

Field Trips Stops for Days 1 & 2

Cal Poly—Geology Club
2005 Field Trip
Western Sierra Nevada/Foothills Metamorphic Belt

GEOLOGY CLUB FIELD TRIP WESTERN SIERRA NEVADA - MOTHER LODE

Introduction

The Mother Lode Belt (MLB) produced in excess of 40 million ounces of gold through 1964 and with reactivation of several mines in the 1980 and 1990's, produced an additional 10-20 million ounces of gold. As such, it ranks as one of the largest gold producing districts in the United States. During this field trip we will examine the MLB and adjacent Sierra Nevada batholith. Our objective will be a better understanding of the geology of the Mother Lode region and some feel for models to explain both gold emplacement and the evolution of the Sierra Nevada.

California can be divided into a series of tectonic provinces (Fig. 1) each playing an important role in the geologic evolution of the western United States. While important from a purely academic standpoint, economic geologists are concerned with integrating paleotectonic reconstructions into some sort of framework that will aid in the exploration for gold deposits. Figure 2 shows the distribution of various metallic mineral deposit types in California. On this trip we will be examining the gold-quartz vein deposits. They occur in many diverse localities in California from the northern Mojave Desert to the Klamath Mountains of the northern Coastal Ranges. By far the most important, however, are the veins of the Mother Lode and adjacent Grass Valley District.

It is noteworthy that the most comprehensive paper on the Mother Lode was published in 1929 (Knopf, 1929). Subsequent to that time, little of significance has been written on the district. Knopf described the Mother Lode as a complex system of quartz veins and mineralized rock 195 km long and about 1.5 km wide localized along an east dipping fault with offsets of 10's of kilometers. The quartz is not a continuous mass, but rather forms discontinuous lenticular pods as much as 20 meters thick. Ore bodies seem to be associated with the thickest portions of the quartz veins and are often localized where the veins intersect or branch. They typically have short strike lengths, but may be continuous in the down dip direction for thousands of meters. All ore zones dip consistently eastward, but according to Knopf dip angle is highly variable and changes generally as a function of lithology.

The quartz veins consist of essentially pure milky white which is coarsely crystalline, often containing inclusions of the host rocks. Alteration is common and pervasive with ankerite dominating. Knopf argued that the alteration of host rock to ankerite (a carbonate) must have released large quantities of silica which then recrystallized as the quartz veins. Localization of gold is a more complex and debatable sub-

ject. In the northern one-third of the MLB the gold seems to occur within the quartz veins. However, to the south the gold lies at the contact between the quartz veins and footwall metamorphics; often finely disseminated in rocks some distance from the quartz veins.

Most of the gold produced from the MLB prior to 1980 was free gold. Gold-bearing pyrite was known to be a major constituent both of the quartz veins and footwall rocks adjacent to the ore zone, but it was rejected during processing. In the 1980's and 90's significant production came from these low grade auriferous pyrite zones. Other sulfide minerals reported from the ore include arsenopyrite, sphalerite, galena, chalcopyrite and tetrahedrite. The gold telluride, petzite, is also a rare constituent of some deposits.

Several models have been proposed for the Mother Lode deposits, but they all fall under three general umbrellas:

1. Syngenetic, based on the general suggestion that the gold was deposited originally in the sedimentary rocks which host the quartz veins and perhaps remobilized during subsequent metamorphic and/or igneous events.
2. Hydrothermal/magmatic, with the gold related to and derived from Mesozoic intrusives (i.e. the Sierra Nevada batholith).
3. Metamorphic (more recently the term amagmatic has been employed), with the gold being emplaced by some unspecified mechanism related to continent-arc collision.

We will have the opportunity to discuss each of these models during the field trip, however, constraints to any model must be kept in mind.

- ◆ Limited fluid inclusion work indicates the presence of CO₂ rich inclusions. This is not surprising given the alteration of the host rock to ankerite. The source of the CO₂ is difficult to establish due to the complexity of the MLB geology, but sedimentary carbonates are rare to nonexistent along strike. In other less structurally complex districts, CO₂ rich inclusions have been taken to indicate a deep (possibly mantle) source for the ore fluids.
- ◆ Stable isotopic studies have shown that much of the water was of meteoric origin.

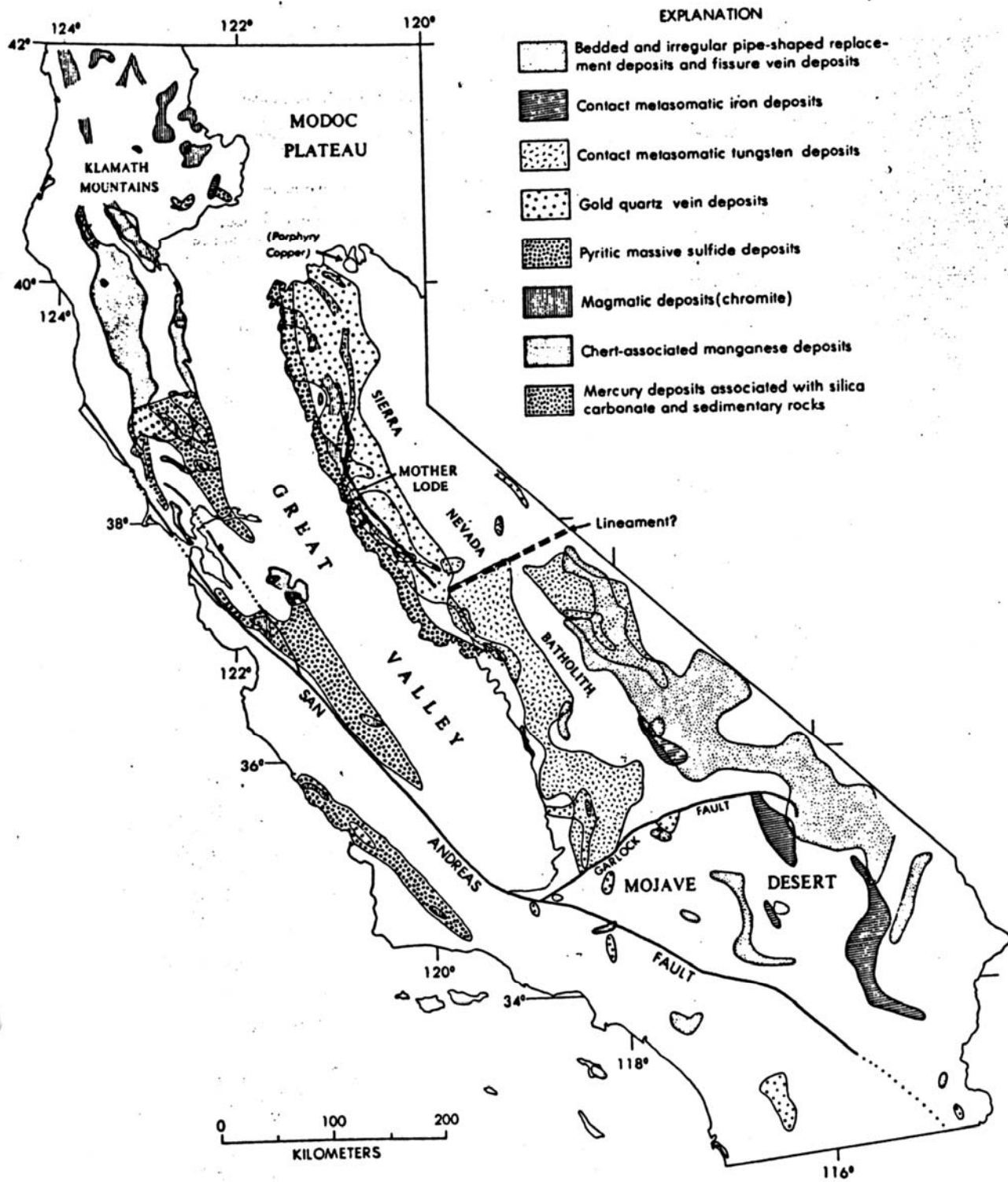


Figure 2. Distribution of metallic mineral deposits in California.

Of course, metamorphism has been extensive so the question might be asked, is this merely an overprint on the original isotopic values.

- ◆ Age dates on alteration assemblages (mariposite) indicate the veins were emplaced approximately 115 Ma (Cretaceous). Again are these age dates accurate or have they been reset by nearby igneous intrusions?
- ◆ Curiously, the ores appear to set on oceanic basement rocks (i.e., generally rocks of basaltic affinity). Gold is absent to the east where the basement has a more continental character.

General Geology-Stratigraphy

Any attempt to construct a generalized stratigraphic column for the Mother Lode can be an exercise in futility. The paucity of fossils in the sedimentary rocks, metamorphic overprint and chaotic nature of the rock units make interpretation problematic. Widely disparate ages have been often placed on the same formation by different authors. Furthermore, there is no general agreement as to which units are part of which terrain (compare for example, Figures 3 and 6).

Figure 3 is a generalized geologic map of the MLB. Note it divides the foothills into three distinct belts, termed the Western, Central or Mother Lode, and Eastern. Unfortunately, although most researchers now adopt the concept of three “belts” there is no general consensus as to which rock units constitute each belt. For the purpose of this discussion we will treat the rock units from east to west.

The oldest rocks in the region are a part of the Shoo Fly Complex of lower Paleozoic age. They are a sequence of eastward dipping sandstones, shales, cherts and minor volcanics apparently deposited on the western limb of a major synclinorium (the Nevadan). These are in turn unconformably overlain by a thick (11 km) sequence of volcanics and volcanoclastic rocks of dacitic to rhyolitic composition. Shoo Fly rocks have been metamorphosed to mid-high greenschist facies. Few fossils have survived the metamorphism, but recently Silurian and Devonian fossils have been discovered. These fossils, in conjunction with detrital zircons (?), suggest that Shoo Fly rocks are Ordovician to Mississippian in age.

The Calaveras Complex lies to the west of the Shoo Fly Complex and is thought to be in fault contact (the Calaveras-Shoo Fly Thrust). Like the Shoo Fly, it is

eastward dipping consistent with deposition in the Nevadan synclinorium. It consists of a metamorphosed (low-mid greenschist facies) basal pillow lava and argillite overlain by additional argillites and chert. Fossil preservation is better with conodonts, fusulinids and radiolaria indicating Permian through latest Triassic ages.

Both the Shoo Fly and Calaveras have been intruded by stocks and batholiths of the Sierra Nevada orogen. Intrusions range in age from 140MY (Jurassic) to 80MY (Cretaceous) and in general are younger from west to east. Provenance studies indicate both rock units are derived from or related to the North American craton. The western boundary of the Calaveras Complex is marked by the Melones Fault Zone (MFZ).

West of the MFZ (to be discussed below), are a series of rocks of markedly different character. Stratigraphy for these rocks is only poorly known. In general, the basement consists of a true ophiolite sequence with pillow lavas, gabbro and serpentinized ultramafics occurring in a chaotic assemblage (mélange). The ophiolite sequence is in turn overlain by a 4 km thick sequence of volcanic rock of largely basaltic to andesitic composition. Capping the sequence is a series of weakly metamorphosed (zeolite-prehnite/pumpellyite facies) fine-grained clastics with minor intercalated graywacke and conglomerate, and volcanics often collectively termed the Mariposa Formation. Trace fossils have placed the age of the Mariposa Formation at early Jurassic.

Rocks of the Western Belt lie to the west of the Bear Mountain Fault Zone (BMFZ). These rocks are poorly exposed and little studied. In general, the stratigraphy suggests similarities to rocks east of the fault zone, leading to the widely held belief that the BMFZ represents a splay of the MFZ with the two merging at depth. Thus, rocks of the Western Belt would be analogous to those of the Central Belt and perhaps are repeated section. Further to the west, Western Belt rocks are unconformably overlain by the submarine fan deposits of the Cretaceous Great Valley Sequence.

General Geology-Structure

The Melones Fault Zone marks a major crustal suture separating dominantly oceanic rocks to the west from largely continental rocks to the east. Its strike length is at least 350 km and may exceed that distance considerably. On most regional scale maps such as Figure 4 the MFZ appears as a thin line, but in reality the fault zone varies from a narrow zone a few hundred meters wide (such as our stop at Bullion Mtn.) to a broad geologically complex zone a kilo-

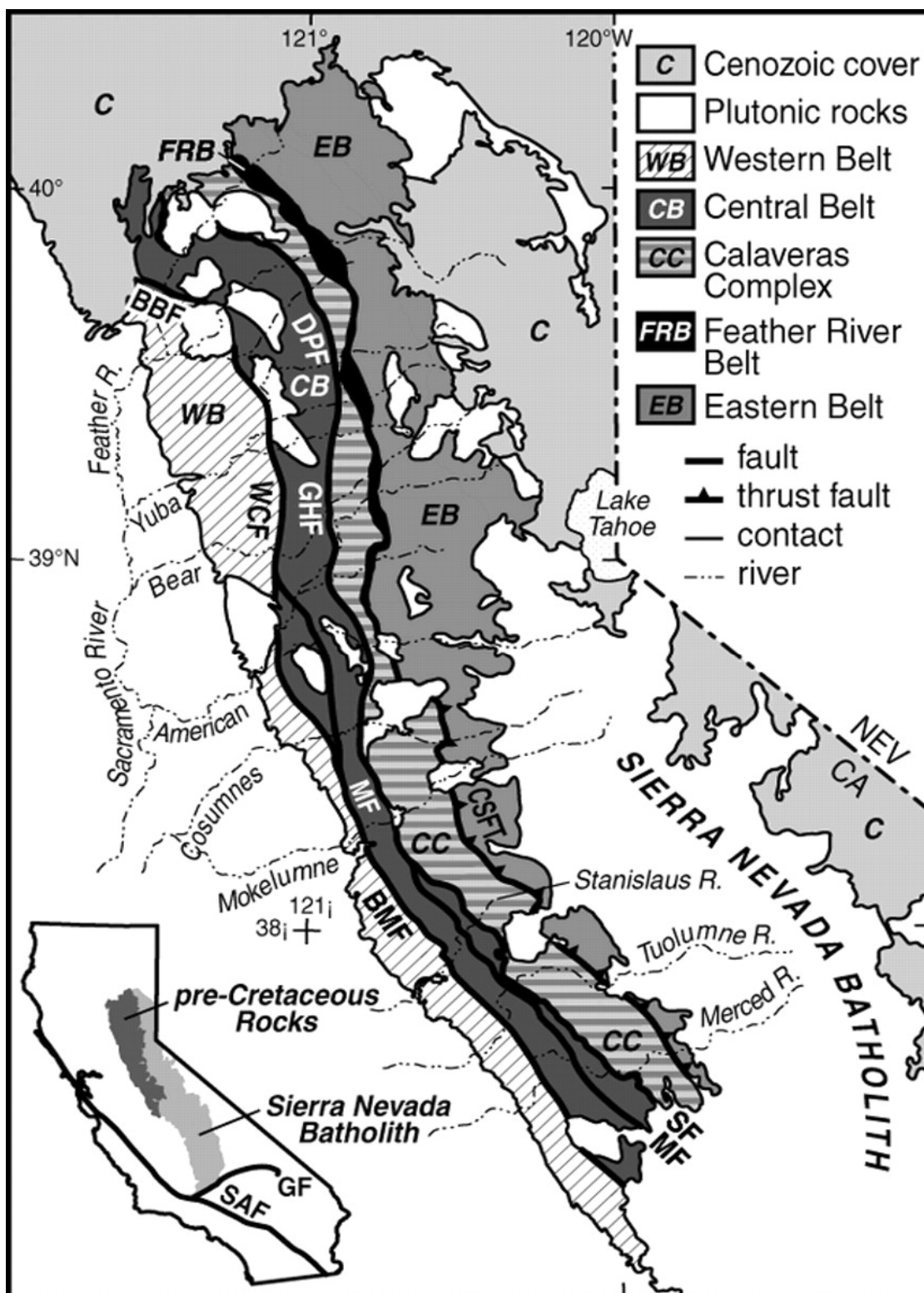


Figure 3. Lithotectonic belts of the Sierra Nevada. The western side of the Sierra is overlain unconformably by undifferentiated Cretaceous and Tertiary sedimentary rocks of the Great Valley, which are unpatterned. Delimiting faults: BBF—Big Bend fault; BMF—Bear Mountains fault; CSFT—Calaveras-Shoo Fly thrust; DPF—Dogwood Peak fault; GHF—Gillis Hill fault; MF—Melones fault; SF—Sonora fault; WCF—Wolf Creek fault. Other faults: SAF—San Andreas fault; GF—Garlock fault.

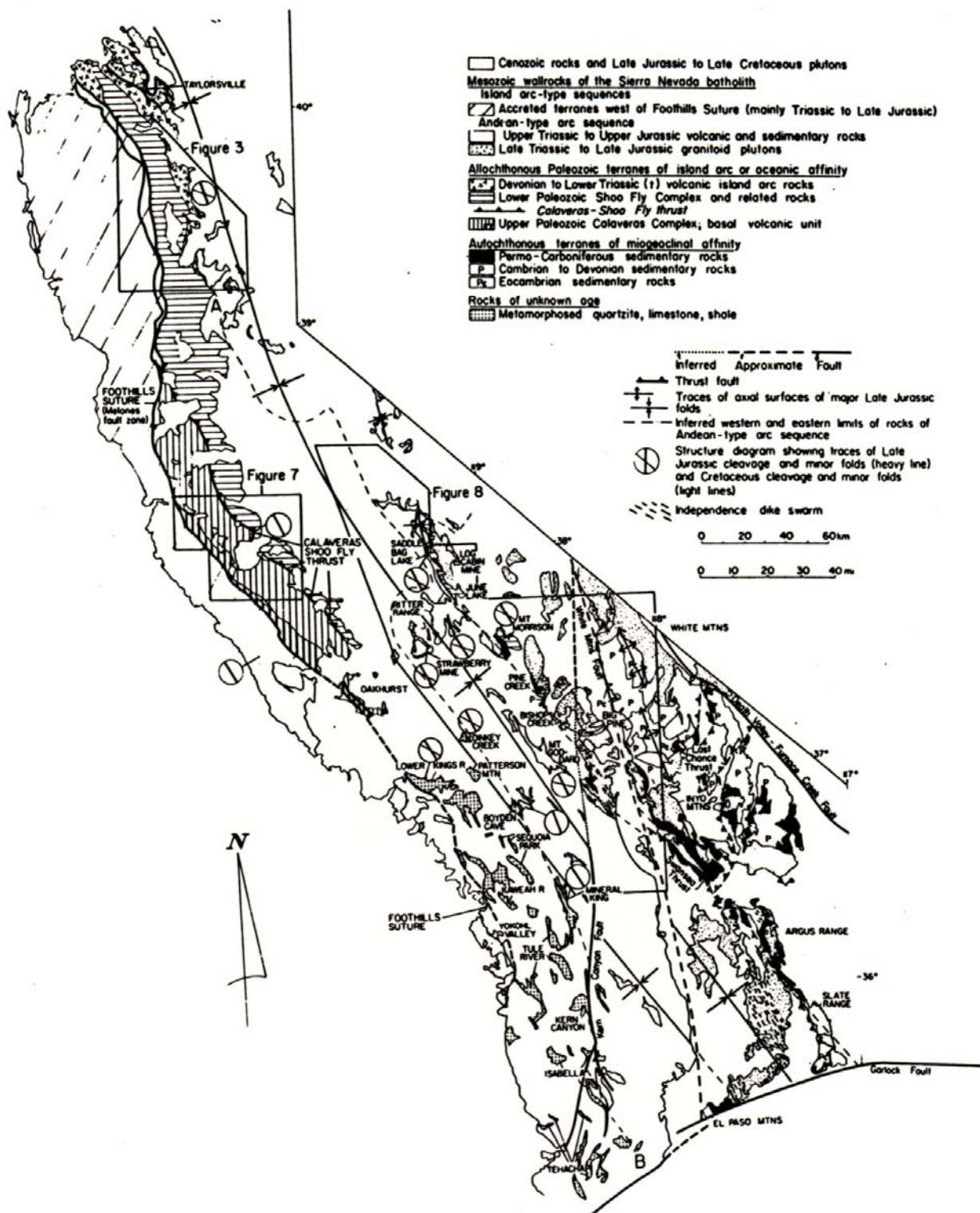


Figure 4. Generalized geologic map of east-central California. Figure numbers refer to another publication.

meter or more in width, north of Sonora. Movement along the fault remains controversial. Most workers view the MFZ as the remnant of an ancient eastward dipping subduction zone. More recent theories have centered on the possibility that the fault zone represents a transpressive environment (i.e. one in which both strike-slip and underthrusting occurred). In all interpretations, it appears that the rocks east of the fault are considered a part of continental North America while those west of the fault are an oceanic terrain. Also be aware that there is some controversy as to where the fault trace actually lies, and that disagreement is considerable (25 km). I will try to avoid this controversy on this trip and make stops only in areas where there is general agreement as to the local geology.

The Calaveras-Shoo Fly Thrust (CSFT) to the east of the MFZ separates lower plate Calaveras Complex from upper plate Shoo Fly Complex. The thrust plate dips gently to the east. Thrusting has extensively mylonitized both lower and upper plate rocks, and west of Sonora folded the Calaveras and Shoo Fly beds into tight east-plunging synforms and antiforms. The Standard pluton of mid-Jurassic age cuts the CSFT (Fig. 5) indicating a lower Jurassic age for thrusting.

The Bear Mountain Fault Zone (BMFZ) lies to the west of the MFZ and is only poorly mapped. In general, the eastward dipping fault separates the Mariposa Formation and volcanic/plutonic rocks to the east from similar volcanic/plutonic rocks to the west. Speculation has it that that at depth the BMFZ may merge into the MFZ.

General Geology-Metamorphism

Figure 6 is a cartoon drawing of metamorphism associated with the MLB. Do not be confused by the use of EB, MLB and WB. These refer to the East, Central and West Belts, but this author has used slightly different subdivisions from those shown on Figure 3. She prefers to define the East Belt as all rocks east of the MFZ, the Central Belt (MLB) as all rocks between the MFZ and BMFZ and the West Belt as all rocks west of the BMFZ.

Her map shows that rocks west of the MFZ range from prehnite-pumpellyite (blueschist) to actinolite-epidote (lower greenschist), while those east of the fault are largely mid-greenschist through amphibolite. This juxtaposition of regional paired metamorphic belts representing high pressure-low temperature and moderate pressure-high temperature is reminiscent of the paired metamorphic belts of Japan first mapped by Myoshira

in the 1960's.

Tectonic Model

The model I am about to present is an oversimplification of the existing geology, but if I complicate it any more no one will be able to understand it, including me! Keep in mind this is not the only model, merely a rather simple one to use as a starting point.

During the Paleozoic, sediment represented by the Shoo Fly and Calaveras Complexes accumulated on the continental margin of western North America. Perhaps as early as mid-Triassic an eastward dipping subduction zone formed along the western continental margin. An island arc represented by a thick sequence of rhyolitic to basaltic volcanics and Triassic to Jurassic intrusives formed on this continental basement. To the west of the subduction zone (MFZ) another island arc emplaced on oceanic crust was slowly approaching North America. Because this arc was floored on oceanic crust the basement consisted of ultramafics and gabbros with the arc itself comprised of basaltic to andesitic volcanics and associated sedimentary packages.

Sometime around the early-mid Cretaceous the two arcs collided and the oceanic arc was sutured to the North American continent. Note also that the center of intrusion shifted eastward as evidenced by the Cretaceous age of plutons in the Yosemite Valley. Following collision, the subduction zone retreated westward to the Coastal Ranges where post-Cretaceous subduction was initiated.

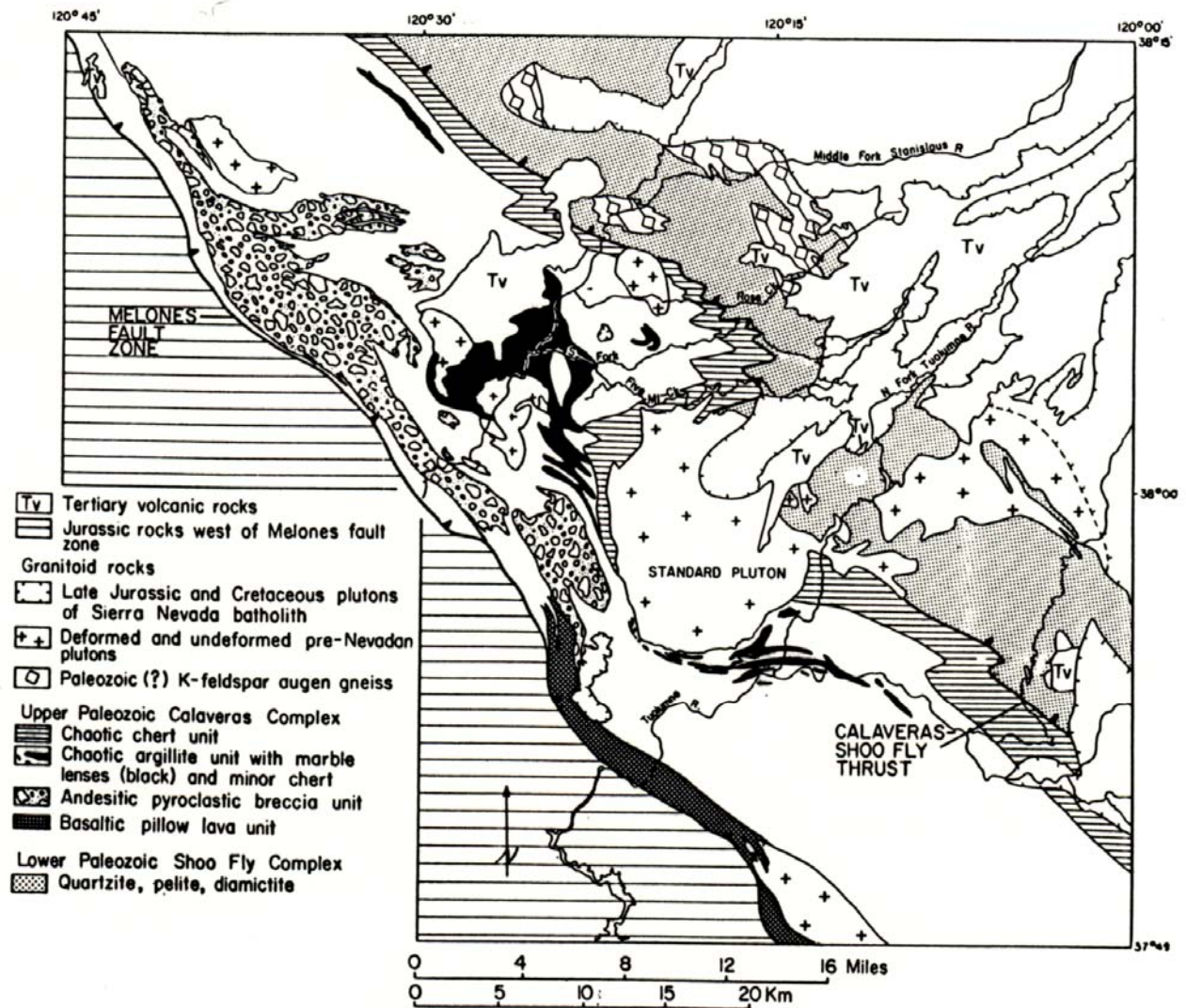


Figure 5. Generalized geologic map of the Calaveras Complex in the central Sierra Nevada.

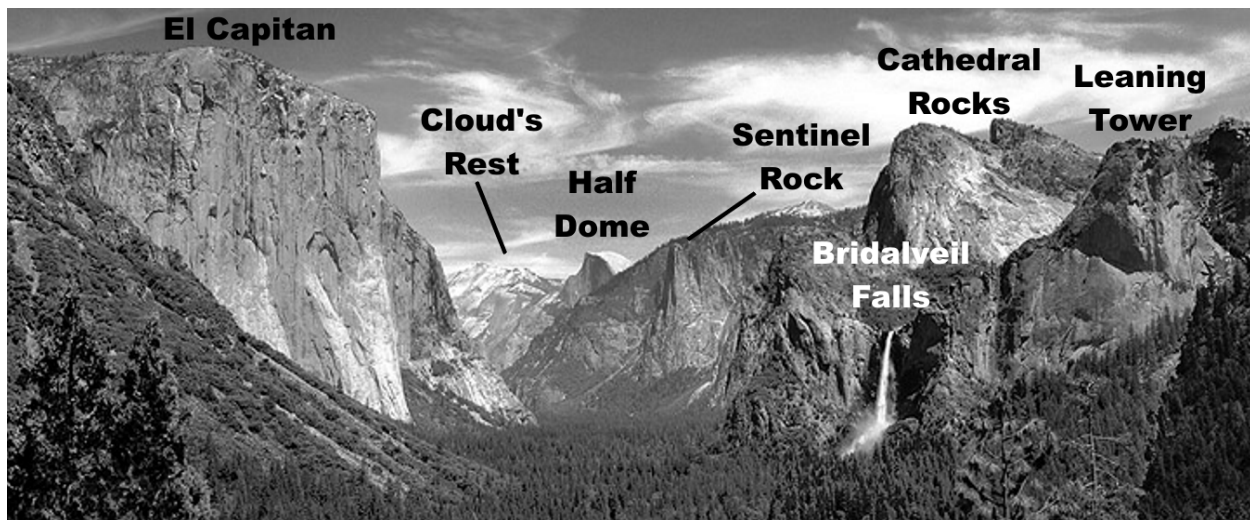


Figure 1. View of Yosemite Valley from the Wawona Tunnel parking area.

ROAD LOG

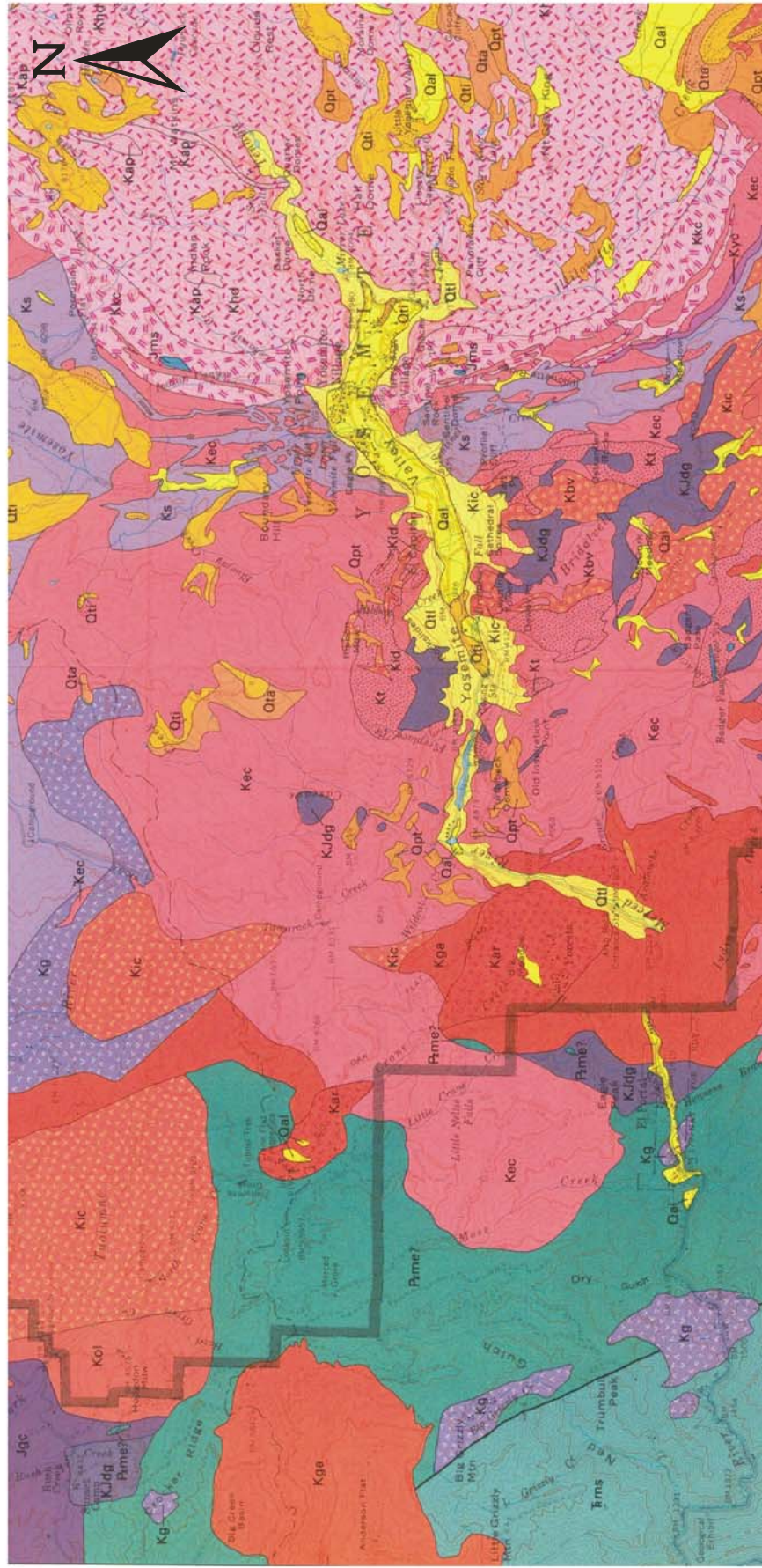
The first day of our field trip will be spent in Yosemite Valley where the igneous rocks that comprise the Sierra Nevada arc can be observed. Dr. Marshall will also discuss the spectacular geomorphic features resulting from Pleistocene glaciation. The trip begins in the town of El Portal, proceeds eastward along the Merced River into Yosemite Valley and then returns to Highway 49 passing through granitoid rocks of the Sierra Nevada batholith, the Paleozoic Shoo Fly Complex and the Permian-Triassic rocks of the Calaveras Complex. (Note that the mileage log for Yosemite National Park is based upon one-way traffic utilizing the North Park Drive. During our scouting trip in March that road was closed. It should reopen in the late Spring or early Summer.) The second day of the trip will be devoted to the Mother Lode. We will traverse rocks of the central (Mother Lode) and western belts as well as rocks within the Melones Fault Zone. Stops will be made at Mother Lode gold-quartz vein and altered rocks that are within the Melones fault zone.

Total Miles *Interval Miles*

0.0	0.0	El Portal. El Portal was named for the fact that it represented the eastern termination of the Yosemite Valley Railroad. The north-south striking contact between the Paleozoic Shoo Fly Complex and the Sierra Nevada batholith lies a few hundred feet east of here. At this locality, the batholith consists of tonalite, diorite and minor gabbro. This part of the Merced River valley was glaciated during two pre-Wisconsin stages. Note the barite mines on the north canyon wall, east of El Portal.
3.6	3.6	Arch Rock entrance station to Yosemite National Park.
3.7	0.1	Arch Rock. Arch Rock is comprised of two huge blocks of medium gray grano-

diorite (the Granodiorite of Arch Rock) that tumbled from the cliffs above. This and the dark gray tonalite (Gateway Tonalite or Bass Lake Tonalite), at 115 Ma, are the oldest plutons in the park. Both are a part of the Fine Gold Intrusive Suite.

8.3	4.6	Intersection with CA 41. Continue east on Highway 41 into Yosemite Valley. Pulpit Rock lies to the south, underlain by El Capitan Granite.
9.2	0.9	Intersection. Turn right and cross the Merced River via Pohono Bridge. At this point you will be in one-way traffic. A gauging station operated by the U.S.G.S. is located just upstream of the bridge. Discharge on the Merced River has been measured as low as 20 cfs (cubic feet per second) in late Fall to as high as 24,000 cfs during the Spring flood of 1997.
9.6	0.4	Bridalveil Meadow is one of the lowest meadows in the valley. The terminal moraine from Tioga glaciation can be seen to the east.
10.1	0.5	Turn right on the road to Glacier Point.
10.2	0.1	STOP 1. Bridalveil Falls. Turn left into the paved parking lot. Walk to the viewpoint at base of the falls. (Note the jumbled, chaotic blocks of Leaning Tower Granite (Illilouette Creek Granodiorite), Bridalveil Granodiorite, and El Capitan Granite that have fallen from the vertical cliffs.) At the falls one can look up at the smooth weathering cliff of Bridalveil Granite that comprises the lip of the falls. Beneath the lip of the falls, and to the right, is Leaning Tower Granite. The darker rock to the left is the Diorite of



Tuolumne Intrusive Series (Late K)

+Kap	Aplite and pegmatite
Khd	Half Dome granodiorite
Kkc	Granodiorite of Kuna Crest
Intrusive Suite of Sonora Pass (Late K)	
Ks	Sentinel Granodiorite
Kyc	Yosemite Creek Granodiorite
Intrusive Suite of Buena Vista Crest (mid K)	
Kbv	Bridalveil Granodiorite

Kol

Granodiorite of Ostrander Lake

Kic

Granodiorite of Illilouette Creek

Intrusive Suite of Yosemite Valley (Early K)

Kt

Taft Granite

Kec

El Capitan Granite

Fine Gold Intrusive Series (Late K)

Kar

Granodiorite of Arch Rock

Kga

Tonalite of Gateway

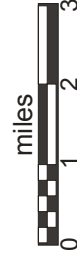
Quaternary rocks (yellow and gold) not shown in legend

Geologic Map of

Yosemite Valley

Huber, Bateman, Wahrhaftig

1989



Granitic rocks, undivided

Kg

Diorite and Gabbro

KJdg

Tonalite of Granite Creek

Jgc

Metasedimentary rocks, undivided

Jms

Metasedimentary rocks, undivided

Tms

Metasedimentary rocks, undivided

Pzme

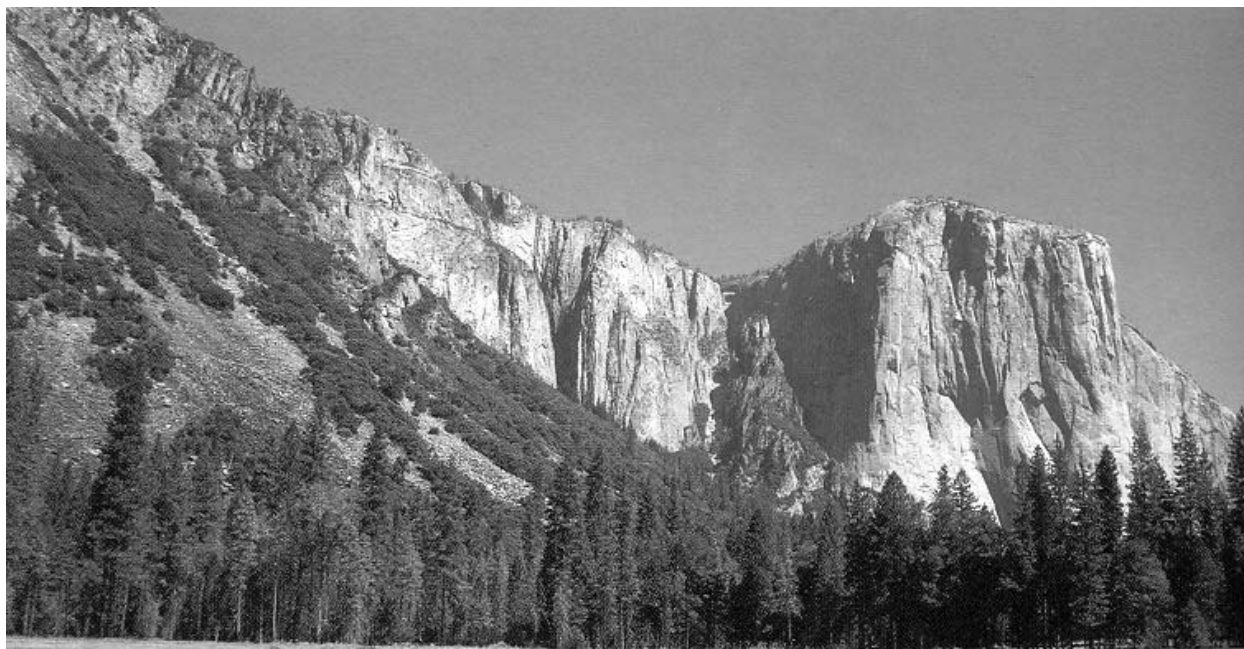


Figure 2. View of El Capitan looking to the northeast. The darker colored rock (to the left) with the apron of talus is the Diorite of the Rockslides. The light-colored vertical outcrops are El Capitan Granite.

		the Rockslides. All of these rock units are a part of the Buena Vista Crest Intrusive Suite.			the major factor shaping the valley, most of the current profile can be attributed to jointing, exfoliation and mass wasting.	
		Leave the parking lot, turn left toward Glacier Point.			Leave parking lot, turn left, proceed back downhill.	
11.6	1.5	<u>STOP 2. Tunnel View.</u> The east portal of Wawona Tunnel (Native American for “Big Trees”) was driven into El Capitan Granite. Note the exfoliation jointing above the tunnel portal. From the parking area we can look east toward many of the famous features of the park (Fig. 1). On the left (north side) of the valley is the sheer cliff of El Capitan with a vertical drop of 3000 feet. In the center distance is the prominent Half Dome and just to the north Cloud’s Rest. On the right (south) side of the valley is the high spire of Sentinel Rock, rounded Sentinel Dome and the three Cathedral Rocks. In the near foreground, to the north, is the rather unspectacular Leaning Tower.		13.3	1.7	Rejoin the Park Loop. El Capitan can be seen straight ahead.
		Although Yosemite Valley is often described as a “classic” U-shaped valley, in profile vertical canyon walls give way to a nearly flat valley floor. The flatness is caused by a lake that once occupied the valley. Over 2000 feet of sediment have accumulated locally since Sherwin stage glaciation. Much of the actual glacial “damage” was done during Sherwin glaciation, Tahoe and Tioga stage glaciers barely reached the west end of the valley. While glaciation is often cast as		14.7	1.4	Intersection. Continue east (straight ahead) on the Southside Drive
				17.4	2.7	Intersection. Bear right and continue east on Southside Drive.
				18.4	1.0	Intersection. Turn left toward Yosemite Village.
				19.7	1.3	<u>STOP 3. Yosemite Falls.</u> Pull off on the right shoulder. Columbia Rock is ahead to the west. Along the north side of the valley, from west to east, are Lower Yosemite Falls, Indian Canyon Creek, and Church Bowl to the right. On the south side, from east to west, are Union Point and Sentinel Rock. This part of the valley is underlain by El Capitan Granite and Sentinel Granodiorite. Down the valley are Cathedral Spires and Cathedral Rocks, underlain by El Capitan Granite and Bridalveil Granodiorite.
						Yosemite Falls is a composite waterfall totaling 2,400 feet with the Upper Fall (1400 feet), Middle Cascades (675 feet) and Lower Fall (325 feet). The step-like nature of the falls is caused by horizontal jointing within the Sentinel Granodio-


		rite. Yosemite Falls ranks as the fifth highest waterfall in the world.			shaped cross section of the valley due to the absence of glaciation.
20.6	0.9	Pass through Leidig Meadow with Sentinel Rock to the south across the Merced River. The upper portion of the Sentinel Granodiorite is exposed in a 2 mile-wide swath trending north-south across the valley from Leidig Meadow to the east edge of the developed portion of the valley. The Sentinel Granodiorite is intruded by the Half Dome Granodiorite (about 87 Ma) the youngest pluton in the valley. The Three Brothers, on the north-west side of the valley, are underlain by El Capitan Granite.	36.9	1.1	On left, folded and metamorphosed argillite and siltstone of the Shoo Fly Complex (?). The reddish stain is caused by the oxidation of pyrite in the argillite.
22.9	2.3	<u>STOP 4. El Capitan.</u> Pull off on the left in El Capitan Meadow. We are now within the core of the Sierra Nevada batholith. The composite nature of the batholith was not recognized by early researchers. The different rock types were ascribed to local variations in one huge pluton crystallizing more or less <i>in situ</i> . With radiometric age dating the complex history of the batholith became evident. The nine plutons in the valley were intruded over a span of about 30 million years (from 117 to 87 million Ma) during the mid-Cretaceous.	39.7	2.7	Mine dumps of the Clearinghouse mine can be seen across the river. The mine yielded more than \$3 million in gold, silver, copper and lead. The Tonalite of Bass Lake (114 Ma) is exposed north of the mine.
		Examining the face of El Capitan (Fig. 2), the dominant lithology is the El Capitan granite and younger, lighter gray, Taft Granite. The El Capitan granite is actually not a granite at all, but quartz monzonite. Small bodies of diorite cut both the Taft and the El Capitan granite. The best known is the "Map of North America Diorite", on the east side of El Capitan. The wide range of pluton composition has posed problems for petrologists. The current hypothesis proposes that mafic magmas intruded into the lower crust, melting the host rocks and generating felsic magmas. Occasionally the mafic and felsic magmas mixed giving rise to intermediate rocks.			Just west of the mine the road passes into Triassic phyllite and chert of Hite Cove Formation (Calaveras Complex). This informal unit is characterized by banded chert in a matrix of phyllite, limestone and basalt.
			41.2	1.6	Bridge over South Fork of Merced River.
			42.8	1.6	<u>STOP 5. Geologic Exhibit Marker.</u> Rocks on the opposite side of river are chert and phyllite of the Hite Cove meta-sedimentary unit of the Permian-Triassic Calaveras Complex (Bateman, 1985) (Fig. 3). The Calaveras Complex is thought to represent deep water sediment while the overlying Shoo Fly Complex (to the east) is probably a Paleozoic cratonal shelf sequence. The units are juxtaposed by the north-trending, east-dipping Calaveras/Shoo Fly Thrust.
			44.6	1.8	Limestone quarry that supplied Portland cement to Merced. The limestone bed, is mappable for over two miles, and is exposed in a roadcut at Mile 45.6. The limestone has yielded early Triassic conodonts.
			52.0	7.4	Former Octagon Restaurant to the left.
24.3	1.4	Valley View pull out. A striking panorama reveals the "gateway" to the valley formed by El Capitan and the Cathedral Rocks, both comprised of El Capitan Granite.			
24.6	0.3	Intersection. Continue west on Highway 41/140 now with 2-way traffic.			
25.5	0.9	Highways 41 and 140 split. Bear left on 140 back toward El Portal.			
33.8	8.3	Pass through El Portal.			
35.8	2.0	Bridge over Merced River. Contact of Paleozoic metasedimentary rock with the Sierra Nevada batholith. Note the V-			

Figure 3. Chert and phyllite of the Calaveras Complex, exposed along the Merced River.

- 52.4 0.4 Contact of metavolcanic rocks with the Phyllite of Briceburg. From here to the town of Midpines the volcanic rocks are generally flows and flow breccias with minor interbedded volcanoclastics.
- 53.2 0.8 Well defined pillows of metabasalt are exposed in the drainage of Bear Creek along the left side of road.
- 53.3 0.1 Bridge over Bear Creek.
- 54.9 1.6 Town of Midpines. The numerous mines in this area follow thin quartz veins. Production came from small, high-grade ore bodies. The ore contained nuggets such as the 40 and 52 pound masses mined from the Diltz mine. There are numerous "pocket mine districts" east of the Mother Lode. Pocket mines typically have thinner veins, lesser wall rock alteration, and higher ore grade than those of the Mother Lode.
- 59.0 4.1 Undeformed, volcanoclastic rock. The unit here is a poorly sorted, reworked pyroclastic deposit. The clasts are dominantly porphyritic basalt in a tuffaceous matrix.
- 61.3 2.3 First of three pods of sheared serpentinite with metapyroxenite and metagabbro inclusions. These pods lie within splays of the Melones fault zone.
- 62.3 1.0 Enter Mariposa.
- 62.8 0.5 Intersection of Highways 140 and 49. Go straight ahead (south) on Hwy. 140-49. Our destination is Mariposa County Fairgrounds and the California State Mining and Mineral Museum south of town. At south end of town, bear left on Hwy. 49. As you drive through the town of Mariposa, note the green mariposite, cream-colored carbonate, and white quartz building stone.
- 65.4 2.6 Turn left into Mariposa County Fairgrounds.
- 65.4 0.0 STOP 6. California Mining and Mineral Museum. After visiting the museum return to cars and turn right (north) on Hwy. 49.
- 65.6 0.2 Pull over on the right shoulder. Walk north along the highway to Stop 6A.
- 65.7 0.1 STOP 6A. Contact Aureole of the Sierra Nevada Batholith. Contact metamorphic aureole of the Tonalite of Bass Lake (114 Ma). The aureole here is about 2,000 feet wide. The metamorphosed rocks are coarse- to fine-grained mafic volcanics. They have been thermally metamorphosed to a biotite-hornblende hornfels (Fig. 4). It is thought that prior to contact metamorphism these rocks



Figure 4. Hornfels formed by contact metamorphism from the Bass Lake Tonalite.

were dynamically metamorphosed to lower to middle greenschist facies.

One hypotheses for genesis of Mother Lode gold deposits postulates that the Sierra Nevada batholith generated the mineralizing fluids. CO₂ and Au-bearing fluids were generated by metamorphic dehydration in the contact aureole of the batholith. The fluids were channeled by the Melones fault zone and formed the Mother Lode gold-quartz veins in the Early Cretaceous. Thus the mineralization is syn-batholith.

However, in the Mother Lode there is no correlation between gold occurrence and proximity to plutons. Furthermore, Mansfield (1979) noted clasts of quartz-mariposite in Cretaceous sedimentary rocks of the Great Valley; thus Mother Lode rocks were being eroded and carried west by Cretaceous time. In addition, age dates for alteration assemblages from the Grass Valley district (northern Mother Lode) indicate the gold-bearing veins may have been emplaced as early as 140 Ma.

Return to vehicles. Continue north toward Mariposa on Hwy. 49. Pull out on wide shoulder on right, and walk north to exposures in roadcut.

- 65.9 0.2 STOP 7. Southern Strand of the Melones Fault Zone. This strand of the Melones fault is 300 feet east of the main fault zone. At this stop, and indeed throughout its length, the Melones fault zone has this distinctive rock assemblage: serpentinite tectonic melange with inclusions of metagabbro, amphibolite, and schist.

Tectonic models for the Melones fault

		<p>zone must explain the character and mode of emplacement of these mélangé blocks, and why and how the fault zone formed where it did. The serpentinite-hosted melange and inclusions are not easily explained by thrust or suture models. Leonardo and Fyfe (1967) emphasized that serpentinization is an exothermic process that results in an increase in volume, the serpentinized rock acting much like a pluton. The less dense serpentine (S.G. = 2.2) could not remain long with the dense ultramafic rocks (S.G. = 3.4). Because of this density contrast the serpentine is buoyantly driven to rise even through volcanic and sedimentary rocks (S.G. = 2.6). The rising blocks most likely followed thrust surfaces in the huge accretionary prism. As the serpentinite blocks rose they entrained inclusions, sampling the rocks through which they passed.</p> <p>Continue north to Mariposa on Hwy. 49.</p>			
66.9	1.0	Re-enter town of Mariposa.			
68.1	1.2	Turn left on Hwy. 49 and head north. Hwy. 49 is known as the "Mother Lode Highway" because it connects the towns and mining districts along the Foothills. In 1933, the number "49" was assigned to it and the state route signs were made in the shape of a miner's shovel.			
70.6	2.5	Highway 49 passes through serpentinite of the Melones fault zone. Here the fault zone is about 2,700 feet wide and has numerous metagabbro and diorite inclusions, one of which yielded an age of about 197 Ma.			
71.6	1.0	Road crosses into slate, pebbly sandstone, and conglomerate of the Mariposa Formation (footwall of the Melones fault zone).			
71.8	0.2	Turn right toward California Youth Conservation Camp. Road climbs Mt. Bullion.			
73.5	1.7	For next 0.1 mile, deformed metabasalts. Still in footwall west of Melones fault zone.			
74.0	0.5	Pass into volcanic sandstone and siltstone.			
74.9	0.9	<u>STOP 8. Narrow Part of Melones Fault Zone.</u> Thin zones of sheared serpentinite characterize the Melones fault zone at this stop. Here, the fault zone is about 1,000 feet wide. Because the fault outcrop is at an elevation of 3,250 feet, it lacks the melange of the previous stop. Rocks exposed in the hanging wall are schist, phyllite, and metavolcaniclastics.			
75.1	0.2				Rocks exposed in the footwall are metabasalt pillow lavas, flows and pebbly sandstone of the Mother Lode Belt.
78.3	3.2				Turn around at the crest of the hill and return to Hwy. 49.
79.5	1.2				Intersection with Hwy. 49, turn right (north). Mariposa International Airport was built in 1937 as a W.P.A. project.
85.4	5.9				Old Toll Road on left. Argillite, siltstone, sandstone, and pebbly sandstone of the Mariposa Formation extend from here to the top of the grade north of Bear Valley.
88.1	2.7				Enter Bear Valley.
					<u>STOP 9. Serpentinized Harzburgite.</u> Pull off to left. The rocks exposed in this roadcut lie within the Melones Fault Zone (Fig. 5). Although highly serpentinized, the protolith is thought to be harzburgite (peridotite). Examining the outcrop you will note the serpentinite is strongly sheared (there are slicks on most surfaces) and locally silicified.
88.4	0.3				<u>STOP 10. Pine Tree-Josephine Mine.</u> Pull off to the right. The view to the north looks down the Merced River and along strike of the Mariposa Formation. The ridge west of the valley is underlain by the Penon Blanco Formation. The lower slopes of the ridge east of the valley are underlain by serpentinite of the Melones fault zone; the upper slopes are underlain by metaclastics of the Calaveras Complex.
					The Pine Tree-Josephine mine formerly produced about 118,000 ounces of gold. Goldenbell Resources was engaged in renewed exploration until 1989 when, after a permitting battle, they withdrew from the property.
					In this roadcut, argillite, siltstone and sandstone of the Mariposa Formation form the footwall to an east dipping ore zone. The mineralized zone is comprised of black schist cut by a stockwork of quartz veins and a zone of carbonate-mariposite-talc-pyrite alteration.
					The Pine Tree and Josephine veins occupy two structures within the Melones fault zone. The Pine Tree vein is a large, low grade, bull quartz vein, whereas the Josephine "vein" is a zone of black schist cut by a stockwork of quartz veinlets. The mafic rocks between the two structures are almost completely altered to carbonate.
					Proceed down hill to the north.
					As you drive down the grade note the

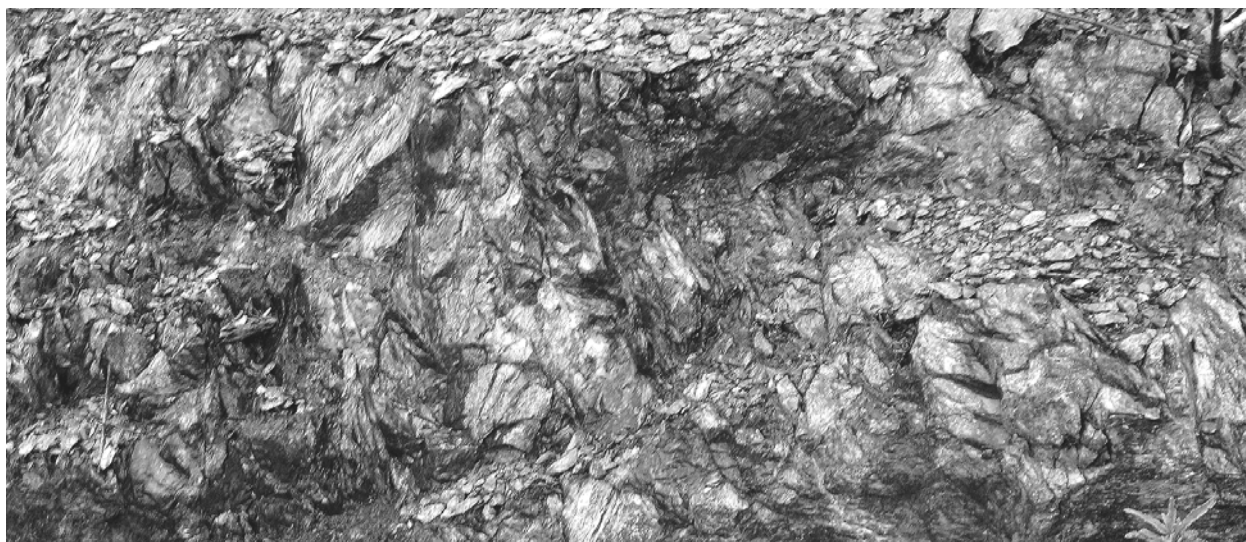


Figure 5. Highly sheared and serpentinized harzburgite (?) from the Melones Fault Zone, Pine Tree-Josephine Mine.

		massive sandstone beds on east side of the road. They are a fining upward turbidite sequence.			
90.9	2.5	Bagby Bridge over Merced River. Lake McClure Campground to the east. DRIVE-BY. Mariposa Formation and Penon Blanco Formation west of Bagby Bridge, along Lake McClure. Exposures along strike of the Mariposa Formation are found on either side of Lake McClure and extend about 4 miles downstream. North of that, the Merced River cuts down section, providing superb exposures of the underlying Penon Blanco Formation. North of the bridge the road enters a pod of serpentinite melange of the Melones fault zone.		99.3	1.2
95.3	4.4	Roadcut at right. Alligator Rock is the reddish rock. It owes its appearance to weathering of bastite, a serpentine mineral.			lena. DRIVE-BY. Albitite Dikes. Albitite dikes (An_{0-3}), are common along the Melones fault zone. The dikes occur at the periphery of the serpentinite melange throughout the fault zone. They are commonly 50-95% albite with accessory aegirine, riebeckite, hornblende, actinolite, chlorite, muscovite, epidote, and sphene. Reportedly, albitite dikes form by Nametasomatism of mafic dikes. However, the large amount of albite in the Mother Lode region is unusual.
98.1	2.8	<u>STOP 11. Virginia Mine.</u> On the hillside to the west you can see the workings of the Virginia mine (Fig. 6). It was opened in 1850 and produced about 37,000 oz. of gold. The mine workings follow a "bull" quartz vein that lies at the contact between serpentinite and metasedimentary and metavolcaniclastic rocks. The quartz vein strikes N. 50°-55° W. and dips 60° NE. The main ore shoot was nearly vertical and was mined to a depth of 1,200 feet where it reportedly pinched out. Ore minerals were native gold, auriferous pyrite, chalcopyrite, and galena.		101.0	1.7
				101.3	0.3
					Enter the town of Coulterville. Intersection with Hwy. 132. Turn left and park near the small museum. Walk along the right shoulder of Hwy. 132 about 200 yards. <u>STOP 12. Mariposite-Carbonate-Quartz Alteration in the Melones Fault Zone.</u> This is the most accessible exposure of mariposite-carbonate-quartz altered serpentinite in the Melones fault zone (Fig. 7). Mariposa Formation (slate, siltstone and a series of dikes) lying within the footwall of the Melones fault zone can be seen to the west. White quartz/carbonate veins cut the rust-colored carbonate-mariposite-quartz rock. Mariposite is the bright green chromium mica seen on fresh surfaces. A large, white, quartz vein crops out in the center of the alteration zone. This outcrop exposes a narrow portion of the Melones fault zone and its footwall rocks. The mariposite-carbonate alteration occurred when a fluid with a rela-



Figure 6. "Bull" quartz vein marking the contact between serpentinite and hanging wall metasedimentary and metavolcanic rocks, Virginia Mine.

tively high content of CO₂, potassium, and sulfur contacted the serpentinitized rocks. Chrome spinel (note the black specks in green mica) was altered to Cr-chlorite and to Cr-muscovite (mariposas); feldspar to sericite; and magnetite to pyrite.

The mariposite-carbonate-quartz assemblage grades eastward into a talc ± carbonate-pyrite schist which in turn grades into unaltered serpentine. The abundant quartz veins are probably products of silica liberated as silicate rocks were transformed into carbonates. The footwall of the fault zone is relatively unaltered because the argillite was relatively unreactive.

Return to vehicles, proceed north on Hwy. 49.

- 105.6 43 Enter Tuolumne County.
- 106.9 0.4 Haigh Mariposite Quarry. Mariposite-carbonate-quartz rock has been mined here and sold as ornamental stone. Kistler and others (1983) calculated an age of 114.6 Ma for mariposite from this quarry.
- 108.8 1.9 STOP 13. Placer Mining by Hand. The piles of cobbles along Moccasin Creek are a remnant of the placer mining days. Gold is separated from quartz by mechanical abrasion in the bed load of streams. Because of its high density (S.G.= 19.3) gold separates from the sand and gravel (S.G. = 2.6) and concentrates on the bedrock surface. Although some gold is carried downstream and some trapped within the gravels, most settles to the bedrock surface where it lodges in cracks and crevasses.

J. D. Borthwick, an artist from Scotland,

caught gold fever and sailed from New York to California in 1851. He described the scene in the goldfields in his diary.

"Along the whole length of the creek, as far as one could see, on the banks of the creek, in the ravines, ... were parties of miners, numbering from three or four to a dozen, all hard at work, some laying into it with picks, some shoveling the dirt into the 'long toms,' or with long-handled shovels washing the dirt thrown in, and throwing out the stones, while others were working pumps or baling water out of the holes with buckets. There was a continual noise and clatter, as mud, dirt, stones, and water were thrown about in all directions; and the men,



Figure 7. Quartz (white) - ankerite (brown) - mariposite (green) alteration within the Melones Fault Zone.

		<p>dressed in ragged clothes and big boots, wielding picks and shovels, and rolling big rocks about, were all working as if for their lives, going into it with a will, and a degree of energy, not usually seen among laboring men. It was altogether a scene which conveyed the idea of hard work in the fullest sense of the words, and in comparison with which a gang of railway navies would have seemed to be merely a party of gentlemen amateurs playing at working."</p> <p>"I should mention that 'dirt' is the word universally used in California to signify the substance dug, earth, clay, gravel, loose slate, or whatever other name might be more appropriate. The miners talk of rich dirt and poor dirt, and of 'stripping off' so many feet of 'top dirt' before getting to 'pay dirt,' the latter meaning dirt with so much gold in it that it will pay to dig it up and wash it."</p> <p>"The apparatus generally used for washing was the 'long tom,' which is nothing more than a wooden trough from twelve to twenty-five feet long, and about a foot wide. At the lower end it widens considerably, and on the floor there is a sheet of iron pierced with holes half an inch in diameter, under which is placed a flat box a couple of inches deep. The long tom is set at a slight inclination over the place which is to be worked, and a stream of water is kept running through it. ... while some of the party shovel the dirt into the tom as fast as they can dig it up, one man stands at the lower end stirring up the dirt as it is washed down, separating the stones and throwing them out while the earth and small gravel [and gold] falls with the water through the sieve into the riffle box. This box is about five feet long, and is crossed by partitions. It is also placed at an inclination, so that the water falling into it keeps the dirt loose, allowing the gold and heavy particles to settle to the bottom, while all the lighter stuff washes over the end of the box along with the water."</p> <p>At the end of each shift, the heavy minerals that concentrated behind the riffles were collected and the gold was recovered by panning.</p>
111.3	2.5	Moccasin Powerhouse. Moccasin power
		<p>plant was completed in 1925. The plant and the town of Moccasin are owned by the city of San Francisco. The project began in 1915 with the construction of the Hetch Hetchy dam on the Tuolumne River. The reservoir flooded Hetch Hetchy Valley much to John Muir's chagrin. It took 20 years and \$100 million to complete seven dams, three powerhouses, and miles of tunnels and power lines. The project supplies water and power to three million customers in the San Francisco Bay area.</p>
112.2	0.9	<p>Junction with Hwy. 120. Continue north (left) on joint Hwy. 49-120.</p> <p>DRIVE-BY. Deformed Pillow Lavas, New Priest Grade. The pillow lavas in this outcrop near the Melones fault zone are flattened to a few inches in thickness.</p> <p>They represent lateral equivalents of undeformed pillow lavas in the lower part of Penon Blanco Formation. The rocks are lower to middle greenschist facies.</p>
116.3	4.1	Bridge over Don Pedro Reservoir.
118.6	2.3	Sheared serpentinite with numerous inclusions of diorite, gabbro, metavolcanic, and metasedimentary rocks. This serpentinite is in a splay of the Bear Mountain fault zone.
120.3	1.7	Chinese Camp. Chinese Camp was settled by Chinese miners in 1849. Evidence of placer mining is everywhere.
120.7	0.4	Highways 49 and 120 separate. Stay to the right on 49.
122.5	1.8	Cross the Sierra Railway. Flat-topped Table Mountain can be seen ahead on skyline (we will stop there time permitting). Table Mountain is a beautiful example of inverted topography. The latite of Table Mountain flowed down the Miocene drainage of the Stanislaus River. The flows erupted from a cluster of volcanic peaks, the Dardanelles, 50 miles to the east in the High Sierra. The 9 Ma lavas are part of the Late Miocene/Pliocene Mehrten Formation. Subsequent erosion removed the less resistant rock of the former river bank, but preserved the Pliocene flows as a sinuous volcanic ridge. Pre-latite auriferous gravels are present locally beneath the latite. The gravels have been mined from drifts beneath Table Mountain.
124.4	1.9	Intersection of Hwy. 49 and Hwy. 108. Turn left (west).
128.0	3.6	Turn right on County Road E 15 (O'Byrnes Ferry Road).
128.2	0.2	Right on Peoria Flat Road.



Figure 8. View looking to the northwest of the sinuous, Table Mountain latite flow. California Highway 108 is in the lower left corner of the photograph. (Source: [http://virtual.yosemite.cc.ca.us/ghayes/Table Mountain.htm](http://virtual.yosemite.cc.ca.us/ghayes/Table%20Mountain.htm))

128.7 0.5 STOP 14. Table Mountain. The vertical cliffs are developed in columnar-jointed latite along the margin of a paleodrainage (Fig. 8). Phenocrysts of augite, olivine, and plagioclase are visible; orthoclase is confined to the groundmass.

The latite of Table Mountain preserves features which document events from the development of an Eocene peneplain to the outpouring of latite in the Pliocene. The earliest gold-bearing stream channels are characterized by quartz gravels. The Eocene streams commonly followed the strike of bedding, cutting gutters (the lowest and usually the richest part of an alluvial deposit) and depositing gold. The Eocene gravels are overlain by a sheet of tuff, gravels, and boulders of andesitic composition known as the Mehrten Formation. In places, post-Mehrten drainages cut through the Mehrten and the underlying Eocene gravels resulting in a channel deposit of mixed gold-bearing gravels.

129.5 0.8 The dumps visible ahead are from the Calaveras Asbestos Company mine. The mining of chrysotile from a serpentinite pod continued until 1987. The annual production was small, about 3,500 tons. Most of the product was sold to Pacific Rim countries.

131.4 1.9 Turn right into parking lot and stop at the Forest Service office. The New Melones Dam is operated by the Bureau of Reclamation and access is through a locked gate. To get permission to enter the dam area you must call the power plant (209-984-3812) and they will remotely unlock the gate. Once that gate is unlocked you quickly drive through the prison (don't pick up any hitchhik-

ers) and to the gate. You will be able to open the gate and drive to the powerhouse. There you will meet an escort who must take you through two additional locked gates (this dam is a very secure place!).

134.2 2.8 New Melones Dam and powerhouse on the right (meet escort here). Proceed through a locked gate past the powerhouse.

136.6 2.4 Turn left on gravel road made of serpentine. Proceed downhill to the northeast end of the spillway.

138.1 1.5 STOP 15. Cross-Section Through the Bear Mountain Fault Zone. This cut exposes a spectacular view of the Bear Mountain fault zone, here a tectonic melange containing slices of oceanic crust and wall rocks of the fault zone; pieces of volcanic and sedimentary rock from the Central (Mother Lode) Belt to the east and from the Western Belt to the west. This fault zone is analogous to the Melones fault zone. The fault zones likely join at depth.

Judging from the similarity of these rocks to those in the Mother Lode Belt, the rocks probably range in age from early to mid Jurassic. The lithologies include serpentinitized plutonic ultramafic rock (harzburgite), gabbro, amphibolite, basaltic dikes, basaltic to andesitic volcanic flows and black argillite. Quartz veins cut all.

The tectonized nature of the fault zone can be seen along the spillway. Zones of sheared serpentine define the boundaries of this fault zone. Economic concentrations of chrysotile formed during serpentinization.

		Return through the U.S. Bureau of Reclamation gate, taking Peoria Flat Road back to E 15 and Highway 108.
148.2	10.1	Turn left (east) toward Jamestown/Sonora.
153.7	5.5	Harvard Gold Mine to the north of highway. Mexican miners from the State of Sonora established the Sonora mining camp in 1848, and stayed until a tax levied on non-citizen miners in 1851 forced most of them to leave. It was first called Sonoran Camp to distinguish it from American Camp. The Sonora mining district was originally a placer district and pocket mining district. Placer gold production was reportedly about \$11 million. Lode gold was commonly mined from high grade, bonanza pockets in quartz veins generally less than a few feet wide in metasedimentary and metavolcanic rocks. The high grade pockets commonly were at the intersections of cross fractures.
		Sonora Mining Corporation began mining the Harvard deposit from an open pit in 1983; the mine closed in 1994. The veins in the Harvard and other mines of the district are localized along smaller faults within the Melones fault zone. A serpentinite melange pod constitutes the footwall for the vein systems. The dominant hanging wall lithologies are phyllite, slate, tuffaceous sandstone, siltstone, and minor metavolcanics.
154.8	1.1	Historic Jamestown to the right. Jamestown was a once-wild boom town, founded in 1848 by Colonel George James. James was a San Francisco lawyer before trying his hand at gold mining. Lured by the discovery of a 75-pound gold nugget at Woods Creek, James became involved in a series of failed land schemes and departed the region a year later owing money to just about everybody in the area. Nicknamed "Gateway to the Mother Lode," this Gold Rush town features restaurants and a picturesque main street complete with covered balcony architecture and handsomely restored buildings. A 1966 fire destroyed some of the old buildings. However, the National Hotel, which has operated continuously since 1859, thrives; it is well known for its food and wine festivals.
158.1	3.3	Sonora, Turn left on Hwy 49.
160.7	2.6	Bear right on Parrots Ferry Road toward Columbia State Historic Park.
162.3	1.6	<u>STOP 16. Columbia State Historic Park.</u>

Columbia was one of hundreds of settlements that sprang up during the gold rush years in central California.

On March 27, 1850, Dr. Thaddeus Hildreth and a handful of other prospectors, made camp near here. They found gold, and miners streamed in to share the wealth. Before the month was out Hildreth's Diggings, a tent and shanty town housing several thousand miners, was created. Its original name was soon changed to American Camp and then, because that sounded too temporary, to Columbia.

After 1860, when the easily mined placer gold was gone, the town began to decline. In the 1870s and '80s many of the vacated buildings were torn down and Columbia's population dropped from a peak of six thousand to about five hundred. The town continued to survive, but not prosper for many years. During the 1920's ideas began to arise for the inclusion of Columbia into the California State Park System. In 1945 the effort was finally successful. Thus, was Columbia State Historic Park born.

End Road Log