage, with a greater proportion of friable and iron oxide-stained gravels.

Cenozoic Sedimentary and Volcanic Paleochannel Deposits

ᵽMm **Mehrten Formation (early Pliocene to Miocene)—**Volcanic debris flow (lahar) deposits interbedded with sandstone and conglomerate. Clasts are compositionally distinct, dominated by andesite and lesser dacite. Debris flow beds laden with volcanic clasts are particularly resistant and often form a cap and corresponding cliff faces. Includes brown, pale reddish-brown tan, white, and grayish-pink andesitic sandstone, pinkish-gray and gray or pale yellowish-brown siltstone, local white waterlain tuff, and conglomerate. Some coarser beds contain abundant bone fragments and fossilized wood; siltstones and mudstones contain leaf impressions. Generally associated with Raynor, Pentz, Peters, and Keyes soils.

MItm **Tuolumne Table Mountain Latite (Miocene)—**High-K trachyandesitic lava, commonly massive, porphyritic with plagioclase and trace augite phenocrysts in a gray aphanitic groundmass (King and others, 2007). Erupted from the Little Walker Center (approximately 70 km northeast of map area) at 10.41 ± 0.08 Ma and flowed westward down paleochannels at least as far as Knights Ferry (Gorny and others, 2009). This unit typically occurs as a resistant, cliff-forming cap on the top of ridges and hills. It displays columnar jointing especially in the Stanislaus River canyon.

MIOGvs **Valley Springs Formation (early Miocene to Oligocene)—**Tuffaceous sandstone, siltstone, and conglomerate interbedded with tuff and minor clay. Deposits are moderately mature compositionally which reflects the peritropical environment at the time of deposition. The formation may be distinguishable by rhyolitic ash component. Conglomerates are compositionally heterogeneous and feature significant proportions of metamorphic rocks (including quartzite and chert), Oligocene-Miocene rhyolitic tuff clasts, and lesser (commonly decomposed) granitic clasts. Tuff beds are often present as resistant, cliff-forming outcrops. Green clay rock, which consists of silica-cemented pebbles of expansive smectitic clay, is present near the base of unit and poses significant geologic hazards related to ground swelling and slope stability (California Geological Survey, 2009; Wood and Glasmann, 2013; Wood, 2015). Queried (MIOGvs?) includes undifferentiated deposits that predate Mehrten formation and may correlate with Valley Springs and Ione Formations as mapped by Woodward-Clyde Consultants (1978) near Table Mountain.

Eoi **Ione Formation (Eocene)—**Clay, sandstone, and siltstone. Distinctly light in color; dominated by white and light pastel shades of buff, rust and lavender on the weathered surface. Compositionally, this unit is very mature and is distinctly dominated by various forms of quartz as described below. Clays are predominantly kaolinitic and are interpreted as having formed in a tropical climate (Wood, 1994), in fluvial, deltaic, and estuarine environments. Sandstones are often silica-cemented. Conglomerates typically feature abundant white quartzite cobbles and vein quartz fragments in a matrix of reddish oxidized silt and sand. Finer beds typically feature striking sedimentary structures such as cross-bedding and convolute laminae crossed by more recent subparallel and subvertical joints typically filled with iron or silica cement.

Eog **Eocene Gravels (Eocene)—**Conglomerate and sandstone. Sandstone is quartzose with variable but lesser feldspar. Conglomerate is heterolithologic but dominated by quartz lithologies such as quartzite, chert, and vein quartz. Distinguishable from younger Valley Springs Fm. sediments by absence of rhyolite, and generally greater compositional maturity, which is interpreted as reflecting a tropical climate at time of deposition. Earlier workers referred to these sediments as “pre-volcanic gravels”, “auriferous gravels”, and “Tertiary gravels” (e.g., Lindgren, 1911). These sediments interfinger with the generally finer-grained Ione Formation sediments to the west, but the lowest Eocene gravels are likely older than the Ione Fm., thus these two units are partly correlative, and the Eocene Gravels partly represent the upstream equivalent of the Ione Fm. Sediments of this unit were the primary target of historic hydraulic and drift gold mining, and within the map area, these sediments have been worked by hydraulic and other mining methods, in some areas to the point of fully exposing the underlying bedrock.

Mesozoic to Paleozoic Sedimentary, Metamorphic, and Plutonic Bedrock

Ku **Upper Cretaceous sediments—**Sandstone and siltstone in a few isolated occurrences. Previously referred to as Chico Formation (Wagner and others, 1981).

fd **Felsite dikes (Mesozoic?)—**Described by Morgan (1976) as massive, coarse-grained, gray to white albite-quartz rocks; often nearly monomineralic albite with minor chlorite and/or riebeckite.

Mzg **Granodiorite and related plutonic rocks, undifferentiated (Mesozoic)—**Plutonic rocks of varying Mesozoic ages and lithologies that have not been adequately studied and differentiated.

Mzgb **Gabbroic and related plutonic rocks, undifferentiated (Mesozoic)—**Plutonic rocks of varying Mesozoic ages and lithologies that have not been adequately studied and differentiated.

Jdi **Diorite, undifferentiated (Jurassic)—**Diorite and quartz diorite identified by Taliaferro and Solari (1948) and thought to be a phase of the granodiorite.

Jdipm **Diorite of Page Mountain (Jurassic)—**Described by Morgan (1976) as massive coarse-grained diorite with hornblende grains from 3-7 mm and plagioclase from 1-4 mm, secondary quartz and minor epidote and chlorite; contact metamorphoses Calaveras and Priest formations. Pb/U zircon age reported by Stern and others (1981) is 148 Ma.

Jglp **La Paloma pluton (Jurassic)—**Described by Saleeby and others (1989) as a homogenous biotite leucotonalite with a reported age of 149 ± 2 Ma.

Jgh **Hornitos pluton (Jurassic)—**Described by Putirka and others (2014) as gabbro to hornblende tonalite. May represent feeder zone of Guadalupe Igneous Complex to south in the Merced 30’x60’ Quadrangle (Saleeby and others, 1989). Saleeby and others (1989) report a Pb/U zircon age of 150 ± 2 Ma.

Jdicc **Cobbs Creek Pluton (Jurassic)—**Described by Herzig and Sharp (1992) as composed of diorite, hornblende-biotite mafic rock and feldspar-muscovite silicic rock. Morgan (1976) describes it as massive coarse-grained rock with hornblende grains from 3-5 mm, plagioclase from l-4 mm, and minor microcline; secondary quartz, chlorite, muscovite, and epidote. Intrudes and contact metamorphoses Calaveras complex. Stern and others (1982) report a Pb/U age of 162.5 Ma; Herzig and Sharp (1992) report an Ar40/Ar39 age of 167 ± 2 Ma.; Ar40/Ar39 age reported by Herzig and Sharp is 167 ± 2 Ma.

Jdis **Standard Pluton (Jurassic)—**Described by Hart (1959) as massive, medium to coarsely crystalline and even-grained, gray to greenish gray. The dominant minerals of the granodiorite are oligoclase-andesine, orthoclase, quartz, biotite and hornblende, although as much as 10 percent partially uralitized augite may be present. A small amount of apatite and garnet is generally present, and hypersthene has been identified. Stern and others (1982) report a Pb/U age of 163.6 Ma.

Jdidt **Dogtown Pluton (Jurassic)—**Described by Herzig and Sharp (1992) as composed predominantly of diorite, Ar40/Ar39 dated at 168 ± 2 Ma.

Jdidp **Diorite of Don Pedro (Jurassic)—**Described by Morgan (1976) as massive gray to white hornblende diorite with variable grain size ranging from very coarse- to medium; rare relict clinopyroxene; plagioclase altered to epidote and white mica; abundant secondary quartz. Intrudes and contact metamorphoses the Peñon Blanco Formation. Stern and others (1981) report Pb/U zircon age of 182 Ma, and Saleeby (1982) reports an age of 200 ± 2 Ma.

Jdich **Diorite of Chinese Camp (Jurassic)—**Described by Morgan (1976) as massive or brecciated, medium-grained diorite with pyroxene grains from 1-4 mm and hornblende from 1-4 mm, partially serpentinized; plagioclase usually completely altered to white micas and fine-grained epidote in the Chinese Camp area. Correlated with diorite in the Marsh's Flat area within the Moccasin 7.5' Quadrangle, which is similar, except that plagioclase (An 40) is unaltered. Diorite intrudes harzburgite, wehrlite, and the Peñon Blanco formation. Saleeby (1982) reports a Pb/U zircon age of 199 ± 2 Ma.

Jgb **Gabbro, undifferentiated—**Undifferentiated gabbroic intrusives. Assumed to be Jurassic based on relations to surrounding diorite stocks.

Jm **Mélange (Jurassic)—**A mixture of metasedimentary and metavolcanic rocks in a pervasively sheared matrix. Blocks and lens-shaped masses of chert, marble, or other rock types common. Matrix may be derived from metasedimentary rocks or from serpentine. Mélange, particularly tectonic mélange, was not recognized as a rock type by earlier mappers, thus many areas now recognized as mélange were mapped as sedimentary units, including areas previously identified as parts of the Calaveras Formation and Mariposa Formation. Detailed mapping in the Sierra Nevada foothills north of the Oakdale 100k Quadrangle first showed the tectonic mélange nature of unit (Duffield and Sharp, 1975). A belt within and adjacent to the Bear Mountains Fault Zone originally mapped as Mariposa Formation and/or Copper Hill Volcanics by Clark (1964) and modified in part to Salt Springs Slate by Wagner and others (1991), is now shown as mélange following Miller and Paterson (1991).

On this map, some rock types identified by early authors, Taliaferro and Solari (1948) in particular, are assumed to refer to blocks of that material where either the matrix or a large proportion of the blocks are probably the lithology identified. Includes:

Jm-mv **Mélange, metavolcanic member—**Material identified as Logtown Ridge Formation or other metavolcanics rocks within areas now interpreted as mélange are probably mélange with a matrix of sheared metavolcanic rocks or with a large proportion of blocks composed of metavolcanic rock.

Jm-sp **Mélange, serpentinite member—**Material identified as serpentine by Taliaferro and Solari (1948) interpreted as mélange with a matrix of sheared serpentinite.

Jm-gb **Mélange, gabbro member—**Gabbro within the mélange unit.

Jm-ms **Mélange, metasedimentary member—**Mostly metamorphosed slate and sandstone.

Jdb **Diabase (Late Jurassic?)—**Metadiabase mapped by Mannion (1960) intruded into Gopher Ridge Volcanics, Copper Hills Volcanics and Salt Springs Slate. Occurrence beyond small area mapped by Mannion is unknown but may be more widespread. Described as medium- to dark-greenish- gray, mottled with gray- green and brownish-green from altered augite phenocrysts. Grain size is fine at margins; increases inwards. Mannion describes diabase bodies as less deformed than surrounding rocks and generally unfoliated.

Jch **Copper Hill Volcanics (Late Jurassic)—**Dark- to medium green meta-andesite and metabasalt. Strongly sheared and crenulated near Bear Mountains Fault Zone. Minor porphyritic rhyolite or dacite with quartz phenocrysts. Named by Clark (1964) with the type section on the Cosumnes River north of the quadrangle. Interfingers with and overlies the

Salt Spring Slate and is likely of Kimmeridgian age (Clark, 1964). Includes areas mapped as Peaslee Creek Volcanics by Clark (1964). Peaslee Creek Volcanics are described as stratigraphically overlying the Merced Falls Slate on the southwest side of the belt of Gopher Ridge Volcanics outcrops. The stratigraphic order suggests correlation of the Merced Falls Slate with the Salt Springs Slate and Peaslee Creek Volcanics with Copper Hill Volcanics. Distinguished locally, includes:

Jchf **Felsic facies (Late Jurassic)—**Described by Mannion (1960) as metarhyolite, silicic tuffs, and lapilli tuffs composed of felsitic fragments and tuff breccia. Some areas originally mapped as quartz porphyry by Turner and Ransome (1897), and Taliaferro and Solari (1948).

Jss **Salt Spring Slate (Late Jurassic)—**Black slate with widespread greywacke and tuff, and some thin conglomerate layers (Clark, 1964). Prior to Clark (1964) naming the formation, these rocks were mapped as Mariposa Formation (Turner and Ransome 1897; Taliaferro and Solari, 1948). Late Oxfordian to early Kimmeridgian in age based on invertebrate fossils collected along Cosumnes River. Plesiosaur fossil reported from Salt Spring Slate at Lake McClure (Clark, 1964). Salt Springs Slate on this map includes areas mapped as Agua Fria formation, described by Mannion (1960) as also containing fine-grained siliceous tuff, mafic tuff, and sandstone. These same areas were mapped as Merced Falls Slate by Clark (1964). Since both Salt Springs Slate and Merced Falls Slate are described as stratigraphically overlying the Gopher Ridge Volcanics and are distinguished mainly by being on opposite sides of the belt of Gopher Ridge Volcanics outcrops, they are both included in Salt Springs Slate on this map.

Jmp **Mariposa Formation (Jurassic)—**Metasedimentary rocks, dominantly slate and greywacke, with lesser metavolcanic rocks. Bogen (1983) describes the protoliths as sandstone, mudstone, mixed sandstone and mudstone, and tuffaceous sandstone which have been metamorphosed to metagraywacke, slate, and tuffaceous metagraywacke. Contacts between subunits are described as generally sharp, but locally gradational. The base of the Mariposa Formation was deposited on the Peñon Blanco formation without noted angular discordance, although the hiatus between the formations may represent 30-40 Ma (Bogen, 1983). Total thickness of Mariposa Formation is estimated to be greater than 2300 m (Bogen, 1983). Metasedimentary rocks east of the Bear Mountains Fault Zone are included with the Mariposa Fm., while those to the west are included with Salt Springs Slate, reflecting the possibility that the Bear Mountains Fault has significant displacement and the sedimentary rocks on either side formed separately. Lithologic subunits distinguished in mapping by Bogen (1983) include:

Jmss **Metagraywacke—**consists of medium- to coarse-grained sandstone in beds from 0.2-14 m thick. Layers are generally massive, but graded bedding, sole markings and rip-up clasts indicate turbidity current deposition. Metaconglomerate layers are up to 8 m thick and include rounded and subrounded pebbles in a sandy mudstone matrix.

Jmsm **Mixed sandstone and mudstone—**in similar quantities is locally distinguished as a separate unit.

Jmt **Tuffaceous sandstone and mudstone—**forms an upper subunit up to 1 km thick. Includes areas mapped as dacite flows and tuff; altered in part to quartz-muscovite schist as noted by Bowen (1969).

Jgo **Gopher Ridge Volcanics (Late Jurassic)—**Described by Clark (1964) as green- to dark-green andesitic to basaltic tuff. Including rhyolitic or dacitic tuff and some pillow lava.

Morgan (1976) describes crystal and vitric felsic tuff with minor reworked tuffaceous sandstone. Quartz and altered plagioclase phenocrysts are abundant and matrix contains secondary chlorite, epidote, and calcite. Graded beds are abundant in several locations. Lapilli tuffs and agglomerate are common. Massive mafic and intermediate tuff, breccia, some basaltic flows with and without pillow structures, and occasional greywacke and agglomerate are also found. Named by Clark (1964) for exposures along the Calaveras River north of the quadrangle. Likely Oxfordian in age (Clark, 1964). Distinguished locally, includes:

Jgoq **Felsic facies—**Originally mapped as quartz porphyry by Turner and Ransome (1897) and Taliaferro (1948) includes areas of intrusive metarhyolite, siliceous tuff and lapilli tuff, and tuff breccia mapped by Mannion (1960) and areas mapped as dacite flows and tuff; altered in part to quartz-muscovite schist as noted by Bowen (1969).

Jlr **Logtown Ridge Formation (Middle to Late Jurassic)—**Thinly- to thickly-bedded very fine- to medium-grained tuff, coarse pumice lapilli tuff in graded beds and thickly-bedded fine- to coarse volcanic breccia that grades upward into medium-fine grained tuff. These include rocks assigned to Peñon Blanco Volcanics by Clark (1964).

Jbms **Bullion Mountain sequence metasedimentary and metavolcanic rocks (Late Jurassic-Callovian-Oxfordian)—**Described by Herzig and Sharp as interlayered volcaniclastic rocks and volcanic debris-rich argillites and siltstones, conglomerate, and Triassic limestone blocks. Rocks are distinguished from Sullivan Creek Terrane by being relatively undeformed. Distinguished locally, includes:

Jbmv **Bullion Mountain sequence volcanics (Late Jurassic-Callovian-Oxfordian)—** Described by Herzig and Sharp as consisting of volcaniclastic breccia with up to 5% other lithologies including augite-plagioclase porphyry, vitric crystal tuffs, pillow lavas, and polymict breccia containing mafic volcanic rocks, tuff, chert with poorly preserved radiolaria, hornblende diorite, sandstone clasts. Primary mineralogy of volcanics includes augite, plagioclase, broken crystals of augite and plagioclase present in the matrix of breccias, Rocks are distinguished from Sullivan Creek Terrane by being relatively undeformed except adjacent to the Melones fault zone. Mapped as Peñon Blanco Formation by Bowen (1969), described by Herzig and Sharp (1992) as similar in age and lithology to Logtown Ridge Formation.

Jbmp **Bullion Mountain pluton (Jurassic)—**Undeformed two-pyroxene hornblende gabbro interpreted by Herzig and Sharp as the feeder for the Bullion Mountain sequence volcanics. Herzig and Sharp (1992) report age of 169 ± 2 Ma based on Ar/Ar dating of hornblende.

Jpb **Peñon Blanco Formation (Jurassic)—**Undifferentiated volcanic and volcaniclastic rocks; includes a major part of Peñon Blanco volcanics from Bowen (1969), Bogen (1983, 1985), Morgan, (1976). Lithologic sub-units from Bogen (1983) described below, include overlapping lithologic composition and gradational contacts, which may therefore be indistinct at outcrop scale.

Jpt **Peñon Blanco Formation, tuffaceous turbidite member—**Described by Bogen (1983) as massive and bedded, augite-, hornblende- and plagioclase-bearing volcaniclastic sandstone gradationally overlies the tuff breccia unit on both limbs of the Cotton Creek anticline. Beds are 0.5-3 m thick, commonly lack stratification or grading and contain scattered cobble and boulder clasts of fine tuff and aphyric lava. The unit extends beyond the mapped region to the northwest and pinches out on both limbs in the southern part of the study area mapped as Jpb by Bowen.

Jptb **Peñon Blanco Formation, tuff breccia member—**Described by Bogen (1983) as composed of subangular- to subrounded fragments 5-10 cm in diameter of augite, hornblende and plagioclase porphyry and less abundant fragments of diabase, microdiorite, aphyric lava and fine tuff in sand-sized matrix of augite, hornblende, and plagioclase crystals and volcanic rock fragments. Beds of tuff breccia generally 1 to 5 m thick intercalated with thick-bedded tuffaceous turbidites as much as 3.5 km thick on east limb of Cotton Creek anticline, 1 km thick on west limb.

Jpa **Peñon Blanco Formation, augite plagioclase porphyry member—**Described by Bogen (1983) as augite, plagioclase and minor hornblende phenocrysts in a gray or green microcrystalline matrix. Phenocrysts in the porphyries average about 5 mm across. Includes flows 0.5-3 m thick and beds of tuff breccia.

Jpbch **Peñon Blanco Formation, tuffaceous and silty chert member—**Described by Bogen (1983) as locally jasperoid; green-to gray-green chert with darker bands mapped on the Coulterville quad by Bowen (1969).

Jpft **Peñon Blanco Formation, fine volcaniclastic sandstone and tuffaceous turbidite member—**Described by Bogen (1983) as an upward thickening and coarsening sequence of clay, silt, and sand sized material in turbidite layers 2-5 cm thick interbedded with finely laminated volcaniclastic siltstone and sandstone. Sandy turbidite layers 5-20 cm thick become more abundant higher in the sequence. Turbidite layers include graded bedding and rip-up clasts. Grains identified by Bogen (1985) include augite, plagioclase, and hornblende, with lithic fragments of volcanic rock, and rip-up clasts of fine tuff and lava. Unit up to 700 m thick, with a gradual transition from the underlying Jasper Point Formation over the lower 50-100 m.

Jasper Point Formation (Early Jurassic to Late Triassic)

JTRjb **Jasper Point Formation, chert member (Early Jurassic to Late Triassic)—**Described by Bogen (1983) as varicolored radiolarian chert in layers typically 3-10 cm thick. Radiolarians abundant in lower parts of unit. Also includes manganiferous and ferruginous lenses and fine tuff up to 100 m thick. Gradational contact with overlying Peñon Blanco Formation with increasing tuff.

JTRjc **Jasper Point Formation, basalt member (Early Jurassic to Late Triassic)—**Described by Bogen (1983) as massive, pillowed, and brecciated basalt; pillow structures about 30x40 cm are common. Unit is up to 900 m thick.

JTRs **Sullivan Creek terrane, undifferentiated (Jurassic or Triassic)—**Distinguished locally, includes:

JTRsi **Sullivan Creek terrane, hypabyssal intrusive porphyry member—**Intruded within J^s. Reported by Herzig and Sharp as predominantly mafic minerology with many of the primary minerals having been lost during metamorphism.

JTRsv **Sullivan Creek terrane, volcanic member—**Described by Herzig and Sharp as pillow lavas, volcaniclastic breccias, crystal tuffs, minor argillite and argillite-matrix breccias, rare vesicular lavas. Primary mineralogy includes plagioclase, clinopyroxene, and uncommon hornblende, unit is highly deformed.

Mzsp **Serpentinite—**Described by Eric and others (1955) as massive, dark-green to almost black, weathering to lighter-green and buff. The weathering clearly discloses the minute magnetite veinlets that are distributed throughout the rock. Bastite pseudomorphs are common in the massive serpentine. The serpentine is intensely sheared along major faults. Irregular rounded pods of massive serpentine, ranging from an inch to 3 feet in diameter, are suspended in a matrix of crushed and granulated serpentine. The surfaces of the rounded serpentine pods are highly slickensided and polished, contrasting strongly with the dull massive unsheared rock.

MzPzcc **Calaveras Complex (Mesozoic or Paleozoic)—**Described by Morgan (1976) as thick monotonous sequences of siliceous graphitic slate and fine-grained poorly bedded chert, consisting predominantly of quartz with abundant biotite and minor graphite, albite, and muscovite; graphite is locally abundant in thin beds. Intraformational conglomerates and thin actinolite-epidote units of probable pyroclastic origin are present throughout the formation. Maximum depositional age is Jurassic based on recent detrital zircon studies (e.g., Attia and others, 2018). Also includes:

Pzcm **Marble—**Mapped locally within the Calaveras Complex by Hart (1959) and Higgins (1997); described by Hart (1959) as variable in composition, ranging from nearly pure calcite to nearly pure dolomite. Dolomite is mostly in masses as partial (disseminated) to nearly complete replacements of the limestone, but occurs as relatively pure bands, fingers, and feathers in the limestone. The limestone is medium- to coarsely crystalline, even textured, and commonly exhibits contorted, discontinuous, sometimes indefinite, dark-gray bands. The dolomite is equigranular, with a fine- to medium texture. Where closely associated, the dolomite crystals are almost invariably smaller than the calcite crystals. Most of the dolomite displays dark-gray, parallel to acutely crossing streaks that probably represent shear planes (cleavage) along which graphite, pyrite, mica, or other minerals have been concentrated. It is probable that most of these shear planes coincide with the narrow grooves seen on the weathered surfaces of the dolomite. The carbonate rocks commonly display cleavage (shear or flow) or a very crude schistosity which is generally parallel to the local contacts and to schistosity of the adjacent rocks. In addition to calcite and dolomite, common minor constituents of the carbonate rocks include graphite and quartz, and lesser amounts of pyrite, garnet, mica, feldspar, apatite, and other minerals. Tremolite, garnet, diopside, and other contact metamorphic minerals exist locally near dikes and veins. Outcrops are commonly white- to gray-blue in color and exhibit elephant-skin texture. Dissolution pits and cavities are common.

Tuolumne Ultramafic Complex (descriptions from Morgan, 1976)

Pzw **Wehrlite (Early Jurassic or older)—**Brecciated clinopyroxene-olivine cumulates ranging from serpentinized dunite to wehrlite and clinopyroxenite; wehrlite is the predominant rock type. Olivine is the cumulate phase; clinopyroxene and rarely hornblende are intercumulate phases. Saleeby (1982) gives a U/Pb age of 280 ± 3 Ma.

Pzh **Harzburgite (Mesozoic or Paleozoic?)—**Coarse-grained, dark-green- to gray-green rocks with prominent orthopyroxene (1-10 mm) and olivine (1-5 mm) crystals and minor chromite; partly (10 percent) to entirely serpentinized to mesh textured lizardite and chrysotile, magnetite, and minor edenite hornblende. Mapped as part of the Tuolumne ultramafic complex and as isolated masses along the Melones fault zone by Morgan (1976); masses along the Melones fault zone are described as completely serpentinized dark green rocks with prominent orthopyroxene pseudomorphs.

Pzdu **Dunite (Mesozoic or Paleozoic?)—**Coarse-grained (1-10 mm), dark-green olivine and minor chromite rocks partly (10 percent) to entirely serpentinized to antigorite magnesite-magnetite with minor (and perhaps earlier) lizardite-chrysotile serpentinization. Unit contains some harzburgite in the Moccasin 7.5’ Quadrangle area.

Pzac **Garnet Amphibolite and Chert (Early Jurassic or older)—**Coarse-grained (3-7 mm) garnet, amphibole, albite, and rutile, partly to entirely replaced by chlorite and epidote; rocks are of basaltic composition. Coarse grained (l- 6 mm) quartz makes up 95 percent (by volume) of the chert; minor epidote, garnet, magnetite, and riebeckite make up the remainder. Amphibolite and chert occur only as tectonic blocks within dunite. Morgan (1976) gives a K-Ar age on amphibole from amphibolite of 200 ± 10 Ma.

Pzsf **Shoo Fly Complex (Paleozoic)—**Described by Higgins (1997) as quartzite, quartzofeldspathic gneiss, and gneissic granitoids, with lesser amounts of schist, calc-silicate rock, marble, and amphibolite, all of Paleozoic age (Merguerian, 1985a, 1985b; Schweickert and others, 1988). Locally may include plutonic rock, of Paleozoic or Mesozoic (Sierra Nevada Batholith) age. Areas of augen gneiss (Pzsg) represent Paleozoic plutonic rock intruded into the metasedimentary rock, as mapped by Merguerian (1985a, 1985b). In the transition area where the Sierra Nevada Batholith intrudes the Shoo Fly Complex, it is commonly unclear whether the plutonic rocks observed in the field or shown on geologic maps are Paleozoic or Mesozoic; this situation will be resolved as future field mapping and radiometric age-dating of these rocks is completed. Includes occurrence described by Herzig and Sharp as Unit 3 of the Sullivan Creek Terrane.

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Imagery

Google Earth imagery, 2021-2022 (source, age and resolution varies)

U.S. Department of Agriculture, 2020, Farm Service Agency-Aerial Photography Field Office, National Agriculture Imagery Program (NAIP), 60cm resolution. http://datagateway.nrcs.usda.gov/

Lidar Datasets

2011 Calaveras and Tuolumne Counties dataset; collected 2012; QL 2; USGS 3DEP.

2019 Tuolumne County dataset; collected 2019; QL unknown; Tuolumne County.

2013 Yosemite Rim Fire dataset; collected 2014; QL 2; USFS, NPS and USGS.

2017 East Sacramento Foothills NRCS dataset; collected 2018; QL 2; USGS 3DEP.

2008-2010 Central Valley Floodplain Evaluation and Delineation (CVFED) Program dataset; collected 2010; QL 3; not in public domain.

AUTHORSHIP DOCUMENTATION AND PRODUCT LIMITATIONS

PUBLICATION TITLE: PRELIMINARY GEOLOGIC MAP OF THE OAKDALE 30’ x 60’ QUADRANGLE, CALIFORNIA: PRELIMINARY GEOLOGIC MAP 22-09.

LIMITATIONS: This map is considered preliminary, and the California Department of Conservation makes no warranties as to the suitability of this product for any given purpose. This map should not be considered as an authoritative or comprehensive source for landslide and seismic hazard data. For landslide data, please visit the California Geological Survey Landslides web page at: https://www.conservation.ca.gov/cgs/landslides. For seismic hazards data and Zones of Required Investigation, please visit the California Geological Survey Seismic Hazards Program web page at: https://www.conservation.ca.gov/cgs/sh/program.

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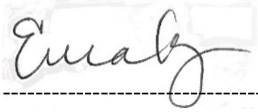

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