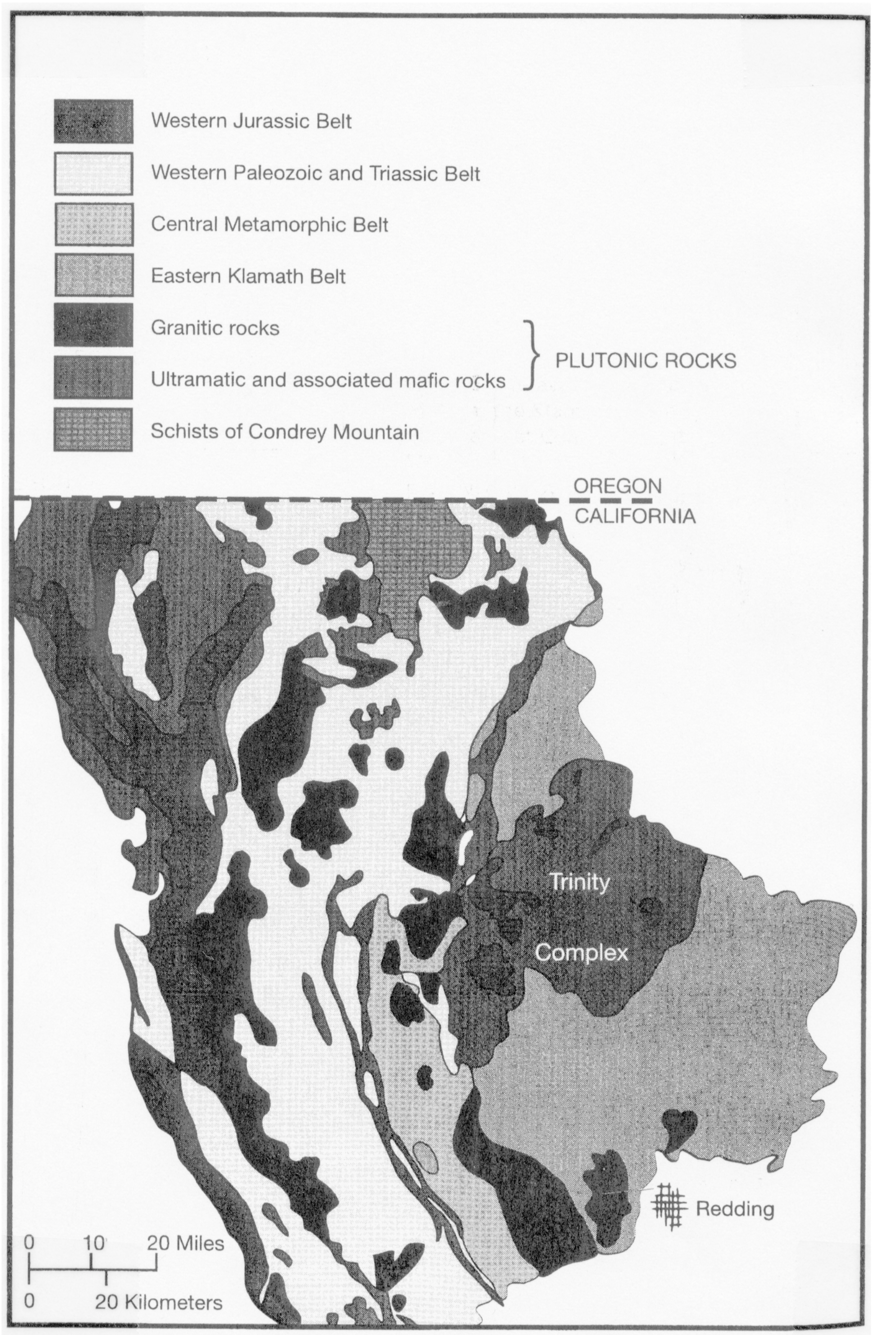
Peninsula Geological Society and Stanford GES-052Q combined field trip, Mount Shasta-Klamath-northern Coast Range area, NW California, 05/17-05/20/2001

DIRECTIONS

On Thursday, May 17, after the drive up from the 8:30 am assembly points (USGS flagpole, or Stanford Geocorner), we will gather in Mount Shasta City, collect strays, and proceed on to the first stop. (From I-5, take the Central Mount Shasta exit (the second exit coming north); at the stop sign, turn R on Lake Street and meet in the parking lot between a large Rite Aid and the Chevron Station.) Please be here by 1:30 or 2:00 pm and gas up!



INTRODUCTION

Northwestern California represents the complex junction among five geologic provinces: (1) the Sierra Nevada, (2) the Klamath Mountains, (3) the Modoc Plateau, (4) the Cascades volcanic arc, and (5) the Sacramento Valley. Yet a sixth—the Franciscan of the northern Coast Ranges—lies directly west of the Great Valley and south of the Klamath salient. These terranes are all Phanerozoic, mostly post-Paleozoic, in age, and reflect the westward growth of North American continental crust.

We travel eastward from Stanford and the USGS/Menlo Park through the San Francisco delta area, and then north along the west side of the Sacramento Valley, eventually viewing, first from a great distance and then up close, the southernmost super-scenic cones of the great Cascade Range (the volcanic dome of Lassen Peak, and the enormous stratovolcano that is Mount Shasta). Turning westward at Yreka, CA, we pass through the various imbricated, eastward-rooting thrust sheets of the Klamath Mountains. After examining the section around Sawyers Bar, we head west, then south through the Central Belt of the Franciscan Complex, and scuttle back home over the Golden Gate.

SIGNIFICANCE OF MOUNT SHASTA

A photogenic signature peak of the Cascades geologic province, this Andean-type volcano reflects ongoing subduction of the Gorda lithospheric plate (born along the Gorda-Juan de Fuca spreading center). Crustal accretion at convergent plate boundaries is still an incompletely understood process. However, if subduction zones constitute the environment where new continental crust is generated (precisely how is still being debated), volcanic-plutonic arcs are the sites where true accretion occurs. All other geologic belts simply represent the redistribution of this sialic (and some oceanic) material.

DESCRIPTION OF MOUNT SHASTA AREA

Mount Shasta is the largest stratovolcano of the Cascade chain. At nearly 500 km^3, it is comparable in volume to such well-known stratocones as Fuji-san (Japan) and Cotopaxi (Ecuador). The peak rises to an elevation of 4,317 m, more than 3,200 m above its base, and dominates the landscape in much of northern California. The geologic map is shown as **Plate 1**.

Shasta Valley, north of Mount Shasta, is largely floored with the debris of an enormous volcanic sector avalanche of about 350 ka that virtually destroyed an ancestral volcano. The volume of the Shasta Valley debris avalanche is about 45 km^3. Because of this huge sector collapse, only a small remnant of the older volcanic edifice remains exposed, and most of Mount Shasta as we see it now is younger.

The bulk of Mount Shasta is a composite volcano built over the stump of the destroyed older volcano; it comprises four major cones built around discrete eruptive centers. Each of these cones appears to have grown mainly in a short episode, perhaps as little as a few hundred or a few thousand years. Each of these episodes produced numerous lavas from a central vent, most of them silicic pyroxene andesites or mafic dacites. Following each of these episodes, the cone underwent significant erosion and less frequent eruptions from its central vent and, typically, from flank vents as well. The last eruptions within each of the central craters produced dacitic domes and pyroclastic flows. The flank eruptions generally produced either basaltic to basoandesitic lavas or dacitic to rhyodacitic domes and pyroclastic flows.

The Mount Shasta magmatic system has evolved more or less continuously for at least 590,000 years. The Sargents Ridge cone, oldest of the four cones that formed the present volcano after major sector collapse, is at least mainly younger than about 250,000 years and has experienced two major glaciations. The next younger, the Misery Hill cone, erupted mainly sometime between about 100,000 and 40,000 ka and was sculpted in one major glaciation. The two younger cones are Holocene: Shastina, west of the cluster of other central vents, formed mainly between 9,700 and 9,400 years; the Hotlum cone may overlap Shastina in age but appears to be mainly younger. Mount Shasta has continued to erupt at least once every 600-800 years for the past 10,000 years. Its most recent eruption was about 200 years ago, perhaps in 1786.

Because of the early date for this field trip, much of Mount Shasta will be snow-covered and, for practical purposes, inaccessible to us. We will focus on features around the base of the mountain and on aspects of the volcano that can be appreciated from a distance. The trip was planned before an onsite visit could be made to check conditions. Thus, for the Mount Shasta part of the trip there is no mileage log, indicated driving distances are approximate, and the tentative itinerary may or may not resemble what we actually do.

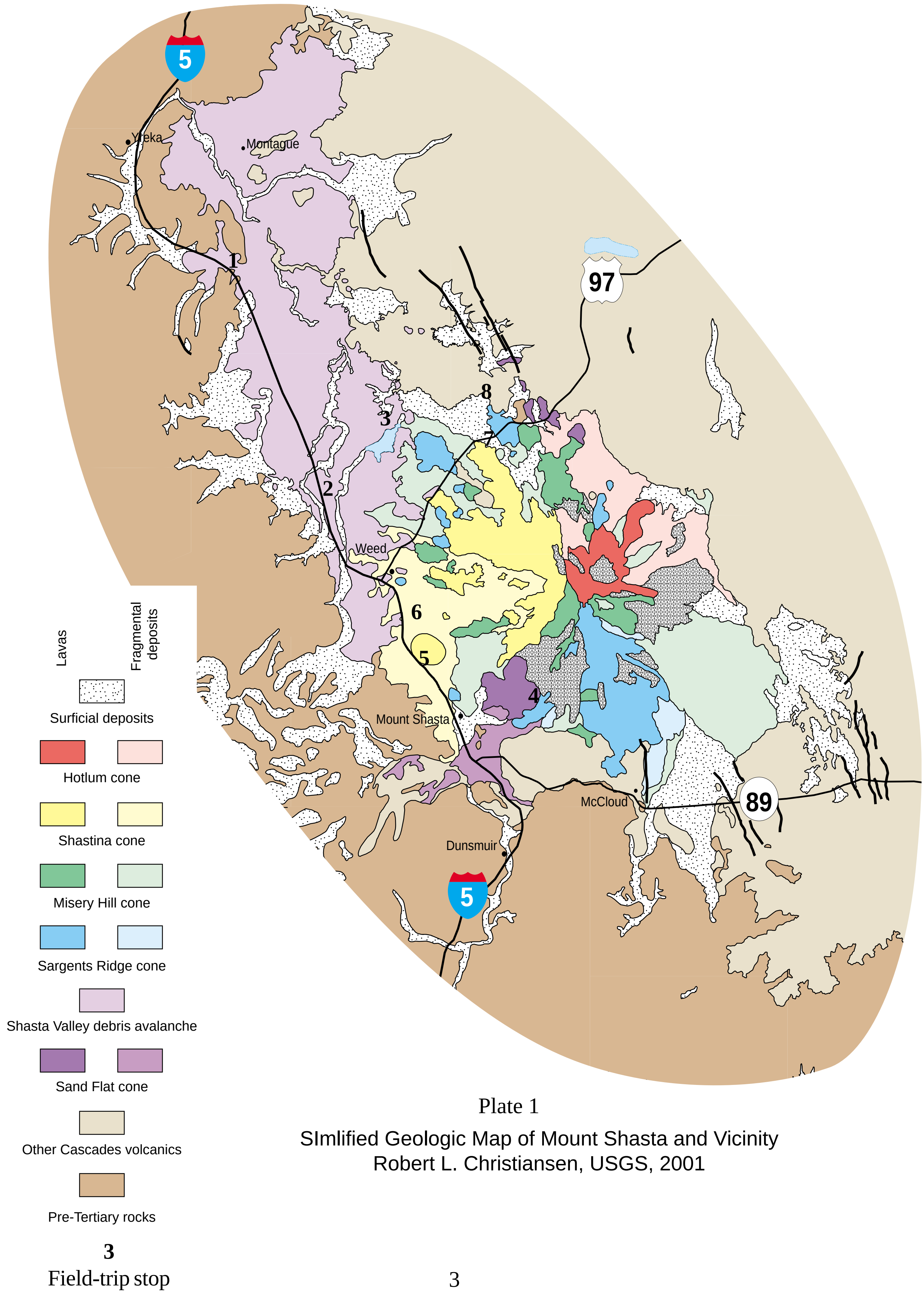


Plate 1

SImlified Geologic Map of Mount Shasta and Vicinity
Robert L. Christiansen, USGS, 2001

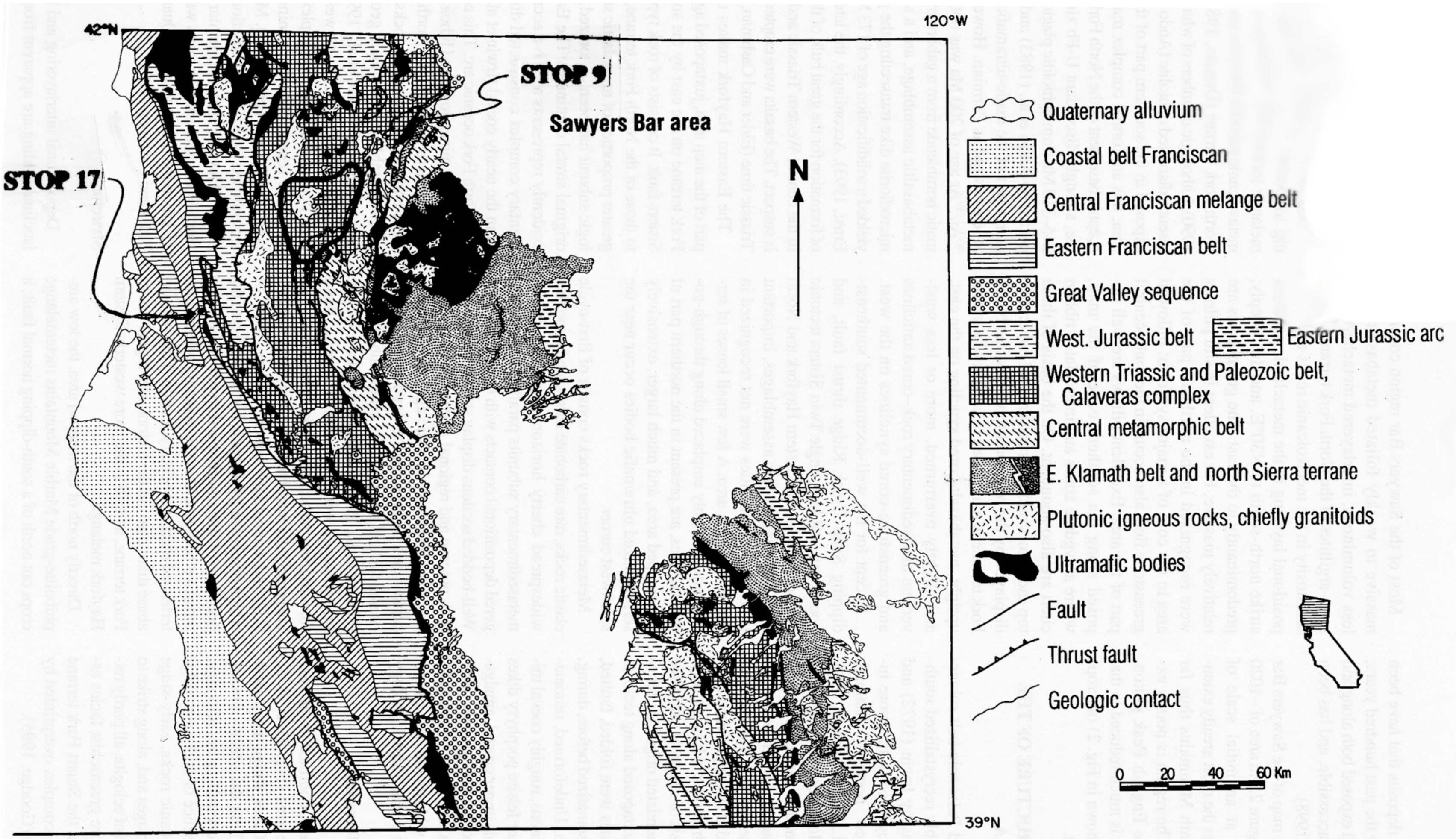


Figure 2. Geologic index map of northernmost California, after Jennings (1977) and Ernst (1983). The disposition **of Sierran-Klamath-Franciscan lithotectonic belts reflects progressive seaward continental growth. For simplification in the Klamath Mountains, the Stuart Fork terrane and the Western Triassic and Paleozoic belt are combined.**

SIGNIFICANCE OF THE KLAMATH MOUNTAINS

Within accreted packages of rocks, internal deformation and metamorphism at different structural levels further complicate the record of continental growth. The Klamath Mountains provide a remarkably complete, well-exposed, and accessible record of crustal evolution that spans most of the Paleozoic and Mesozoic Eras (Irwin, 1966, 1994; Irwin and Mankinen, 1998). A regional geologic map is presented as **Fig. 2**. The terrane concept, in which continental growth is accomplished by the stranding of exotic, fault-bounded lithotectonic units arose from seminal studies in this mountain belt by Irwin (1972). The largest and perhaps least-well-understood terrane within the Klamath Mountains is the Western Triassic and Paleozoic Belt (WTrPz). It is generally considered to be part of the Cache Creek assemblage, a regionally extensive belt that constitutes a significant component of the Cordilleran realm in western North America (Davis *et al*., 1978; Burchfiel and Davis, 1981; Monger *et al*., 1982). The present distribution of Cache Creek-type rocks ranges from the northern Sierra through the Klamath WTrPz, eastern Oreg., northern Wash., and central British Columbia. This lithotectonic belt has been interpreted to represent far-travelled paleo-Pacific oceanic crust accreted to North America in the Mesozoic and, along with continent-derived clastic sedimentary debris and later granitoids, records the processes of continental growth at the western margin of North America. More recent studies have suggested that much of the Cache Creek assemblage actually formed in a suprasubduction-zone setting in proximity to the continent (Saleeby, 1990; Ernst, 1990; Ernst *et al*., 1991; Hacker *et al*., 1993). The rocks around Sawyers Bar belong to this WTrPz terrane.

DESCRIPTION OF THE CENTRAL KLAMATHS

The Klamath Mountains consist of diverse oceanic and arc-related rocks, and preserve a clear record of Phanerozoic continental accretion. Irwin (1966) divided the province into four NS-striking arcuate belts of rock. From structurally lowest on the west to highest on the east, these are: (1) the Western Jurassic belt, (2) the Western Triassic and Paleozoic belt (WTrPz), (3) the Central Metamorphic belt, and (4) the Eastern Klamath plate. These units form a stack of gently east-inclined thrust sheets. Some of the original belts of Irwin are now considered to be amalgamated terranes. The WTrPz is such a composite unit that has been divided further into five subterranes, mainly based on work in the southern Klamaths (*e.g.* Wright, 1982; Wright and Fahan, 1988). From structurally lowest to highest, these subterranes are: (a) the Rattlesnake Creek terrane; (b) the Western Hayfork terrane; (c) the Eastern Hayfork terrane; (d) the North Fork-Salmon River terrane; and (e), the Stuart Fork terrane. **Fig. 1** illustrates the terrane subdivision proposed by Irwin (1994). On our trip, we will look at rocks belonging to the Eastern Hayfork, the North Fork-Salmon River, and the Stuart Fork terranes.

The Hayfork terrane structurally overlies the Rattlesnake Creek terrane; it consists of the Western and Eastern Hayfork units. Western Hayfork rocks are predominantly crystal + rock-fragment tuff and tuff breccias of andesitic to basaltic composition, and have isotopic ages ranging from 168-177 Ma; superjacent units are intruded by the ~172 Ma Ironside Mountain batholith. The Eastern Hayfork is a mélange consisting of argillite, chert, quartzose sandstone, mafic to silicic volcanic rocks, exotic limestone pods, and serpentinite, overlying the Western Hayfork along the Wilson Point thrust. Chert contains Triassic to Early Jurassic (?) radiolarians (Irwin *et al*., 1982), and limestone pods contain Permian Tethyan fusilinids (Irwin and Galanis, 1976). In the southern Klamath Mountains, metamorphism is generally of greenschist and lower grade (Wright, 1982).

The North Fork-Salmon River terrane, as defined by Irwin (1981), is the structurally highest subterrane of the WTrPz. These rocks form a 1-10 km wide, NS-striking zone bounded by high-angle faults in the southern Klamaths. They consist of gabbro, plagiogranite, diabase, serpentinite and interlayered pillow basalt, chert, argillite, and limestone. Chert and siliceous tuff interbedded with mafic volcanics contain Triassic and Early Jurassic radiolarians, whereas far-traveled lenses of chert and limestone contain Permian radiolarians and Late Paleozoic fusilinids and foraminifers (Blome and Irwin, 1983). A discordant, Late Paleozoic U/Pb age was reported by Ando *et al*., (1983) from a plagiogranite pod within a shear zone, but Hacker *et al*. (1993) obtained a more reliable $^{40}Ar/^{39}Ar$ age of 200 Ma on hornblende from gabbro within this terrane. These rocks have been metamorphosed to greenschist grade.

The Stuart Fork terrane on the east consists of interlayered metapelitic and metabasaltic subunits that structurally underlie the yet older Central Metamorphic belt. Lawsonite-, high-Si white mica- (phengite-), and glaucophane-bearing assemblages, and rare eclogitic lenses characterize the northern part

(Hotz, 1973); to the south, rocks of this terrane contain epidote + crossite (Goodge 1989). K-Ar and $^{40}Ar/^{39}Ar$ geochronological data indicate that blueschists formed during earliest Mesozoic subduction beneath the North American margin or an offshore arc (the Fort Jones event of Coleman *et al.*, 1988). A 227 Ma K-Ar white mica age (Hotz *et al*., 1977) probably represents the time of Late Triassic exhumation + cooling through the argon-retention temperature. The Stuart Fork sheet subsequently was thrust over more westerly, coeval and younger outboard rocks of the WTrPz belt (Goodge, 1990); greenschist-facies recrystallization, contraction, and thickening accompanied this tectonic juxtaposition (the Siskiyou metamorphic event of Coleman *et al.*, 1988).

GENERAL INSTRUCTIONS

Excursion stops are described briefly below. Notes are indexed to trip mileage as follows: day #1, 0.0 at Stanford/Geocorner or the Survey flagpole, then reset to 0.0 at Yreka, Calif. the afternoon of day #2; days #2 and #3, reset to 0.0 at Idlewild Campground, east of Sawyers Bar, Calif.

Roadcuts at some of our stops (especially in the Sawyers Bar area) are cliffy, roads are very narrow with small turnouts, falling rocks are common, and curves are pretty much blind, and there is little or no shoulder. ***So, after looking and listening for approaching vehicles, PUHLEEZE be extremely careful crossing the roadway, do not stand in the roadway, and do not scatter rocks on the pavement!***

ROAD LOG, DAY #1 (THURSDAY, MAY 17)

0.0 mi)—Stanford/USGS—>I-280—>US-101 (Bay Bridge at 35.0 mi)—>I-80.

(63.8 mi)—Carquinez Bridge (toll).

(92.0 mi)—Junction with I-505 northbound, then I-5 northbound at 125.6 mi.

(129.5 mi)—Rest stop (optional).

(134.0 mi)—View to the distant east of Marysville (Sutters) Buttes. These are the eroded remnants of a Quaternary volcanic center composed of flow breccias, ash deposits and mud flows. Probably mostly andesite and dacite.

(155.8, 180.3, 204.6 mi)—Optional rest stops (pick one!).

(219.0 mi)—Red Bluff. Good views of Mount Lassen to the east, gigantic Mount Shasta looming up to the north, and the Trinity Alps of the Klamaths to the northwest. NO STOP.

(276.8 mi)—Rest stop and lunch!

(306.0 mi)—Castle Crags granite on the west. We are driving through the eastern Klamath plate. This terrane consists of the very-broadly outcropping, plagioclase-bearing, Trinity peridotite (an ophiolite complex?) of Cambrian emplacement age; it is overlain, apparently along a poorly exposed disconformity or angular unconformity, in the south by the Redding section of sedimentary and volcanic rocks as old as Siluro-Devonian, and in the north by the Yreka section of strata as old as Ordovician. Of course, younger, layered volcanics and sedimentary strata occur above these basal sections. The whole complex is punctured by Late Jurassic and Cretaceous granitic plutons. Great Valley strata to the SW rest with clear angular unconformity on the Eastern Klamath plate, and are faulted over the more westerly coeval Franciscan Eastern Belt rocks along the Coast Range thrust.

(319.1 mi)—Central Mount Shasta City offramp. Meet at Chevron Station by 1:30 or 2:00 PM—or else!.

From I-5, take the Central Mount Shasta exit; at the stop sign, turn R on Lake Street and meet in the parking lot between a large Rite Aid and the Chevron station. Please gas up there. From there we will get back onto I-5 N and proceed through the town of Weed. From the North Weed exit, continue N on I-5 for another 18.9 miles to the highway offramp for Grenada and Gazelle. Take the offramp, at the stop sign, turn L toward the highway overpass, park on the shoulder, and exit the cars ***carefully*** *for a view S from the overpass.*

STOP 1. From here we have a good overview of the Shasta Valley sector-collapse avalanche deposit. Southward across Shasta Valley is Mount Shasta. The conspicuously hummocky topography of Shasta Valley is the expression of the volcanic debris-avalanche deposit that extends S past Black Butte, the prominent steep-sided volcanic dome at the western foot of Mount Shasta. The generally flat valley floor between the hummocky megablocks is a matrix facies of debris flows. At the N end of Shasta Valley, these debris flows were forced through the narrow valley of the Shasta River and ponded upstream to an average thickness of 75 m; downstream, farther to the N, the debris flows must have entered the Klamath River. A few of the larger hills to the NE of here, surrounded by the hummocky debris avalanche, are eroded remnants of Tertiary Western Cascades volcanic rocks that once extended into Shasta Valley.

On the skyline to the E is a group of late-Pliocene-to-early-Holocene mafic-andesite shield volcanoes along the main Cascades axis, including (L to R) Eagle Rock, Willow Peak, Bald Mountain, The Goosenest, Herd Peak, The Whaleback, and Ash Creek Butte. The Goosenest has a prominent agglutinate cone at its central vent, probably typical of many of these shields but not always well preserved on the older ones; Ash Creek Butte is carved by prominent glacial cirques that removed much of a similar agglutinate cone.

The higher terrane to the W is entirely underlain by metamorphic rocks of the Klamath Mountains; the prominent high peak to the SE is Mt. Eddy, underlain by the Trinity ophiolitic complex.

After returning to the cars, proceed across the highway and turn L onto the onramp back to I-5 S. Drive about 12.0 miles, passing closed depressions as well as megablock hummocks, both characteristic of debris-avalanche deposits. Take the offramp to the Rest Area and Vista Point. (This can, if necessary, be a pit stop.) From the Rest Area, continue along the frontage road, turn R on the road to Weed Airport; at the intersection, turn L and continue under the highway. Park at the turnout on R, opposite the junction with a road to Weed airport.

STOP 2. The flat surface around the highway Rest Area, the airport, and this stop is developed on debris flows of the matrix facies of the Shasta Valley avalanche deposit. The surface is marked by prominent stone polygons and other patterned-ground features, produced by periglacial processes during a middle Pleistocene glaciation. Walk a few meters S to cross a barbed-wire fence and descend to low cuts along the railroad. These cuts provide exposures of debris flows in the matrix facies. The variety of volcanic rock types in the deposits is representative of the ancestral Mount Shasta, consisting mainly of porphyritic silicic andesites and subordinate dacites. A few more mafic andesites are also present. Note the rounding of the fragments and the indurated fine-grained matrix. The deposit dates from about 350 ka and has a fairly well-developed soil, mainly expressed as a deep zone of oxidation. From the banks above the railroad cuts is a good view S to Mount Shasta and to Black Butte, the dacitic dome complex at its W foot.

Turn around and return by the same roads to the frontage road and merge onto I-5 S. Beyond the offramp to Stewart Springs Road and Edgewood, the highway climbs through large ridges that are megablocks in the Shasta Valley volcanic debris avalanche—virtually intact remnants of the ancestral edifice of Mount Shasta. The roadcuts used to provide excellent exposures of these megablocks, but recent work by Caltrans has pretty-well effaced them. Leave the highway at the exit to N Weed and US Highway 97; at the stop sign, turn L through the underpass beneath I-5 then R at the next stop sign, following signs to Weed and Klamath Falls. In town, turn L at the intersection with a flashing light, onto US-97 toward Klamath Falls. From this intersection continue on US-97 for about 4.3 miles to County Road A-26 to Lake Shastina and Big Springs. Along the way we pass more megablocks as well as pyroclastic-flow fans and some lava flows from Mount Shasta.

Turn L onto the road to Lake Shastina and Big Springs. Drive about 4.1 miles to the entrance to the Lake Shastina development. At the first stop sign, turn R and proceed about 0.9 miles farther to the crest of the hill; turn around and park along the roadside. Cross on foot the cable strung as a gate across a dirt road and walk about another 250 m across the dam of Lake Shastina to a quarry on the other side.

STOP 3. This quarry provides an excellent exposure into one of the megablocks of the Shasta Valley volcanic debris avalanche. The materials of the block are principally unconsolidated pyroclastic flows, volcanic debris flows, and sediments, including several successive buried soils. Numerous normal faults of varied orientations and displacements cut the block, but the section remains subhorizontal and upright and its stratigraphy remains coherent.

To the SE is Mount Shasta. The summit and N and NE flanks are the young Hotlum cone. Shastina is in front and to the R but is not clearly outlined from this perspective. The small ridge between these cones is part of the breached crater rim of the Misery Hill cone. Below Mount Shasta in a line toward us are andesitic lava flows erupted from the summit vent of Shastina. One lava flow from the older Sargents Ridge cone emerges from beneath Shastina in a line toward Lake Shastina, abutting megablocks of the Shasta Valley debris flow. Black Butte, to the S, is a young dacite flank dome of the Shastina cone; between it and Shastina but closer to us are several older dacitic flank domes overlapped by Shastina lavas.

Along the skyline to the E (R to L, N from Mount Shasta) are The Whaleback, Sheep Mountain (eroded andesitic breccias of the older Western Cascades), Herd Peak, and The Goosenest. The sparsely tree-covered area of Shasta Valley beyond the grassy surface of the Whitney Creek debris-flow fan is underlain by basalt of about 160 ka that overlaps the Shasta Valley debris avalanche.

Return to vehicles and back S along the same road toward US-97. Turn R to Weed, L in town at the flashing light and another 0.9 miles to the onramp to I-5 S (L lane). Take the highway S about 8 miles to the Central Mount Shasta exit, turn R at the intersection, proceed to the "T" intersection with a stop sign. Turn L onto Old Stage Road; follow it about ¼ mile to a "Y" intersection, where you go R onto W.D. Barr Road. Continue on for about another 3½ miles through a four-way stop, across the dam of Lake Siskiyou, staying R, to the entrance to the <u>Lake Siskiyou camping facilities, where we will stay for the night</u>.

Road Log, DAY #2 (FRIDAY, MAY 18)

Hoping for the best, we will drive up Mount Shasta as far as we can get. Depending on the snow conditions, we may turn around at Bunny Flat or, higher, at the old Ski Bowl. Return by yesterday's route from Lake Siskiyou to Mount Shasta City, cross I-5 on the overpass, and continue to a stop light at the intersection of Lake Street and Mount Shasta Boulevard. From there, continue straight ahead on Lake Street, following the bend to a 4-way stop at Mount Shasta High School. From that intersection, continue straight ahead on Everitt Memorial Highway and on up the west side of Mount Shasta. About 4.6 miles past the four-way stop, the road climbs onto outcrops of andesite that are a remnant of the ancestral volcano that predates Mount Shasta as we know it now. These rocks erupted at 590 ka, and once formed a volcanic mountain as high as present Mount Shasta. Continue up the road to a wide shoulder 8.9 miles past the four-way stop at the High School.

STOP 4. From here we get an excellent view of the SW side of Mount Shasta. On the L is the early Holocene cone of Shastina, overlapping lavas from what appears from here to be the summit cone but is actually the older Misery Hill cone. The apparent summit from this view is Misery Hill itself, a dacite dome that rises within the crater of the cone named for it. A prominent glaciated valley leading directly towards us from below Misery Hill is Avalanche Gulch; at its head the prominent ledge, Red Banks, is agglutinated fallout pumice erupted from the summit crater of the Misery Hill cone at about 9.7 ka. On the R is Sargents Ridge, which exposes lavas that dip N, back under the Misery Hill cone, and define the N flank of the old Sargents Ridge cone; S dips on the skyline define the opposite flank of the Sargents Ridge cone.

A N-S line of flank vents marks the skyline of the S flank of the Sargents Ridge cone. The highest prominent vent feature is Gray Butte, a glaciated dacite dome; next below is a lower cinder cone; next are two more dacite domes (upper and lower McKenzie Buttes, with ski runs cut into the vegetation of the upper); less conspicuous at the foot of the mountain at the S end of the line is the top of Signal Butte, an andesitic lava cone. Farther R is Everitt Hill, a mafic-andesite shield volcano of 450 ka.

The roadcut across from the turnout exposes a deep soil developed on 590-ka andesitic lava of the ancestral Mount Shasta. Spoil from the cut lies at the roadside in the turnout, providing relatively fresh samples of the andesitic lava. Note the abundant corroded plagioclase and moderately abundant hypersthene phenocrysts.

Continue up the road. About 0.8 miles beyond the stop is Red Fir Flat at the top of the remnant of the ancestral Mount Shasta that predated the Shasta Valley sector collapse. About 1 mile farther on is a good exposure of the L-lateral moraine of Avalanche Gulch. Ahead is Mount Shasta and the glaciated valley of Avalanche Gulch, with Sargents Ridge on the R. Below Sargents Ridge is Gray Butte, a *glaciated dacitic dome at the head of the N-S vent alignment on the S flank of the Sargents Ridge cone. In the far distance to the S, Lassen Peak may be seen if the day is clear. About 0.5 miles beyond, we may have to turn around at Bunny Flat; otherwise, continue on another 2.5 miles to the end of the road at the old Ski Bowl. We won't have time for a walking stop from either of these places, but the views are good.*

Return by the same road to Mount Shasta City. From Lake Street take the onramp to I-5 and drive N 4.0 miles on the highway to a large pulloff on the R at the base of Black Butte. This is not a particularly pleasant place, next to the freeway and full of trash, but some neat rocks can be seen here.

STOP 5. At this roadside turnout, talus from the dome comes down to the roadside and offers opportunities to examine the lithology of this interesting hornblende dacite. Fresh rocks from the interior of the dome are gray with dark hornblende phenocrysts, generally with hollow centers and plagioclase cores; a pink lithology with oxyhornblende phenocrysts represents the original hot surficial carapace of the dome.

Return to I-5 N; about 3.9 miles beyond take the S Weed Exit. Continue straight east past roadside shops, turning right at Taco Bell to an unpaved road, and turn L. Follow the VERY DUSTY road about 0.5 miles to Black Butte Siding. Turn R along the tracks about another 0.1 mile to a low bluff on the R that exposes Holocene pyroclastic flows.

STOP 6. This bluff exposes two pyroclastic flows whose lithologies, though similar, can be readily distinguished. The lower one, 9,400 years old, has phenocrysts of plagioclase, hypersthene, augite, and needle-like hornblende. It represents the last summit eruptions of Shastina. The overlying pyroclastic flow, also 9,400 years old but stratigraphically above, you will recognize as having the same hornblende-dacite lithology as Black Butte. The flank eruption that emplaced the Black Butte dome complex also produced this pyroclastic flow.

Return by the same route to the area of roadside businesses that we passed earlier and turn R on S Weed Boulevard. Continue on about 2 miles to Weed. Pass under the freeway and on to the flashing light at the intersection with US-97. Turn R on US-97 and drive about 9.6 miles to a wide roadside area adjacent to Whitney Creek. (Depending on the group and the vehicles we may make the equivalent of this stop 1.5 miles farther on where a better view can be had by driving up a short but crummy road to the north).

STOP 7. Walk through the gate near the bridge across Whitney Creek and a short distance S along the bank of the creek. During the late summer this creek is fed by daily meltwater runoff from the Whitney Glacier. The creek is often dry in the morning but runs later in the day; runoff may vary from a trickle to a torrent. Note the debris-flow levees along both banks. The last big debris flow to come down this channel was in August 1997. Part of it came through the channel in front of us, but most of it overflowed the bank to the W and covered about 0.3 miles of US-97. In the view S from here, the Hotlum and Shastina cones are prominent, with a remnant of the breached crater rim of the Misery Hill cone between them at the head of the Whitney Glacier; the edge of the summit dome of Misery Hill is also visible to the L of the rim. In the middle distance to the SW is the Lava Park flow, the only Shastina lava flow that erupted from a flank vent, visible but inconspicuous from here, with a few trees growing on it at the head of the flow. Note the very young appearance of the flow surface despite its age of about 9.5 ka. Behind the Lava Park flow but rising above it is the Pleistocene basaltic flank vent of Cinder Cone. Behind and above it are andesites from the central vent of Shastina. Across US-97 to the N is an older dacitic dome named Haystack.

Continue E on US-97 about 2.6 miles to County Road A-12 that heads back N and NW toward Shasta Valley (the "Grenada Cutoff"). Continue about 3.3 miles on this road to a fairly inconspicuous dirt road on the L, with a small Forest Service sign for "Pluto Cave." Drive in on this graded road for about 0.2 miles to a well-marked parking area with a picnic table.

STOP 8. Follow the footpath a few hundred meters to the large entrance to Pluto Cave. This is a nice example of a large lava tube that fed this voluminous basaltic pahoehoe lava flow from a vent high on the axis of the Cascades to the E. The flow continued past here onto the E edge of the Shasta Valley sector-collapse debris avalanche. This lava flow, about 160 ka, also flowed E from its vent to the other side of the Cascades, where it overlies a middle-Pleistocene moraine complex. Such long and voluminous basaltic flows represent significant episodes of sustained activity; they can remain active for so long only by being fed through a major lava tube in which they can conserve their heat. Such flows in places like Hawai‘i have remained active for months or even years. A second window into the Pluto Cave complex can be visited a few hundred meters N of the main cave entrance.

Return to the Grenada Cutoff, turn L and drive about 15.4 miles, through the town of Grenada, to I-5. Take the onramp N and continue 9 miles on I-5 to the Central Yreka exit. **Bye-bye, Mount Shasta, hello Sawyers Bar!**

(0.0 mi) Yreka. RESET ODOMETER TO 0.0 Leave I-5 and proceed SW on Calif. Hwy.-3 towards Fort Jones. Initially, we drive through Lower Paleozoic strata of the Yreka section of the Eastern Klamath plate, but as we turn westward and begin ascending to the pass at Forest Summit, the road transects underlying serpentinized rocks of the Trinity peridotite.

(5.7 mi)—Forest Summit. **BRIEF STOP 9 (Fig. 2).** BE CAREFUL OF TRAFFIC!!! Dark-green, heavily sheared serpentinite of the Eastern Klamath terrane. The matrix is antigorite serpentine, and the shiny surfaces are mostly lizardite serpentine. The Trinity peridotite, the Josephine peridotite of westernmost Calif. and SW Oreg., and the Feather River peridotite of the NW Foothills belt of the Sierra are three of the largest fragments of mantle material stranded on the North American continent. Alaska may have a lot of such material (I don’t know how well it is exposed), but we have more in California than any of the other Lower 48 states for sure. Hah!

(14.7 mi)—Fort Jones (where there’s a Chevron Station at the west end of town; <u>please gas up here</u>). Poorly exposed blueschists and related rocks of the Stuart Fork blueschist terrane surround us; these rocks were recrystallized within an east-dipping subduction zone at about 227 Ma. Continue on Calif. Hwy.-3, but leave it at Etna by continuing south straight through town, then turn west for Sawyers Bar and Forks of Salmon. Beyond (west of) town, we pass through deeply weathered granitic rocks of the Russian Peak plutonic complex. As we ascend toward the pass, on the north, dark metabasaltic (OIB) rocks are in contact with the granitic pluton.

(36.6 mi)—Etna Summit, and Pacific Crest Trail crossing. **STOP 10 (Fig. 3)**. We are within the North Fork *sensu stricto* (OIB) metavolcanic unit here. Beautiful view of Russian Peak to the south, and to the west, Yellow Dog Peak (nearer) and Tanners Peak (farther). The valley directly west of us contains Russian Creek. The North Fork of the Salmon and Idlewild Campground lie between the ridges defined by Yellow Dog and Tanners peaks.

(45.7 mi)—Idlewild Campground, on the west bank of the North Fork of the Salmon River. This locus is well within the major synclinorium cored by the Salmon River greenstones. <u>We will camp here for two nights</u>. This being before the season opens, there are maintained privy-type toilets but not running water except for the adjacent North Fork of the Salmon River, so you may want to bring or purify your drinking water.

SAWYERS BAR MAP AREA

The Sawyers Bar area consists of three tectonically juxtaposed supracrustal units: (a) on the east, the Stuart Fork metabasalt + metachert + metagraywacke terrane above the low-angle, east-dipping Soap Creek Ridge thrust; (b) the medial North Fork-Salmon River meta-ophiolitic terrane, comprised of intercalated St. Clair Creek laminated cherts and fine-grained quartzofeldspathic argillites (distal turbidites), interstratified with, and overlain by two mafic igneous, largely extrusive suites—North Fork *sensu stricto* mildly alkaline ocean-island basalts (OIBs), and Salmon River basaltic + diabasic + gabbroic island-arc tholeiites (IATs); and (c), the cherty, Eastern Hayfork metagraywacke mélange terrane west of the minor, high-angle Twin Sisters fault. Mineral and bulk-rock elemental and isotopic data, integrated with geologic mapping, document deformation and fluid-rock interaction in the upper ~10 km of a suprasubduction-zone basaltic arc during tectonic accretion to the western margin of North America or nearby offshore arc. The Stuart Fork was recrystallized initially under relatively high-pressure blueschist-facies conditions, whereas the North Fork-Salmon River and Eastern Hayfork were metamorphosed under greenschist-facies conditions. The following geohistory, based on the new geologic map of **Fig. 3**, and cross-sections of **Fig. 4**, provides us with the final, ultimate truth (Ernst, 1998, 1999):

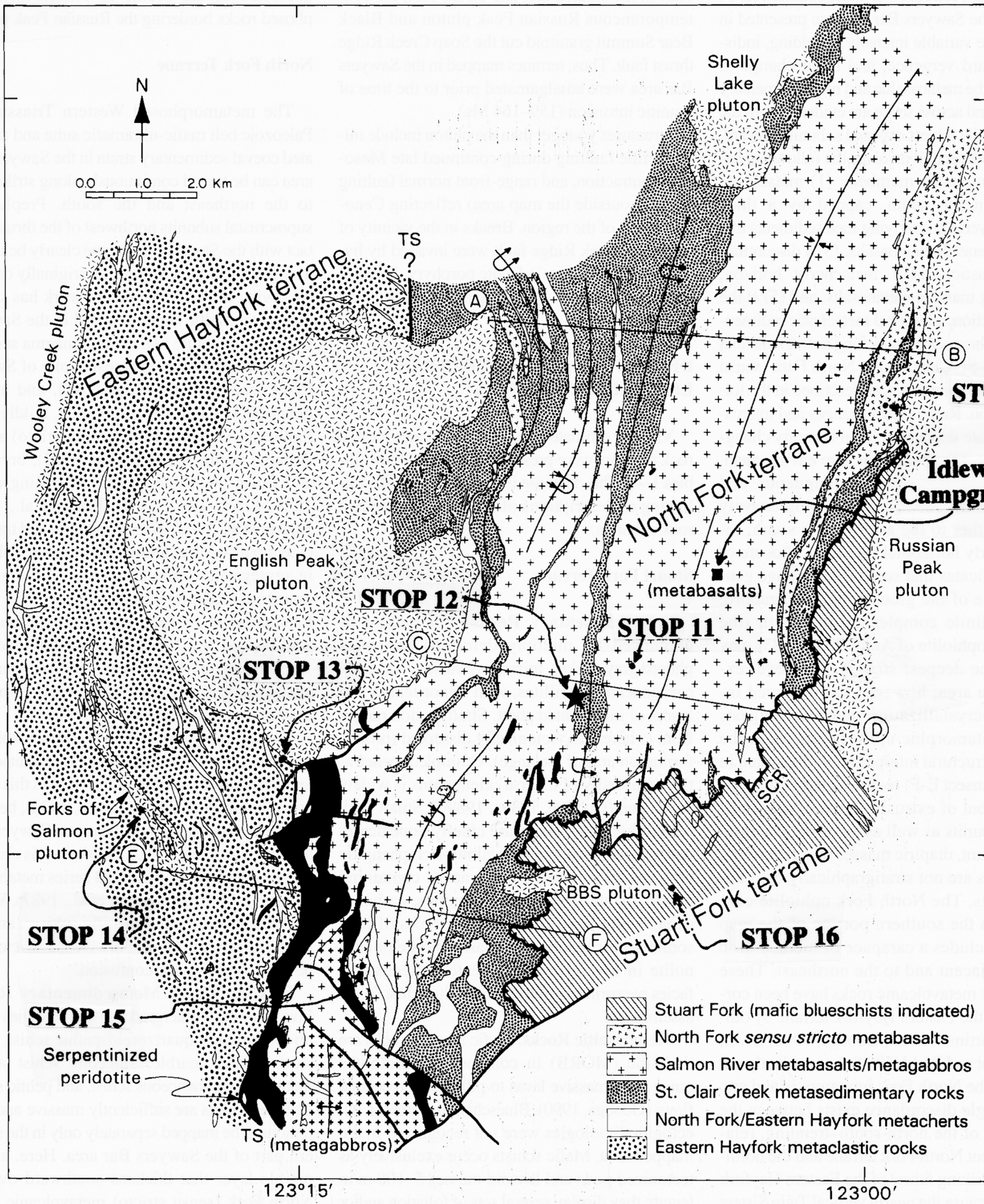


Figure 3. Geology of the Sawyers Bar area, simplified after Ernst (1998). The hamlet of Sawyers Bar is represented by a star. Sites of cross sections A–B, C–D, and E–F are indicated. Abbreviations: BBS—Black Bear pluton; SCR—Soap Creek Ridge thrust; TS—Twin Sisters high-angle fault. Compositional zonation in the granitoid plutons is not shown.

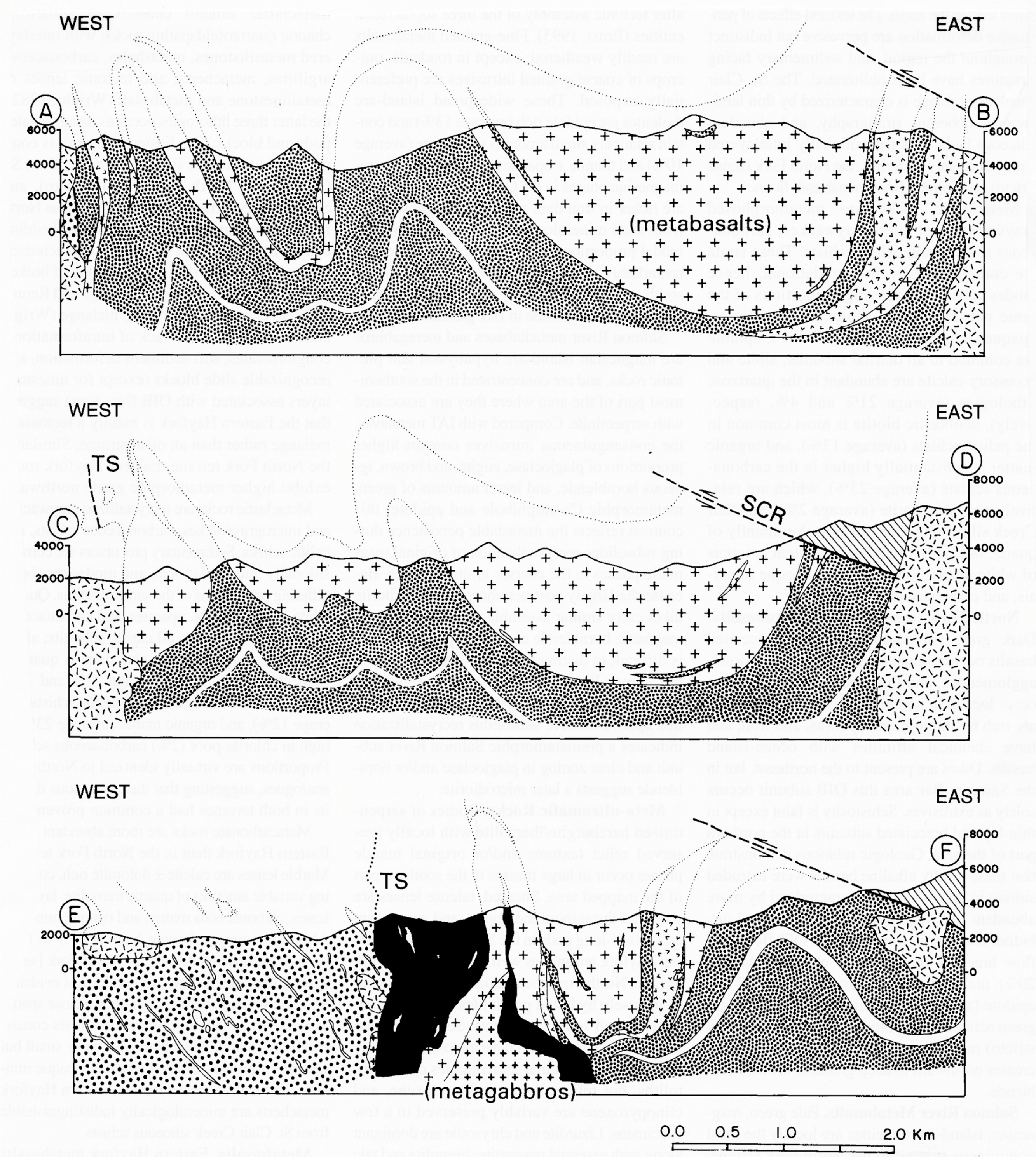


Figure 4. East-west cross sections through the Sawyers Bar area; no vertical exaggeration. For abbreviations, locations, and map units, see Figure 3

(1) Light rare earth-enriched arc tholeiites + alkaline basalts and distal turbidites of the North Fork-Salmon River + Eastern Hayfork terranes were deposited in a subsea environment during Permian(?), Triassic, and Early Jurassic time. Landward, subduction resulted in production of the high-pressure Stuart Fork blueschist complex (physical conditions: 300 ± 50 °C, 700 ± 200 MPa), then its exhumation at ~227 Ma. (2) Submarine eruption and sedimentation continued outboard during Early and Middle Jurassic time, producing the west-facing North Fork-Salmon River oceanic arc and, adjacent on the west, tectonically disrupted Eastern Hayfork mélange. These two terranes underwent low-T alteration by seawater at 100-200 °C and <100 MPa; alkali exchange and modest Mg enrichment were accompanied by increases in greenstone bulk-rock $\delta^{18}O$ values from 6 to ~10‰, preceeding and during initial stages of island-arc formation at 175-200 Ma. By the end of this time, the outboard Western Hayfork calc-alkaline arc had accreted to the Eastern Hayfork terrane. (3) Suturing of the North Fork-Salmon River oceanic arc beneath the exhumed, landward Stuart Fork terrane at 165-170 Ma resulted in regional folding and ~sub- to greenschist-facies metamorphism. Pervasive recrystallization took place without substantial chemical or isotopic exchange under conditions of 300-425 °C, 300 ± 100 MPa, higher metamorphic grade in the north and lower in the south. (4) East-descending subduction or transpression continued seaward, and granitoid plutons were emplaced locally during 159-164 Ma, heating adjacent wall rocks to a maximum of ~500-600°C at pressures of 200-300 MPa. These granitic plutons are compositionally zoned and solidified with an early, high-temperature quartz diorite, followed by the main volume of granodioritic melt, and finished with a small residuum of granite *sensu stricto*. The temperature increase caused devolatilization of adjacent metasedimentary wall rocks, and the exchange of high-$\delta^{18}O$ fluids with intimately intercalated greenstones; $\delta^{18}O$ values in metavolcanic rocks locally increased to more than 15‰. Subsequent cooling yielded 150-164 Ma apparent mineral ages for the metamorphic aureoles. (5) Minor intrusion took place at the very end of Jurassic time, when distinctive muscovite porphyry felsite dikes transected the Stuart Fork/North Fork-Salmon River thrust contact; formation of hydrothermal gold-bearing quartz veins, dated at 147 ± 3 Ma, may be associated with this event. Cenozoic exhumation resulted in range-front faulting and erosion. The documented interplay between Phanerozoic convergence/ transpression and petrochemical evolution in a suprasubduction-zone setting provides an illuminating model for growth of the continental margin crust.

ROAD LOG, DAY #3 (SATURDAY, MAY 19)

(0.0 mi)—Drive west from the campground on the road toward Sawyers Bar, passing through voluminous massive Salmon River (IAT) greenstones ± dikes (these shallow, tabular intrusives are much fresher and more resistant to erosion than are the flows). These metabasalts are pale gray-green where fresh, and weather to a red-brown soil.

(3.0 mi)—Somewhat weathered, massive IAT greenstone outcrop. **BRIEF STOP 11 (Fig. 3)**. In this region, major phases are relict igneous calcic clinopyroxene ± newly grown actinolitic hornblende, abundant sodic plagioclase, and minor chlorite, epidote, titanite + magnetite. On the east, small medium-grained diabase dikes (containing hornblende + plagioclase) cut the flows. On the west end of the outcrop, crude pillows are present. To the south, across the North Fork of the Salmon River, the metabasaltic section layering appears to be dipping gently eastward.

(5.4 mi)—Shaley and silty/calcareous St. Clair Creek metasediments directly east of, and within the hamlet of, Sawyers Bar. These recrystallized strata appear to be distal turbidites, although they are too foliated to reveal graded bedding. Detrital and new metamorphic minerals include dominant quartz and lesser amounts of white mica, sodic plagioclase, calcite, chlorite, and carbonaceous matter. The minor amount of opaque minerals are chiefly pyrite, judging by the limonitic stain on the rocks. CONTINUE ON ROAD WEST TOWARD FORKS OF SALMON.

(5.7 mi)—Sawyers Bar's claim to fame is the Catholic church, constructed in 1855, and graveyard. These are a must-see. **BRIEF STOP 12 (Fig. 3).**

(9.5 mi)—Little North Fork. Beyond the bridge, the road nearly parallels the contact between the quartz diorite border phase of the English Peak granitoid pluton and the Salmon River greenstones. The typical mineral assemblage in the pluton is intermediate plagioclase, hornblende, clinopyroxene, biotite, modest amounts of quartz ± K-spar. At 11.2 mi we see weathered granite grus (coarse granitic sand) on the north side of the road.

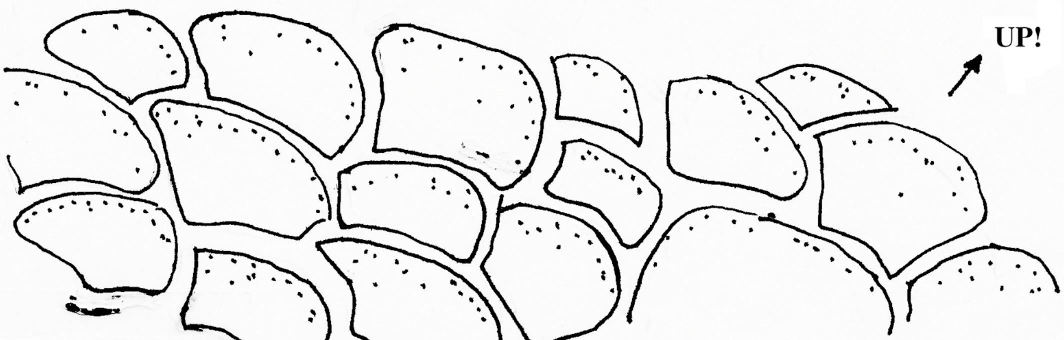


Figure 5. Sketch of OIB pillows.

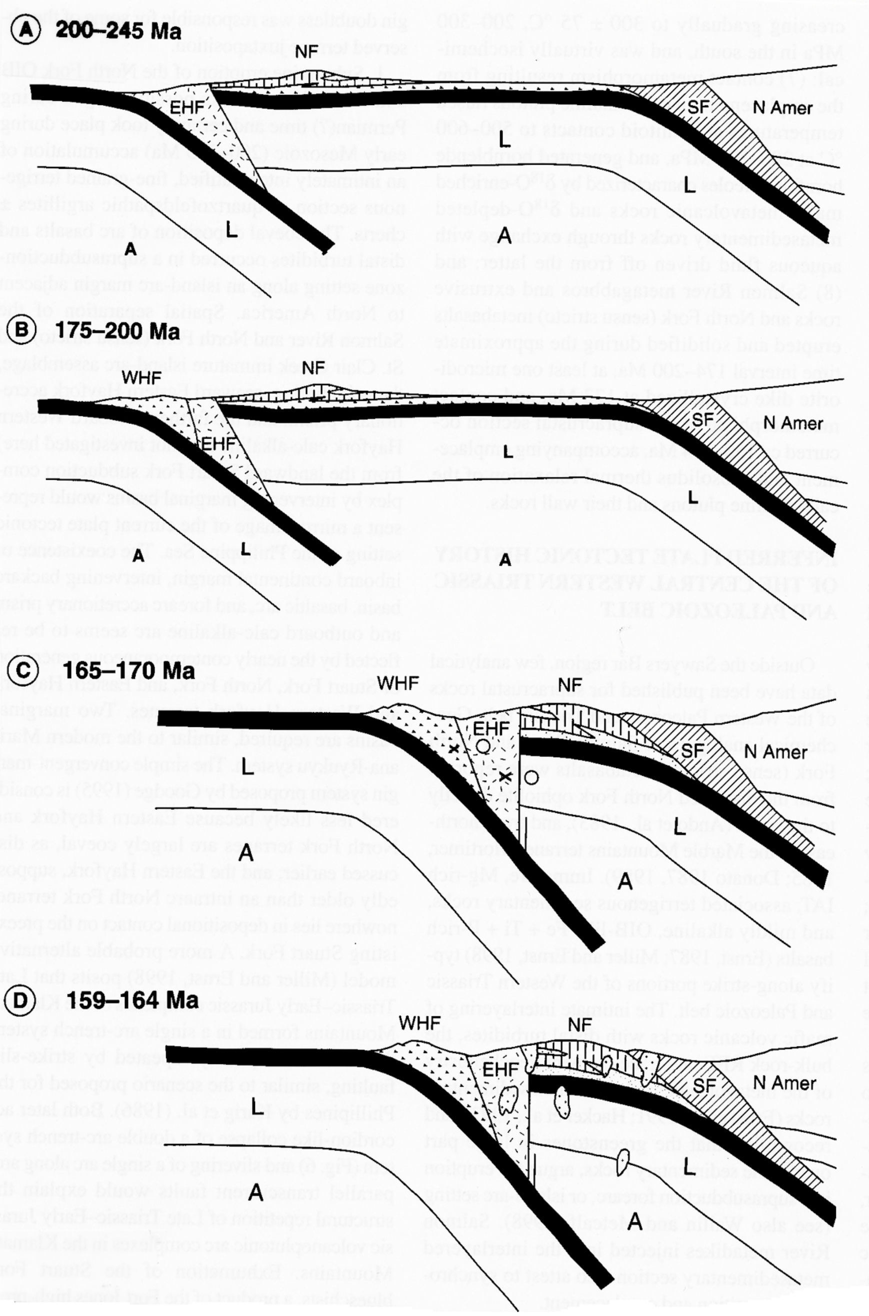


Figure 6. Speculative plate tectonic history of the central portion of the Western Paleozoic and Triassic belt, based on detailed mapping, petrotectonics, and geochemistry of the Sawyers Bar area. View is to the north. Abbreviations: A—asthenosphere; L—lithosphere; WHF—Western Hayfork terrane; EHF—Eastern Hayfork terrane; NF—North Fork terrane; and SF—Stuart Fork terrane. (A) Triassic-earliest Jurassic time; eastern subduction zone becomes inactive and Stuart Fork terrane is sequestered at midcrustal levels by ca. 227 Ma; (B) Early and Middle Jurassic time; Western Hayfork is juxtaposed against inboard Eastern Hayfork through consumption of intervening basin or due to transpression; (C) late Middle Jurassic time; outer subduction zone is still active (X indicates relative movement into the plane of section, i.e., northward; bull's eye indicates relative movement out of the plane of section, i.e., southward); and (D) early Late Jurassic time; local termination of convergence and thermal relaxation. See text for discussion.

(14.2 mi)—Heiney Bar granodiorite, rich in plagioclase, quartz, biotite, and K-spar, with minor chlorite and hornblende. This is a blob of the main mass of magma that cut across and outside of the original, earlier-solidifying quartz-diorite border phase of the pluton.

(15.4 mi)—Contact between the English Peak pluton on the east and Eastern Hayfork cherty metasediments on the west. **STOP 13 (Fig. 3)**. Finer-grained granitoid dikes suggest that this is an intrusive contact locally obliterating the Eastern Hayfork/North Fork-Salmon River terrane boundary (the Twin Sisters high-angle fault).

(18.6 mi)—Metashale of the Eastern Hayfork terrane (No STOP).

(20.1 mi)—Contact between small, rather ferromagnesian Forks of Salmon quartz diorite and the Eastern Hayfork metasedimentary rocks. **STOP 14 (Fig. 3)**. Watch the traffic!

(20.5 mi)—<u>Forks of Salmon rest stop</u>. Whew! TURN SOUTH ON CECILVILLE ROAD.

(24.6 mi)—Sheared serpentinite lens in the Eastern Hayfork. The large white block is probably a rodingite (a low-temperature, low-pressure metasomatized gabbro inclusion in the original peridotite—now consisting of hydrous Ca and Ca-Al silicates such as xonotlite, wollastonite, and hydrogrossular). During serpentinization of the original mantle peridotite, the Ca liberated from clinopyroxene was added to the gabbroic inclusion, which in turn lost Si to the surrounding, serpentinizing olivine.

(26.0 mi)—At another, much bigger serpentinite body, cross eastward into North Fork-Salmon River terrane. Salmon River (IAT) gabbros make up the section east of the serpentinite. Then back into serpentinite again. Is this the base of an ophiolite? If so, why do the Salmon River metabasalts stratigraphically overlie the St. Clair Creek distal metasediments farther north?

(28.6 mi)—Magnificent dark pillow lavas of the North Fork *sensu stricto* (OIB) metabasalts. **STOP 15 (Fig. 3).** Major minerals are calcic plagioclase, chlorite, hornblende, epidote, titanite and magnetite. This mafic rock elsewhere is an amygdule-rich flow breccia, but here amygdules are confined to the upper parts of beautifully developed pillows (see diagrammatic sketch of **Fig. 5**). Flow tops are up and to the NE. This is a steeply dipping but right-side-up section.

(30.1 mi)—<u>Matthews Creek Campground and rest + lunch stop</u>. Although we won't bother studying them here, St. Clair Creek metasediments are exposed in this area, including prominent, stratigraphically continuous, thick layers of metachert defining an anticline overturned to the west. THEN, CONTINUE ON SOUTHEASTWARD TOWARD CECILVILLE.

(34.7 mi)—Major limestone (marble) layer holding up massive bluff. This carbonate unit rests depositionally on North Fork *sensu stricto* (OIB) metabasalts. Indistinct faulting just outside the map area drops the limestone to road level. The strata probably represent a reef carbonate deposited on an oceanic island. The association of OIB metabasalts with carbonate metasediments is common in the mélange blocks in the Eastern Hayfork terrane as well. Both Eastern Hayfork and North Fork-Salmon River terranes evidently had similar provenances—just differing amounts of the several rock types.

(38.2 mi)—Cecilville. Yahoo!! TURN WEST FOR SAWYERS BAR.

(45.9 mi)—Junction with road eastward to Eddy Gulch Lookout and good exposure of Stuart Fork metasediments east and structurally above tectonic terrane boundary juxtaposing North Fork-Salmon River and Stuart Fork terranes (Soap Creek Ridge thrust) These appear to be chiefly phengitic (white mica) metagraywackes, rarely containing lawsonite. Several stages of deformation characterize the 227 Ma blueschist belt on the east, where only one stage has affected the 165-170 Ma greenstone belt on the west. **THIS IS AN OPTIONAL SIDE TRIP (STOP 16, Fig. 3)**. The gate at approximately 0.4 mi from the lookout probably will be locked.

(63.8 mi)—Sawyers Bar. TURN EAST.

(69.2 mi)—Idlewild Campground. CONTINUE EASTWARD.

(78.6 mi)—Etna Summit. **(STOP 10 from yesterday, Fig. 3)**. Take Pacific Crest trail NW for as long as you have time and snow conditions (?) permit. At the roadway pass and for about 0.5 mi northwestward, North Fork *sensu stricto* (OIB) metabasalts crop out. They are strongly foliated, but display abundant breccia fragments and sparse amygdules. Farther along the trail, after a turn to the north, we encounter steeply west-dipping metasediments and then massive Salmon River (IAT) greenstones in the core of the major synclinorium. If you have more time, walk south from the pass along the Pacific Crest Trail through IOB, then IAT gabbroic and Russian Peak granitic intrusive bodies, then St. Clair Creek metasediments, then across the Soap Creek Ridge thrust to the Stuart Fork white-mica-rich metasediments, and finally the main part of the Russian Peak granitic complex. However, rocks along this southern hike are not well exposed. Sorry! After returning to the Idlewild Campground and dinner, examine the eye-witness account of the plate-tectonic evolution of the Sawyers Bar region (**Fig. 6**).

ROAD LOG, DAY #4 (SUNDAY, MAY 20)

(0.0 mi)—Drive west from Idlewild on road past Sawyers Bar and bearing right at Forks of Salmon past the suburban golf course (a laugher for sure!). Near Somes Bar, TURN SW FOR ORLEANS on Calif. Hwy.-96. In this general region where the Salmon empties into the Klamath River, we are passing through the northern extension of the voluminous, massive, volcanogenic Western Hayfork andesitic arc, then complexly faulted bits and pieces of the ophiolitic Rattlesnake Creek terrane (the westernmost belt of the WTrPz), tectonically (?) underlain by serpentinite invaded by at least two generations of microgabbro.

(44.1 mi)—Orleans. From a couple of miles north of town south through the Hoopa Indian Reservation to just beyond Willow Creek, Calif. Hwy.-96passes through the Western Jurassic Belt, chiefly the Late Jurassic Galice Formation (similar lithologically and in age of deposition and recrystallization to the Mariposa Formation of the Sierran Foothills).

(58.8 mi)—Witchpec. Continue south to Hoopa.

(69.2mi)—Downtown Hoopa.

(81.5 mi)—Willow Creek and junction with US-299. TURN WEST at the statue of Bigfoot. Going up the grade, the road transects imbricate slices of the Rattlesnake Creek terrane tectonically thrust westward over the underlying Western Jurassic belt, and downdropped along high-angle faults against the Western Jurassic belt. About three miles east of Berry Summit, US-299 breaks out of the more easterly Klamath province into a short section of massive-bedded Franciscan metagraywacke (of the Eastern Belt?), then hummocky, heavily landslid clay-matrix mélange of the Central Belt of the Franciscan Complex, northern California Coast Ranges.

(91.8 mi)—Berry Summit Overlook. TURN LEFT for amazing panorama of the Franciscan Central Belt to the west and south. **STOP 17 (Fig. 2)**. Note the incoherent and crazy, hummocky topography, a reflection of the nature of the underlying bedrock—chaotic tectonic mélange. Gracious!

(118 mi)—Arcata. (lots of gas stations on south side of Eureka, but you'll have to go to Rio Dell for Chevron.)

(119.3 mi)—Junction with US-101. TURN SOUTH AND HEAD FOR THE AVENUE OF THE GIANTS (leave US-101 at about fifth exit—it says Visitors' Center), SANTA ROSA, GOLDEN GATE BRIDGE, AND THE FARM/USGS.

(~180 mi)— Avenue of the Giants Visitors' Center: picnic tables and <u>LAST good rest + lunch stop</u>. From here, you're on your own!

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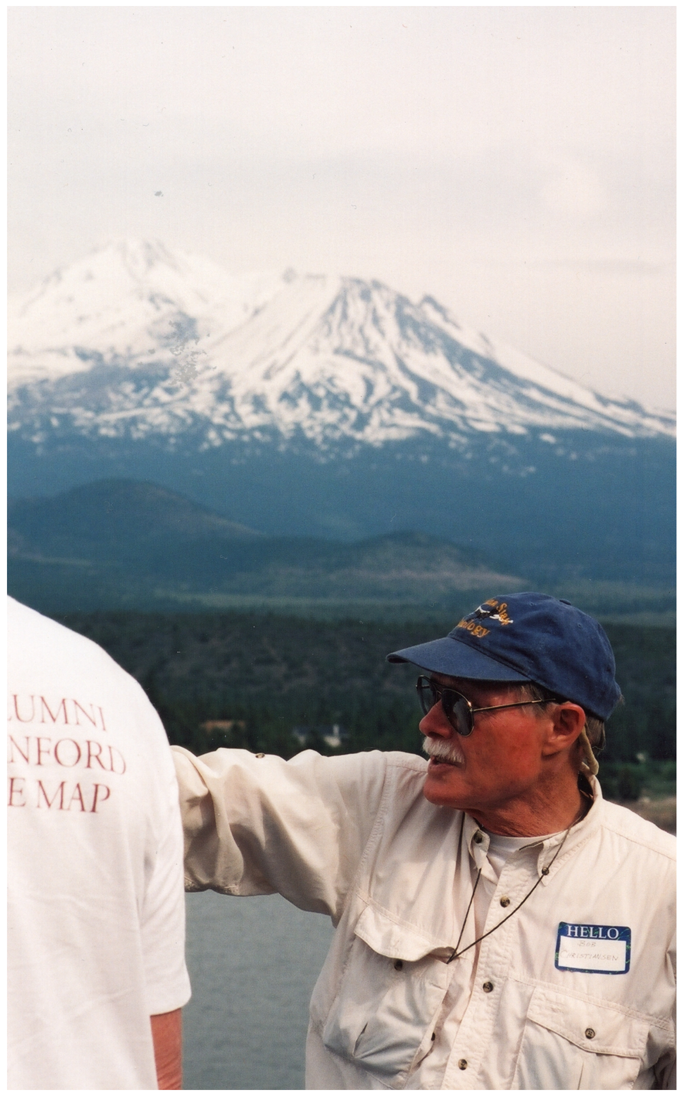
Gary Ernst explaining subduction



Bob Christiansen explaining eruption