Geology of the Marin Headlands and the Half Moon Bay coast

Saturday, May 19, 2001

California Rocks!

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GEO 116, Continuing Studies
Stanford University

Time	**Mileage**	**Directions**
8:45	0.0	Meet at the Bambi parking lot (intersection of Panama St. and Via Ortega)

The Stanford campus is built on unconsolidated Quaternary alluvial sediments. As you drive west from campus, we will pass through mostly Tertiary marine sediments and some older Mesozoic Franciscan Complex rocks and across several blind thrust faults.

9:00		Leave Bambi parking lot, re-set odometers to zero
		L on Panama St.
		L on Campus Drive West
		As you drive up this small hill, you're driving up a blind (not exposed) thrust fault called the Stanford Fault
		R on Junipero Serra Blvd.
	1.3	***Look Left*** **–** Eocene Whiskey Hill Formation – turbiditic sandstone & mudstone
	1.5	Left on Alpine Rd.
	2.1-2.2	***Look Right*** **–** Mid to Upper Miocene Ladera basal bioclastic member – shallow marine sandstone & mudstone, locally fossiliferous
	2.3	***Look Right*** – Mid-Miocene Page Mill Basalt (14 Ma)
	2.6	Right on 280 North
	3.5	***Look Left*** **–** landslide scar on roadcut
	6.3	**Left and Right –** Blocks of Franciscan serpentinite (greenish gray rock)
	6.5-6.6	***Look Left*** **–** landslide scar on roadcut
9:15	10.2	Exit R to Vista Point

STOP 1: VISTA POINT OVERLOOKING THE CRYSTAL SPRINGS RESERVOIR

9:45	10.7	Enter 280 North
	30.2	Junction Highway 1 North (stay in left lanes)
	32.7	Veer left to 19th Avenue (Highway 1 North)
		Cross Golden Gate Bridge
		Pass Vista Point on R
10:20	41.5	Exit R to Alexander Ave.
	41.7	L toward 101 South & Marin Headlands
	41.9	R to Marin Headlands, Conzelman Rd. (do not enter the freeway, do not cross the bridge)
10:25	42.4	Park on Conzelman Rd.

STOP 2: GOLDEN GATE NATIONAL RECREATION AREA, MARIN HEADLANDS

11: 10	42.4	Return to 101 North via Conzelman Rd.
	43.1	Enter 101 North
		Look Left **–** shortly after Waldo Tunnel, you can see pillow basalts in the roadcut

	48.4	Exit Tiburon Blvd., turn R at Tiburon Blvd.
	50.3	Turn L onto Trestle Glen Blvd.
11:18	50.8	Turn L onto Shepard Way (marked by signs to the Shepard of the Hills Lutheran Church) and park along street or in the church lot

STOP 3: RING MOUNTAIN OPEN SPACE PRESERVE

12:40	50.8	Return down Shepard Way and turn R onto Trestle Glen Blvd.
	51.3	Turn R onto Tiburon Blvd.
	53.2	Enter 101 South
12:50	58.5	Cross Golden Gate Bridge
		Return on 19th Avenue (Highway 1 South)
	67.3	Veer R toward Highway 1/280 South
	69.8	Take Eastmoor Ave./Mission St. exit
	69.9	Turn L onto Sullivan Ave.
	70.6	Turn R onto Eastmoor Ave. (Eastmoor Ave. becomes Westmoor Ave.)
	70.9	Straight across 35/Skyline Freeway
	71.3	Turn L onto Skyline Dr.
		Look Right – Note the houses that have lost their backyards
	72.3	Turn R onto Longview Dr.
		We are now crossing the ***San Andreas fault zone***
1:05	72.3	Turn R onto Westline Dr. and park

STOP 4A: SAN ANDREAS FAULT AND BAD URBAN PLANNING

1:15	72.3	Return to Longveiw Dr.
	72.4	Turn R on Longview Dr.
	72.4	Turn R immediately on Rockford Ave.
	72.5	Turn L on Westline Dr.
	72.6	Veer R and head downhill to Westline Dr.
	72.6	Turn R on Westline Dr.
1:20	72.9	Drive to the end of the road and park

STOP 4B: MUSSEL ROCK AND THE SAN ANDREAS FAULT

1:40	72.9	Return down Westline Dr.
		Continue to end of Westline Dr.
	73.4	Turn R on Palmetto Ave.
1:45	74.6	Enter Highway 1 South
	77.3	***Look Right –*** Rockaway Beach limestone (Franciscan)
	79.2	***Look Left (Southeast) –*** Pilarcitos fault forms this valley (old branch of the San Andreas fault)
	79.7	***Look Right –*** San Pedro Point seaward dipping turbidite beds
	80-80.1	***Look Left –*** Devils Slide - Note bedding in turbidites dips seaward
	81.6	***Look Right –*** Note granite on headland

2:00	82.8	Turn R into parking lot for Montara State Beach or park on Highway 1

STOP 5: MONTARA STATE BEACH

2:45	82.8	Turn R/continue on Highway 1 South
	84.1	Turn R at sign to Marine Refuge (~50 m south of Post Office)
2:55	84.5	Continue to end of road and turn R into parking area

STOP 6: MOSS BEACH

4:00	84.5	Return to Highway 1
	84.9	Turn R onto Highway 1 South
	86.7	***Look Right*** - Seal Cove/San Gregorio fault trace runs along the base of the hill at Pillar Point near the runways of the Half Moon Bay airport
	88.1	***Look Right*** **-** El Granada Beach – Note dunes to North, no sand South of breakwater as a sign of longshore drift
	91.1	Pass Junction 92

****** Anyone who needs to be back at Stanford by 5pm should leave the group here ******

	94.9-96.4	As we drive this long section of road, notice the flat terrane we're driving across (old wave-cut platforms) and the hills off to the left (East) which are old sea cliffs. Also take this opportunity to appreciate the emergent coastline and the high modern sea cliffs
	98.9	Roadcut - Tertiary sandstone with lumpy weathering
4:30	108.8	Turn R into Pebble Beach parking lot

STOP 7: PEBBLE BEACH/BEAN HOLLOW

5:15	108.8	Turn L onto Highway 1 North
	126.5	Turn R onto Highway 92 East
	129.1	***Look Left*** **-** view of Tertiary sandstone
	130.8	Pilarcitos fault crosses 92 at this tight bend in the road
	131	***Look Right*** **-** Fake rock on R has been designed to look real, but fractures never change apparent orientation as you go around bends
	131.6	Cross over Jct 35/Skyline
		At the Crystal Springs Reservoir, we are crossing from the ***Pacific plate to the North American plate***
	134.8	Turn R onto 280 South
	144.5	Exit Alpine Rd., return to Stanford campus
5:50	147.1	Bambi parking lot

STOP 1: VISTA POINT OVERLOOKING THE CRYSTAL SPRINGS RESERVOIR
At this viewpoint, we will take time for an overview of the geology we will see today. First, make sure you take note of the serpentinite that makes of the walls around the parking lot and along the paths and the individual blocks above the parking lot - this is typical Franciscan Complex serpentinite.

As you stand and look across 280 and the Crystal Springs reservoir, you are seeing the contact between the North American and Pacific plates. The San Andreas fault trace runs along the reservoir and separates the North American plate (where you are standing) from the Pacific plate (the coastal hills and beyond). The San Andreas is a right-lateral transform fault that has transported the rocks in the hills to the west hundreds of kilometers from the south. The granite that forms Montara Mountain is part of the Salinian block and is related to the granites from the southern Sierra Nevada.

Turn around now and look across the San Francisco Bay. If it's a clear day, we will be able to see the foothills in the east bay. Near the base of the hills and following a line of vegetation, is the trace of the Hayward fault. You will remember from class that the Hayward fault is another major right-lateral transform fault that runs from the south bay through Fremont, Hayward, and Berkeley (straight through the UC stadium). The San Andreas fault along with the Hayward fault and the other transform faults that pass through the Bay Area form a wide zone that is the plate boundary between the North American and Pacific plates. While most of the motion between the two plates is taken up by the San Andreas, some slip is accommodated by these other faults.

STOP 2: GOLDEN GATE NATIONAL RECREATION AREA, MARIN HEADLANDS
(description of Stop 2 is taken from the California Department of Conservation Special Publication 119, *Geologic field trips in northern California*)

The Franciscan ribbon cherts exposed along the road are intricately folded that overall represents north-vergent thrusting. The chert section of the Marin Headlands was deposited in the deep ocean over an extremely long period of time - the chert section is probably less than 80 m thick and spans a period of deposition from about 200 to 100 Ma based on studies of the radiolarian fossils found within the cherts. If you break a fresh surface in the chert and wet it, you can see the radiolaria in the rock with a hand lens. In the Headlands terrane, cherts depositionally overlie basalt and graywacke depositionally rests upon the cherts.

The geochemistry of the basalt is consistent with formation at an oceanic spreading center - most Franciscan volcanic rocks appear to have formed at spreading ridges or were erupted off-axis at seamounts or oceanic rises. Pillow structures are occasionally visible in the basalts (very fine examples of pillow structures are found at Tennessee Point just north of here). The history recorded in the Marin Headlands is one of deposition of cherts on basalt in the open ocean for 100 million years. As the oceanic plate moved toward the Franciscan subduction zone, followed by deposition of graywacke on top of the chert at 95 Ma, this particular piece of the ocean floor neared the Franciscan trench. The sequence of basalt-chert-graywacke is repeated many times at the Marin Headlands by thrust faults that formed during the underplating of the Marin Headlands units.

STOP 3: RING MOUNTAIN OPEN SPACE PRESERVE
(description of Stop 3 is taken from the California Department of Conservation Special Publication 119, *Geologic field trips in northern California*)

Tiburon Peninsula may be the best locality for observing high-grade (high-pressure and temperature) metamorphic blocks in the Franciscan. The high-grade blocks display individual metamorphic minerals of several millimeters to even several centimeters in size that grew during metamorphism at great depths in the subduction zone. Blocks include amphibolites, eclogites, and blueschists that exhibit the highest grade of metamorphism of any rocks in the Franciscan. These high-grade rocks are found in a shale and serpentinite matrix melange that give the local topography is distinctive look - large blocks of resistant metamorphic rocks in a matrix of soft-easily erodable shale and serpentinite. Minerals to look for in these outcrops include garnet, amphibole, epidote, omphacite (clinopyroxene), and a blue amphibole called glaucophane. Geochronologic data indicate that the high-grade blocks are the oldest rocks in the Franciscan Complex having been metamorphosed about 160 Ma.

STOP 4: SAN ANDREAS FAULT AND BAD URBAN PLANNING
(description taken from California Department of Conservation Special Publication 109, *Geologic excursions in Northern California: San Francisco to the Sierra Nevada*)

The main scarp of the San Andreas fault forms the southwest-facing slope about 2000 ft. (600 m) north of Mussel Rock. The view to the north is the Marin Peninsula where we looked at rocks from the Franciscan Complex; the peninsula is bounded on the west by the San Andreas fault which separates it from the Point Reyes Peninsula composed of granitic rocks of the Salinian block (which also includes the Farallon Islands 19 mi. offshore). The cliff exposures to the northwest of Mussel Rock contain the type section of the Pleistocene Merced Formation which is predominantly upward shallowing sequences. The hills immediately to the southeast of Mussel Rock are Franciscan consisting mainly of greenstone and graywacke with minor amounts of chert, limestone, and serpentinite. The prominent headland to the south is Montara Mountain (Salinian granite). The Pilarcitos fault runs along San Pedro Valley on the north side of the mountain and goes out into the ocean near Point San Pedro. The Pilarcitos fault is a formerly active, but now inactive branch of the San Andreas fault.

This coastal zone is an example of an area where rapid urban development took place in the post-WWII years without an adequate study of the geological hazards. Although the coastline here is flanked by steep and treacherous cliffs, it became the location at the beginning of this century of the Ocean Shore Railway that was in operation until 1920. The railroad bed in this area became the site of Highway 1 in the 1930s until its closure in 1957 due to landslide damage from a nearby M 5.3 earthquake epicenter. Housing developments expanded into this are between the late 1950s and early 1970s; the homes that can be seen above the cliffs date from this period. The main landslide at Mussel Rock involves approximately 9 million cubic yards of the Merced Formation. Homes of the Westlake development fringe the steep cliff that marks the head of the slide. Slumping and erosion have cause rapid retreat of the cliff line, which endangered many of the perimeter homes. Dozens of homes have been removed from this area and several more homes have been condemned or threatened by the landslide. Virtually no damage occurred in this area due to the 1989 Loma Prieta earthquake.

STOP 5: MONTARA STATE BEACH
This is one of the traditional introductory geology sites visited regularly by Stanford students. The main goal of bringing students here is to try to reconstruct the geologic history of these rocks. There are several interesting geologic relationships between the rocks of Montara beach - faults, dune deposits, erosional unconformities, marine terrace deposits, granites, to name a few.

STOP 6: MOSS BEACH SYNCLINE AND THE SEAL COVE FAULT
(description taken from Wiley and Moore, 1983, Pliocene shallow-water sediment gravity flows at Moss Beach, San Mateo County, California *in* SEPM Pacific Section, Cenozoic Marine Sedimentation, Pacific Margin, USA, p. 29-43.)

The rocks exposed at Moss Beach are from the upper part of the Pliocene Purisima Formation overlying the Cretaceous Montara granodiorite and are part of the Salinian block. The rocks crop out in two northwest-trending synclines on the northeast side of the Seal Cove fault. The Seal Cove fault (part of the San Gregorio-Hosgri fault system) is a major northwest-trending right-lateral strike-slip fault that is exposed here (or was - it is now covered by rubble brought in to keep the cliff from falling into the ocean) and continues offshore to the north from here. The fault juxtaposes the shallow-water deposits of the southern Moss Beach syncline against a deeper-water facies of the Purisima Formation.

These sections contain fine- to very coarse-grained clastic rocks that were deposited in a shallow-marine environment. The succession consists of three facies: (1) alternating shell/pebble conglomerate and massive, cross-stratified or laminated sandstone beds interpreted as shelf sediments deposited and reworked by wave-generated currents; (2) conglomerate and pebbly sandstone with cross-stratified and ripple-laminated fine sandstone that is interpreted as sediment gravity flows deposited in a background of shelf sediment and reworked by shelf waves and tides; and (3) boulder and granule conglomerate interpreted as subaqueous sediment gravity flows with only minor reworking. The depositional setting for these rocks is interpreted as a fan delta building into a south-facing bay or partly protected west-trending coastal segment.

STOP 7: PEBBLE BEACH TURBIDITES
Here we have the opportunity to walk out beyond the edge of the Cretaceous continental shelf into water that was 2 km deep. The Cretaceous Pigeon Point Formation is made up of a complex sequence of turbidite unites, each 1-8 m thick. The base of each turbidite is a relatively massive and structureless conglomerate or pebbly sandstone (commonly with rip-up clasts from underlying units) that grades upward into coarse-grained sandstone (fining-upward sequence). Some units may be topped by parallel-bedded medium-grained sand and cross-bedded and rippled sands and silts. Most of the deposits represent channel deposits in a huge deep-sea fan that fed off the continental shelf (similar to the setting off Monterey Bay today). Water depths are estimated to have been around 2 km. In one place, there are several meters of mudstone that represent fine-grained material that spilled over from an adjacent channel of the deep-sea fan. Look for fine laminations, cross laminations, scour- and fill-features, and soft-sediment folding in the finer-grained layers, and various water-escape and soft-sediment deformation features including "pillar", "dish", and "flame" structures.