NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

FIELD TRIP - MAY 10-11, 1975

WESTERN MARGIN SACRAMENTO VALLEY - CLEAR LAKE AREA

by

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This trip, which extends through 2 days with an overnight stop in the resort area bordering Clear Lake, provides an opportunity to see typical sedimentary and volcanic rocks of the western Sacramento Valley and northern Coast Ranges, as well as "sedimentary" (?) and intrusive masses of serpentine and an unusually interesting major mercury mine.

Sketch of Geology

The Coast Ranges and western Sacramento Valley in the area extending north from San Francisco to Clear Lake consist chiefly of two very thick sequences of Late Jurassic to Late Cretaceous age, which were deposited in a deep fore-arc basin. The Franciscan Formation consists of graywacke, shale, altered mafic volcanic rock, chert, limestone, and locally metamorphic rocks of the blueschist facies. It is not emphasized on this trip. The shelf, slope and basin plain which have been called the Great Valley sequence, consist largely of clastic sediments, sandstone, shale, and conglomerate. So far as is known, these two great sequences, though coeval, do not interdigitate, and in many places they are separated by a sheet of serpentine. It has been suggested that the Franciscan assemblage represents tectonic deformation in a late Mesozoic trench. The Great Valley sequence may represent deposition in an arc-trench gap between the Franciscan trench and the Sierran arc.

The first day of the trip is devoted chiefly to viewing the Mesozoic strata of the Great Valley sequence in the exposed steep western limb of the Sacramento Valley. The section here is at least 30,000 feet thick. It is overlapped by the continental Pliocene Tehama Formation that contains a rhyolitic tuff, the Nomlaki Tuff member, near its base. The Cretaceous part of the Great Valley sequence is notable for its sedimentary structures - groove casts, flute casts, other kinds of sole markings, shale pull-aparts, and large submarine slumps. Fossils are present but are not common.

Of unusual interest are beds of "sedimentary serpentine" (?) that will be seen in part of the section. Some of these are over 1,000 feet thick, and as they consist almost entirely of shreds and blocks of serpentine, they closely resemble the normal sheared serpentine sills found through much of the Coast Ranges. Others, however, are very thin, some being less than an inch thick, and in places they form dozens of layers alternating with equally thin layers of black Paskenta shale. Locally the "sedimentary serpentine" (?) beds contain lenses of very fossiliferous limestone. This unusual sediment is thought to have formed as a result of serpentine slides descending into the sea during the deposition of the mudstones. Other workers believe the serpentinite has been injected into the section.

Volcanic rocks of Pleistocene to Recent age, the Clear Lake Volcanic Series of Brice (1953), are found about the southern half of Clear Lake, and the lake itself results from the outlet being dammed by one of these volcanic flows. The volcanic rocks show great diversity both in composition, which ranges from olivine basalt to rhyolitic obsidian, and in kind of accumulation, which ranges from formless volcanic fields to tableland flows, obsidian domes, and volcanoes so young they still retain their conical shape and central crater depressions. They have been extensively studied by C. A. Anderson (1936) and Brice (1953).

The Sonoma Volcanics, which will be seen extending from a point 15 miles south of Clear Lake essentially to San Francisco Bay, are Pliocene and therefore older than the Clear Lake Volcanic Series. Although they are widespread, they have not yet been adequately studied. Included in the Sonoma Volcanics are basalt flows and breccias, extensive andesitic breccias and tuffs, and rhyolitic tuffs and welded tuffs. In many areas they are pervasively altered either by deep weathering or by hydrothermal solutions perhaps related to those that formed the mercury deposits in the span from Calistoga to Clear Lake.

The trip passes through several mercury districts which are in order: the Wilbur Springs district, the Clear Lake district, and the Mayacmas district, in the main Mayacmas range crossed between Clear Lake and Calistoga. These districts together have yielded about a fifth of the mercury recovered in the United States. Most of the mercury deposits are in Franciscan rocks or in silica-carbonate rock formed from serpentine. The mineralization, however, is very young, being Pleistocene or Recent in age. At the Sulphur Bank mine, hot waters are now depositing mercury, and at The Geysers in the western part of the Mayacmas district, natural steam is being used for the commercial generation of electricity.

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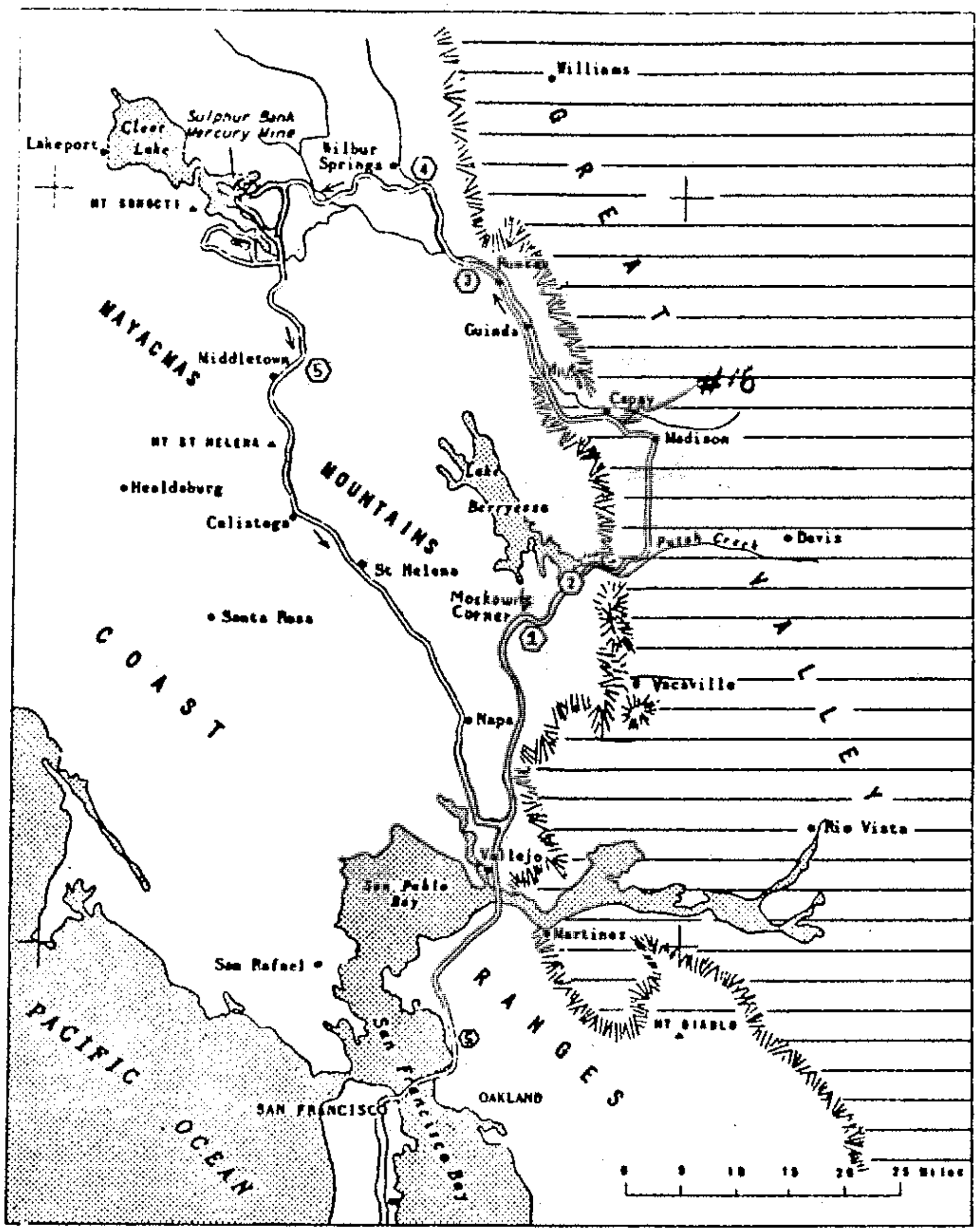

Figure 1. Index map of area between San Francisco and Clear Lake, showing boundary between Coast Ranges and Great Valley and route of field trip. Stops in road log are indicated by numbers in hexagons.

Mileage

Mileage	
0.0	Intersection Interstate 80 and Gilman (Berkeley).
2.0	Franciscan graywacke underlies El Cerrito Hill on the right.
6.5	San Pablo Dam Road exit. Within the next half mile, the highway curves westward and crosses the Hayward fault. This fault or fault zone, buried under alluvium at this location, generally separates the Franciscan of the San Francisco-Marin block from the younger sedimentary rocks of the Berkeley Hills block on the east. For about 9 miles beyond this fault, the highway crosses a folded and faulted series of Tertiary sedimentary rocks that is notable for rapid facies changes. The formations included are the nonmarine Pliocene Orinda formation, the Pinole Tuff, the middle Miocene Monterey formation, the marine Upper Miocene San Pablo Group, and at the far eastern side the Paleocene Martinez formation.
9.2	Newly repaired section of highway. This section of the highway was destroyed by a large landslide in the spring of 1969.
12.3	California Highway 4 exit.
13.6	Gently dipping San Pablo Group sandstone and shale can be seen on both sides of the road.
14.5	Union Oil Company Oleum refinery on left side of highway.
14.8	Near-vertical Cierbo Sandstone of the San Pablo Group.
15.9	Just west of Crockett exit. The Franklin fault, a fault dipping steeply to the northeast, is crossed nearly at right angles by this large road-cut, and is best seen on the left side of the highway near the eastern end of the cut. Along the Franklin fault undifferentiated Upper Cretaceous rocks are thrust relatively eastward over the Tertiary section.
16.1	Carquinez Bridge across Carquinez Straits through which drains the waters of the Sacramento-San Joaquin Rivers from Suisun Bay on the right to San Pablo Bay on the left.
18.3	Carquinez Bridge toll plaza. Undifferentiated Cretaceous sandstone and shale are exposed on both sides of the highway. From here, through the town of Vallejo, the highway traverses Upper Cretaceous rocks that are poorly exposed.
23.0	Napa (California Highway 37) exit. Sulphur Springs Mountain on the left.

24.0 Bold outcrops of red, radiolaria-bearing chert of the Franciscan assemblage are exposed on the left. The chert, together with associated sandstone, serpentinite, and Jurassic Knoxville (Stony Creek petrofacies) have been tectonically emplaced within the Cretaceous section along numerous faults.

24.6 Fault contact of Cretaceous shale with Franciscan chert and sandstone to the east. The rust-brown rock exposed in the roadcut is silica-carbonate rock, a hydrothermal alteration product of serpentine, which in many places is the host rock for mercury deposits.

24.8 Parking area. Serpentinite is well exposed along eastern end of parking strip.

25.0 Greatly contorted fault contact of serpentinite and Cretaceous rocks.

26.1 Ahead and to the left, Eocene sandstone resting unconformably on Lower Cretaceous shale. The lowest Tertiary formation in this section is the Domengine sandstone. Above this sandstone is the thick Upper Eocene Markley sandstone member of the Kreyenhagen formation.

29.2 Entering Green Valley. The hills ahead, across Green Valley and on both sides of highway, are underlain by the Sonoma Volcanics. The trace of the Green Valley fault, which some workers correlate with fault strands south of Suisun Bay, underlies this valley. Many geomorphic features within the alluvial fill indicate that movement along the fault is continuing at the present time.

30.3 Green Valley exit

31.2 Turn off Interstate 80 at Suisun Valley Road exit. Turn left at stop sign and cross over the freeway. Follow signs to Lake Berryessa.

32.5 Solano Community College on right. Outcrops of Sonoma volcanics on left.

33.2 Stop light in town of Rockville. Continue straight ahead.

35.0 Putah South Canal Pump Station. On the left, Lower Cretaceous rocks underlie the lower hills in the middle distance and the skyline-hills are capped by the Sonoma volcanics. Low hills on right are underlain by Lower Cretaceous sediments.

37.9 Napa County line. For the next 0.9 miles the road borders the eastern margin of a small window of the Franciscan assemblage within Lower Cretaceous rocks. Hills straight ahead are capped by the Sonoma volcanics.

38.8 Junction with Wooden Valley Crossroad. Keep straight ahead. The Lower Cretaceous sandstone and shale exposed in roadcut is most likely within the Lodoga petrofacies. A small pod of intensely sheared serpentinite, within the Cretaceous section, also is exposed in the roadcut.

39.8 Bold outcrop of medium- to thick-bedded sandstone in roadcut. Handlens identification of framework composition of the sandstone suggest that the rocks are part of the Lodoga petrofacies (Lower Cretaceous).

41.4 Entering small alluviated valley. The hills bordering this valley are underlain by Lower Cretaceous rocks.

42.7 Wooden Valley School.

43.4 At about 2 o'clock in middle distance, bare hill with stone fence is underlain by another thin lens or stringer of serpentinite enclosed in Lower Cretaceous rocks.

43.7 Junction California Highway 121. Turn right onto Highway 121 toward Lake Berryessa. On left, roadcuts expose Sonoma volcanics and on right another view of the serpentinite lens seen at mileage 43.4. For the next 4.9 miles the rocks exposed in roadcuts are, in general, successively lower in the section, although the continuity of the section is disrupted by numerous faults with small displacements.

48.6 At stone bridge. Bold outcrop on left is part of a conglomerate lens enclosed in the Upper Jurassic Stony Creek petrofacies (Knoxville ?). The contact between the Upper Jurassic and Lower Cretaceous rocks is uncertain at this locality but is unconformable about 20 miles to the north.

48.7 High hill ahead and on the left is underlain by a small Tertiary intrusive breccia, probably of Pliocene (?) age.

49.3 Moskowits Corner, Junction with California Highway 128. Continue southeast on Highway 128.

49.4 STOP 1. The rocks exposed in the roadcut are near the base of the Late Mesozoic marine Great Valley Sequence which borders the western margin of the Sacramento Valley. The Great Valley Sequence is more than 30,000 feet thick and consists entirely of interbedded and interfingering sandstone and shale with locally exposed discontinuous lenses of conglomerate. The sandstone beds form discrete "packets" within a predominantly shaly section and provide a basis for subdividing of the Great Valley Sequence into lithologically and petrologically mappable units.

The rocks in this roadcuts are part of the Stony Creek petrofacies (Knoxville ?) which is characterized by sandstone beds containing a generalized detrital framework composition of a low percentage of quartz, moderate percentage of plagioclase fledspar (K-feldspar usually absent), and high percentage of lithic fragments, commonly of basaltic or andesitic composition. The exposure here is extremely high in basaltic and andesitic lithic fragments and may be equivalent to the "basaltic sandstone" unit of Brown and Rich (1961), and Rich (1971). The bedding characteristics suggest deposition in an interchannel area on the inner or middle part of a submarine fan.

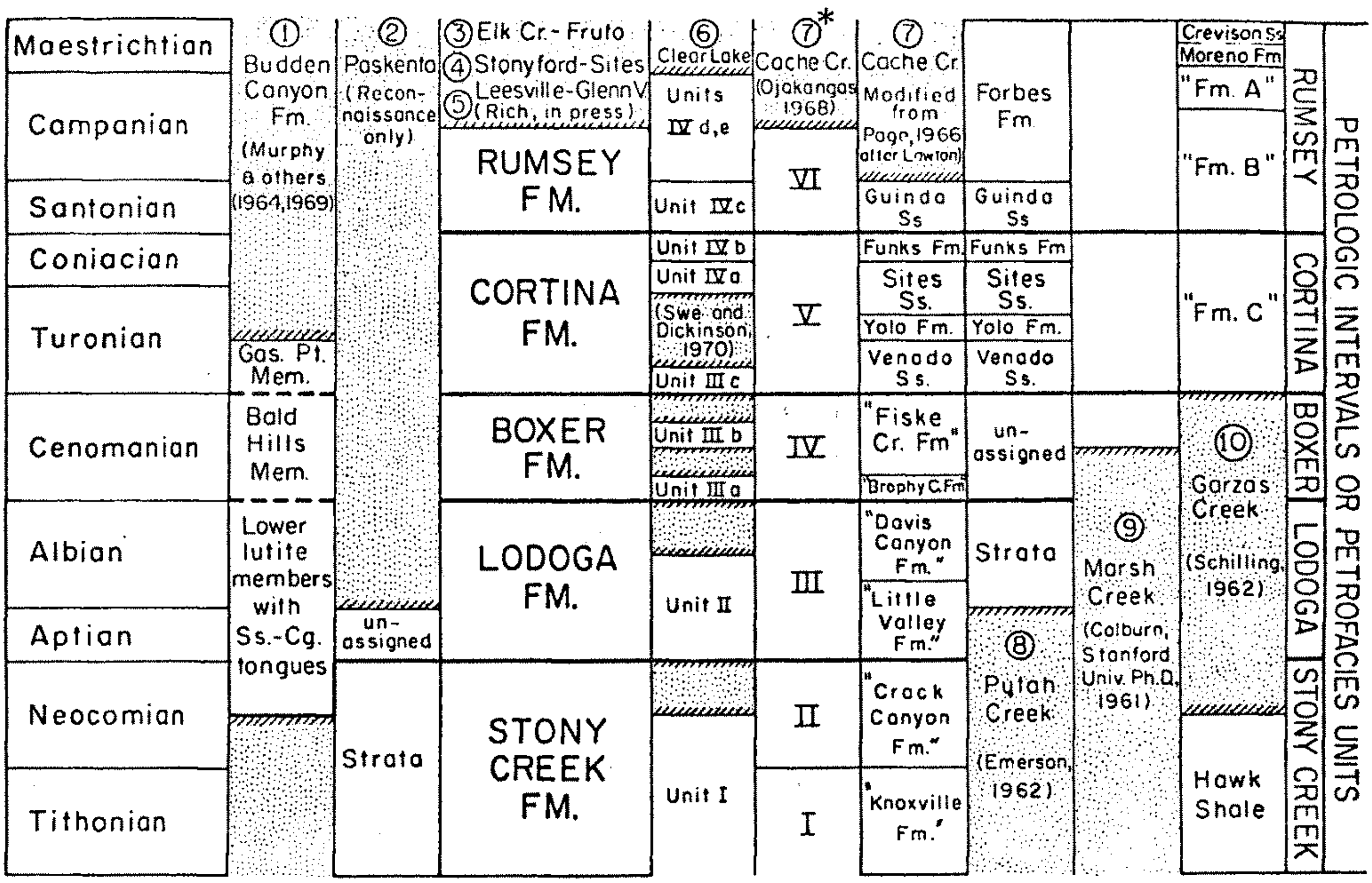

Figure 2. Correlation chart of units used in the Sacramento and northern San Joaquin Valleys for the Great Valley Sequence. From Dickinson and Rich (1972).

In the general vicinity of this stop, the area to the west is underlain by shale and sandstone of the Stony Creek petrofacies. The hill and large block alongside the road ahead (east) is a large "knocker" of basalt imbedded in serpentinite which may be near the basal contact of the unit.

50.2 On left, massive conglomerate unit in the Lodoga petrofacies. The conglomerate consists of discrete lenses one atop another and may represent fan-channel deposits within a shaly slope environment. The contact between the Stony Creek (Upper Jurassic) and the Lodoga (Lower Cretaceous) is concealed in this area, but it is commonly unconformable.

52.0 Roadcut on left is a massive sandstone unit within the Lodoga petrofacies. A generalized framework composition of the Lodoga facies is: very high percentage quartz, high percentage plagioclase (commonly only 1 to 5% K-feldspar), and low percentage of lithic fragments.

52.8 Wragg Canyon. The western margin of this narrow valley is bounded by the Wragg Canyon Fault. The displacement along the fault at this point is uncertain but it is probably no more than 100 feet. The fault dies out within one mile north (left) of this area but can be traced for about 3 miles toward the south (right). An analysis of ERTS-imagery suggests that this fault, or a branch thereof, may be present as far south as the Sacramento River. Exposures of the upper Lodoga petrofacies in roadcuts for the next 4.3 miles. In this area the upper part of the Lodoga petrofacies is predominantly continuous thin bedded to laminated shale, typical of deposition in a basin plain or slope environment. The number and thickness of individual sandstone beds increases toward the north.

56.8 Outcrop on left shows syndepositional slumping possibly within a slope environment.

57.1 On left, massive pebbly sandstone marks the contact between the Lodoga and Boxer petrofacies. This pebbly sandstone is probably equivalent to the "Salt Creek Conglomerate" in the Cache Creek and Wilbur Springs areas. The rocks may have been deposited in or near inner fan channels which are transitional both vertically and laterally to shaly slope facies. The Boxer petrofacies (in older literature informally referred to as "Antelope Shale") marks the first appearance of K-feldspar as an appreciable component in the framework composition. The percentage of quartz and of lithic fragments is variable and in many places is similar in composition to parts of the overlying petrofacies. The Boxer petrofacies may be distinguished, however, from lower petrofacies on the basis of the K-feldspar content and often higher lithic percentage.

57.2 On left, slump structures. For next 2.6 miles the route traverses the shaly slope deposits of the Boxer petrofacies.

57.8 Lake Berryessa visible on the left.

58.2 Directly ahead a view of Blue Ridge which is underlain by the Venado sandstone of the Cortina petrofacies.

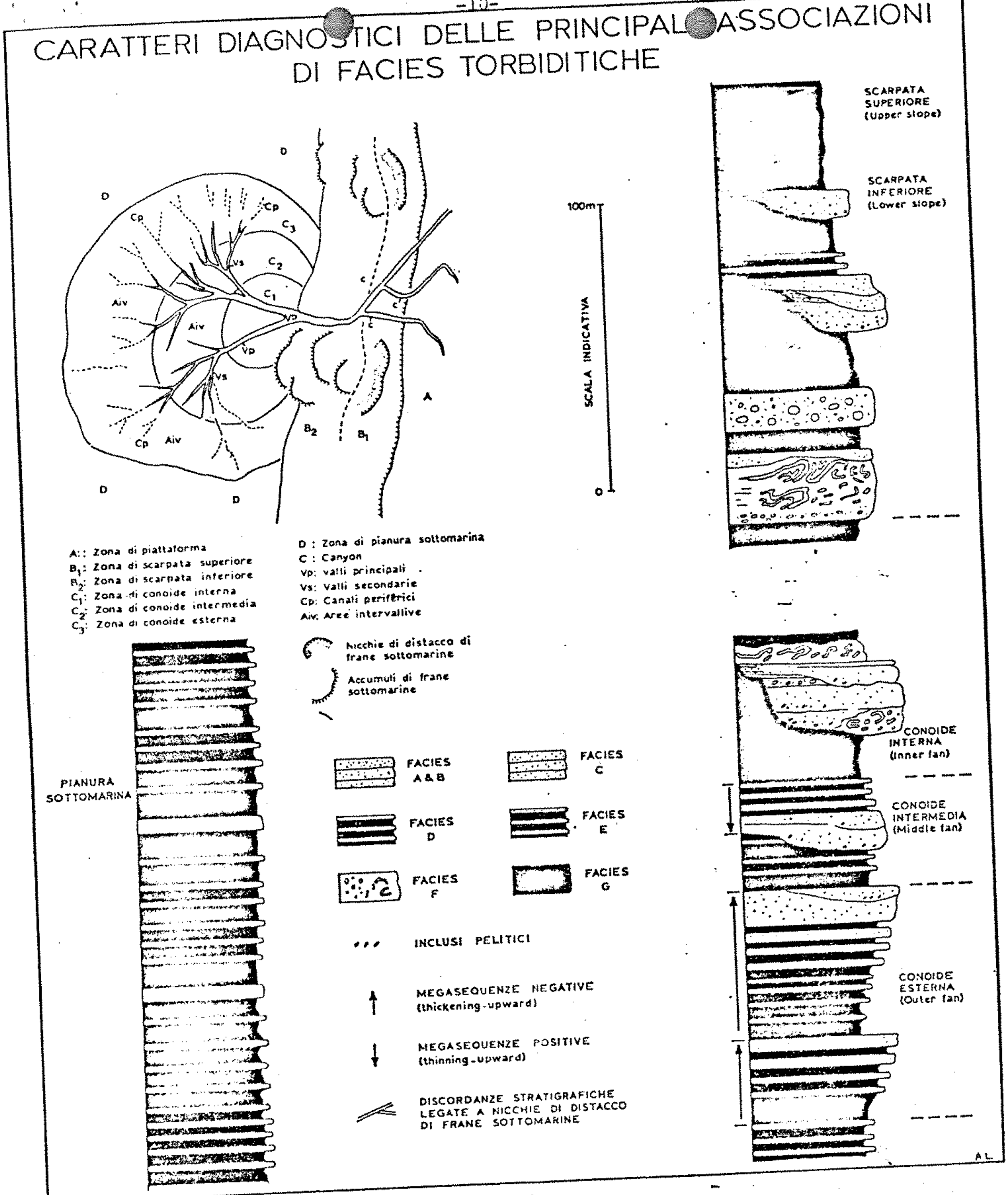

Figure 3. Diagnostic characteristics of the principal associations of turbidite facies. Submarine fan model is shown in upper left and sedimentary sequences expected on different parts of the fan are shown below and to the right. From Mutti and Ricci Lucchi (1972).

59.9 STOP 2. Monticello Dam

The Venado formation (Cortina petrofacies) exposed here was presumably deposited concurrently with a marine transgression eastward onto the Sierran arc. Paleocurrent studies have shown that the sediment was deposited by generally westward flowing currents (gravity flow currents) at this time. As a result, the Venado formation shows a retreat of fan facies from bottom to top. Slope facies (Boxer petrofacies) underlie the Venado and the base of the Venado consists of chaotic slump and channel-fill deposits (pebbly mudstone, pebbly sandstone and conglomerate) which are excellently exposed west of the dam in the road cut. (These conglomerates can be traced for at least 1 1/2 miles north of the dam indicating a channel of "significant" proportions and suggesting an inner fan environment of deposition.) Overlying these channel-fill deposits are massive sandstones and pebbly sandstones showing thinning-upward sequences suggesting a middle fan depositional environment. These massive sandstone deposits constitute most of the Venado at this location.

Directly south of the dam proper are excellent exposures of "overbank" deposits probably representing an interchannel area on the middle fan. These interchannel deposits are overlain by more middle fan sandstones, which are, in turn, overlain by shaly units showing slump features indicative of either a slope or channel-wall environment.

60.2 Approximate contact of Yolo shale on Venado sandstone.

60.6 Bridge across Putah Creek. The contact of Sites sandstone on Yolo shale is below the bridge. Excellent view of Monticello Dam on left.

60.8 Recreation Beach.

61.4 Basal contact of Funks shale on Sites sandstone.

61.6 Basal contact of Guinda sandstone on Funks shale.

61.7 Cannonball Park (LUNCH STOP). Painted concretion across creek is in the Guinda sandstone of the Rumsey petrofacies.

61.8 Approximate contact of Forbes shale on Guinda sandstone (the lower shaly part of the Forbes has been designated the Dobbins shale by some workers). The top of the Forbes is not exposed along the western margin of the Sacramento Valley.

62.8 Black Rocks of Putah Creek. Large slump blocks of basalt have slid from the top of the ridge on left into Putah Creek. This is the approximate contact of Tertiary rocks with the underlying Cretaceous rocks.

64.3 Basal Tehama (Plio-Pleistocene?) gravel and conglomerate exposed in roadcut on left.

64.8 "Nomlaki" tuff member of Tehama formation exposed in roadcut on left.

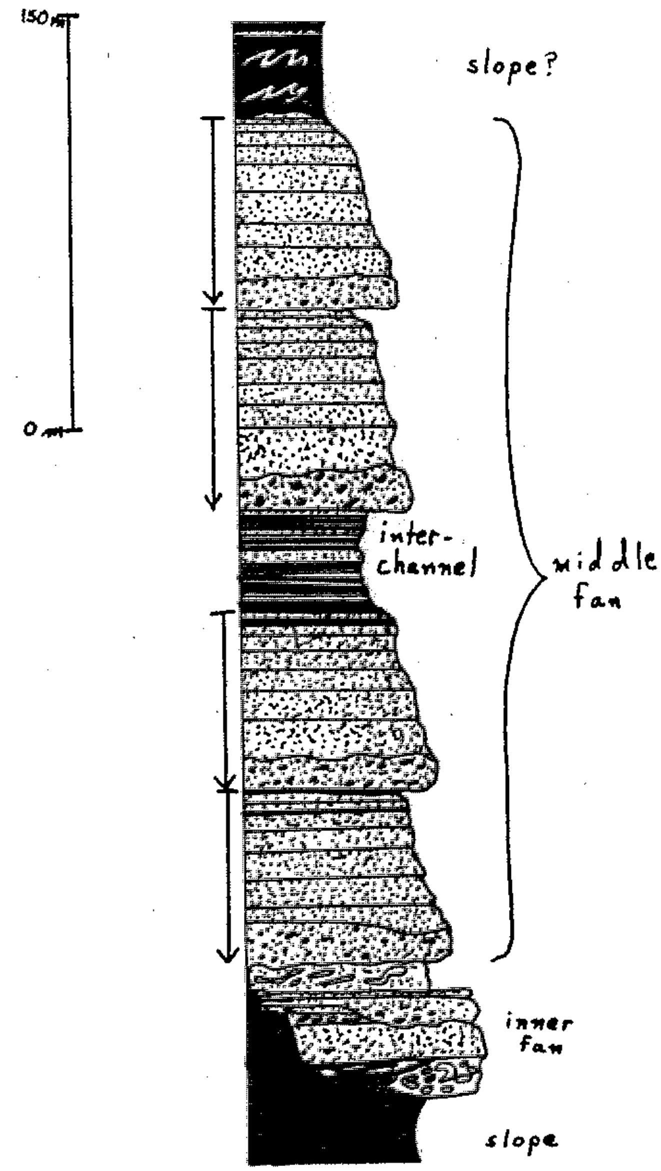

Figure 4. Schematic columnar section of the lower two-thirds of the Venado formation exposed at Monticello Dam. Stop 2.

65.3 Junction with Pleasants Valley Road. Keep straight ahead to Winters. Road traverses the alluvial plain of the Sacramento Valley. On both sides of the highway leading to Winters are numerous apricot orchards.

69.4 Junction in town of Winters. Turn left toward Madison on the Winters-Madison road.

71.1 On left, about 2 miles away, in the gently rolling hills underlain by the Tehama formation is the Pleasant Creek gas field. The skyline ridge is underlain by the Venado-Sites sandstones. On the right, about 3 miles away, is the Winters field. Production here is from Upper Cretaceous sandstones which lie above those exposed in Putah Creek.

80.4 Junction with California Highway 16. Turn left toward Esparto.

83.1 Follow highway right toward Esparto.

83.6 Follow highway left toward Capay.

85.8 Capay. From here to Brooks the highway passes through the Tehama formation. Cache Creek flows through Capay Valley. The valley is bounded on the east by the Rumsey Hills, which have an Upper Cretaceous core directly overlain by the Pliocene Tehama formation, and on the west by the Blue Ridge of the Vaca Mountains.

93.2 Brooks. The type locality of the lower Eocene Capay formation is in Smith Canyon about 2 miles northwest of Brooks. From north of Brooks the Capay formation rapidly changes from a section of channel conglomerates to fine-grained estuarine deposits to the south. The crest of Blue Ridge on the left is underlain by the Upper Cretaceous Venada sandstone. The Capay formation may represent deposition within a submarine canyon cut into a shelf.

99.8 Guinda. Rumsey Hills on the right is a faulted anticlinal structure about 22 miles long and striking northwest. The prominent escarpment on the western front of the Rumsey Hills is the trace of the high-angle reverse Sweitzer fault. The displacement along this fault rarely exceeds the actual height of the escarpment, and although it varies from place to place only locally does it exceed 450 feet. North of Guinda, the crestal zone of the anticline is further complicated by the low-angle Eisner thrust fault, which thrusts Cretaceous beds over Tehama gravels.

103.2 Blue Slides in the Tehama formation on the right. The blue color has been attributed to iron that has been reduced by natural gas seeping out along faults through the Rumsey Hills.

104.6 Rumsey.

107.2 STOP 3. Cache Creek. Upper part of the Sites formation (Cortina petrofacies). Most of the Sites formation consists of thickening upward sequences of interbedded sandstones and shales which are suggestive of an outer fan depositional environment. Paleocurrent studies (in particular, Ojakangas (1968)) have demonstrated that most currents flowed southward and south-eastward suggesting that the contemporaneous middle and inner portions of fans lay to the north.

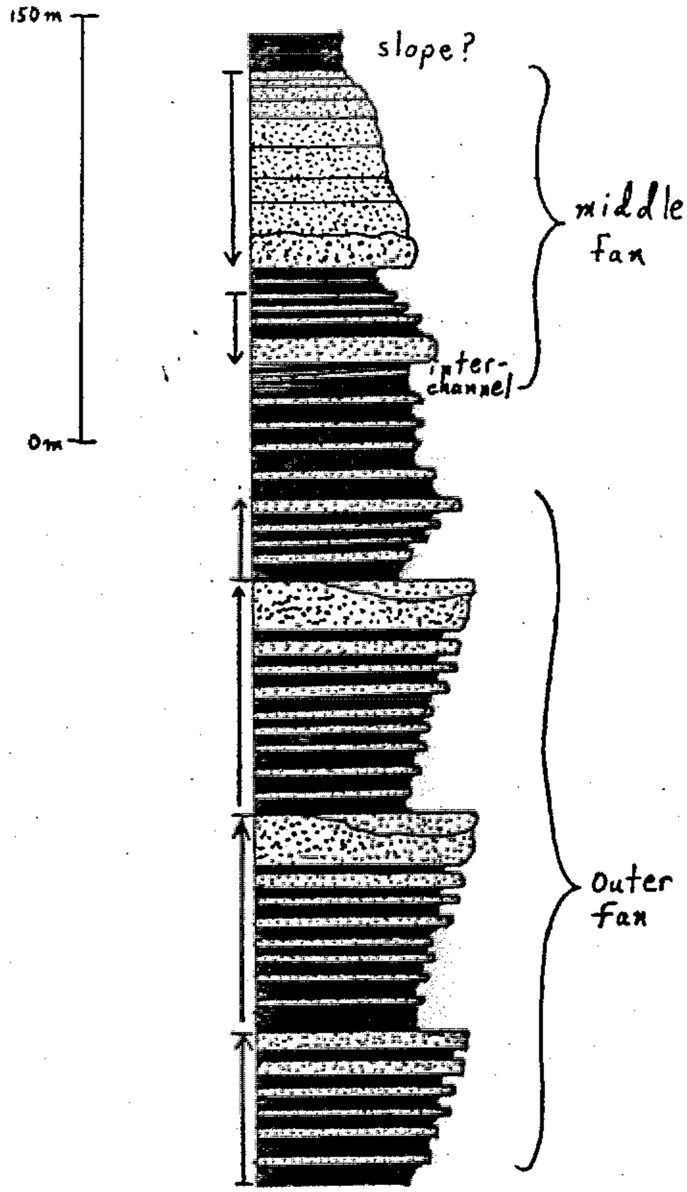

Figure 5. Schematic columnar section of the upper one-half of the Sites formation exposed along Cache Creek. Stop 3.

The portion of the Sites exposed in the roadcut represents interchannel (middle fan ?) or fan-fringe depositional environments. Numerous bedding angularities and sharp-topped sandstones suggest deposition where overbank processes predominated. Across Cache Creek (to the east) are exposures of massive sandstones in the uppermost Sites. They presumably represent a middle fan depositional environment as they show a thinning-upward sequence. Paleocurrent indicators point south-westward in this portion of the Sites suggesting a closer proximity to a presumed north-easterly source. These sandstones are overlain by the shaly Funks formation which was deposited either in a basin plain or slope environment.

108.1 Basal contact of Sites sandstone on the type section of the Yolo shale. The Yolo is about 800 feet thick.

109.1 Basal contact of Venado sandstone on the Boxer petrofacies. Throughout the next 3 miles this shale shows deformation due to local faulting and folding. Most of the shaly portion of the Boxer along Cache Creek presumably was deposited in a basin plain environment.

113.2 Highway 16 leaves Cache Creek and follows a tributary named Bear Creek. Route parallels strike of rocks.

115.8 First bridge over Bear Creek. Beyond the bridge, and exposed on the left, is one of several highway crossings of the "Salt Creek conglomerate". Pebbles in this thin, persistent bed, are reworked from the underlying Lower Cretaceous beds and are chiefly clay-ironstone concretions or well-rounded, very durable rocks. The "Salt Creek conglomerate" is a stratigraphic marker that can be traced 30 miles to the north; it separates Upper from Lower Cretaceous rocks and is thought by some to indicate an unconformity. However, deposition of the conglomerate within submarine channels appears more likely. Scouring of the underlying beds probably occurred in a submarine environment rather than subaerially.

116.9 Second bridge over Bear Creek.

118.9 Bare-hill on left exposures of serpentinite.

120.3 Junction with California Highway 20, turn left toward Clear Lake.

120.4 Stop 4. Roadcut in "detrital serpentine." For the next 7 miles to the west, Highway 20 passes through 5,000 to 7,500 feet of Lower Cretaceous breccia. The origin of the serpentinite is controversial. One interpretation suggests that Upper Jurassic serpentine was elevated above sea level to form headlands during Lower Cretaceous time from which huge serpentine slides moved eastward into an adjacent sea. As these slides continued intermittently during a large part of the Lower Cretaceous, the slide breccia is interbedded with Lower Cretaceous sandstone and shale. Ocean currents and wave action reworked and spread the serpentine breccia to the north and south, drawing out breccia beds so that they interfinger with the other sediments. Other workers interpret these exposures as tectonically implaced.

121.7 Quarry site on the left. Lower Cretaceous sandstone, shale, and silica-carbonate rock is overlain by "detrital serpentine."

122.3 On left contact between serpentinite and "Leesville sandstone" member of Lodoga petrofacies. This sandstone and shale unit marks the contact between the Lower Cretaceous Lodoga petrofacies and the Upper Jurassic Stony Creek petrofacies.

122.8 On left fault contact between serpentinite and Lodoga petrofacies. This fault is thought to be a continuation of the Stony Creek Fault that commonly separates the Franciscan assemblage and the Great Valley Sequence.

123.8 Lake County Line. Lower Cretaceous sandstone is exposed in roadcut. Highway continues through areas of sandstone and detrital serpentine for next 5 miles.

126.2 On the right is the headframe and mill of the Abbott mine. The cinnabar mined here occurs chiefly in silica-carbonate rock formed from serpentine near its contacts with Lower Cretaceous sandstones.

127.5 Oasis. One mile west, the highway will wind through a 2-mile complex of Jurassic shale, intrusive serpentine, and graywacke, shale, and greenstone of the Franciscan assemblage.

130.5 Grizzly Spring. Here we leave the serpentine and enter a basin filled with gravels of the non-marine Plio-Pleistocene Cache formation. Whitish travertine from Grizzly Spring can be seen on the slope on the right.

132.0 Carbonate-cemented concretions are conspicuous in the Cache beds on the left. The Cache deposits of gravel and silt are interbedded with some tuffaceous sand, marl, pebbly limestone, and diatomite near the top of the section. The maximum thickness is reported to be 6,500 feet. These sediments must have collected in tectonic basins that subsided by faulting and minor downwarping.

133.3 Bridge over the North Fork of Cache Creek.

134.5 West-dipping Cache beds to the right across the gravel pit and creek.

136.9 The cliffs ahead and to the left are quartz-bearing olivine basalt flows that are interbedded with the uppermost sediments of the Cache formation.

138.4 Fault contact with Franciscan metavolcanics to the west. Divide above Clear Lake basin. Ahead are Recent cinder cones composed of reddish basaltic lapilli, and beyond is Clear Lake.

138.9 Turn left toward Lower Lake on California Highway 53.

139.6 Re-cross fault contact from the Franciscan into the olivine basalt of the Cache formation.

142.3 To the right, across Clear Lake (elev. 1326') is Mount Konocti (elev. 4200'). This composite volcanic cone of rhyodacite consists of several summit craters and parasitic cones developed during the middle or upper Pleistocene. Quackenbush Mountain on the left, is underlain by olivine basalt. (See air photo with the Santa Rosa Sheet, Geologic Map of California.)

142.7 Quartz-bearing, olivine basalt is interbedded with the gravels of the Cache formation. The medium-gray, inconspicuously porphyritic basalt contains small (2 mm) crystals of olivine, pyroxene, and locally some plagioclase. An unusual feature is the presence of inclusions of clear, shattered quartz which in this area average about 2 mm in length but in other areas attain lengths of 15 cm. These are locally known as "Lake County Diamonds."

143.5 Junction, Clearlake Highlands. Turn right and proceed to hotels.

143.9 On left excellent exposure of Pleistocene lake deposits.

144.7 Parking lot of U.S. Post Office.

END DAY ONE

0.0 The second day of the trip starts from the U.S. Post Office in Clearlake Highlands. Continue toward the north.

3.0 View of Borax Lake. This lake is so named because of the considerable quantities of borax crystals that were removed from the muds in the early 1860's. The first commercial mining of borax in California was from here, but the discovery of the much larger ulexite (1873) and colemanite (1882) deposits of the Death Valley area led to its being abandoned.

The elevation of Borax Lake is nearly the same as that of Clear Lake, and may have been an extension of Clear Lake at one time. It was apparently formed when an obsidian flow dammed the valley. The source of the borax appears to have been a group of hot solfataric springs, now almost extinct, issuing from the obsidian at the southeastern end of the lake.

4.5 View of Sulphur Bank mercury mine, Clear Lake, and east toward breached cinder cone and quarrying operations. Interbedded sedimentary rocks of the Franciscan assemblage are exposed in roadcuts.

5.4 Sulphur Bank mercury mine. The mine was originally opened in 1865 as a sulphur mine and produced over 2 million pounds of sulphur during the ensuing 3 years. The falling price of sulphur and increasing contamination by cinnabar forced the closure of the mine in 1868. It was reopened in 1873 to exploit the mercury ores, and from the period 1873-1965 more than 129,000 flasks of mercury were produced. At today's prices (1965, $500 a flask) the output would be worth about $65,000,000, though when mined it was worth much less than this. The known rich ores have been mined but the deposit still contains low grade ore. Today the ore that has been roasted to remove the mercury is used for the manufacture of concrete blocks.

The sulphur is found above the water table as a product of near-surface oxidation of H_2S. The cinnabar was deposited from solution below the water table as incrustations on boulders and blocks of altered andesite. At depth along the faults, which act as channels for the escape of thermal fluids, cinnabar has been deposited in Quaternary volcanic rocks and lake beds, and in metagraywacke of the Franciscan. Hot waters and vapors charged with carbon dioxide, hydrogen sulfide, methane gas, nitrogen, and minor mercury still issue from vents at Sulphur Bank.

6.8 Junction of Sulphur Bank mine entrance road and State Highway 20. Turn right onto Highway 20.

7.2 Cinder quarry in breached cinder cone. Cinders from this quarry are used as road metal, as aggregate, and perhaps more commonly as decorative material in landscape gardening.

8.9 Junction State Highway 20 and 53; turn right onto Highway 53. Ridge to left of highway is underlain by the Franciscan and capped by olivine basalt flows.

13.5 Junction Highway 53 and road to Clearlake Highlands. Exposures in roadcut just south of this intersection are tuffaceous beds in the Cache formation of Plio-Pleistocene age.

15.5 Bridge over Cache Creek. The discharge from this creek, which is the outlet to Clear Lake, is controlled by a dam about 3 miles down stream.

16.1 Lower Lake. The end of California Highway 53. Turn right toward Kelseyville on California Highway 29.

17.2 Undifferentiated Cretaceous sandstone. Within the next half mile, these sands are overlain by the poorly exposed Cache formation which, in turn, is overlain by the rhyodacite of Mount Konocti.

18.0 Turn right onto Jago Bay Road. Here one traverses a small, late basaltic lava flow from the Recent cinder cone of Roundtop Mountain ahead and to the right.

18.8 Small quarry in the basaltic cinders of Roundtop Mountain. This cone post-dates all nearby volcanic activity and appears to be the same age as the cinder cones seen earlier near the junction of Highways 59 and 20.

20.0 Lake Thurston on the left. This flat-bottomed basin has no outlet and is filled by a shallow lake. The basin, which is floored by Cache sediments, formed when viscous rhyodacite flows failed to coalesce.

21.4 Keep left toward Soda Bay on the Point Lake View Road.

21.9 On the right jutting into Clear Lake is Baylis Point of Franciscan rocks that escaped being covered by the Konocti volcanics.

24.7 Turn left, away from the lake, on Soda Bay Road. To the right at several places along this road are good views of Mount Konocti.

26.2 Recent obsidian flow is exposed in roadcut on the left.

26.7 Turn left toward Lower Lake on California Highway 29, which for the next 2 miles crosses flows of obsidian.

32.6 Jago Bay turnoff. Continue straight ahead on Highway 29.

33.5 Lower Lake. Turn right toward Middletown. Rocks exposed about 0.1 mile south of intersection are sandstone and shale of Lower Cretaceous age and on basis of petrology and microfossils are equivalent to the "Salt Creek Conglomerate". These rocks overlie, in thrust contact, strata equivalent to the "Leesville sandstone" (lowermost Lodoga petrofacies) which border and underlie the alluviated valley ahead. Here the rocks are along the core of the northwest trending Soda Creek Anticline. For the next 11.0 miles the route traverses complexly folded and faulted Klippen of Great Valley sequence rocks.

35.5 Pebbly sandstone and sandstone exposed in roadcut are probably equivalent to the Venado sandstone (Cortina petrofacies) and are in normal fault contact with the "Leesville sandstone" equivalent (Lodoga petrofacies).

35.8 Perin Hill, ahead, is capped by andesite flows with abundant quartz xenocrysts of so-called "Lake County Diamonds". Cretaceous rocks equivalent to the Forbes (Rumsey petrofacies) are intermittently exposed in the surrounding hills. They are folded into a broad syncline, in the center of which, about three-fourths of a mile east of the highway, fossiliferous Eocene Martinez Formation is exposed.

36.9 Massive sandsone in Forbes (Rumsey petrofacies) seen in roadcut on left strikes nearly parallel with highway and dips about 65° into the hill and is part of the southwest flank of the syncline. Sole markings are well exposed on base of many of the sandstone beds.

40.7 Here the highway crosses the Childer's Peak fault which separates the Upper Cretaceous from the Upper Jurassic (Knoxville?) rocks in thrust relations. Gravels in roadcut represent a small remnant of Cache formation of Plio-Pleistocene age which was deposited across the structure.

42.2 Bridge across Putah Creek. Hills on right are underlain by serpentinized ultramafic rocks.

43.3 Contact of serpentinite against Upper Jurassic (Knoxville ?) exposed in roadcut. For the next 1.0 miles the Upper Jurassic rocks which dip 25 to 30 degrees eastward are exposed in roadcuts.

44.4 STOP 5. Thrust fault, intruded(?) by serpentinite, separates Upper Jurassic (Knoxville ?) in the upper plate from Upper Cretaceous Guinda sandstone (Rumsey petrofacies) in the lower plate. The time of thrusting is uncertain but may have been post-Eocene in as much as farther to the north (mileage 35.8) the Eocene Martinez formation, is involved in thrusting. Walk south along the highway where the dip of the beds of the Upper Jurassic shale gradually steepen, become contorted and veined but are little altered by thermal metamorphism into intensely sheared serpentinite. Near the center of the cut the serpentinite is slightly less sheared and exhibits larger blocks of coherent serpentinite. Continue along the highway through the unexposed section which to the northwest is underlain by intensely sheared serpentinite, into the next roadcut. Here are exposed relatively undeformed sandstone and shale of the Guinda sandstone in the lower plate of the thrust.

45.1 Bridge across St. Helena Creek at northern city limits of Middletown.

45.7 Mirabel Mines left side road across St. Helena Creek. This mercury mine lies at the border of a large serpentine mass and is in a zone of faulted and sheared Franciscan rocks. Most of the rocks are altered: Graywacke is softened by kaolinization or hardened by silicification, greenstones are converted to clay or altered to sheared chloritic rock, and serpentine is altered to silica-carbonate rock. Cinnabar occurs in the silica-carbonate rock as shoots of both tabular and pipelike forms. With the cinnabar are also found metacinnabar and native mercury. Associated with these are pyrite, hydrocarbons, and veinlets of dolomite and quartz.

This mine first opened in the early 1870's and continued operation until 1898. It was reopened in 1930 through a well planned program of exploration and was in production until 1946. Its output was more than 41,000 flasks of mercury, and it is but one of the many mercury mines of the Mayacmas district, which has an aggregate production of nearly half a million flasks.

47.9 Contact of serpentine and Sonoma Volcanics visible on right side of road. Nearly all exposures of the Sonoma Volcanics along the highway have been involved in landslides, so that the relations of volcanics to serpentine and individual flows to each other are obscure.

50.5 Entrance to Robert Louis Stevenson State Park at the top of the grade. The Sonoma Volcanics are predominantly andesitic with some rhyolite flows, pyroclastics, and intrusive equivalents. In general, the series is basaltic at the base and is composed of rhyolitic tuffs, tuff-breccia, and probably welded tuffs at the top. The eruptive sources are unknown: although Mount St. Helena to the west superficially resembles an eroded volcano, its internal structures suggest that it probably is not an old vent.

The famous author, Robert Louis Stevenson, lived in a miner's small cabin about one mile west of this point while writing his novel Silverado Squatters, based on the Silverado mines lying on the slope of Mount St. Helena.

54.2 View of Palisades, Mount St. Helena, and Napa Valley. The Palisades are made up principally of flows, debris flows, and welded tuffs. The horizontal banding defines individual flows. Vertical jointing in the uppermost layers is clearly visible. The Palisades mine, the only really productive silver mine in the Coast Range, lies in the canyon southeast of here, but it cannot be seen from the highway. To the north Mount St. Helena rises to a height of 4,343 feet.

58.8 Junction Highways 29 and 128 in town of Calistoga. Turn left at junction. From this point southward the highway is in the Napa Valley that is famed for its wines. The alluviated valley is bordered by hills of Cretaceous and Jurassic sedimentary rocks. The hills on the east (left) are capped by the Sonoma Volcanics. The valley occupies the Napa Valley syncline which is thought to be downdropped along a fault trending nearly parallel with the valley along its eastern side.

63.7 Old Bale Mill on left side of highway. This old grist mill was erected by Dr. E.T. Bale, grantee of the Carne Humann Ranch, in 1846. Water wheel measures about 30 feet in diameter.

66.0 Entrance of Charles Krug winery at St. Helena. This winery, like many others in western California, provides visitors with an opportunity to sample their products and to view the wine making process.

END OF LOGGED TRIP. From this point on, enjoy the products of the Napa Valley!