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

Scale 1:100,000

By

Chris J. Wills, Matt D. O’Neal, Peter J. Holland, and Erica L. Key

2022

California
Department of Conservation
California Geological Survey

Preliminary Geologic Map 22-10

CALIFORNIA GEOLOGICAL SURVEY

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Suggested citation:
Wills, C.J., O'Neal, M.D., Holland, P.J., and Key, E.L., 2022, Preliminary Geologic Map of the Merced 30' x 60' Quadrangle, California: California Geological Survey Preliminary Geologic Map 22-10, scale 1:100,000.

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Introduction

The Merced 30’x 60’ Quadrangle covers 4,925 km² (1,901 mi²) of Stanislaus, Merced, Mariposa, Fresno and Madera counties, California (Fig. 1). The map area measures 89 km (55 mi) east-west and 55 km (34 mi) north-south. Elevations range from about 15 m (50 ft) on the floor of the San Joaquin Valley north of Hills Ferry, to over 853 m (2,800 ft) in the Sierra Nevada east of Catheys Valley. Physiographic features of the Merced 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 rugged slopes in the lower Sierra.

Geologic hazards in the area range from landslides in some of the weaker rock units and steeper slopes, to naturally occurring asbestos and potential sources of radon gas in some of the bedrock 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 better 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.

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. For this compilation, paper copies of existing geologic maps were scanned and converted into digital lines and polygons using Geographic Information Systems (GIS) software. The most detailed and accurate maps of a particular area were digitized.

In 1976, Denis Marchand of the USGS completed geologic maps of parts of 25 7.5’ quadrangles covering large portions of the western and central Merced 30’ x 60’ quadrangle (Fig. 1). The compiled geologic map sources in these areas were remarkably consistent because a single mapping method was applied by a single geologist. Similar methods were used for parts of eight quadrangles in the southwestern map area by William Lettis and published by the USGS in 1982. These maps from Marchand and Lettis use soils maps to distinguish areas underlain by different materials, then group soil units by material type and geomorphic position into geologic units. Despite similar methods, Marchand (1976a, 1976b and 1976c) and Lettis (1982) did not map geologic boundaries in exactly the same place in the areas where their maps overlap, nor did they use the same nomenclature for the units that they described. Inconsistencies between geologic sources are more significant in the eastern part of the quadrangle, where maps by Marchand (1976a, 1976b, 1976c and 1976d) emphasizing Quaternary units overlap with maps by others that emphasize bedrock units. Other inconsistencies include different terminology in naming geologic units and faults, along with occasional drafting errors and accuracy issues. Although the source maps have been accurately digitized, mapping errors by the original authors may still exist.

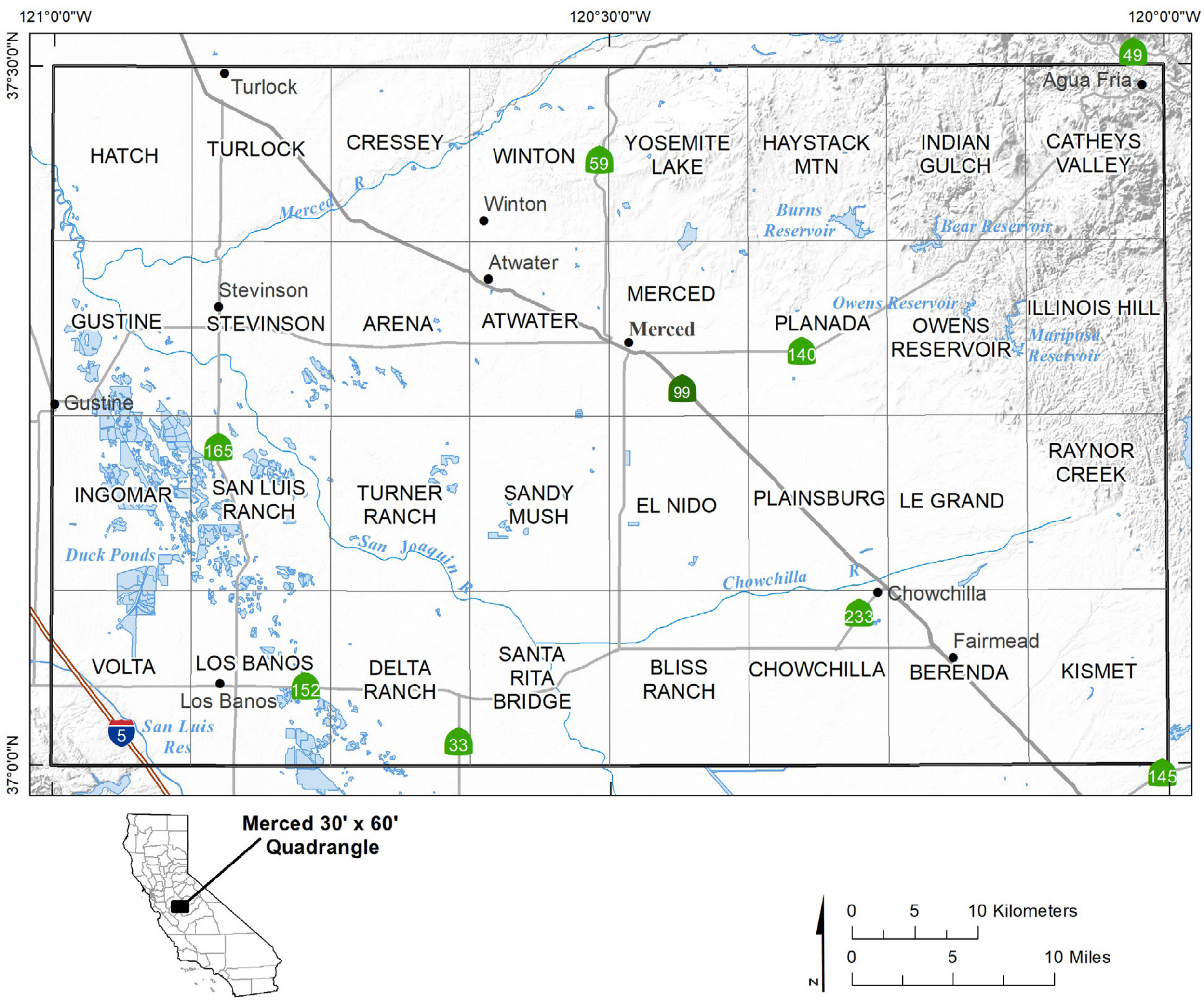

Figure 1. Map showing the study area location and index of 7.5’ quadrangles within the Merced 30’ x 60’ Quadrangle. DEM from U.S. Geological Survey

Compiled mapping was checked and revised primarily using lidar 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.

In preparation of this Preliminary Geologic Map, the detailed geodatabase compilation was prepared into the California Geological Survey’s GeMS Level 3 compliant geodatabase, according to the U.S. Geological Survey’s requirements, and retained as a separate geodatabase. Generalization processes were performed on a separate copy of the geodatabase to combine geologic contacts and features too small to be readable at 1:100,000 scale and includes merging / generalization of map sub-units and is used in preparation of this study

Sources of Geologic Mapping

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

Arena: Marchand, 1976b (1:24,000).

Atwater: Marchand, 1976b (1:24,000).

Berenda: Marchand, 1976d (1:24,000).

Bliss Ranch: Marchand, 1976d (1:24,000).

Catheys Valley: Best, 1961 (scale undetermined); Best, 1963 (scale undetermined).

Chowchilla: Marchand, 1976d (1:24,000).

Cressey: Marchand, 1976a (1:24,000).

Delta Ranch: Lettis, 1982 (1:24,000).

El Nido: Marchand, 1976c (1:24,000).

Gustine: Marchand, 1976b (1:24,000); Lettis, 1982 (1:24,000).

Hatch: Marchand, 1976a (1:24,000).

Haystack Mtn: Marchand, 1976a (1:24,000); Paterson and others, 1991 (scale undetermined).

Illinois Hill: Best, 1961 (scale undetermined); Best, 1963 (scale undetermined).

Indian Gulch: Marchand, 1976a (1:24,000); Best, 1961 (scale undetermined); Best, 1963 (scale undetermined); Paterson and others, 1991 (scale undetermined).

Ingomar: Lettis, 1982 (1:24,000).

Kismet: Marchand, 1976d (1:24,000).

Le Grand: Marchand, 1976c (1:24,000).

Los Banos: Lettis, 1982 (1:24,000).

Merced: Marchand, 1976b (1:24,000).

Owens Reservoir: Marchand, 1976b (1:24,000); Best, 1961 (scale undetermined); Best, 1963 (scale undetermined).

Plainsburg: Marchand, 1976c (1:24,000).

Planada: Marchand, 1976b (1:24,000).

Raynor Creek: Marchand, 1976c (1:24,000); Ehrreich, 1965 (scale undetermined).

Sandy Mush: Marchand, 1976c (1:24,000).

San Luis Ranch: Marchand, 1976c (1:24,000); Lettis, 1982 (1:24,000).

Santa Rita Bridge: Marchand, 1976d (1:24,000); Lettis, 1982 (1:24,000).

Stevinson: Marchand, 1976b (1:24,000).

Turlock: Marchand, 1976a (1:24,000).

Turner Ranch: Marchand, 1976c (1:24,000); Lettis, 1982 (1:24,000).

Volta: Lettis, 1982 (1:24,000); Dibblee and Minch, 2007 (1:24,000).

Winton: Marchand, 1976a (1:24,000).

Yosemite Lake: Marchand, 1976a (1:24,000).

Regional Geology

The Merced 30’ x 60’ quadrangle spans three physiographic provinces: the Coast Ranges province in the southwest, the Great Valley province in the central map area, and the Sierra Nevada province in the northeast (Fig. 2; Jenkins, 1938; Norris and Webb, 1990). In a regional tectonic context, the map area is mostly 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). The Bears Mountains Fault Zone which occurs in the eastern portion of the map area is regional feature that was mostly active in the Mesozoic however there have been locations north of the map area where it has been partially reactivated during the Quaternary. In the southwest corner of the map area is tectonically more active as the Coast Ranges have been uplifted due to transpressional movement along the San Andreas Fault System (Page and others, 1998)

The Great Valley physiographic province represents the bulk of the map area. Within the quadrangle, this province is underlain by gently dipping sedimentary rocks and surficial deposits ranging in age from Eocene to Quaternary, which overlie Mesozoic metamorphic, sedimentary, and plutonic basement rocks at depth. The older (Eocene to Pliocene) rocks predominantly crop out along the eastern margin of the valley, with the bulk of the valley covered by onlapping Quaternary rocks and surficial deposits.

The Sierra Nevada province within the quadrangle is dominated by Mesozoic metamorphic and plutonic basement rocks, with a minor, discontinuous cover of Cenozoic sedimentary and volcanic rocks. Tertiary rocks, present along the western margin of the range, consist largely of erosional remnants of once-continuous fluvial sediments and volcanic flows deposited in paleo-river channels before uplift of the range. Quaternary surficial deposits are present more extensively within the range. Alluvial sediments deposited along modern streams are present discontinuously. Alluvial and debris flow fans and landslides are present locally but are often too small to be shown at map scale. Bedrock in the quadrangle records assembly of California at the western edge of the North American continent from late Paleozoic through Jurassic time. The oldest rocks may represent subduction zones, island arcs, and fragments of oceanic crust and mantle that were accreted to North America in Mesozoic time. Some structural blocks may represent distinct (exotic) terranes that formed far from North American 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. Metamorphic rocks were intruded by plutons of the Sierra Nevada Batholith during Jurassic and Cretaceous time. An example includes the Jurassic Guadalupe Igneous Complex, a zoned pluton including layered gabbro at the base, and granophyre at the top.

The Coast Ranges physiographic province is underlain by Cretaceous sedimentary rocks exposed in the southwest corner of the Quadrangle. These sedimentary rocks were deposited in a forearc setting, and generally have a homoclinal easterly dip. The eastern flank of the Coast Ranges is accompanied by broad, gently sloping, alluviated, plateau-like surfaces that have been slightly uplifted along unremarkable marginal faults (Page and others, 1998).

Middle to Late Jurassic Metasedimentary and Volcanic Rocks

The Merced Quadrangle includes tectonite rocks of the Melones Fault Zone in the extreme northeast corner, where the metasedimentary and metavolcanic units correspond to what is referred to as the “overlap sequence” which is present in the Oakdale 30’ x 60’ Quadrangle to the north. West of

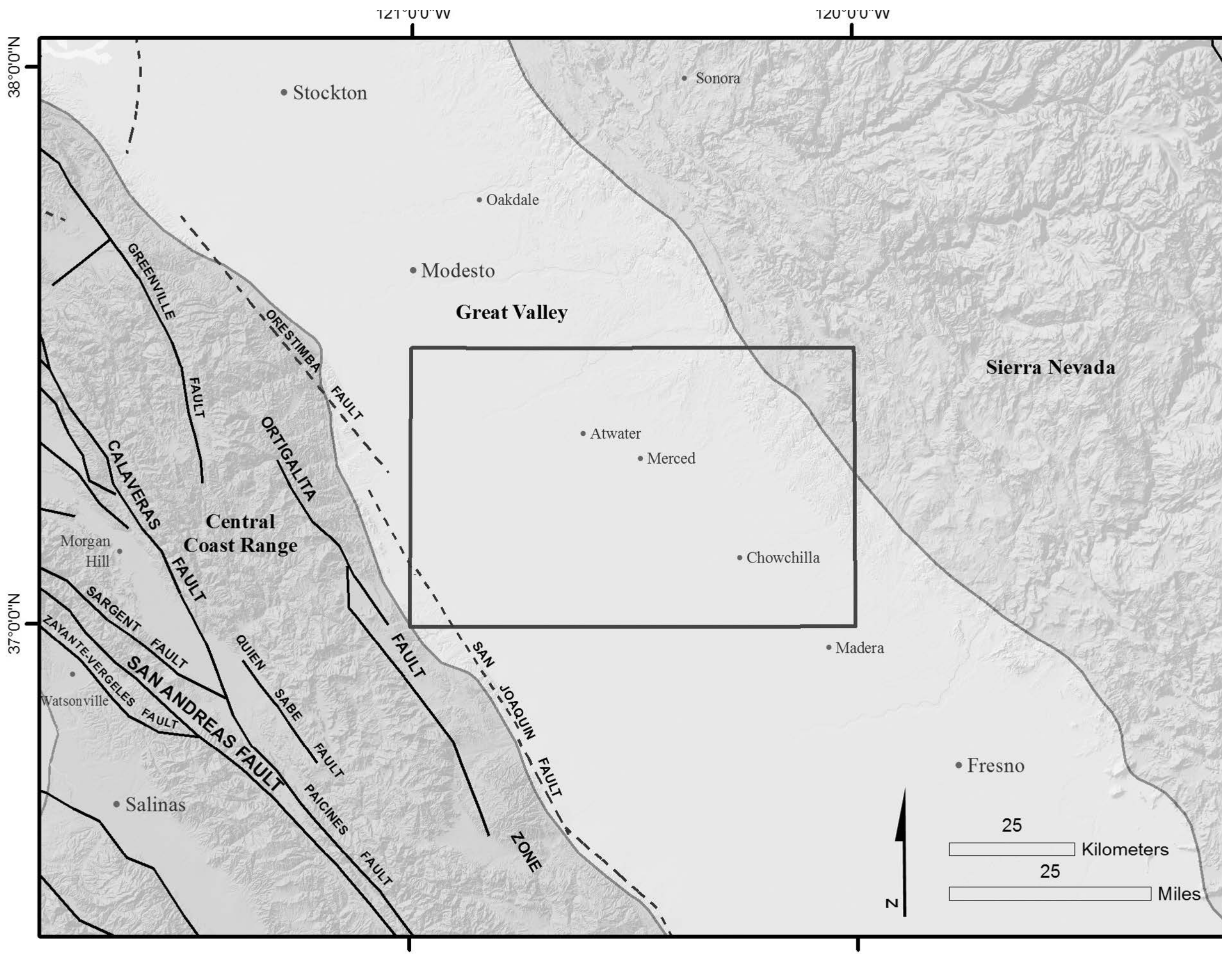

Figure 2. Map of physiographic provinces.

the Melones Fault Zone is an extensive belt of metasedimentary and metavolcanic rocks that extend north and south from the Merced Quadrangle along the foothills of the Sierra Nevada. This sequence has metavolcanic rocks at its base, overlain by metasedimentary rocks that are overlain locally by another unit of metavolcanic rocks. The basal metavolcanic rocks of the “overlap sequence” represent a volcanic arc or arc sequence. These are called the Logtown Ridge volcanics east of the Bear Mountains Fault Zone and the Gopher Ridge volcanics to the west. The overlying metasedimentary rocks are similarly called the Mariposa Formation east of the Bear Mountains Fault Zone and the Salt Spring Slate to the west. 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 volcanic island arcs. The differences in nomenclature on either side of the Bear Mountains Fault Zone reflects the interpretation that the fault zone may have significant displacement. Schweickert and others (2015) interpret the Logtown Ridge Formation as being derived from a different island arc from the Gopher Ridge volcanics.

Plutonic Rocks

The metamorphic rocks in the northeastern Merced 30’x 60’ Quadrangle are intruded by plutonic rock of the Sierra Nevada Batholith. Several of the plutons in the area were emplaced in the Late Jurassic (ca 150 Ma) indicating that accretion and deformation of the metamorphic belts was essentially complete

Figure 3. Photograph showing magma mixing textures in the heterogeneous mixing zone of the Guadalupe Igneous Complex, in an outcrop along Old Highway Road.

by that time. The Bear Mountains Fault Zone is mapped along the boundaries of the Hornitos Pluton and Guadalupe Igneous Complex, both of which are more sheared closer to the fault, indicating that movement on the fault extended at least into the Jurassic (Paterson and others, 1991).

The Guadalupe Igneous Complex (GIC) has been the focus of studies for the last 60 years (e.g. Ratschbacher and others, 2018). As summarized by Ratschbacher and others (2018), the GIC is 151 ± 2 Ma and has intruded into Jurassic sedimentary and volcanic rocks only a few million years older than it. An interesting aspect of the GIC is that it is compositionally stratified with gabbro at the base on the west side of the pluton. It grades upward into a heterogeneous melanocratic diorite and then into granite on the east. The heterogeneous intermediate zone features abundant magma mixing textures as shown in Fig. 3. The GIC experienced southwest-side-up tilting of about 28° after solidification.

Cretaceous Sedimentary Rocks

Cretaceous marine sedimentary rocks occur in the southwest corner of the quadrangle as part of the Great Valley Sequence. These include mostly fossiliferous sandstones and conglomerates that were deposited in a forearc setting. A similar small occurrence of upper Cretaceous sedimentary rocks has also been mapped in the eastern portion of the quadrangle.

Paleogene to Neogene Sedimentary and Volcanic Rocks

Paleogene to Neogene sedimentary and volcanic rocks crop out in the lower Sierra Nevada foothills along the foothill-valley transition. These deposits rest unconformably on Jurassic bedrock and are onlapped to the west by younger Pliocene to Quaternary sediments. These rocks were deposited in ancient river channels cut into and flowing over the igneous and metamorphic bedrock of the map area. The absence of mapped occurrences of these rocks further upslope indicates that their erosion in this area is complete. Three rock units, distinctive in age and composition, were deposited in these river channels.

The oldest Cenozoic rocks in this area belong to the Ione Formation. The Ione Formation sediments were deposited in a fluvial-deltaic-estuarine environment during the Eocene, and the distribution of Ione Formation outcrops approximately represents the Eocene shoreline. These rocks consist of quartzose sandstones, kaolin clay beds, and lesser siltstone and conglomerates. These sediments feature a relatively high compositional maturity, which is interpreted to reflect an intense tropical weathering regime operative at this time. The Ione Formation has been an important source of kaolin clay, especially north of the quadrangle in Amador County.

The Valley Springs Formation overlies the Eocene sediments and consists 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 river channels. These channels extended far to the east, with their headwaters in what is now central Nevada, and drained a high elevation plateau (termed the Nevadaplano) (DeCelles, 2004). The ash-flow tuffs within this unit erupted from a belt of supervolcanoes in central 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, which consists predominantly of debris flow deposits (commonly interpreted as lahars) and fluvial sediments deposited in river channels which flowed westward across the range. These materials are conspicuously composed almost exclusively of volcanic material of intermediate composition (especially andesite). This volcanic material was erupted from a chain of volcanoes running approximately along the modern Sierran Crest which represents subduction arc volcanism of the Ancestral Cascade Arc.

Pliocene to Quaternary Sedimentary Deposits

Much of the Merced 30'x 60' quadrangle is underlain by Quaternary (and lesser Pliocene) sedimentary rocks and unconsolidated surficial deposits. Excepting minor input from the Coast Ranges in the southwestern map area (discussed in the following paragraph), these sediments were 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 (listed from oldest to youngest): 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 the Quaternary, the formations are tilted at different angles. The (youngest) 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 (Holocene) deposits are found in the lowest, western part of the valley and along modern river channels 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. Artificial fill, including engineered fill for dams and other structures, and deposits of 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.

Similar to the Quaternary sedimentary units that originate from the Sierra Nevada, there are units that originate from the Coast Ranges and were deposited in the southwestern portion of the map, west of the San Joaquin River. These units have different names from the units on the east, which reflect their differing composition and somewhat different age ranges. Lettis (1982) is the primary source for these units and interprets that the deposition of these units resulted primarily from climactic change rather than intermittent uplift of the Diablo Range.

Fault Zones

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). 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 and was active from the Middle Jurassic into Early Cretaceous (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 transform motion can also be inferred, but the amount of displacement is not known (Miller and Paterson, 1991).

O’Neill and San Joaquin Faults

The O’Neill Fault Zone and San Joaquin faults, both in the southwest corner of the quadrangle, displace Quaternary alluvium which is commonly overlain by unfaulted late Pleistocene and Holocene alluvium (Lettis, 1982). Vertical displacement of the O’Neal Fault is estimated up to 100 meters while vertical displacement for the San Joaquin Fault system ranges from 0 to 140 meters (Lettis, 1982).

Economic Geology

Historically mined commodities within the Merced quadrangle include gold and aggregate (Fig. 4). Cement was not mined in the area but was manufactured at a plant operated by the Yosemite Portland Cement Corporation 2 miles north of Merced (Davis and Carlson, 1952).

Placer Gold

Most rivers and streams sourced from the Sierra Nevada contain some gold. Gold produced in the quadrangle was primarily from placer gold deposits (Fig. 4 and 5) that were mined using bucket dredges. The Snelling dredge field 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 (after the introduction of the continuous bucket-line dredge) and continued until the early 1950s. The dredged area at Snelling is about nine miles long and 1/2 to 1 1/2 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 have also been recovered as a byproduct of the gold dredging process (Clark, 2005).

Currently, gold dredge tailings from the Snelling dredge field are mined for aggregate. Calaveras Materials, Inc. presently mines the aggregate for use in asphalt, however testing shows that with the appropriate processing this material could also be used in concrete. Other aggregate mining operations in the area sell the dredge tailings for use as base rock and road base (Parrish, 2021).

Copper

The copper, zinc, and lead deposits of the Foothill Copper Belt (Fig. 4) are volcanogenic massive sulfide deposits occurring in Middle to early Late Jurassic marine terranes of the Sierra Nevada foothills

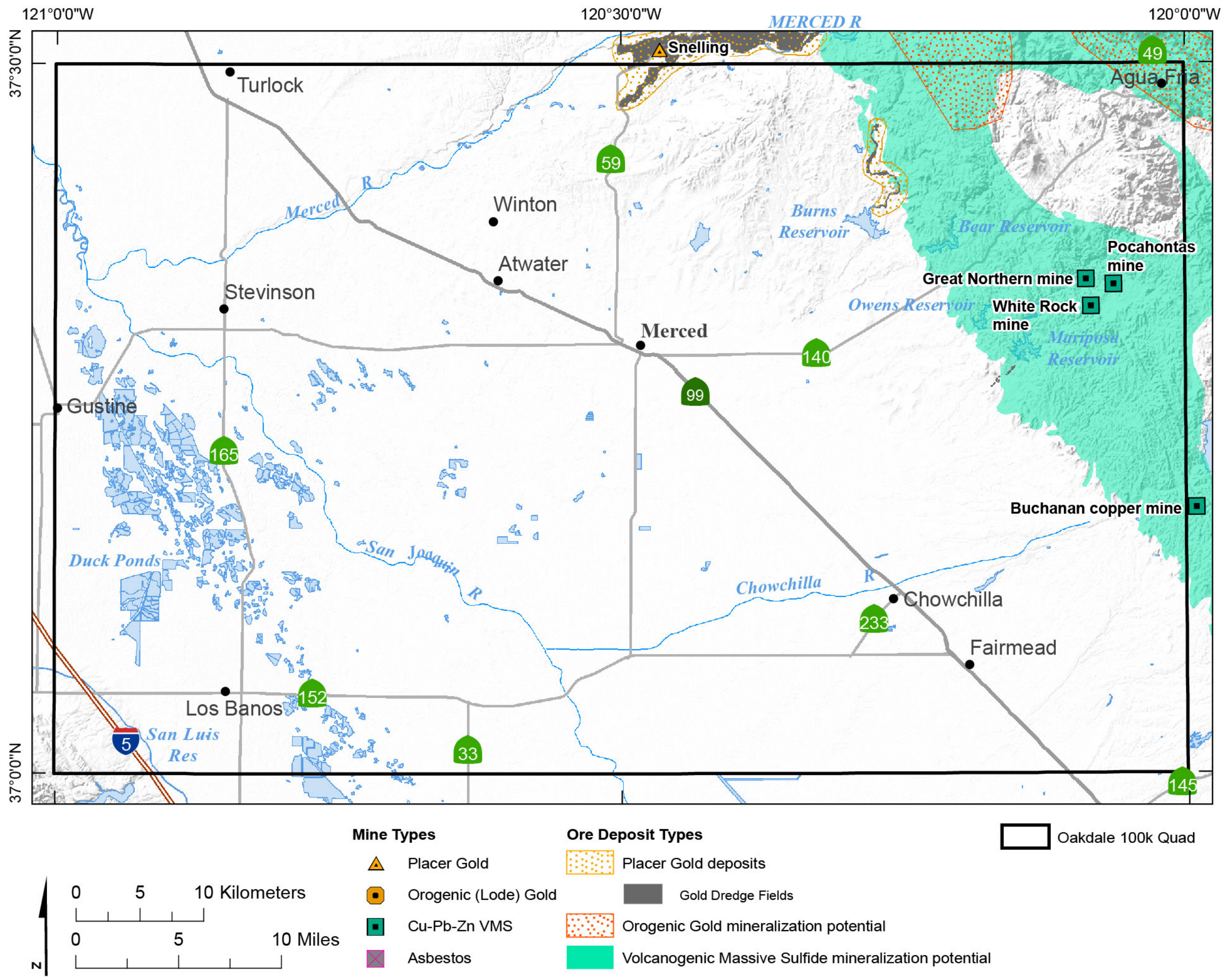

Figure 4. Map showing mineral resource potential and major mines within the Merced 30' x 60' quadrangle.

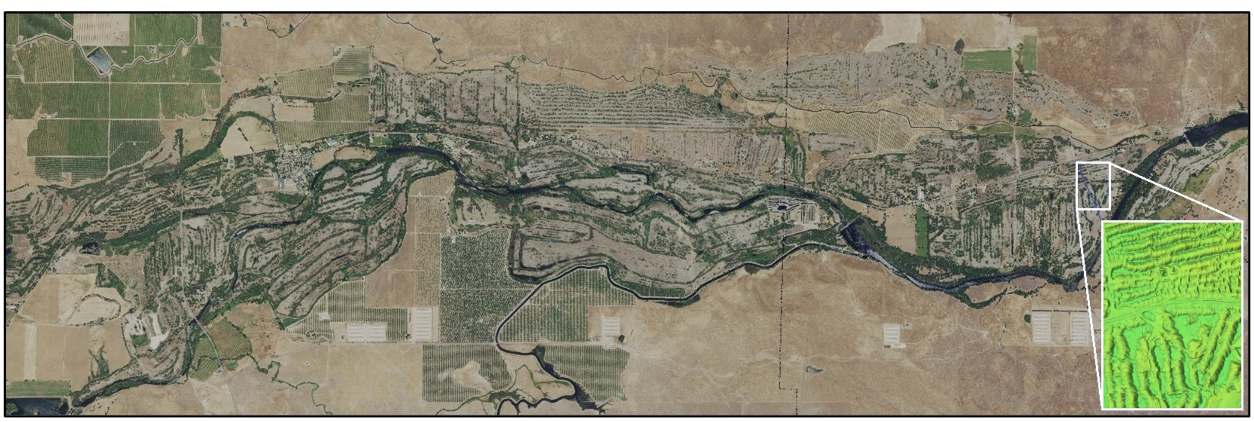

Figure 5. Aerial photo of a portion of the Snelling dredge field, on the Merced River. Arcuate pattern of tailing windrows (visible in photo inset) is produced by the dredge stacker oscillating back and forth ejecting coarse sediments (gravel and boulders) as the dredge moves forward. Finer material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

(Barton and others, 2011; Martin, 1988). The Pocahontas mine was the most productive copper mine in Mariposa County and produced more than 700,000 pounds of copper. The Pocahontas deposit was discovered in the early 1860s but was not mined until the early 1900s (Bowen and Gray, 1957).

Copper mineralization at the Pocahontas mine is concentrated in a shear zone which strikes N 35°- 45° W and dips northeast at angles between 65° and 80°. The primary sulfide ore zones occur in brecciated and silicified lenticular masses. Much of the ore is a dark blue, massive, fine-grained rock composed predominantly of chalcopyrite, pyrite, sphalerite, and pyrrhotite. The sulfide ore typically ran 6-12% copper. A secondary oxidized ore zone parallel to the main sulfide ore zone consists primarily of malachite, chrysocolla, and azurite, and averaged 30-35% copper (Bowen and Gray, 1957).

Aggregate

Currently, gold dredge tailings from the Snelling dredge field are mined for aggregate. Calaveras Materials, Inc. presently mines the aggregate for use in asphalt, however testing shows that with the appropriate processing this material could also be used in concrete. Other aggregate mining operations in the area sell the dredge tailings for use as base rock and road base (Parrish, 2021).

Geologic Sites of Interest

Fossil Discovery Center

Though not a geologic feature, the Fossil Discovery Center of Madera County located in the City of Chowchilla, hosts a collection of Middle-Pleistocene (780,000 years ago) vertebrate fossils mostly recovered from the nearby Fairmead Landfill. Their collection includes Mammoth, Smilodon, Sloth, Dire Wolf, Camel and Horse fossils, among many others. This fossil assemblage was recovered from sediments of the Turlock Lake and Riverbank Formations described in the next section.

Magma Mixing Textures along Old Highway Road

The Guadalupe Igneous Complex (GIC) crops out well along Old Highway Road running east from Highway 140 through Catheys Valley. These outcrops show various lithologies of the GIC (described below). Especially in the stretch of road east of Stonehouse (including the Bull Run Valley area), many outcrops exhibit magma mixing textures (Fig. 3) resulting from the mixing of two hot, fluid magmas of differing compositions. The lighter and darker colored parts of the rocks in this area represent the two different magmas, which have differing compositions. The lighter parts of the rock represent a more felsic (higher in silica, lower in magnesium and iron) magma that is granitic in composition. The darker parts of the rock represent a more mafic (higher in magnesium and iron, lower in silica) magma that is gabbroic in composition.

Snelling Dredge Field

A relatively minor portion of the Snelling Dredge Field extends into the Merced 30’ x 60’ Quadrangle from the north and is visible along HWY 59 and Snelling Road near the quadrangle boundary. Gold dredging within this field was active intermittently from 1907 to 1952 (Clark, 2005). Gold recovered is estimated at $17M. Gold dredging was a major method of placer gold recovery during the California Gold Rush and during some years, the dominant source of gold statewide. Gold dredging in California picked up about a decade after the curtailment of hydraulic mining (the other major method of placer gold recovery). Dredge fields changed the landscape significantly, by churning sediments and bring deeper sediments up to the surface, sorting them, and redepositing them in alternating layers of fine sediments and coarse gravels. The most visible remnant of dredging are the massive fields of dredge tailings. In some areas these tailings have been graded and residential and commercial developments have been constructed upon them. In other areas (including within the Snelling dredge field) the tailings are actively mined as a source of concrete-grade construction aggregate.

Schist and Copper Mineralization at the Buchanan Townsite

The historic Buchanan Town Site is located about one mile east of the quadrangle boundary near Eastman Reservoir. This town and several others northwest of this site and within the Merced 30’ x 60’ Quadrangle are situated along the NW-SE structural trend of the metamorphic rocks in the region. This town and others formed around significant copper mines which exploited Cu-Zn-Pb mineralization of the Foothills Copper Belt (Fig. 4). The rocks near the Buchanan Town Site are predominantly schist, which represents a higher grade of metamorphism than that present in the same geologic units along trend to the northwest. This higher grade of metamorphism resulted from the nearby intrusion of the Leucotonalite North of Eastman Lake (Bateman and others, 1982) which intruded the Jurassic metamorphic rocks in the Cretaceous, and “baked” the lower-grade slates and argillites.

Description of Map Units

The arrangement of map unit descriptions below roughly illustrates the correlation of map units among different tectonic blocks. The map area includes parts of three geomorphic provinces: the Coast Ranges, Great Valley, and Sierra Nevada, and several bedrock structural blocks as described above.

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. Where informal subunits are represented by subscripted numbers, numbers increase with decreasing age (i.e., of subunits 1-4, 1 is the oldest and 4 is the youngest). Some compiled mapping, especially of Quaternary deposits, was simplified for display at the 1:100,000 map scale but was retained in the detailed database.

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. Only large deposits are shown.

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 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 (1976a, 1976b, 1976c and 1976d) have divided this unit into subunits based on relative position to modern stream channels.

Qhb **Basin deposits (Holocene)—**Fine grained basin deposits consisting mostly of silt and clay.

Qhe **Eolian deposits (Holocene)—**Fine sand deposits associated with modern dunes.

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

Patterson alluvium (early Holocene to modern)—Young alluvial fans on the west side of the valley mapped by Lettis (1982). Includes:

Qhp **Patterson alluvium, proximal fans (early Holocene to modern)—**Coarse-grained sediments derived from the Coast Ranges and deposited on alluvial fans.

Qhpc **Patterson alluvium channel deposits (early Holocene to modern)—**Coarse-grained sediments derived from the Coast Ranges and deposited in channels on alluvial fans.

Qhpf **Patterson alluvium, medial and distal fans (early Holocene to modern)—**Fine-grained sediments derived from the Coast Ranges and deposited on alluvial fans.

San Luis Ranch alluvium (Latest Pleistocene and early Holocene)—Alluvial fans on the west side of the valley mapped by Lettis (1982). Includes:

Qsu **San Luis Ranch alluvium, coarse upper member (Latest Pleistocene and early Holocene)—**Coarse-grained sediments derived from the Coast Range and deposited as terraces and upper parts of alluvial fans.

Qsuf **San Luis Ranch alluvium, fine upper member (Latest Pleistocene and early Holocene)—**Fine-grained sediments derived from the Coast Range and deposited as middle and lower-fan and floodplain deposits.

Qsm **San Luis Ranch alluvium, coarse middle member (Latest Pleistocene and early Holocene)—**Coarse-grained sediments derived from the Coast Range and deposited as terraces and upper parts of alluvial fans.

Qsmf **San Luis Ranch alluvium, fine middle member (Latest Pleistocene and early Holocene)—**Fine- to coarse-grained sediments derived from the Coast Range and deposited as mudflows.

Qsl **San Luis Ranch alluvium lower member (Latest Pleistocene and early Holocene)—**Coarse-grained sediments derived from the Coast Range and deposited as terraces and upper parts of alluvial fans.

Los Banos alluvium (middle and late Pleistocene)

Qplu **Los Banos alluvium upper member—**Coast Range derived sand and gravel. Youngest geomorphically distinguishable alluvial unit and situated in the lowest topographic position of the three members.

Qplm **Los Banos alluvium middle member—**Coast Range derived sand and gravel. Geomorphically the middle terrace of the three Los Banos units.

Qpll **Los Banos alluvium lower member—**Coast Range derived sand and gravel. Oldest geomorphically distinguishable alluvial unit of the Los Banos Alluvium and situated in the highest topographic position of the three members.

Modesto Formation (Late Pleistocene)

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.

Qmub **Modesto Formation upper member, basin deposits (Late Pleistocene)—**Alluvial sand, silt, and clay of interdistrubutary areas, lower fans and floodbasins, commonly stratified. Generally mapped as Dinuba soil.

Qme **Modesto Formation, eolian deposits (undifferentiated) (Late Pleistocene)—**Arkosic eolian sand associated with subdued, stabilized dunes generally mapped as Atwater 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, basin deposits (Late Pleistocene)—**Alluvial sand, silt and clay of interdistributary areas, lower fans, and floodbasins, commonly stratified. Generally mapped as Fresno, Waukena, Dinuba, Traver, Pond and Rossisoils.

Qr **Riverbank Formation, undifferentiated (Late Pleistocene)—**Arkosic sand, silt and minor gravel forming alluvial fan remnants.

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

Qrm **Riverbank Formation, middle member (Late Pleistocene)—**Arkosic sand forming terraces along the Stanislaus River. Contains alluvial gravel, glacial outwash from the 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 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.

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.

Pl **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 oxidized gravels. The iron oxidation is both surficial and internal within the clasts.

Plc **Laguna Formation, China Hat Gravel member (Pliocene)—**Thick cobble gravel and granitic matrix and interbedded granitic sand and minor silt; uppermost member of Laguna Formation, exposed through topographic inversion of an old alluvial distributary system south of the Merced River. Generally mapped as Redding and Corning soils.

Cenozoic Sedimentary and Volcanic Deposits

PlMm **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.

MOgvs **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 (MOgvs?) 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.

Ei **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.

Sedimentary rocks of the Great Valley Sequence

Km **Moreno shale (Cretaceous)—**Gray, poorly bedded, weak, micaceous, argillaceous claystone (Dibblee and Minch, 2007). At its type locality, about 25 miles south of the Merced 30'x 60' Quadrangle, Anderson and Pack (1915) describe the Moreno Formation as composed predominantly of thin-bedded, rather brittle brownish and lavender-colored shales, that weather into small bits and flakes. In the lower part of the formation there are numerous beds of sandstone, locally containing poorly developed concretions and in general similar to the sandstone of the Panoche formation. The contact with the underlying Panoche Formation is reported to be gradational (Anderson and Pack, 1915).

Kp **Panoche Formation (Cretaceous)—**Dark gray, weak, micaceous, argillaceous claystone with thin interbeds of sandstone (Dibblee, 2007). At its type locality, about 25 miles south of the Merced 30'x 60' quadrangle, Anderson and Pack (1915) describe Panoche Formation shale as "dark-brown to black clay shale with local beds of thin-bedded light-brown sandstone, dark-gray to black calcareous layers, and yellow calcareous nodules."

Kps **Panoche Formation (Cretaceous)—**Sandstone layers, light gray to light brown, well bedded, hard, fine- to medium-grained arkosic sandstone (Dibblee and Minch, 2007). At its type locality, about 25 miles south of the Merced 30'x 60' quadrangle, Anderson and Pack (1915) describe Panoche Formation sandstone as medium to fine grained massive sandstone, blue-gray when fresh but weathering to a light tawny yellow on exposure, formed very largely of angular or subangular grains of quartz and feldspar. It contains beds of clay shale and shaly sandstone alternating with the prominent sandstone beds.

Cretaceous to Jurassic Granitic Rocks

Kbl **Bass Lake Tonalite (Cretaceous)—**Bateman and others (1982) describes typical Bass Lake Tonalite as medium-gray, medium-grained, equigranular tonalite with a conspicuous foliation that is shown both by the preferred orientation of minerals, chiefly hornblende and biotite, and by crudely lens-shaped mafic inclusions. The Bass Lake Tonalite is exposed over a large area east of the Merced 30'x 60' quadrangle; extending into the eastern part of the quadrangle, where it intrudes the Guadalupe Igneous complex. One U-Pb age from within quadrangle indicates an age of 120.9 Ma. The central and eastern parts of the pluton are younger, with ages ranging up to 105 Ma (Lackey and others, 2014).

Kea **Leucotonalite North of Eastman Lake (Cretaceous)—**Fine-grained, but otherwise resembles and may be cogenetic with the Granodiorite of Knowles (Bateman and others, 1982). Poikilitic K-feldspar occurs sporadically in the interior of the body. Most of this unit is mapped immediately east of the map area in the Raymond 15' Quadrangle (Bateman and others, 1982).

Kwr **White Rock Pluton (Cretaceous)—**Biotite-hornblende tonalite. Saleeby and others (1989) report a U238/Pb206 zircon age of 123 Ma. Two small areas northwest of the main pluton, mapped by Best (1961) as quartz-monzonite, may be related.

Guadalupe Igneous Complex (Jurassic)—Originally mapped by Best (1961) as a layered pluton ranging in composition from gabbro at the base to granophyre at the top. The compositional zoning has been interpreted as the result of in-place fractionation of a melt with gabbroic layers settling to the bottom, granitic melts rising to the top, and a central zone of diorite and magma mixing. Saleeby and others (1989) report a U238/Pb206 zircon age of 151 Ma. See Putirka and others (2014) for a more complete description. Individual units include:

Jgb **Layered Gabbro (Jurassic)—**Gray-brown to black on fresh surfaces, but weathers readily as poorly exposed outcrops with deep reddish brown soil. Outcrops reflect northerly trending variations in grain size, and individual layers within the gabbro (Best, 1961). Samples analyzed by Best (1961) are 50-85% plagioclase, 5-35% clinopyroxene and up to about 10% orthopyroxene, olivine, or hornblende. Layering in gabbro generally trends northwesterly and dips to the east.

Jgd **Meladiorite (Jurassic)—**Within the Guadalupe Igneous Complex, Best (1961) describes the central zone as a meladiorite, which is gradational with the gabbro, but lacks the layering, is generally fine-grained and contains dominantly hornblende rather than pyroxene.

Jgm **Agmatite (Jurassic)—**The central Guadalupe Igneous Complex is described by Best (1961) as agmatite and by Putirka and others (2014) as a mingled zone composed of diorite, resembling the underlying unit to the west and granite resembling the overlying unit. Putirka and others (2014) interpret the contacts between different lithologies as indicating intrusion of gabbroic magmas into granitic rocks that were still at least partly molten. Best (1961) described this unit as typically consisting of dense, very fine-grained fragments of diabase and gabbro an inch to a few feet in diameter in a matrix of granodiorite to granite.

Jqm **Quartz Monzonite (Jurassic)—**Mapped by Best (1961) as part of the Guadalupe Igneous Complex where it forms resistant outcrops. The unit is described as composed of similar proportions of fine-grained anhedral grains of quartz, microcline and plagioclase, with up to 10 percent biotite and hornblende.

Jg **Granite (Jurassic) —**Within the Guadalupe Igneous Complex as described by Best (1961). Light-gray to buff, very fine-grained (0.2-0.5 mm), hard and resistant to weathering.

Jgp **Granophyre (Jurassic)—**Mapped by Best (1961) as part of the Guadalupe Igneous Complex and nearly indistinguishable from granite in outcrop or hand sample but shows complex intergrowths of quartz and potassium feldspar in thin section.

Jsg **Sodic Granophyre (Jurassic)—**Mapped by Best (1961) and distinguished from the adjacent granophyre by texture, very fine-grain size and characteristic white-to very light-gray color.

Jdb **Diabase (Jurassic)—**Fine-grained mafic metavolcanic rock occurs in scattered locations.

Jgh **Gabbro of the Hornitos pluton (Jurassic)—**Gabbro to hornblende tonalite. Described by Putirka and others (2014). Saleeby and others (1989) report a U238/Pb206 zircon age of 150 Ma.

Jmr **Metamorphic and heterogenous altered rock (Jurassic?)—**Described by Best (1961) from within and east of the Guadalupe Igneous Complex. Generally composed of quartz, plagioclase, and epidote but with a wide range of colors, textures and grain sizes, reflecting alteration of a variety of pre-existing rock.

Jag **Coarse altered gabbro (Jurassic?)—**Described by Best (1961) from an area east of the Guadalupe Igneous Complex. Original gabbro texture includes relict pyroxene grains up to 2-inch diameter, now altered to fibrous actinolite.

Jdi **Diorite (Jurassic)—**Includes diorite, and melanocratic diorite mapped by Best (1961). Other individual plutons described separately, including:

Jdilp **La Paloma pluton (Jurassic)—**Biotite leucotonalite mapped by Paterson and others (1991). Saleeby and others (1989) report a U238/Pb206 zircon age of 149 Ma.

Jdisc **Santa Cruz Mountain pluton (Jurassic)—**Hornblende tonalite with biotite granodiorite mapped by Paterson and others (1991). Saleeby and others (1989) report a U238/Pb206 zircon age of 147 Ma.

Jdicr **Courthouse Rock pluton (Jurassic)—**Biotite-hornblende diorite mapped by Paterson and others (1991). Saleeby and others (1989) report a U238/Pb206 zircon age of 146 Ma.

Jurassic Metasedimentary Rocks

Jss **Salt Spring Slate (Late Jurassic)—**Described as sericite slate with widespread greywacke and tuff, and some thin conglomerate layers by Clark (1964). Prior to Clark (1964) naming the formation, these rocks were mapped as Mariposa Formation (Turner, 1897; Taliaferro, 1943). 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). Within the quadrangle the Salt Spring Slate is described as a mica-quartz-feldspar schist, generally yellow-brown with intercalated siliceous schist (Best, 1961); and, Biotite-quartz-feldspar schist (Jsc) lithologic sub-unit described by Best (1961) and Ehrreich (1965) as schist derived from tuffaceous sediment. Originally well-sorted, fine-grained, lithologically uniform tuff, which has been metamorphosed to uniform gray schist with lenses of quartz and feldspathic lamellae.

Jsa **Salt Spring Slate, argillaceous sandstone (Late Jurassic)—**Metasandstone and slate described by Best (1961) as massive and poorly foliated with conglomeratic lenses, includes poorly sorted relict clastic grains of quartz and feldspar.

Jmp **Mariposa Fm (Jurassic)—**Metasedimentary rocks, slate and greywacke with lesser metavolcanic rocks. Bogen (1983) describes the protoliths as sandstone, mudstone, mixed sandstone and mudstone, and tuffaceous sandstone. These are reflected in the current metagraywacke, slate, and tuffaceaous metagraywacke. Metagraywacke (Jmss) consists of medium to coarse grained sandstone in beds from 0.2 to 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. Mudstone, now metamorphosed to argillite or slate, is massive or includes thin lamellae of silt, representing pelagic mud or distal turbidite deposits. The base of the Mariposa Fm was deposited on the Penon Blanco formation without noted angular discordance, although the hiatus between the formations may represent 30-40 Ma (Bogen, 1983). Total thickness of Mariposa Fm is estimated to be greater than 2,300 m (Bogen, 1983). Metasedimentary rocks east of the Bear Mountains Fault Zone are included with the Mariposa Formation, while those to the west are included with Salt Spring Slate, reflecting interpretation of Bear Mountains Fault as a suture separating different terranes.

Jmpa **Mariposa Formation schist (Jurassic)—**Mapped by Best (1963) near the Bear Mountains Fault Zone and described as yellow-brown friable mica-quartz-feldspar schist with intercalated platy siliceous schist.

Jgn **Gneiss (Jurassic?)—**Described by Best (1961) as hornblende-quartz-plagioclase gneiss with common compositional layering. Becomes finer grained and more micaceous to the southeast.

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. 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 Spring Slate by Wagner and others (1991), is now shown as mélange following Miller and Paterson (1991). Includes:

Jm-s **Mélange, metasedimentary member—**Biotite-quartz-feldspar schist. Described by Best (1963) as fine-grained, fairly massive; lithologically uniform except for small lenses of quartz & thin feldspathic laminae; derived from well-sorted tuffaceous sediment.

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-vs **Mélange, variegated schist member—**Quartz-feldspar variegated schist. Described by Best (1963) as: yellow-brown friable schist with intercalated platy siliceous schist.

Jgo **Gopher Ridge Volcanics (Late Jurassic)—**Described by Clark (1964) as 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. Named by Clark (1964) for exposures along the Calaveras River north of the quadrangle. Likely Oxfordian in age (Clark, 1964). Where queried, includes salic metavolcanic rocks mapped by Best (1961) described as micaceous metarhyolite, locally blastoporphoritic, and including muscovite schist and massive quartz-feldspar-epidote rocks.

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.

Jpb **Penon Blanco Fm (Jurassic)—**Volcanic and volcaniclastic rocks described by Bogen (1983) as flows, tuffs and tuff breccias with associated tuffaceous turbidite deposits. Generally fine grained, flows may be porphyritic with augite, plagioclase, and hornblende phenocrysts in a gray or greenish-gray microcrystalline matrix.

Mzsp **Serpentinite (Mesozoic?)—**Mapped along Melones Fault Zone in extreme northeast corner of quadrangle. Described by Eric and Cox (1948) as massive, dark green to almost black, weathering to lighter green and buff. 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

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Lidar Datasets

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.

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AUTHORSHIP DOCUMENTATION AND PRODUCT LIMITATIONS

PUBLICATION TITLE: PRELIMINARY GEOLOGIC MAP OF THE MERCED 30’ x 60’ QUADRANGLE, CALIFORNIA: PRELIMINARY GEOLOGIC MAP 22-10.

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This authorship document accompanies the geologic map with the following citation:

Wills, C.J., O’Neal, M.D., Holland, P.J., and Key, E.L., 2022, Preliminary Geologic Map of the Merced 30’ x 60’ Quadrangle, California: California Geological Survey Preliminary Geologic Map 22-10, scale 1:100,000.