

# SIERRA NEVADA EARTH SCIENCE ATLAS

## Geologic Data Map 9

Scale 1:400,000

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# CONTENTS

APPENDIX A: DESCRIPTION OF MAP UNITS .....	1
OVERLAP UNITS .....	1
Pliocene to Quaternary Surficial Units .....	1
Eastern Sierra Nevada.....	3
Long Valley Caldera Region .....	3
Broader Eastern Sierra and High Sierra Regions .....	7
Coso Region.....	8
Northern Sierra Nevada .....	10
Southern Sierra Nevada .....	19
BASEMENT.....	28
Underthrust Forearc and(or) Accreted Seafloor Rocks .....	28
Pelona Schist Terrane.....	28
Plutons and Intrusive Suites .....	29
Wall Rock .....	50
Sierra Crest-High Sierra-Kings Terrane Overlap .....	50
Kernville Terrane .....	51
Fault Zone Rocks .....	52
Kings Terrane (Early Cretaceous to Late Triassic).....	53
Merced River Terrane .....	54
Calaveras Complex.....	55
Kettle Rock Terrane .....	58
Cosumnes Terrane .....	60
Western Belt Subterrane.....	60
Mother Lode Subterrane .....	60
Moccasin Peak Subterrane.....	61
Yuba River Superterrane .....	62
Overlap Strata .....	62
American River Terrane .....	63
Slate Creek Terrane.....	65
Sierra Crest Terrane .....	67
Northern Sierra Terrane .....	69
Walker Lake Terrane.....	76
High Sierra Terrane.....	77
Bean Canyon Terrane.....	79
Tehachapi-San Emigdio Terrane.....	79
Snow Lake Terrane.....	79
White-Inyo Mountains Craton Margin Formations (Jurassic to Neoproterozoic).....	80
Twin Lakes Terrane .....	81
Feather River Terrane.....	82
Owens Terrane.....	83
El Paso Terrane .....	84
Eagle Rest Peak Terrane.....	85
Pastoria Terrane .....	86
REFERENCES.....	87
AUTHORSHIP DOCUMENTATION AND PRODUCT LIMITATIONS .....	115

## **PLATES**

PLATE 1A: GEOLOGIC MAP OF THE SIERRA NEVADA.....PDF

PLATE 1B: CORRELATION OF MAP UNITS..... SEE PDF

## APPENDIX A: DESCRIPTION OF MAP UNITS

This appendix provides a description of geologic map units for the Geologic Map of the Sierra Nevada (Plate 1A). Map units depicted on the geologic map use a labeling system that differs from conventional uppercase age and lowercase name found on the majority of published geologic maps. Geologic age is not used in the map unit labels, and capitalization is varied based on the unit type: lowercase for overlap units; uppercase G followed by lowercase for plutonic units; fully uppercase or uppercase with a single trailing lowercase for wall rock units. We do this for several reasons: to avoid having numerous similar labels (over 30 units would have labels that begin with K); to emphasize tectonostratigraphic association (the overlap Chico Formation, the Coloma pluton, and the wall rock Goldstein Peak Formation would all have labels that begin with K); to more closely associate units of different age within a given tectonostratigraphic unit (the Jurassic through Silurian units in the Northern Sierra Terrane are all labeled NS\_\_ instead of KJtt, JPst, J^ts, DPsb, ODSa, etc.); and to make the map more readable by reducing map clutter.

Detailed stratigraphic relations between geologic units described here and depicted on Plate 1A are shown on the correlation of map units diagram (Plate 1B).

### OVERLAP UNITS

Late Cretaceous to (dominantly) Cenozoic units separated from underlying basement by major range-wide unconformity.

### PLIOCENE TO QUATERNARY SURFICIAL UNITS

- aft**      **Artificial fill and mine tailings (Holocene)**—Artificial fill, including compacted engineered (e.g. dam fill), noncompacted nonengineered fills, and mine tailings of variable composition derived from a variety of mining processes (including dredging, hydraulic mining, and hard rock mining).
- al-y**      **Alluvium, young (Holocene to late Pleistocene)**—Young fluvial deposits occurring within active channels, adjacent younger alluvial terraces, and active alluvial fans. Minimally consolidated and dissected; grain size is variable and includes gravel (pebble to cobble and rarely boulder), sand, silt, and minor clay. Composition is highly variable and dependent on source rock types. Locally includes undifferentiated glacial outwash, lacustrine, eolian, colluvial, and debris flow deposits. Includes Modesto Formation fluvial facies (Davis and Hall, 1959; Marchand and Allwardt, 1981) and many undifferentiated young alluvial units.
- ba-y**      **Basinal deposits, young (Holocene to late Pleistocene)**—Young fine-grained alluvium occurring in low-relief lower elevations of the Great Valley bordering the western range margin. Unconsolidated or minimally consolidated, poorly stratified, silt, clay, and fine sand deposited by still or slow-moving water in floodplains, overbank environments, marshes, and locally in intermorainal ponds, sag ponds, and other similar environments. Includes fine-grained basinal facies of Modesto Formation (Davis and Hall, 1959; Marchand and Allwardt, 1981), and several undifferentiated young basinal deposit map units.
- lc-y**      **Lacustrine deposits, young (Holocene to late Pleistocene)**—Young fine-grained lacustrine deposits. Occurs in tectonic basins such as Sierra Valley, Owens Valley, Mono Basin, and locally elsewhere in relatively low areas with water accumulation, such as in the

Great Valley. Unconsolidated or minimally consolidated, commonly thinly bedded to laminated clay, silt, and lesser sand. May contain evaporite minerals; includes deposits in playas; locally may include beach sand and gravel deposits. Includes Modesto Formation lacustrine facies (Davis and Hall, 1959; Marchand and Allwardt, 1981) and many other undifferentiated lacustrine and playa map units.

- eol **Eolian deposits, undifferentiated (Holocene to late Pleistocene)**—Undifferentiated eolian deposits commonly occurring on the lee side of valleys along the range margins. Generally unconsolidated and well-sorted sand and silt deposited as dunes or sheets. Locally may include somewhat older eolian deposits and interbedded lacustrine deposits. Includes eolian subunits within the Modesto Formation (Davis and Hall, 1959; Marchand and Allwardt, 1981) and several other undifferentiated eolian map units.
- ba **Basinal deposits, undifferentiated (Quaternary)**—Basinal deposits; fine-grained alluvium occurring mainly in low-relief lower elevations of the Central Valley bordering the southwestern range margin, and sparsely in higher elevation valleys along the eastern range boundary. Unconsolidated or minimally consolidated, poorly stratified, silt, clay, and fine sand deposited by still or slow-moving water in low-relief floodplains, overbank environments, and other similar environments. Age unconstrained within Pleistocene.
- gl **Glacial deposits, undifferentiated (Quaternary)**—Undifferentiated glacial deposits occurring within the higher elevations of the range. Includes glacial moraines, till, and outwash deposits; also includes rock glaciers and (locally) ice fields and intermixed talus or colluvial material. Variably unsorted (till, moraines) to well sorted (outwash); unconsolidated to weakly or moderately consolidated; boulder to clayey gravel, sand and silt. Depending on age, clasts may be slightly to extensively weathered, and glacial morphology may be pronounced, subdued or absent. Age ranges from early Pleistocene to Holocene (e.g., Clark and Gillespie, 1997; James and others, 2002; Hildreth and others, 2018). Includes deposits associated with many named glacial stages.
- ls **Landslide deposits, undifferentiated (Holocene to Pliocene)**—Unconsolidated to moderately consolidated mass wasting deposits of variable thickness. Composition and internal texture are highly variable and dependent upon source rock unit(s). Not differentiated by age; predominantly later Pleistocene to Holocene but includes earlier Pleistocene to Pliocene deposits. Spatial distribution reflects both relative landslide susceptibility of source rock units and variability in landslide mapping in source maps. Includes both individual failures and landslide complexes depicted as single polygons. Mega-landslides occur in the eastern Sierra and are depicted separately with overlay polygons to preserve compiled geologic mapping and with consideration to the uncertainty of some interpreted mega-landslides.
- al-i **Alluvium, intermediate age (middle Pleistocene)**—Intermediate age fluvial deposits mainly occurring on elevated terraces and intermediate age alluvial fans. Predominantly includes coarser alluvial fan material of intermediate age, with lesser early- and late-Pleistocene alluvium. Weakly to moderately consolidated; generally moderately dissected; generally moderately to poorly sorted; grain size is variable and includes gravel (pebble to cobble and minor boulder), sand, silt, and lesser clay. Composition highly variable and

dependent on source rock types. Locally includes somewhat older and younger alluvium, undifferentiated glacial outwash, lacustrine, eolian, talus, colluvial, and debris flow deposits. Includes Riverbank, Friant, and Red Bluff Formations (Diller, 1894; Marchand and Allwardt, 1981), and many undifferentiated intermediate age alluvial units from map sources.

- lc-i **Lacustrine deposits, intermediate age (middle Pleistocene)**—Older fine-grained lacustrine deposits occurring in low-relief and lower elevation parts of basins (e.g., Fremont Valley, in the Mojave immediately south of the El Paso Mountains), as elevated terraces along basin margins (e.g., Mono Basin), and in smaller high alpine basins (e.g., in the northern Sierra near Quincy). Poorly to moderately consolidated, moderately dissected, commonly thinly bedded to laminated clay, silt, and lesser sand, with intercalated coarser beds of fluvial or near-shore deposits. Includes both deeper water and littoral deposits. Locally may include somewhat older and younger lacustrine deposits, and evaporite minerals, beach sand, and gravel deposits.
- al-o **Alluvium, old (early Pleistocene)**—Old alluvial deposits mostly occurring in old alluvial fans. Well consolidated and highly dissected; grain size is variable, generally coarse, but includes cobbles, gravel, sand, silt, lesser clay, and locally boulders. Composition highly variable; dependent on source rock types. Includes debris flow and lag gravel deposits, and locally may include somewhat older and younger alluvium, and relatively minor and undifferentiated glacial deposits. Includes North Merced Gravel, Turlock Lake Formation (Marchand and Allwardt, 1981), and many undifferentiated old alluvial units from map sources.
- al-vo **Alluvium, very old (early Pleistocene to Pliocene)**—Very old fluvial deposits occurring primarily within elevated terraces and abandoned fans along the western Sierra foothills, the margins of the San Emigdio Mountains, and margins of basins on the east side of the range. Moderately to well consolidated and commonly deeply dissected; grain size is variable and includes gravel, sand, cobbles, boulders, and lesser siltstone (locally diatomaceous) and claystone. Composition highly variable; dependent on source rock lithologies. Locally may include lag gravel, debris flow deposits, and lesser undifferentiated glacial outwash and lacustrine deposits. Includes Laguna (Piper and others, 1939; Marchand and Allwardt, 1981), Meeke Mine, and Horned Toad Formations (Dibblee, 1958, 1967), the informally named Hallelujah formation of Van Couvering (1962), and many undifferentiated Pliocene to early Pleistocene alluvial units.

## EASTERN SIERRA NEVADA

### Long Valley Caldera Region

- v-y **Volcanic deposits, young, undifferentiated (Holocene to late Pleistocene)**—Undifferentiated young volcanic deposits occurring within and between the Long Valley caldera and Mono basins. Includes various undifferentiated, generally low-volume or locally occurring pyroclastic flow and fall deposits, lava flows, and minor (locally) cinder cones (Hildreth and Fierstein, 2016; Bailey, 1989). Compositions vary from basalt to rhyolite and include alkalic rock types (trachybasalt, basaltic trachyandesite, trachydacite) (Hildreth and Fierstein, 2016; Bailey, 1989). Includes mostly reworked part of the silicic pyroclastic apron from Mono-Inyo chain vents (map unit mic). Includes Holocene to historic age eruptive units

within and adjacent to Mono Lake. Includes mafic to intermediate composition monogenetic vent field surrounding the silicic lavas and domes of Mammoth Mountain (map unit mmv).

mic

**Rhyolites of the Mono-Inyo Chain (Holocene to late Pleistocene)**—A series of rhyolitic vents aligned approximately south from Panum Crater, just south of Mono Lake, to Deadman Creek lava flow just within the northwestern topographic boundary of Long Valley caldera. Composed of a series of >35 lava domes, coulees, explosion craters, and ejecta rings, with a variably extensive apron of pyroclastic flow and fall deposits, some reworked (apron mostly included in unit v-y; Hildreth, 2004). Lavas are predominantly sparsely porphyritic high-silica (~75-77% SiO<sub>2</sub>) rhyolite, lesser sparsely porphyritic lower-silica (~70-74% SiO<sub>2</sub>) rhyolite and uncommon coarsely porphyritic rhyodacite (e.g., Hildreth, 2004). Lava volume is ~4 km<sup>3</sup> (Hildreth, 2004), but total erupted volume is greater and includes some additional volume of pyroclastic material, an unknown proportion of which may be buried, eroded, or deposited away from the chain.

Predominantly Holocene in age, with relatively few units as old as ~20 ka, and earliest eruption at ~42 ka (based on dating of domes), or possibly as early as 60-70 ka (based on dating of nearby tephra layers; Marcaida and others, 2019, and references therein). Several lava flows and pyroclastic flows and fall (some subplinian) were released most recently during a ~1345 CE episode on Mono Craters (Sieh and Bursik, 1986), and a ~1350 CE episode on Inyo Chain (Millar and others, 2006; Hildreth, 2004; Hildreth and Fierstein, 2016).

Included in unit v-y are Black Point on the north side of Mono Lake, volcanic rocks exposed as islands in the lake, and the Red Cones southwest of Mammoth Mountain, which Bailey (2004) includes in the Mono-Inyo chain. Bailey included Red Cones based on age, chemistry, and isotopic data. However, Hildreth (2004) notes that the northern rocks are compositionally distinct from the Mono Craters magmas.

mmv

**Mammoth Mountain volcanic rocks (late Pleistocene)**—Consists of a cluster of mostly silicic domes and flows that constructed the volcanic edifice of Mammoth Mountain and are centered on the southwestern topographic boundary of Long Valley caldera. This dome and flow cluster is composed predominantly of mildly alkaline porphyritic trachydacite, lesser phenocryst-poor alkalic rhyodacite, and one set of alkalic rhyodacite, pumice-lapilli, pyroclastic fall deposits (Hildreth, 2004; Hildreth and Fierstein, 2016). The oldest dated unit is  $99 \pm 7$  ka and the youngest is  $50 \pm 3$  ka (both Ar-Ar), although older extrusive units may be buried and undated (Hildreth and Fierstein, 2016).

These rocks represent a focus of silicic magmatism, which is surrounded by a field of genetically related mafic to intermediate composition monogenetic vents distributed within 5-9 km of Mammoth Mountain that is included within unit v-y (e.g., Hildreth and Fierstein, 2016).

lvmy

**Moat Rhyolites, young (late to middle Pleistocene)**—Consists of a cluster of five rhyolite domes, flows, and lesser fragmental ejecta in Long Valley caldera west of the resurgent uplift. Domes are typically steep-sided with up to 240 m relief and are partly covered by pyroclastic ejecta (map unit v-y) from Inyo Domes (map unit mic). Composed of subalkaline rhyolite containing 20-35% phenocrysts of plagioclase, sanidine, quartz, biotite,

- hornblende, and other trace minerals (Hildreth, 2014; Hildreth and Fierstein, 2016). Rhyolites are compositionally similar except in SiO<sub>2</sub> and Ba, which distinguish two clusters (Hildreth, 2004). Total volume estimated to be ~3-5 km<sup>3</sup>, most of which is the West Moat Coulee flow that is up to 5 km long and 574 m thick based on boring logs (Hildreth, 2004; Hildreth and Fierstein, 2016). Ar-Ar sanidine ages range from 163 ± 2 ka (Mahood and others, 2010) to 101 ± 8 ka (Heuman and others, 2002).
- lvmi **Moat Rhyolites, intermediate (middle Pleistocene)**—Consists of rhyolite lavas and vents in the southeast moat of Long Valley caldera. Includes four crystal-poor (1-2% phenocrysts) rhyolites and two porphyritic hornblende-biotite rhyolites; all subalkaline; notably the four crystal-poor eruptive units are an exception to the otherwise phenocryst-rich post-Early rhyolite (map unit lve) eruptive units (Hildreth, 2004; Hildreth and Fierstein, 2016). Material erupted from six vents, but here the mapped extent only represents the Rhyolite of Hot Creek (Hildreth and Fierstein, 2016); other vents and flows located to the east (see Bailey, 1989) are partly covered by younger sediments and their map extent is too small to show at map scale. Total volume ~1.5 km<sup>3</sup>, most of which is the phenocryst-poor Rhyolite of Hot Creek, which flowed at least 4 km to the north, where interaction with a water body produced flow breccia and perlite (Hildreth, 2004; Hildreth and Fierstein, 2016). K-Ar glass ages range from ~369 to ~329 ka (Mankinen and others, 1986), excluding the anomalously young 288 ± 31 ka K-Ar age at Hot Creek, for which Simon and others (2014) obtained an Ar-Ar sanidine age of 332 ± 2 ka; ages for three of the eruptive units cluster around 330 ka.
- lvmo **Moat Rhyolites, old (middle Pleistocene)**—Chain of rhyolite domes and flows on resurgent uplift in northwestern part of Long Valley caldera. Consists of at least four extrusive units and one intrusive, all subalkaline porphyritic rhyolites erupted through underlying Early rhyolite (map unit lve), with ~10-20% phenocrysts of sanidine, plagioclase, and lesser hornblende, biotite, and sparse quartz, and other trace minerals (Hildreth, 2004; Hildreth and Fierstein, 2016). Domes vary from very small to moderate size with up to 145 m relief (Hildreth and Fierstein, 2016). Lavas are typically blocky and massive with glassy groundmass; variably vesicular; some with finely to micropumiceous texture; some with coarse basal flow breccia; with sparse to common crystal-poor mafic enclaves; the distal end of one relatively extensive lava that flowed downslope toward the topographic moat is strongly hydrated, probably from interaction with a water body (Hildreth and Fierstein, 2016). K-Ar sanidine ages on extrusive units range from 527 ± 12 ka to 481 ± 10 ka (Mankinen and others, 1986), but Ar-Ar sanidine ages are 570 ± 8 ka on two of the same extrusive units (Simon and others, 2014).
- lve **Early Rhyolite (middle Pleistocene)**—Rhyolitic pyroclastic deposits and subordinate lava domes and flows located within Long Valley caldera on, and north of, the resurgent uplift. Represents first major post-caldera eruptive phase. Pyroclastic component is volumetrically dominant and consists of varied rhyolitic pyroclastic flow and fall deposits, with most being nonwelded but some welded, and some reworked; typically massive to vaguely bedded, and phenocryst poor; commonly containing accidental lithics of Bishop Tuff, and more rarely of basalt and Mesozoic granitic and metavolcanic rock types (Bailey, 1989; Hildreth and Fierstein, 2016). Domes and flows are aphyric to sparsely porphyritic with

- 0-3% phenocrysts of plagioclase, orthopyroxene, rare biotite, and other trace minerals (Bailey, 1989; Hildreth, 2014). Rare mafic enclaves and small blebs are reported to occur in one dome and four lava flows (Bailey, 2004; Hildreth and Fierstein, 2016). Mankinen and others (1986) reported K-Ar ages ranging from  $751 \pm 16$  ka to  $652 \pm 14$  ka. Maximum thickness is at least 622 m (Hildreth, 2004); unit occurs much more extensively across caldera floor in the subsurface (Hildreth and others, 2014). Volume  $\sim 100$  km<sup>3</sup>, similar to pre-caldera Glass Mountain Rhyolite (map unit lvg; Hildreth, 2014). Notably, includes Lookout Mountain, a topographically prominent rhyolitic shield with unusual summit caldera (Hildreth and Fierstein, 2016), with Ar-Ar glass date of  $678 \pm 9$  ka (Simon and others, 2014). Also includes Tuff of Little Antelope Valley, a relatively voluminous and extensively distributed high-silica rhyolitic tuff cropping out around and north of Antelope Spring and stratigraphically overlying Bishop Tuff in the subsurface (Hildreth and Fierstein, 2016) and probably one of the earliest post-caldera releases.
- bt** **Bishop Tuff (middle Pleistocene)**—Highly voluminous rhyolitic ignimbrite erupted from Long Valley caldera in the eastern Sierra north of Bishop, CA. Thermally and compositionally zoned (71-78% SiO<sub>2</sub>); variably nonwelded to densely welded; phenocryst content ranges from 1-25% and consists of sanidine, quartz, plagioclase, biotite, allanite, Fe-Ti oxides and zircon (Hildreth and Fierstein, 2016). Erupted from a cataclysmic, caldera-forming eruption at  $\sim 767$  ka, with outflow sheets emplaced radially about the caldera, substantial ponding of pyroclastic material within the caldera, pyroclastic flows emplaced  $>20$  km down the San Joaquin River drainage, and pyroclastic fall dispersed widely (e.g., Hildreth and Fierstein, 2016). Eruptive volume was  $\sim 600$ - $650$  km<sup>3</sup>, approximately half of which ponded within the subsiding caldera (Hildreth, 2004; Hildreth and Fierstein, 2017). An Ar-Ar date of  $767 \pm 2$  ka reported by Rivera and others (2011) represents the most precise date on this unit. Tuff ponded within the caldera is now buried by younger volcanic, fluvial and lacustrine units; pyroclastic fall is also present as unmapped interbeds within alluvial, glacial, and other surficial deposits, and serves as an important stratigraphic marker in coeval sediments across a broad swath of the western U.S.
- lvg** **Glass Mountain rhyolite (early Pleistocene)**—A complex of lava domes and flows, pyroclastic deposits, and lesser intrusions cropping out along and beyond the northeastern margin of Long Valley caldera. Near caldera margin, consists of an amalgamation of high-silica rhyolite lava domes, low-volume lava flows, flow breccias, pyroclastic deposits, and shallow intrusive masses including plugs and dikes (Bailey, 1989; Metz and Bailey, 1993; Hildreth, 2004). An associated broad pyroclastic fan/apron composed of pyroclastic flow and fall deposits, block and ash flows, and reworked volcanic material extends beyond caldera margin to northeast, east, and south and is substantially dissected (Bailey, 1989). Exposed thickness  $>1,050$  m (Hildreth, 2004). Total magmatic volume estimated to be  $\sim 100 \pm 20$  km<sup>3</sup>, which includes material now exposed, material inboard of caldera ring fault zone that is downfaulted and buried by younger caldera fill, and widely dispersed pyroclastic fall deposits emitted by up to 17 plinian or subplinian eruptions (Hildreth, 2004; Hildreth and Fierstein, 2016). All eruptive products are exclusively high-silica rhyolite, almost all crystal-poor, with 0-8% of (variably) quartz, sanidine, plagioclase, biotite, allanite, zircon, apatite, and Fe-Ti oxides (e.g., Hildreth, 2004). Metz and Mahood (1985) reported numerous K-Ar ages (mostly

on glass and felsite) that range from  $2.13 \pm 0.03$  to  $0.79 \pm 0.02$  Ma. Mapped in detail by Metz and Bailey (1993). Represents an extended rhyolitic magmatic phase leading up to the cataclysmic caldera-forming eruption of the Bishop Tuff (map unit bt) at ~767 ka.

### Broader Eastern Sierra and High Sierra Regions

**bpv**      **Big Pine volcanic field (late to early Pleistocene)**—Consists of a dominantly basaltic volcanic field, composed of scoria/cinder cones, lava flows, and other eruptive products distributed across the central Owens Valley south of Big Pine. Compositions typically range from olivine tholeiite to alkali olivine basalt (e.g. Darrow, 1972; Ormerod and others, 1991; Vazquez and Woolford, 2015). The only documented exception is the high-silica rhyolite of the Fish Spring coulee (e.g. Macdonald and others, 1991).

Several Ar-Ar dates ~1.2 Ma provide the oldest age estimated for the field (e.g., Gillespie, 1982; Gillespie and others, 1983; Blondes and others, 2008). However, the stratigraphically lowest flows are not exposed; undated basalts have been documented at up to ~250 m depth in the subsurface (Coufal and others, 1991 cited in Vazquez and Woolford, 2015). The youngest age determination for the field is ~17 ka, determined by cosmogenic  $^{36}\text{Cl}$  dating on a relatively unweathered basaltic lava flow with well-preserved surface morphology in the younger Aberdeen part of the field (Vazquez and Woolford, 2015). Eruptive products are interbedded with glacial and alluvial deposits. Vents are typically monogenetic and concentrated along the Sierra Nevada frontal fault and White Mountains fault zones (e.g. Vazquez and Woolford, 2015); many volcanic deposits are displaced by faults.

Many volcanic features, including cinder cones, a’*a* and pahoehoe lava flows with tumuli, pressure ridges, columnar joints, lava rafts, and other features are present in the field and were produced by Strombolian and lesser Hawaiian-style eruptions (e.g. Woolford, 2009).

**gtv**      **Golden Trout volcanic field (late to early Pleistocene)**—Consists of at least eight mafic to felsic cinder cones and lava domes, with associated lava flows and fragmental deposits, extruded onto the Kern Plateau, in the southern Sierra Nevada, at approximately 2,750 m elevation. Includes volcanics mapped as the Toowa volcanic field by earlier workers (e.g. Webb, 1950). Compositions range from basalt to rhyolite and include trachybasalt and basaltic trachyandesite (Browne and others, 2017a). The more mafic lavas typically contain phenocrysts of plagioclase, olivine, and clinopyroxene (Browne and others, 2017a). Though there is substantial overlap in ages, spatial-compositional patterns are more discrete: rhyolitic domes are generally older and occur in the eastern/southeastern part of the field whereas mafic vents are generally younger and occur in the northwestern part of the field. Multiple ~2.4 Ma ages on rhyolitic domes, determined by K-Ar and Ar-Ar (Bacon and Duffield, 1981) establish maximum determined ages for the volcanic field. A minimum age of 52-59 ka was determined by cosmogenic  $^{36}\text{Cl}$  dating of the unglaciated basaltic Groundhog cone (Browne and others, 2017b) and is the youngest age determination for a volcanic unit within the southern part of the Sierran block.

**auv**      **Aurora volcanic field (late Pleistocene to Pliocene)**—The Aurora volcanic field consists of compositionally variable, high-K to shoshonitic lavas, dominantly basaltic

andesite to andesite plus high-silica rhyolite, forming monogenetic lava and cinder cones, lava flows, shield volcanoes, and rhyolitic domes, erupted across ~325 km<sup>2</sup> in the uplands northeast of Mono Lake, mostly beyond map extent (e.g., Lange and Carmichael, 1996; John and others, 2015). The basaltic andesite of Locomotive Point (~3.9 Ma) and the hornblende trachydacite of Cedar Hill (~3.5 to ~2.4 Ma) of John and others (2015) crop out in the map area. Unconformably overlies the more porphyritic volcanic rocks of the Miocene Bodie Hills volcanic field (part of the ancestral Cascade arc; map unit aca).

Compositions vary continuously from trachybasalt to trachydacite (66% SiO<sub>2</sub>), plus high-silica rhyolite (75% SiO<sub>2</sub>; John and others, 2015). In order of decreasing volume, rock types include basaltic andesite, hornblende andesite, two-pyroxene andesite, high-silica rhyolite, dacite, and basalt (Lange and Carmichael, 1996). Generally weakly to moderately porphyritic (1-30%) with phenocrysts variably consisting of olivine, plagioclase, augite, hornblende, orthopyroxene, and sparse biotite (Lange and Carmichael, 1996).

John and others (2012, 2015), Kingdon and others, (2013), and Kingdon (2016) interpret the field to be bimodal on the basis of the gap between ~66 and 75 wt% SiO<sub>2</sub>, but Lange and Carmichael (1966) do not due to the presence of intermediate compositions.

Youngest ages reported are 0.04 ± 0.04 Ma (Reheis and others, 2002) or 0.11 ± 0.08 Ma (Lange and others 1993); oldest ages reported are ~3.9 Ma (Lange and others, 1993; John and others, 2015).

**imf Inyo Mountains fanglomerate (late to middle Miocene)**—Fanglomerate occurring on the southern and southwestern flanks of the Inyo Mountains east of Owens Lake. Consists of weakly consolidated to well-cemented, massive to bedded pebble to cobble conglomerate, locally with boulders up to 1-3 m (Conrad, 1993; Stone and others, 2004). Deeply dissected; clast composition consists of limestone, dolomite, siliceous sedimentary and minor plutonic lithologies all reflecting derivation from Paleozoic to Mesozoic basement units of the Inyo Mountains (Conrad, 1993; Stone and others, 2004). Locally (in northeastern area of occurrence) includes coarse strata composed almost entirely of quartz monzonite (Stone and others, 2004). Ash bed near base of unit is 13.62 Ma based on average of four Ar-Ar measurements (Conrad, 1993) and tephra in upper section is estimated to be 9-6 Ma based on tephrochronology (Stone and others, 2004). Inferred to stratigraphically underlie the ~7.7 to 4.2 Ma Darwin Plateau Basalts (map unit dpb; Conrad, 1993; Swanson, 1996; Stone and others, 2004). Includes the fanglomerate of Slate Canyon and fanglomerate of Bonham Canyon of Stone and others (2004). May be partially correlative with the Coso Formation (map unit cos) that occurs to the south.

## Coso Region

**cov Coso Volcanics, young (late to middle Pleistocene)**—Composed of rhyolitic domes and flows and basaltic cinder cones and flows typically erupted from low-volume monogenetic vents distributed across the southern Coso Range adjacent to southern Owens Valley. At least 19 basaltic cinder cones and 38 rhyolitic domes and flows represent bimodal volcanism in the middle to late Pleistocene (Duffield and others, 1980; Bacon, 1982; Simon and others, 2009) in contrast to more diverse and continuous compositions erupted in the older (late Miocene to Pliocene) volcanic field (map unit cov). Basalts are mildly alkalic and

porphyritic, with up to 30% phenocrysts of olivine, plagioclase, clinopyroxene, and opaque oxides, and erupted from vents peripheral to rhyolitic foci between ~1.1 and ~0.4 Ma per K-Ar dating (Duffield and others, 1980). Rhyolites are typically phenocryst poor (<2%) and often contain mafic inclusions, with Ar-Ar sanidine ages ranging from ~613 to ~56 ka (Duffield and others, 1980; Simon and others, 2009). However, Burgess and others (2021) report zircon ages of ~78 to ~100 ka on the youngest rhyolites. Unconformably overlies older Coso volcanic and sedimentary deposits (map units cov, cos) and granitic bedrock (map unit Gm).

cov

**Coso Volcanics (Pliocene to late Miocene)**—Composed of widespread basaltic vents and lava flows, and andesitic to rhyolitic domes, lava flows, and pyroclastic deposits localized in polygenetic volcanic centers, distributed across the Coso Range adjacent to the southern Owens Valley. Duffield and others (1980) reported K-Ar ages ranging from ~6 to 2.5 Ma. Novak and Bacon (1986) interpret two major late Miocene and Pliocene volcanic episodes: the first (~6 Ma; ~5 km<sup>3</sup> eruptive volume) primarily erupted basaltic lavas with subordinate, intermediate to high-silica composition magmas (andesite to high-silica rhyolite); the second and most voluminous episode (~4 to 2.5 Ma; ~30 km<sup>3</sup> eruptive volume) erupted diverse products and constructed polygenetic volcanic centers. They also interpret a third (Pleistocene) episode, which is represented by map unit covy.

Basalt is typically mildly porphyritic with several percent plagioclase and olivine phenocrysts, and less commonly clinopyroxene, and erupted from widely dispersed and commonly moderately to highly eroded monogenetic cinder cones, primarily in eastern part of Coso Range (Duffield and others, 1980; Novak and Bacon, 1986).

Andesite, dacite, rhyodacite, and rhyolite erupted from polygenetic volcanic centers near Haiwee Ridge and elsewhere.

Andesite occurs primarily as moderately porphyritic lava flows with ≤15% phenocrysts of plagioclase, clinopyroxene, minor olivine, and rare orthopyroxene (Duffield and others, 1980).

Dacite occurs predominantly as pyroclastic deposits and mildly to moderately porphyritic (10-30%) lava flows with phenocrysts of plagioclase and quartz ± clinopyroxene ± orthopyroxene ± amphibole ± biotite, plus local / uncommon olivine and common accessory zircon, sphene, and opaque oxides; contains up to 30% andesitic to basaltic inclusions (Duffield and others, 1980).

Rhyodacite occurs as moderately porphyritic lava flows with ~20% phenocrysts of plagioclase, hornblende, biotite, opaque oxides, and quartz, and accessory clinopyroxene, orthopyroxene, apatite, zircon, and sphene in a glassy and perlitic groundmass, and as pyroclastic fall deposits including a ca. 3 Ma eruption from a center near the west margin of the field which blanketed the range with a few to several meters of pumiceous pyroclastic fall material (Duffield and others, 1980).

Rhyolite occurs as volumetrically minor primary and reworked pyroclastic deposits intercalated with Coso Formation sedimentary strata (map unit cos), including a ~3.14 Ma unwelded, pumiceous pyroclastic flow and fall deposit (Power, 1958; Duffield and others, 1980).

**cos** **Coso Formation (Pliocene to late Miocene)**—Consists of alluvial and lacustrine sediments and lesser interbedded pyroclastic material intermittently blanketing and onlapping the northwestern to northeastern flanks of the Coso Range in the southern Owens Valley. Fluvial packages, consisting of fanglomerates, are generally coarsest at higher elevations proximal to the source, with grain size decreasing distally and grading into and interfingering with lacustrine strata in the adjacent lowlands (Power, 1958). Fanglomerates consist of crudely bedded and poorly sorted near-source boulder conglomerates rapidly grading to moderately well-sorted pebble conglomerate and coarse sandstone; composition is dominantly arkosic, consisting of materials derived from granitic uplands, with a subordinate fraction of intermixed predominantly rhyolitic volcanic materials (especially pyroclastic), which increases in abundance more distally (Power, 1958). Lacustrine beds consist of thin-bedded and commonly tuffaceous silt and fine-grained sand, comprised of reworked volcanic and lesser granitic materials (Power, 1958). Fluvial and lacustrine strata are intercalated with typically massive and unwelded vitric-ash, crystal-ash, and pumice-lapilli tuff beds containing granitic and metamorphic rock fragments (Power, 1958).

Hosts Blancan and Hemphillian mammalian fauna (e.g., Bacon and others, 1982). Maximum age  $> \sim 6$  Ma based on K-Ar ages on volcanic domes intruding lower strata; minimum age  $> 2.5$  Ma based on K-Ar ages of interbedded to strictly overlying volcanic units (Bacon and others, 1982; map unit cov). Exposed stratigraphic thickness locally exceeds 200 m but base is not exposed; unconformably overlies basement and is unconformably overlain by Pleistocene volcanic rocks (map unit covy); stratigraphic sequence is continuous (conformable) in basin lowlands but strata in upland areas were deposited more episodically with intervening disconformities (Power, 1958).

**dpb** **Darwin Plateau basalts (early Pliocene to late Miocene)**—consists of a series of flood-like olivine basalt lava flows and minor interbedded basaltic lapilli tuff and tuff breccia cropping out in the Coso Range and on the Darwin Plateau. Basaltic lavas are olivine-phyric with compositions ranging from calc-alkaline high-alumina basalt to alkali-olivine basalt (Larsen, 1979; Schweig, 1989). Flows range in thickness from 1 m to more than 60 m and are typically areally extensive (Schweig, 1989). Described as more fluid and flood-like compared to Coso volcanic units (map units cov, covy; Jayko, 2009). K-Ar ages range from  $7.7 \pm 0.5$  Ma (Schweig, 1989) to  $4.3 \pm 0.2$  Ma (Larsen, 1979). Sourced at least in part from cinder cones and basaltic dikes in the Rainbow Canyon area (Schweig, 1989).

## NORTHERN SIERRA NEVADA

**mcy** **Modern Cascade arc rocks, young (late(?) to middle Pleistocene)**—Consists of basalt to rhyodacite lava flows, lava domes, cinder cones, and two small shield volcanoes, distributed across the northwestern map area, south of Lassen Peak.

Compositions include basalt, basaltic andesite, andesite, and one rhyodacite; lavas are variably porphyritic with olivine  $\pm$  augite  $\pm$  hypersthene  $\pm$  pyroxene; typically erupted from cinder cones and/or formed lava domes and constructed at least two small shield volcanoes (Clynne and Muffler, 2010).

Represents the southernmost extent of young Cascade arc volcanism. Post-dates deposition of the Tuscan Formation (map unit tus). Youngest dated eruptive unit is 167 ka;

oldest is 667 ka; however, undated units are estimated to range from ~75 to ~725 ka (Clynne and Muffler, 2010).

v-i **Volcanic deposits, intermediate (middle Pleistocene)**—Consists of undifferentiated volcanic rocks dispersed across the northern and eastern Sierra, described here from north to south.

Mafic lava flows of low volume occur on the broad western slope of the Sierra, northwest and southwest of Lake Tahoe. These mafic lavas include basalt, olivine basalt, trachybasalt, and latite, and may be correlative with units of the Tahoe-Truckee volcanic field (map unit ttv) to the east.

A small basaltic trachyandesite lava flow is well exposed in the Middle Fork Stanislaus River canyon, south of Hwy 108, near Pigeon Flat. The lava is known as the Columns of the Giants because of prominent columnar joints exhibited by lower parts of the flow. This lava has an Ar-Ar age of  $177 \pm 7$  ka (Farmer and others, 2013) and represents the youngest dated mafic volcanic rock in the region (Busby and others, 2018b).

Varied pyroclastic flow and fall deposits, some reworked, are interbedded with tuffaceous sediments east of Long Valley caldera. These include older distal pyroclastic deposits erupted from the Glass Mountain rhyolite volcanic complex (map unit lvg) and may also include younger material from other (mostly or entirely Long Valley) eruptive sources.

otb **Olivine tholeiitic basalt (middle to early Pleistocene)**—Low-K olivine tholeiitic basalt; typically erupted from fissures as widespread lava flow sheets; commonly has ropy (pahoe-hoe) surfaces; notably chemically (48-50% SiO<sub>2</sub>) and petrographically (sparse olivine phenocrysts) homogeneous (Clynne and Muffler, 2010). Co-located with (but chemically and petrologically distinct from) the calc-alkaline Cascade arc volcanic units in the northern map area (map units mcy, mco). These primitive low-K tholeiitic lavas differ from the calc-alkaline arc rocks by having lower concentrations of large ion lithophile elements (LILE), higher concentrations of heavy rare earth elements (REE), lower LILE/high field strength element ratios, and lower ratios of light to heavy REE (Borg and others, 2002). Clynne and Muffler (2010) reported several K-Ar and Ar-Ar ages ranging from late Pleistocene (e.g.  $65 \pm 45$  ka) to middle Pleistocene (e.g.  $610 \pm 22$  ka) and note that older tholeiitic lavas are present to the east and north of the Lassen region (north of map area). This unit is broken out where adequate data are available but probably occurs more extensively than depicted.

ttv **Tahoe-Truckee volcanic field (early Pleistocene to Pliocene(?))**—Consists of basaltic to trachyandesitic lavas extruded in numerous relatively low-volume subaerial and lesser subaqueous eruptions, which produced diverse volcanic features, including lava flows, cinder cones, breccias, pillows, and tuffs (e.g. Kortemeier and others, 2018) distributed along and adjacent to the northwestern shoreline of Lake Tahoe, across the region north of the lake, and along the Truckee River. Chemically similar to the older (underlying/stratigraphically lower) Cascade arc volcanic rocks (map unit aca) but differ by having higher concentrations of high field strength elements and phosphorus, light REE enrichment, as well as other chemical differences (e.g., Cousens and others, 2011, 2012; Kortemeier and others, 2018). The Tahoe-Truckee volcanic field (TTVF; map unit ttv) also differs from the underlying arc volcanics by being generally aphyric and small volume (Cousens and others, 2011, 2012).

Depending on how the boundary between earlier arc volcanism and younger TTVF post-arc volcanism is defined, the oldest TTVF rocks could be interpreted to be Pliocene ( $3.17 \pm 0.02$  Ma per Cousens and others, 2011) or Quaternary ( $2.3 \pm 0.05$  Ma per Kortemeier and others, 2018). The youngest dated eruptive unit is  $0.94 \pm 0.003$  Ma (Kortemeier and others, 2018).

v-vo

**Volcanic and shallow intrusive deposits, very old (early Pleistocene to Pliocene)**—Predominantly undifferentiated basalt, olivine basalt, pyroxene basalt, basaltic andesite, lesser andesite, and minor rhyolite and dacite, scattered across the central and northern Sierra. May locally include alkalic rocks (e.g. latite). Silicic rocks are restricted to the region west of Antelope Valley; these consist of rhyolitic to dacitic lava flows, pyroclastic flows, and hypabyssal intrusions, including those at Tryon Peak. Includes Tuscan and pre-Tuscan age lavas. Age is generally regarded as Pliocene to Pleistocene but may include a minor component of Miocene lavas. Likely includes both magmatic arc and post-arc volcanic products.

In the Tehachapi Mountains, this unit also includes the dacite and red andesite of Michael (1960), who interpreted these lavas as Quaternary based on interpreted stratigraphic relations and thermoluminescence dating.

mco

**Modern Cascade arc rocks, old (early Pleistocene to Pliocene)**—Consists of a wide range of mafic to silicic, predominantly andesitic to rhyolitic, lava flows, cinder cones, and lava domes distributed across the northern map area, south of Lassen Peak.

Volcanic units are all calc-alkaline but include a broad range of compositions and phenocryst assemblages. Basalt and basaltic andesite (of subordinate volume) are commonly sparsely olivine-phyric; andesite typically contains hypersthene  $\pm$  augite phenocrysts; dacite typically contains hornblende  $\pm$  hypersthene  $\pm$  pyroxene  $\pm$  biotite phenocrysts; rhyodacite (of subordinate volume) is coarsely porphyritic with augite  $\pm$  hypersthene; rhyolite is typically sparsely porphyritic with hypersthene  $\pm$  hornblende  $\pm$  biotite (Clynne and Muffler, 2010).

Includes rocks of Maidu volcanic center, Dittmar volcanic center, and Rockland caldera complex, among others (Clynne and Muffler, 2010). Oldest dated unit has K-Ar age of 1.78 Ma; youngest has K-Ar age of  $803 \pm 27$  ka (Clynne and Muffler, 2010). Broadly coeval with, interfingers with, and overlies late Pliocene Tuscan Formation (map unit tus). Represents more proximal volcanic deposits, whereas the Tuscan Formation represents more distal volcanoclastic debris flow and fluvial deposits.

shc

**Sandstone of Hunter Creek (Quaternary to Miocene)**—Consists of a thick, conformable, and broadly fining-upward sequence of coarse conglomerate to diatomite, with sparse interbedded lava flows and pyroclastic fall deposits, cropping out along the margins of the Verdi basin around and west of Reno, Nevada, and to the north in Lemmon Valley.

Basal section consists of coarse (cobble to boulder) conglomerate and debris flow deposits (including lahars) interbedded with lesser sandstone and variably diatomaceous siltstone (Trexler and others, 2012). Clasts are predominantly volcanic rock types, with lesser metamorphic and locally substantial granitoid clasts, all commonly subrounded to well rounded (Bell and Garside, 1987; Bingler, 1965; Trexler and others, 2012). Some debris flow deposits contain prismatically jointed blocks indicating emplacement as hot syn-eruptive lahars (Trexler and others, 2012). Basaltic andesite lavas are present only in the basal section

and have Ar-Ar dates of ~10.1 to ~10.4 Ma (Henry and Perkins, 2001; Trexler and others, 2012).

The middle section consists of pebbly sandstone, siltstone, and muddy diatomite; cross-lamination and channel structures are common, as are rooted horizons (Trexler and others, 2012). Minor interbedded pyroclastic fall deposits and volcanic clast-dominated conglomerates are also present. Hosts late Clarendonian to Hemphillian terrestrial vertebrates, including gomphothere, camel, and horse species (Kelly, 2001; Kelly and Secord, 2009). Also hosts the “Verdi flora” which consists almost entirely of riparian and lake-border plant species (Trexler and others, 2012).

The upper section consists of diatomite, variably diatomaceous siltstone, and sandstone with minor interbedded pyroclastic fall deposits (Trexler and others, 2012) and stratigraphically minor but areally extensive dune deposits (Bingler, 1965). Pyroclastic fall beds contain plagioclase grains as young as  $2.67 \pm 0.42$  Ma (Trexler and others, 2012). Also hosts assemblage of vertebrate fossils indicating age no older than 2.6 Ma, and possibly as young as 1.5 Ma (Kelly, 2001; Kelly and Secord, 2009).

Throughout the unit, material is >80% volcanic (Trexler and others, 2012; Queen, 2008). Deposited in predominantly fluvial to deltaic to lacustrine environments within a closed, extensional basin (Ramelli and others, 2011; Trexler and others, 2012). Present as east-plunging syncline with thickness up to 2.6 km and truncated on east, in subsurface, by normal down-west fault (Cashman and others, 2012; Trexler and others, 2000, 2012).

Informally named the sandstone of Hunter Creek by Bingler (1965), who applied the name only to fill strata in a part of the Reno-Verdi basin. Here we generalize to include units to the north, in Lemmon Valley, which were deposited in a different basin from those of the sandstone of Hunter Creek proper and differ stratigraphically, but which are otherwise similar in age, composition, and depositional environment.

**mhd Mokelumne Hill domes (Pliocene)**—Consists of five volcanic domes located in the western Sierra foothills near Mokelumne Hill and Jackson. The domes consist of porphyritic hornblende biotite dacite, hornblende dacite, and porphyritic hornblende rhyodacite that intrude the Mehrten Formation fluvial strata (part of map unit aca) and are depositionally overlain by the youngest Mehrten Formation strata (e.g., Rose, 1959; Turrin, 1982; Bartow, 1979). Turrin (1982) reported the most recent K-Ar ages for the domes, which range from  $4.73 \pm 0.16$  Ma (Golden Gate Hill dome) to  $3.73 \pm 0.29$  Ma (Hamby dome).

**tus Tuscan Formation (late Pliocene)**—Consists of a succession of volcanoclastic debris flow deposits interbedded with lesser volcanoclastic conglomerate, sandstone, and siltstone, and minor tuff, sporadically blanketing the northwestern map area.

Clasts are dominantly volcanic (e.g. andesite and basaltic andesite), and include material sourced from the Maidu, Yana, and Butt Mountain volcanic centers, however, lower strata also contain variable proportions of metamorphic basement rock types (Lydon, 1968; Helley and Harwood, 1985; Poletski, 2010). Debris flow deposits are typically poorly sorted or chaotic, often reversely graded, with angular to subrounded clasts typically up to 20 cm and locally up to 3 m; they are volumetrically dominant and generally regarded as volcanogenic (i.e. lahars) due to presence of cooling fractures and wood casts (e.g., Lydon,

1968; Helley and Harwood, 1985; Clynne and Muffler, 2010). Volcaniclastic conglomerates, volcanic lithic sandstones, and siltstones are predominantly fluvial, but transitional (e.g. hyperconcentrated flow) deposits are also present.

Pyroclastic deposits are volumetrically minor but important for stratigraphic age control and include the Nomlaki Tuff and Ishi Tuff. The Nomlaki Tuff is a dacitic pumice to pumice lapilli tuff (e.g., Helley and Harwood, 1985), which has an Ar-Ar age of  $3.339 \pm 0.016$  Ma (Sarna-Wojcicki and others, 2021) and a magnetostratigraphically estimated age of  $3.27 \pm 0.04$  Ma (Henry and Perkins, 2001). The Ishi Tuff is a fine-grained, pumiceous, pyroclastic fall deposit, commonly reworked, which has a zircon fission-track age of  $\sim 2.7$  Ma (Helley and Harwood, 1985). Some have reported the presence of block-and-ash flows (e.g. Blake and others, 2000), but others reported no evidence of their presence (e.g. Poletski, 2010).

The Nomlaki Tuff is present near the base of the sequence and constrains the lower age limit. The Ishi Tuff is present approximately midway up the section (Helley and Harwood, 1985). Lava flows as old as 2.4 Ma sourced from the Maidu volcanic center unconformably overlie the Tuscan Formation and constrain its age in this region to  $>2.4$  Ma (Clynne and Muffler, 2010). Thus, the age of the Tuscan Formation spans approximately  $\sim 600$  kyr and may extend into the earliest Pleistocene.

aca

**Ancestral Cascade arc rocks (Pliocene to Miocene)**—Consists of predominantly intermediate composition volcanic and volcaniclastic sedimentary deposits distributed extensively across the central and northern Sierra. Collectively, this unit represents arc volcanic products and derivative sediments, referred to as Mehrten Formation by Curtis (1954).

Volcanic component is calc-alkaline and predominantly andesite and basaltic andesite with lesser basalt and sparse dacite and rhyolite (e.g., Busby and others, 2018). Andesite is commonly porphyritic with plagioclase  $\pm$  hornblende  $\pm$  augite  $\pm$  hypersthene  $\pm$  biotite phenocrysts. Basalt is commonly finely porphyritic with olivine  $\pm$  plagioclase  $\pm$  clinopyroxene  $\pm$  augite phenocrysts. Less commonly, alkalic compositions including trachyandesite, trachydacite, and trachybasalt are present (notably within map units sg, tml, and tkt). Volcanic rocks occur as lava flows and domes and varied pyroclastic deposits (most commonly tuff breccia  $\pm$  pumiceous pyroclastic flow and fall deposits). Intrusive equivalents commonly occur as dikes, plugs, and (less commonly) sills. Most dated volcanic deposits range in age from  $\sim 15$  to 3.4 Ma (e.g., Busby and others, 2008a, b, 2016, 2018; Cousens and others, 2008; John and others, 2015; Sylvester and others, 2012;). However, Saucedo and others (1992) reported K-Ar ages of up to  $\sim 19.7$  Ma in the northern Sierra, and Cousens and others (2008) reported a small volume of 28 Ma pyroxene andesite lavas that erupted in the Carson Range east of Lake Tahoe.

Sedimentary component includes volcanic debris flow (lahar) deposits, volcanic lithic sandstone and conglomerate, lesser siltstone, and minor clay. Debris flow deposits are typically poorly sorted or chaotic, with angular to subrounded polyolithic volcanic clasts of variable size supported in a tuffaceous sandy to silty to clayey matrix. Across all sedimentary deposit types, clasts and matrix are predominantly derived from volcanic material (described above), with lesser material incorporated from older Cenozoic deposits and granitic and

metamorphic basement, especially in lower strata. Rare debris avalanche deposits are also present (e.g., Berkebile, 2003; Busby and others, 2016, 2018; Harwood and others, 2014).

Vent locations are along and east of the modern Sierran crest. Composition (especially alkalinity) varies somewhat north-south along the length of the arc (e.g., Putirka and others, 2012). Exhibits pronounced lateral facies changes: proximal (near arc) strata occur at higher elevations near and east of the modern range crest and consist predominantly of primary volcanic deposits (lavas, tuff breccias and ignimbrites); intermediate strata occur at mid elevations on the western slope and consist predominantly of debris flow and fluvial deposits interbedded with lesser, farther-travelled lava flows and (uncommonly) pyroclastic deposits; distal strata occur at lower elevations along the western Sierra Nevada foothills and consist predominantly of fluvial strata, lesser volcanic debris flow deposits, and rare interbedded lavas.

Relatively persistent and voluminous volcanic centers have been identified and include the 15-6 Ma Bodie Hills volcanic field (John and others, 2012); the 12-5 Ma Little Walker-Sierra Crest volcanic center and the 6-4.6 Ma Ebbetts Pass volcanic center in the central Sierra Nevada (Busby and others 2018); and the Squaw Peak, Martis Peak, and Mount Pluto (inferred) stratovolcanoes north of Lake Tahoe (Sylvester and others, 2012). Unit includes Mehrten, Kate Peak, Disaster Peak, and Relief Peak Formations.

sg

**Stanislaus Group (late Miocene)**—Consists of an extensive sequence of dominantly high-K, trachyandesite to basaltic trachyandesite and minor trachydacite lavas and trachydacite ignimbrites with lesser interstratified volcanoclastic sediments and lower-K (subalkaline) mafic to intermediate lava flows, distributed across the central Sierra Nevada in a strip approximately 60 km wide (north to south) and 150 km long (east to west). Divided into three formations or members, described below in descending stratigraphic order:

The Dardanelle Formation is the uppermost formation of the Stanislaus Group and consists of lava that has been confused with lavas of the stratigraphically lower Table Mountain Latite, but where its stratigraphic position is well established, consists of a single aphyric shoshonite lava with an Ar-Ar age of  $9.137 \pm 0.017$  Ma (Busby and others, 2018).

The Eureka Valley Tuff (EVT) is the middle formation of the Stanislaus Group and consists of the following, in ascending order (Busby and others, 2018): (1) Basal Lava Flow Member, trachydacite lavas and hypabyssal intrusions with an Ar-Ar age of  $9.94 \pm 0.03$ ; (2) Tollhouse Flat Member trachydacite welded ignimbrite with an Ar-Ar age of  $9.54 \pm 0.04$  Ma; (3) Lava Flow Member, with trachydacite, trachyandesite, trachybasaltic andesite and basalt lavas; (4) By-Day Member trachydacite welded ignimbrite with an Ar-Ar age of  $9.4 \pm 0.3$  Ma; and (5) Upper Member trachydacite nonwelded ignimbrite with an Ar-Ar age of  $9.34 \pm 0.04$  Ma.

The Tollhouse Flat member is the most widespread of EVT members, and the upper member is the least widespread. The Tollhouse Flat Member welded ignimbrite has more biotite than the By-Day Member welded ignimbrite, and the Upper Member is easily distinguished by its non-welded character (Busby and others, 2016, 2018). Anisotropy of magnetic susceptibility in the Eureka Valley Tuff Member indicates that ignimbrites flowed radially away from the Little Walker caldera (King and others, 2007).

The Table Mountain Latite is the lowest formation of the Stanislaus Group and consists largely of trachyandesite to basaltic trachyandesite lavas with lesser basalts, basaltic andesites and andesites, with Ar-Ar ages of  $10.41 \pm 0.08$  Ma to  $10.36 \pm 0.06$  Ma (Busby and others, 2018). It erupted from fissure vents up to 10 km long as well as point sources sited on faults, mapped along the range crest between Sonora Pass and Ebbetts Pass (Busby and others, 2018). It has been proposed that additional Table Mountain Latite vents may lie in the Little Walker caldera southeast of Sonora Pass (Noble and others, 1974; Priest, 1979) but this has not been confirmed. The Table Mountain Latite is easily recognized in most places by its large (up to 13 mm), abundant (up to 40%) flow-aligned sieve-textured plagioclase and smaller black pyroxene. Table Mountain Latite lavas are voluminous and flowed 140 km down the Cataract paleochannel, from vents at the Sierra Crest to Knights Ferry in the foothills (Gorny and others, 2009; Busby and others, 2016). Where map scale allows, this unit is broken out as map unit tml.

Volcanic rocks of the Stanislaus Group are interpreted to be a part of the ancestral Cascade arc (map unit aca; e.g. Busby and others, 2008b) but are broken out here due to regional extent, distinctive high-K composition, and because they serve as an important stratigraphic marker within the ancestral Cascade arc sequence. Where present, Stanislaus Group strata separate volcanic and volcanoclastic rocks of the underlying Relief Peak Formation from those of the overlying Disaster Peak Formation, which are both subalkaline.

- tml **Table Mountain Latite (late Miocene)**—Consists largely of trachyandesite to basaltic trachyandesite lavas with lesser basalts, basaltic andesites and andesites, distributed across the central Sierra, with Ar-Ar ages of  $10.41 \pm 0.08$  Ma to  $10.36 \pm 0.06$  Ma (Busby and others, 2018). Lowest member of the Stanislaus Group; see map unit sg for more information.
- ljb **Lovejoy Basalt (middle Miocene)**—Tholeiitic flood basalt consisting of a series of voluminous lava flows erupted from Thompson Peak, in the northern Sierra, at  $\sim 15.4$  Ma (Garrison and others, 2008). Most flow units are glassy and aphyric, but the uppermost flow unit occurs sporadically and contains conspicuous plagioclase phenocrysts (Coe and others, 2005; Garrison and others, 2008). Paleomagnetic remanence directions generally form a tight cluster of reversed polarity distinct from the mean field direction indicating eruption within a relatively short time period (Coe and others, 2005). This is the most widespread and far-travelled lava flow documented within California, and is referred to as “California’s only flood basalt” (Garrison and others, 2008); it flowed  $\geq 240$  km westward across the Great Valley to Putnam Peak in the Coast Ranges (Wagner and others, 2000), and is traceable in the Sacramento Valley subsurface via wells and negative aeromagnetic anomalies (van den Berge, 1968; Langenheim and others, 2014). It is coeval with ancestral Cascade arc volcanic rocks (map unit aca) but is compositionally distinct, with major- and trace-element characteristics of the coeval Columbia River Basalt Group to the north in northern Nevada, Oregon, and Washington (Garrison and others, 2008).
- ivs **Ignimbrite Flareup volcanic and sedimentary rocks (early Miocene to early Oligocene)**—Rhyolite ignimbrites and interbedded fluvial deposits occurring in east-west paleochannels crossing the central Sierra (where mapped as Valley Springs Formation) and northern Sierra (where mapped as Delleker Formation).

Pyroclastic flows erupted from calderas of the western Nevada volcanic field in central Nevada (Henry and John, 2013). These eruptive products are dominantly rhyolitic with lesser trachydacite and minor dacite; typically high-K to shoshonitic (Henry and John, 2013). Pyroclastic material is present as nonwelded to densely welded and thick (up to >100 m) primary pyroclastic flow deposits and reworked tuffaceous sediments. At least 15 discrete ignimbrites have been identified within the Sierra Nevada, and range in age from 31.7 Ma (Holland and others, 2015; O’Neal, 2023) to 23.0 Ma (Roche and others, 2022; Holland and others, 2015). These flows exhibit a general pattern of southward younging, which reflects southward younging of source calderas (e.g., Henry and others, 2012; Henry and John, 2013; Best and others, 2015).

Sedimentary strata consist predominantly of heterolithologic conglomerates and tuffaceous sandstones with lesser tuffaceous siltstone and mudstone. Conglomerate clasts typically consist of variable proportions of metamorphic, plutonic, and volcanic (ignimbrite) clasts; however, proportions vary substantially and locally may be predominantly rhyolitic tuff or other rock types. Sedimentary strata are dominantly fluvial, but some marsh and lacustrine deposits are present locally (Bartow, 1994).

In more proximal parts of the paleochannels at higher elevations, the unit is thicker (up to >300 m) and dominated by ash-flow tuff (or ignimbrite). In more distal parts of the paleochannels, in the foothills, the unit is thinner, with a higher proportion of tuffaceous sandstones and conglomerate commonly deposited in alluvial fans (Cherven, 2020) and locally passing distally into ephemeral lake and marsh deposits (Bartow, 1994). Unit conformably (to locally unconformably) overlies the Tertiary pre-volcanic gravels (map unit pvg) and Ione Formation (map unit io) and is overlain by Miocene andesitic rocks of the Ancestral Cascade arc (map unit aca) in erosional unconformity. Contact of fluvial strata with underlying pre-volcanic gravels may be indistinct or gradational.

**pvg Tertiary pre-volcanic gravels (early Oligocene to Eocene)**—Consists predominantly of fluvial sandstones and conglomerates with lesser siltstone and minor clay interbeds deposited in paleochannels at moderate to lower elevations of the central and northern Sierra. Referred to as Tertiary gravels, auriferous gravels, and pre-volcanic gravels (Lindgren, 1911). Clast composition typically exhibits moderate to high compositional maturity (though maturity decreases up-section); sandstones are quartzose to arkosic, and conglomerates are commonly dominated by vein quartz and quartzite clasts. Attains maximum recorded thickness of ~160 m on the San Juan Ridge in the lower foothills (Yeend, 1974). Cassel and Graham (2011) interpret a variably high-energy braided stream environment wherein coarser sand and gravel packages represent high-energy channel deposits and finer siltstone and clay intervals, locally with thin paleosols, represent floodplain deposits.

Generally interpreted to be time-equivalent and interfingering with the Ione Formation (map unit io), with the Tertiary gravels and Ione Formation representing more proximal and distal (respectively) deposits of the same system (e.g., Lindgren, 1911; Allen, 1929; Jenkins, 1946; Creely and Force, 2007) but these units may have different maximum/minimum ages.

Sparse Cenozoic detrital zircon ages of ~43 to ~33 Ma (Cassel and others, 2012; Cecil, 2009) constrain maximum depositional ages for parts of those strata and support

correlation with Ione Formation (map unit io) and broadly conformable contact with overlying Valley Springs and Delleker Formations (ignimbrite flareup volcanic and sedimentary rocks; map unit ivs). Sparse and possibly reworked pyroclastic deposits are also interbedded with fluvial strata in at least two localities in the northern Diamond Mountains near Susanville, California and contain ~35 Ma zircon grains which constrain maximum depositional age to <35 Ma for those strata (Lovelock, 2010). Maximum age of unit is poorly constrained, though generally regarded as Eocene. Separated from underlying basement (minimum age ~90 Ma) by major erosional unconformity. The minimum age of the unit is well constrained by overlying Oligocene tuffs (~31.7 Ma or younger; varies spatially; see unit ivs).

Excepting the sparse pyroclastic material near Susanville, the unit contains no primary volcanic deposits and pre-dates input of Oligocene ignimbrites from the Nevada caldera belt (see map unit ivs). Note, however, that the contact between units pvg and ivs is not always well located in source mapping, thus, as mapped, some syn-volcanic (ivs) deposits are erroneously included in unit pvg and vice versa. The Tertiary gravels host substantial placer gold and were the primary target of historic hydraulic and drift mining within the Sierra (e.g., Lindgren, 1911; Yeend, 1974).

**io** **Ione Formation (Eocene)**—Predominantly finer-grained fluvial and deltaic, estuarine, and minor shallow marine deposits that crop out along the western valley margin approximately from Oroville to Fresno. Consists of interbedded sandstone and clay, with lesser pebbly sandstone and gravel interbeds. Exhibits moderate to high compositional maturity; sandstones are quartzose to arkosic; clays are predominantly kaolinitic; gravel clasts are predominantly vein quartz and quartzite. Compositionally maturity decreases up-section. Attains maximum recorded thickness of ~190 m near type section (Creely and Force, 2007).

Generally interpreted to be time-equivalent and interfingering with the Tertiary pre-volcanic gravels (map unit pvg), with the Tertiary gravels and Ione Formation representing more proximal and distal (respectively) deposits of the same system (e.g., Lindgren, 1911; Allen, 1929; Jenkins, 1946; Creely and Force, 2007) but these units may have different maximum/minimum ages. Some upper(?) Ione Formation strata contain middle Eocene mollusks (Creely and Force, 2007).

Sparse Cenozoic detrital zircon ages of 44.1 and 43.6 Ma (Sharman and others, 2015) constrain maximum depositional ages for those strata and support correlation with Tertiary pre-volcanic gravels (map unit pvg). Conformably overlies older Eocene strata (mainly in the subsurface) but is separated from underlying basement by major erosional unconformity.

**chi** **Chico Formation (Late Cretaceous)**—Variably fossiliferous nonmarine to marine sedimentary sequence occurring along the western margin of the central and northern Sierra. Haggart and Ward (1984) divide the Chico Formation into four members, with dominant lithologies (from stratigraphically lowest to highest) consisting of coarse fluvial conglomerate, coarse conglomeratic sandstone, fine-grained silty sandstone, and muddy siltstone to silty mudstone, which they interpret to represent a transgressive sequence. Clast lithologies consist of chert, metavolcanics, quartzite, schist, and slate (Haggart and Ward, 1984). Depositional environments likely range from fluvial, to deltaic, brackish nearshore (or littoral) to shallow marine. Strata interpreted to be nonmarine to littoral contain woody debris

and lack normal marine fauna. However, much of the other strata host numerous species of Santonian to Campanian (~86 to ~72 Ma) ammonites, inoceramids, and other mollusks, as well as bivalves, gastropods, and cephalopods (e.g. Stanton, 1893; Diller and Stanton, 1894; Matsumoto, 1959; Popenoe and others, 1960; Haggart and Ward, 1984; Ward and others, 2012). Detrital zircon age spectra indicate a depositional age of ~88-77 Ma (deGraaf-Surpless and others, 2002). Magnetostratigraphy from Verosub and others (1989) identified an interval of reversed polarity consistently associated with the *Baculites chicoensis* Zone and correlated with the first reversed interval following the Cretaceous long normal interval, which indicates that this zone is not significantly time-transgressive. Strata dip gently to southwest and unconformably overlie metamorphic basement.

## SOUTHERN SIERRA NEVADA

**krf**      **Kern River Formation (early Pleistocene(?) or Pliocene to Miocene)**—Consists of fluvial sandstone, conglomerate, and lesser interbedded siltstone and mudstone cropping out across a broad arcuate belt along the foothills-valley transition east and northeast of Bakersfield.

Sandstone is commonly coarse and arkosic and consists predominantly of angular to subrounded quartz and lesser feldspar grains with accessory biotite and minor hornblende, garnet, and pyrite (Bartow and Pittman, 1983). Sandstone and conglomerate units are typically poorly sorted and crudely bedded; grain size grades laterally from coarser proximal deposits in the east and south, to finer distal deposits in the west and north (Bartow and Pittman, 1983).

Maximum thickness is 800 m (measured with subsurface data); lower strata interfinger westward with the marine Etchegoin Formation in subsurface; unconformably overlies the Chanac Formation (included in map unit ben); upper surface is typically deeply dissected and is unconformably overlain by Pleistocene alluvium (Bartow and Pittman, 1983).

Age is late Miocene to Pliocene or early Pleistocene based on stratigraphic relations and presence of Hemphillian age mammalian fauna (Bartow and Pittman, 1983).

**cpf**      **Cache Peak Formation (Pliocene(?))**—Consists of lava flows, fluvial sediments, and lesser pyroclastic deposits cropping out in the Tehachapi Mountains northeast of Monolith, CA. Named by Michael (1960), who divided it into a lower member, comprised of fluvial sediments and pyroclastic deposits, and an upper member, comprised predominantly of dacitic to andesitic lava flows. Michael (1960) interpreted the formation to unconformably overlie the Bopesta Formation (map unit bop) and tentatively assigned a Pliocene age based on stratigraphic position and geomorphic expression. However, the unit may be late Miocene or younger.

**oso**      **Oso Canyon Formation of Dibblee [1967] (early Pliocene(?) to late Miocene)**—Consists of a sequence of coarse interbedded alluvial deposits cropping out in the westernmost Mojave Desert region, in the southern map area between the Garlock and San Andreas faults. Dibblee (1967) describes these deposits as predominantly coarse and fluvial, including fanglomerate, conglomerate, sandstone, and siltstone. Fanglomerate consists of unsorted and subrounded clasts ranging from pebble to boulder size in a matrix of coarse

- arkosic sandstone. Conglomerates contain moderately sorted, pebble- to cobble-size clasts. Fanglomerate and conglomerate clasts consist of granitic detritus and weathered volcanics (especially rhyolite) sourced from the adjacent Neenach Volcanics (map unit nev). Sandstone is arkosic, friable, and fine to coarse grained or conglomeratic. Siltstone is micaceous, argillaceous to sandy and commonly pebbly. Originally mapped as Oso Canyon Formation by Dibblee (1967), this unit was later reassigned to the Santa Margarita Formation (e.g., Sims, 1989). However, the Oso Canyon name is retained here due to uncertain stratigraphic correlation between this occurrence and the Santa Margarita Formation across the Tehachapi Mountains to the northwest. Unconformably overlies Neenach Volcanics (thus the lower age limit is constrained to late Miocene) and overlies marine Monterey Formation; upper age limit is less well constrained, though generally regarded as early Pliocene.
- skv **Southern Sierra high-K volcanics (Pliocene to middle Miocene)**—Variable but generally high-K to ultrapotassic mafic to intermediate low-volume eruptive and hypabyssal (sub-eruptive) units including dikes, volcanic necks, and partially eroded (or glaciated) lava flow remnants distributed sporadically across the central and (primarily) southern Sierra (e.g., Moore and Dodge, 1980; Feldstein and Lange, 1999). Includes the San Joaquin, Kings River, and Kern volcanic fields. Also includes ~3.5 to ~2.5 Ma precaldera dacite field and older Miocene alkalic volcanic units surrounding Long Valley caldera (Hildreth, 2004; Bailey, 1989). Compositions include alkali olivine basalt, potassic olivine basalt (trachybasalt), ultrapotassic basalt (leucite basanite, tephrite, phonolite), basaltic andesite, trachybasaltic andesite, and trachyandesite (e.g., Moore and Dodge, 1980; Van Kooten, 1980; Farmer and others, 2002). Variable phenocryst content includes phlogopite ± olivine ± clinopyroxene ± biotite ± sanidine ± plagioclase ± augite (Van Kooten, 1980; Bergquist and others, 1982; Farmer and others, 2002). Radiometric dates range from ~12.3 Ma (e.g. Bergquist and others, 1982) to ~2.5 Ma (e.g. Farmer and others, 2002; Hildreth, 2004). K<sub>2</sub>O content ranges from moderate to >8 wt% (Dodge and Moore, 1981; Farmer and others, 2002). Per Farmer and others (2002), includes pulses of magmatism in Miocene (~12-8 Ma) and Pliocene (~4-3 Ma) and a third (Quaternary) pulse represented by the Golden Trout volcanic field (map unit gtv). Various workers reported systematic spatial changes in K content of eruptive products; Van Kooten (1980) reported east to west increasing K in the central Sierra; Putirka and others (2012) reported southward increasing K across the range; Farmer and others (2002) reported higher K content in the northern San Joaquin and Kings regions and lower in the southern Kern volcanic field. In addition to generally distinctive high-K content, these rocks also include compositions with the lowest SiO<sub>2</sub> and highest MgO concentrations of any Sierran volcanic rocks (Farmer and others, 2002). Predominantly erupted through and overlying granitic terrain; glacially eroded.
- dos **Dove Spring Formation (late to middle Miocene)**—Predominantly fluvial and lacustrine sediments interbedded with lesser pyroclastic deposits and lava flows occurring in the El Paso Mountains (in southeastern map area) and northwest-adjacent basin (Loomis and Burbank, 1988). Sedimentary deposits are quite varied and consist of arkosic to lithic sandstone, pebble to local boulder conglomerate, clay, mudstone, limestone, chert, and siltstone (Loomis and Burbank, 1988). Coarser clastic sediments are typically poly lithic with predominantly plutonic and volcanic clasts. Sandstones are massive to planar bedded and

cross bedded. Interbedded volcanics include pyroclastic flow and (some waterlain) pyroclastic fall deposits, tuff breccia, and basaltic lava flows. Upper unit of Ricardo Group defined by Loomis and Burbank (1988), unconformably underlain by lower unit (Cudahy Camp formation; map unit cuv). Composite stratigraphic thickness is 1,560-2,000 m (Loomis and Burbank, 1988). Contains Clarendonian vertebrate fossils (e.g., Cox and Diggles, 1986). Magnetostratigraphy established by Loomis and Burbank (1988) using the Clarendonian fossil ages,  $8.4 \pm 1.8$  and  $10.4 \pm 1.6$  Ma zircon fission-track ages (Cox and Diggles, 1986) and a  $11.8 \pm 0.9$  Ma fission-track age from their study, gives an interpreted total age range of  $\sim 13.5$  to  $\sim 7$  Ma.

ms

**Monterey Shale and similar-age marine units (late to early Miocene)**—Thin-bedded siliceous to semi-siliceous marine shale occurring in southern and southwestern map area, cropping out at lower elevations of the San Emigdio Mountains, and along the southeastern San Joaquin Valley / foothills transition. In eastern to southeastern extent, locally contains or interfingers with nonmarine sandstone (Kellogg and others, 2008). Also locally includes thin dolomitic intercalations and a basal marine sandstone (Kellogg and others, 2008; Chapman and Saleeby, 2012). Attains a stratigraphic thickness of  $\sim 2,100$  m in the Temblor Range west of map area, but is significantly thinner within map area (Nilsen and others, 1973). Conformably(?) overlies Temblor Formation (e.g., Kellogg and others, 2008).

Based on diatom biochronology, Barron (2022) interpreted an age range of  $\sim 16.2$  to  $\sim 5.5$  Ma (late Relizian to Delmontian) for his San Joaquin Valley section of the Monterey Shale, which is subdivided (from stratigraphically lowest to highest) into the Gould Shale, Devilwater Shale, McDonald Shale, Antelope Shale, and Reef Ridge Shale Members. However, not all of these members crop out within the map area. The Gould Shale crops out within the map area (Kellogg and others, 2008; Nilsen and others, 1973) and ranges in age from  $\sim 16.2$  to  $\sim 14.5$  Ma (Relizian to Luisian) based on diatom biochronology (Barron, 2022). Knott and others (2022) also reported a  $\sim 15.77$  Ma tephra interstratified with Monterey Shale sediments within the map area, which presumably belong to the Gould Shale. Kellogg and others (2008) reported a section bearing Mohnian foraminifera, which represents the McDonald Shale and/or the Antelope Shale which are, respectively,  $\sim 13.4$  to  $\sim 11.9$  Ma (Luisian to early Mohnian) and  $\sim 11.9$  to  $\sim 7.1$  Ma (early to late Mohnian, possibly to early Delmontian) based on diatom biochronology (Barron, 2022). This indicates that the Devilwater Shale, and possibly the McDonald Shale, are absent in outcrops, which indicates a  $\sim 1.1$  m.y. or greater hiatus in the exposed section.

Eastern extent of unit, cropping out along the eastern side of the southern San Joaquin Valley, includes occurrences of several other early to late Miocene marine units mapped and described by Bartow (1984) from stratigraphically lowest to highest as: Freeman Silt and Jewett Sand, undifferentiated marine sandstone, Olcese Sand, Round Mountain Silt, undifferentiated marine siltstone and sandstone, and undifferentiated marine sandstone and conglomerate. Collectively, these units predominantly consist of fine- to coarse-grained sandstone, sandy siltstone, siltstone, silty claystone, claystone, and subordinate coarse- to very coarse-grained pebbly sandstone and pebble conglomerate, and diatomaceous shale.

ben

**Bena Gravel (late to middle Miocene)**—A sequence of alluvial conglomerate, sandstone, and lesser siltstone and mudstone, partly interfingering with marine sandstone,

cropping out along the margin of the southeastern San Joaquin Valley.

Nonmarine component consists predominantly of poorly sorted conglomerate of pebble- to cobble-size granitic clasts in a sandy matrix interbedded with massive coarse-grained arkosic sandstone (Bartow and McDougall, 1984; Chapman and Saleeby, 2012), which mostly represents a near-shore alluvial fan facies, that, in the lower part of the sequence, grades into a paralic facies. The marine strata consist of compositionally similar conglomerate and sandstone with interbedded laminated claystone and siltstone with rare oyster, barnacle, diatom, foraminifer, and marine mammalian fossils (Bartow and McDougall, 1984).

Thickness ~950 m; age middle to late Miocene based on fossil assemblage (Bartow and McDougall, 1984). Includes the Chanac Formation.

- tkt** **Trachyandesite of Kennedy Table (middle Miocene)**—Trachyandesite lava erupted from a vent ~7 km southwest of Mammoth Mountain, in the eastern Sierra, with flow remnants distributed across the range to the west-southwest along the modern San Joaquin River drainage (Hildreth and Fierstein, 2016; Hildreth and others, 2021). Hildreth and others (2021) reported Ar-Ar ages of ~9.3 Ma. Vent site exposes lateral gradations from intrusion to lava flow; unit is generated from one continuous eruption (Hildreth and others, 2021). Chemical composition is remarkably uniform; flow is phenocryst-rich with plagioclase and minor clinopyroxene and olivine (Hildreth and Fierstein, 2016; Hildreth and others, 2021).
- bop** **Bopesta Formation (middle Miocene)**—Fluvial and lesser lacustrine sediments with subordinate, interbedded volcanic deposits that crop out in the uplands northeast of Monolith and Tehachapi Valley. Sedimentary component is variable, consisting predominantly of volcanoclastic conglomerates, lithic to quartzose and arkosic sandstones, mudstones, and debris flow deposits, and is interstratified with subordinate pyroclastic deposits including tuff breccias, fluvially reworked tuff and waterlain pyroclastic fall, and basalt lava flows (Buwalda and Lewis, 1955; Dibblee, 1967; Dibblee and Louke, 1970; Quinn, 1987). Deposited in fluvial and somewhat lesser lacustrine environments (e.g., Quinn, 1987). Clast composition is predominantly volcanic material sourced from Cache Peak Volcanics (map unit cpv). Maximum thickness >1,000 m (Buwalda and Lewis, 1966) or 1,370 m (Quinn, 1987); however, stratigraphic boundaries and definitions vary between workers. Based on substantial vertebrate fauna, including several equine species, Quinn (1987) interprets the age to be late Hemingfordian to late Barstovian (~17 to ~13 Ma). Coles and others (1997) revise this age to late Hemingfordian to early Barstovian. They correlate their magnetostratigraphic data with chrons C5Adn to C5Cn1 (~16.3 to ~14.2 Ma per Ogg (2020)). Conformably overlies Kinnick Formation (Buwalda and Lewis, 1955; Quinn, 1987).
- cuV** **Cudahy Camp formation of Loomis and Burbank [1988] (early Miocene)**—Predominantly mafic to intermediate lava flows, pyroclastic deposits, and volcanic breccias interbedded with (though mostly overlying) coarse conglomerates and sandstones occurring in the El Paso Mountains (in southeastern map area) and northwest-adjacent basin (Loomis and Burbank, 1988). Volcanic deposits include basaltic to andesitic lava flows, flow breccias, tuff breccias, and pyroclastic flow and fall deposits (some waterlain; Cox and Diggles, 1986; Loomis and Burbank, 1988). Basal sedimentary unit consists of poly lithologic boulder to cobble conglomerate and arkosic sandstone (Loomis and Burbank, 1988). The

stratigraphically highest and capping unit is the Black Mountain Basalt, a succession of at least 15 subalkaline olivine-augite basalt flows dated by K-Ar at  $15.1 \pm 0.5$  Ma,  $17.1 \pm 0.5$  Ma, and  $17.9 \pm 1.6$  Ma (Cox, 1982; Cox and Diggles, 1986; Loomis and Burbank, 1988). Intruded by a series of predominantly east-west-trending dikes that are petrographically similar to and may be the source of the Black Mountain Basalt (Loomis and Burbank, 1988). Defined as the lower unit of the Ricardo Group by Loomis and Burbank (1988); unconformably overlain by the upper Dove Spring Formation unit of the group (map unit dos). Cox and Diggles (1986) obtained K-Ar ages of  $18.1 \pm 1.2$  and  $17.2 \pm 0.8$  Ma on andesite flows and breccia underlying the Black Mountain Basalt.

**tuv** **Tunis volcanics (early Miocene)**—A series of mafic to intermediate composition volcanic rocks interbedded with nonmarine sediments in the San Emigdio Mountains in the southwestern map area.

Predominantly fine-grained ophitic, and variably scoriaceous, basalt with phenocrysts of olivine  $\pm$  feldspar, and lesser andesite flows and plagioclase porphyritic dacite (Nilsen and others, 1973; Kellogg and others, 2008; Chapman and Saleeby, 2012). Includes minor shallow intrusive component (e.g., diabase) and locally includes hornblende-rich pyroclastic fall deposit (Chapman and Saleeby, 2012).

Turner (1970) reported K-Ar ages ranging from  $\sim 22$  to  $\sim 25$  Ma; Dickinson (1997) reported ages of  $\sim 22.5$  Ma. Thickness locally reaches  $\sim 450$  m but is typically less (Nilsen and others, 1973). Often mapped as interbedded with, and a member of, the Tecuya Formation (map unit tec), though Kellogg and others (2008) note it is also interbedded with the Temblor Formation (map unit tmb).

**cpv** **Cache Peak Volcanics (middle(?) to early Miocene)**—Consists of hypabyssal intrusions, pyroclastic flow and fall deposits, and lava flows, interbedded with lesser arkosic to volcanoclastic sedimentary strata in the Tehachapi Mountains in southern map area.

Hypabyssal intrusions consist of dikes, plugs, sills, and domes, which intrude basement units, the Witnet Formation (map unit wit), and lower sections of the Cache Peak Volcanics sequence (e.g., Dibblee, 1967; Saleeby and Saleeby, 2019).

Volcanic deposits consist of pyroclastic flow and fall deposits (some with pumice lapilli), lava flows (some vesicular and amygdaloidal), and volcanic breccias (e.g., Quinn, 1987; Saleeby and Saleeby, 2019). Compositions range from basalt to rhyolite, with silicic compositions primarily in the volumetrically dominant pyroclastic deposits.

Sedimentary strata are commonly tuffaceous and consist of arkosic to volcanic lithic sandstone, pebble to cobble conglomerate, siltstone, mudstone, and minor local (basal?) sedimentary breccia (e.g., Dibblee, 1967; Quinn, 1987).

Proportions of hypabyssal intrusions, extrusive volcanics, and sedimentary strata vary across mapped locations, with intrusive units dominant in the proximal northern area, sedimentary strata dominant in the distal southwestern area (where they are mapped as kin and bop), and volcanics dominant in the intervening region. Volcanics are interbedded with the Kinnick Formation (map unit kin) and lower(?) Bopesta Formation (map unit bop). The boundaries between this unit and the distal map units kin and bop are gradational rather than discrete, though depicted as lines on the map.

- Lower to central part of section is intruded by an  $18.63 \pm 0.55$  Ma dacite dike and includes two ash-flow tuffs with Ar-Ar plagioclase dates of  $18.34 \pm 0.20$  Ma and  $17.57 \pm 0.13$  Ma (Saleeby and Saleeby, 2019).
- kin **Kinnick Formation (early Miocene)**—Fluvial and pyroclastic deposits cropping out in the Tehachapi Mountains, in southern map area. This unit represents a (partial) distal equivalent to the Cache Peak volcanics (map unit cpv), from which the volcanic component is derived. Sedimentary strata are commonly tuffaceous and consist of arkosic to volcanic lithic sandstone, pebble to cobble conglomerate, siltstone, mudstone, and minor local (basal?) sedimentary breccia (e.g., Dibblee, 1967; Quinn, 1987). Pyroclastic strata are comprised of lenticular beds of quartz-bearing tuff and tuff breccia (Dibblee, 1967). Conformably overlain by middle Miocene Bopesta Formation (map unit bop). Early Miocene age based on stratigraphic relations to the Cache Peak Volcanics and Bopesta Formation. Boundary between Cache Peak Volcanics and Kinnick Formation is gradational, not discrete.
- bob **Bobtail Quartz Latite Member of the Gem Hill Formation (Miocene)**—Volcanic and hypabyssal intrusive rocks located between the town of Mojave and the Garlock fault. Consists of rhyolitic or quartz latitic dikes and volcanic plugs intruded into the Gem Hill Formation and extrusive flow breccias intercalated with Gem Hill Formation sedimentary strata (Dibblee, 1958, 1967). Commonly porphyritic (up to 30%) with plagioclase, sanidine, and quartz; locally flow-laminated (Dibblee, 1958, 1967). Only one occurrence within map area, which is undated. May be correlative with the volcanic complex at Soledad Mountain southeast of map extent, for which McCusker (1982) reports K-Ar ages ranging from  $21.5 \pm 0.8$  Ma to  $16.9 \pm 0.7$  Ma. Unconformably overlain by the late Miocene to early Pliocene Horned Toad Formation (May and others, 2011).
- nev **Neenach Volcanics (early Miocene to late Oligocene)**—A volcanic sequence of andesitic to rhyolitic lava flows interbedded with lesser pyroclastic deposits and agglomerate cropping out in the western Mojave Desert immediately northeast of the San Andreas fault, in southern map area.

Compositions are calc-alkaline and include andesite, dacite, and rhyolite lavas and lesser pumice lapilli tuff (Matthews, 1976). Andesite lavas are variably porphyritic with plagioclase  $\pm$  augite  $\pm$  olivine  $\pm$  hypersthene  $\pm$  pyroxene phenocrysts; dacite lavas are volumetrically minor and typically porphyritic with plagioclase and lesser biotite and quartz phenocrysts; rhyolite lavas are aphyric to moderately porphyritic with plagioclase, biotite and quartz phenocrysts (Matthews, 1976). Pyroclastic deposits range in composition from andesitic to rhyolitic and include vitric lapilli tuff and pumice lapilli tuff, some of which contain minor accidental granitic clasts (Matthews, 1976). Also includes perlite and heterolithologic boulder agglomerate (Matthews, 1976).

The southwestern margin of the outcrop area is truncated by the San Andreas fault; this unit has been correlated with the Pinnacles Volcanic formation that occurs 315 km northwest on the opposite side of the fault (Matthews, 1976).

Matthews (1973) reported K-Ar dates of about 18 to 23 Ma for the Neenach Volcanics based on preliminary analyses conducted by Turner, similar to dates obtained by Turner (1968) at the Pinnacles Volcanics. Sims (1993) published recalibrated ages for these

original analyses of about 19 to about 24 Ma. However, Weigand and Swisher (1991) reported Ar-Ar whole rock ages of only 11.95 to 14.28 Ma for the dacite and andesite units, respectively (also see notes in Stanley and others (2000)). Recent, unpublished Ar-Ar dating of the dacite and andesite units produced similar ages ranging from about 10.9 to 15.0 Ma for the andesite and dacite units, but an age of about 23 Ma for the lower rhyolite unit (Matt Heizler, New Mexico Tech Geochronology Lab, written commun., 2023). However, subsequent U-Pb dating yielded ages of about 27.0 to 27.6 Ma for the dacite and lower rhyolite units, respectively (Josh Schwartz, CSUN Laser Lab, written commun., 2023). Also, Anttila and others (2025) report a U-Pb zircon age of ~24.3 Ma on the flow-banded rhyolite. These new U-Pb dates and evidence of alteration in the dacite and andesite units suggest that Ar loss occurred during alteration, producing incorrect young ages.

**tmb** **Temblor Formation (Miocene to Oligocene)**—A thick sequence of marine shale and sandstone occurring in the San Emigdio Mountains in southwestern map area. Shale is typically micaceous and locally silty; interbedded sandstone is typically massive to thickly bedded, locally cross bedded, locally coarse and pebbly to conglomeratic, especially near base of unit (Nilsen and others, 1973; Kellogg and others, 2008; Chapman and Saleeby, 2012).

Generally conformably overlies Pleito Formation but locally exhibits unconformable contact with underlying Pleito, San Emigdio, and Tejon Formations or basement. Interfingers with, and overlies, Tecuya Formation. Locally includes porphyritic dacite clasts (Nilsen and others, 1973) probably sourced from adjacent Tunis volcanics member of Tecuya Formation (map unit tuv). Maximum thickness ~1,650 m near lower Santiago Creek, but thins laterally (e.g. Kellogg and others, 2008). Molluscan fauna, stratigraphic relations, and rare volcanic clasts indicate late Oligocene to Miocene age. Unconformably(?) overlain by Monterey Shale (map unit ms).

**tec** **Tecuya Formation (early Miocene to Eocene)**—Consists of interbedded pebble to boulder conglomerate, sandstone, siltstone, and mudstone occurring at moderate to higher elevations of the San Emigdio Mountains near southwestern map extent. Pebble to boulder conglomerates have varying abundances of granitic, quartzite, metavolcanic, and marble clasts in a matrix of coarse sand (Nilsen and others, 1973; Chapman and Saleeby, 2012).

Contains or is interstratified with Tunis Volcanics member (map unit tuv). Locally (west of Tecuya Canyon) includes a basal granitic breccia that Nilsen and others (1973) interpreted as a landslide deposit.

Conformably overlies the Tejon Formation; interfingers the San Emigdio and Pleito Formations (map unit sep); interfingers and is overlain by the Temblor Formation (map unit tmb), and is generally interpreted as a time-equivalent proximal alluvial fan complex of the same system (e.g., Nilsen and others, 1973). Attains maximum thickness of ~700 m near eastern extent and thins westward, pinching out near Pleito Creek (Nilsen and others, 1973; Kellogg and others, 2008).

Late Eocene to early Miocene age indicated by late Oligocene to early Miocene K-Ar ages on interbedded Tunis volcanics, locally occurring mammalian fossils, and interfingering relations to more distal marine units (Nilsen and others, 1973; Kellogg and others, 2008).

Roughly similar in age and depositional environment to the Walker Formation (map unit wlk), which occurs across the San Joaquin Valley to the northeast.

wlk

**Walker Formation (early Miocene to late Eocene)**—Consists of a diachronous sequence of nonmarine clayey sandstone, siltstone, and claystone, with very minor intercalated pyroclastic deposits, exposed in a fairly continuous, arcuate strip near the southeastern margin of the San Joaquin Valley. Unconformably overlies basement and interfingers laterally (basin-ward/westward) with several marine sedimentary sequences.

Significant age and compositional changes occur from north to south within the formation. Bartow and McDougall (1984) reported compositional changes across the Bakersfield arch: arkosic sandstone, conglomerate, and minor sandy claystone predominate to the south, whereas sandy claystone predominates to the north. Saleeby and others (2016) also reported that the base of the unit is time-transgressive, grading from late Eocene in the north, to early Miocene in the south. For this reason, Saleeby and Saleeby (2019) designate the northern and southern parts of the Walker Formation outcrop belt as “paleo”-Walker and “neo”-Walker, respectively.

Includes strata comprised of kaolinitic claystone and quartzose sandstone, which resemble the Eocene Ione Formation to the north (map unit io; Bartow and McDougall, 1984). Also includes the Bealville fanglomerate, which occurs along Caliente Creek in the southeastern mapped extent, and which Bartow and McDougall (1984) describe as a coarser equivalent to the type Walker Formation, but Saleeby and Saleeby (2019) interpreted as rock avalanche deposits. Thickness varies laterally from 200 to  $\geq 900$  m (Bartow and McDougall, 1984).

Lowest strata (of “paleo”-Walker) include a  $40.10 \pm 0.27$  Ma reworked pyroclastic fall deposit; a  $26.94 \pm 0.20$  Ma ash bed occurs in upper section (of “paleo”-Walker); uppermost (“neo”-Walker) strata are interbedded with  $19.79 \pm 0.27$  and  $19.56 \pm 0.30$  Ma ash beds; formation is unconformably overlain by the  $17.0 \pm 0.20$  Ma Ilmon Basalt (all ages are Ar-Ar from Saleeby and Saleeby, 2019).

May be regarded as a composite unit which could be subdivided, but extant mapping has not divided it.

sep

**San Emigdio and Pleito Formations (Oligocene to upper Eocene)**—Consists of a sequence of marine sandstone, shale, and minor conglomerate that crops out in the San Emigdio Mountains in the southwestern map area.

This sequence exhibits both stratigraphic and lateral changes in grain size and fossil type and abundance, reflecting cyclic sea-level changes and, more prominently, lateral changes reflecting position within the basin. Sandstone is arkosic and fine- to medium-grained, locally pebbly, grading to massive to thickly bedded medium- to coarse-grained and variably conglomeratic; shale is typically planar-bedded, micaceous, and locally sandy; granitic breccia is present locally; strata range from nonfossiliferous to abundantly fossiliferous with a variety of molluscan fauna and foraminifera (Nilsen and others, 1973; Kellogg and others, 2008; Chapman and Saleeby, 2012).

Maximum thickness exceeds 2,700 m but varies laterally (e.g., Nilsen and others, 1973). Interfingers with and laterally grades into nonmarine strata of Tecuya Formation. Late

Eocene to Oligocene age based on fossil fauna and stratigraphic relations (e.g., Nilsen and others, 1973).

**tej** **Tejon Formation (Eocene)**—Consists of a faulted and moderately folded sequence of marine shale, sandstone, conglomerate, and local breccia that crops out in the San Emigdio Mountains in southwestern map area.

Lower strata consist of coarser conglomerate and sandstone to pebbly sandstone, with a discontinuous coarse basal breccia, grading laterally to finer-grained sandstone and shale; upper strata consist of sandstone with interbedded conglomerate and shale (Nilsen, 1987).

Shale is typically thin bedded or platy and micaceous to argillaceous and locally silty to sandy; sandstone is arkosic, variably resistant and ledgy or friable, and fine to coarse grained and locally pebbly, and rarely flat stratified and well sorted (indicative of beach sand); conglomerate may include clasts of chert, quartz, porphyry, granite, and various other rock types sourced from the western San Emigdio mafic complex (Nilsen, 1987; Kellogg and others, 2008; Chapman and Saleeby, 2012).

Inferred depositional environments are near shore, shallow marine, brackish water to lagoon or (locally) beach, grading laterally to deeper marine (Nilsen, 1987). Attains a maximum thickness of 1,200 to 1,300 m in the central part of the range, but thins laterally to 300 m (Be, 1983; Nilsen, 1987; Kellogg and others, 2008). Locally fossiliferous, containing foraminifera and invertebrate megafossils, including numerous species of gastropods, pelecypods, and lesser other types, all diagnostic of Eocene age (Nilsen, 1987). Coarser shallow marine facies hosts substantial oil (Nilsen, 1987). Separated from time-equivalent Domengine Formation by the Bakersfield arch depositional barrier present in the subsurface (Be, 1983).

**wit** **Witnet Formation (early Cenozoic)**—Sequence of fluvial strata exposed along Oil Canyon and elsewhere in the uplands northeast of Tehachapi Valley, consisting of arkosic sandstone interbedded with micaceous siltstone to sandy shale and lesser pebble to cobble conglomerate (Dibblee, 1967; Buwalda and Lewis, 1955). Base is locally comprised of cobble conglomerate up to ~180 m thick (Dibblee, 1967). Strata are steeply dipping, unconformably overlie basement, and are unconformably overlain by subhorizontal Miocene strata. Age poorly constrained due to lack of volcanic and fossil materials but generally regarded as early Cenozoic. Tentatively correlated with the Goler Formation (map unit gol) based on textural and compositional similarities and spatial proximity (Dibblee, 1967; Cox, 1982). More recent detrital zircon sediment provenance data (Lechler and Niemi, 2011) show divergent age spectra for the Witnet Formation and upper Goler Formation; however, this does not preclude correlation with the lower two members of the Goler Formation.

**gol** **Goler Formation (Paleocene)**—A succession of interbedded sandstone, conglomerate, and shale up to 4,300 m thick (Dibblee, 1952; Cox, 1982), cropping out in the southeastern map area, in the El Paso Mountains north of the Garlock fault. Cox (1982) divided the formation into four members, across which clast composition varies. In the lower three members (nos. 1-3), clast lithologies are predominantly granitic and metasedimentary. In the upper member (no. 4), clast lithologies consist of mostly silicic volcanic rock types and quartzite (Cox, 1982).

The bulk of the strata are interpreted to have been deposited by fluvial systems operating within alluvial fans and distal alluvial plain environments, by braided rivers within a structural basin also hosting minor lacustrine environments. However, an interval of siltstone, sandstone, and conglomerate is present within the upper member, which bears marine fossils and records a period of marine transgression (Cox, 1982, 1987).

The upper two members host a very significant trove of Paleocene mammalian and other fossils, which are the only significant Paleocene terrestrial (nonmarine) fossils found in North America west of Utah (Lofgren and others, 2020, and references therein).

The upper two members host fossils of latest Torrejonian to middle Tiffanian age (Albright and others, 2009; Lofgren and others, 2020). These fossil ages coupled with magnetostratigraphy indicate an age of ~62 to 57 Ma for the upper two members (Albright and others, 2009). The lower two members are not fossil-bearing, and the maximum age of the formation is poorly constrained. The formation unconformably overlies granitic and metamorphic basement (map units Gep and EPS).

Detrital zircon age spectra and inferred sediment provenance reported by Stone (2021) changes across the lower to upper members and suggests that the lower members may differ significantly from the upper members in both age and provenance. May be partly correlative with the Witnet Formation (map unit wit; Cox, 1982). Coarse fluvial gravels in the lowest member host placer gold which has been exploited historically (Dibblee and Gay, 1952).

Chemical composition and clay mineralogy of numerous paleosol horizons present in the upper two members indicate globally warm temperatures and locally high seasonal precipitation and resultant wet and dry cycles, transitioning to more arid climate in the uppermost member (no. 4; Torres and Gaines, 2013).

## **BASEMENT**

### **UNDERTHRUST FOREARC AND(OR) ACCRETED SEAFLOOR ROCKS**

#### **Pelona Schist Terrane**

**PS** Pelona-Rand Schist and related units (Paleocene to Late Cretaceous)—Consists of thin-layered, light to dark schist containing varying amounts of quartz, muscovite, biotite, and plagioclase. Local thin-layered quartzite (derived from meta-chert) with garnet, mica, and feldspar. Local mafic metavolcanic layers composed of albite, actinolite, epidote, and sphene. Local layers of schistose hornblende amphibolite and antigorite serpentinite, and chlorite schist. Local calcareous, silicic, and pelitic schist, and gneiss. Local hornfels adjacent to granitic plutons. Pelitic schist locally contains andalusite, lesser sillimanite and garnet. In the map area, is located in San Emigdio Mountains [there named the San Emigdio schist by Chapman and others (2011) and Rand Schist by Kellogg and others (2008)], and within the Garlock fault zone in the southwestern Tehachapi Mountains (mapped as Pelona Schist by Dibblee (1967), but more likely Rand Schist or San Emigdio schist based on its position along the fault separating those two parts of this unit). Part of the larger Pelona-Orocopia-Rand schist terrane which extends from southwest Arizona to the Sierra de Salinas near Monterey Bay in central California. Terrane is an exhumed, shallow, subduction-zone

complex or underthrust forearc. Detrital zircons suggest that the depositional age of the protolith varies from Late Cretaceous (early Turonian) for the schist in the San Emigdio Mountains to Late Cretaceous (Santonian-Campanian) for the Rand Schist south of the map area to Late Cretaceous (late Campanian to Maastrichtian) for the Pelona Schist to latest Cretaceous (Maastrichtian) to Paleocene (possibly early Eocene in Arizona) for the Orocochia Schist (Jacobson and others, 2011). Ar-Ar dating of metamorphic minerals (Chapman, 2017) suggests a similar southward-younging trend in timing of metamorphism, with muscovite and hornblende Ar-Ar ages ranging from late Turonian for the schist in the San Emigdio Mountains to late Eocene in Arizona. Uplift from lower crustal levels may have occurred during subduction of one or more oceanic plateaus (Chapman and others, 2012). Down-thrusting occurred beneath Sierra Nevada and southern California batholith to 9 Kbar or more pressure (~30 km?) and subsequently elevated to upper crustal depths. Terrane exhibits inverted regional metamorphism caused by shallow subduction beneath hot roots of the Sierra Nevada arc (Kidder and Ducea, 2006). The timing and nature of uplift varies across the terrane, with latest Cretaceous to Eocene uplift of both upper plate (Tehachapi-San Emigdio intrusive suite or unit Gte) and lower plate consisting of the San Emigdio schist in the San Emigdio Mountains, whereas emplacement pressure and thermochronologic constraints in the Rand Mountains require significant unroofing via detachment reactivation of the Rand thrust (Chapman and others, 2010) that continued into Miocene time (Shulaker and Grove, 2015). Terrane structurally overlain by Tehachapi-San Emigdio terrane (unit TSS) and the Tehachapi-San Emigdio intrusive suite (unit Gte). Terrane occurs in lower plate of Rand thrust.

## PLUTONS AND INTRUSIVE SUITES

[Note that we do not map most individual plutons within the batholith, as that level of detail is beyond the scope of this product. We urge users who want that level of detail to refer to the larger scale maps of portions of the map area that include more detail, available through the national geologic map database (<https://ngmdb.usgs.gov>). Note also that “intrusive suite” and “intrusive complex” herein are used in the more expansive grouping style of Bateman (1992) and Lackey and others (2008), which groups plutons intruded over a longer period of time and is meant to reflect one or more regional periods of intrusion, and is quite distinct from the much more restricted “intrusive suite” of Moore and Sisson (1987), which is meant to reflect a single pulse of magma with a very limited age span. “Plutonic complex” is used for a smaller group of plutons, in some cases forming a single body in map view but revealed by age or composition to be composed of multiple intrusions.]

- Gm**        **Granitic rocks, undivided (Mesozoic)**—Chiefly granodiorite and quartz monzonite, and lesser granite, diorite, and gabbro. Unit defined for areas in which detailed geologic mapping and/or isotopic age data are lacking.
- Gjm**        **John Muir Intrusive Suite (Late Cretaceous, ~76-106 Ma)**—Occurs along the eastern crest of the central Sierra Nevada and in scattered plutons extending west near the San Joaquin River. One of the Sierra Crest intrusive suites (e.g., Lackey and others, 2008; Hildebrand and Whalen, 2021). Chiefly granodiorite, granite, and alaskite. Major plutons: Lamarek Granodiorite, Lake Edison Granodiorite, granite of Rock Creek Lake, Round Valley Peak Granodiorite, Mono Creek Granite, Evolution Basin Alaskite, granodiorite of Lone Pine Creek, and Alabama Hills Granite. Unit also includes small intrusions west of the Mount

Givens Granodiorite, including the leucogranites of Big Sandy Bluff, Lion Point, and Bald Mountain, and granodiorites of Red Lake, Eagle Peak, and Big Creek, as well as to the southeast the Dragon Pluton, Bullfrog Pluton, Independence Pluton, and granodiorite of Lone Pine Creek. Bateman (1992) states that the optimum ages for this unit range from 88-90 Ma, but zircon (and one titanite) U-Pb ages reported from this unit range from ~76-106 Ma (Stern and others, 1981; Chen and Moore, 1982; Saleeby and others, 1990; Tobisch and others, 1995; Lackey and others, 2008; Davis, 2010; Frazer and others, 2014, 2022). In addition, this unit has yielded ages as follows: whole rock Rb-Sr ~75-87 Ma, biotite K-Ar and Ar-Ar ~75-104 Ma, hornblende K-Ar and Ar-Ar ~77-98 Ma (excluding two ages of ~150-151 Ma that are clearly too old and probably represent wall rock inliers or contamination), K-feldspar Ar-Ar ~76-78 Ma, apatite fission track ~54-93 Ma, sphene fission track ~71-100 Ma, epidote fission track ~84 Ma, and allanite fission track ~86 Ma (Kistler and others, 1965; Naesser and Dodge, 1969; Evernden and Kistler, 1970; Tobisch and others, 1995; Davis, 2010). The unit as mapped here also includes very small slivers of Jurassic plutonic rock (zircon U-Pb ages of 149-181 Ma, Chen and Moore, 1982; Davis, 2010; Attia and others, 2022), which are too small to show at map scale.

**Gps** **Pastoria intrusive suite (Cretaceous, ~80-105 Ma)**—Occurs in the western Tehachapi Mountains and easternmost San Emigdio Mountains north of the Garlock fault south branch and south of the Pastoria fault, intruding the Pastoria terrane (unit PAS). Chiefly granodiorite, tonalite, and granite. Includes the Lebec granodiorite and monzogranite of Brush Mountain of Kellogg and others (2008); Lebec granodiorite, granite of Brush Mountain, and tonalite of San Emigdio Creek of Chapman and Saleeby (2012); granodiorite of Lebec and granite of Brush Mountain of Kistler and Ross (1990) [each work defines and maps the units somewhat differently]. The granite of Brush Mountain of Kistler and Ross has yielded a Rb-Sr age of ~91 Ma, whereas the granite of Brush Mountain of Chapman and Saleeby (2012) has yielded a zircon U-Pb age of ~105 Ma, and James (1986) assigned it a U-Pb age of ~98 Ma. The granodiorite of Lebec has yielded zircon U-Pb ages of ~80-92 Ma (Chapman and others, 2012; Kellogg and others, 2008, Nourse and others, 2020). However, the only age in this unit less than 88 Ma is the 80 Ma age of Nourse and others (2020), which is from rock within the Garlock fault zone at the intersection with the San Andreas fault, so that anomalous age may indicate lead loss near the San Andreas fault or may indicate that the sample is actually from a fault sliver of a younger part of the Northernmost Mojave intrusive suite (unit Gnm) which crops out just south of the Garlock fault south branch. On the other hand, Kistler and Ross (1990) correlate the granodiorite of Lebec with the granodiorite of Gato Montes (in unit Gnm), offset by the Garlock fault, so differentiation between units Gps and Gnm may be moot. Local pervasive alteration to sausserite and sericite. Discrete secondary muscovite and chlorite. Widespread, disseminated hornblende phenocrysts. Aluminum in hornblende indicates igneous pressure of 3.1-5.8 kbar (Chapman and others, 2012). This suite is in the upper block of the Pastoria normal (detachment) fault.

**Gnm** **Northernmost Mojave intrusive suite (Cretaceous and Jurassic, ~82-96 Ma; ~147 Ma)**—Occurs in the northernmost Mojave block south of the Garlock fault, intruding the Bean Canyon terrane (units BCB and BCT). Chiefly granodiorite, tonalite, and granite. Includes Tejon Lookout Granite of Swanson and Olson (2016) and Olson and Swanson

(2017; 2019); the granite of Tejon Lookout, the granodiorite of Gato Montes, granite of Bean Canyon, and granodiorite of Cameron of Ross (1989); the granite of Bean Canyon, granite of Tejon Lookout, and granodiorite of Gato Montes of Chapman and others (2012), and various unnamed plutonic units of Dibblee (1963; 1967) [each work defines and maps the units somewhat differently]. This unit has yielded Rb-Sr ages of ~96 Ma (Kistler and Ross, 1990) and zircon U-Pb ages of ~82-90, 92, and 96 Ma (James and others, 1986; Chapman and others, 2012; Nourse and others, 2020). Evernden and Kistler (1970) reported a biotite K-Ar age (representing cooling through ~300 degrees C) of ~80-81 Ma. Kistler and Ross (1990) stated that their granodiorite of Gato Montes in this unit is the same as their granodiorite of Lebec (part of unit Gps), offset along the Garlock fault. This unit has aluminum in hornblende emplacement pressure of about 2.4-2.8 kbar (Chapman and others, 2012), somewhat less than the possibly correlated Pastoria intrusive suite (unit Gps). This unit as mapped also incorporates the granodiorite of Gamblespring Canyon of Chapman and others (2012) [not mapped in detail], which has a zircon U-Pb age of ~147 Ma. The Gamblespring Canyon granodiorite is probably the same as the unnamed hornblende diorite unit of Dibblee (1963) which crops out in lenses adjacent to the schist of Tylerhorse Canyon (part of unit BC) and pods in the Cretaceous granitics too small to show on the map, and probably is part of the wall rock for the later Cretaceous plutons. Chapman and others (2012) note the similarity in age and lithology between the Gamblespring Canyon granodiorite and the Independence dike swarm (unit Gid), but in their model they do not restore the block to the area of the dike swarm, so correlation is unclear. This unit is apparently in the upper plate of the Pastoria Normal fault based on depth of emplacement, although that fault does not bound this block.

**Gpa Papoose Flat intrusive suite (Late Cretaceous, ~83 Ma)**—Located in the White Mountains. Biotite quartz-monzonite with large (up to 5 cm long) K-feldspar crystals and primary muscovite common. Major plutons: Granite of Papoose Flat, and Birch Creek pluton to east of study area. Biotite K-Ar dates of about 75-81 Ma (Kistler and others, 1965; Evernden and Kistler, 1970) and U-Pb monazite age of 83 Ma (Miller, 1996; Saint-Blanquat and others, 2001). The Papoose Flat pluton is discussed in detail by Sylvester and others (1978) and Saint-Blanquat and others (2001).

**Gwh Mount Whitney Intrusive Suite (Late Cretaceous, ~83-92 Ma)**—Occurs along crest of southern Sierra Nevada. One of the Sierra Crest intrusive suites (e.g. Lackey and others, 2008; Hildebrand and Whalen, 2021). Chiefly granodiorite, in most places porphyritic, and granite. Zircon (and one sphene) U-Pb ages of 83-92 Ma (Chen and Moore, 1982; Lackey and others, 2008; Davis, 2010; Sisson and Moore, 2013); hornblende K-Ar and Ar-Ar ages of 80-90 Ma and biotite K-Ar and Ar-Ar ages of 78-83 Ma (Evernden and Kistler, 1970; Davis, 2010), as well as a zircon Ar-Ar age of 91 Ma and zircon U-Th/He ages of 75 and 84 Ma (Davis, 2010). Aluminum in hornblende emplacement pressures range from 0.2-3.5 kbar (Chapman and others, 2012). Hildebrand and Whalen (2021) report relatively high Nb/Y, La/Yb, and Sr/Y for this unit. Lackey and others (2008) report low zircon  $\delta^{18}\text{O}$  (~5-6.5 ‰ relative to Vienna Standard Mean Ocean Water [VSMOW]) and whole-rock  $\delta^{18}\text{O}$  (~5-8 ‰ VSMOW) and  $^{87}\text{Sr}/^{86}\text{Sr}$  values between ~.706-.708. Major plutons: Paradise Granodiorite, granite of Carroll Creek, granite of White Mountain, granodiorite of Castle Creek, granodiorite of Chagoopa, granodiorite of Mitchell Peak, granite of Mount Kaweah,

granodiorite of Mountain Home, granodiorite of Sugarloaf, granodiorite of White Divide, Paradise Granodiorite, Pyramid pluton, and Whitney Granodiorite. One of the largest and youngest plutonic suites in the eastern Sierra Nevada.

- Gwa Walker Lake intrusive suite (Late Cretaceous and Late Jurassic, ~83-96 and ~155 Ma)**—Occurs in west-central Nevada and eastern Sierra Nevada. Chiefly granodiorite and quartz monzonite with lesser granite, diorite, and gabbro. Includes coarse-grained, massive, light-gray quartz monzonite with numerous local aplite and pegmatite dikes, and medium- to coarse-grained massive granodiorite with local aplite and pegmatite dikes. Predominantly Late Cretaceous, with one zone of Late Jurassic plutons east of Antelope Valley (Stewart and others, 1989). Zircon U-Pb ages of ~83-96 Ma and whole-rock Rb-Sr ages of ~82 and ~88 Ma (Robinson, 1985; Stewart and others, 1989), along with whole rock Rb-Sr and feldspar Pb-Pb ages of ~155 Ma (Robinson and Kistler, 1986; Wooden and others, 1999), as well as one biotite K-Ar age of ~119 Ma and hornblende K-Ar of ~61 and 82 Ma (Evernden and Kistler, 1970). The older part is coeval with and potentially intrusively linked to marine metavolcanic rocks (unit WLVI) in the Walker Lake terrane.
- Gop Owens Peak intrusive suite (Cretaceous, ~83-108 Ma)**—Forms a broad northwest-trending band from the southeasternmost Sierra Nevada to the San Joaquin Valley foothills near the Tule River. Chiefly granodiorite, tonalite, granite, and mafic gneiss and amphibolite. Occurs in the southern Sierra Nevada, east and west of the upper drainage of Kern River. Zircon U-Pb ages from this unit west of the Kern Canyon fault range from ~96-108 Ma, whereas those east of the fault range from ~83-100 Ma (Busby-Spera and Saleeby, 1990; Saleeby and others, 2008; Chapman and others, 2012; Sisson and Moore, 2013; Clemens-Knott and Gevedon, 2023; Langenheim and others, 2025). Evernden and Kistler (1970) report biotite K-Ar ages of ~85-92 Ma west of the fault and ~49-79 Ma east of the fault. Evernden and Kistler (1970) also report hornblende K-Ar ages of ~88 and ~96 Ma, as well as ~73 Ma (plagioclase), ~88 Ma (K-feldspar), and ~58 Ma (quartz) from the unit west of the fault. Major plutons: granodiorite of Claraville, mafic gneiss and amphibolite of Jawbone Canyon, granodiorite of Mountain Home, granite of Bishop Ranch, granite of Tehachapi Airport, granodiorite of Castle Rock, granodiorite of Rabbit Island, alaskite of Sherman Pass, granite of Long Meadow, granite of Black Mountain, granodiorite of Alta Sierra, granodiorite of Church Dome, granodiorite of Bedrock Meadow, and Kern River, Needles, Domelands and South Fork intrusive suites of Saleeby and others (2008).
- Gso Sonora Pass intrusive suite (Cretaceous, ~84-98 Ma)**—Occurs in eastern central Sierra Nevada in the Sonora Pass area. One of the Sierra Crest intrusive suites (e.g. Lackey and others, 2008; Hildebrand and Whalen, 2021). Chiefly granodiorite. This unit has yielded zircon U-Pb ages of ~84-98 Ma (Wooden and others, 1999; Lackey and others, 2008; Leopold, 2016). Evernden and Kistler (1970) report biotite K-Ar ages of ~80-86 Ma, as well as a hornblende K-Ar age of ~84 Ma. Macias (1996) reports emplacement pressures of ~2.0 and ~3.5 kbar. Hildebrand and Whalen (2021) report relatively high Nb/Y, La/Yb, and Sr/Y for this unit. Lackey and others (2008) report low zircon  $\delta^{18}\text{O}$  (~-5-6.5 o/oo VSMOW) and whole-rock  $\delta^{18}\text{O}$  (~-5-8 o/oo VSMOW) and  $^{87}\text{Sr}/^{86}\text{Sr}$  values between ~.706-.708. Major plutons: granodiorites of Kinney Lake, China Garden, Mill Creek; Topaz Lake; Fremont Lake, and smaller satellite plutons.

- Gtu Tuolumne Intrusive Suite (Cretaceous, ~86-96 Ma)**—Occurs along crest and to west of crest of central Sierra Nevada. One of the Sierra Crest intrusive suites (e.g. Lackey and others, 2008; Hildebrand and Whalen, 2021). Chiefly granodiorite, tonalite, and granite. Zircon U-Pb ages from this unit range from ~86-96 Ma (Stern and others, 1981; Coleman and Glazner, 1997; Coleman and others, 2004; Burgess and Miller, 2008; Bracciali and others, 2008; Memeti and others, 2010, 2022; Paterson and others, 2016). Biotite K-Ar ages range from ~80-85 Ma (with an outlier of ~69 Ma), along with single K-Ar ages of ~84 Ma (hornblende), ~70 Ma (plagioclase), ~74 Ma (K-feldspar), and ~89 Ma (quartz) (Evernden and Kistler, 1970). Naesser and Dodge (1969) report an apatite fission track age of ~85 Ma. Hildebrand and Whalen (2021) report relatively high Nb/Y, La/Yb, and Sr/Y for this unit. Lackey and others (2008) report low zircon  $\delta^{18}\text{O}$  (~5-6.5 o/oo VSMOW) and whole-rock  $\delta^{18}\text{O}$  (~5-8 o/oo VSMOW) and  $^{87}\text{Sr}/^{86}\text{Sr}$  values between ~.706-.708. Major plutons: granodiorites of Kuna Crest and Grayling Lake and tonalites of Glen Aulin and Glacier Point, equigranular Half Dome Granodiorite, porphyritic Half Dome Granodiorite, Cathedral Peak Granodiorite, Johnson Granite Porphyry, Yosemite Creek Granodiorite and Sentinel Granodiorite. Best-known intrusive suite in Sierra Nevada.
- Gks Kaweah-Sequoia intrusive suite (Cretaceous, ~86-135 Ma)**—Occurs in eastern part of central Sierra Nevada. Chiefly granodiorite, granite, quartz diorite. This unit has zircon U-Pb ages ranging from ~86-135 Ma, with the great majority of the ages ~90-106 Ma (Saleeby and Sharp, 1980; Chen and Moore, 1982; Lackey and others, 2008; Holland and others, 2013; Sisson and Moore, 2013). Evernden and Kistler (1970) report biotite K-Ar ages of ~83-93 Ma and hornblende K-Ar ages of ~86-93 Ma, along with plagioclase K-Ar age of ~88 Ma and potassium feldspar K-Ar age of ~87 Ma. Major plutons: granite of Big Meadows, granite of Case Mountain, granite of Big Meadow, granite of Coyote Pass, granite of Dennison Peak, granite of Eagle Scout Peak, granite of Little Kern Lake, granite of Maggie Mountain, granite of Mount Kaweah, granite of Redrock Meadows, granite of White Mountain, granodiorite of Giant Forest, granodiorite of Burnt Camp Creek, granodiorite of Lookout Peak, granodiorite of Milk Ranch Peak, granodiorite of North Dome, granodiorite of Pecks Canyon, granodiorite of Shepherds Saddle, granodiorite of Windy Ridge, Mitchell Peak Granodiorite, and quartz diorite of Empire Mountain. Unit includes Sequoia Intrusive Suite and Mitchell Intrusive Suite (see Moore and Sisson, 1987).
- Gmg Mount Givens pluton (Late Cretaceous, ~88-98 Ma)**—Occurs along axial part of central Sierra Nevada. Chiefly granodiorite and granite with lesser tonalite, granite, and minor alaskite. Small bodies of aplite granite occur in center of northern and southern parts of pluton. Bulbous northern part of pluton exhibits both equigranular facies and K-feldspar megacryst facies with K-feldspar up to 3 cm long. One of largest single plutons in Sierra Nevada batholith. Pluton located between younger John Muir Intrusive Suite (unit Gjm) to east and older Shaver Intrusive Suite (unit Gsl) to west. Unit included in John Muir Intrusive Suite by Bateman (1992). Delineated separately herein because it consists of a single, large, distinct pluton. Zircon U-Pb ages from this unit range from ~88-98 Ma (Stern and others, 1981; Frazer and others, 2014). Kistler and others (1966) report biotite K-Ar ages of ~82-88 Ma, hornblende K-Ar ages of ~87 and ~88 Ma, and a whole rock Rb-Sr age of ~82 Ma. Naesser and Dodge (1969) report sphene fission track ages of ~77-90 Ma and apatite fission

track ages of ~74-84 Ma.

- Gikt Lake Tahoe intrusive suite (Cretaceous, ~90-126 Ma)**—Occurs around Lake Tahoe from northwest of Reno south to Highway 4. Chiefly granodiorite, granite, and adamellite. Major plutons: Bryan Meadow Granodiorite, Ebbetts Pass Granodiorite, Carson Pass Tonalite, Castle Valley plutonic assemblage, Freel Peak Granodiorite, granodiorite of Kingsbury Grade, Stanislaus Meadow Adamellite, Burnside Lake Adamellite, granodiorite of Deadwood Lake, Keiths Dome quartz monzonite. Zircon U-Pb and feldspar Pb-Pb ages from this unit range from ~90-126 Ma (Kulow and others, 1997; Wooden and others 1999; Rotberg, 2008; Cecil and others, 2012; Langenheim and others, 2025). Also includes outcrops too small to show at map scale east of French Meadows Reservoir, one of which has yielded a zircon U-Pb age of ~109 Ma (Langenheim and others, 2025). In addition, this unit has yielded K-Ar hornblende and biotite ages of ~91-100 Ma and ~87-102 Ma, respectively, as well as plagioclase K-Ar age of ~93 Ma, K-feldspar K-Ar age of ~100 Ma, and quartz K-Ar age of ~109 Ma (Evernden and Kistler, 1970).
- Gja Jack Main Canyon intrusive suite (Late Cretaceous, ~91-110 Ma)**—Occurs west of the crest of central Sierra Nevada, in northwest Yosemite Park. Chiefly granodiorite and diorite. Feldspar Pb-Pb and zircon U-Pb ages from this unit range from ~91-110 Ma (Wooden and others, 1999; Leopold, 2016; Ardill and others, 2018). This unit also has biotite K-Ar ages from ~87-94 Ma and hornblende K-Ar ages from ~90-98 Ma, as well as one plagioclase K-Ar age of ~91 Ma, one K-feldspar K-Ar age of ~84 Ma, and one quartz K-Ar of ~108 Ma (Evernden and Kistler, 1970). In addition, two localities in the northwest part of this unit have yielded much older K-Ar ages (biotite ~125 and ~145 Ma, hornblende two ages of ~148; Evernden and Kistler, 1970). These ages are considerably older than the emplacement age of the unit indicated by feldspar Pb-Pb ages, and suggest that the unit as mapped contains some rocks that belong to an older unit, probably the adjacent Don Pedro intrusive suite (unit Gdp). Major plutons: granodiorites of Boundary Lake, Lake Vernon, Bearup Lake, Rancheria Mountain, and Bummers Flat, and quartz diorite of Mount Gibson. East of Calaveras Big Trees State Park, includes:
- Gjam Mafic plutonic member**—Gabbro, diorite, and quartz diorite. A single undated mass within the larger complex. There are also many bodies too small to map. Leopold (2016) suggests that these are equivalent to Jurassic mafic plutonic bodies to the east (unit Gidg).
- Gbv Bear Valley intrusive suite (Cretaceous, ~92-113 Ma)**—Occurs in southwestern Sierra Nevada and Tehachapi Mountains. Suite generally occurs west of Proto-Kern Canyon fault. Medium-size pluton (tonalite of Hoffman Canyon), part of suite, occurs east of fault in southeastern Sierra Nevada, west of Jawbone Canyon fault. Chiefly tonalite, gabbro, granodiorite, and associated mafic and ultramafic rocks, mafic gneiss, and granulite. Zircon U-Pb age ~92-113 Ma (Saleeby and others, 2007, 2008; Chapman, 2012); hornblende K-Ar and Ar-Ar ages of ~85-88 Ma (Ross, 1983; Saleeby and others, 2007); zircon U-Th/He age of ~84 Ma and biotite Rb-Sr age of 85 Ma (Saleeby and others, 2007); biotite K-Ar and Ar-Ar ages of ~75-87 Ma (Evernden and Kistler, 1970; Ross, 1983; Saleeby and others, 2007). Major plutons: mafic gneiss and amphibolite of Jawbone Canyon, biotite-hornblende-bearing tonalite of Bear Valley Springs, hypersthene-bearing tonalite of Bison Peak, gabbro of Tunis Creek (norite and hornblende gabbro, commonly recrystallized), tonalite of Mount Adelaide,

- granodiorite of Poso Flat, granodiorite of Pine Flat, tonalite of Dunlap Meadow, granodiorite of Hatchet Peak, tonalite of Hoffman Canyon, granodiorite of Hershey Ranch, tonalite of Walt Klein Ranch, tonalite of Fountain Springs, tonalite of Carvin-Bower Ranch, granodiorite of Peppermint Meadow, granodiorite of Deer Creek, gabbro of Live Oak, tonalite of Zumwalt Ranch, along with unnamed mafic and ultramafic plutonic rocks, amphibolite, gneiss, and granulite. Equivalent to parts of the Domelands, Needles, Bear Valley, and Kern River intrusive suites of Nadin and Saleeby (2008). Suite interpreted as forming in a deep level of the middle Cretaceous Sierra Nevada batholith during mixing of mantle-derived magma and old metasedimentary continental rocks (Saleeby and others, 2008).
- Gmw Merced Peak and Washburn Lake intrusive suite (Late Cretaceous, ~93-100 Ma)**—Occurs along southeastern margin of Yosemite Valley in the central Sierra Nevada. Chiefly granodiorite, leucogranite, and granite. This unit has yielded zircon U-Pb ages of ~93-100 Ma (Stern and others, 1981; Tobisch and others, 1995; Attia and others, 2022), as well as biotite Ar-Ar ~85 Ma, hornblende Ar-Ar ~87 Ma, and an allanite fission track age of ~87 Ma (Naeser and Dodge, 1969; Tobisch and others, 1995). Major plutons: granodiorite of Jackass Lakes, leucogranites of Timber Knob and Norris Creek, granodiorite of Red Devil Lake, granite of Turner Lake, and granite porphyry of Cony Crags. May be a younger phase of the ~100-112 Ma Buena Vista Crest intrusive suite (unit Gbvc). Correlated with roughly coeval meta-volcanic and meta-shallow intrusive rocks of Sierra Crest terrane (units SHKOV, SHKOG), forming part of the Monarch arc.
- Gyo Yosemite intrusive suite (middle Cretaceous, ~97-104 Ma)**—Occurs in Yosemite Valley and adjacent areas in the central Sierra Nevada. Chiefly granite and leucogranite. Zircon U-Pb ages from this unit are ~97-108 Ma (Stern and others, 1981; Wooden and others, 1999; Ratajeski and others, 2001; Lackey and others, 2008), although the ~108 Ma age is probably an unmapped inlier of the adjacent Bass Lake pluton (part of unit Gfg; Lackey and others, 2008). In addition, Evernden and Kistler (1970) report a biotite K-Ar age of 90 Ma, and Naeser and Dodge (1969) report an apatite fission track age of 65 Ma and sphene fission track age of 99 Ma. Major plutons: El Capitan Granite, granite of Rancheria Mountain, Taft Granite, and leucogranite of Ten Lakes. Intruded by Buena Vista Crest intrusive suite. Coeval with Shaver Intrusive Suite (unit Gsl) to south.
- Gsl Shaver Intrusive Suite (middle Cretaceous, ~99-114 Ma)**—Occurs along western slopes of central Sierra Nevada, across San Joaquin River. Extends northward into area west of Sonora Pass, including several isolated small plutons. Chiefly granodiorite and granite. Zircon U-Pb ages from this unit range from ~99-114 Ma (Stern and others, 1981; Chen and Moore, 1982; Saleeby and others, 1990; Tobisch and others, 1993; Lackey and others, 2012; Ardill and others, 2018). This unit has also yielded hornblende K-Ar and Ar-Ar ages of ~86-92 Ma and biotite K-Ar and Ar-Ar ages of ~83-91 Ma (Kistler and others, 1965; Tobisch and others, 1993), along with sphene fission track ages of ~83-88 Ma and apatite fission track ages of ~79-95 Ma (Naeser and Dodge, 1969). Major plutons: Dinkey Creek Granodiorite, granodiorite of McKinley Grove, granodiorite of the Pick and Shovel Mine area, granite of Ordinance Creek, the southernmost body of the granite of Shuteye Peak, granites of Dinkey Dome, Short Hair Creek, Sheepthief Creek, lower Bear Creek, and Mushroom Rock. May

include granodiorites of Whisky Ridge and Stevenson Creek. This unit differs from the formally accepted definition of Bateman (1992) in age and extent based on the subsequent work cited above. We do not include the ~116 Ma date of the Tombstone Creek pluton (Chen and Moore, 1982) because it is from a locality near two others with much younger dates (~99-102 Ma; Chen and Moore, 1982; Saleeby, 1990). We suspect the ~116 Ma age may be affected by the proximity of the locality to adjacent older wall rock.

- Gte** **Tehachapi-San Emigdio intrusive suite (Cretaceous, ~100-136 Ma)**—Occurs in the southern Sierra Nevada, Tehachapi Mountains and San Emigdio Mountains. Chiefly tonalite, diorite, migmatite gneiss, orthogneiss, and gabbro. Intrudes the Kernville and Tehachapi-San Emigdio terranes (units KE and TSS, respectively), and is in turn intruded by the Bear Valley intrusive suite (unit Gbv). Zircon U-Pb ages from this unit range from ~100-136 Ma (James, 1986; Sams, 1986; Saleeby and others, 2007; Chapman and others, 2012; Chapman and Saleeby, 2012). In addition, Kistler and Ross (1990) report whole rock Rb-Sr ages of ~94 Ma and ~117 Ma, and Kellogg and others (2008) report a hornblende Ar-Ar age of ~100 Ma from this unit. Major plutons: garnet-biotite tonalite of Grapevine, gabbroids of Squirrel Spring, San Emigdio quartz diorite orthogneiss, Digier Canyon quartz diorite orthogneiss, quartzofeldspathic gneiss of Pastoria Creek, migmatite gneiss of Cloudburst Canyon, Antimony Peak tonalite, San Emigdio tonalite, and mixed orthogneiss and mafic tonalite. Generally metamorphosed to upper amphibolite facies. Suite interpreted as forming in a deep level of the Early Cretaceous Sierra Nevada batholith during mixing of mantle-derived magma and old metasedimentary continental rocks (Chapman and Saleeby, 2012). Suite structurally underlies the Pastoria terrane (unit PAS) and Pastoria intrusive suite (unit Gps) along the Pastoria Normal fault, and structurally overlies the Pelona Schist terrane (unit PS) along the Rand thrust. Some prior studies (e.g. Kellogg and others, 2008) map the ~91-105 Ma (monzo)granite of Brush Mountain crossing the Pastoria normal fault (and so partially within this unit), which would restrict the timing of offset on that fault, but others (e.g. Chapman and Saleeby, 2012) restrict that pluton to the hanging wall (unit Gpa). Al-in-hornblende emplacement pressures for this unit range from 7.1 to 10.7 kbar (Chapman and others, 2012), indicating uplift from deep crustal levels (~30-35 km).
- Gbvc** **Buena Vista Crest intrusive suite (late Early Cretaceous, ~100-112 Ma)**—Occurs in eastern Yosemite Valley and adjacent areas in central Sierra Nevada. Chiefly tonalite, granodiorite, and granite, and quartz diorite dikes. This unit has zircon U-Pb ages of 100 Ma and 112 Ma (Stern and others, 1981). Major plutons: quartz diorite dikes in El Capitan, granodiorites of Illilouette Creek and Tamarack Creek, tonalite of Crane Creek, Leaning Tower Granite, granodiorite of Ostrander Lake, granodiorite of Breeze Lake, Bridalveil Granodiorite and granodiorite of Horse Ridge, granite of Chilnualna Lake, and sparse quartz diorite dikes in El Capitan Granite of Yosemite intrusive suite. Locally intrudes older parts of the Yosemite intrusive suite (unit Gyo). May be an older phase of the ~93-100 Ma Merced Peak and Washburn Lake intrusive suites (unit Gmw). Unit magmatically linked to Cretaceous metavolcanic, meta-shallow intrusive and metagranitic rocks in the central Sierra Nevada (units SHKOV and SHKOG), forming part of the Monarch arc.
- Gfg** **Fine Gold Intrusive Suite (Early Cretaceous, ~101-128 Ma)**—Occurs in western part of central Sierra Nevada. Originally defined by Bateman (1992). Chiefly tonalite,

trondhjemite, granodiorite, and granite, with small bodies of diorite and gabbro. Zircon U-Pb ages from this unit range from ~101-128 Ma (Saleeby and Sharp, 1980; Stern and others, 1981; Chen and Moore, 1982; Wooden and others, 1999; Lackey and others, 2008, 2012; Ardill and others, 2018). This age range excludes one age of 91 Ma from a locality in the northeast corner of the unit reported by Wooden and others (1999), which is ~10 Ma younger than any other in the unit, and probably belongs to the adjacent ~84-98 Ma Sonora Pass intrusive suite (unit Gso) or ~91-102 Ma Jack Main Canyon intrusive suite (unit Gja). This unit has also yielded biotite K-Ar ages of ~83-113 Ma and hornblende K-Ar ages of ~88-128 Ma (Kistler and others, 1965; Evernden and Kistler, 1970; Saleeby and Sharp, 1980; Tobisch and others, 1995), excluding one hornblende K-Ar age of ~144 Ma (Evernden and Kistler, 1970), which is at least ~16 Ma older than any other hornblende K-Ar age from this unit and is also older than the zircon U-Pb ages. This unit has also yielded a muscovite K-Ar age of ~110 Ma (Evernden and Kistler, 1970), apatite fission track ages of ~78-125 Ma, and sphene fission track ages of ~96 Ma and ~99 Ma (Naeser and Dodge, 1969). Major plutons: tonalite of Ross Creek, Bass Lake Tonalite, Poopenaut Valley granodiorite, and granite porphyry of Star Lakes. May include granodiorite of Arch Rock, Ward Mountain Trondhjemite, Knowles Granodiorite, granodiorite of Sawmill Mountain, and the northern part of the granite of Shuteye Peak. As mapped, this unit includes deformed and altered gabbro, diorite, tonalite, and local peridotite, locally named the tonalite of Millerton Lake by Bateman (1992) with an optimal U-Pb zircon age of ~134 Ma, too small to be mapped separately. This unit intrudes across the Melones fault which separates the Cosumnes terrane and Yuba River superterrane from the rest of the Sierra Nevada.

Gdm

**Diamond Mountains intrusive suite (late Early Cretaceous, Late Jurassic and Early Jurassic, ~104-114 Ma, ~121-128 Ma ~148-163 Ma, and ~178-184 Ma)—**

Occurs in the northeastern Sierra Nevada. Chiefly quartz diorite, granodiorite, quartz monzonite, and granite. Major plutons: Lights Creek, China Gulch, Goodrich, and Genesee-Reward. This unit appears to be composed of plutonic rocks from four or five separate intrusive periods. Sparse older quartz diorite and gabbro associated with Lights Creek quartz monzonite stock, which has zircon U-Pb ages of ~178 and ~184 Ma (Stephens, 2011; Dilles and Stephens, 2010); younger units, such as China Gulch granite have zircon U-Pb ages of ~148-163 Ma (Stephens, 2011; Langenheim and others, 2025); and still younger plutonic rocks, including local porphyritic pegmatite zones, have zircon U-Pb ages from ~104-114 Ma (Van Buer, 2011; Langenheim and others, 2025). Langenheim and others (2025) also report two zircon U-Pb ages of ~121 Ma for this unit, plus an age of ~128 Ma for plutonic rock just north of the map area, indicating a fourth period of intrusion. They also report zircon U-Pb ages of ~94 and ~95 Ma from the southeastern-most part of this unit, but it is likely that these represent small inliers or a previously unmapped body of one of the coeval plutonic units to the south or east (units Glkt or Gwa). Evernden and Kistler (1970) reported biotite K-Ar ages of ~87-100 Ma from the eastern part of this unit, as well as a biotite K-Ar and a hornblende K-Ar age of ~105 Ma from the southwest part of the unit. They also reported a biotite K-Ar age of ~101 Ma and a hornblende K-Ar age of ~102 Ma from just outside this unit (an undescribed lithology probably from an outcrop of this unit too small to map within Cenozoic units roughly in the center of the extent of the intrusive suite). Van Buer (2011) reports apatite fission track ages of ~75-89 Ma, and apatite He ages of ~50-53 Ma, from the northeast

- part of the unit (colocated with the younger zircon U-Pb ages of ~104-111 Ma). The K-Ar and apatite fission track ages probably represent cooling ages following the final intrusive phase. Lights Creek stock and associated units intrude Kettle Rock terrane (unit KR) to west. The oldest part of the intrusive suite, along with volcanics in the Kettle Rock terrane, are coeval with, and may form a northern extension of, the Tuttle igneous arc that includes older parts of the Tuttle and Emigrant Gap intrusive sequence (unit Gtt and Gegg) and the Tuttle Lake Formation and upper Lake Tahoe sequence (unit NSTT).
- Gu**      **Undifferentiated granitic plutons (Early Cretaceous to Late Jurassic)**—Scattered plutons in the western metamorphic belt without radiometric ages and not close to or easily associated with named plutons or intrusive suites.
- Ggu**      **Unnamed gabbroic plutons (Early Cretaceous to Late Jurassic)**—Scattered gabbro and gabbro-diorite plutons in the southwestern part of the Western Belt subterrane of the Cosumnes terrane (units CWCH, CWSS, CWGR, and their subunits) without radiometric ages. Might be correlative with ~138-149 Ma plutons farther north in the same subterrane.
- Gsm**      **Stokes Mountain intrusive suite (Early Cretaceous, ~110-130 Ma)**—Occurs in foothills along western slopes of central Sierra Nevada. Chiefly cumulate gabbro, norite, tonalite, and granodiorite with lesser granite. Zircon U-Pb ages are ~110-130 Ma (Saleeby and Sharp, 1980; Chen and Moore, 1982; Clemens-Knott and Saleeby, 1999). This unit has also yielded amphibole K-Ar ages of 123, 142, and 176 Ma, but the older two ages are anomalously old and may represent remnants within the plutons of the older Late Jurassic mafic dikes that intrude the adjacent Merced River terrane wall rock (Saleeby and Sharp, 1980). Hildebrand and Whalen (2021) report relatively low Nb/Y, La/Yb, and Sr/Y for this unit. Lackey and others (2008) report low zircon  $\delta^{18}\text{O}$  (~-5.5‰ VSMOW) and whole-rock  $\delta^{18}\text{O}$  (~-6.7‰ VSMOW) and  $^{87}\text{Sr}/^{86}\text{Sr}$  values between ~.703-.706. Major plutons: the eastern and western ring complexes in the Stokes Mountain area north of the Kaweah River, and the ring-like Academy Pluton located farther north (Mack and others, 1979; Clemens-Knott and Saleeby, 1999). In the Stokes Mountain area, low-pressure contact metamorphism and coeval volcanic xenoliths indicate that the ring dike complexes are shallow, subvolcanic structures. The primitive geochemical and isotopic signatures of these Early Cretaceous plutonic rocks reveal the role of a depleted-mantle-derived parental magma for the westernmost and earliest phases of the Cretaceous Sierra Nevada batholith (Clemens-Knott and Saleeby, 1999). Saleeby and Sharp (1980) attributed a distinctive, elongate gravity and aeromagnetic high to dense and magnetically susceptible magnetite-rich cumulate rocks of this unit in the subsurface, although small outcrops of the unit extend southward beyond the main geophysical anomaly (perhaps the small volumes of the plutonic bodies of this unit there minimize its geophysical expression).
- Gbr**      **Bald Rock plutonic complex (Early Cretaceous, ~133-134 and ~140-142 Ma)**—Trondhjemite and hornblende-biotite quartz diorite east of Lake Oroville. Zircon U-Pb ages suggest two periods of emplacement, with two ages obtained for each: ~133-134 Ma (Rousseau, 2016; Langenheim and others, 2021), and ~140-142 Ma (Saleeby and others, 1989b; Langenheim and others, 2021). Note the similarity with the two age groupings of the nearby Merrimac plutonic complex (unit Gmm). Aluminum-in-hornblende geobarometry indicates pressures of 3 kbar for the Bald Rock pluton (McLeod, 1990).

- Gmm Merrimac plutonic complex (Early Cretaceous, ~134 and ~140-142 Ma)**—Three overlapping plutons north of Lake Oroville. 1) An eastern pluton, predominantly tonalite with lesser diorite and quartz diorite in its southern part; undated but oldest based on cross-cutting relations. 2) A northern pluton, composed of concentrically zoned granodiorite and tonalite, with zones of quartz diorite within the tonalite, yielding zircon U-Pb dates ~140-142 Ma (Irwin and Wooden, 2001; Langenheim and others, 2021). 3) A southern pluton composed of a central granodiorite with minor tonalite and granite surrounded by tonalite with minor granodiorite and quartz diorite, yielding zircon U-Pb ages of ~134 Ma (Irwin and Wooden, 2001; recalculated in Langenheim and others, 2021). Al-in-hornblende geobarometry indicates emplacement of these plutons at ~2-3 kbar (McLeod, 1990).
- Gtt Tuttle intrusive complex (Early Cretaceous to Middle Jurassic, ~136-164 Ma)**—Chiefly diorite and gabbro, and local mafic intrusive breccia, and local anorthosite west of Lake Tahoe. This unit has yielded zircon U-Pb ages of ~136 and ~164 Ma (Wooden and others, 1999; Sabine, 1992), as well as biotite K-Ar ages of ~103 and ~105 Ma (Sabine, 1992). Unit includes Pyramid Peak granite and the small Azure Lake quartz diorite southwest of Lake Tahoe, as well as a small body northwest of Lake Tahoe. Unit mainly intrudes Sailor Canyon and Tuttle Lake Formations (units NSTS, NSTT), as well as Devonian Sutter Butte formation (part of unit NSSB) in the northwest. Local dikes associated with this unit interpreted as feeders for, and coeval with volcanic rocks of Tuttle Lake Formation (unit NSTT). Unit occurs mainly in Mount Tallac area in southwest part of Fallen Leaf Lake roof pendant. Unit forms plutonic part of the Tuttle igneous arc that includes volcanic and associated rocks of Tuttle Lake Formation (unit NSTT). Unit magmatically linked to coeval mafic units of the Emigrant Gap intrusive suite, unit Gegm.
- Gbl Bucks Lake plutonic complex (Early Cretaceous, ~139-140 Ma)**—Three plutons, two overlapping and a small separate pluton on the northwest of Quincy. An eastern pluton, pyroxene diorite core surrounded by quartz diorite (Bucks Lake Pluton); a western normally zoned pluton transitioning from strongly foliated hornblende-biotite quartz diorite at the margin to unfoliated, coarse-grained monzotonalite in the central part (Grizzly Pluton); and the much smaller northern pluton, monzotonalite and hornblende diorite (Oliver Lake Pluton). This unit also includes a small unnamed and undated pluton of biotite tonalite along the Dogwood Peak fault to the southeast. The Grizzly Pluton, and perhaps the very small southeastern pluton, cross the Dogwood Peak fault (Foothills suture) between the western metamorphic belt and the remainder of the Sierra Nevada. This unit has zircon U-Pb ages of 139-140 Ma (Saleeby and others, 1989b; Langenheim and others, 2021; Langenheim and others, 2025), as well as hornblende K-Ar ages of ~136, 142, and 143 Ma, and a biotite K-Ar age of ~132 Ma (the two older hornblende K-Ar ages are a bit older than the zircon U-Pb ages, so the actual age of those samples is probably at the low end of their error bar). Al-in-hornblende geobarometry indicates emplacement at ~3 kbar for the Grizzly pluton (McLeod, 1990). This complex may be in part correlative with coeval plutons or parts of plutons to the south in the western metamorphic belt such as the Merrimac plutonic complex (unit Gmm) and Bald Rock plutonic complex (unit Gbr).
- Gco Concow pluton (Early Cretaceous, ~141 Ma)**—Biotite-hornblende quartz diorite north of Lake Oroville. This small pluton has a zircon U-Pb age of ~141 Ma (Irwin and Wooden,

2001).

- Gc Coloma pluton (Early Cretaceous, ~141-146 Ma)**—Granodiorite and hornblende diorite east of Folsom Lake. This pluton has zircon U-Pb ages of ~143 Ma (Graymer and Jones, 1994) and ~141-146 Ma (Langenheim and others, 2025).
- Grp Rocklin-Penryn plutons (Early Cretaceous, ~142 Ma)**—Originally mapped as two separate plutons northwest of Folsom Lake, the older Penryn and younger Rocklin. The Penryn pluton is mainly medium- to coarse-grained quartz diorite, the Rocklin pluton is mainly fine- to medium-grained trondhjemite. This unit has a zircon U-Pb age of ~142 Ma (Irwin and Wooden, 2001), along with biotite K-Ar ages of ~128-140 Ma, two muscovite K-Ar ages of ~128 Ma, and a hornblende K-Ar age of ~131 Ma (Curtis and others, 1958; Swanson, 1978, recalculated in Wagner and others, 1981).
- Ggb Granite Basin pluton (Early Cretaceous, ~142 Ma)**—Normally zoned pluton located southwest of Bucks Lake ranging from hornblende-biotite quartz diorite at the margin to monzotonalite in the center. This unit has two zircon U-Pb ages of ~142 Ma (Langenheim and others, 2021).
- Gca Cascade plutonic complex (Early Cretaceous to Late Jurassic, ~143(?) and ~152-156 Ma)**—Irregularly zoned from hornblende-biotite quartz diorite, tonalite, monzotonalite, diorite, and granodiorite east-northeast of Lake Oroville. Most zircon U-Pb dates from this pluton are ~152-156 Ma (Rousseau, 2016; Langenheim and others, 2021), but one is ~143 Ma (Day and Bickford, 2004), suggesting a possible second phase for this pluton, perhaps equivalent to the roughly coeval early phase of emplacement for the adjacent Bald Rock plutonic complex (unit Gbr). This unit has also yielded a hornblende Ar-Ar date of ~150 Ma (Fagan and others, 2001). Al-in-hornblende geobarometry indicates emplacement at about 4 kbar for this pluton (McLeod, 1990).
- Gid Independence dike swarm (Cretaceous and Jurassic, mostly earliest Cretaceous to latest Jurassic, ~146-148 Ma)**—Occurs in the White-Inyo Mountains, east south-central and southern Sierra Nevada, and the Spangler Hills on the east end of the El Paso Mountains (just east of the southeast corner of the map area). Swarm extends over 250 km along a north-northwest trend in the map area from outcrops adjacent to the Garlock fault. Unit occurs to the southeast of the map area in the Granite Mountains across the Garlock fault, offset about 65 km to the east by left-lateral offset on the fault (Smith, 1962), and from there extends over 250 km to the south (James, 1989). Chiefly very fine-grained mafic diorite, quartz diorite, and granodiorite, but also includes microcrystalline granite and granodiorite porphyry and elsewhere basalt and basalt porphyry. Dikes in Sierra Nevada are pervasively metamorphosed. Individual dikes mostly strike NNW, sub-parallel to trend of swarm. Swarm consists of hundreds of dikes, filled with mainly mafic rocks and are individually about 3 m in width. The swarm may be the root of linear-fissure-array volcanoes. Swarm interpreted to be dextrally offset post-emplacement about 65 to 130 km across Owens Valley based on offset of the axis of maximum dilation (Bartley and others, 2007). Dikes are thought to be predominantly ~148 Ma (Chen and Moore, 1982), but also include dikes as young as Late Cretaceous (Coleman and others, 2000), though most studies (e.g. Bartley and others, 2007; Glazner and others, 2008) exclude the younger dikes in discussion of the dike

swarm. Latest Jurassic to earliest Cretaceous dike emplacement overlapped in time with the formation of wall rock mylonite zones which accommodated shear varying in sense from sinistral to west-side-down reverse displacement. Many of the dikes have a foliation related to the orientation of mafic minerals that suggests sinistral movement of dike walls during magma cooling (e.g. Moore, 1963). Swarm intruded along dilatant fractures within a regional sinistral shear system (Glazner and others, 1999) and(or) extension related to western migration of the subduction margin following the Nevadan orogeny (Chen and Moore, 1979). Associated wall rock deformation denotes partitioning into the magmatic arc of the sinistral component of strongly oblique Late Jurassic subduction. Unit constitutes a major temporal break between suites of older, pre-Late Jurassic and younger Early Cretaceous granitic plutons in the eastern Sierra Nevada, though roughly coeval with the Guadalupe igneous complex and other plutons emplaced in the western metamorphic belt during or immediately following the Nevadan Orogeny. The presence of younger, Cretaceous dikes indicates that the region maintained a preferred orientation for dike emplacement over an extended period of time. The younger dikes lack foliation suggesting sinistral offset during cooling (Coleman and others, 2000), so do not support continuation of the sinistral component of deformation into the Cretaceous. Instead, Cretaceous dike intrusion may follow the orientation of previously developed regional deformation. The pattern of dikes in this unit shown on the map is schematic and depicts longer dikes and general area of shorter dikes.

**Gido** **Osa ring complex (Late Jurassic, ~146-148 Ma)**—Semi-circular ring dike complex in southern Sierra Nevada composed of alternating, semi-circular dikes of hornblende-biotite gabbro and diorite emplaced as sheets, from 0.1 to 5 m thick, with each sheet commonly chilled against, and separated by thin (1 to 25 cm) septa of lighter-colored and coarse rock ranging from granite to hornblende-plagioclase pegmatite (Sisson and Moore, 2010). Septa partially molten during sheet injection. At least 28 thicker (5-250 m) conformable granitic sheets are spaced through the gabbroic layers and are increasingly thicker and abundant toward the higher elevation outer edges of the structure. Granite sheets also dip steeply inward, further defining the basin-shaped structure. Ring-dike complex approximately 5,300 m wide, E-W and 10,100 m wide, N-S. Terminated on western margin by a NNE-striking fault. On basis of Late Jurassic zircon U-Pb isotopic age (~146-148 Ma) for both gabbro and granite dikes (Sisson and Moore, 2010; Clemens-Knott and Gevedon, 2025), interpreted as coeval with other units in Independence dike swarm. Clemens-Knott and Gevedon (2025) propose that this unit should be combined with two units in the Buck Meadow intrusive suite (unit Gbm) along with coeval volcanic bodies too small to map to make up their Summit igneous complex.

**Gidg** **Gabbroic complexes (Late Jurassic, ~148 Ma)**—Unnamed small gabbro intrusions in central and southern Sierra Nevada. Unit also occurs in various small bodies, mainly in east-central Sierra Nevada, intruding and adjacent to Snow Lake roof pendant (the northern part of unit SL). Many other very small bodies, too small to display at 400,000 scale, occur in central and southern Sierra Nevada. Mainly a composite suite of gabbro, fine-grained diorite, and hornblende gabbro with large crystals. Extremely variable in grain size, texture, and composition. Unit has same compositional range, similar structural relations, and coeval U-Pb zircon ages (~148 Ma; Lahren and others, 1990) with main part of the Independence dike

swarm.

- Gbm** **Buck Meadow intrusive suite (Jurassic, ~146-175 Ma)**—Occurs in southern Sierra Nevada, east of the north fork of the Kern River. Chiefly tonalite and granodiorite, with lesser gabbro and granite. Generally metamorphosed to upper amphibolite facies. This unit has yielded zircon U-Pb ages of ~146-175 Ma (Saleeby and Dunne, 2015; Clemens-Knott and Gevedon, 2025), consistent with a whole-rock Rb-Sr age of ~177 Ma (Ross, 1995). The unit as mapped also has an anomalous age of ~94 Ma in the northernmost part of the unit (Clemens-Knott and Gevedon, 2025) which is probably a body too small to map of the adjacent Mount Whitney Intrusive Suite (unit Gwh). Major plutons: Sacatar Quartz Diorite, Summit gabbro, quartz diorite of Round Mountain, tonalite of Falls Creek, alaskite of Kern Peak, granodiorite of Church Dome, quartz diorite of Long Valley, granodiorite of Schaefer Meadow, granodiorite of Redrock Meadow, granodiorite of Monache Creek, granite of Haiwee Creek, and gabbro of Deer Mountain. As mapped, also includes the small granite of Noname Canyon, granite of Sand Canyon, and unnamed felsic bodies in the southeasternmost part of the unit, but the granite of Noname Canyon has a Rb-Sr age of ~81 Ma and the granite of Sand Canyon is tentatively correlated with the ~90 Ma granodiorite of Castle Rock, so these are inliers too small to map of the adjacent Cretaceous Owens Peak intrusive suite. On its eastern margin, intruded by Late Jurassic Independence dike swarm (unit Gid). Ross (1995) suggests that the hornblende K-Ar ages were reset at the time the dikes were intruded, and the undeformed ~148 Ma Long Valley pluton was also intruded at that time. The unit also has whole rock or hornblende K-Ar ages of ~145-146 Ma and a biotite K-Ar ages of ~81 and ~88 Ma which have been thermally reset by younger intrusions (Bergquist and others, 1982). Clemens-Knott and Gevedon (2025) suggest that the Summit Gabbro and the quartz diorite of Long Valley should be excluded from this unit and combined with the Osa ring complex (unit Gido) into their Summit igneous complex.
- Gscm** **Santa Cruz Mountain pluton (Late Jurassic, ~147 Ma)**—A single mass intruding the Gopher Ridge Volcanics (unit CWGR), part of the Western Belt subterrane of the Cosumnes terrane north of Highway 140. Hornblende tonalite with subordinate biotite granodiorite in the eastern part of the pluton. Weakly deformed on the northeast, strongly mylonitic throughout most of the pluton. Saleeby and others (1989a) report a zircon U-Pb age of ~147 Ma for this pluton, along with a hornblende Ar-Ar age of ~146 Ma and a biotite Ar-Ar age of 141 Ma.
- Gsp** **Soldier Pass Intrusive Suite (Late and Middle Jurassic, ~148-196 Ma)**—Crops out in the Inyo Mountains. Chiefly granodiorite and quartz monzonite. Major plutons in the study area: Paiute Monument Quartz Monzonite, Pat Keyes pluton of the Hunter Mountain Quartz Monzonite, Santa Rita Flat pluton, granite of French Spring (Ross, 1967b; 1969; Dunne and Walker, 1993; Dunne and others, 1998). Intrudes and overlaps in age with the Jurassic Sequence 4 of the White-Inyo Mountains Craton Margin Formations (unit I4), which are largely volcanic and volcanoclastic, so these plutons may be part of the same arc system. The youngest plutonic rocks of this unit are also coeval with the adjacent Independence dike swarm (unit Gid), but that unit extends far beyond the extent of the intrusive suite, so their proximity probably indicates the development of the dike swarm cutting through the final stages of the older arc regime. Zircon U-Pb ages from this unit range ~148-196 Ma (Chen,

1977; Chen and Moore, 1979; Dunne and Walker, 1993). This unit also has biotite K-Ar ages of ~123-157 Ma, hornblende K-Ar ages of ~156-178 Ma, and apatite fission track age of ~93 Ma (Kistler and others, 1965; Evernden and Kistler, 1970; Naeser and Dodge, 1969). This unit differs from the formally accepted definition of Bateman (1992) in age and extent based on the subsequent work cited above.

- Gmo** **Mill Creek and Owens Mountain intrusive suite (Late to Middle Jurassic, ~148-170 Ma)**—Crops out on the western slopes of the southwestern Sierra Nevada. Major plutons: (1) Mill Creek complex consisting of penetratively-deformed lenticular gabbro, diorite, and tonalite plutons that intrude the eastern part of the Kings River ophiolite belt (unit MRKI). This part of the unit has yielded zircon U-Pb ages of ~157-170 Ma (Saleeby and Sharp, 1980; Saleeby and Dunne, 2015). Saleeby (2011) states the age of this unit is 156-170 Ma.; and (2) Owens Mountain complex consisting of penetratively-deformed basaltic, gabbroic, dioritic, and trondhjemitic dikes and small lenticular stocks that intrude as screens into the western Kings River ophiolite. This part of the unit has zircon U-Pb ages ~148-155 Ma (Wolf and Saleeby, 1992). Both complexes intruded by the mildly to non-deformed plutons of Early Cretaceous Fine Gold Intrusive Suite (unit Gfg).
- Gpal** **La Paloma pluton (Late Jurassic, ~149 Ma)**—A small body west of the Bear Mountains fault, intrudes the Gopher Ridge Volcanics (unit CWGR) in the southern part of the Cosumnes terrane. Biotite leucotonalite, little deformed. This pluton has a zircon U-Pb age of ~149 Ma (Saleeby and others, 1989a)
- Gg** **Guadalupe igneous complex (Late Jurassic, ~149-153 Ma)**—Compositionally layered pluton intruding the southeast part of the western metamorphic belt. Gabbro at base grading upward (eastward) into meladiorite and granite, with an upper body of granophyre and rhyolite. Strongly foliated along the western margin where the pluton is bounded by the Bear Mountains fault, otherwise unfoliated. This unit has zircon U-Pb ages of ~149-153 Ma (Saleeby and others, 1989a; Ernst and others, 2009; Schweickert, 2015; Ratschbacher and others, 2018). The ~152 Ma age comes from the upper rhyolite part of the unit, which may be part of the wall rock (Ratschbacher and others, 2018). This pluton intrudes the roughly coeval Mariposa Formation (unit CMMS), so must have formed during or slightly after the regional deformation that formed the slaty cleavage predominant in the Cosumnes terrane.
- Gcr** **Cosumnes River pluton (Late Jurassic, ~150 Ma)**—Small bodies of unfoliated granodiorite and hornblende diorite north and south of the Cosumnes River between the Melones and Bear Mountains faults. Intrudes Mariposa Formation and Sierra Foothills mélange members of the Mother Lode subterrane of the Cosumnes terrane (units CMMS and CMFM). This unit has a preliminary zircon U-Pb age of ~150 Ma (J. Saleeby, California Institute of Technology, written commun., in Graymer and Jones, 1994).
- Ghor** **Hornitos pluton (Late Jurassic, ~150 Ma)**—Hornblende tonalite, diorite, and gabbro with numerous mafic to felsic dikes. Exposed in two small bodies just east of the Bear Mountains fault near the old town of Hornitos, west of Mariposa. Intrudes the Mariposa Formation of the Cosumnes terrane (unit CMMS). Mylonitic deformation is widespread throughout the pluton. This unit has a zircon U-Pb age of ~150 Ma, and a hornblende Ar-Ar age of ~140 Ma from the sheared rock along the Bear Mountains fault zone at the western

margin of the pluton (Saleeby and others, 1989a).

- Giv**     **Indian Valley pluton (Late Jurassic, ~150-155 Ma)**—A small, composite body of metagabbro and biotite-hornblende tonalite east of Lake Oroville. This pluton has zircon U-Pb ages of ~152 Ma (Day and Bickford, 2004) and ~155 Ma (Langenheim and others, 2025). Day and Bickford (2004) also report a zircon U-Pb age of ~150 Ma for a tonalite dike that cuts foliation in the Clipper Gap Formation (unit YACG) just east of the pluton, which they relate to the pluton. The pluton has also yielded a hornblende K-Ar age of ~143 Ma (Bohlke and McKee, 1984).
- Givg**     **Gabbro member**—Undated metagabbro located just northwest of the main body. Coarse- to medium-grained hornblende gabbro, foliated in places.
- Glu**     **Lumpkin pluton (Late Jurassic, ~151 Ma)**—Diorite and quartz diorite east of Lake Oroville. Grades into coarse-grained hornblende gabbro at the northern border. This pluton has a zircon U-Pb age of ~151 Ma (Rousseau, 2016).
- Gsr**     **Stanislaus River intrusive suite (Late Jurassic, ~151 and ~162-166 Ma)**—Occurs east of the western metamorphic belt in the central Sierra Nevada. Chiefly tonalite and granite. Major plutons: foliated tonalite of Granite Creek and unfoliated granite of Woods Creek. This unit has zircon U-Pb ages of ~151 Ma from the granite of Woods Creek and ~162-166 Ma from the foliated tonalite of Granite Creek (Stern and others, 1981). Intense schistosity and local lineation in the tonalite of Granite Creek is continuous with schistosity and lineation in adjacent metamorphic rocks. Unit intrudes across the Calaveras-Shoo Fly thrust. Stern and others (1981) combine this unit with the Standard and Cobb Creek plutons (part of our Don Pedro intrusive suite, unit Gdp) as their Jawbone granitoid sequence, but we retain a separate unit because of the more felsic composition of the plutons and the presence of younger unfoliated granite.
- Gyr**     **Yuba Rivers pluton (Late Jurassic, ~154-162 Ma)**—Biotite-hornblende tonalite and granodiorite grading northward into pyroxene diorite and gabbro southeast of Lake Oroville. This unit has zircon U-Pb ages of ~154-162 Ma (Edelman and others, 1989; Saleeby and others, 1989b; Day and Bickford, 2004; Rotberg, 2008), as well as a hornblende K-Ar age of ~146 Ma and a biotite K-Ar age of ~143 Ma (Evernden and Kistler, 1970).
- Gyrd**     **Diorite member**—Pyroxene diorite and gabbro.
- Gse**     **San Emigdio intrusive suite (Late to Middle Jurassic, ~155-161 Ma)**—Forms a small, faulted body in the western San Emigdio Mountains. Includes the White Ridge tonalite (hornblende tonalite, zircon U-Pb age ~155 Ma [Chapman and others, 2012]), gabbro of Eagle Rest Peak (cumulate and static gabbro, zircon U-Pb age ~161 Ma [James, 1986]), and unnamed mafic and ultramafic plutonic rocks and serpentinite. Intrudes the Paleozoic Eagle Rest Peak terrane (unit ERP). Equivalent to the Jurassic part of the Western San Emigdio mafic complex of Chapman and Saleeby (2012). Base defined by the north-dipping Maricopa (detachment) normal fault which is everywhere concealed by overlying Tertiary strata. Both dense and magnetically susceptible, this unit forms a distinctive gravity and especially aeromagnetic high, superimposed on broader and lower highs related to the rocks below the Maricopa normal fault to the south, which emphasize its limited extent, reaching less than 15 km eastward from the San Andreas fault. Gravity and magnetic modelling of this unit (Fuis

and others, 2012; Appendix A) show this unit as a 3 km thick slab extending to about 7 km depth. This unit has been correlated with the Logan gabbro roughly 300 km to the northwest, constraining offset on the San Andreas fault (Ross, 1970).

- Gpc Palisade Crest Intrusive Suite (Late and Middle Jurassic, ~155-171 Ma)**—Occurs along crest of central Sierra Nevada, with two isolated bodies northwest of Mono Lake, as well as several bodies farther east on the northwestern margin of Owens Valley and east of the Long Valley caldera. Chiefly granodiorite and leucogranite. This suite has zircon U-Pb ages of ~155-167 Ma (Stern and others, 1981; Bateman, 1992; Mundil and others, 2004; Lackey and others, 2008), along with Rb-Sr whole rock ages (included in the unit age) of ~169-171 Ma (Bateman, 1992), K-Ar ages of ~78-154 Ma (biotite) and ~150-183 Ma (hornblende; Kistler and others, 1966; Evernden and Kistler, 1970), as well as apatite fission track age of ~87 Ma and sphene fission track age of ~85 Ma (Naeser and Dodge, 1969). Major plutons: Tinemaha Granodiorite, granodiorites of McMurry Meadows, of Goddard Canyon, and of upper Blue Canyon, granites of Tunemah Lake, of Tehipite Dome, of Bear Dome, and of Alpine Peak, and leucogranites of Casa Diablo Mountain, of Hell for Sure Pass, of Red Mountain Creek and of Taboose Creek. In the Goddard Range, this unit is intrusively linked to shallow-level metagranitic rocks (unit SCGG) and coeval metavolcanic rocks (units SCGV and HSV) of the Sierra Crest and High Sierra terranes to make up the Goddard arc.
- Ghb Hartman Bar pluton (Late Jurassic, ~156 Ma)**—Trondjhemite, tonalite, and hornblende-biotite quartz diorite northeast of Lake Oroville. This pluton has a zircon U-Pb age of ~156 Ma (Rousseau, 2016).
- Gsj San Juan Ridge pluton (Late Jurassic, ~156-162 Ma)**—Low-K tonalite southeast of Lake Oroville. This pluton has zircon U-Pb ages of ~156-162 Ma (Irwin and Wooden, 2001; Day and Bickford, 2004). The eastern part of the pluton appears to be older than the western part. Interpreted as part of the plutonic component of the Smartville volcanic complex.
- Gsjg Granodiorite member**—Exposed along southern extent of pluton. Undated.
- Gpp Pilot Peak pluton (Late Jurassic, ~157-160 Ma)**—Zoned gabbro-diorite southwest of Grass Valley. Interpreted as part of the plutonic component of the Smartville volcanic complex. This pluton has zircon U-Pb ages of ~157-160 Ma (Day and Bickford, 2004).
- Gbg Banner Grange pluton (Late Jurassic, ~158 Ma)**—Tonalite and granodiorite southwest of Grass Valley. This pluton has a zircon U-Pb age of ~158 Ma (Day and Bickford, 2004). Intrudes across contact between units YOSD and YOSV. Interpreted as part of the plutonic component of the Smartville volcanic complex.
- Emigrant Gap intrusive suite (Late to Middle Jurassic, ~158-169 Ma)**—Includes Emigrant Gap and Haypress Creek composite plutons in the northern Sierra Nevada northwest of Lake Tahoe. In part magmatically linked to the Tuttle Lake Formation and associated units forming the Tuttle arc. Divided into:
- Gegg Granitic units**—Chiefly diorite and granodiorite. The southern part of this unit forms a large, composite pluton (the Emigrant Gap composite pluton) to the north and northeast of Emigrant Gap mafic units (unit Gegm), comprised of several diorite and granodiorite plutons (French Lake pluton, Downey Lake pluton, Grouse Ridge pluton) with zircon U-

Pb ages of ~158-164 Ma and plagioclase K-Ar ages of ~156-179 Ma, surrounding a quartz monzonite (Black Buttes quartz monzonite) with a zircon U-Pb age of ~168 Ma (Drake and others, 1975; Snoke and others, 1982; Saleeby and others, 1989b; Girty and others, 1995; Howell, 1998; Wooden and others, 1999). The southern part also includes a body of biotite granite along the Middle Fork American River below French Meadow Reservoir (Harwood and others, 2014), which has yielded a zircon U-Pb age of ~165 Ma (Langenheim and others, 2025). The northern part of this unit, the Haypress Creek composite pluton includes the Yuba Pass granodiorite and quartz diorite, Bald Ridge granodiorite, Berry Creek quartz diorite and tonalite, Bear Valley quartz monzonite to gabbro, and Dead Horse Canyon gabbro and quartz monzonite (Phillipson, 1995). This part of the unit has zircon U-Pb ages of ~165-169 Ma (Girty and others, 1995; Phillipson, 1995; Langenheim and others, 2025), as well as biotite K-Ar ages of ~97 and ~99 Ma and hornblende K-Ar age of ~125 Ma (Evernden and Kistler, 1970) and Rb-Sr isochron ages of ~153-157 Ma (John and others, 1994). A locality yielding a zircon U-Pb age of ~167 Ma (Langenheim and others, 2025), from a body too small to map in Cenozoic cover just north of the pluton east of the Mohawk Valley fault, shows that the unit extends across that fault. Younger ages of 128 to 101 Ma in northeastern part may represent unmapped plutons or dikes. Unit intrudes Early to Middle Jurassic Sailor Canyon Formation (unit NSTS). The younger part of the unit intrudes the Tuttle Lake Formation (unit NSTT), postdating the deformation, whereas the older part is coeval with and has been interpreted as source of the parent magma for volcanic rocks in the Tuttle Lake Formation (Howell, 1998).

Gegm

**Mafic units (Middle Jurassic, ~162-163 Ma)**—Consists of an ultramafic complex composed of concentrically zoned peridotite, gabbro, diorite, granodiorite, and quartz monzonite. Unit forms the southernmost part of the Emigrant Gap composite pluton. Complex exhibits a well-developed magmatic foliation parallel to pluton margins, formed by fractional crystallization and flowage differentiation during forceful emplacement. Complex derived from a single gabbro magma by crystal fractionation, with ultramafic rocks formed by mechanical accumulation of early crystallized mafic minerals, and the slightly younger two-pyroxene granodiorite (part of unit Gegg) crystallized from a felsic differentiate (James, 1971). The age of this unit is based on the ~163 Ma age of the related two-pyroxene granodiorite in unit Gegg (Snoke and others, 1982), and a body of gabbro mapped by Loyd (1995) along the Rubicon River below Hell Hole Reservoir, which has yielded a zircon U-Pb age of ~162 Ma (Langenheim and others, 2025). Wall rocks metamorphosed up to amphibolite facies adjacent to complex. Inclusions of country rock in ultramafic rock metamorphosed to pyroxene--hornfels facies and are partly melted. Complex is similar in structure, rock texture, and mineralogy to zoned ultramafic complexes in southeastern Alaska that form roots to island arc overlap assemblage (James, 1971). Northeast-trending ductile shear zones up to several hundred meters wide occur in the wall rocks along the margins of the southwestern part of the pluton.

Gspm

**Sugar Pine Mountain pluton (Late Jurassic, ~158 Ma)**—Granodiorite and granite(?), intrudes Lake Combie complex and Clipper Gap Formation (unit YACG) north of Auburn. This pluton has a zircon U-Pb age of ~158 Ma (Langenheim and others, 2025).

- Gsf Swedes Flat pluton (Late Jurassic, ~159-165 Ma)**—Granodiorite south of Lake Oroville. This pluton has zircon U-Pb ages of ~159 Ma (Irwin and Wooden, 2001) and ~165 Ma (Rousseau, 2016). Interpreted as part of the plutonic component of the Smartville volcanic complex.
- Ggv Grass Valley pluton (Late Jurassic, ~159-162 Ma)**—Intrudes the Lake Combie complex beneath and south of the town of Grass Valley. Medium- to coarse-grained gray to pinkish-gray hornblende granodiorite, with biotite locally. This unit has a zircon U-Pb age of ~159 Ma (Irwin and Wooden, 2001), as well as amphibole Ar-Ar ages of ~160 and ~162 Ma, and a biotite Ar-Ar age of ~162 Ma (Taylor and others, 2015).
- Gwc Window Cliffs intrusive suite (Late to Middle Jurassic, ~159-170 Ma)**—Occurs in eastern part of central Sierra Nevada. Major plutons: alaskite of Hells Hole, granite of Kern Peak, alaskite of Upper Funston Meadow, granite of Grasshopper Flat, granite of Window Cliffs, granodiorite of Cold Meadows, granodiorite of Doe Meadows, granodiorite of Kern Canyon Ranger Station, granodiorite of Sheep Creek, granite of Rattlesnake Creek, granite of Angora Creek, granodiorite of Leggett Creek, alaskite of Window Cliffs, and granodiorite of Left Stringer. Cut by mafic dikes related to the Independence dike swarm (unit Gid), this unit has discordant zircon U-Pb minimum ages of ~159-170 Ma (Chen and Moore, 1982).
- Gph Pine Hill pluton (Late Jurassic, ~162-164 Ma)**—Crops out along Highway 50 east of Folsom. Unfoliated gabbro and gabbro-diorite with minor pyroxenite and diorite. Composed of augite, plagioclase, with magnetite and accessory biotite (which may be an alteration product). Forms a prominent gravity and aeromagnetic high. Includes a lens north of, and separated by, a fault from the main body, but which has similar gravity and magnetic properties. Interpreted as part of the plutonic component of the Smartville volcanic complex. This pluton has zircon U-Pb ages of ~162-164 Ma (Saleeby, 1982). This unit is described in detail by Springer (1980).
- Gdp Don Pedro intrusive suite (Middle and Early Jurassic, ~162-177 Ma)**—Chiefly metamorphosed granodiorite and diorite in the west-central Sierra Nevada. Typical description: light-gray granodiorite, approximately equal proportions of fine- to medium-grained quartz and plagioclase feldspar, with 5 to 10% mafic minerals (primarily biotite and hornblende). This unit has zircon U-Pb ages of ~162-177 Ma (Sharp and Saleeby, 1979; Stern and others, 1981; Wooden and others, 1999; Bedrossian and Saucedo, 1981; Irwin and Wooden, 2001; Rotberg, 2008), excluding one age of ~133 Ma (Irwin and Wooden, 2001), which is anomalously young and is probably a western outlier of younger plutonic units to the east. This unit also has biotite K-Ar ages of ~138-152 Ma and hornblende K-Ar and Ar-Ar ages of ~136-168 Ma (Evernden and Kistler, 1970; Herzig and Sharp, 1992). Unit occurs in small to large plutons intruding the Merced River and Northern Sierra terranes and is itself intruded by younger plutonic units on the east. On the west, two plutons of this unit are truncated by the Melones fault zone. This unit, along with units of phyllite (MRDPH) and greenschist (MRDGS), is interpreted as an Early and Middle Jurassic Don Pedro island arc overlap assemblage deposited on and intruded into the western margin of the marine sedimentary member of the Calaveras Complex (MRCS) and associated carbonate lenses (MRCC) and across the Calaveras-Shoo Fly thrust into the Shoo Fly complex (units NSSA and NSSF).

- Gby** **Bloody Run pluton (Middle Jurassic, ~165 Ma)**—Diorite and granodiorite, small body intrudes Clipper Gap Formation (unit YACG) and metavolcanic member of Slate Creek Complex (unit YSSCv) across the Slate Creek thrust east of New Bullards Bar Reservoir between the Middle and South Yuba Rivers. No zircon U-Pb data, age based on hornblende Ar-Ar (Hacker, 1993), which is likely a minimum age.
- Gscp** **Scales pluton (Middle Jurassic, ~167-168 Ma)**—Hornblende gabbro and quartz diorite east of Sly Creek Reservoir, north of Highway 49. This pluton has zircon U-Pb ages of ~167-168 Ma (Saleeby and others, 1989b; Day and Bickford, 2004). The Scales pluton intrudes both the Slate Creek and American River terranes across the Slate Creek thrust, constraining the timing of amalgamation.
- Gsjd** **Tonalite at Deer Creek of Day and Bickford (2004) (Early Jurassic, ~177 Ma)**—Hypabyssal tonalite. This unit includes the tiny outcrop area of the tonalite at Deer Creek which has a zircon U-Pb age of ~179 Ma (Day and Bickford, 2004; supersedes the widely cited age of ~198 Ma in Edelman and others, 1989). The tonalite at Deer Creek is interpreted as the youngest part of the Slate Creek terrane (unit YSSS) wall rock into which the Smartville volcanic complex plutons were emplaced.
- Gcc** **Chinese Camp igneous complex (Early Jurassic, ~196-200 Ma)**—Pyroxene and hornblende diorite and gabbro, melagabbro, pyroxenite, and wehrlite. Crops out west of New Melones Lake and around Don Pedro Reservoir. This unit has zircon U-Pb ages of ~196-200 Ma (Saleeby, 1982). Intrudes the Moccasin Peak subterrane of the Cosumnes terrane (units CPTO, CPJP, and CPPB, described below). Thought to be the shallow-level feeder system for the Penon Blanco volcanics. Same as Chinese Camp-Don Pedro intrusives of Saleeby (1982), not to be confused with similarly named, but younger, unit Gdp.
- Gsc** **Scheelite Intrusive Suite (Early Jurassic(?) and Late Triassic, ~197-226 Ma)**—Occurs in eastern Sierra Nevada, west and southwest of Mono Lake. Chiefly weakly to moderately foliated granodiorite and granite. Generally metamorphosed to upper amphibolite facies. This pluton has zircon U-Pb ages from ~197-226 Ma (Chen and Moore, 1982; Stern and others, 1981; Barth and others, 2011), excluding an anomalously young age of ~154 Ma (Chen and Moore, 1982; Wooden and others, 1999) that probably represents small outliers of nearby younger intrusive suites. This unit also includes biotite K-Ar ages of ~69-210 Ma, hornblende K-Ar ages of ~84-206 Ma (Kistler and others, 1966; Evernden and Kistler, 1970), a hornblende Ar-Ar age of ~206 Ma (Crowder and others, 1973), and apatite fission track ages of ~76 and ~88 Ma and a sphene fission track age of ~82 Ma (Naeser and Dodge, 1969). Major plutons: granite of Lee Vining Canyon, Tungsten Hills Granite, Wheeler Crest Granodiorite, granodiorite of Mono Dome, and granite (quartz monzonite) of Mono Lake. Suite includes Laurel-Convict felsite intruded along Laurel-Convict fault in Mount Morrison roof pendant. Unit, together with coeval High Sierra terrane volcanic and sedimentary rocks (unit HSV), forms High Sierra arc.
- Gep** **El Paso intrusive suite (Middle Triassic to Early Permian, ~239-274 Ma)**—Intrudes Paleozoic metamorphic rocks of the El Paso terrane (unit EPS) in the southeast Sierra Nevada and El Paso Mountains. North of the Garlock fault in the El Paso Mountains, this unit consists of Late Permian Weiss Mountain gneiss (granodiorite), Early to Late

Permian unnamed foliated granite, non-deformed, unnamed, Late Permian-Early Triassic quartz monzonite and tonalite stocks (too small to show), the Early-Middle Triassic Burro Schmidt (quartz monzonite to quartz diorite), and Last Chance Canyon (granodiorite to tonalite) plutons (Carr and others, 1997; Cecil and others, 2019). The Permian foliated unnamed granite and Weiss Mountain pluton are coeval with volcanoclastic and volcanic rocks in the El Paso terrane (Permian andesite of Goler Gulch of Carr and others, 1997) consisting of volcanoclastic sandstone, and andesite formed in a continental-margin volcanic arc (Carr and others, 1997). In the southeastern Sierra Nevada this unit consists of highly deformed Permian to Middle Triassic granitic plutons intruded into the Kern Plateau shear zone bordering metasedimentary rocks of the El Paso terrane (Clemens-Knott and Gevedon, 2023). Rock types are chiefly medium- to fine-grained hornblende quartz diorite, tonalite, hornblende granodiorite, hornblende-biotite granite, and leucocratic granite. This unit has zircon U-Pb ages of ~239-274 Ma in the El Paso Mountains (Cecil and others, 2019), and ~249-274 Ma in the southeastern Sierra Nevada (Clemens-Knott and Gevedon, 2023). Zircons in some plutons display Precambrian and early Paleozoic inheritance (Saleeby and Dunne, 2015). This unit in southeast Sierra Nevada also yields a reset hornblende K-Ar date of ~86 Ma and biotite K-Ar date of ~74 Ma (Evernden and Kistler, 1970). In the El Paso Mountains, on the other hand, this unit has hornblende K-Ar ages of ~224-246 Ma and biotite K-Ar ages of ~146-230 Ma (Carr and others, 1997). This granitoid suite records initiation of subduction and arc magmatism along the southwestern margin of the North America craton.

Gsb

**Sierra Buttes intrusive complex (earliest Mississippian and Late to latest Middle Devonian, ~352-385 Ma)**—In central and northeastern part of complex, chiefly granite, granodiorite, trondhjemite. Unit also includes rhyolite and andesite dikes. Major units are the Bowman Lake batholith, Wolf Creek Stock, and coeval hypabyssal intrusions. Farther south, felsic orthogneiss and local metagabbro are inferred to be a continuation of the unit.

The Bowman Lake batholith is a composite batholith composed chiefly of trondhjemite, granodiorite, biotite granite, and hornblende tonalite, formed from discrete batches of magma injected into a common plutonic chamber (Hanson and others, 1988). The trondhjemitic rocks form inclusion-rich and inclusion-poor facies. The inclusion-rich facies contains abundant ovoid inclusions of biotite-hornblende tonalite and less common hornblende gabbro, less than 4 m diameter within a trondhjemite and trondhjemitic tonalite host containing biotite and hornblende in smaller amounts. Inclusions in the inclusion-poor facies are petrographically identical to those in the inclusion-rich facies but are smaller and present in much lower amounts. The inclusions in many cases exhibit fluidal cusped margins against the more felsic host rocks and in some cases also show chilled margins, supporting the interpretation that the enclaves represent blobs of gabbroic to tonalitic magma that mingled with cooler, more felsic magma during emplacement of these parts of the batholith. The Bowman Lake batholith has zircon U-Pb ages of ~353-409 Ma (Girty and others, 1984; Hanson and others, 1988; Rotberg, 2008; Powerman and others, 2020). Both Girty and others (1984) and Hanson and others (1988) analyzed multigrain zircon fractions, which can yield unreliable results. The result from Girty and others (1984) is now inferred to reflect inheritance. The results from Hanson and others (1988) suggest a modelled age range of ~364-385 Ma, but they note that the data record multiple mechanisms of discordance. More

recent U-Pb zircon SHRIMP analyses by Powerman and others (2020) yielded ages of ~353-371 Ma, with a weighted mean age for the batholith of ~361 Ma. The smaller Wolf Creek stock, in the northernmost part of this unit, is biotite granite. Saleeby and others (1987) obtained an age of ~378 Ma for this pluton, using multigrain zircon analyses. Powerman and others (2020) reported an age of ~352 Ma (Early Mississippian), which is considered a more reliable result.

The more southerly bodies in this unit include the Mokelumne Peak roof pendant of McKee and Howe (1981) at the Mokelumne River east of Salt Springs Reservoir and scattered small bodies around the Stanislaus River northeast of the Calaveras-Shoo Fly thrust. They are predominantly granitic gneiss, with lesser amounts of syenitic gneiss. The latter rock type has yielded a preliminary whole rock Rb-Sr isochron age of ~363 Ma (Merguerian and Schweickert, 1987) and a zircon U-Pb age of ~275 Ma from a granitic body (Sharp and others, 1982), which clearly falls well outside the time frame of this unit. An additional age from a blastomylonitic granite was originally reported with an anomalously low zircon U-Pb age of ~216 Ma (Saleeby and Sharp in Bedrossian and Saucedo, 1981) but later reported as ~370 Ma (Merguerian and Schweickert, 1987). This U-Pb age is based on multigrain zircon analyses, so should be regarded as preliminary. The Mokelumne Peak roof pendant has yielded biotite and hornblende K-Ar ages of ~87-98 Ma, the same as those from the surrounding Cretaceous plutonic rocks (McKee and Howe, 1981).

The Devonian part of the intrusive complex is intrusively linked to the coeval Sierra Buttes Formation, which consists of arc-derived sedimentary and volcanic rocks of Taylorsville sequence (in unit NSSB) in the Northern Sierra terrane (Hanson and others, 1988). Together, the plutonic and volcanic rocks comprise the Sierra Buttes arc. Younger U-Pb zircon ages of ~275 Ma represent later plutonism, though still prior to the several Permian(?) to Middle Jurassic phases of regional metamorphic overprint (Merguerian and Schweickert, 1987).

Unit regionally deformed with an older generation of E to NE-appressed folds and parallel schistosity, and a younger generation of NW-trending appressed folds and parallel schistosity. The younger deformation is equivalent to the Middle Jurassic deformation of the Tuttle Lake Formation (unit NSTT) during emplacement of the Emigrant Gap and related plutons (unit Gegg) as described above (Hanson and others, 1996). Plutons crosscut older schistosity in Shoo Fly Complex marine sedimentary rocks (unit NSSF).

## WALL ROCK

### Sierra Crest-High Sierra-Kings Terrane Overlap

**SHKOV** **Younger metavolcanic rocks (middle Cretaceous, ~95-106 Ma)**—Occurs in the Strawberry Mine, eastern Boyden Cave, western Ritter Range, southwestern Goddard, and associated smaller roof pendants in central Sierra Nevada. Chiefly metamorphosed rhyolite to dacite ash-flow tuff, andesite, and basalt volcanoclastic rocks and flows. Local metaandesite and metabasalt flows. In Merced Peak Quadrangle, chiefly metarhyolite to metadacite ash flows, which have yielded a zircon U-Pb age of ~100 Ma (Peck, 1980). The Strawberry Mine roof pendant is chiefly metamorphosed and deformed, shallow-level, andesite to rhyolite flows, tuff, and breccia. The closely spaced Merced Peak and Strawberry Mine roof pendants

have yielded whole rock Rb-Sr ages of ~95-98 Ma (Peck, 1980; Nokleberg, 1981). In these areas, the unit overlies the Kings terrane (unit KSV). In the eastern Boyden roof pendant, metavolcanic units are chiefly metarhyolite and metadacite tuff and airfall ash, with lesser rhyolite lava and metavolcanic sedimentary rocks. These rocks have zircon U-Pb ages of ~104 and ~106 Ma (Saleeby and others, 1990). The western Ritter Range roof pendant, contains highly varied units of metamorphosed tuff breccia, crystal tuff, flows, hypabyssal intrusives, and bedded tuff ranging in composition from rhyolite to basalt, but with an average composition of dacite to rhyodacite. The unit is weakly schistose with dominant primary textures. The unit here has a zircon U-Pb age of ~100 Ma (Bateman, 1992), as well as a detrital zircon maximum depositional age (MDA) of ~101 Ma (Attia and others, 2022). In the Ritter Range area, the unit stratigraphically overlaps the metavolcanic member of the Goddard terrane of Nokleberg (1983; herein part of the Sierra Crest terrane, unit SCGV). Unit intrusively linked to Merced Peak and Washburn Lake intrusive suite (unit Gmw; Peck, 1980). This unit forms part of the Monarch arc, along with units SHKOG, Gmw, and Gbvc.

**SHKOG Metamorphosed hypabyssal intrusive bodies and metagranitic rocks (middle Cretaceous, ~98-110 Ma)**—Occurs in the Boyden Cave, Strawberry Mine, Goddard, and Saddlebag Lake/Mount Dana roof pendants in central and southern Sierra Nevada. Predominantly small granitic plutons, in places intruding coeval metavolcanic rocks (unit SHKOV). In the western Boyden Cave roof pendant, this unit is ~108 Ma (zircon U-Pb) schistose hypabyssal hornblende-biotite dacite porphyry (Saleeby and others, 1990; Moore and Nokleberg, 1992). In the Strawberry Mine roof pendant, the unit is chiefly metamorphosed hypabyssal intrusive bodies of quartzofeldspathic gneiss and dikes of quartzofeldspathic hornfels, which have yielded a whole-rock Rb-Sr isochron age of ~98 Ma (Nokleberg, 1981). In these areas, the unit intrudes the metavolcanic member of the Kings terrane (unit KSV). In the eastern Boyden Cave pendant, this unit is a subvolcanic intrusion of massive hypersthene-bearing metadacite and a stock of metagranodiorite. These have a zircon U-Pb age of ~102-103 Ma (Saleeby and others, 1990). In that area, the unit intrudes the roughly coeval metavolcanic rocks (unit SHKOV) and is roughly the same age as the surrounding granitic units. In the Saddlebag Lake and Mount Dana roof pendants, chiefly shallow intrusive dacite porphyry and quartz monzodiorite. This part of the unit has yielded a whole rock Rb-Sr age of ~118 Ma (Kistler and Swanson, 1981), but Nokleberg and Kistler (1980) shows a Rb-Sr isochron age of ~100 Ma and Ardill and others (2020) report zircon U-Pb ages of ~100-101 Ma. In this area the unit intrudes and overlies the High Sierra terrane (units HSS and HSV). Saleeby and others (1990) report zircon U-Pb ages of ~105-110 Ma for bodies too small to show of similar rocks in the Oak Creek roof pendant, where they intrude rocks of the Sierra Crest terrane (unit SCGV). Unit intrusively linked to Merced Peak and Washburn Lake intrusive suite (unit Gmw) and to Buena Vista Crest intrusive suite (unit Gbvc). Along with the two intrusive suites and associated metavolcanic rocks (unit SHKOV), this unit forms the Monarch arc, a major volcanic arc overlap assemblage.

#### Kernville Terrane

**KE Kernville terrane - southern Sierra Nevada (Cretaceous, Jurassic and early Paleozoic(?))**—Consists of quartz arenite turbidite, and massive metaquartzite blocks in an argillite matrix with lesser graphite slate, felsic to intermediate metavolcanic rocks and tuff,

banded calcsilicate rock, marble, and lenses of mafic schist. Local metamorphosed barite lenses. Local thick marble units (> 100 m) in southeastern pendants. Metamorphosed to upper greenschist to amphibolite facies. Detrital zircon ages for massive quartzite blocks and turbidites suggest diverse origin for units. Unit contains turbidites derived from the Cordilleran Craton margin, and quartz-rich detritus in mélange blocks with an uncertain provenance (Saleeby and Dunne, 2015). Metasedimentary units of terrane may correlate with early Paleozoic marine sedimentary rocks of Shoo Fly Complex (unit NSSF) in northern Sierra Nevada (Harding and others, 2000) and others resemble strata in Death Valley (Memeti and others, 2010). Unit includes metasedimentary rocks of Keen (Ross, 1989), French Gulch and Fairview pendants, and Long Canyon and Tehachapi metasedimentary belts (Ross, 1995). Interpreted as metamorphosed craton-margin sedimentary rocks. Detrital zircon MDAs of ~142, ~159, ~171, ~178, ~625 ~680, ~700 Ma (Saleeby, 2011; Attia and others, 2018, 2021). Igneous zircon U-Pb ages of volcanic and hypabyssal rocks in the terrane (Erskine Canyon sequence) range from ~97-105 Ma (Busby-Spera and Saleeby, 1990; Saleeby and others, 2008) and probably reflect marginal intrusives or overlapping volcanics related to surrounding plutons (parts of units Gbv and Gop). Saleeby and others (1978) report an Early Jurassic fossil from this unit near Lake Isabella. Ross (1989) interprets these rocks as Mesozoic, but others (e.g. Chapman and others, 2012) interpret them as Paleozoic rocks unconformably overlain by Late Triassic to Jurassic metavolcanic and metasedimentary rocks.

## Fault Zone Rocks

[Rocks of mixed or uncertain affinity in fault-bounded lenses within larger fault zones]

- FZM**      **Fault zone mélange (Early Cretaceous to Middle(?) Jurassic)**—Blocks of various rock types in a sheared sedimentary rock matrix, locally includes pieces of both Cosumnes and Merced River terranes. Age between youngest incorporated rocks and last major fault offset (age of stitching plutons).
- FZMg**      **Gabbro blocks**—Small blocks and lenses around New Melones Lake.
- FZMI**      **Limestone and marble blocks**—A small lens north of, and an even smaller block east of, New Melones Lake.
- FZMs**      **Slate and metasandstone blocks (Late Jurassic)**—Similar to Mariposa Formation (unit CMMS) to the west. Imlay (1961) reports several fossil localities indicating Late Jurassic age. Southeast and immediately east of New Melones Lake.
- FZMu**      **Serpentinite blocks**—Crops out as lenses along the Melones fault between Mariposa and the Mokelumne River and the Gillis Hill fault at the American River.
- FZMv**      **Volcanic blocks**—Two blocks, one north of Mariposa and one between Don Pedro Reservoir and New Melones Lake. Greenstone, chlorite schist, hornblende schist, tuff, volcanic breccia.
- FZS**      **Fault zone serpentinite (Early Cretaceous to Middle(?) Jurassic)**—Sheared serpentinite along both terrane-bounding and intraterrane faults in the western metamorphic belt.

## Kings Terrane (Early Cretaceous to Late Triassic)

[Occurs in the central and southern Sierra Nevada in the Boyden Cave and Mineral King roof pendants, and in adjacent roof pendants to north and south. Terrane metamorphosed from upper greenschist to lower amphibolite facies. Roof pendants containing this terrane form a NNW-trending belt that extends for about 170 km. Terrane faulted against Sierra crest terrane to the east along the Kings River suture. Units in terrane intensely folded at map and outcrop scales, sheared, and structurally imbricated. Units occur in dismembered isoclinal folds that are locally refolded into NNW-trending, SSE-plunging synclines and anticlines. Units display intense schistosity and parallel foliation aligned with bedding. Terrane consists of a sequence of marine, craton-margin sediments with interlayered intermediate to siliceous volcanic rocks formed along a continental margin.]

**KSM Marble layers in metasedimentary and metavolcanic rocks (Early Cretaceous to Late Triassic)**—Chiefly thick marble layers in calc-schist, pelitic schist, and metasandstone. Only thicker units are displayed and occur in the southern Sierra along the Kings River, east of Pine Flat Lake, and along and north of the Kaweah River northeast of Lake Kaweah.

**KSV Metasedimentary rocks, metavolcanic rocks, and minor shallow metagranitic plutons (Early Cretaceous to Late Triassic)**—Occurs in central and southern Sierra Nevada in the Boyden Cave, Iron Mountain, and Mineral King roof pendants, and in adjacent roof pendants to the north and south. Metasedimentary rocks are chiefly marine quartzite, pelitic schist, metasandstone, calc-schist, and minor marble. Marine ammonites occur in metasedimentary rocks. Metavolcanic rocks are chiefly metamorphosed andesite, dacite, rhyolite flows and breccia, and dacite and rhyolite tuff. Minor metamorphosed basalt and basaltic andesite. Locally intruded by dikes of Independence dike swarm (unit Gid). Minor shallow metagranitic plutons are chiefly schistose dark granodiorite and lesser schistose diorite and gabbro occurring mainly in the Triple Divide Peak roof pendant. Samples with middle Cretaceous detrital zircon MDAs possibly from high-faulted and folded units of overlap (unit SHKOV).

Metavolcanic rocks from the Iron Mountain pendant have yielded zircon U-Pb ages of ~123-156 Ma (Attia and others, 2020; Bennett and others, 2024). Metavolcanic rocks from the western part of the Strawberry Mine pendant have yielded a detrital zircon MDA of ~103 Ma (Memeti and others, 2010). However, this age is within the span for the overlying Cretaceous overlap unit (SHKOV and SHKOG), so this age probably reflects a body of that unit too small to differentiate at map scale. From farther south in the western Boyden Cave pendant, Attia and others (2021) reported a detrital zircon MDA of ~114 Ma from this unit. From farther south, in the Big Baldy pendant, Sisson and Moore (1994) report a U-Pb age of ~110 Ma from metarhyolite tuff. From nearby in the southeast part of the Sequoia Park pendant, Attia and others (2021) reported a poorly constrained detrital zircon MDA of ~188 Ma. From still farther south in the Mineral King pendant, Sisson and Moore (2013, recalculated from Busby-Spera, 1983) report zircon U-Pb concordia ages of ~111 from metaandesite, ~131-140 Ma from metarhyolite tuff, ~171 and ~189 Ma from metadacite tuff, and ~214 and ~236 Ma from metaandesite. From the same pendant, Attia and others (2021) report detrital zircon MDAs of ~187 and ~265 Ma.

## Merced River Terrane

**MRGP Goldstein Peak Formation (Early Cretaceous, ~129-140 Ma MDA)**—Consists of metaconglomerate, sillimanite-biotite-quartz schist, hornblende-rich amphibolite, and local carbonate and calc-schist. Crops out in the southwestern Sierra Nevada foothills northwest of the Kaweah River in a pendant within the Stokes Mountain intrusive suite (unit Gsm). Protoliths are conglomerates and sandstones from fluvial and alluvial fan environments, mud-rich sediments and air-fall tuffs deposited in a lacustrine(?) environment, and subaqueous to subaerial basalt to dacite volcanic rocks. Approximate stratigraphic thickness of 1,250 m. Unit stratigraphically overlies metasedimentary rocks of the Merced River terrane (unit MRCS) to the east and northeast. This unit has yielded detrital zircon MDAs of ~129-140 Ma (Martin and Clemens-Knott, 2015). This unit is cut by a granitic dike that has evidence of wet-sediment intrusion with a U-Pb age of ~139 Ma (Clemens-Knott and others, 2013). Unit coeval with forearc deposits of the Great Valley sequence in the Diablo and Templor Ranges and the subsurface of San Joaquin Valley to the west of the map area. Unit is one of the youngest sedimentary deposits (excluding volcanoclastic sedimentary rocks in the dominantly volcanic unit SHKOV) preserved within the metamorphic framework of the exhumed batholith.

**MRDPH Phyllite member (Jurassic and Late Triassic(?))**—Primarily phyllite, phyllitic sandstone, and metaconglomerate chiefly derived from sandstone, shale, andesite tuff, and sparse marble. Forms an elongate belt east of the Melones fault and west of the Sonora fault from the Mokelumne River southeast to the Oakhurst pendant at Coarsegold. Unit includes part of phyllite of Briceburg (Triassic) of Bateman and Krauskopf (1987). Part of the Don Pedro terrane of Schweickert (2015). Unit locally structurally interleaved with volcanic flows and lesser pyroclastic rocks unit (unit MRDGS). This unit also includes a limestone block (olistolith) that has yielded Late Triassic conodonts (Paterson and Wainger, 1991). This unit is intruded by the ~167-177 Ma plutons of the Don Pedro intrusive suite (unit Gdp), thus much of the unit must be that age or older. In addition, detrital zircon analysis from this unit has yielded MDAs in two groups, ~168-171 Ma and ~255-350 Ma (Attia and others, 2021). The younger MDAs match the Jurassic age of the other age indicators, but the older MDAs are much older, and so perhaps reflect recycling of older rock, as suggested by the limestone olistoliths. However, part of the greenstone (see unit MRDGS below), so also probably the interleaved phyllite of this unit, is Late Jurassic, postdating the plutonic intrusion. Metamorphosed at lower greenschist facies. Metamorphic Ar-Ar age for greenstone of 163-161 Ma is probably the same as phyllite metamorphism of this unit. Primary structures in most areas obliterated by intense deformation. This unit, along with units of volcanic flows and lesser pyroclastic rocks (unit MRDGS) and granitic rocks (unit Gdp) interpreted as parts of the Early to Middle Jurassic Don Pedro island arc overlap assemblage deposited mainly on the western margin of Calaveras Complex (unit MRCS).

**MRDGS Greenschist member (Jurassic)**—Chiefly greenschist and lesser metamorphosed pyroclastic rocks in the southern part of the western metamorphic belt. This unit forms part of the Don Pedro terrane of Schweickert (2015). It forms a discontinuous elongate band east of the Melones fault between Placerville and Mariposa with a disconnected continuation in the Coarsegold and nearby roof pendants. Greenschist derived from basalt and andesite breccia,

pillow lava, and mafic tuff. Unit locally contains hypabyssal intrusive rocks and lenses of metagabbro. Pyroclastic rocks chiefly consist of metamorphosed tuff containing mostly saussuritized feldspar and actinolite with some epidote, chlorite and sericite. Pyroclastic rocks similar in mineralogy to greenschist, but more commonly bedded, with small-scale folding and boudinage structures. Primary structures in unit in most areas obliterated by intense deformation. Metamorphosed at lower greenschist facies. Metavolcanic rocks in the southern roof pendants are higher grade, largely amphibolite.

Metavolcanic units near the Merced River yielded a ~187 Ma Rb/Sr whole-rock age (Bateman and others, 1985), and a small pluton in this unit near Mariposa yielded an Ar-Ar age of ~169 Ma (Herzig and Sharp, 1992). Farther southeast, near Hwy 41 in the Coarsegold roof pendant, this unit has yielded a detrital zircon MDA of ~187 Ma, and an MDA of ~165 Ma in an unnamed pendant about 10 km south of that. The unit is locally intruded by the ~162-177 Ma Don Pedro intrusive suite (unit Gdp), so much of the unit is probably that age or older. However, a greenstone body northwest of Mariposa and one northeast of Lake Don Pedro have yielded Late Jurassic ammonites (Imlay, 1961; Clark, 1964), and elsewhere a metavolcanic body includes an ~167 Ma clast (Sharp, 1988; Schweickert, 2015), so those parts of the greenstone are Late Jurassic, postdating the plutonic intrusion. The unit in this area is also called the volcanic member of the Sullivan Creek terrane or the greenstone of Bullion Mountain.

The Early and Middle Jurassic part of this unit is magmatically linked to the coeval Don Pedro intrusive suite (unit Gdp) forming Don Pedro Island arc deposited on and intruded into the western margin of the Calaveras Complex.

West of Millerton Lake, also includes:

MRDGG      **Gabbro**—Hornblende gabbro and other mafic plutonic rocks.

MRSB      **Serpentinite mélange with ultramafic and mafic igneous rocks (Early Jurassic or older)**—Forms a discontinuous belt along and northeast of the Melones fault between Angels Camp and Mariposa plus an isolated outcrop at the San Joaquin Valley margin south of the Kaweah River. Largely interleaved with units MRDGS and MRDPH. Deformed and dismembered blocks of serpentinitized harzburgite, gabbro, and serpentinite. Local minor basalt layers. Includes thin, lensoidal diorite plutons, one correlated with the ~163 Ma Cobb Creek pluton of the Don Pedro intrusive suite (unit Gdp) (Morgan, 1976). Also includes felsic dikes and conspicuous mariposite-bearing quartz veins. Mariposite from this unit has yielded a K-Ar age of ~123 Ma (Evans and Bowen, 1977), probably marking hydrothermal mineralization related to formation of gold-bearing quartz veins along the Melones fault. This unit possibly represents oceanic crust that formed the basement of the Don Pedro terrane.

### *Calaveras Complex*

MRCG      **Greenstone member (Early Triassic, Permian, and Pennsylvanian)**—Greenschist facies metabasalt, basaltic andesite, agglomerate, and tuff. Association of marble with mafic volcanics near the Stanislaus River led Schweickert and others (1977) to suggest this unit there is part of a large fragment of basaltic seamount. Near the South Fork Cosumnes River north of Fiddletown and the Middle Fork American River, southwest of Foresthill, this unit includes small bodies of ultramafic rock. This unit also occurs in highly deformed lenses

within phyllite (unit MRCS) north of Placerville. Together, these rocks north of Placerville form the unit named phyllite-greenschist by Schweickert (2015), who tentatively correlated it with the Don Pedro terrane to the south. However, a marble lens 5 km long in the phyllite north of the South Fork Feather River has yielded Permian to Pennsylvanian conodonts (Hietanen, 1981), so at least that part of the phyllite (and probably the interleaved metavolcanics) is substantially older than the Don Pedro terrane.

- MRCC** **Marine carbonate member (Early Triassic, Permian, and Pennsylvanian)**—Medium- to coarse-grained marble derived from limestone and dolomite. Most of the mapped bodies are in the central Sierra with one outlier north of Lake Kaweah. The large marble bodies shown on the map generally lack known preserved fossils. However, the largest body, near Columbia, is reported to have Late Devonian fossils (Haughy and others, 2024). Schweickert and others (1977) report “Permo-Carboniferous” horn corals from an olistolith near the Tuolumne River. In contrast, a marble layer too small to show at the scale of this map in the northern part of the Calaveras Complex includes Permian to Pennsylvanian conodonts (Hietanen, 1981), and in the south-central part of the complex, another layer of marble too small to show includes Early Triassic conodonts (Bateman and others, 1985). In both cases, the geometry of the marble body strongly suggests that it is not an olistolith. The association of this unit with mafic volcanics near the Stanislaus River, including the Devonian body near Columbia, led Schweickert and others (1977) to suggest this unit there is made of a large fragment of basaltic seamount accreted to the continental margin. We differ from the formally accepted age for this unit based on younger fossils found within its accepted extent (Bateman and others, 1985).
- MRCS** **Marine sedimentary member (Triassic, Permian, and Carboniferous)**—Primarily phyllite and metachert with interlayered limestone and marble. Extends almost the entire length of the western Sierran Nevada, including a narrow band north of Placerville, a broader band roughly between Placerville and Mariposa, and extending as scattered pendants south to the Kern River area.

In the northern band, the unit consists of phyllite and metachert with lesser limestone interbeds. One 5-km long, 50-100 m-thick limestone interbed has yielded Pennsylvanian to Permian conodonts (Hietanen, 1981). Phyllite is quartz with muscovite, biotite, and(or) chlorite. Pebbly layers crop out locally, with pebbles of metachert, quartzite, and calcite. Metachert is recrystallized and lacks preserved fossils. The primary cleavage in this area is tightly folded, resulting in a secondary transecting cleavage. This unit is interleaved with and locally overlain by metavolcanic rocks (unit MRCCG). Schweickert (2015) correlated this band with his Don Pedro terrane to the south, but the Paleozoic age of the limestone bed precludes that correlation.

In the central band, the unit is well-foliated argillite, phyllite, schist, and metachert, with marble bodies ranging from small blocks up to interleaved bodies up to 10 km in length (unit MRCC), and localized lenses of serpentinite and talc schist. Includes the phyllite and chert of Hites Cove and part of the phyllite of Briceburg of Bateman and others (1985). A small limestone bed in metachert at the south end of the belt near the Merced River yielded Early Triassic conodonts (Bateman and others, 1985). Another limestone nearby was reported to have Pennsylvanian or Permian foraminifers (Clark, 1964), but those collected specimens

have been lost and the exact location of sample location is unknown, so that age is not certain and the limestone body could be an olistolith. The central band includes far fewer interleaved volcanic rocks, primarily limited to mafic metavolcanics associated with the large limestone bodies. Schweickert (2015) suggests that all the limestone bodies in this unit are olistoliths, but Bateman and others (1985) indicate that the limestone bed containing the Early Triassic conodonts was interbedded with chert and was not an olistolith. It seems likely, therefore, that at least the southeastern part of this band was deposited in the Early Triassic and incorporates Paleozoic olistoliths. Farther west, the unit locally contains Early Triassic conodonts collected from limestone blocks that are probably olistoliths, perhaps derived from limestone to the east (Bateman and others, 1985). Bateman and others (1985) further suggest that small masses of metagabbro within this unit are hypabyssal equivalents to nearby ~187 Ma volcanic rocks (unit MRDGS), so the unit there would be older than that, but younger than the Early Triassic age of the olistoliths.

In the southern roof pendants, this unit is higher grade, predominantly quartz-biotite schist and quartzite with lesser interbedded marble and metavolcanic rock (amphibolite). In the southernmost roof pendants in this unit, south of the Kaweah River, the metasedimentary rocks are interleaved with and overlain by siliciclastic and volcanoclastic strata assigned by Saleeby (2011) to the Late Triassic to Early Jurassic Kings sequence but included by us in this unit. Saleeby and others (1987) report a Late Permian Tethyan fauna from an olistolith in the Yokohl Valley pendant. A hornblende diorite dike in the northwest part of this unit in the same pendant has yielded a zircon U-Pb age of 168 Ma (Saleeby and Sharp, 1980). The middle Jurassic age suggests that this part of the pendant could instead be part of the Don Pedro terrane.

This unit is bounded to the east by the Calaveras-Shoo Fly thrust and Feather River terrane and to the west by the Sonora, Melones, Gillis Hill, and Dogwood Peak faults. We differ from the formally accepted age for this unit based on younger fossils found within its accepted extent (Bateman and others, 1985).

**MRKA**     **Serpentinite mélangé member (Early Jurassic to Late Triassic and Early Permian to Late Pennsylvanian)**—Occurs in western slopes of central Sierra Nevada adjacent to the Kaweah River. Roughly equivalent to the Kaweah serpentinite mélangé of Saleeby and Sharp (1980). Consists chiefly of foliated serpentinite matrix containing dismembered ophiolitic blocks of a wide range of sizes, shapes, and compositions. Serpentinite matrix derived from highly deformed peridotite, serpentinite diapirs, and serpentinitic debris flows and detrital rocks. The mélangé blocks consist mainly of serpentinitized peridotite, gabbro, diabase, basalt, chert, and ophicalcite. Mélangé interpreted as forming during pillow basalt eruption and tectonic disruption of the seafloor, resulting in extrusion of serpentinite. Pillow basalts, pillow breccias, and hyaloclastites are locally interbedded with ophicalcite and sedimentary serpentinite, but in most localities such flows into serpentinitic sediments were broken into blocks or intergradational lenses with matrix material during subsequent deformation. Pillow lavas erupted over the highly disrupted ophiolitic substrate are commonly interbedded with and overlain by radiolarian chert. Saleeby and Sharp (1980) report a zircon U-Pb age of ~191-225 Ma from a diorite pod within gabbro

in ophiolite mélangé, as well as discordant zircon U-Pb ages of ~270-305 Ma from metaplagiogranite blocks and metaplagiogranite within gabbro and peridotite blocks. They suggest that the younger ophiolitic rocks formed during disruption of the older ophiolite. Saleeby (2011) reports a multi-rock Sm-Nd isochron age of ~299 Ma for this unit and assigns the Mesozoic rocks to his Kings sequence (included in this area in unit MRCS). Farther north, near the Kings River, small unmapped bodies of this unit are seen to be emplaced into the older Kings River ophiolite belt (unit MRKI). Geochemistry of this unit suggests a mid-ocean ridge basalt (MORB) affinity (Saleeby, 2011). This unit probably formed by ophiolitic extrusion in a transform fault within the older seafloor of the Kings River ophiolite and was subsequently intruded and overlain by Mesozoic volcanic and sedimentary rocks.

**MRKI Kings River ophiolite belt (Early Ordovician, ~484 Ma)**—Occurs in western slopes of central Sierra Nevada adjacent to the Kings River. Consists of narrow to large fault-bounded masses of dismembered ophiolite, serpentinite, and serpentinite mélangé. Belt occurs in a series of tectonic slabs as long as 20 km and separated by serpentinite-matrix mélangé zones and crosscutting plutons of the Sierra Nevada batholith. Principal slabs consist of peridotite-cumulate gabbro, sheeted dike-pillow lava slabs, and depleted peridotite-mafic tectonite slabs. Belt interpreted as MORB pillow basalt eruptions that formed the upper crustal levels of an abyssal lithosphere section above a coherent interval of basaltic sheeted dikes. Bounded on the northeastern margin by nonconformably overlying Mesozoic metasedimentary and metavolcanic rocks (unit KSV).

Saleeby and Sharp (1980) report discordant U-Pb zircon ages of ~198-210 Ma from a metadiorite layer within metagabbro, and an amphibole K-Ar age of ~190 Ma for nearby metagabbro. They also report even more discordant U-Pb zircon ages of ~190-305 Ma from plagiogranite pods within metaperidotite. Saleeby (2011), however, reports a multi-rock Sm-Nd isochron age of ~484 Ma for the disrupted ophiolite at Kings River, and states that the Permo-Triassic ages are from later MORB magmatism associated with the Kaweah serpentinite mélangé (unit MRKA) emplaced into and on the disrupted Ordovician ophiolite of this unit.

## Kettle Rock Terrane

**KR Kettle Rock terrane – Eastern Mesozoic belt (earliest Cretaceous to latest Triassic)**—This unit crops out in the northeastern-most Sierra Nevada, east and north of Taylorsville, as well as pendants east of the map area. We note that rocks in the Petersen Mountain area north of Reno included by Garside (1998) in the Peavine sequence (part of our unit NSTT) are more silicic (chiefly rhyodacite) and include maroon and red sedimentary beds, and we assign them to this terrane.

The Kettle Rock terrane consists of, from bottom to top, the Kettle Rock, Mount Jura, and Evans Peak sequences with variable lithologies across multiple structural blocks. The Kettle Rock and Mount Jura sequences exhibit greenschist, with local amphibolite, facies metamorphism, whereas the Evans Peak sequence displays a substantially lower prehnite-pumpellyite facies overprint.

The Kettle Rock sequence in the Mount Jura block consists mostly of very shallow marine, Early Jurassic fossiliferous clastic rock and carbonate. Silicic volcanic rocks crop out

locally at the base of the sequence. Christe (2021a) cites a U-Pb age of ~206 Ma for these rocks. Fossils in the overlying rocks range from late Sinemurian to early Toarcian (Harwood, 1992). Christe (2021a) describes a hypabyssal basaltic andesite (~187 Ma) that cuts the Early Jurassic strata. Christe (2020) interprets it as a hypabyssal intrusive breccia that postdates deposition of the upper part of the sequence. In other structural blocks of this terrane, the Kettle Rock sequence is composed of proximal volcanic rock, mostly flow rock and hypabyssal intrusions, but also eruptive breccia and tuff breccia. Christe (2020) points out that Th/Ta ratios suggest these volcanic rocks formed in a continental margin arc. Flow-banded plagioclase porphyry from this block has yielded a zircon U-Pb age of ~180 Ma (Christe, 2020), somewhat younger than the pre-~187 Ma sedimentary rock at the top of the sequence in the Mount Jura block and the intrusive breccia found there. The volcanics are intruded by a number of stocks, one of which (the quartz monzonite Lights Creek stock) has yielded zircon U-Pb ages of ~178 and ~184 Ma (Christe and Dilles, 2014), roughly coeval and part of the same eruptive system as the metavolcanic wall rock. Christe (2020) notes that the base of the volcanics locally is a shear zone with remnants of sedimentary and tuffaceous rock similar to those found in the Mount Jura block, and suggests that the sedimentary rock may have originally been under the volcanic rock, but has been faulted out. Similarly, eruptive volcanic rocks once overlying the sedimentary rocks of this sequence in the Mount Jura block may have been eroded or faulted away.

The Kettle Rock sequence is unconformably overlain by the Middle to Late Jurassic Mount Jura sequence. In the Mount Jura block, the Mount Jura sequence is composed of volcanic clast conglomerate, sandstone that is locally rich in shallow marine fossils including brachiopods and corals, and shale, which are overlain by feldspathic clastic rocks with thin tuff interbeds, and then overlain by pyroclastic rocks, ash flow tuff, and lesser shale, sandstone, and tuffaceous rocks. Fossils in the sequence in this block range from late Aalenian to Oxfordian (Harwood, 1992, Christe, 2020, 2021a), and detrital zircons from just above the base have an MDA of ~172 Ma (Aalenian; Christe, 2021a). A plagioclase porphyry andesite near the top of the sequence has a zircon U-Pb age of ~148 Ma (Tithonian age; Christe, 2020). In the other blocks, the Mount Jura sequence is made up of volcaniclastic rock with minor volcanic flow interbeds, intruded by a plagioclase-porphyry breccia and plagioclase-biotite-quartz porphyry sills and dikes. The plagioclase-porphyry breccia has a zircon U-Pb age of ~162 Ma, an ash flow tuff ~160 Ma, and an intrusive breccia in the tuff ~155 Ma (Christe, 2011, 2020). A granite dike in this sequence has yielded a muscovite Ar-Ar age of ~146 Ma (Dilles and Stephens, 2010).

The uppermost sequence of this terrane is the Evans Peak sequence. It is composed of chert pebble conglomerate, quartz sandstone, and shale/slate overlain by coarse-grained fossiliferous sandstone, shale, and volcanic-cobble conglomerate. The sequence grades from shallow marine to nonmarine. The fossiliferous sandstone of the upper part has many plant fossils and dinosaur-bone fragments. In the Mount Jura block, a tuff near the top of the fossiliferous section has yielded zircon U-Pb ages of ~127 and ~129 Ma, whereas in the Kettle Rock block a porphyry volcanic interbed near the base of the fossiliferous section has a zircon U-Pb age of ~128 Ma (all Barremian age; Christe, 2020). The base of the Evans Peak sequence is not well exposed, and where exposed a structural overprint is typical (Christe, 2020).

Unit is overthrust on the west by Paleozoic and Triassic units of the Northern Sierra terrane along the Taylorsville fault. The terrane is intruded by granitic plutons or stocks of the Diamond Mountains intrusive suite (unit Gdm) with Jurassic and Cretaceous U-Pb isotopic ages. Christie and Pecha (2012) report a diorite stock that intrudes across the bounding thrust with a zircon U-Pb age of ~117 Ma.

## Cosumnes Terrane

### *Western Belt Subterrane*

- CWCH Copper Hill Volcanics (Late Jurassic, Kimmeridgian)**—Chiefly schistose greenstone and phyllonite derived from mafic and intermediate flows with lesser felsic volcanic rocks. Includes metamorphosed tuff, volcanic breccia, and amygdaloidal basalt flows. Pillow lava is interbedded locally, as is minor chert and amphibolite. Metamorphosed to greenschist facies. At the base, it interfingers with the Salt Spring Slate (unit CWSS). Interpreted as marine island arc volcanic rocks based on interfingering with the Salt Spring Slate at the base and the presence of pillow lava and chert. Includes rocks previously mapped by Clark (1964) as Peaslee Creek Volcanics.
- CWCG Gabbro**—Small bodies of gabbro mapped within the volcanics. Intrusions into the volcanics or basement on which the volcanics were deposited.
- CWSS Salt Spring Slate (Late Jurassic, Oxfordian to Kimmeridgian)**—Chiefly black sericite slate with lesser widespread graywacke and tuff along with local thin conglomerate layers. Small lenses of dark-gray limestone are found locally in the slate. Unit also contains local amphibolite and chlorite schist derived from mafic to siliceous metavolcanic rock. Chiefly marine sedimentary rocks containing dominantly epiclastic rocks that overlie and intertongue with Gopher Ridge Volcanics (unit CWGR). Includes rocks previously mapped as Merced Falls Slate. In southernmost part of belt close to the batholith and in the Adobe Hill roof pendant, the unit consists chiefly of biotite-quartzite schist, metadacite and metarhyolite schist, chlorite schist, andalusite schist, and amphibolite derived from basalt or mafic tuff. Imlay (1961) reports late Oxfordian to early Kimmeridgian *Buchia* from this unit along the Cosumnes River.
- CWSV Volcanic member**—Interbedded metavolcanics, shown locally.
- CWGR Gopher Ridge Volcanics (early Late and late Middle Jurassic, Callovian to Oxfordian)**—Volcanic breccia, tuff, and flow rock, ranging from basalt to rhyolite but mostly andesite. Some massive felsic rock probably formed as shallow, late-stage intrusives. Some flow rock exhibits pillowed structure. In most areas the tuffaceous rocks have a slaty parting whereas the breccia and flow rock are unfoliated; locally schistose. Metamorphic minerals include epidote, albite, tremolite, and some chlorite, indicative of greenschist facies metamorphism.

### *Mother Lode Subterrane*

- CMMS Mariposa Formation (Late Jurassic, Oxfordian to Kimmeridgian)**—Chiefly slate and graywacke with lesser pebble conglomerate, fine-grained mafic tuff, and massive tuffaceous greenstone. Local mafic volcanic breccia, and thin mafic tuff beds. Local

metachert and quartz slate. Locally intruded by porphyritic hypabyssal sills. Locally highly metamorphosed to mica- and andalusite-schist. Overlies Logtown Ridge Formation (unit CMLV).

- CMMB**      **Brower Creek Volcanic Member**—Intertonguing dark-green coarse volcanic breccia and lesser tuff. Pillow lava in one location.
- CMFM**      **Sierra foothills mélange of Duffield and Sharp [1975] (Late Jurassic, Oxfordian to Kimmeridgian)**—Sedimentary-matrix mélange, including bodies of gabbro, marble/limestone, andesite, serpentinite, and chert. Grades northward near Cosumnes River into conglomerate and olistostrome, including andesite clasts probably derived from underlying Logtown Ridge Formation. Conglomerate there includes granitic clasts and is interfingering with Mariposa Formation (unit CMMS). Previously mapped in part as Mariposa, Cosumnes, and Calaveras Formations (Clark, 1964). Previously thought to depositionally underlie the Logtown Ridge Formation, but probably lateral stratigraphic equivalent to intertongued Mariposa Formation.
- CMFG**      **Gabbro bodies**
- CMFL**      **Limestone bodies**
- CMFS**      **Metasedimentary bodies**
- CMFU**      **Ultramafic bodies**
- CMFV**      **Volcanic bodies**
- CMLM**      **Mariposa and Logtown Ridge Formations, undivided (Late to Middle Jurassic, Kimmeridgian to Callovian)**—Interleaved or tightly folded bodies too small to differentiate the two units at map scale.
- CMLV**      **Logtown Ridge Formation (early Late to late Middle Jurassic, Oxfordian to Callovian)**—Chiefly interbedded massive volcanic breccia metamorphosed to greenstone. Local augite porphyry andesite, pillow lava, and volcanic breccia. Local massive sills or flows of plagioclase-augite porphyry greenstone. Also includes volcanogenic gritstone and pebbly mudstone with lesser silty slate and tuff. Units form a nearly vertical homocline with tops toward the east, structurally repeated multiple times. Interfingering with overlying Mariposa Formation (CMMS). The western part contains more non-volcanic detritus, suggesting a western source of limestone, amphibolite, chert, and granite. Chert clasts in the western part of the unit contain Late Permian radiolarians derived from chert blocks at the base of the underlying Brandon formation (unit CMBS). Formed in an island arc setting.
- CMBS**      **Brandon formation (Middle Jurassic, Bathonian)**—Basaltic sandstone and structurally imbricated cherty argillite overlying basal fragments of Permian chert and basalt. Basaltic sandstone contains Middle Jurassic radiolarians. Chert blocks at base contain Permian radiolarians. Chert and basalt blocks may be related to the Jasper Point Formation of the Moccasin Peak subterranean (unit CPJP).

*Moccasin Peak Subterranean*

- CPPB**      **Penon Blanco Volcanics (Early Jurassic to Late Triassic)**—Andesite pillow breccia

and flows, massive flows, minor tuff, and dark-green mafic rocks. Tuff, lapilli tuff and breccia constitute the upper part with lava and pillow lava forming the lower part. Both mafic and andesitic volcanics locally intensely deformed into a structural *mélange*. Intruded by the ~182-200 Ma Chinese Camp igneous complex (Gcc). The age of the intruding unit suggests that this unit is at least in part Late Triassic, which differs from the formally accepted age of Jurassic.

- CPJP Jasper Point Formation (Triassic and Permian(?))**—Consists of massive, pillowed, and brecciated basalt overlain by 100 m of red, white, brown, and black, rhythmically layered radiolarian chert, both altered to prehnite or chlorite grade. Top of chert interbedded with and gradationally underlies the Penon Blanco Volcanics. Locally intensely deformed into a structural *mélange*. Structurally overlies the Tuolumne ophiolite-*mélange* (unit CPTO). Units CPTO and CPJP may be upper and lower part of the same ophiolite. This unit does not have recognized fossils nor radiometric ages. The age is constrained by the overlying and underlying units. As such, it may be as old as Permian, which differs from the formally accepted age of Triassic.
- CPTO Tuolumne ophiolite-*mélange* (Triassic(?) and Permian)**—Deformed blocks of harzburgite, dunite, wehrlite, gabbro, serpentinized ultramafic rocks, greenstone, and limestone. Local minor basalt layers. Local narrow chrysotile veins and pods of chromite. Includes a metaplagiogranite block that yielded a zircon U-Pb age of roughly 280-300 Ma (Saleeby, 1982). Structurally overlain by Penon Blanco Volcanics (unit CPPB) and Jasper Point Formation (unit CPJP). Large mass in the southern part of the terrane is named the Tuolumne ultramafic complex (e.g. Wills and others, 2022). Occurs along and east-northeast of the Bear Mountains fault. Interpreted as part of the basement of an Early Jurassic to Late Triassic island arc.
- CPTG Gabbro member**—*Mélange* blocks and other bodies of gabbro within the serpentinite matrix *mélange*.
- CPTL Limestone member**—*Mélange* blocks and other bodies of limestone and marble within the serpentinite matrix *mélange*.
- CPTS Metasedimentary member**—*Mélange* blocks and other bodies of metamorphosed clastic sedimentary rocks within the serpentinite matrix *mélange*.
- CPTV Metavolcanic member**—*Mélange* blocks and other bodies of metavolcanic rocks within the serpentinite matrix *mélange*.

## Yuba River Superterrane

### *Overlap Strata*

[The American River and Slate Creek terranes, described below, are intruded across the suture by the ~167-168 Ma scales pluton (unit GSCP), described above. as such, units of the Yuba Rver superterrane younger than ~167 Ma formed after the amalgamation of the two terranes, and are therefore considered part of an overlap sequence, even though only the Smartville volcanic complex (YOSV) has been mapped as overlying both the American River and Slate Creek terranes.]

- YOMO Monte de Oro Formation (Late Jurassic, Oxfordian to Kimmeridgian)**—Slate,

slightly sheared sandstone and siltstone, and minor conglomerate. Contains plant and mollusk fossils. Probable nearshore deposition. Overlies the Oregon City Formation. Imlay (1961) reports fossils that are probably late Oxfordian to early Kimmeridgian.

- YOOC Oregon City Formation (early Late and late Middle Jurassic, Callovian to Oxfordian)**—Andesite and basalt, pyroclastic breccia and tuff with lesser flow rock, very locally pillowed, and volcanoclastic sedimentary rocks. This unit is Included by most workers in the Smartville volcanic complex but is separated from the main body of Smartville by a high-angle fault (Long Ravine-Spenceville fault); Creely (1965) notes a significant difference in metamorphic grade between these units. Creely (1965) reports one fossil of probable Oxfordian age from the northern part of this unit, and Saleeby and others (1989b) report a zircon U-Pb age of ~164 Ma from roughly the same area. Previously mapped as along-strike continuation of Copper Hill Volcanics to the south but note the age difference. The formally accepted age of this unit is Late Jurassic, but the ~164 Ma zircon U-Pb age indicates that it extends back into Middle Jurassic.
- YOSV Smartville volcanic complex (Late to Middle Jurassic)**—Mafic to intermediate plutonic and volcanic rocks. Intrudes the Slate Creek terrane, Shingle Springs complex (YSSS) near Folsom Lake (Folsom dike swarm of Saleeby, 1982). Zircon U-Pb ages of ~160-162 Ma from volcanic rocks in this unit have been reported (McJunkin and others, 1979; Saleeby and others, 1989b), but at least part of the unit is at least slightly older than the oldest (~165 Ma) intruding pluton (unit Gph). Structurally (and perhaps depositionally) overlies and(or) intrudes the Clipper Gap Formation (unit YACG) near Higgins Corner (Day and others, 1985; Day and Bickford, 2004). Includes several named granitic and gabbroic plutons [from north to south: Swedes Flat (unit Gsf), San Juan Ridge (Gsj), Pilot Peak (Gpp), Banner Grange (Gbg), and Pine Hill (Gph)]. Interpreted as a rifted volcanic arc.
- YOSD Diabase member**—Massive diabase and diabase dikes
- YOSG Gabbro member**—Unnamed gabbro and gabbro-diorite plutons
- YOSU Ultramafic member**—Highly serpentinized ultramafic rocks, intruded by plutonic and volcanic members.
- YOFC Colfax Formation (Middle Jurassic, early Callovian)**—Slate, quartzose wacke, and conglomerate. Ammonites from this unit indicate an early Callovian age (Imlay, 1961). Chert blocks and pebbles from the conglomerate have yielded Early Jurassic (Toarcian-Pleinsbachian) and Late Triassic (Norian) radiolarians (Graymer, 1992; Graymer and Jones, 1994). Conglomerate includes clasts apparently derived from underlying Clipper Gap Formation (unit YAGC). The formally accepted age of this unit is Late Jurassic based on work in the early 20<sup>th</sup> century, but that is belied by the age of the fossils found later. Previously mapped as Mariposa Formation (e.g. Chandra, 1961), but these rocks are older.
- American River Terrane*
- YACG Clipper Gap Formation (early Middle Jurassic to Late Triassic)**—Originally named by Lindgren (1900). Includes the olistostrome member of American River terrane of Graymer and Jones (1994). Equivalent to the southern part of the chert-argillite unit of Day and others (1985) and part of the Fiddle Creek Complex of Edelman and others (1989).

Cherty argillite and chert, with minor volcanoclastic sandstone, diamictite, breccia, and conglomerate. Includes large blocks and lenses of gabbro, chert, and marble. Late Triassic chert interbedded in the northern part of the unit (Hietanen, 1981) and early Middle to late Early Jurassic (Aalenian-Toarcian) chert interbedded in the southern part of the unit (Graymer and Jones, 1984). This unit also includes a lahar that has yielded a hornblende Ar-Ar date of ~174 Ma (Hacker, 1993). Lowermost greenschist facies. The formally accepted age of this unit is early Mesozoic and Mississippian, but the Mississippian age is based on fossils from limestone blocks (Lindgren, 1900) now seen to be olistoliths (Day and others, 1985) thus only providing a maximum age for the unit. We assign the age of this unit based on age of interbedded chert and volcanics.

- YACC**      **Chert blocks**—Large chert blocks and lenses in sheared argillite matrix. Probably olistoliths. Around the North Fork American River, chert blocks have yielded Late Triassic (Norian), Early Jurassic to Late Triassic (Sinemurian(?) to Norian), and Early Jurassic (Toarcian to Pleinsbachian) radiolarians.
- YACL**      **Limestone blocks**—Large blocks of limestone and marble in sheared argillite matrix; probably olistoliths. This unit has yielded Late Paleozoic (Carboniferous-Permian) fossils (Lindgren, 1900; Clark, 1976; Hietanen, 1981).
- YACGb**      **Gabbro blocks**
- YACGv**      **Volcanoclastic member**—Volcanoclastic sandstone, breccia, and conglomerate. Locally in channels eroded into argillite.
- YACV**      **Volcanic member**—Includes Owl Gulch volcanics of Edelman and others (1989). Basalt, locally pillowed, and breccia. Minor felsic volcanics. Low metamorphic grade.
- YACU**      **Serpentinite lens**
- YALC**      **Lake Combie complex (Early Jurassic(?) to Late Triassic)**—Includes volcanic member of American River terrane of Graymer and Jones (1994). Mafic to intermediate plutonic and volcanic rocks and lesser ultramafic rocks at the structural base. Interpreted as an island arc volcanic assemblage overlying disrupted oceanic crust. Day and others (1985) correlated the Lake Combie complex with the Smartville volcanic complex, but diorite from this complex near Colfax has yielded zircon U-Pb ages of ~203 Ma and ~198 Ma (Langenheim and others, 2025; Rack and Roeske, 2025). The volcanic member of the Lake Combie complex is interleaved with the Clipper Gap Formation (unit YACG) east of Auburn.
- YALV**      **Volcanic member**—Mafic volcanic rocks. Primarily flow rocks at the base, grading upward into interleaved flow rock, breccia, tuff, and volcanoclastic sandstone. Flow rock locally pillowed. Andesite tuff and flow rock with lesser volcanic breccia near the American River.
- YALD**      **Diabase member**—Dikes and massive diabase
- YALG**      **Gabbro member**—Gabbro with lesser diorite and minor quartz diorite.
- YALU**      **Ultramafic member**—Serpentinite and foliated peridotite.

**Mount Ararat complex (Early Jurassic and Late Triassic)**—Equivalent to the Mount Ararat terrane of Graymer and Jones (1994). Interpreted as a deformed remnant of a

seamount and its underlying oceanic crust.

- YAAB Basalt and chert member**—Chaotic assemblage of chert, basalt, and diamictite. Chert has yielded radiolarians of Early Jurassic (Pleinsbachian to Toarcian) and Late Triassic (Norian) age.
- YAAM Serpentine-matrix mélange member (Early Jurassic(?) and Late Triassic)**—Serpentine-matrix mélange with blocks of chert, argillite, basalt, diabase, and gabbro with lesser amphibolite and mica schist. Chert blocks have yielded radiolarians of Early Jurassic(?) to Late Triassic (Sinemurian(?) to Norian) and Late Triassic (Norian) age.
- Cool Quarry complex (Permian)**—Equivalent to the Cool Quarry terrane of Graymer and Jones (1994). Interpreted as a deformed remnant of a seamount. Cool Quarry complex might be a giant olistolith in the Clipper Gap Formation (unit YACG), based on position at the contact between Clipper Gap Formation and Lake Combie complex (unit YALC) and the similarity between the marble member and marble blocks in the Clipper Gap Formation. However, the presence of serpentinite along the eastern boundary fault, probably derived from the Mount Ararat terrane to the south or the Lake Combie complex to the west and north, shows substantial deformation at the unit margin.
- YACM Marble member (Late Permian)**—Limestone and marble, locally fossiliferous; has yielded a trepostome bryozoan of Late Permian age.
- YACB Basalt member**—Greenstone (Greenschist facies metabasalt). Protolith includes pillow basalt, breccia, and tuff.
- YALO Lake Oroville olistostrome (Permian)**—A small unit along the western arm of Lake Oroville. Boulders and megaboulders (olistoliths) of Early Permian limestone in a slaty matrix of pebbly mudstone. Originally mapped as part of the Clipper Gap Formation (unit YACG), the sedimentary matrix of the unit has yielded Paleozoic fossils (Watkins and others, 1987), so this unit is much older than the Clipper Gap Formation. Limestone block fossils are correlative with the McCloud Limestone of the eastern Klamath Mountains (Watkins and others, 1987). This unit is comparable with the lower part of the western (Soda Ravine) block of unit NSST in the Northern Sierra terrane.

### *Slate Creek Terrane*

- YSSS Shingle Springs complex (Early Jurassic)**—Equivalent to the Bear Mountains ophiolitic mélange of Saleeby (1982). Mafic amphibolite-facies hornblende schist, probably metabasalt but entirely recrystallized. Locally includes gneiss and migmatite. Locally includes felsic metavolcanics as quartz-rich schist, metasedimentary rocks as mica-actinolite schist, pelitic phyllite and quartzite, metalimestone as calcite-chlorite schist and marble. Interleaved with serpentinite, serpentinite-matrix mélange, and metaserpentinite as cummingtonite-schist. Early Jurassic age is the metamorphic age, based on a hornblende K-Ar age of ~190 Ma (Behrman, 1977). Protolith age is uncertain, but a metaplagiogranite in an amphibolite block in serpentinite-matrix mélange has yielded a zircon U-Pb age of ~300 Ma (Saleeby, 1982). Interpreted by Saleeby (1982) to be dismembered and metamorphosed Paleozoic ophiolite. Locally divided into:
- YSSM Metasedimentary member**—Metasedimentary blocks and lenses in serpentinite-

matrix mélange.

- YSSG      **Gabbro member**—Gabbro blocks in serpentinite-matrix mélange.
- YSSU      **Ultramafic member**—Serpentinite-matrix mélange and serpentinite lenses within amphibolite.
- French Creek complex (Early Jurassic)**—Equivalent to the French Creek terrane of Graymer and Jones (1994). The French Creek complex is probably a dismembered ophiolite overlain by pelagic and island arc deposits. Minor relict blueschist metamorphism indicates subduction accretion prior to upper greenschist to amphibolite-facies metamorphism. Early Jurassic age is the metamorphic age, based on Ar-Ar ages of  $191.3 \pm 0.5$  Ma and  $189.4 \pm 0.7$  Ma from metamorphic hornblende taken from amphibolite-facies metamorphosed intermediate igneous rocks (Graymer, 1992). Protolith age unknown. Based on similar lithology, metamorphic grade, and age of metamorphism, French Creek complex is probably a fragment of the Shingle Springs complex (YSSS) isolated east of the Bear Mountains fault zone.
- YSFB      **Metabasalt member**—Upper greenschist- to amphibolite-facies metabasalt, well foliated to massive, possible relict pillow structure in one place. Locally interleaved with greenschist- to lower blueschist-facies mica-schist metatuff.
- YSFC      **Metachert member**—High-grade metachert in flat-lying contact with serpentinite and metabasalt.
- YSFS      **Serpentinite member**—Sheared serpentinite and serpentinite-matrix mélange.
- YSFV      **Metavolcanic and metasedimentary member**—Interleaved pelitic schist and hornblende-quartz schist of andesite protolith.
- YSSC      **Slate Creek Complex (Early Jurassic and Late Triassic, ~193-209 Ma)**—Tectonostratigraphic stack of mafic volcanic rocks, mafic to intermediate plutonic rocks, and serpentinite-matrix mélange. Felsic tuff from this unit has yielded a zircon U-Pb age of ~193 Ma (Saleeby and others, 1989b), whereas tonalite from this unit has zircon U-Pb ages of ~207 and ~209 Ma (Edelman and others, 1989). Hornblende K-Ar ages of ~148 Ma and ~162 Ma (Hietanen, 1981) and a hornblende Ar-Ar age of ~171 Ma (Fagan and others, 2001) are probably metamorphic ages (Edelman and others, 1989). The formally accepted age of this unit is Early Jurassic, but the radiometric ages of the diorite member (unit YSSCd) extend the age of this unit into Late Triassic. Locally divided into:
- YSSCI      **Marble member**—Two closely spaced large lenses of marble in the northern part of the complex.
- YSSCm      **Metasedimentary member**—Phyllite and slate, volcanoclastic sandstone and sedimentary breccia, quartzite, metachert, and metatuff.
- YSSCv      **Metavolcanic member**—Greenstone. Epidote-actinolite-albite. Breccia, pillow lava, bedded tuff, and volcanoclastic rocks.
- YSSCd      **Diorite member**—Hornblende-epidote-biotite-chlorite tonalite and diorite. Rocks from this unit have yielded zircon U-Pb ages of ~202-207 Ma (Saleeby and others, 1989b; Edelman and others, 1989; Day and Bickford, 2004).

- YSSCg **Gabbro member**—Amphibolite-facies hornblende meta-gabbro. Cumulate texture locally preserved near the base.
- YSSCu **Ultramafic member**—Serpentinite-matrix mélange, with blocks of amphibolite, plutonic rock, and volcanic rock like that of other members, and tectonized harzburgite, plus, quartzite (metachert?), argillite, and chert like that of the structurally underlying Clipper Gap Formation (unit YACG) (tectonically inmixed?).
- YSJO **Jarbo Gap ophiolite (Early Jurassic and Late Triassic, ~196-204 Ma)**—Ophiolitic mélange. Tectonized ultramafic, metagabbro, amphibolite, metavolcanic, and metasedimentary rocks. Serpentinite is commonly schistose but also includes serpentinized harzburgite and dunite with chromite-rich layers. Serpentinite and metagabbro intruded by multiple generations of mafic to felsic dikes; dikes folded. Subsequently overlain by mafic breccia, then intruded by plagiogranite and randomly oriented mafic dikes. A plagiogranite dike has yielded an age of ~196 Ma (Dilek, 1989). Metasedimentary rocks include phyllite and metachert. Metagabbro locally strongly foliated. Equivalent in part to ophiolite mélange member of Fiddle Creek Complex of Edelman and others (1989), but that designation is herein abandoned because the chert-argillite member of the Fiddle Creek Complex includes relatively unmetamorphosed rocks of the same age.
- YSJC **Metachert member**—Two large lenses of metachert mapped separately in the south part of the unit.
- YSJD **Metadiabase member**
- YSJG **Metagabbro member**—Layered gabbro, strongly foliated locally. Foliated gabbro intruded by deformed leucodiorite that has yielded a zircon U-Pb age of ~204 Ma (Dilek, 1989).
- YSJL **Marble member**—White to light-gray bedded marble.
- YSJS **Metasedimentary member**—Phyllite and metaquartzite.
- YSJV **Metavolcanic member**—In the north and south part of the unit, schistose metavolcanics. Protoliths include flow rock, tuff, epiclastic rock, and tuff breccia. Some pillow lavas; pillows deformed and stretched. In the central part of the unit, amphibolite and gneiss. Amphibolite foliation is overprinted by a crenulation cleavage.

### Sierra Crest Terrane

[This terrane includes the Goddard terrane of Nokleberg (1983). The early to late Jurassic volcanics of the terrane are part of the Goddard arc, a major volcanic arc overlap assemblage. The shallow-level intrusive rocks are intruded into both the Owens and Kings terranes, as well as older metavolcanic rocks of this terrane. The Triassic and earliest Jurassic parts of this terrane make up part of the High Sierra arc.]

- SCGG **Shallow-level metagranitic rocks, medium-level granodiorite and lesser diorite and gabbro (Late to Middle Jurassic, ~153-165 Ma)**—Chiefly shallow-level metagranitic rocks, medium-level granodiorite, and lesser diorite and gabbro. Occurs in the northwestern Ritter Range (granodiorite, diorite, and gabbro), western Goddard Range (granite, leucogranite, granodiorite, and ~157 Ma, zircon U-Pb, quartz syenite, Bateman, 1992), and eastern Oak Creek (gneissose and undeformed granodiorite and quartz monzonite,

mafic plutonic rock, and ~154-165 Ma zircon U-Pb, alaskitic quartz monzonite, Chen and Moore, 1982; Saleeby and others, 1990) roof pendants, as well as a small body near Taboose Pass (Red Mountain Creek pluton, alaskitic quartz monzonite, ~153 Ma zircon U-Pb, Chen and Moore, 1982), and as small bodies at the south end of the Goddard Range in the Marion Peak Quadrangle (sheared granodiorite) and on the South Fork of Bishop Creek (sheared granite with an apatite fission track age of ~83 Ma and a sphene fission track age of ~72 Ma, Naeser and Dodge, 1969). Also occurs between Sheep Ridge and Sequoia roof pendants (sheared and unsheared granodiorite and granite of Yucca Mountain, which has yielded zircon U-Pb age of ~162 Ma, Saleeby and Dunne, 2015) as well as a small body of sheared granodiorite to the northeast at Muir Grove. Unit intrudes approximately coeval metavolcanic rocks (unit SCGV) as well as the older Kings and Owens terranes. Terrane magmatically linked to Palisade Crest Intrusive Suite (unit Gpc).

**SCGV Older metavolcanic rocks (Late Jurassic to Late Triassic, ~150-233 Ma)**—Occurs in Ritter Range, Mount Goddard, and Oak Creek roof pendants. In the eastern Ritter Range roof pendant, highly varied unit composed of metamorphosed crystal-lithic tuff, metarhyolite to metabasalt pyroclastic units, tuff breccia, tuffaceous sandstone and siltstone, thin-layered calcareous tuffaceous rocks, marble, slate, rare conglomerate, and mafic flows and hypabyssal intrusives. Kistler and Swanson (1981) report two whole rock Rb-Sr isochron ages of ~185 Ma from the unit in this area, and Huber and Rinehart (1965) reported Early Jurassic pelecypod fossils. However, detailed studies by Barth and others (2018) and Attia and others (2020) reveal a pattern of zircon U-Pb ages ranging from ~152-233 Ma (plus one outlying age of ~101 Ma) that suggest tightly folded Triassic and Jurassic rocks, plus a narrow infolded layer of the overlying Cretaceous metavolcanics (unit SHKOV) too small to show at scale. In the western Ritter Range pendant, this unit is largely metamorphosed pyroclastic strata with interlayered flow rock and hypabyssal intrusives, with zircon U-Pb ages of ~150-158 Ma (plus an outlier age of ~102 Ma that indicates an infolded or infaulted body of the overlying Cretaceous metavolcanic rocks; Attia and others, 2020). In Mount Goddard and Oak Creek roof pendants, chiefly metamorphosed rhyolite to dacite ash-flow tuff, andesite, and basalt volcanoclastic rocks and flows. Local metaandesite and metabasalt flows, and local thin layers of pelitic schist, calc hornfels, and minor quartzite. In the Oak Creek pendant, this unit has yielded zircon U-Pb ages of ~165-166 Ma (Saleeby and others, 1990), whereas in the Goddard roof pendant ages are ~131-159 Ma (Chen and Moore, 1979; Tobisch and others, 1986). This unit also crops out in the Alabama Hills, where it is locally schistose metatuff, meta-volcanogenic sedimentary rocks, and lesser meta-volcanic flow rock, which has yielded minimum U-Pb ages of ~167 Ma and ~170 Ma (Dunne and Walker, 1993; Dunne and others, 1998), along with small bodies of similar metatuff to the west along the east edge of the Mount Whitney 15' Quadrangle, near Mount Bago in the southwestern part of the Mount Pinchot 15' Quadrangle, and to the south at Braley Creek in the Olancho 15' Quadrangle.

Unit is highly metamorphosed and multiply deformed with minor and major isoclinal folds. Locally contains narrow bands of mylonite schist. Unit is broadly coeval with metavolcanic rocks of High Sierra terrane but contains quite different stratigraphy. Unit faulted against High Sierra terrane to east along Gem Lake fault (Gem Lake shear zone of Green and Schweickert, 1995). Also faulted against the Owens terrane to east, though note

that unit SCGG intrudes the Owens terrane in the Oak Creek pendant. Unit stratigraphically underlies Monarch arc (unit SHKOV, SHKOG, Gmw, and Gbvc) that is only weakly schistose with primary textures predominant. The Early to Late Jurassic part of this unit is magmatically linked to roughly coeval shallow intrusive rocks (unit SCGG) and the Palisade Crest Intrusive Suite (unit Gpc), which, together with coeval rocks in the High Sierra terrane (unit HSV) make up the Goddard arc. Triassic and earliest Jurassic rocks in this unit, along with coeval rocks in the High Sierra (unit HSV) and Twin Lakes (unit TL) terranes and the Scheelite Intrusive Suite, make up the High Sierra arc

## Northern Sierra Terrane

[The Northern Sierra terrane is interpreted as an allochthonous fragment accreted to the western margin of the North American plate. The terrane formed outboard of the North American miogeocline.]

**NSTT Tuttle Lake Formation and upper Lake Tahoe sequence (Cretaceous and Late to Early Jurassic)**—Harwood (1988, 1992) mapped the Tuttle Lake Formation northwest of Lake Tahoe. It is chiefly andesite tuff breccia, tuff, and minor volcanoclastic sandstone, unconformably overlying the Sailor Canyon Formation (part of unit NSTS). John and others (1994) reported a whole-rock Rb-Sr isochron age of ~165 Ma from hypabyssal plagioclase-porphphyry breccia in this formation. Harwood (1992) reports a late Early through Middle Jurassic pelecypod in a volcanoclastic siltstone interbed at English Mountain, the northernmost body of this unit. Fisher (1989) mapped the Tuttle Lake Formation at the Mount Tallac roof pendant, southwest of Lake Tahoe. There it is composed of diamictite and conglomerate overlain by intermediate to mafic hypabyssal and extrusive breccia, lava flow rock, and tuffaceous sandstone.

West of Lake Tahoe, Harwood (1988, 1992) mapped the Lake Tahoe sequence, the upper part of which is roughly coeval with the Tuttle Lake Formation. The upper Lake Tahoe sequence is mostly sedimentary, made up of slate, limestone, and volcanoclastic sandstone debris-flow deposits overlain by quartz arenite and calcareous pelite with local volcanoclastic sandstone. Ammonite fossils from the debris-flow deposits are suggestive of Early Jurassic deposition (Harwood, 1992). Christe and others (2018) report a detrital zircon MDA of ~177 Ma for a quartz sandstone in this unit.

East of Lake Tahoe (Genoa Peak pendant), this unit includes the mafic metavolcanic and minor metaclastic rocks of the Peavine sequence, which has a zircon U-Pb age of ~163 Ma, the metaconglomerate, meta-arenite, and slate of the South Camp sequence with a detrital zircon MDA of ~142 Ma, and the overlying tuff breccia of Genoa Peak (Christe and Schweickert, 2020). This unit also includes the type Peavine Peak sequence mapped northwest of Reno, composed predominantly of mafic to intermediate, locally felsic, flow rock, ignimbrite, breccia, and tuff with subordinate volcanoclastic sedimentary rocks. Godwin (1958) reported Jurassic(?) plant fossils from this area. Garside (1998) reported whole-rock Rb-Sr ages of ~167 Ma and ~117 Ma. Garside noted the younger age is roughly equivalent to the intruding plutonic units (e.g. unit Glkt), though somewhat older than the closest dated intruding pluton at the head of Long Valley Creek (~97 Ma; Langenheim and others, 2025).

Fisher (1989) notes that mafic to intermediate plutonic rocks in the partly coeval Tuttle intrusive complex (unit Gtt) are the same lithology as dikes and hypabyssal rocks

within the Tuttle Lake Formation in the Mount Tallac pendant. Similarly, Howell (1998) noted that the older part of the Emigrant Gap intrusive suite (Black Butte quartz monzonite) was coeval with and equally deformed as this unit and suggested it might be part of the magmatic source for the volcanic rocks. These observations suggest that the lower part of this unit forms the volcanic part of the Tuttle arc that includes the older part of the Tuttle Intrusive Sequence (unit Gtt) and Emigrant Gap intrusive suite granitic unit (unit Gegg). Christe (2010) suggests a correlation of the Middle Jurassic Peavine sequence and Tuttle Lake Formation of this unit with coeval volcanic rocks in the Kettle Rock terrane (unit KR) and marine volcanic rocks of Walker Lake terrane (unit WLV), and suggests they form a Middle Jurassic overlap assemblage linking the three terranes at that time.

**NSST Volcanic and sedimentary rocks (Jurassic, Triassic, and Permian)**—This unit crops out in the northwestern part of Northern Sierra terrane. This unit is composed of three fault bounded blocks, a northern block where this unit overlies Paleozoic rocks questionably assigned to the Taylor Formation (part of the Taylorsville sequence in unit NSSB), and two southern blocks composed of Permian to Jurassic rocks of this unit.

The northern block (Butt Valley block of Jayko, 1990) is bounded on the west by the western block of this unit and on the east by rocks of the Shoo Fly Complex. In this block, the unit is composed of a basal conglomerate and sandstone overlain by a thin discontinuous limestone overlain by a thick sequence of volcanoclastic sandstone, argillite, and conglomerate with minor tuff and andesite sills/dikes. The basal conglomerate has yielded late Carnian to Norian conodonts (Jayko, 1988), the limestone (called Hosselkus Limestone by Jayko, 1990) has yielded Late Triassic (Norian) conodonts, and black slate in the upper unit has yielded probably Early Jurassic pelecypods (Jayko, 1990; Harwood, 1992), although Christe (2021b) states that this block includes marine strata as young as Late Jurassic (Oxfordian).

The western block (Soda Ravine block of Jayko, 1990) is bounded on the west by the Feather River peridotite belt, and south of the northern block on the east by rocks of the Shoo Fly Complex along with a lens of serpentinized peridotite. In this block, the unit is composed of slate, chert pebble conglomerate, and sandstone with intercalated limestone lenses. Limestone blocks crop out at two levels. The lower limestones have yielded Pennsylvanian to Early Permian conodonts and Early Permian fusulinids of McCloud affinity, whereas the upper limestones have yielded Middle to Late Triassic (Ladinian to Norian) conodonts, ammonites, and other fossils (Jayko, 1990; Harwood, 1992). Jayko (1990) calls the Norian limestones Hosselkus Limestone, as in the northern block. The sedimentary rocks structurally above the Paleozoic limestones are interlayered with quartz-, hornblende-, and plagioclase-porphphyry flows, dikes and sills, along with a small stock (including the Humbug intrusives of Robinson, 1975). Jayko (1990) suggests that these are Triassic, because they are interleaved with the Hosselkus Limestone blocks, but Christe (2021b) describes zircon U-Pb ages spanning the late Aalenian through late Pliensbachian (Early to early Middle Jurassic), averaging ~178 Ma from the Humbug intrusives. As such, if the interleaved lava flows are related to the dated intrusives, the Hosselkus Limestone blocks are probably olistoliths in a Jurassic olistostrome. On the other hand, Christe (2021b) states that the Humbug intrusives lack the foliation of the surrounding metasedimentary rocks, so the metasedimentary and

interleaved flow rocks could be older. The uppermost rocks in this block, east of the Triassic limestone, are a thick sequence of slate and phyllite with lesser sandstone and siltstone. These rocks must be Middle Jurassic or younger based on their stratigraphic position over the Humbug intrusives.

The southeastern block is a relatively narrow sliver bounded on all sides by Shoo Fly Complex. No fossils are reported from this sliver, but Harwood (1992) questionably correlates the rocks in this block with the western block based on the mapping of Standlee (1978).

Jayko (1990) builds on the McCloud affinity of the Paleozoic limestones to suggest that the rocks of the western block (and presumably the southeastern block) correlate with some, though not all, of the units in the Eastern Klamath terrane. Because the stratigraphic section is disrupted and incomplete, she interprets the block tentatively as an attenuated tectonic sliver of the Eastern Klamath terrane structurally emplaced along the west side of the Northern Sierra terrane. However, the Early to Middle Jurassic Humbug intrusives and overlying metasedimentary rocks are not like rocks in the Eastern Klamath terrane and preclude many of the correlations proposed by Jayko (1990). Mesozoic rocks in the northern block rest unconformably on Paleozoic rocks of the Northern Sierra terrane, but Jayko maps the Norian limestone as the same (Eastern Klamath) unit, Hosselkus Limestone, suggesting that the limestone was deposited across both Eastern Klamath and Northern Sierra terrane basement, or perhaps that the limestone bodies in this unit are olistoliths shed from the Eastern Klamath terrane onto basement of the Northern Sierra terrane. Christe (2021b) points out that rocks of this unit are not like coeval rocks in other parts of the Northern Sierra terrane (units NSTT and NSTS). We assign this unit to the Northern Sierra terrane largely based on the mapped depositional contact on rocks of another unit in the terrane. The differences are perhaps the result of differences in depositional and volcanic setting across the large extent of the terrane.

## NSTS

### **Sailor Canyon Formation and associated units (Middle Jurassic to Late**

**Triassic)**—In the type area northwest of Lake Tahoe, the Sailor Canyon Formation is chiefly black slate, volcanoclastic sandstone, tuff, siltstone, and minor limestone. Fossils here range from late Sinemurian ammonites near the base to early Bajocian ammonites near the top (Clark and others, 1962; Imlay, 1968; Harwood, 1992). In the Mount Tallac roof pendant, it is made up of marine sedimentary rock; tuffaceous sandstone overlying feldspathic sandstone overlying quartzose sandstone, with a basal unit of laminated sandstone, siltstone, and calcarenite. The basal unit here contains probable late Pleinsbachian ammonites (Fisher, 1989). This part of the unit extends southeast to the roof pendants near Hope Valley, which are made up of metamorphosed graywacke, calcareous sandstone and siltstone, limestone, and andesite flows and tuffs (Armin and others, 1984).

The Sailor Canyon Formation is underlain in the type area northwest of Lake Tahoe by a relatively thin unit of conglomerate overlain by limestone and limestone breccia overlain by volcanoclastic sandstone, tuff, and andesite lapilli tuff, which pinch out to the north, and are in turn overlain by sandstone and conglomerate (the Big Valley sequence of Christe and others, 2018). The basal conglomerate lies in angular unconformity on the underlying Paleozoic rocks, and clasts in the basal conglomerate reflect local detritus derived from them.

The limestone has yielded late Carnian through Norian conodonts (Harwood, 1983), whereas the uppermost sandstone unit has yielded a detrital zircon MDA of ~187 Ma (Christe and others, 2018). This entire sequence pinches out to the north, and the Sailor Canyon Formation rests directly on Paleozoic rocks north of the Emigrant Gap intrusive complex.

East of Talbot fault, correlative units in the Lake Tahoe sequence (Harwood, 1992) are the Early Jurassic Blackwood Creek Formation and the gradationally overlying Ellis Peak Formation, but these are too small to depict on this compilation and are included in the Tuttle Lake Formation and upper Lake Tahoe sequence (unit NSTT).

The formally accepted age of this unit is Early and Middle Jurassic, but we extend the age range to Late Triassic based on ages of conglomerate and limestone units described above.

**NSRO Permian volcanic sequence (early Late Permian to late Early Permian)**—Consists chiefly of Arlington Formation (volcaniclastic sandstone, slate, conglomerate, and breccia), which locally grades up into the Goodhue Formation (pillow basalt, basaltic tuff breccia, and tuff). These two formations, together with the locally overlying Reeve Formation (plagioclase-rich andesitic tuff, flows, and hypabyssal intrusive rocks, and lesser volcaniclastic sandstone, chert, and conglomerate) and Robinson Formation (volcaniclastic conglomerate, sandstone, shale, and minor limestone) make up the Permian volcanic arc sequence (Harwood, 1992). Unit occurs in various thrust-fault bounded slices, with the older parts of the unit only cropping out in the northern blocks, the Arlington Formation pinching out north of the Middle Fork Feather River, and the Goodhue Formation pinching out near the North Yuba River. Between the Middle Fork Feather River and the American River area northwest of Lake Tahoe, the unit consists of only the Reeve and Robinson Formations, and is unconformably overlain by the Sailor Canyon Formation and associated units (unit NSTS) along a Permian to Triassic unconformity. The base of the Arlington Formation has yielded late Early Permian (early Leonardian [Kungurian]) conodonts and other fossils in the northwestern block, and a sliver of the formation has yielded probable equivalent age fossils in the northeastern block along the basal contact with the underlying Carboniferous rocks (Harwood, 1992). The Goodhue Formation lacks fossils or other internal age control. In the northernmost block, the Reeve Formation has yielded Early Permian (Leonardian) radiolarians and other fossils of similar age, in the northeastern block late Early Permian (early Leonardian) McCloud affinity fusulinids along with other late Early Permian and early Late Permian fossils, south of the Middle Yuba River late Early Permian (middle to late Leonardian) fossils, in the southernmost block late Early Permian or early Late Permian (Leonardian or Roadian-Wordian) fossils (Harwood, 1992). Spurlin and others (2000) collected detrital zircons from sandstone in the block south of the Middle Yuba River that they correlated with the Arlington Formation, but fossils found nearby are too young to support that correlation. Detrital zircons have an MDA of ~357 Ma (earliest Mississippian), much too old to represent the depositional age of the unit, and probably reflective of redeposition of detritus derived from underlying units. In the northeastern block, the Robinson Formation has yielded early Late Permian (Wordian to Capitanian) conodonts (Harwood, 1992).

**NSSB Taylorsville sequence and lower Lake Tahoe sequence (Pennsylvanian to Late**

**Devonian**)—Consists mainly of: (1) Devonian Grizzly Formation (conglomerate, sandstone, slate, and minor chert and limestone), gradationally overlain by (2) Devonian Sierra Buttes Formation (quartz-rich felsic tuff, tuff breccia, and minor rhyolite, dacite, and andesite intrusive rocks); (3) Mississippian Taylor Formation (andesite flows, tuff breccia, tuff, and tuffaceous turbidites); and (4) Mississippian and Pennsylvanian Peale Formation (chert and minor siliceous argillite, felsic tuff, tuff breccia, flows, and volcanoclastic sandstone and siltstone, and basalt, latite, rhyolite volcanic, and volcanoclastic rocks). These units crop out in several structural blocks between the northern margin of the Sierra Nevada and the Middle Fork American River. East of Talbot fault, this unit (locally named the Lake Tahoe sequence) includes (1) Devonian and Mississippian Picayune Valley (black slate, quartzite, chert-clast conglomerate, limestone, felsic tuff, felsic lahar deposits, and andesitic tuff breccia), (2) Mississippian or younger Serena Creek (recrystallized ribbon chert and minor black siliceous argillite), and (3) Mississippian(?) or younger(?) Onion Creek (limestone, quartzite, and calc-silicate rock) Formations (Harwood, 1992; Harmon, 2015).

In the northwesternmost block (Butt Valley block of Jayko, 1990), this unit lacks geochronologic control but is composed of pyroxene-bearing metaandesite assigned to the Taylor Formation (D’Allura and others, 1977), unconformably overlain by Triassic and Jurassic strata (part of unit NSST). The base of the unit there is faulted.

Farther east, the full sequence unconformably overlies (and is intruded by) Devonian plutonic rocks (unit Gsb) and the Shoo Fly Complex (unit NSSA), and is in turn unconformably overlain by the Permian volcanic sequence (unit NSRO), although the Grizzly Formation is limited in extent and missing at the base of the sequence in many areas. The Grizzly Formation north of the North Yuba River has yielded Frasnian (early Late Devonian) corals and gastropods and middle Famennian conodonts, which are also found on the Middle Yuba River (Hanson and Schweickert, 1986; Harwood, 1992). Conodonts from a limestone clast in the Grizzly Formation are the same genera as those in the underlying Sierra City *mélange* of the Shoo Fly Complex, supporting the idea that detritus in this part of the unit was sourced from the underlying rocks. The overlying Sierra Buttes Formation (which includes the Elwell Formation of Durrell and D’Allura, 1977) near Taylorsville has yielded Frasnian to Famennian (Late Devonian) radiolarians from chert low in the section, with similar radiolarians along with middle Famennian ammonites higher in the section near Gold Lake and Bowman Lake (Harwood, 1992). The Taylor Formation lacks internal age control, but the age is tightly constrained by the age of the units above and below. It is conformably overlain by the volcanic lower member of the Peale Formation, which has yielded late Kinderhookian (middle Tournasian, middle Early Mississippian) conodonts from limestone lenses in tuff south of Genesee and near Frazier Falls (Harwood, 1992). The upper chert member, which gradationally overlies the volcanic member locally, has yielded radiolarian assemblages that range from late Osagean (early Viséan, early Middle Mississippian) to Desmoinesian (early Moscovian, early Middle Pennsylvanian) throughout the outcrop area of the unit from the northernmost block east of Lake Almanor to the southernmost block west of Big Valley (Harwood, 1992).

West of Lake Tahoe this unit also includes the lower part of Lake Tahoe sequence of Harwood (1988). The Picayune Valley Formation at the base of the unit has yielded only

echinoderm fragments suggestive of a Late Silurian to Late Devonian age (Harwood, 1992). This formation is mapped as unconformably overlying the Shoo Fly Complex, and on Five Lakes Creek as interfingering with and overlying the Late Devonian Sierra Buttes Formation (Harwood and others, 2014), so it must be Late Devonian as well. The Picayune Valley Formation is gradationally overlain by the Serena Creek Formation. No fossils have been found in the Serena Creek Formation, but it may correlate with the chert member of the Early Mississippian to Early Pennsylvanian Peale Formation (Harwood and others, 2014). The Serena Creek Formation is gradationally overlain by the Onion Creek Formation. Quartzite near the base of the Onion Creek Formation has yielded a bivalve shell fragment suggestive of a nucleosporid brachiopod, which ranges in age from Late Silurian to Mississippian. If the fossil is indeed a nucleosporid, that would mean the age of the Onion Creek Formation would be Mississippian, given the age and correlation of underlying units.

Devonian volcanic members of this unit are coeval with, and intrusively linked to, the Devonian part of the Sierra Buttes intrusive suite (unit Gsb), together comprising the Sierra Buttes arc. The Sierra Buttes Formation is locally cut by hypabyssal intrusions, mainly basaltic andesite to rhyolite and exhibit evidence of interaction with wet, unconsolidated sediments beneath the seafloor (Hanson and others, 1996).

NSSM

**Shoo Fly Complex, Sierra City *mélange* (earliest Late to latest Early**

**Devonian)**—Composed chiefly of disrupted blocks of serpentinite, gabbro, pillowed and massive basalt, chert, sandstone, pebbly mudstone, limestone breccia, and bioclastic limestone in a sheared matrix of slate, sandstone, and chert. A wide variety of sedimentary clasts occur in the *mélange*, including subarkose and quartz-rich sandstone, conglomeratic mudstone with volcanic clasts, pebbly mudstone, and chert. Blocks of limestone in the *mélange* have yielded Late Ordovician and Middle to Late Ordovician conodonts and Late Ordovician corals and brachiopods (Harwood, 1992). A chert block has yielded Ordovician to Silurian radiolarians (Varga and Moores, 1982). A tuff in the *mélange* matrix has yielded a zircon U-Pb age of ~423 Ma (Late Silurian; Saleeby and others, 1987). A sandstone block in the *mélange* has a detrital zircon MDA of ~395 Ma (Grove and others, 2008) which provides a maximum age for the formation of the *mélange*. The *mélange* is unconformably overlain by the Late Devonian Grizzly and Sierra Buttes Formations (part of unit NSSB) and intruded by ~358-369 Ma hypabyssal volcanic rocks (Powerman and others, 2020), so formed prior to deposition and emplacement of those rocks. The Sierra City *mélange* is truncated southward by the downcutting unconformity and is not present south of Bowman Lake.

This unit is interpreted as part of a subduction complex (Girty and Pardini, 1987) that formed in the Devonian, perhaps at the same subduction zone related to the unconformably overlying and intruding Sierra Buttes arc (units NSSB and Gsb). The *mélange* occurs east of, and structurally overlies, the coherent units of the Shoo Fly Complex (unit NSSA).

NSSA

**Shoo Fly Complex, coherent units (Ordovician to Middle Devonian)**—Unit

consists of three regionally extensive thrust blocks: the Lang sequence, and the Duncan Peak and Culbertson Lake allochthons. At the base of the unit, the Lang sequence is chiefly interbedded quartz arenite and pelite with scattered lenses and beds of chert and limestone. Locally the sequence is mapped with subunits of breccia; pelite, breccia, and conglomerate; interbedded quartzite and pelite with minor limestone and chert; and thick-bedded quartzite.

A lens of limestone in slate and quartzite in the middle of the Lang sequence near Bluenose Mountain west of Mohawk Valley has yielded middle Middle to Late Ordovician conodonts (Harwood, 1992). Relict radiolarians are found locally throughout the unit but are not preserved enough to provide significant age control (Girty and others, 1996), although the presence of radiolarians, which are uncommon in the Cambrian, suggests an age of Ordovician or younger. This unit is intruded by, and therefore predates, the latest Middle to Late Devonian metaplutonic rocks of the Sierra Buttes intrusive complex (unit Gsb).

The Duncan Peak allochthon, which structurally overlies the Lang sequence on an east-dipping thrust fault, is composed chiefly of chert locally interlayered with chert breccia, and black siliceous argillite. This unit lacks good internal age control. Poorly preserved radiolarians are present, suggesting an age of Ordovician or younger, and the unit is intruded by the ~353-380 Ma (earliest Mississippian to early Late Devonian) Bowman Lake batholith (part of unit Gsb), so the Duncan Peak is considered roughly the same age as the similarly situated units structurally above and below.

The uppermost thrust block comprises the Culbertson Lake allochthon, which overlies the Duncan Peak allochthon in the south, but rests directly on the Lang sequence in the north. The Culbertson Lake allochthon is composed of a lower sequence of pillow basalt and basaltic breccia interlayered with chert and overlain by limestone, chert, and argillite. Lower sequence interpreted as intraplate seamount (Girty, 1983). Upper sequence chiefly subarkosic and quartz-rich sandstone interpreted as a submarine fan complex. Unit deformed into west-verging tight to isoclinal folds. This unit also lacks good internal age control, although a chert bed yielded spheroidal radiolarians with simple spines characteristic of early Paleozoic forms (probably Ordovician because radiolarians are rare in the Cambrian; D.L. Jones in Girty and Wardlaw, 1985).

The three structural blocks were tectonically assembled before Late Devonian, prior to intrusion of the Bowman Lake batholith. Unit structurally overlays Shoo Fly Complex - marine sedimentary rocks (unit NSSF).

**NSSF Shoo Fly Complex, marine sedimentary rocks (Devonian to Silurian)**—Mapped south of Highway 50, in central and southern Sierra Nevada. A southward extension of the Antoine Canyon Formation (Harwood, 1992). Chiefly quartzite and schist (metapelite), with lesser marble, calc-silicate rock, and amphibolite. Unit intruded by Early and Middle Jurassic Don Pedro intrusive suite (unit Gdp) and the southern plutons of the Sierra Buttes intrusive complex (unit Gsb) with preliminary dates as old as ~370 Ma (Merguerian and Schweickert, 1987). Unit structurally overlain by Shoo Fly Complex – coherent units (unit NSSA). Harwood (1992) has the Antoine Canyon Formation depositionally overlain by the other members of the Shoo Fly Complex.

Samples with Jurassic detrital zircon MDA ages may be from fault-bounded or infolded younger units originally overlying the Shoo Fly Complex. This unit is bounded on the west by Calaveras-Shoo Fly thrust and on the east by plutonic rocks of several igneous complexes. This unit may correlate with Kernville terrane (unit KE) in southern Sierra Nevada.

## Walker Lake Terrane

[This unit is roughly the same as the western part of the Pine Nut terrane of Stewart (1997) and the Pine Nut assemblage of the Walker Lake terrane of Crafford (2007). Occurs in west-central Nevada and the eastern Sierra Nevada.]

**WLV**     **Marine volcanic rocks (Early Cretaceous to Late Triassic)**—Chiefly greenschist-facies metamorphosed andesite breccias and lava flows, tuff breccia, and ash-flow tuff, and lesser limestone, siltstone, and argillite. Unit locally includes metamorphosed rhyolite flows, breccia, tuff, and volcanogenic sedimentary rocks. Local phyllite, volcanoclastic sedimentary rocks, quartz arenite; slate, limestone. Unit includes Late Jurassic and Early Cretaceous volcanic and volcanoclastic Double Spring Formation, Early Jurassic clastic sedimentary Preachers Formation, Jurassic metavolcanic rocks of Hot Springs Mountain, and Late Triassic and Early Jurassic Gardnerville Formation (siltstone and volcanic conglomerate) at the base in west-central Nevada. Moderately to strongly schistose. Penetrative schistosity locally grades into slaty cleavage. Most of unit metamorphosed to greenschist facies and locally to amphibolite-facies near intrusive contacts.

Includes Middle Jurassic Gold Bug (flow rock over welded tuff) and Veta Grande (volcanic and volcanoclastic rock) Formations (Wyld and Wright, 1993) locally between the Preachers and Double Spring Formations. The Gold Bug and Veta Grande Formations have zircon U-Pb ages of ~162-170 Ma (Wyld and Wright, 1993).

East of Carson City, intruded by the Mount Siegel pluton, which has Pb-Pb age of ~166 Ma (Wooden and others, 1999).

Age diagnostic fossils from the Gardnerville Formation in this unit include: In Topaz Lake 15' Quadrangle, late early Toarcian to late late Toarcian fossils from Holbrook Junction area (R.W. Imlay in Silberling, 1984); in the Desert Creek Peak 15' Quadrangle, probably Triassic ammonites and Halobia in Risue Canyon (Halsey, 1953); in the Mount Siegel 15' Quadrangle, Late Toarcian fossils near Buffalo Canyon (Silberling, 1984); just east of the map area in Dayton 15' Quadrangle, Late Triassic and Early Jurassic fossils from argillite (equivalent to Gardnerville Formation according to Bingler, 1977) west of Sand Canyon (Stewart, 1997). Sparse fossils of Late Jurassic to Early Cretaceous age have been found in the Double Spring Formation (Noble, 1962).

Unit magmatically linked to the Walker Lake intrusive suite (unit Gwa). Christe (2010) further notes differences with the Middle Jurassic volcanic rocks of the Tuttle Lake Formation in the Northern Sierra terrane (part of unit NSTT) to the west and suggests they were formed well apart.

**WLS**     **Deep-marine sedimentary rocks (Late Triassic)**—Chiefly Late Triassic basinal-marine carbonate rocks with interbeds of sedimentary and volcanic rocks. In the Pine Nut Mountains east of the map area, the base of this unit is Early(?) to Late Triassic felsic volcanic rocks. Late Triassic rocks are chert, phyllite, shale, minor carbonate, volcanogenic sedimentary rocks, limestone, quartzite, marl, chert, argillite, slate, quartzite, chert conglomerate, limestone, andesite tuff, tuff breccia.

The age of this unit is constrained by fossils. In the Mount Siegel 15' Quadrangle, early late Norian and late early Norian fossils from the Oreana Peak Formation near Buffalo

Canyon (Silberling, 1984). In the Desert Creek Peak 15' Quadrangle, late Karnian to earliest Norian fossils in limestone at the northwest end of Pine Grove Hills, east of the map area (Silberling, 1984). In the Topaz Lake 15' Quadrangle a Late Triassic *Septocardia*(?) fossil in the Oreana Peak Formation (isolated exposure too small to show) near Holbrook Junction (Silberling, 1984). Just east of the map area in the Dayton 15' Quadrangle, early late Norian fossil from marble in Sand Canyon, and a questionable fossil of possible Late Triassic age from marble at Brunswick site (Stewart, 1997).

## High Sierra Terrane

[Terrane faulted against the Owens terrane to east. Faulted against the Sierra crest terrane to west along the Gem Lake fault (Gem Lake shear zone) of Green and Schweickert (1995). Terrane may correlate with the coeval and stratigraphically similar Walker Lake terrane to north.]

**HSV High Sierra terrane, volcanic and sedimentary rocks, and small, shallow-level granitic plutons (Cretaceous to Triassic (Pennsylvanian(?)))**—Occurs in the east-central Sierra Nevada in the Saddlebag Lake, Tioga Pass, eastern Ritter Range, western Mount Morrison, and adjacent roof pendants. Chiefly conglomerate, sandstone, rhyodacite ash-flow tuff, andesite, tuff breccia, volcanic conglomerate, and local basalt. Mostly subaerial deposition with local marine deposition. Named as Koip sequence (Kistler, 1966) and Virginia Lakes sequence (Chesterman, 1975) but further divided by Paterson and Memeti (2014), Schweickert and Lahren (2006), and Attia and others (2021) into the unconformably separated Cretaceous Cinko Lake, Jurassic Shadow Creek and Sawmill Canyon, and Triassic Koip sequences. Unit includes local shallow intrusive bodies ranging from quartz diorite, andesite porphyry, diorite, and dacite breccia. Unit includes Triassic-Jurassic silicic ash-flow tuff and andesite flow, sandstone, and local conglomerate on Mount Unit named the Dana sequence, which has yielded zircon U-Pb ages of ~195, ~213, and questionably ~222 Ma (Kistler, 1966; Ardill and others, 2020). Faulted against the Owens terrane to east. Faulted against the Goddard unit to the west along the Gem Lake fault (Gem Lake shear zone of Green and Schweickert (1995). Unconformably overlies unit HSS.

In the northwesternmost part of the unit, the Cinko Lake pendant is made up of thin-bedded quartzite and metasilstone with lesser dolomite, amphibolite, and hornblende gneiss. The quartzite has yielded a detrital zircon MDA of ~145 Ma (Memeti and others, 2010). Just to the east, the Piute Meadow pendant is composed of felsic to mafic metatuff, with local flow rock, volcanoclastic, and metasedimentary interbeds. The metavolcanic rocks have yielded detrital zircon MDAs of ~103, ~104, and ~108 Ma (Memeti and others, 2010), and are probably part of unit SHKOV but too small to map separately. Stanback (2018) also maps coeval hypabyssal intrusives that are probably part of unit SHKOG but too small to show at scale as well. Metasediment about 3 km farther east in the same pendant has a detrital zircon MDA of ~136 Ma, which Attia and others (2021) assign to their sedimentary Cinko Lake sequence. Previous studies (Keith and Seitz, 1981; Wahrhaftig, 2000) mapped that area as metavolcanic, however, so the sample is either from a metasedimentary bed within the larger metavolcanic sequence (suggesting the sample better belongs to the younger volcanics) or is from a small unrecognized window of older metasediments beneath the metavolcanics. A few kilometers to the east, in the same pendant in the Matterhorn Peak 15' Quadrangle, Chesterman (1975) mapped the Virginia Lakes sequence of interbedded rhyolite to basalt

metavolcanics and mostly hornfels metasedimentary rocks including metaconglomerate and marble. Attia and others (2021) reports detrital zircon MDAs of ~154 and ~162 Ma from metasediments of this sequence, which they assign to their Shadow Creek sequence. They further report metasedimentary rocks from within an area mapped as metavolcanics with a detrital zircon MDA of ~230 Ma, which they assign to the volcanic lower part of their Koip sequence. Still farther east in the same pendant, Cao (2016) reports detrital zircon MDAs of ~320, ~335, ~340, and ~420 Ma from metavolcanic rocks, and ~430 Ma from metasedimentary rocks. If these MDAs reflect the depositional age of these rocks, then the rocks of the Virginia Lakes sequence spans from earliest Cretaceous to Silurian, though Attia and others (2018) suggest that a Late Devonian to Early Permian age is more likely representative of the actual depositional age. South of Twin Lakes in the Virginia Lakes sequence of Chesterman (1975) in the Saddlebag Lake pendant, Attia and others (2021) and Cao and others (2015) report volcanic zircon U-Pb ages of ~220 Ma, and detrital zircon MDAs of ~186, ~187, ~221, and ~225 Ma. Cao and others (2015) divide these rocks into a Triassic mostly volcanic Koip sequence on the east with a Jurassic mostly sedimentary Sawmill Canyon sequence in fault contact on the west. Farther south, around Saddlebag Lake, Schweickert and Lahren (2006) report volcanic zircon U-Pb ages of ~211 and ~222 Ma. They further report the presence of caldera deposits related to the ~222 Ma volcanics (tuff) marking a Late Triassic eruptive center near Tioga Pass. In the same area, Barth and others (2011) report volcanic zircon U-Pb ages of ~219, ~224, and ~232 Ma, and Attia and others (2021) report detrital zircon MDAs of ~163, ~171, ~191, ~212, and ~247 which they assign to their Shadow Creek and Koip sequences. From the Tioga Pass area just to the south, Ardill and others (2020) report volcanic zircon U-Pb ages of ~220 and ~230 Ma and detrital zircon MDAs of ~217 and two of ~220 Ma.

The Triassic and earliest Jurassic part of this unit, along with coeval parts of the Sierra Crest (unit SCGV) and Twin Lakes (unit TL) terranes and the Scheelite Intrusive Suite, make up the High Sierra arc. The Early to Late Jurassic part of this unit, along with coeval parts of the Sierra Crest terrane (units SCGV and SCGG) and the Palisade Crest Intrusive Suite (unit Gpc) make up the Goddard arc.

## HSS

**High Sierra terrane, oceanic and continental-rise sedimentary and volcanic rocks (Late Triassic(?) to Mississippian(?) (Silurian(?)))**—Occurs in the Paiute Meadows, Saddlebag Lake, Mount Dana, and Ritter Range roof pendants. In the Saddlebag Lake and Mount Dana roof pendants, unit consists of highly deformed and thrust-imbricated deep-marine to continental-rise rocks. Major lithologies are chert, phyllite, siltstone, quartzite, conglomerate, arkosic sandstone, minor limestone, local volcanoclastic sandstone, and pillow basalt. In the eastern Ritter Range pendant, unit consists of a highly-deformed sequence of black chert, siliceous argillite and slate, and minor calc-silicate hornfels. Unconformably overlain by unit HSV. In the Ritter Range pendant, unit is named the chert-argillite unit (Green and others, 1997). In the Mount Dana and Saddlebag Lake roof pendants, unit is named the Lewis sequence (Kistler, 1966). In the Saddlebag Lake pendant, unit is correlated by Schweickert and Lahren (1993, 2006) with the Candelaria, Diablo, and Palmetto Formations in the Roberts Mountain allochthon. This correlation is precluded by late Paleozoic fossils (Brook and others, 1979) and Late Triassic detrital zircon MDAs. The

upper part of this unit may correlate with the coeval and stratigraphically similar Late Triassic sedimentary member of the Walker Lake terrane (unit WLS) to the north.

In the easternmost Paiute Meadows pendant, Chesterman (1975) mapped this unit as interleaved metavolcanics and metasediments of the Virginia Lakes sequence, along with serpentinite and diorite. Cao (2016) reports a detrital zircon MDA of ~355 Ma from these rocks. In the Saddlebag Lake pendant, Brook and others (1979) report a fossil assemblage from marble interbedded in chert suggestive of a Mississippian age. Farther south, near Tioga Pass, Ardill and others (2020) report a detrital zircon MDA of ~435 Ma (Silurian) from metachert-argillite of this unit. In the Ritter Range pendant, Attia and others (2020) report zircon U-Pb ages of ~216 and ~233 Ma from hypabyssal volcanic rocks that plot within this unit, although near the margin with, and probably part of, the overlying unit (HSV). Brook and others (1979) report fossils from chert in this area suggestive of a Mississippian age.

### Bean Canyon Terrane

**BCT Tylerhorse Canyon schist (Early Jurassic and Late Triassic(?))**—Gray schist, marble, and metatuff. Intruded by (predates) ~147 Ma granodiorite dikes. Has yielded one specimen of a bivalve strongly resembling the Early Jurassic genus *Weyla* along with a detrital zircon MDA of ~240 Ma (Chapman and others, 2012).

**BCB Bean Canyon Formation (Paleozoic)**—Marble, quartzite, pelitic schist, silicic metatuff, and calc-silicate hornfels overlying metabasalt and ultramafic rocks. The amphibolite metabasalt has yielded a latest Cambrian zircon U-Pb age of ~487 Ma, and a dacite metatuff from the overlying section has a Permian zircon U-Pb age of ~273 Ma (Chapman and others, 2012). Trace element analysis of metatuff from the top of the section suggests a volcanic arc origin (Chapman and others, 2012). The formally accepted age of this unit is Jurassic, but that is based on a Rb-Sr age of ~150 Ma (Ross, 1989) without a reported location. We suggest the age-dated sample is from the Tylerhorse Canyon area that has yielded Jurassic fossils which we have designated Tylerhorse Canyon schist. We retain the larger portion of the previously mapped extent of the unit which has yielded Paleozoic U-Pb ages.

### Tehachapi-San Emigdio Terrane

**TSS Grapevine Canyon paragneiss and Grapevine Peak migmatite of Chapman and Saleeby [2012] (Mesozoic and(or) Paleozoic(?))**—Strongly foliated kyanite- and garnet-bearing metasediments and metapelite. This unit lacks protolith age control, though it predates the surrounding ~100-136 Ma Tehachapi-San Emigdio intrusive complex (unit Gte). The unit has yielded biotite K-Ar, Ar-Ar, and Rb-Sr ages of ~86-91 Ma (Evernden and Kistler, 1970; Saleeby and others, 2007).

### Snow Lake Terrane

**SL Snow Lake terrane (Early Jurassic and Cambrian to late pre-Cambrian)**—The terrane occurs in the Snow Lake, Benson Lake, May Lake, and Quartzite Peak roof pendants of the central Sierra Nevada. It consists of a lower sequence of quartzite, feldspathic quartzite, quartz-mica schist, marble, and calc-silicate schist, unconformably overlain by an Early Jurassic upper sequence of a basal conglomerate with clasts of marble and quartzite, overlain by calcareous siltstone and marble, siltstone, and limestone. Both units intruded by

dikes. In the Snow Lake pendant, the lower sequence is intruded by Late Jurassic felsic and mafic dikes, probably related to the Independence dike swarm (unit Gid) that have yielded zircon U-Pb ages of ~147-153 Ma (Lahren and others, 1990). There the upper unit is also intruded by dikes but those have not been dated, and Memeti and others (2010) suggest they are related to the nearby younger plutons. Units in some pendants isoclinally folded. The lower sequence has yielded detrital zircon MDAs of ~600-1790 Ma (Grasse and others, 2001, Memeti and others, 2010; Attia and others, 2021). The upper sequence in the Snow Lake pendant has yielded Early Jurassic fossils (Memeti and others, 2010), and in the Snow Lake and Strawberry Mine pendants detrital zircon MDAs of ~183 and ~188 Ma (Memeti and others, 2010). Earlier detrital zircon analyses (Grasse and others, 2001) suggest the lower sequence is correlative with late Pre-Cambrian and Cambrian sedimentary units in Mojave Desert, but later detrital zircon analyses (Memeti and others, 2010) suggest the lower sequence derived from somewhere in Neoproterozoic to Ordovician passive craton-margin. On basis of lithology, Lahren and Schweickert (1989) initially correlated upper sequence with Triassic Fairview Valley Formation in Mojave Desert. However, with discovery of two Early Jurassic ammonites, Memeti and others (2010) correlate the upper sequence with similar marine miogeoclinal lithologies in various axial Sierra Nevada roof pendants, or with units in west-central Nevada. The early Jurassic upper member of this unit possibly correlates with the Kings terrane (unit KSM) on basis of lithology and age.

#### White-Inyo Mountains Craton Margin Formations (Jurassic to Neoproterozoic)

- 14 **Sequence 4 (Jurassic)**—Volcanic and nonmarine volcanoclastic sedimentary rocks of the Inyo Mountains volcanic complex of Dunne and others (1998) and the unnamed Jurassic-Triassic volcanic and continental sedimentary rocks unit of Ross (1967a). Unconformably overlies the Union Wash Formation of Sequence 3 (Stone and others, 1991). Zircon U-Pb dates from the more volcanic middle part of the unit range from ~168-169 Ma, whereas those from the volcanic interbeds in the more sedimentary upper part of the unit range from ~148-163 Ma (Dunne and others, 1998). Intruded by dikes of the Independence dike swarm (unit Gid) and the granite of French Spring (part of unit Gsp) which has a zircon U-Pb age of ~148 Ma (Dunne and Walker, 1993).
- 13 **Sequence 3 (Triassic to Mississippian)**—Includes the following units of Ross (1965, 1967), Dunne and others (1981), and Stone and others (1989, 2000, 2009): Triassic Union Wash Formation (marine sandstone, shale, and limestone); Early Triassic to Early Permian Owens Valley Group (lithologically diverse marine and nonmarine sedimentary rocks including conglomerate, sandstone, shale, and limestone) divided into the Conglomerate Mesa Formation, sedimentary rocks of Santa Rosa Flat, and Lone Pine Formation; Early Permian to Early Pennsylvanian Keeler Canyon Formation (limestone, calcareous siltstone and shale; Late Mississippian Rest Spring Shale (marine shale, probably deep-water); Mississippian Tin Mountain Limestone (thin- to medium-bedded fine-grained limestone with chert lenses and nodules); and Mississippian Perdido Group (sandstone, shale, and limestone, shallow to deep marine).
- 12 **Sequence 2 (Devonian to Ordovician)**—Includes the following units of Ross (1963, 1965, 1967) and Stone and others (1989, 2000, 2009): Devonian Lost Burro Formation (mainly limestone and marble, some dolomite and sandstone); Devonian and Silurian Hidden

Valley Dolomite (massive dolomite with minor sandy dolomite and sandstone); Devonian(?) and Silurian Vaughn Gulch Formation (bioclastic limestone and argillaceous limestone); Devonian(?) and Silurian Sunday Canyon Formation (limy shale, shale, and lesser limestone); Silurian and Ordovician Ely Springs Dolomite (thick-bedded dolomite characterized by chert nodules and lenses); Ordovician Johnson Spring Formation (mixed quartzite, dolomite, and limestone); Ordovician Barrel Spring Formation (shale, mudstone, siltstone, limestone, and impure quartzite); Ordovician Eureka Quartzite (fine- to medium-grained quartzite and basal argillite); Ordovician Badger Flat Limestone (laminated dolomite); Ordovician Pogonip Group (thick-bedded dolomite and limestone, with chert and sandy limestone in the upper part, and shale and mudstone in the lower part); and Ordovician Al Rose Formation (siltstone, shale, and mudstone, with lesser limestone).

- 11 **Sequence 1 (Cambrian and Neoproterozoic)**—Includes the following units of Ross (1963, 1965, 1967) and Stewart (1970): Cambrian Tamarack Canyon Dolomite (thin-bedded dolomite with chert nodules in basal part); Cambrian Lead Gulch Formation (limestone, siltstone, shale, and chert); Cambrian Bonanza King Formation (generally fine-grained dolomite); Cambrian Monola Formation (upper member is limestone with interbedded siltstone and shale; middle member is massive limestone; lower member is siltstone and silty limestone); Cambrian Mule Spring Limestone (thin- to medium-bedded limestone); Cambrian Saline Valley Formation (upper member is siltstone and quartzite, lower member is siltstone and minor sandstone overlain by thin-bedded limestone); Cambrian Harkless Formation (silty shale with interbedded quartzite); Cambrian Poleta Formation (upper member is shale, limestone, and quartzite; lower member is massive limestone); Cambrian and Neoproterozoic Campito Formation (upper member is shale and interbedded sandstone and siltstone; lower member is massively bedded quartz sandstone and interbedded siltstone and shale); Neoproterozoic Deep Spring Formation (upper member is sandstone and siltstone overlain by dolomite and limestone; middle member is quartzite overlain by interbedded limestone, sandstone, and shale; lower member is limestone with minor interbedded dolomite, sandstone, and shale); Neoproterozoic Reed Dolomite (massive fine-grained dolomite over a tongue of interbedded quartzite, sandy dolomite, and calcareous sandstone over massive coarse-grained dolomite); and Neoproterozoic Wyman Formation (argillite, sandstone, and siltstone, locally phyllitic, with a lenticular member of limestone).

## Twin Lakes Terrane

- TL **Twin Lakes terrane – central Sierra Nevada crest (Early Jurassic and Triassic(?) to Paleozoic)**—Deformed and imbricated thrust slices of late Paleozoic deep-marine, pelagic, argillite, chert, pillow basal, and fault-bounded slivers of serpentinite and peridotite. Unit also includes local sandstone, quartzite, shale, conglomerate, and intermediate to silicic volcanic rocks, and silicic ash-flow tuff. Correlated in part by Schweickert and Lahren (1993, 2006) with late Paleozoic Golconda allochthon, a late Paleozoic thick sequence of metamorphosed basalt, siltstone, shale, chert and limestone. Samples with Jurassic detrital zircon MDAs may be from faulted slivers of Middle to Late Jurassic (221 to 151 Ma) volcanic rocks from the Goddard arc, Sierra Crest terrane (unit SCGV), whereas the Late Triassic and earliest Jurassic volcanics of this unit, along with parts of the High Sierra (unit HSV) and Sierra Crest (unit SCGV) terranes and the Scheelite Intrusive Suite (unit

Gsc), make up the High Sierra arc.

In the Saddlebag Lake pendant, this unit was mapped by Chesterman (1975) as the late Paleozoic Twin Peaks sequence. Later detailed mapping by Cao and others (2015) shows the unit is formed of a lower section of Paleozoic well-bedded volcanic, volcanoclastic, and sedimentary rocks that they correlate with the Golconda allochthon, structurally overlain by Early Jurassic sedimentary rocks. The lower section has yielded a detrital zircon MDA of ~350 Ma and is intruded by a small granodiorite pluton that has yielded a zircon U-Pb age of ~233 Ma (Cao and others, 2015), probably a part of the Scheelite Intrusive Suite too small to map separately. The upper section has yielded detrital zircon MDAs of ~186 and ~187 Ma. At the northern tip of the pendant, Attia and others (2021) report a detrital zircon MDA of ~194 Ma from metasedimentary rocks that they assign to their Sawmill Canyon sequence, and a poorly constrained detrital zircon MDA of ~220 Ma from metasedimentary rocks they assign to their Koip sequence.

The two structural blocks of this unit to the east were mapped by Chesterman and Gray (1975) as metavolcanic and metasedimentary rocks that are part of the Jurassic(?) Virginia Lakes sequence, but this is precluded by intrusion of Late Triassic plutons of the Scheelite Intrusive Suite. These rocks were mapped as Triassic metavolcanics by Huber and others (1989). More recently Schweickert and Lahren (2006) have mapped the smaller block north of Virginia Lakes as metasedimentary rocks that are part of the Triassic Candelaria Formation, but the larger eastern block as metasedimentary and metavolcanic rocks, part of their Paleozoic Golconda thrust sheet.

## Feather River Terrane

[Feather River terrane is interpreted as a disrupted, polygenetic Paleozoic ophiolite, part of an oceanic plate, preserved in a subduction zone assemblage. cross cutting dikes show that at least part of the Feather River belt ultramafic suite is older than Middle Devonian (-388 Ma). Amphibolite facies metamorphism of part of this unit occurred during the Middle to Late Paleozoic (236 to 345 Ma). unit also named Feather River peridotite belt.]

**FRS Red Ant Schist (Jurassic or older)**—Chiefly blueschist facies metasedimentary and metavolcanic rocks. Disharmonically folded quartz schist, black schist, and phyllite plus schistose and brecciated greenstone. Blueschist facies minerals crossite, glaucophane, and lawsonite are preserved locally. Protolith age unknown. Schweickert and others (1980) report muscovite K-Ar ages of ~157, ~173, and ~175 Ma, and whole-rock K-Ar ages of ~176 and ~190 Ma for this unit.

**FRM Mafic igneous member (Triassic(?) and(or) Paleozoic)**—Chiefly Sheep Ranch metabasite and Devil's Gate ophiolite that consists of amphibolite facies metabasite derived from basalt, andesite, and trachyandesite. Forms southern extension of the Feather River ultramafic belt (Jackson, 2012). Unit occurs in a narrow klippen thrust over the Calaveras Complex - marine sedimentary rocks (unit MRCS).

A large mafic amphibolite body within the ultramafic rocks (unit FRU) from the northernmost part of the unit in the Feather River area has yielded a hornblende K-Ar age of ~241 Ma (Hacker and Peacock, 1990). In the Devil's Gate area, this unit has yielded a hornblende K-Ar age of ~248 Ma (Hietanen, 1981), and hornblende Ar-Ar ages of ~272 and

~395 Ma (Standlee, 1978). In the Yuba River area, this unit has yielded hornblende K-Ar ages of ~322 and ~345 Ma, and muscovite K-Ar age of ~273 Ma (Bohlke and McKee, 1984). Saleeby and others (1989b) report a zircon U-Pb age of ~388 Ma for a small granitic intrusive nearby, and they suggest that it represents the timing of amphibolite-facies metamorphism. They further note that this age is coeval with the Bowman Lake batholith (part of unit Gsb) intruded into the Northern Sierra terrane to the east.

**FRU Ultramafic member (Devonian or older)**—Occurs in the northern Sierra Nevada along branches of the Calaveras-Shoo Fly thrust between the Northern Sierra terrane to east and Calaveras Complex to the west. Chiefly variably serpentized peridotite, mainly harzburgite, lesser dunite, and minor lherzolute. Unit includes massive and layered metagabbro, sheeted dikes, pillow lava, and chert. Sparse metagabbro crosscutting dikes. Unit also includes local gabbro and diorite, amphibolite derived from metabasalt, and plagiogranite. Unit intensely faulted and sheared.

About half of unit consists of unserpentized peridotite bodies ranging from 2-6 km long. Bodies generally elongate in a north-south direction and have gradational boundaries with surrounding massive serpentinite. Ultramafic rocks display both cumulate and tectonite fabrics.

A plagiogranite from the northernmost part of the unit in the Feather River area has yielded a zircon U-Pb age of ~314 Ma (Saleeby and others, 1989b). Northwest of Downieville, a relatively small body of metagabbro within this unit has yielded a hornblende K-Ar age of ~285 Ma (Hietanen, 1981).

## Owens Terrane

**OW Owens terrane - central Sierra Nevada Crest (Permian to Cambrian)**—Chiefly calc-silicate hornfels, quartzite, quartzofeldspathic hornfels, dark-gray siliceous argillite, and marble. Dominant protoliths are calcareous sandstone with local conglomerate, shale, limestone, and chert, with minor marl, and dolomite. Terrane interpreted as a deep-water, continental-margin assemblage with local gradation into shallow water. Occurs in the Log Cabin, Ritter Range, Mount Morrison, and adjacent roof pendants in the eastern Sierra Nevada. Unit modified from the Owens terrane of Nokleberg (1983), Rush Creek sequence of Green and others (1997), and Morrison block of Stevens and Green (1999). Terrane correlated with broadly similar fossiliferous continental-margin sedimentary strata in the White-Inyo Mountains to southeast and similar rocks in west-central Nevada (Stevens and Green, 1999). Schweickert and Lahren (1993, 2006) correlate this unit with rocks of the Antler orogenic belt (Roberts Mountains allochthon), but Stevens and Green (1999) point out important stratigraphic differences (e.g. lack of metavolcanic rocks in this unit and missing Carboniferous section in the Roberts Mountains section).

In the Mount Morrison roof pendant, the unit consists of two assemblages. The older is a Cambrian to Devonian, submarine fan to deep-water hemipelagic, continental-margin sequence of dark, fine-grained argillite, locally with thin marble interbeds; thick-bedded calcareous sandstone; and black radiolarian chert and argillite. The sequence contains conodonts indicating an age near the Cambrian-Ordovician boundary, Ordovician graptolites, (probably Middle) Devonian conodonts, and Late Devonian conodonts (Stevens and Green,

1999). The younger assemblage is a Mississippian to Permian continental-margin sequence of siliceous hornfels, chert, thick marble, and calc-silicate hornfels; transitioning from shallow water in the lower half to deep water hemipelagic and base of slope in the upper half. The sequence contains reworked Devonian and Mississippian conodonts near the base, Early Pennsylvanian crinoids, corals, brachiopods, and conodonts, Middle Pennsylvanian conodonts, and early Early Permian conodonts.

In other pendants, the lithologies and fossils are similar, although not every subunit is present. In the Bishop Creek pendant, only the Cambrian to Upper Devonian older assemblage, plus the Mississippian lowest part of the upper assemblage, is present. In the Gull Lake pendant, only the upper, Silurian(?) and Devonian part of the older assemblage is present. In the Log Cabin Mine roof pendant, the unit is chiefly older assemblage calcareous sandstone, shale, and chert; minor marl, limestone, and dolomite with Ordovician graptolites (Stevens and Greene, 1999), with only a sliver of younger assemblage mapped. North of Lundy Canyon, this unit is chiefly younger assemblage marble with probably Carboniferous crinoid stems (Chesterman and Gray, 1975).

The older sequence exhibits three generations of penetrative structures and isoclinal folds and faults. Younger sequence exhibits the younger two generations of penetrative structures with moderately appressed folds. Two sequences are generally in fault contact along the NNW-trending Laurel-Convict fault, along which the Laurel-Convict felsite is intruded with a U-Pb zircon age of 225 Ma, part of the Late Triassic and Early Jurassic Scheelite Intrusive Suite (Gsc).

In the northern Ritter Range pendant, the unit is named the Rush Creek sequence (Green and others, 1997). It is composed chiefly of calc-silicate hornfels, siliceous argillite, bedded chert, sandy marble, and calcareous quartzite. This sequence lacks diagnostic fossils but has been correlated with the Ordovician to Devonian part of the early sequence in the Mount Morrison pendant. A nearby lens of fossiliferous marble has yielded crinoids, brachiopods, corals and bryozoans suggestive of Late Mississippian through mid-Permian age (Green and others, 1997). It is correlated with the thick Pennsylvanian marble in the Mount Morrison pendant and thought to be a fault sliver offset from that pendant along the Gem Lake shear zone (Green and others, 1997).

In the Mount Pinchot 15' Quadrangle, this unit is interbedded marble, calc-hornfels, biotite schist, and pelitic hornfels and quartzite. No recognizable fossils have been collected from this southern area, although similar rocks in Big Pine Canyon to the north (outcrops too small to show at scale) have Early Cambrian fossils (Moore and Foster, 1980).

## El Paso Terrane

**EPS El Paso terrane (Permian to Cambrian)**—Stratigraphically and structurally complex, mostly deep-water metasedimentary and metavolcanic rocks present in the El Paso Mountains and southeastern Sierra Nevada. Rocks in the El Paso Mountains were mapped in detail by Carr and others (1997), who defined the following major units: andesite of Goler Wash (Permian: meta-andesite flows, flow breccia, and hypabyssal intrusions); metasedimentary rocks of Holland Camp (Permian: meta-argillite and calcareous metasiltstone (member D), volcanogenic meta-arkose and metaconglomerate (member C), slate and interbedded

metalimestone (member B); and slate, meta-arkose, metaconglomerate, and dolomitic marble (member A)); metasedimentary rocks of Benson Well (Pennsylvanian: upper slate and quartzite member, lower metalimestone member); metasedimentary rocks of Apache Mine (Mississippian: meta-argillite, quartzite, and metaconglomerate; Robbers Mountain Formation (Mississippian: upper meta-argillite member and lower metaconglomerate member); metasedimentary rocks of Gerbracht Camp (Devonian: meta-argillite member, sandy marble member, metatuff member, and metachert member); greenstone (Devonian(?): metamorphosed basaltic rocks including pillow lava); metasedimentary rocks of Colorado Camp (Ordovician and Cambrian: meta-argillite and marble); metasedimentary rocks of El Paso Peaks (Devonian(?), Silurian(?), Ordovician, and Cambrian: calc-silicate hornfels and minor marble (upper member), schistose slate, quartzite, and pelitic hornfels (middle member), and meta-argillite, metalimestone, and orthoquartzite (lower member)); and schist, quartzite, and marble (Cambrian(?): equivalent to Mesquite schist of Dibblee, 1952). Unit ages reported by Carr and others (1997) are based on conodonts, graptolites (Ordovician), and fusulinids (Permian; Ross and Sabins, 1966). A detrital zircon study by McDonald (2016) indicates MDAs of ~256-258 Ma for member C and ~263-283 Ma for member A of the Permian metasedimentary rocks of Holland Camp. The Paleozoic metasedimentary and metavolcanic sequence is intruded by Middle Triassic to Early Permian plutonic and metaplutonic rocks of unit Gep (Carr and others, 1997; Cecil and others, 2019).

Rocks of the El Paso terrane in southeastern Sierra Nevada are composed of carbonaceous, locally phosphatic argillite and fine-grained quartz arenite in association with minor limestone, quartz arenite, basalt, stratiform barite, and conglomerate (Dunne and Suczek, 1991). These rocks are broadly equivalent to the Rockhouse Basin and Big Meadow metasedimentary belts of Ross (1995). As in the El Paso Mountains, terrane in this area is intruded by Middle Triassic to Early Permian plutonic rocks of unit Gep (Clemens-Knott and Gevedon, 2023).

Pre-Permian detrital zircon age spectra from the El Paso terrane indicate clastic derivation from a Paleoproterozoic to Archean craton and have similar detrital sources to rocks of the Roberts Mountains allochthon to the north (Chapman and others, 2015; Attia and others, 2018; Clemens-Knott and Gevedon, 2023). Permian detrital zircons in metasedimentary rocks of Holland Camp are interpreted to have been derived from the incipient Cordilleran magmatic arc to the west (McDonald, 2016). The terrane is interpreted to be offset from the vicinity of the Roberts Mountains allochthon during left-lateral strike-slip faulting along North American continental margin in late Paleozoic time (Saleeby and Dunne, 2015) and later thrust approximately 100 km eastward onto North American Craton by about 175 Ma (Miller and others, 1995).

## Eagle Rest Peak Terrane

**ERP Eagle Rest Peak terrane – western San Emigdio Mountains (Paleozoic)—**  
Amphibolite after pillow basalt and sheeted dikes, with rare plagiogranite pods. Intruded by the Jurassic San Emigdio intrusive suite (unit Gse). Equivalent to the Paleozoic part of the Western San Emigdio mafic complex of Chapman and Saleeby (2012). Chapman and others (2012) show the trace-element chemistry of these rocks lies between normal and enriched mid-ocean ridge basalt, and is comparable to that of the Paleozoic Kings-Kaweah ophiolite

belt (units MRKA and MRKI).

## Pastoria Terrane

**PAS**     **Pastoria terrane – western Tehachapi Mountains (early(?) Paleozoic(?))**—Chiefly marble, quartzite, quartz-feldspar gneiss, mica schist, Escapula Peak migmatite, and hornfels. Unit includes Metasedimentary Rocks of Salt Creek of Ross (1989). U-Pb detrital zircon data suggests early Paleozoic to Neoproterozoic age (Chapman and others, 2012). Metamorphosed to upper amphibolite and granulite facies. Contact-metamorphosed by Late Cretaceous Lebec granodiorite and other units in Unit Gps. Terrane structurally overlies the Pelona-Rand Schist and the Tehachapi-San Emigdio terrane (units PS and TSS) along the Pastoria normal (detachment) fault. Terrane elevated to near-surface, along with enclosing middle to Late Cretaceous granitic rocks, during early Tertiary extension along the Pastoria normal (detachment) fault.

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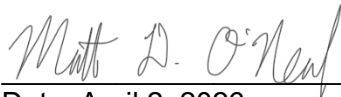
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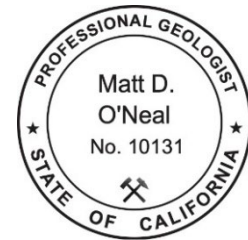
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