ARMA 2008
San Francisco, California

Private Melange/Bimrocks Field Trip

A MELANGE: CHUNKS OF FRANCISCAN GEOLOGY IN A MATRIX OF TOURIST CHATTER

Saturday June 28 2008

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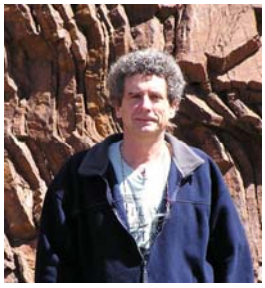
TRIP LEADER



Dr. Edmund Medley, PE, CEG, F.ASCE is a geological engineer with over 30 years of international experience in geological and geotechnical engineering. His career includes chapters as a mineral exploration prospector, teacher, university lecturer, vagabond and bimrock researcher. He is a Senior Consultant with Geosyntec Consultants in Oakland, California where he practices Geological Engineering and performs failure investigations. In his spare time, he pursues his passion for researching melanges and other species of geological complexity, which is a particularly apt area for him, given his surname and his chaotic life style. He is licensed as an engineer and geologist in USA, Canada and the UK.

You shall see some bimrocks today. **Do not hesitate to ask me questions**: I am both an engineering geologist and a civil engineer and thus can say "I Don't Know" with more embarrassment than many! Please ask your questions loudly since I am HARD OF HEARING and other folk may want to hear your questions as well.

ASSISTANT: Julien Waeber, PE, PG, Senior Engineer, Geosyntec Consultants, Oakland

A NOTE ABOUT THESE NOTES

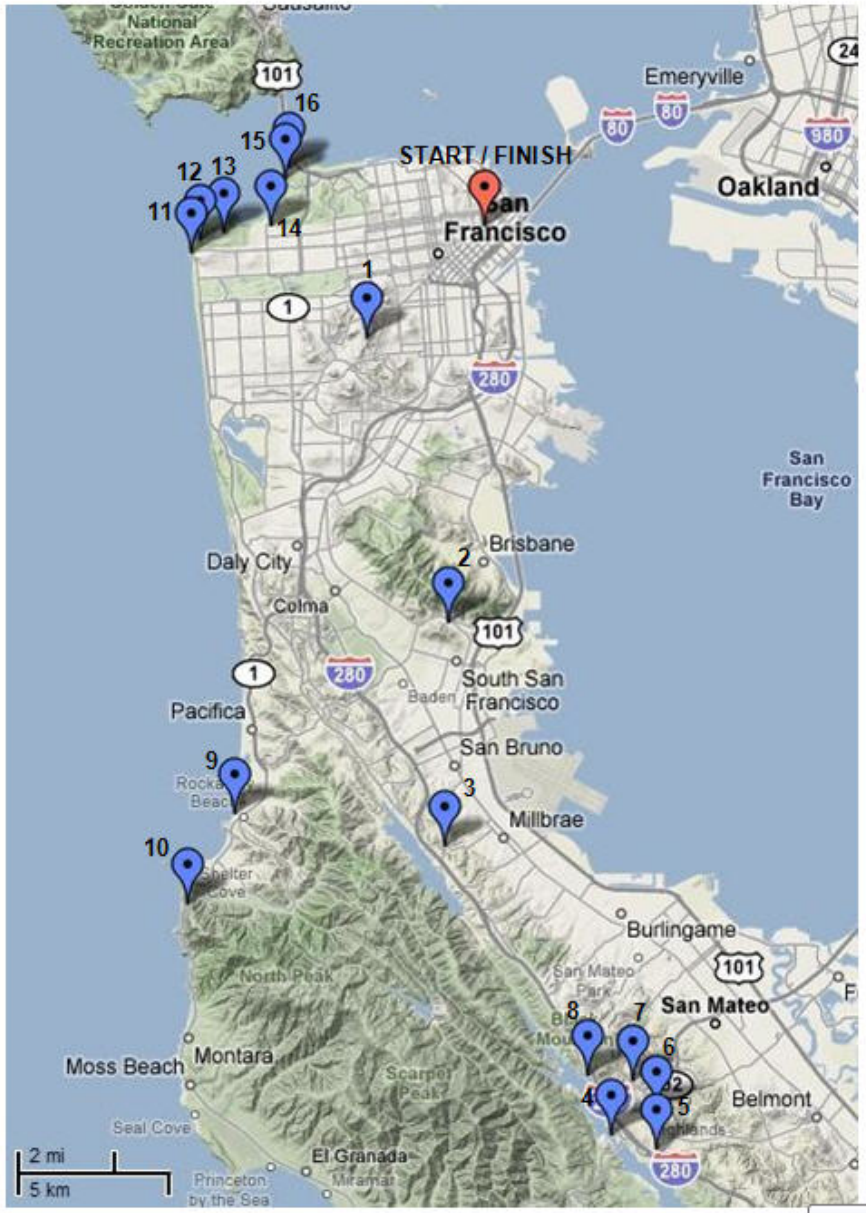
These notes are just that. They are not a dissertation: been there once and don't want to go there again. But I have tried to make them informative. References appear as footnotes. I took nearly all the photographs except for the one above which was taken by Julie Grau, my wife, who for once declined to be "scale". Yes, the photos in these Notes are small but you shall be taking your own lovely pictures! If you want copies of the photographs just ask me. In some cases I photographed information displays that you shall read for yourself.

TRIP OVERVIEW

You shall enjoy today's field trip because you are going to see a lot of lovely sights and sites on the San Francisco Peninsula. The stuff you may learn about Franciscan Complex geology, melanges and bimrocks are an added benefits Mostly though, you will enjoy what we who live here really get off on.

You will enjoy yourself more IF you brought along clothes to withstand the possible windy fog. You did bring something warm, did you not?? By the way, Mark Twain never said "The worst winter I ever spent was summer in San Francisco", although the quote is pithy enough to have come from him. No, that complaint was probably from someone visiting from Boca Raton. The fog is a result of cool ocean air condensing as it blows towards warmer climes inland.

STOPS FIGURE: NEXT PAGE



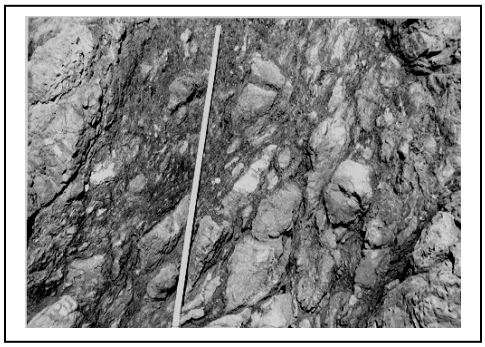
ARMA 2008: Personal Field Trip - Melanges and Bimrocks, June 28, 2008
Trip Leader: Dr. Edmund Medley, PE, CEG, F.ASCE

Start/Finish: Westin Hotel.

1. **Twin Peaks**: San Francisco overview and contorted chert.
2. **Larch Street:** Suburban melange - Effects on residential development.
3. **Pinehurst Landslide:** Landslide case history (2000) - factors influencing slope instability in Franciscan melange
4. **Drive-by:** San Andreas fault from the "world's most beautiful freeway".
5. **Drive-by:** Grazing blocks.
6. **Crystal Springs Village Shopping Center:** BREAK - 30 mins.
7. **Polhemus Rd Landslide:** Effects of major landslide in melange - ruptured road access, threatened regional water supply, remediation construction.
8. **Crystal Springs Dam:** LUNCH, look at 1890 Dam, sheared serpentinite and serpentinite melange in road cuts.
9. **Pacifica:** Rockaway Beach - Calera Quarry; Franciscan shale melange.
10. **Devil's Slide:** Drive-by: turbidites, weathered granites.
11. **Cliff House / Sutro Baths:** Geomorphological expressions of headland blocks and intervening matrix-rich rock. **Optional break.**
12. **Fort Miley / El Camino Del Mar:** Overview of Land's End Franciscan melanges & landslides. Short walk to Legion of Honor. Golden Gate Bridge views.
13. **Legion of Honor:** Did you get your shot of the Golden Gate Bridge?
14. **Sea Cliff:** Scene of the Sea Cliff Incident: Story of famous people's houses, leaky sewers and sink holes...
15. **Presidio:** Serpentinite overlook with a dash of spectacular Golden Gate Bridge and Marin Headlands views.
16. **Golden Gate Bridge:** Wander under/around/on the bridge.

RETURN to Westin Hotel approx 6pm

INTRODUCTION



In California, 500 million years of active plate tectonics has created an abundance of fault rocks, melanges and similar bedrock composed of complexly mixed, often heterogeneous strong blocks embedded in a sheared, weaker matrix. Such rocks are *bimrocks* (block-in-matrix rocks). Volumetrically, the most intractable bimrocks are melanges (from the French, *mélange*, or mixture) associated with tectonic subduction complexes. Bimrocks are of particular significance in California, because they constitute a large proportion of the Franciscan Complex, a regional scale jumble that makes up about a third of the bedrock in the central and northern Coast Ranges of northern California. The Franciscan is famous because it was the workshop that allowed greater understanding of convergent plate margin tectonics. Although the Franciscan is a famous locality for bimrocks, they are also common in many other geologic units in California and the world, essentially all in mountainous areas, so the engineering problems associated with them are global in scope.

The goals of this one day Field Trip (and associated Workshop and conference Session) are to alert engineers to the engineering significance of bimrocks (of which melanges and many fault rocks are a subset) and give geologists guidance to more clearly communicate the nature of such materials to engineers. We also wish to introduce geo-practitioners to the problems of bimrocks, as well as some rational approaches that have been developed to characterize such rocks. Trip participants are encouraged to ask these questions:

- How can I produce dependable maps and cross sections in bimrocks?
- What is a block? What is matrix?
- What should I measure?
- Everything is so chaotic: why bother describing it at all?
- What is the strength of a melange?
- What does all this geology stuff have to do with rock engineering?

The trip starts in San Francisco. We drive to Twin Peaks upon which stands the tall Sutro Tower. If we can see it. If we cannot, we will not go there…

STOP 1: TWIN PEAKS OVERLOOK

As can *hopefully* be seen from Twin Peaks: The city is hilly due to the resistant blocks of rock in the **Franciscan Complex**, at various times called the Franciscan Formation and Franciscan Assemblage. The latter two names give no sense of the geological chaos of "the Franciscan" (which is how most folk get around the problem of not knowing what the second noun should be). San Francisco is the type locality for the Franciscan. The Franciscan is world-famous because it is a showcase for subduction processes and complex tectonic shredding[1]. Simply, the Franciscan is a regional jumble of chunks of tectonic plates from various places, stirred together and separated by faults and shears zones. In places the shredding and shears are so pervasive that bands of **melange** form. Melanges (from the French, *mélange*, for "mixture") are rock masses formed of mixtures of hard blocks of rock surrounded by weaker matrix. Block sizes range between mountains and gravel. I could fill pages here on the Franciscan and melanges (and have elsewhere in my PhD dissertation and papers) since it is my research and professional passion - but we don't have all day! For more info see my bimrock papers, at the bimrocks website (http://bimrocks.geoengineer.org).

TOURIST CHATTER

San Francisco is as lovely a city as it looks! I first came to San Francisco in 1976 as a tourist from Vancouver, British Columbia. Vancouver is lovely too. But, San Francisco reminded me then of a full scale Disneyland. I still have wonder and delight in the city despite many years of traveling and living in lovely places, including Maui and Oahu. The city, named after St. Francis of Assisi, has some 800,000 people living in about 47 square miles, many in heavy debt: the median home price is about $750,000 with an average value of about $850,000. But you can probably afford to buy a place soon since prices are creeping down. Prices are about as high just about everywhere we stop today.

In San Francisco, there are several sub-parallel block-rich, hilly, bands (or "terranes") separated by block-poor, shear zones melanges which trend across the city in more or less NW-SE directions (Figure 3, Steinpress, 1998)[2] as suggested by the tonal fabric in the Landsat air photo on the next page. Several of our last Stops are within the "**Marin Headlands**" terrane and the **Hunters Point Melange**, which exhibit a mosaic of sandstone blocks, blocks of interbedded sandstone and shales, sheared shales, chert/greenstone blocks and serpentinite melange. The red dots are several of the Stops we make today (a couple more are south of the satellite image other northern few being in the melange belts shown roughly as the yellow alignments in the left figure above (Steinpress, 1998) and the Landsat photo.

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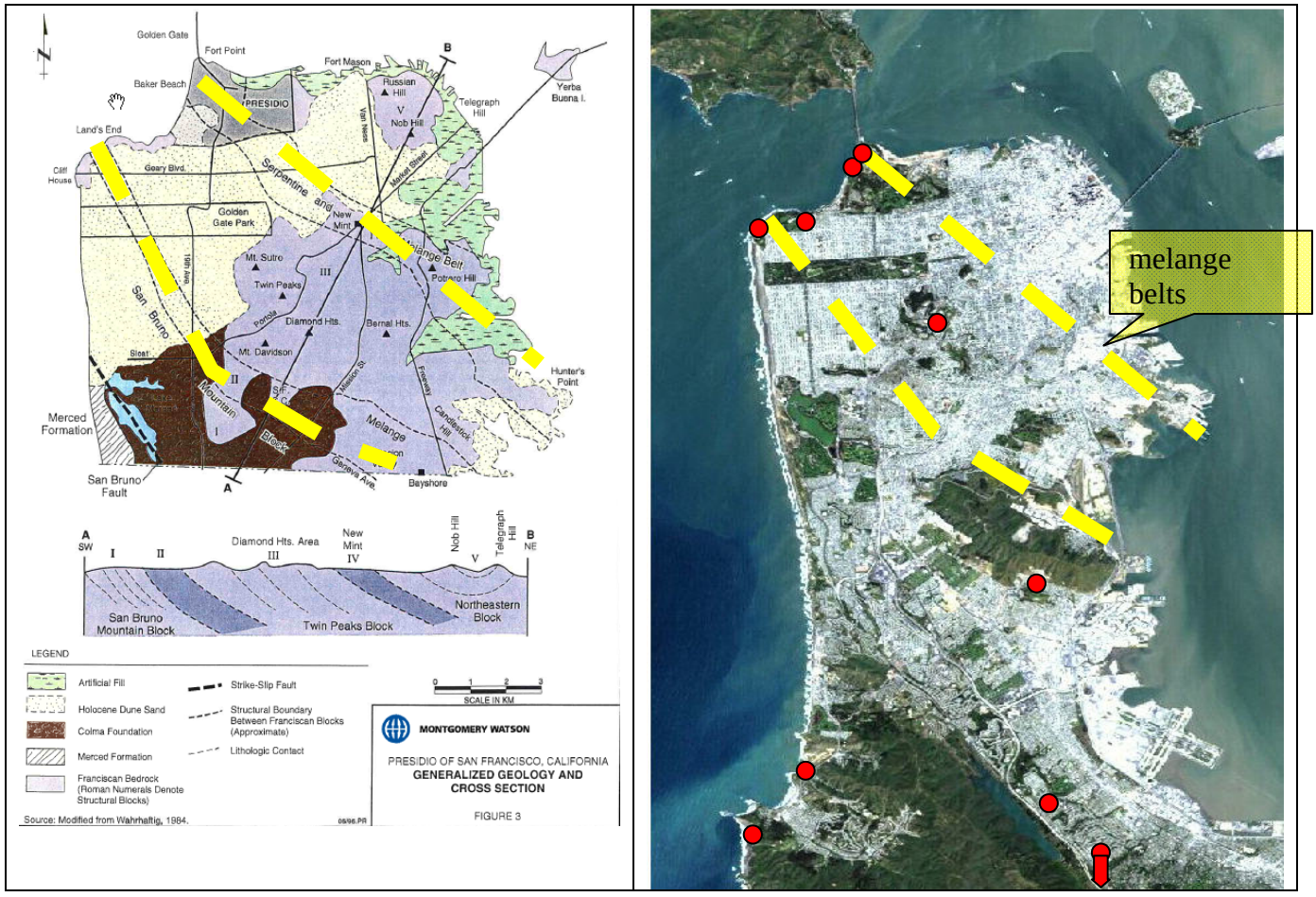
[1] Wakabayashi, 1999; "Franciscan Complex, San Francisco Bay Area: A Record of Subduction Complex Processes:, in Wagner, 1999, "Geologic Field Trips in Northern California" for Centennial Meeting of GSA; publ. California Division Mines and Geology, Special Publication 119. See also Konigsmark, 1998: "Geologic Trips - San Francisco and the Bay Area", Published by Geo Press, Gualala, CA . I also recommend the 1979 classic by the late Clyde Wahrhaftig, "A Streetcar to Subduction and Other Plate Tectonic Trips by Public Transport in San Francisco", published in periodically Revised Editions by the American Geophysical Union. For a real fun read try "*Assembling California*" by John McPhee.

[2] Steinpress, 1998 ("Transformation of the Presidio of San Francisco, Hydrology and Environmental Restoration: Field Trip Guidebook Chapter 4, California Groundwater Resources Association, San Francisco Branch.).



Left: general geology of northern San Francisco Peninsula (Steinpress, 1998). Right: Landsat image. General location of two melange belts shown as yellow dashed lines. Location of several field trip stops shown as red dots.

Drive from Twin Peaks to I-280: via O'Shaunessy- see contorted cherts.. Take 280 north to 101, then 101 south; pull off at Brisbane exit to Bayfront. Drive south beside San Bruno Mnt; onto to Hillside Blvd, head west to Irving, left and two blocks to 700 block Larch. Park opposite barricaded right side of street .

STOP 2 LARCH STREET, SOUTH SAN FRANCISCO

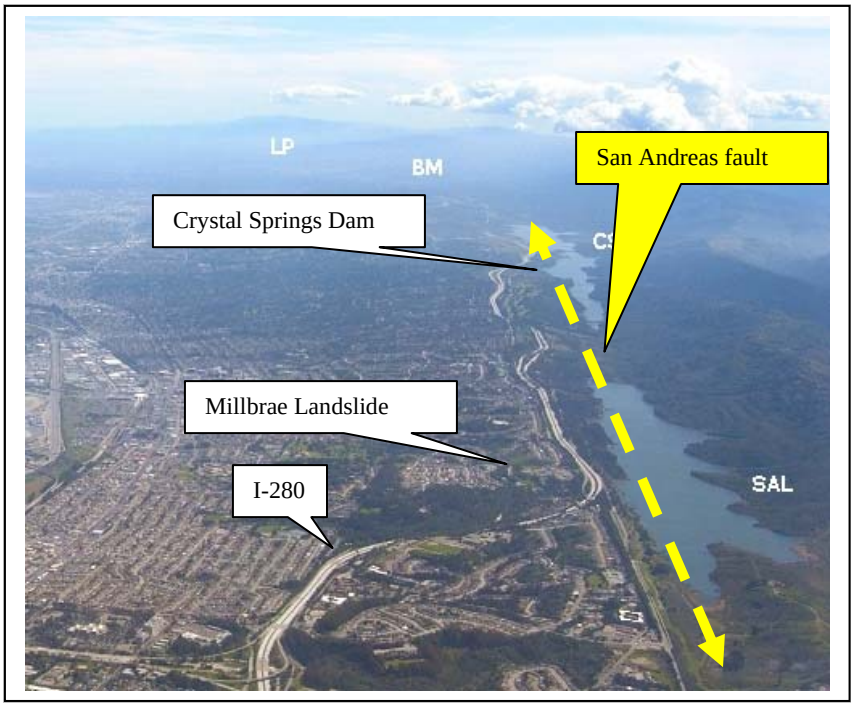
Standing on the north side of the "South San Francisco – The Industrial City" block. Now a biomedical Mecca; old steelworks and industrial plants replaced by Genentech etc. That is another story. San Bruno Mt. is to the north, and was where Medley in worked 1989 and first saw melange. San Bruno Mt. is a very large block; the ridge of Larch St. is a smaller one. The blocks are separated by sheared matrix, with smaller blocks. A problem at Terrabay (the development at hill) was "faults" interpreted from the sheared matrix, which looks like fault gouge. Melange plastered on side of the San Bruno Mt. blocks had spawned landslides; many buried and not discovered until development started.

At Larch street we observe blocks of different sizes, with scaly clay shale matrix, typical of "argille scagliose". Blocks in Franciscan are often sandstone but range from limestone to highly metamorphosed "exotics". Block sizes range from sand to mountains. There are a few large blocks and many small ones: fractal block size distribution. Also find scale independence and self-similarity in block size distributions. So we will always find blocks. **What is block? What is matrix**/? Depends on the scale of interest. Hence the *characteristic dimension* $\mathbf{L_c}$. Blocks are between 0.05 L_c and 0.75 L_c.

Play the hand gap picture game: strips are boreholes. What we see: "interbedded sandstones and shales?" **NOT!**. One of the largest problems is engineers not recognizing the fabric of blocks in matrix. Common in geology: weathered rocks, fault rocks, etc. So bimrocks (block-in-matrix rocks). Need block/matrix contrast to force failures around blocks. Can be modest. Also enough blocks to make a difference mechanically. Enough blocks make bimrock stronger by tortuosity of

failure surfaces. Simple relationship between volumetric block proportion and strength: which means how to find volumetric proportion? Can do with linear block proportions from borings. And enough can estimate volumetric proportion. But never have enough in geotech engineering. So: Uncertainty!!!

To Millbrae via 101/380 to 280. Pull off at Larkspur Drive exit. Notice San Andreas lake on right as we exit. This is owned by City SF and part of the city's Hetch Hetchy water supply. San Andreas fault in lake. Down Larkspur to intersection with Pinehurst. Park near intersection.



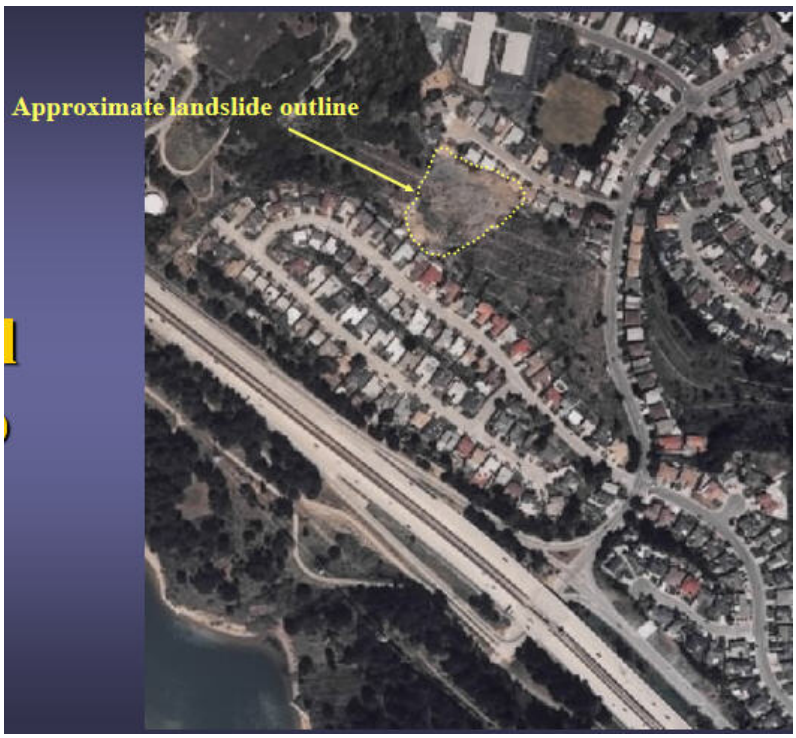
TOURIST GEO CHATTER about SAN ANDREAS FAULT

(Text from Andrew Alden, About.com)

South of Mussel Rock, the San Andreas fault passes through Daly City and into City SF watershed land. "The highway is Interstate 280, a good drive for seeing and contemplating this part of the fault. Three small reservoirs, San Andreas (SAL) and Upper and Lower Crystal Springs (CSR), lie on the fault trace. The stout earthen dams holding back these reservoirs held firm in 1906 and are not considered major hazards. Beyond them, the fault begins to take a slight leftward bend as it runs behind Black Mountain (BM) and through the notch directly beyond. Loma Prieta (LP) gave its name to the 1989 earthquake because the greatest shaking occurred in the wooded highlands to its west"

The bend in the fault results in compression across it as the Pacific plate on the right side moves toward the viewer. This thickens the crust and raises the Santa Cruz Mountains.

STOP 3 MILLBRAE LANDSLIDE at PINEHURST CT., MILLBRAE



2000 Air Photo (from Exponent)

March 2000; Photo by B Mathieson, Exponent.

In January 2000 a landslide occurred between Crestview and Pinehurst in Millbrae. One home was completely destroyed. There were several parties to ensuing lawsuits including the City of San Francisco, who owns the San Andreas Lake to the west of Freeway I-280. Plaintiffs claimed the City caused the landslide by excavating the hill for fill for the Airport. They also claimed that water from the Lake caused landslide. Actually, the Airport was built by the military in WWII and was not owned by City at that time. The quarry stopped in Franciscan shale melange. Investigation showed that the hydraulic conductivity of the Franciscan melange between here and San Andreas Lake is about 10^{-7} cm/sec. Large contributors to the failure were deterioration of the hillside and lack of maintenance/ The failed slope was repaired with engineered fill with geogrid, and piers.

Pinehurst to Larkspur, head up hill, turn left at Skyline Blvd; turn right on Hillcrest Drive. Park near end to see sheared serpentinite boulder commemorating Potrero, a Spanish explorer. This is the north of the Camp Sawyer Trail, which threads about 7 miles besides San Andreas and Crystal Springs lakes. The lakes are reservoirs formed by dams in 1850-1900, mostly to provide water to swank Hillsborough.

***4:** Turn onto 280 head south, see views of Lakes **(San Andreas fault zone valleys)** .*

5: Near 280/92 intersection notice blocks popping out of ground like grazing sheep. Typical melange terrain.

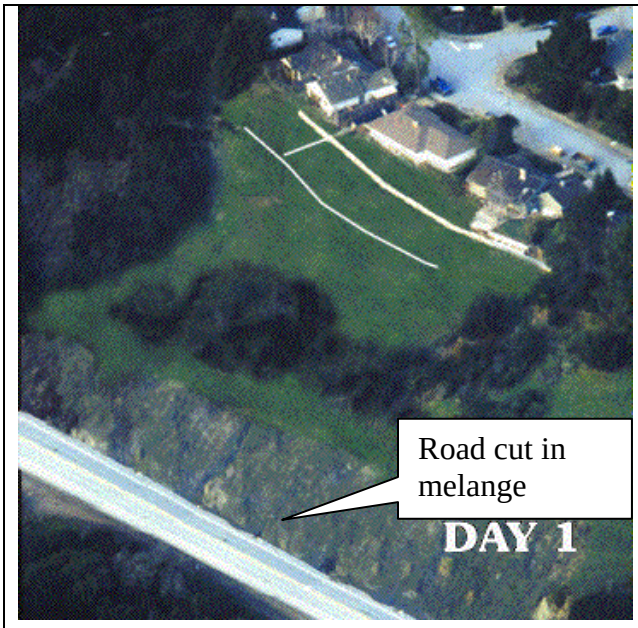
280 to 92 east; immed. pull over to right for Ralston, right lane in exit. Turn right on Polhemus, About 1 mile to Crystal Springs Village SC at intersection with de Anza.

STOP 6: CRYSTAL SPRINGS VILLAGE:

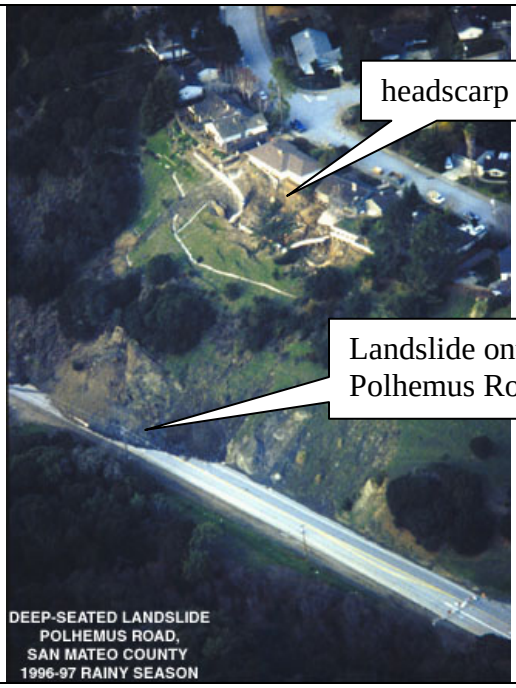
Stop here for sandwiches, drinks, coffee, WC.

Continue north on Polhemus Rd., Note blocks in hillside and road cuts, This is rural San Mateo County and San Mateo/Hillsborough. Go to intersection with Ascension Drive. Park in big dirt area on west side road just past the intersection.

STOP 7 POLHEMUS ROAD LANDSLIDE



Polhemus landslide before failure (USGS photo)



Polhemus Landslide after failure (USGS photo

FROM USGS el Nino site http://elnino.usgs.gov/landslides-sfbay/photos.html still from animation depicts the movement of a deep-seated "slump" type landslide in San Mateo County. Beginning a few days after the 1997 New Year's storm, the slump opened a large fissure on the uphill scarp and created a bulge at the downhill toe. As movement continued at an average rate of a few feet per day, the uphill side dropped further, broke through a retaining wall, and created a deep depression. At the same time the toe slipped out across the road. Over 250,000 tons of rock and soil moved in this landslide. (USGS website text)

During the 1996/1997 El Niño winter, a landslide damaged houses at the top of slope. The slide initially piled up at base of slope, buttressed by a large block with oak trees (no longer there). Oak trees grew because grounds stable at block and different soil development. Shale matrix ground more mobile, less chance for trees to develop. Eventually the slide moved out over Polhemus road, a major rural traffic route to 280. Under the road is an 8 foot diameter concrete pipe from Hetch Hetchy reservoir in the Sierra Nevada Mountains; it provides water to San Francisco and it is vital that it not be damaged. City of San Francisco was sued because it owned a tiny fraction of land on the hillside.

Slide had developed over the years. The County was sued too because road maintenance and clearing of slope debris "undermined" the slope stability. The Litigation was resolved when a contractor bought the land and paid off claimants. Tie-back wall with soldier piles to 40+ feet deep installed. In the process of building the wall, contractor encountered "unexpected' blocks, particularly one very strong greenstone block. A construction claim was submitted to the City of Can Francisco, but the claim was eventually denied. See paper by Kim et al 2004[3] for a stability some analysis of the slide.

Drive north on Polhemus to Crystal Springs Rd, turn left. Note pipes hanging on sides of sloughing slopes. Pass under 280 viaduct. Park near intersection with Skyline Blvd. Southern trailhead of Camp Sawyer trail head. ***WC, benches. Lunch****. Can walk south on footpath to dam.*

STOP 8 CRYSTAL SPRINGS DAM: (picnic lunch)

TOURIST CHATTER

Crystal Springs Dam impounds San Mateo creek. The dam was built in 1888, raised a few feet in 1891, and again in 1911, to 154 feet. The dam is 176 feet wide at the base and 600 feet long at the crest. The San Andreas fault is 400 feet west of the sit and follows along much of east sides of the lakes, but the dam showed no damage from the 1906 earthquake or the 1989, 7.1 Loma Prieta earthquake. Geologic investigations show the dam to be safe.

Drive north on Skyline Blvd less than ½ mile. Right hand side, close to top hill pullover.

Look at sheared serpentinite and serpentinite melange. Note slickness (shining in sunshine). You may be able to see why the rock is named after the smooth, scaly skin of snakes. Serpentinite is California State rock. Although pretty, serpentinite is a troublesome material prone to landsliding when sheared, hosts Naturally Occurring Asbestos, and is source of chromium, cobalt and other metals. Serpentinite flora is distinctively subdued and serpentinite terrains are often termed "barrens". Serpentinite, is metamorphosed oceanic plate rich in Mg, in subduction trench volume increase with hydration of water and density decrease, serpentinite bodies "float up" through subduction accretions as diapirs, shredding material.

[3] Kim, C, C. Snell and E. Medley, 2004; "Shear Strength of Franciscan Complex Mélange as Calculated from Back-Analysis of a Landslide," Proceedings 5th International Conference on Case Histories in Geotechnical Engineering, New York, NY, April 2004 .

Continue north on Skyline to Hayne, turn right then immed. left onto 280. Note melange blocks in road cuts on left side road. Take 280 North to Hwy 1, head west/south 1 to Pacifica, take Rockaway Beach exit and got to parking lot. Take paved footpath north.

STOP 9 ROCKAWAY BEACH- PACIFICA QUARRY.

In 1776, an ancestor of this now-abandoned quarry yielded limestone to the Spanish to whitewash the Presidio in San Francisco. The quarry later yielded cement. The excavated slopes show one of the best exposures of classic shale matrix melange in the San Francisco Bay area. Most of the blocks are limestone; a few are greenstone and chert. The limestone is formally known as the Calera Limestone, which is the largest and most stratigraphically extensive oceanic limestone in the Franciscan. The type locality is at this quarry The limestone has a tropical provenance; the masses here define this part of the Franciscan as the Permanente *terrane*, an original piece of tectonic crust that has been shredded and widely dispersed within the Franciscan. There are several limestone quarries in the surviving fragments.

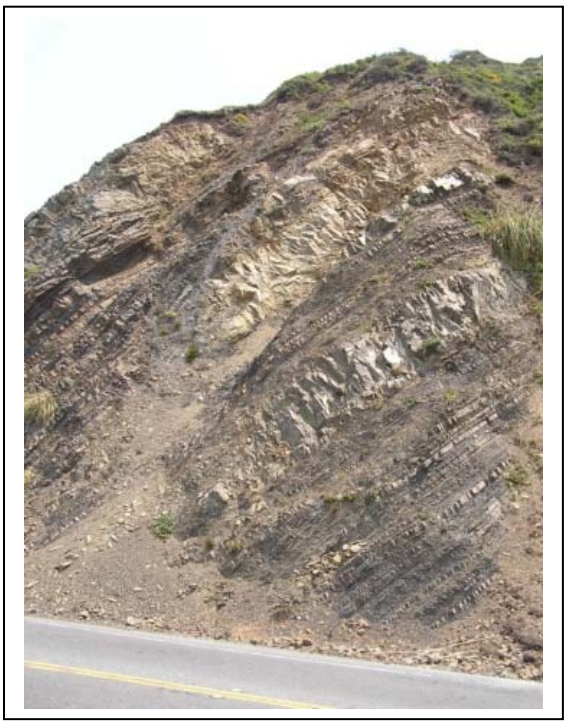
Observe the range in block sizes and that the blocks are evidently much more competent than the surrounding weak, sheared matrix. The matrix has raveled and failed in many places, and is gullied by surface drainage. It is also evident in the quarry slopes how impossible it would be to accurately characterize the blocks in the rockmass on the basis of a few borings, or even many borings. This is a good place to take hands-slightly-apart "slit" pictures to imagine drilled borings or scanlines and how these would look depict apparent "interbedded" shale and limestone "beds".

Drive back to Hwy 1 turn right (south) Observe the blocks in shale matrix in the road cuts. Also, the isolated hilly bumps between the road and the ocean are large blocks in the Franciscan. Head south into the San Pedro Mountain at the south end of Pacifica. The north face of the hill is the expression of the Pilarcito fault, a splay of the San Andreas fault.

The road winds through Tertiary interbedded sandstones and shales. You will see widespread activity of the construction kind. A new highway with bridges and a tunnel and being constructed to bypass the Devil's Slide which has plagued coast side motorists for years because its periodic lurching lead to frequent months-long road closures.

Stop at narrow pull over just as the road reaches the top of the sea cliffs.

STOP 10 DEVIL'S SLIDE



The interbedded sandstones and shales here are Tertiary turbidites. They are mechanically complex but straight forward to characterize from mapping and borings. Core of these rocks is a series of alternating sandstone and shale bands rightly called "layers" or beds. But in melanges, the (commonly) sandstone blocks and shale matrix is also recovered as apparent alternating "layers". Clearly characterization of a melange (such as the one at Pacifica Quarry nearby) would not be correct and would lead to grossly erroneous characterization and design basis.

The view to the south shows the infamous Devil's Slide.

The slide has a long, very pricey history, having destroyed previous roads and a railway since the 1890's. Failure occurs as kinematically unstable blocks of steeply dipping, faulted and sheared rocks daylight on the very steep slopes continually destabilized by the ocean. You will see the evidence of the more heroic Caltrans (California Department of Transportation) efforts as tie-back walls. Stop lights are used to halt traffic automatically when slope movement instrumentation is triggered by movements. The currently constructed bypass and tunnels will be much appreciated by many motorists, although there was energetic opposition to the tunnel by many people.

Drive southward along Hwy 1 to observe granite of the Salinian Block. The granite has been transported from the southern Sierra Nevada Mountains by the San Andreas fault. It is is here deeply weathered and some previously good exposures have been masked by construction. Observe the old WWII battery structure, almost undermined. Drive to the first beach parking lot after the construction work entrances and turn around after viewing the coastline from the cliff tops.

Drive north on Hwy 1 to Skyline Boulevard (Hwy 35) and continue through Daly City past Lake Merced to the Great Hwy at the stoplights. Turn left and see if you can beat all the red lights along the Great Highway. As you proceed up the hill you will see on the left the recently renovated Cliff House perched above the cliffs. On the right side of the road, at base of the slope, was the shaft for access to the Richmond Transport tunnel which was under construction at the time of the Sea Cliff Incident in December 1995 (story to be told later).

The road becomes Point Lobos Ave, after the bend; a shortly afterward there is a parking lot on the right hand side – park the car there and cross the crosswalk to the ocean side near Louise's restaurant.

If you are tired this is a good place to take a break from the field trip. Go to the lovely Cliff house and have a beer or cup of tea. The res of us will go on a short wander and end up at he the Legion of Honor while you relax. You will be picked up and driven to the rendezvous.

STOP 11 CLIFF HOUSE-SUTRO BATHS

TOURIST CHATTER

This area is part of the Golden Gate National Recreation Area. The structure below is the remains of the Sutro Baths, a public bathing place. A picture of the Baths in its heyday is hanging in the window of Louise's. The baths are named after a famous San Francisco financier, Adolph Sutro. His home used to be on the hill behind you. The Cliff House was a well-known bawdy house. There have been several of them: at least two burned down. A railway line brought visitors to Ocean Beach and to a fun fair that used to be located just south of the Cliff house in the general area of the southern end of the Richmond Transport tunnel.

The Cliff House is on a large headland block within the Franciscan. Across the open space to the north is another headland formed by a block-rich mass of melange. The blocks and gray shale matrix are clear. The intervening space is occupied by block-poor melange which is weak enough to have been preferentially eroded by the ocean. It is also slide-prone.

For those of us continuing on for a bit: drive out of the parking lot. Turn right and then left at the stop lights onto El Camino del Mar. Drive to the end to park in the large parking lot at Fort Miley, which used to be the military facilities nearby. Now there is a Veterans Affairs Hospital. At the west end of the parking lot is a memorial to the USS San Francisco, a battleship that saw long and brave service during WWII, particularly at Guadalcanal. The battle-torn bridge of the ship forms part of the memorial.

USE the Porta Potties HERE: there are no other public restroom facilities for a while….

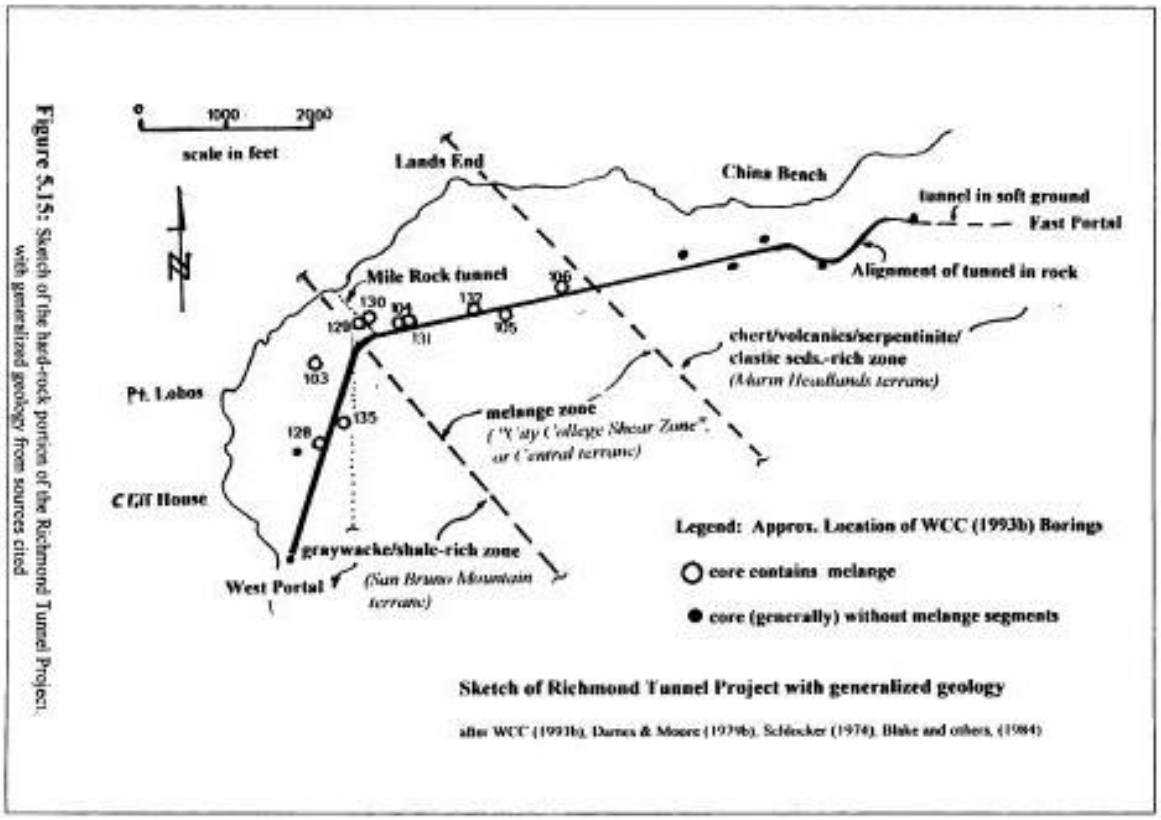
There is a coastal trail from here to the Golden Gate Bridge. Access to the beach is possible but there are over 300 steps to climb and we do not have the time. We take the paved road, which is El Camino del Mar. It does not go far as a road. Once connected to Sea Cliff, the road was destroyed by landsliding. We walk about 0.4 miles across the slide to the Legion of Honor.

STOP 12 FT. MILEY-MILE ROCK-LAND'S END

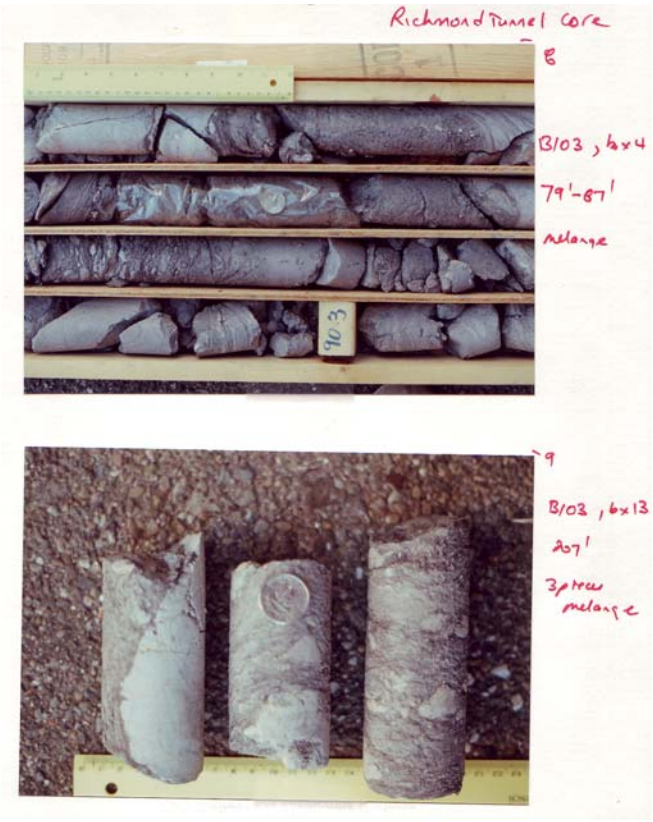
This is the Land's End promontory of San Francisco. But there are great exposures of Franciscan melange in the cliffs. You will note many rocks near the shoreline: These are relict blocks in the melange remaining after the matrix has been eroded, The beaches are also formed of cobbles of a varied lithologies, colors and textures.

To the north are splendid views of the Golden Gate Bridge and across the strait the cliffs of the Marin Headlands. The headland below is of green, red and tan colors is formed of red chert, green greenstone (metamorphosed basalt) and sandstone in gray shale matrix.

This area was mapped by engineering geologists as part of an investigation of ground conditions for the Richmond Transport tunnel which passes nearby underneath us. I reviewed the drill core form the exploration as a part of my PhD research



From Medley 1995 PhD dissertation: Location of Richmond Transport tunnel.



Drilled Core from Richmond Transport Tunnel exploration boring B103

Much of the tunnel traversed melange. I reviewed nearly all the core; example as pictured here. Light gray is (mainly) greywacke sandstone blocks and the dark gray is shale matrix.

Based on work I had performed on block size distributions in the Franciscan I estimated the size of the largest reasonable **possible** block that the tunnel could encounter. (The tunnel had barely started when I wrote my thesis). A rule of thumb is that the largest block is 0.75 the length of the characteristic dimension L_c scaling the problem at hand. At the scale of the entire tunnel length through the melange**,** L_c is $\sqrt{A}$, where A was the area between the tunnel and the coastline. On this basis a block of about 600m could have been encountered. The tunnel did intersect several hundred feet of unexpected hard sandstone.

Continue to walk on the dirt trail walk. You pass by the head scarp of the landslide that likely destroyed El Camino del Mar here. Note the block at the top of the slope until we reach the paved road below the Legion of Honor art museum located in Lincoln Park which is a golf course.

STOP 13 LEGION OF HONOR

Try your best to capture a picture of the Golden Gate Bridge without trees obscuring part of the view (think frames!!). Note the green colored cliffs near the Bridge: those are landslides in sheared serpentinite.

TOURIST CHATTER

The Legion of Honor museum is formally called the California Palace of the Legion of Honor, a ¾ scale model of the Parisian original. The museum was a gift of the Spreckels family, sugar magnates. There are statures by Rodin in the courtyard, and a Holocaust Memorial near the fountain and parking lot in front of the Legion of Honor. It houses intermittent exhibitions of fine art and a permanent collection of several thousand pieces. It is affiliated with several other fine art museums in San Francisco.

Walk along El Camino del Mar down hill. The community in the distance, perched above the cliffs, is Sea Cliff, an affluent and architecturally distinctive area, famous for being Where the Movie Stars Live (such as Robin Williams and Sharon Stone).

Drive along el Camino del Mar through Sea Cliff until just past the intersection with 25th Avenue. Park after 3 or 4 houses on right side beside the chained link fence and the Presidio sign.

STOP 14 SEA CLIFF

TOURIST CHATTER

Sea Cliff is the locale of the Sea Cliff Incident, a 1995 urban catastrophe which occurred when a 100-year storm sewer failed and created a pit 240 feet wide and 40 feet deep, that swallowed tens of millions of dollars of expensive real estate. The failure of the sewer occurred in part due to pressurization of the sewer related to ongoing sewer renovations in the Sea Cliff area. A further contributor was a sinkhole that formed above an adit constructed as part of the Richmond Transport tunnel. The southern end of the tunnel ended near the Cliff House. The northern end was at a shaft less than 200 feet north of where you are now standing.

The Sea Cliff Incident caused about $30 million of public and private property damage. A very dramatic scene was the total collapse of a multi-million dollar mansion that fell into the pit caused by the failed sewer. That scene was viewed on TVs around the world. It is replayed in (to date) 5 documentary programs in which I also appear, since I was the Principal Investigator for the Failure Analysis Associates (Exponent) team that solved the mystery.

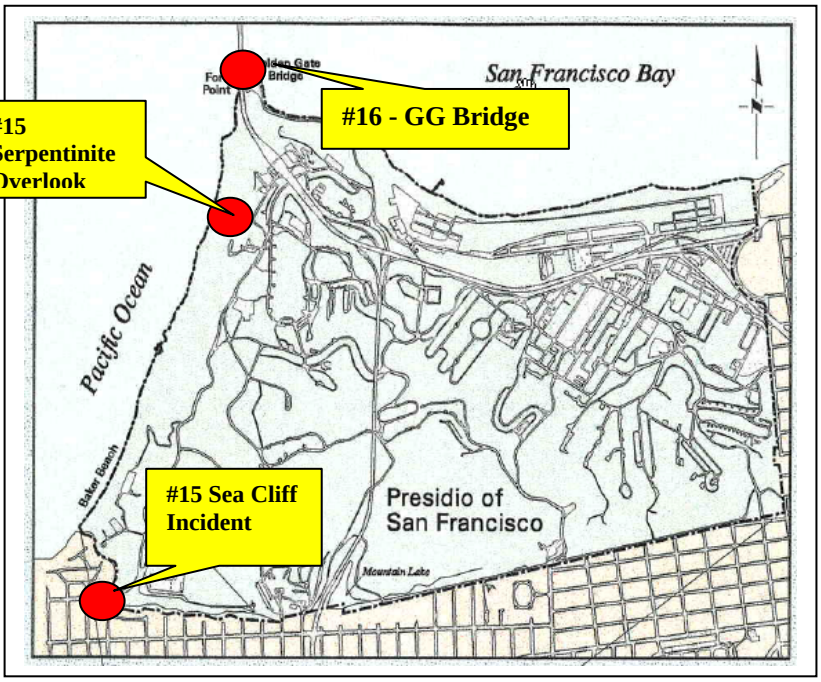
Read a paper by going to bimrocks.geoengineer.org/about and clicking on Sea Cliff link in my Biography.

Sea Cliff Incident Dec 1995 (Exponent)

From Sea Cliff continue on El Camino del Mar as it changes to Lincoln Blvd. Pass entrance to Baker Beach (lovely views there by the way). Continue to Overlook on ocean side road.

STOP 15 THE PRESIDIO OF SAN FRANCISCO

At the interpretive display read the descriptions on serpentinite rock and flora. Note in views the cliffs of greenish rocks: these are landslides in sheared serpentinite, as you glimpsed when walking toward Sea Cliff from the Legion of Honor.



TOURIST CHATTER:

Founded in 1776, the 1400 acre Presidio was the longest-occupied military installation in the nation, with soldiers serving for Spain, Mexico and the US to defend the Golden Gate. The discovery of gold in 1849 resulted in the rapid growth of San Francisco and the strategic need to protect commercial interests. The City grew around what eventually became an operational military base, a neighborly relationship that proved very valuable when the base provided care for refugees from the 1906 Earthquake and Fire. The Presidio lands were transferred to the National Park Service in 1994. Except for the coastal lands (now Golden Gate National Recreation Area), the Presidio is now administered by a Trust charged with making the Presidio self-sufficient by 2013. A considerable environmental restoration effort is underway at the Presidio, aspects of which the Oakland office of Geosyntec has been engaged.

Our final stop is at the south end of the Bridge. Because parking at the regular lot Visitor Area at the Bridge can be a pain we shall probably park on Merchant Road, on the west side of the Bridge Toll Plaza close to ***Battery Boutelle****, an abandoned concrete gun emplacement that was active in the early 1900's. A tunnel below the Toll Plaza provides a somewhat boring pedestrian access to the main Visitor Area but there is a more interesting route via a footpath along the cliff side. For the purposes of these Notes, I assume that we shall park near the Battery and walk to the Visitor Center. (If we do park at the Visitor Center then just read these notes in reverse order.)*

STOP 16: GOLDEN GATE BRIDGE VISITOR AREA AND THEREABOUTS- MOSTLY A TOURIST FROLIC

"Landfills" are being removed from around the battery areas. The irregularly graded footpath along the cliff edge seaward of the Battery Boutelle is a good place to see the landslides in serpentinite.

During the late Pleistocene, sea level was up to 400 feet lower than currently. The Golden Gate was a valley through which the Sacramento River flowed toward an earlier shoreline some 25 to 30 miles to the west (Steinpress, 1998). Sea level changes resulted in Quaternary estuarine, alluvial, near –shore and aeolian deposits. Several deep paleo-valleys in the Franciscan bedrock were filled with soil deposits.

The footpath to the Visitor Area is narrow, and likely to be busy with bikers. Take care.

From the footpath, you can clearly see the additional structural steelwork installed as a part of the seismic retrofit for the bridge.

This is a good place to look at the Bridge, which is suspension structure. Serpentinite supports the

foundations of the bridge. The road deck hangs from vertical cables attached to the curved ("catenary") cables supported by the two towers. The cables are in tension (pulling away from the towers) so the towers are in compression, bearing down on the foundations. It is because of the large bearing forces that a controversy broke out between in 1934 between two eminent geologists[4]: Professor Andrew Lawson of University of California at Berkeley and Professor Bailey Willis of Stanford University (a rival school, south of San Francisco). Based on geological mapping, Professor Willis interpreted a vulnerable adverse-dipping fault contact between the serpentinite and a graywacke sequence. A single exploration boring proved serpentinite was continuous. However, serious deficiencies were recently identified in the seismic capacity of the Bridge, and it is the remediation of those which has been the focus of recently-completed construction.

From the time it was erected in the 1930's, the Bridge has been continually painted in a hue known as Universal Orange. One cannot think of the Bridge being any other color! But generations of lead-based paint have had to be removed. You shall have a chance to see a number of informative signs detailing the vital statistics of the Bridge Visitor Area.

On the east side of the Bridge is a plaza, which contains a number of sights, a snack bar, toilets and a good gift shop. The premier attraction is the Bridge itself, as well as a statue of Joseph Strauss, the designer. Much of the design was actually performed by two unheralded and visionary engineers, Charles Ellis and Leon Moissieff, who performed calculations for the bridge using slide rules, pencil and paper. There is a display with a section of cable used in the construction of the Bridge, but your patience will be challenged while you wait to take a picture of the cable section in which no other tourist appears.

I suggest that you walk on the Bridge by accessing the sidewalk north of the Gift Shop. You should walk to the first tower, which will take about 15 minutes. It is only when you get near the tower that you have unobstructed views of San Francisco and the Bay since there is a high chain link fence attached to the handrails up to that point. The fence is not to deter jumpers but to protect workers and visitors to Fort Point below. There are suggestions for a jumper-proof fence but there is debate surrounding the proposals.

Give yourself 20 minutes to walk back along the Bridge and to the van. Next stop WESTIN HOTEL. Thanks for coming!!!

[4] Vantine, 2000 (Field Trip : "Northern San Andreas Fault System and Sonoma County Slope Instability", in Alvarez, 2000, AEG/GRA 2000 Field Trip Guidebook "From the Pacific Ocean to the Sierra Nevada: Taming Shaky Ground")

Tourist Chatter: **The Other Big Bridge**

By the way from various places in San Francisco you see two big bridges. One is big, red and beautiful. That is the Golden Gate Bridge which this trip ends at. The other bridge is gray, clunky and even more important than the Golden Gate bridge **San Francisco-Oakland Bay Bridge**, collectively a causeway, a truss bridge, a tunnel and a suspension bridge. The bridges are double-deckers – the lower deck is Oakland-bound and the upper is for San Francisco traffic. So: you get the lovely views on the way over to San Francisco. There is a serious proposal to name the Bridge after Norton I, Emperor of the United States. Norton was an early 1800's resident who declared himself emperor and for the next 20 years wandered the city wearing a military uniform with sword. He may well have been an early pioneer of the Homeless Caste, that is now the shame of the city. Beside the Bay Bridge, you will see a new bridge a-building, to replace part of the truss portion of the Bay Bridge which revealed seismic weaknesses during the 1989 Loma Prieta earthquake, when part collapsed.

The Bay Bridge tunnel passes through **Yerba Buena Island** ("good herb") originally named for the wild mint that the Spanish pioneers flavored their tea with. The island is a craggy block of the Franciscan Complex, which we all know about now, right? To the right of the island is an extensive flat area called **Treasure Island** that is geologically Very Recent. It is composed of hydraulic fill sluiced behind embankments to form a flat platform for the 1939 Golden Gate International Exposition. It was a military installation between 1941 and 1998.

STOP 16 + 1 (AN EXTRA): FORT POINT (BELOW THE BRIDGE)

The Military bastion at **Fort Point** is one of several installations that were actively occupied and used for coastal defense between the 1840's and the 1940's. The Fort is open and you should have

a reconnaissance to appreciate this windy promontory, which was probably quiet before the 1933 construction of the Golden Gate Bridge brought the incessant rumble of traffic.

Access is limited around the Fort, and has been since the 9/11 terrorist attack. There is also ongoing construction at the bridge that has closed a once-convenient footpath between the Fort and the Visitor Area for the Bridge. The access road to the Fort is now open to traffic (which is why we can park here). You will have to give way to runners, who you may see pat a metal plate on the chain link fence at the far end of the road way against the fort wall. The plate is "**Hoppers' Hands**" (and one for dog paws below it), which recognizes the lives lost every year by suicides jumping from the Bridge. Ken Hopper is a Bridge Ironworker who counsels people intending to jump. He and his volunteer colleagues have saved many lives. Nevertheless, since the Bridge opened in 1937, more than 1300 have died by jumping.

Along the access road are exposures of sheared serpentinite, several landslides, and abundant seeps. The serpentinite has a block-in-matrix (bimrock) fabric evident here and there by blocks of intact serpentinite surrounded by sheared matrix. The bimrock fabric is also present in the steep cliff of serpentinite that ends close to the south wall of the Fort. Note the curved boundaries of blocks.

STOP 16 + 2 (REALLY, NO TIME!) MARIN HEADLANDS AND NORTH END OF THE BRIDGE

If we had time we would cross over the Golden Gate Bridge and look at the splendid exposures of the Marin Headlands terrane which includes chunks of chert and greenstones (slightly metamorphosed basalt) from subducted oceanic plate.

We do not have time to visit the Vista Point area at north end of the Bridge, nor to view the Bridge and San Francisco from the vantage points of the Marin Headlands. There are also some splendid geological outcrops of contorted chert, and great examples of melange. But, for a starting point on your next visit to San Francisco here are some photos….

Thanks for coming!!