State Mining and Geology Board

Field Trip Guide to the

Golden Gate Bridge

Strong Motion Instrumentation Program
California Geological Survey

May 11, 2006

STATE OF CALIFORNIA, RESOURCES AGENCY
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Stephen M. Testa
Executive Officer

Ms. Kit Gonzales
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Dear Board Members:

I am pleased to welcome you to the Golden Gate Bridge tour hosted by the California Geological Survey. The elements of the tour are noted in the article entitled "Golden Gate Bridge Field Guide", authored by Moh Huang of the California Geological Survey, and Jerry Kao of the Golden Gate Bridge, Highway and Transportation District (Geological Society of America, Field Guide 7, 2006). The Golden Gate Bridge staff who will lead the tour include Dennis Mulligan, PE, District Engineer, and Jerry Kao, PhD, PE, of his staff. Strong Motion Instrumentation Program (SMIP) staff will include Tony Shakal, SMIP Manager, and Carl Peterson of the technical staff.

The tour will begin Thursday, May 11, 2006, at 1:30 pm, and will be about 2 – 2½ hours in duration, and will involve a half-mile walk one-way across the bridge. We will be meeting at the Administration Building, at the south end of the bridge. There is a staff and visitor parking area south of the toll plaza, on the west side of the road. It is the first right after the toll plaza, when coming from the north. If coming from the south, go under the bridge toll plaza through the tunnel, from the tourist parking area on the east side to the west side, to get to the parking lot.

The tour will begin in the District's Board Room on the second floor of the Administration Building, where the District Engineer will welcome the group and have a short presentation about the bridge and the retrofit and strengthening underway. A driver's license is required for identification. Hard hats are required, and will be provided if needed. Bridge staff will provide traffic vests. It is often much cooler out on the bridge than on land, and it will likely be windy, and possibly damp. Wear shoes and clothes appropriate for a field trip.

Also included in this field guide for your information and reading enjoyment is the first geological report produced for the San Francisco Bay vicinity. William Phipps Blake, the first professional geologist to visit the region as part of the Pacific Railroad Survey in 1853, authored the report.

I am indebted to Dr. John Parrish, State Geologist and Director of the California Geological Survey, for coordinating this tour. I am confident that you will find this tour informative.

Stephen M. Testa
Executive Officer

Geological Society of America
Field Guide 7
2006

Golden Gate Bridge field guide

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OVERVIEW OF THE FIELD TRIP

This field trip consists of stops in four locations (Fig. 1) that provide insight into the seismic retrofit and strong motion instrumentation of the Golden Gate Bridge (Figs. 2 and 3). Only one of the four stops is normally open to the public (Stop 3a). The first stop at the Golden Gate Bridge Highway and Transportation District (GGBHTD) office board room will include an introduction to the bridge history and presentation of the seismic retrofit schemes, strong motion instrumentation of the bridge, and the data products available from the California Strong Motion Instrumentation Program (CSMIP) of the California Geological Survey (CGS). At the second stop, participants will see a free-field instrument in the maintenance area.

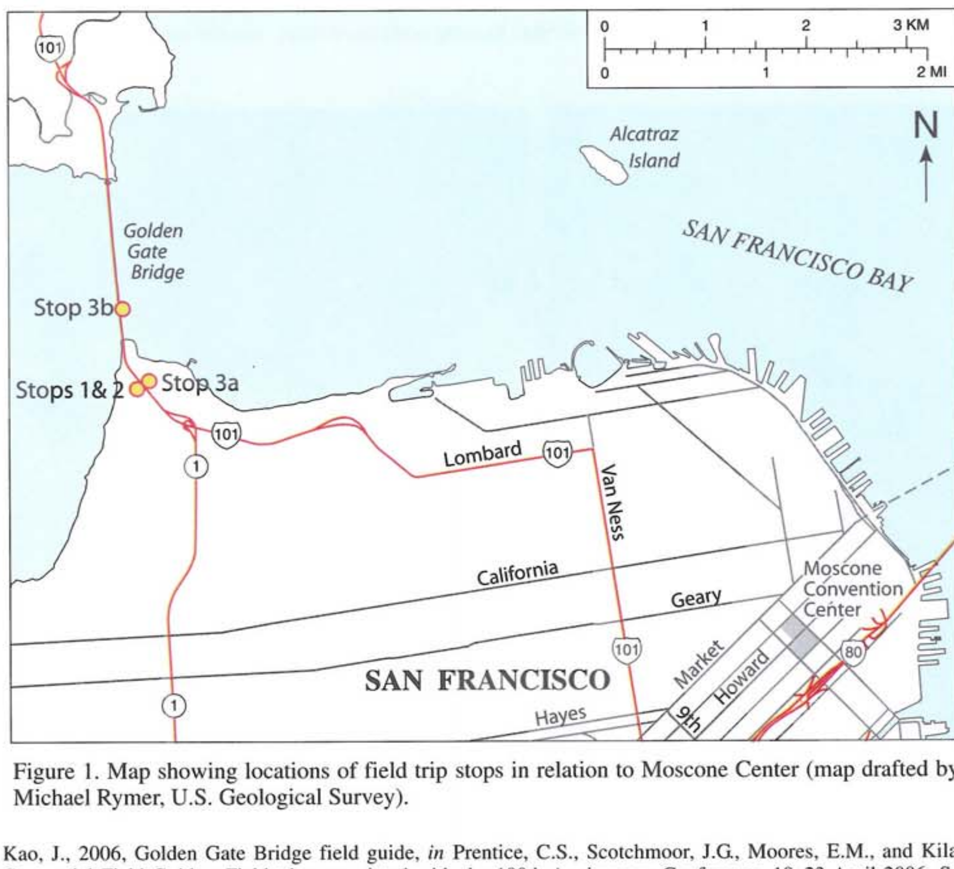


Figure 1. Map showing locations of field trip stops in relation to Moscone Center (map drafted by Michael Rymer, U.S. Geological Survey).

Huang, M., and Kao, J., 2006, Golden Gate Bridge field guide, *in* Prentice, C.S., Scotchmoor, J.G., Moores, E.M., and Kiland, J.P., eds., 1906 San Francisco Earthquake Centennial Field Guides: Field trips associated with the 100th Anniversary Conference, 18–23 April 2006, San Francisco, California: Geological Society of America Field Guide 7, p. 111–122, doi: 10.1130/2006.1906SF(09). For permission to copy, contact editing@geosociety.org.

Figure 2. Photograph of the Golden Gate Bridge looking northward from near the southern anchorage.

Figure 3. Aerial view looking down on the south anchorage of the Golden Gate Bridge. Stops 1–3a are visible in this view.

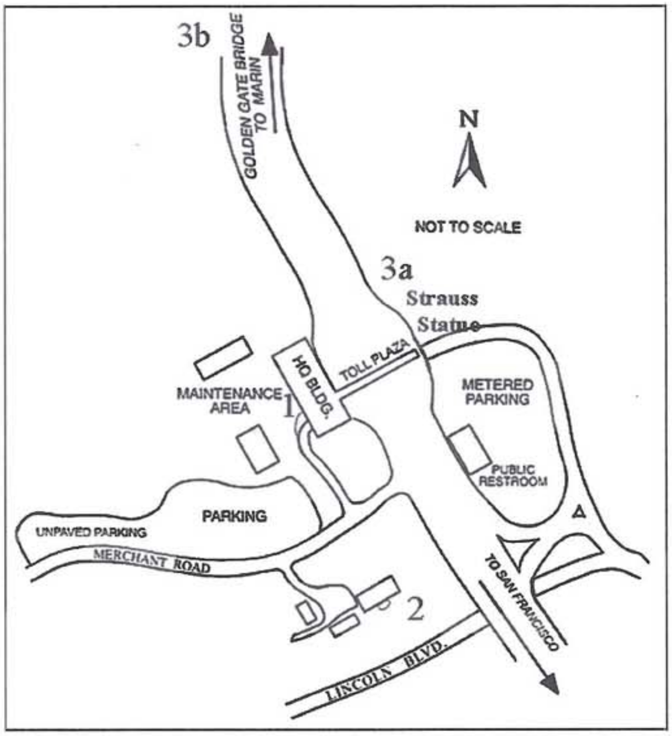


Figure 4. Map showing locations of field trip stops.

At the third stop, we will observe retrofit work under way (in 2006) from a public overlook area. At the fourth stop, we will see the seismic sensors and instrumentation installed on the bridge. The locations of these four stops (Stops 1, 2, 3a, and 3b) are shown in Figure 4.

Keywords: Golden Gate Bridge, seismic retrofit, strong motion instrumentation, ShakeMap.

STOP 1: BRIDGE DISTRICT OFFICE BOARD ROOM

Significance of the Site

The board room at the district office provides a convenient location for an introduction to the Golden Gate Bridge and the design of its seismic retrofit. Bridge District personnel will introduce the history of the bridge and give an overview of the seismic retrofit schemes for the bridge. A representative from the California Geological Survey will present an overview of the California Strong Motion Instrumentation Program, its products (including ShakeMaps and data available at the Engineering Data Center on the internet), and the instrumentation placed on the bridge.

Accessibility

The lectures provided in the board room must be prearranged with the Bridge District.

Directions

From Moscone Center, follow Howard Street southwest. Turn right onto 9th Street. Turn left on Hayes immediately after crossing Market Street. Turn right on Van Ness, and follow signs to the Golden Gate Bridge. Exit at "Last San Francisco Exit" immediately before the toll plaza, following the sign to the "Golden Gate National Recreation Area View Area." Bear left, crossing under the bridge to a stop sign, then continue into the public parking lot.

Stop Description: Overview of Golden Gate Bridge Seismic Retrofit

The following description for Stop 1, through the information about Phase 3 of the retrofit, is reprinted with permission from the GGBHTD Web site at http://goldengatebridge.org/projects/retrofit.php (updated October 2005).

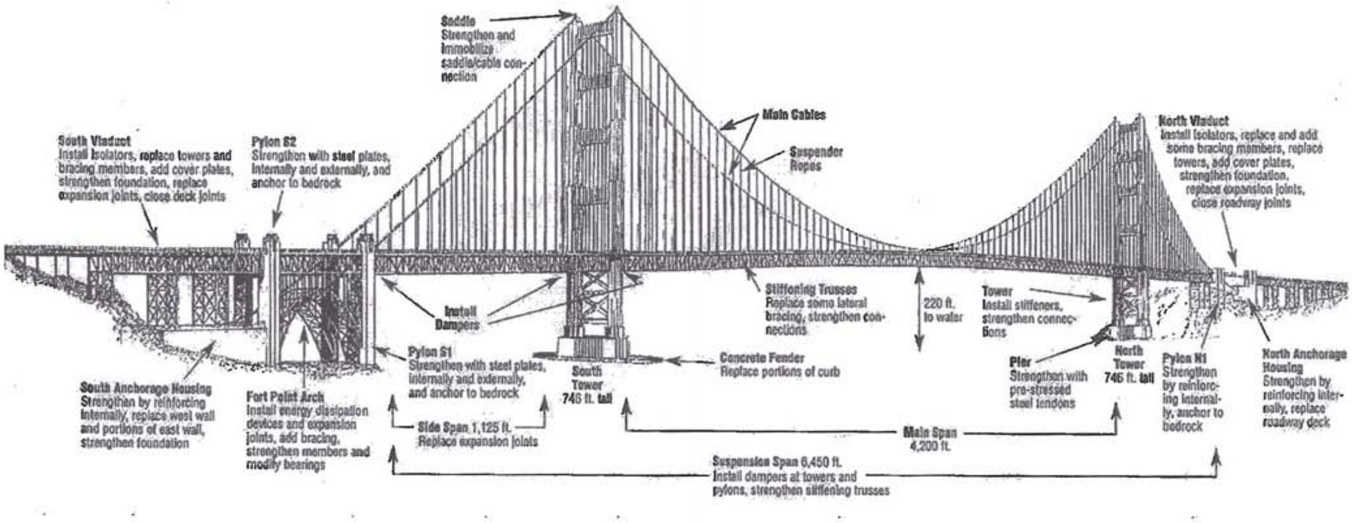
It was a bone rattling, concrete crushing, nerve-racking 15 seconds. At 5:04 p.m. on Tuesday evening, October 17, 1989, the 6.9 magnitude Loma Prieta earthquake caused 68 deaths, at least 3,700 injuries, and an estimated dollar loss of $6 billion to $7 billion. The earthquake reminded the world that the San Francisco Bay region remains vulnerable. Although the Golden Gate Bridge suffered no observed damage from the Loma Prieta earthquake (the epicenter was located some 60 miles to the south), the earthquake became a catalyst for the extensive seismic retrofit program that the historic structure is undergoing today.

Perhaps the most impressive statistic resulting from research conducted since the Loma Prieta earthquake is the conclusion by the U.S. Geological Survey (USGS) and other scientific organizations that there is a 62 percent probability of at least one magnitude 6.7 or greater earthquake, capable of causing widespread damage, impacting the San Francisco Bay region by 2032.

The Golden Gate Bridge represents a vital transportation link to the San Francisco Bay area, serving more than 40 million vehicles a year. The bridge is recognized by the American Society of Civil Engineers as one of seven civil engineering wonders of the United States. The bridge is a national treasure known and admired around the world. Spanning 1.7 miles from abutment to abutment, the Golden Gate Bridge consists of six main structures (Fig. 5):

1. San Francisco (south) approach viaduct;
2. San Francisco (south) anchorage housing and pylons S1 and S2;
3. Fort Point Arch;
4. Main suspension bridge;
5. Marin (north) approach viaduct;
6. Marin (north) anchorage housing and pylons N1 and N2.

Immediately following the Loma Prieta earthquake, the Golden Gate Bridge Highway and Transportation District, San Francisco, California, the owner and operator of the Golden



Golden Gate Bridge Seismic Retrofit Measures

Figure 5. Drawing of the Golden Gate Bridge showing seismic retrofit measures.

Gate Bridge, engaged a team of consultants to conduct a seismic vulnerability study. The conclusion of the study was that under a Richter magnitude 7.0 or greater earthquake with an epicenter near the bridge, it would experience severe damage that could close this important transportation link for an extended period of time. If a Richter magnitude 8.0 or greater earthquake occurred near the bridge, there would be a substantial risk of collapse or impending collapse of the San Francisco and Marin approach viaducts and the Fort Point Arch, and extensive damage to the remaining bridge structures, including the main suspension bridge.

It was also determined that retrofitting the bridge would be more cost effective than replacing it. In 1992, the Golden Gate Bridge Highway and Transportation District hired engineering consultants to develop seismic retrofit design criteria. As part of this task, the site-specific design ground motions associated with different magnitudes of earthquakes and expected performance levels were defined as the basis for the bridge retrofit design. The site-specific, moderate earthquake was defined as one having a 10% chance of being exceeded in a 50-year period and producing an acceleration of 0.46 g at the bridge. The site-specific, maximum credible earthquake was defined as one having a return period of 1000 yr or having an acceleration of 0.65 g, which is equivalent to an earthquake of magnitude 8.3 on the Richter scale.

Because of financial constraints, the Highway and Transportation District proceeded with the construction of the seismic retrofit in phases reflecting the degree of structural vulnerabilities.

In 1996, the three construction phases were established as follows: Phase 1 (completed 2002): retrofit the Marin (north) approach viaduct. Phase 2 (scheduled completion, middle 2006): retrofit the San Francisco (south) approach viaduct, San Francisco (south) anchorage housing, Fort Point Arch, and pylons S1 and S2. Phase 3 (awaiting funding): retrofit main suspension bridge and Marin (north) anchorage housing.

The total estimated steel and concrete quantities for the entire retrofit project are as follows: structural steel: 22.3 million pounds; structural concrete: 24,000 cubic yards; reinforcing steel: 5.3 million pounds.

A schematic of retrofit measures for the Golden Gate Bridge is shown in Figure 5.

Phase 1—Completed in 2002

On 27 June 1997, the Board of Directors of the Highway and Transportation District awarded a contract to Balfour Beatty Construction, Inc., El Dorado Hills, California, for the first phase of seismic retrofit construction. It also organized a construction administration team made up of district staff and consultants. HNTB Corporation, St. Louis, Missouri, was selected to provide construction management and inspection of the project. HNTB's subconsultants included Towill, Inc., for surveying; Thomas Jee and Associates, Inc., for steel bridge engineering and inspection; Kennedy/Jenks for hazardous materials (hazmat) technical support; and Al Gok Consultants, Inc., for construction safety.

The seismic retrofit measures applied to the bridge structures consisted of various methods of structural upgrades and included both the strengthening of structural components and the modification of structural response of the structures, so they can better respond to strong motions without damage. The cost of phase 1 totaled $71 million, which was funded using Golden Gate Bridge tolls.

The major strengthening measures implemented on the Marin (north) approach viaduct include the following: (1)

strengthening of the existing foundations; (2) total replacement of the four supporting steel towers and strengthening of bent N11; (3) replacement and addition of top and bottom lateral bracing and strengthening of vertical truss members and truss connections; and (4) modification of the structural system to minimize the effects of ground motions on the structure by connecting five, simply supported truss spans into a continuous truss, installing seismic expansion joints at the north and south ends of the viaduct truss, and installing isolator bearings atop the new steel support towers at the pylon N2 support and at bent N11.

The scope of retrofit within the viaduct truss was significantly reduced through the installation of lead-core-rubber–type isolator bearings. These bearings enable displacements of the truss relative to its supports, thereby significantly reducing the transfer of seismic forces onto the truss.

The maximum credible earthquake is predicted to create up to 12-inch displacements of the truss. To prevent the truss from crushing against the Marin (north) abutment and pylon N2, seismic expansion joints were constructed at these locations by removing a section of the orthotropic steel deck of the viaduct at pylon N2 and removing and reconstructing the Marin abutment back wall. These joints enable truss displacements of up to 15 inches, thereby preventing damage that could jeopardize the integrity of the structure.

A primary challenge of phase 1 was to construct the retrofit measures under continuous traffic. The construction inspection team closely monitored the structure throughout the complex process of installing temporary bracing, constructing and loading temporary supports for replacement of the towers, removing and replacing members, and strengthening members and connections.

The first work undertaken was to connect the viaduct spans to create a continuous superstructure capable of distributing lateral forces to prescribed points while the structure underwent tower replacements. Bent N11 near the Marin (north) abutment was substantially strengthened to substitute for temporary loss of longitudinal stiffness at the removed supporting towers. Before the individual towers could be replaced, the retrofit sequence required that truss members directly above each of the towers be replaced and truss panel points be strengthened.

The contractor retrofitted the tower foundations in a two-stage operation. The first stage was constructed with the existing towers still in place, which allowed them to schedule this work outside of the project critical path.

During the first stage, cast-in-drilled-hole (CIDH) piling and pile caps were added around the perimeter of the original foundation pedestals. The new concrete to existing concrete interfaces were strengthened with post-tensioning of monostrands, clamping the new footings to the pedestals of the existing foundations. The existing grade beams between the foundation pedestals were also substantially strengthened, and additional grade beams were constructed.

After the existing tower was removed, the second stage of the foundation retrofit proceeded. First, the remaining upper portions of the existing pedestals were demolished. Then, new upper pedestals were constructed and closure pours placed to incorporate these elements into the entire foundation system. The erection of a new tower followed.

The most visually dramatic Phase 1 work was the complete removal and replacement of the four steel support towers with footprints of 50 feet by 75 feet and heights of up to 150 feet. The contractor sequentially replaced the existing towers with new ones that very closely imitated the appearance of the original towers.

Jacking of the superstructure continuously under traffic was an interesting aspect of the tower removal and replacement operation. Once erection of the temporary supports was completed on the sides of the original tower, a series of synchronized jacks lifted the superstructure from the six original tower bearings by loading the six temporary support bearings. The temporary supports and jack were located 25 feet away from the adjoining original tower. At the jacking points, the superstructure had to be lifted by up to 1 1/2 inches to provide for up to 1/4-inch of lift at the existing bearings. This separation was sufficient for the contractor to proceed with removal of the original bearings, which was followed by demolition of the tower below.

The synchronous lift system used by the contractor was controlled at an electronic central control panel that was capable of raising the individual jack rams in precise increments of 0.2 inch and of shutting down the individual jacks once the superstructure was raised the prescribed height.

A total of six jacking points were used per tower; each point consisting of a cluster of four 200 ton jacks. Each jack cluster was tied to a single manifold, such that all four jacks received the same hydraulic and electronic signals from the controller. This system included highly accurate (up to 0.04 inch) sensors, which were attached to the superstructure to control its position. Aside from this means of displacement monitoring, a licensed land surveyor was also deployed on a nearby hillside to monitor structure location prior to, during, and after the jacking operations so as to detect any unplanned movement. Locking collars were placed on the jacks as a means of providing redundancy in the event of a hydraulic failure of the jacking system. Workers monitored the existing tower bearings and reported on their status via radio.

The overall jacking operations typically required approximately half an hour, the majority of which was spent checking and monitoring the status of the lift, with frequent instrument readings and status verifications.

Phase 2—To Be Completed Mid-2006

On 10 October 2000, the district began soliciting for bids for phase 2 of the Golden Gate Bridge Seismic Retrofit Project. On 11 May 2001, the Board of Directors of the district authorized award of the phase 2 construction contract to Shimmick Construction Company, Inc./Obayashi Corporation, a Joint Venture, Hayward, California.

In June 2001, the second construction phase began; it is the most complex part of the project in terms of design and construction. Federal, state, and regional funds totaling $171 million were aggressively sought and authorized to complete this phase. This phase, set to be completed in 2006, encompasses the retrofit of several different types of structures associated with the south approach: the south approach viaduct, south anchorage housing, Fort Point Arch, and south pylons. Retrofit measures developed for each of these structures reflect their individual behavior under seismic ground motions and their interaction at points of interface while accommodating their already-in-place historic configuration.

Without closing the Golden Gate Bridge to traffic, the steel support towers and bottom lateral bracing of the south approach viaduct is being entirely replaced, and seismic isolation bearings and joints are being installed at the roadway level. The west wall of the south anchorage housing is being replaced, and massive internal shear walls are being constructed. Five million pounds of external and internal steel plating are being added to south pylon walls. The historic architectural appearance of the external surfaces of the pylons will remain unchanged with the addition of a new external concrete cover on top of the new plating.

The Fort Point Arch is being retrofitted with new arch bearings and energy dissipation devices, and isolation joints are being installed. Steel members throughout the entire arch are undergoing extensive strengthening.

Not only were immense challenges presented in the design and engineering of this phase of retrofit construction, but the construction site itself presents very unique project limitations. The construction site is located in a very compact area bounded on the west by the Pacific Ocean and on the east by very steep slopes. Severe weather, including strong wind and high waves, is nearly constant. Access consists of two narrow roads that must be shared with thousands of tourists visiting the Golden Gate Bridge and the Historic Fort Point Site located directly below the Fort Point Arch structure of the bridge. Construction on the arch is limited to four days per week to allow limited visitation to the Historic Fort Point Site. The small construction staging areas available near the work site further restrict the logistics of the construction operations.

Phase 3—Remains Unfunded (January 2006)

The $160 million third and final phase of construction is planned to retrofit the main suspension span, the two main towers, and the north anchorage and pylon N1. The district continues to work diligently at the state and federal levels to assure funding for this phase and has secured $5 million toward this project to date. Once funding is available, the project can be completed in approximately 4 years.

Strong Motion Instrumentation of the Golden Gate Bridge

Instrumentation of the Golden Gate Bridge was planned by the California Geological Survey and California Strong Motion Instrumentation Program (CSMIP) and the Golden Gate Bridge Highway and Transportation District in cooperation with an appointed seismic instrumentation advisory panel in 1992. A total of 76 sensors (including 72 accelerometers and 4 relative displacement sensors) were installed in 1995 prior to retrofitting the bridge. Specifically, the numbers of sensors installed at each structure are: 15 at the north viaduct and north anchorage housing; 33 on the suspension bridge; 22 at the south viaduct, south anchorage housing, and Fort Point Arch; 3 at the south free-field; and 3 at the downhole geotechnical array near south viaduct.

The locations of these 76 sensors are shown in Figures 6–9. The purpose of the pre-retrofit instrumentation was to measure the response of the various bridge structures to ground motions. In the main suspension bridge, the instrumentation was designed to measure three-dimensional motions of the towers, plus vertical, longitudinal, transverse, and torsional motions of the suspended trusses. These measurements were accomplished mainly with accelerometers (for example, a sensor as shown in Fig. 10). Additional instrumentation with relative displacement sensors measure relative displacements across the expansion joints at the south tower and pylon S1, and uplift due to rocking at the base of the tower shafts.

After completion of the retrofit for the north viaduct, 18 additional sensors were installed (Fig. 11). In addition, a downhole geotechnical array was installed near the north viaduct. When the retrofit of south viaduct is completed in 2006, 25 more sensors will be added. The total then will be 119 sensors.

ShakeMaps

A ShakeMap is a graphical representation of the intensity, or the amount of ground shaking, at a particular place due to an earthquake. The information it presents is different from the earthquake magnitude because it focuses on the effect of the earthquake, the ground shaking, rather than on how much energy was released at the earthquake source. Magnitude (for example 5.1 for the Napa earthquake illustrated in Fig. 12) reflects the energy released in the earthquake. In contrast, intensity indicates how the ground shook at a particular site. While an earthquake has only one magnitude and epicenter, it causes varying shaking severity throughout a region. The intensity (which varies with distance to the earthquake, site geology, and other factors) indicates the potential damage. The purpose of ShakeMap is to quickly provide a picture of the intensity of ground shaking after an event.

The California Integrated Seismic Network (CISN, a partnership of CGS, the U.S. Geological Survey, Caltech and the University of California at Berkeley) produces ShakeMaps after significant earthquakes in California. Critical to improving emergency response, ShakeMaps require the measured data from many stations, and these agencies began pooling their data after the 1994 Northridge earthquake, a project that was encouraged by the Office of Emergency Services (OES) and Federal

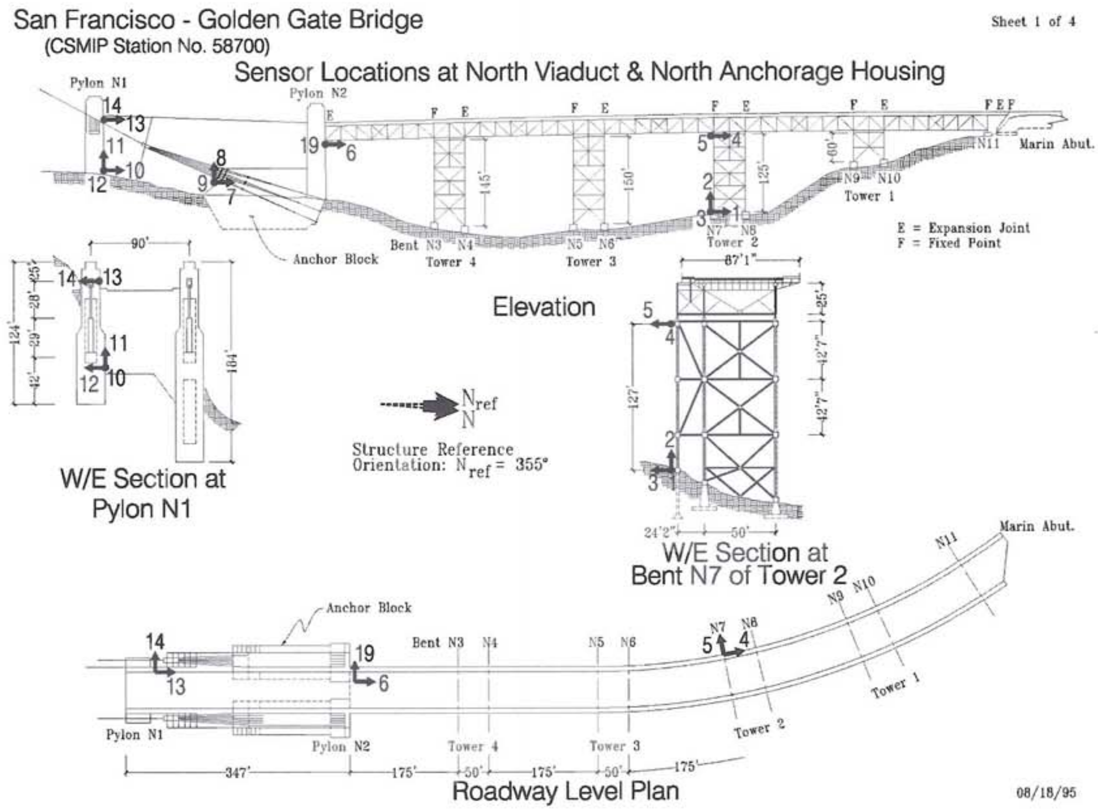


Figure 6. Drawing showing locations of strong motion instrumentation near north anchorage of the Golden Gate Bridge.

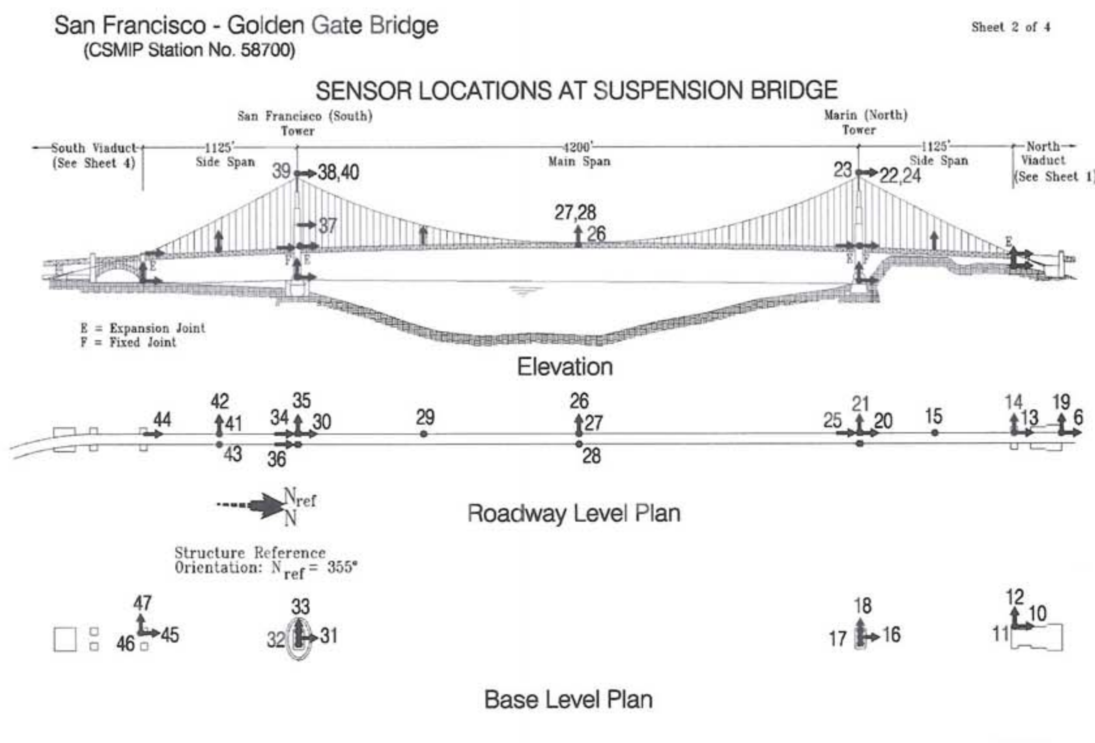


Figure 7. Drawing showing locations of strong motion instrumentation on suspension bridge section of the Golden Gate Bridge.

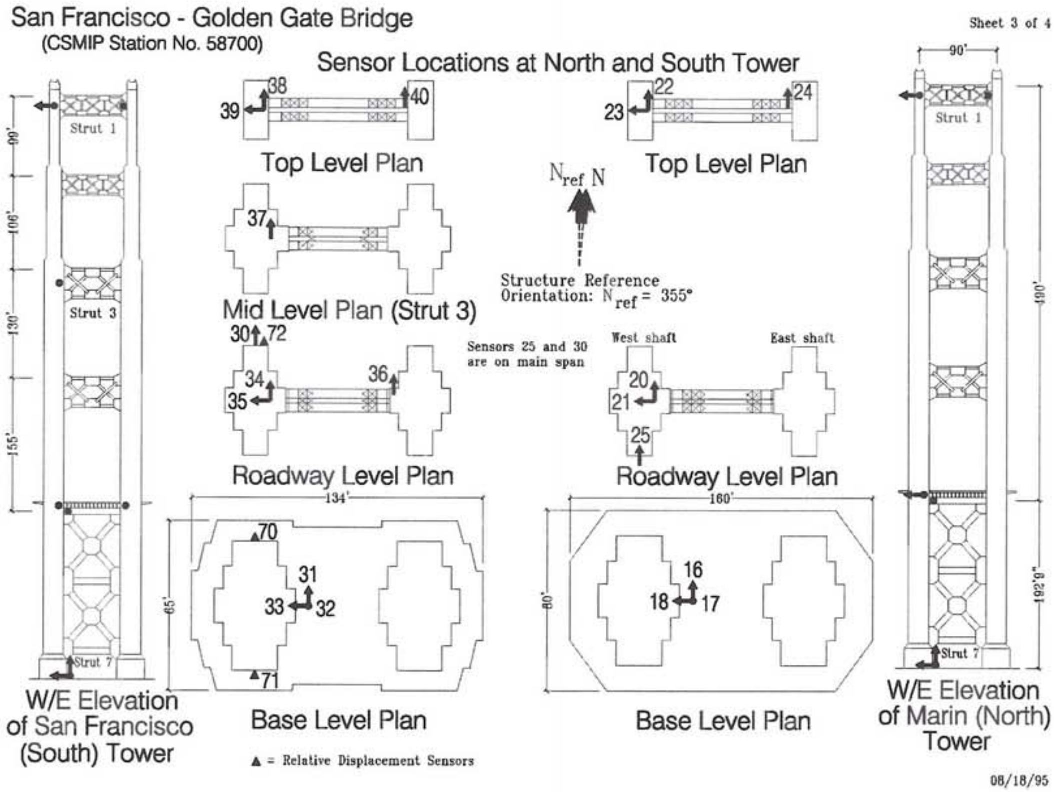


Figure 8. Drawing showing locations of strong motion instrumentation near north and south towers of the Golden Gate Bridge.

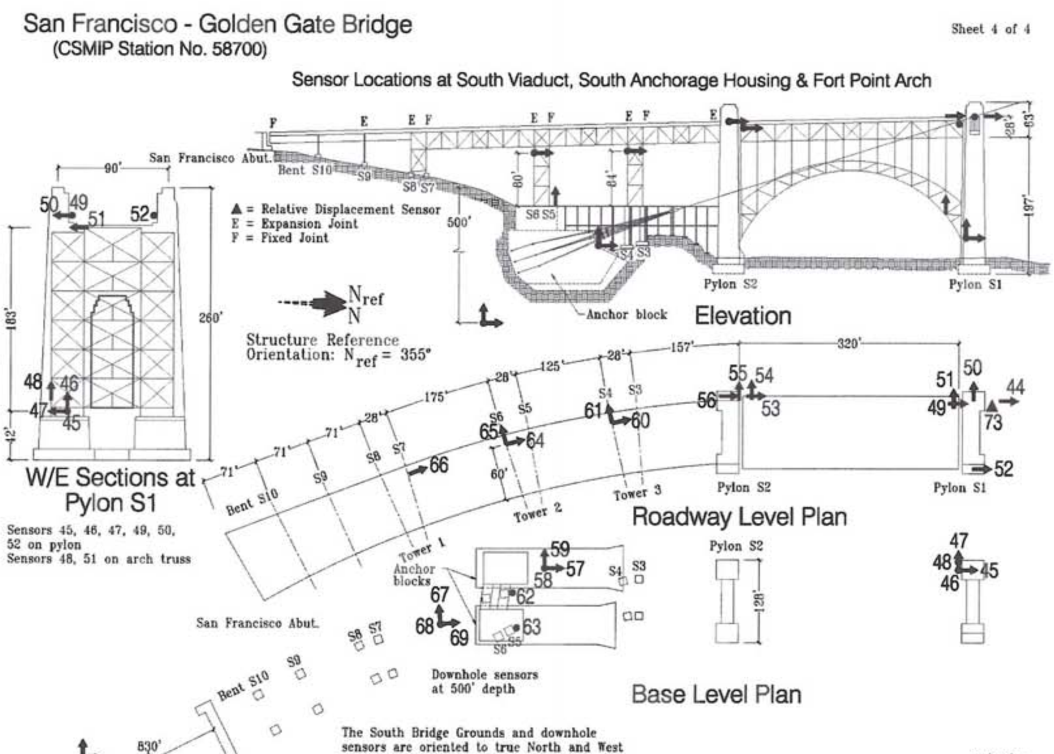


Figure 9. Drawing showing locations of strong motion instrumentation near south anchorage of the Golden Gate Bridge.

Figure 10. Photograph of accelerometer installed as part of instrumentation of the Golden Gate Bridge.

Emergency Management Agency (FEMA). Rapid-response ground motion maps (ShakeMaps) are generated automatically after earthquakes for use by emergency responders, the media, and the public. The maps use the recorded ground motions to calculate local shaking levels and areas of likely damage distribution. ShakeMaps are computed and posted within minutes of the occurrence of the earthquake (www.cisn.org/shakemap.html). Maps are updated as additional data become available. Currently, ShakeMaps are available for instrumental intensity, peak ground acceleration, peak ground velocity, and spectral response.

A measuring station on the grounds at the south end of the Golden Gate Bridge is one of many CGS/CSMIP stations that record the ground shaking for use in producing ShakeMaps.

ShakeMaps are valuable for postearthquake response in many applications, for example: (1) conducting damaged building and safety inspections; (2) for use at hospitals and other emergency response facilities; (3) assessing the impact on status of utility systems and transportation networks (see Fig. 13 for an example); (4) estimating shelter needs from housing loss projections; (5) evaluating hazardous material release and debris from collapsed structures; (6) preliminary estimation of economic loss (cities, counties); and (7) management of insurance claims.

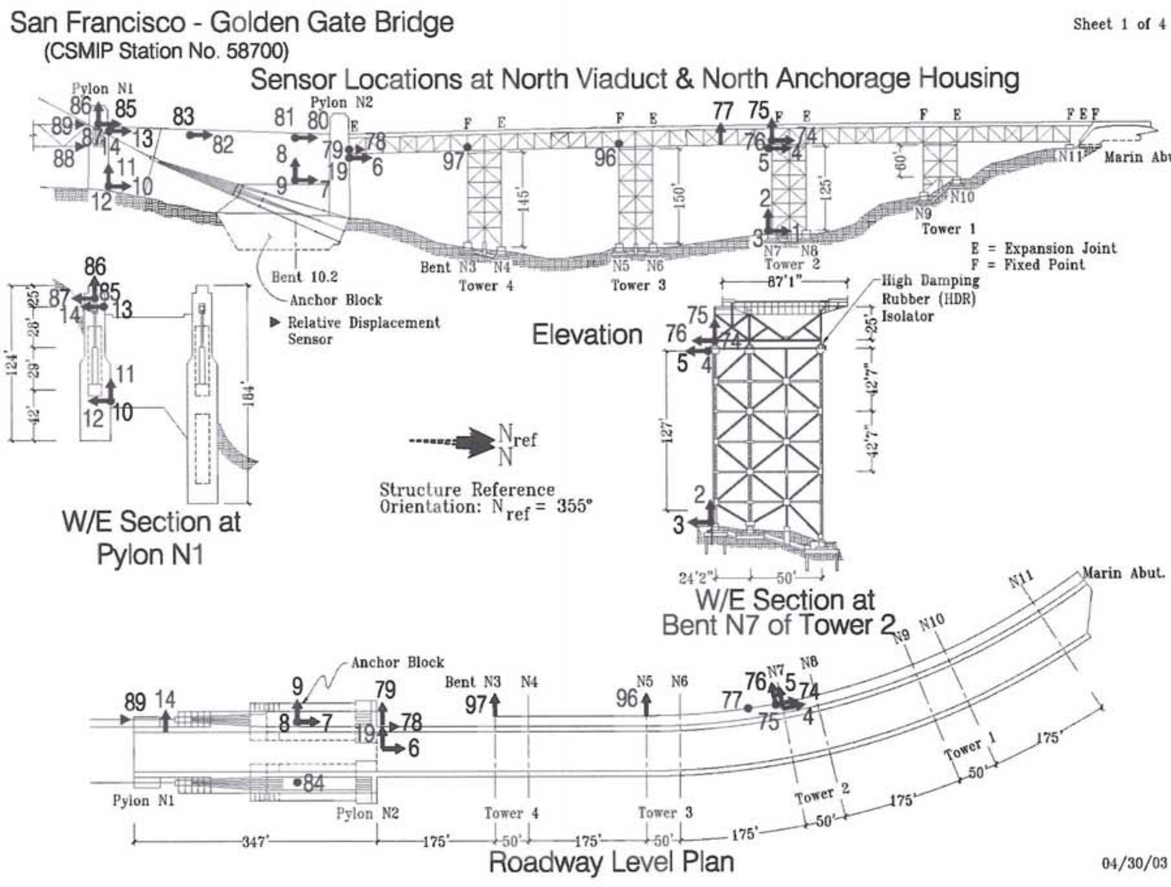
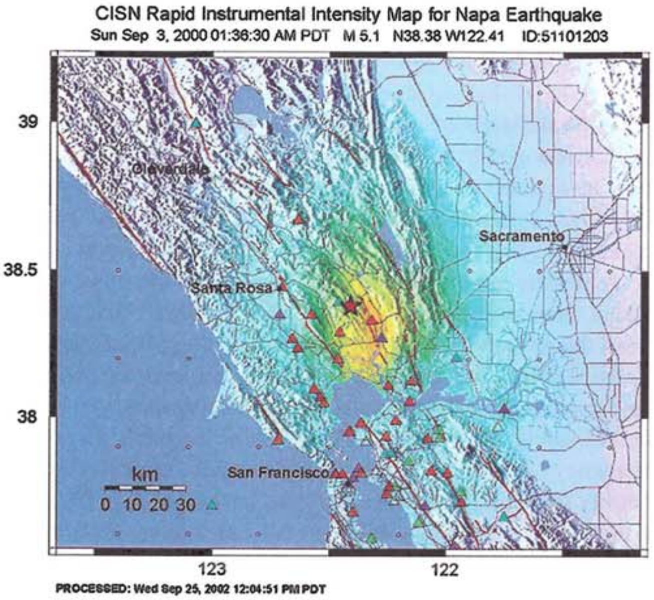


Figure 11. Drawing showing 18 additional sensors installed near north anchorage of the Golden Gate Bridge after completion of Phase 1 of the seismic retrofit project.

The CISN Engineering Data Center

Information on the instrumented bridges and other stations and the sensor locations on the structures are available at the Engineering Strong Motion Data Center (EDC; http://www.quake.ca.gov/cisn-edc) of the California Integrated Seismic Networks (CISN) (see the CGS home page at http://www.quake.ca.gov for more links). The strong motion data recorded are also available at the EDC. Internet Quick Reports (IQR) at the EDC list strong motion records immediately after a significant earthquake. IQR use internet technology as a means to provide engineers access to processed strong motion data and spectral information, as well as information about the structures and sites, very rapidly after an earthquake.

Users of the EDC have direct access to the processed strong motion data from previous earthquakes and detailed information on instrumented structures. The users can also download all the records from a specific station. The EDC increases the ability of earthquake engineers and emergency managers to respond knowledgeably and rapidly after earthquakes.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 12. Example of a ShakeMap, produced by the California Integrated Seismic Network (CISN) for the 3 September 2000 M 5.1 Napa earthquake (courtesy California Geological Survey, www.cisn.org/shakemap/nc/shake/51101203/intensity.html).

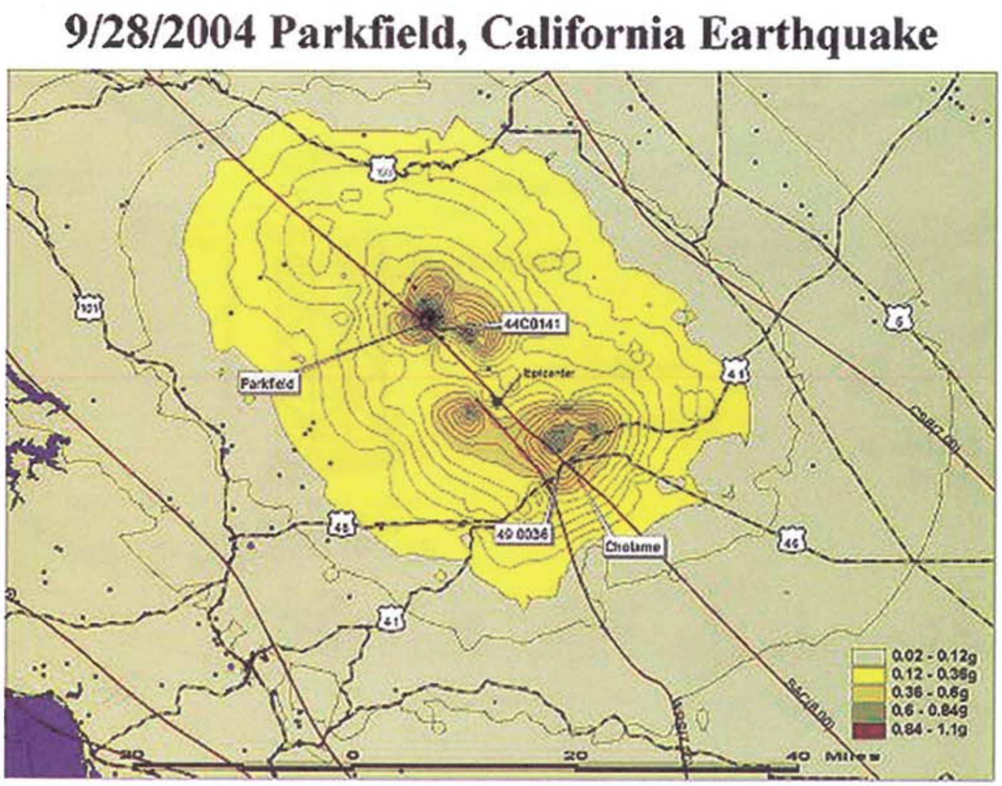


Figure 13. Map showing contours of peak ground acceleration for the 28 September 2004 Parkfield earthquake. This is an example of the application of ShakeMap to rapidly assess the impact of this earthquake on the status of utility systems and transportation networks; g—force of gravity.

STOP 2: FREE-FIELD STATION IN THE MAINTENANCE AREA

Significance of the Site

This is one of the strong motion instruments that measures the shaking produced during large earthquakes.

Accessibility

This area is not open to the public.

Directions

From the district office building, cross Merchant Road to the instrument location shown on Figure 4.

Stop Description

The group will view the free-field instrument located on a rock outcrop in the maintenance area south of the district office. This instrument measures three components of ground motion on the south end of the Golden Gate Bridge. The measured ground motion is incorporated into the ShakeMaps routinely generated after a significant earthquake. In addition, instruments are installed on the north side of the bridge, in a downhole geotechnical array near the south viaduct, and at the bases of both towers. Measurements from these instruments will provide information on the input ground motions to the bridge superstructure.

STOP 3A: FORT POINT OVERLOOK AREA

Significance of the Site

This is a short walking tour that will visit a display about the details of the bridge construction and then proceed to an overlook of the bridge.

Accessibility

This is a public-access site; see http://goldengatebridge.org/visitors/whattodo.php for additional information.

Directions

From Stop 2, cross under the bridge to Strauss Statue. Follow the brick sidewalk located behind the Strauss Statue and continue to follow the bricks to the right until they join an asphalt overlook.

Stop Description

The tour group will visit the Strauss Statue located on the southeast side of the bridge and view a display of a cross section of one of the bridge's main cables behind the statue. The tour group will then take a short walk to the Fort Point overlook from the southeast parking lot. At the overlook, the participants will view the seismic retrofit work under way or completed at the south viaduct and the Fort Point Arch (Fig. 14).

Figure 14. Photograph of the Golden Gate Bridge undergoing Phase 2 of the seismic retrofit project.

Figure 15. Photograph of San Francisco Tower.

STOP 3B: THE SAN FRANCISCO TOWER

Significance of the Site

The instruments located at this stop record the strong ground motion during large earthquakes.

Accessibility

Pedestrians are normally not allowed on the west sidewalk; however, the east sidewalk is open to pedestrians. The west sidewalk is normally only open to cyclists.

Directions

From the Fort Point overlook, follow the bridge sidewalk to San Francisco Tower.

Stop Description

The group will walk on the west sidewalk to the San Francisco Tower (Fig. 15). The participants will be able to view the seismic recorders and sensors.

WEB REFERENCES

California Geological Survey: http://www.conservation.ca.gov/cgs; http://www.quake.ca.gov.

California Integrated Seismic Networks: http://www.cisn.org.

CISN Engineering Data Center: http//www.quake.ca.gov/cisn-edc.

Golden Gate Bridge, Highway and Transportation District, http://www.goldengatebridge.org.

Printed in the USA

Early Geological Observations of the San Francisco Bay Area

Stephen M. Testa
Executive Officer
State Mining and Geology Board

Recently assigned to the Williamson expedition, or commonly referred to as the Pacific Railroad Survey, William Phipps Blake arrived in the San Francisco Bay area on July 8, 1853. A twenty-seven year old Chief Scientist, Blake presented himself as an imposing but disarmingly charming, six-feet tall individual with piercing blue eyes and an abundance of hair already turning white.

The Williamson expedition was one of four expeditions authorized by Congress under the administration of President Pierce, and Jefferson Davis as Secretary of War, with the purpose of exploring the span of country, virtually unknown at the time, lying between the Mississippi River and Pacific Ocean. Williamson was already in Benicia, ready to proceed with an expedition, but did not yet have a geologist and mineralogist, despite earlier efforts to obtain one. Josiah D. Whitney (California's second State Geologist and first Director of the California Geological Survey years later, and distant cousin of Blake) mentioned Blake to Professor Spencer F. Baird, Assistant Secretary under Joseph Henry of the Smithsonian Institute, recommended Blake to Williamson's second senior officer, Lieutenant Amiel W. Whipple, who concurred with the appointment.

As part of the Williamson's expedition, Blake was the first person to conduct a comprehensive geological reconnaissance and examination of California. Blake made several trips to the San Francisco are between the years 1853 and 1910. In review of Blake's field notebooks, his reconnaissance of the San Francisco Bay area was mainly undertaken between the periods between about September 14 to 20, 1854. Blake's geological report pertaining to this area has been reproduced herein.

Blake's geologic description and map of the headlands and adjoining shores, in the vicinity of San Francisco was prepared for the Pacific Railroad Survey report, Volume V. Units delineated included blown sand (dunes), San Francisco sandstone, traprock at Point Cavallos, and serpentine. The rocks observed included what was to become the type locality for what is now referred to as the Franciscan formation, first described by Andrew C. Lawson, at its type location in the northern part of the San Francisco peninsula. Blake in preparation of his geologic report, also had the opportunity to review Beechy's report, and commented on the geological observations presented by Buckland.

Blake recognized and described in significant detail a variety of lithologies, evaluated the structural relationship of the rock units encountered and correlated rock units throughout the area. Blake made observations relating to weathering and erosion, and coastal processes in relation to the formation of the channel where the Golden State bridge now resides (i.e., the Straits of Carquinez connecting the Bay of San Pablo with Suisuin Bay). Observations were made regarding the depositional structures and processes involved in the formation and migration of sand dunes. These sand dunes rose as high as 20 to 60 feet or more, and Blake noted that they were increasingly being leveled for housing.

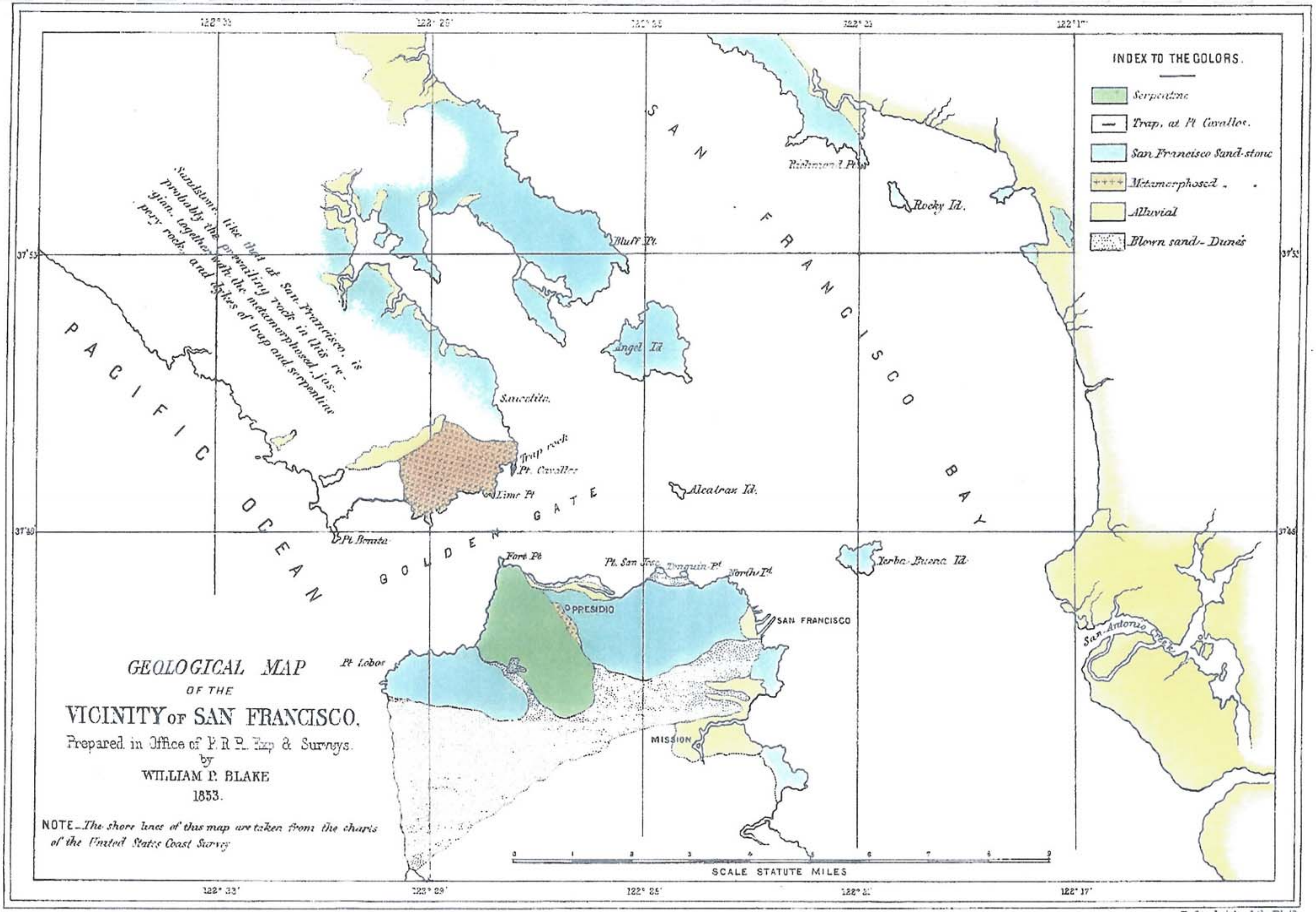
Based on fossil evidence (i.e., Trochus, Turritella and a shark's tooth), Blake assigned the sedimentary (sandstone) rocks in the Benicia area to Tertiary, in the immediate Bay area fossils were scare, chiefly being Scutellae. Blake interpreted the age of the thick sequence of sandstone and shale to be Tertiary, and referred to the unit as the San Francisco of California Sandstone. He believed it to be the "*most extensive and highly developed sedimentary formation on the California coast.*"

Blake evaluated the suitability of certain rock types for construction and building materials, and described the quarrying activities being conducted at the time. He also provided an overview of groundwater resources in the area. He recognized that although numerous, artesian conditions were restricted to the "superficial drift or alluvium" and discussed aspects of yield, water use and cost.

William Phipps Blake Report On Geology of the Vicinity of San Francisco (1858)

From

Geological Reconnaissance in California (W.P. Blake, 1858)



GEOLOGICAL MAP
OF THE
VICINITY OF SAN FRANCISCO.
Prepared in Office of P. R. R. Exp & Surveys.
by
WILLIAM P. BLAKE
1853.

NOTE.—The shore lines of this map are taken from the charts of the United States Coast Survey

T. Sinclair's lith, Phila.

Chapter XII
Geology of the Vicinity of San Francisco

ENUMERATION OF THE PRINCIPAL FORMATIONS -- GRANITE NORTH AND SOUTH OF THE GOLDEN GATE.--GEOLOGICAL MAP.--SAN FRANCISCO SANDSTONE.--POINTS AT WHICH IT IS EXPOSED.--SECTION AT YERBA BUENA.--SANDSTONE AND SHALES.--DECOMPOSITION OF THE ROCK.--UNDER THE CITY.--RESEMBLANCE TO TRAP ROCK.--POINT LOBOS--ANGEL ISLAND.--STATE'S PRISON QUARRY.--SECTION OF THE STRATA.--DISLOCATION OF A BED OF THE SANDSTONE.--MARIN ISLAND.--BENICIA SANDSTONE.--NAVY POINT.--CONGLOMERATE.--SECTION OF THE STRATA AT NAVY POINT.--HARD BLUISH-GREEN MASSES.--PROBABLE SYNCHRONISM OF THE STRATA WITH THOSE NEAR SAN FRANCISCO.--EXTENSION OF THE STRATA SOUTHWARDS NEAR MOUNT DIABLO.--SANDSTONE AT NEW ALMADEN, SAN JUAN, AND NORTH OF THE GOLDEN GATE.--BELLINGHAM BAY SANDSTONE PROBABLY THE SAME.--AGE OF THE FORMATION.--FOSSILS.--PROBABLE TERTIARY AGE.--SECTION FROM SAN FRANCISCO TO THE PACIFIC.--METAMORPHIC SANDSTONE.--JASPERY OR PRASOID CHARACTERS.--ERUPTED ROCKS.--GRANITE.--TRAP.--SERPENTINE.--FORT POINT.--DIALLAGE OR BRONZITE.--GLOBULAR CHARACTER OF THE ROCK.--STRATA IMBEDDED IN THE SERPENTINE.--POST TERTIARY AND ALLUVIAL DEPOSITS.--ENCROACHMENTS OF THE SEA.--DRIFT OR SURFACE ACCUMULATIONS--SAND DUNES.--BEACH ON THE PACIFIC SIDE--HAPPY VALLEY.--STRATIFICATION AND RIPPLE MARKS.--ARTESIAN WELLS AT SAN FRANCISCO AND SAN JOSÉ.

The principal rock formations of the vicinity of San Francisco are sandstones and shales, together with erupted trappean rocks and serpentine--all, probably, of comparatively recent geological age. Granite and the associate rocks were not seen near San Francisco, but they, probably, form the central portion of the San Francisco or San Bruno range, as far south as San José, or the mines of New Almaden, where a white crystalline limestone occurs. Granite is found in the Santa Cruz Mountains, and at Point Pinos, Monterey. It also outcrops on the coast north of the Golden Gate, forming the projecting headland called Punta de los Reyes, and the group of small islands, about twenty miles from the Golden Gate, known as the Farallones.

A small Geological Map of the vicinity of the entrance to the Bay of San Francisco is presented with this chapter, and will serve to show the geology of the headlands and the adjoining shores.[1] A fine-grained, compact sandstone, associated with shales, is the prevailing rock. It underlies the city of San Francisco, and is exposed along the shores of the bay, both north and south of the city, forming the principal promontories and points, and several islands. On entering the bay, from the Pacific, the rock is first seen at Point Lobos, the outer point, and again at North and Tonquin points. It borders a part, at least, of the Golden Gate, on the north, and forms the shores of Richardson's and Saucelito bays. Angel and Yerba Buena islands are also of this sandstone formation. In several places, hills and ridges, of over two or three hundred feet in elevation, are formed entirely of this rock, and the wearing action of the sea, at their base, and the break in the ranges forming the Golden Gate, have produced favorable sections where the characters of the strata may be studied. Availing myself, therefore, of these natural exposures, and of the excavations made in quarrying, the strata were examined at the following places: City of San Francisco, Points Lobos, San José, Tonquin, and North, Yerba Buena island, Alcatrazes island, Angel island, Point San Quentin, north side of the Golden Gate, and along the shores of the Saucelito bay. Rocks, probably identical in age, were also examined at Benicia, New Almaden, and between San Juan and Monterey.

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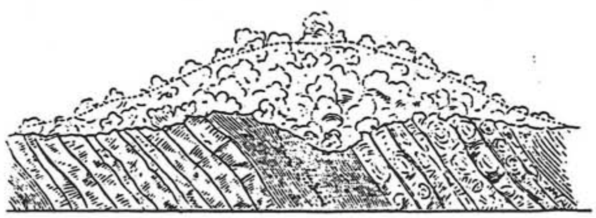
[1]Since the printing of this report commenced, I have had the opportunity of seeing the volume on the Zoology of Captain Beechey's Voyage, in which I find some observations on the geology of the vicinity of San Francisco, prepared from the notes and collections of Lieutenant Belcher, by Professor Buckland. A map of the headlands, embracing about the same area as in the map accompanying this report, is also given in illustration. This is colored around the shores so as to indicate the several formations. Serpentine, sandstone, and jasper rock are represented.--*Zoology of Captain Beechey's Voyage to the Pacific and Behring's straits in 1825,-'26,-'27, and 28.* 4to, London, 1839.

One of the best sections, where the lithological characters of a part of the formation are fully exposed, is at Yerba Buena, the island directly opposite San Francisco. This is composed entirely of

the sandstone and shale; the strata are laid bare by the action of the water around the base of the island, and form a bold rocky shore, which in many places appears to offer great resistance to the persistent denuding action of the waves and strong currents. On approaching the island from the west the evidences of stratification become visible, and the beds are seen to dip westward, toward the observer. There are also several places where the strata are bent and contorted, as in the figure.

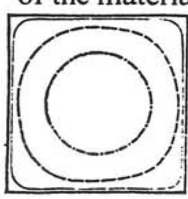
On the south end of the island a quarry has been opened. At this point the edges of the strata are distinctly exposed, and are seen to dip about 20 N. of E., at an angle of 45°. The position and general characters of the strata may be best exhibited by a short local section, the total thickness represented being about two hundred feet. The thicknesses of the compact beds of sandstone vary from a few

SECTION OF SANDSTONE AND SHALE, YERBA BUENA



inches to six and eight feet; the layers alternate with beds of argillaceous slates and shales. All the weathered surfaces of this series of beds are of a rusty-brown or drab color, which extends throughout the rock to a depth of from ten to twenty feet, down to the limit of atmospheric influences. There are, however, parts of the upper beds that have not yet been reached and changed by decomposition; these parts are found in the condition of spherical or ellipsoidal masses, from which the weathered parts scale off in successive crusts. These nuclei have the appearance of great rounded boulders, and have accumulated in great numbers at the base of the cliff. They are of various sizes, but are smallest in the upper parts of the strata, near to the surface.

This spherical or globular condition does not appear to be the result of any peculiar arrangement of the material of the strata, a concretionary action, such as takes place in the igneous rocks, but is



probably due to decomposition--the result of the absorption of infiltrating waters, charged with impurities. A solid and homogeneous cube of sandstone thus exposed, under conditions favorable for absorption of the water on all its sides, would decompose most rapidly on the angles, producing a succession of curved surfaces gradually approaching a sphere, as is represented in the figure.

These necessary conditions for the infiltration of water exist in the strata. Each layer of rock is divided into blocks of various sizes by joints, or cleavage planes, similar to those traversing crystalline rocks; these are nearly vertical to the planes of stratification, and cut through all the beds. Seams are thus formed for the access of air and water.

The color of this sandstone is dark bluish-green, inclining to gray. It is exceedingly compact and tough, and does not break so easily as the fine-grained red sandstone of the Connecticut river and New Jersey quarries. Its texture varies but little in the different beds; the grain is close and even, and generally very fine.

The grains are chiefly silicious, and are mingled with those of finely triturated glassy feldspar and other minerals, the whole being apparently cemented together by fine particles, or probably, in part, by carbonate of lime. Nearly all of the specimens submitted to examination were found to be calcareous, and effervesced freely with acid. This is true of specimens from the other localities, so far as examined, and the rock may with propriety be called a calcareous sandstone. Oxide of iron is an important constituent of the rock, and it is probably in the form of protoxide, for the interior portions are greenish-blue, and on exposure become rusty brown or drab, the result of the formation of the sesquioxide. The iron may be present in combination with sulphur; one or two minute grains of pyrites were detected in some of the specimens.

Numerous films of a dark slate-colored substance are distributed in parallel planes through the mass of the rock. They are often coal black, and some are soft, like clay or shale, and are sometimes in small lenticular masses, which can be easily excavated with the point of a knife. Some of the beds contain many more of these masses than others, and they determine the direction of easy fracture of the rock. One of the beds of soft shale was highly charged with black masses, and they were, without doubt, the remains of plants, a coaly substance being distinct in the thickest layers. The films in other parts of the rock were, in most cases, composed chiefly of clay, and may be fragments of shale.

The position of these beds of sandstone is highly favorable to the operation of quarrying, and the stone can be readily loaded at a wharf and ferried over the channel to the city. It will be found to be a highly valuable and elegant building material.

The same formation of sandstone and shales underlies the city, but there is no exposure where the strata can be so conveniently studied as at Yerba Buena, or where they are so free from decomposition and fissures. The strata are apparently much more bent and broken up, and the action of the atmosphere and surface water has extended to a greater depth below the surface. The best section, at the time of my observations, was along Pacific street, where Telegraph Hill had been cut away. At that place the stratification was very distinct, and the alternation of thick beds of argillaceous sandstone, with shales and slate, was visible. Numerous curves and flexures of the beds render the dip variable, but its prevailing direction is eastward. The rocks crop out on the top of the hill, and look like ordinary trap-rock which has been exposed to the weather. These rocks are again exposed along Dupont street and Broadway, and they form the shores of North Point. They also project out into the channel between Telegraph Hill and Fort Point, forming Tonquin Point and Point San Josef. At all these places decomposition of the rock has extended so deeply that the unaltered portions had not been reached by the excavations, and the true color and lithological characters of the rock were not exhibited. At one or two points about the city, however, deep excavations in to the rock for wells showed that, in color and composition, the rock was similar to that at Yerba Buena. In fact, the general characters of the strata are the same, and the rusted and decomposed exterior crust of rock has nearly the same appearance at both places. The detailed description of the Yerba Buena stone may, therefore, be regarded as, in general, applicable to the unchanged portion of the rock at San Francisco, and at other points about to be mentioned. The sandstones at Point San Josef and those of Telegraph Hill are traversed by thin and irregular seams of quartz, running in various directions. These may have had their origin at the time of the intrusion of neighboring igneous rocks, being deposited along the sides of slight racks and fissures by escaping hot vapors. Veins of carbonate of lime, nearly the same in size and appearance as those of quartz, are also found traversing this sandstone in some places, but the two minerals were not found together. Point Lobos--the outer headland of the Golden Gate on the south side--is likewise of sandstone, similar to that of San Francisco. The continued action of the ocean swell has worn the rocks into rugged cliffs and excavated caverns and arches. Many large masses are detached from the cliff, and lie scattered about in the surf. These isolated island rocks are the places of resort for sea-birds and the huge "sea-lion."

The direction and dip of these strata are not very distinct at this point. The greater part of the formation is hidden from view by an immense deposit of blown sand, and the surf prevents any extended examination under the cliffs. A local trend of a few degrees north of west was, however, observed. On the opposite side, or north shore of the channel, the prevailing dip is westward, and it is more than probable that the rocks of Point Lobos have the same direction. These strata extend eastwardly as far as a little brook that descends from the Mountain lake, and empties into the channel.

Excavations for building-stone have been made on the southeast end of Angel island, which bears northwest from Yerba Buena, and is in the range of the strata. It is composed of sandstone, similar to that on Yerba Buena island, but is not so dark in color or so hard. Specimens which I have examined contain a notable quantity of carbonate of lime. The strata dip westwardly, and the quarry is opened on their upturned edges, and not at the ends of the beds, as at Yerba Buena. The weathered surfaces of the strata present the same rusty color as those at San Francisco and Yerba Buena, and the divisional planes or cleavages are numerous.[2]

Another extensive outcrop of sandstone, and a quarry, is found at the State's Prison, on Point San Quentin. It is worked, by convicts, to a greater depth than either of the other places that have been described. It is the same sandstone formation, and furnishes a large quantity of good "blue stone." The excavation (in 1854) had extended to a depth of about thirty feet below high-water mark; at that depth the blocks of stone are larger, and without the rusty color attendant on surface decomposition. The trend of the strata is nearly north 50° west; the dip southwest at variable angles, ranging from 45 to 55 degrees. The lay of the strata and the general outline of the quarry is shown in the annexed section; the horizontal line on the left representing, nearly, the height of the waters of the bay.

The strata rise into a slight hill on the east side of the opening, and soon lose the compact, massive character, becoming thinner and more broken, and then pass into a thick body of argillaceous shales.

The operation of quarrying below the surface is, necessarily, more expensive than excavating the stone from a bank or elevation; in addition to the inconvenience of working a quarry in this form, the waters of the bay percolate through the bank and accumulate in the lower part of the excavation. The bank of stone does not, however, rise much over 30 or 40 feet above high-water mark, and it is very much decomposed and broken up, so that the excavations are necessarily below tide.

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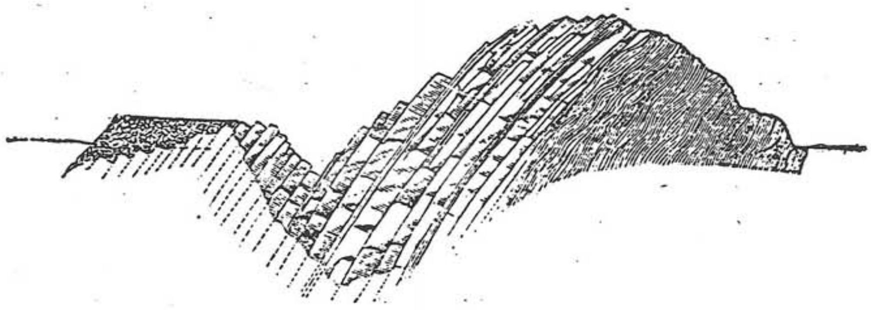
[2]I have represented Angel island on the map as wholly formed of sandstone and shales, although I did not visit the western portions. It has, however, the appearance of the sandstone. Lieutenant Belcher, it appears, collected specimens of serpentine on the western side, and the occurrence of jasper rock is noted. It is further stated that the opposite shores of the main land, or promontory on the north, afford specimens of actynolite, mica slate, and talc slate.--*Zoology of Captain Beechey's Voyage: Geology, p.* 175. It is possible that fragments of the slaty serpentine are here mentioned as *talc slate*, and the mica slate may have been a transported mass, for it is not probably that the true micaceous slates occur at that point.



SECTION OF THE STRATA AT THE STATE'S PRISON QUARRY

Large blocks of stone are taken out of this place. They split readily into various desired sizes, and are easily cut and chipped. When dressed or hammered, the surface has a pleasing shade of color, which is much lighter than the bluish-green stone of Yerba Buena, being more gray. Fragments of the stone effervesce briskly when placed in dilute hydrochloric acid, and many of the blocks are traversed by thin veins and seams of white, crystalline carbonate of lime. Where these veins are exposed on a weathered surface, they stand out above the sandstone, showing their superior resistance to degradation.

The slaty character of some of the beds is well seen in the excavation. Thin layers of only a few inches in thickness occur between the beds of solid stone. These slates or shales are darker than the sandstone, and appear to have been subjected to great pressure. Many bendings and plications of the strata have occurred at this locality, and at one side of the quarry there is an interesting dislocation and fault of one of the beds, which bears interesting testimony to the action of violent compressing forces. This dislocation is represented in the figure.

DISLOCATION OF A BED OF SANDSTONE, STATE'S PRISON QUARRY

This bed must once have been continuous, the several parts being joined on to each other in the order in which they are numbered. It is now broken in three places, and the two ends of the main portions were pressed together so as to throw out a fragment on each side. The space between the blocks is occupied by highly contorted and crushed shales, enclosing some angular fragments of sandstone.

Stone from this quarry, roughly broken out into blocks, was selling in the city of San Francisco for ten dollars a tone--[1854.] It is readily chipped and dressed, and, when hammered, makes a good surface for the fronts of buildings. It is certainly a valuable building material, and is far superior to the partly decayed and friable stone from the Benicia beds.

Another interesting outcrop of the strata is found at Marin island, a small island about four miles northeast of the State's Prison quarry, and nearly opposite the Mission of San Rafael. The strata are highly inclined, and dip W. 30° N., at an angle of about 60°, trend N. 30° E.

They are composed of thickly bedded sandstones, alternating with shales, and the stone is more like that from Yerba Buena than that taken from the State's Prison quarry. It has a dark bluish-green color and a fine grain, and the black spots are not so abundant as at the other localities. Abundance of good building-stone can be obtained at this place, and it is accessible for tonnage vessels.

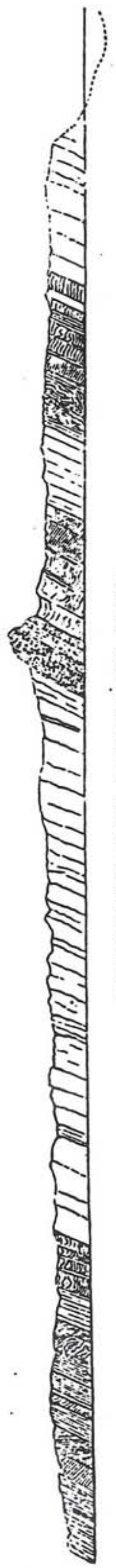
All the points and headlands around Marin island appear to be formed of similar rocks. They outcrop also on the opposite side of the channel, and form low ridges, trending about northwest and southeast. In sailing up the bay towards Benicia, the same strata appear to be continuous, and seem to be the only formation. The strata are exposed at many points along the shores, always with the same rusty drab or brown color.

At Benicia, the hills are soil-covered, and there are few outcrops; but there is an extensive and favorable natural section of the strata at Navy Point, produced by the Straits of Carquinez connecting the Bay of San Pablo with Susuin Bay. The current flows nearly at right angles to the trend of the outcropping beds; and their ends are well exposed along the shore, forming a bluff of slight elevation. The strata are uplifted, being inclined at an angle of from twenty to sixty degrees, and dipping towards the southwest. The trend of the outcrops is 75° west of north, and the strata underlie, or rather form, the hill upon which the government buildings are erected.

These strata, as here exposed, differ somewhat from the outcrops at San Francisco, Yerba Buena, and other places described; but there is much reason to consider them as a portion of the same formation, although they may prove to be much higher in the series. The surface decomposition appears to have been more complete, or perhaps the strata were never so hard and firm as those nearer San Francisco.

The great ridge of conglomerate, already described in the notes, forms the prominent feature of the section exposed at this point. It is the hardest and most unyielding of all the strata, and its resistance to abrasion and atmospheric influences has determined the form of the hill and the shape of Navy Point. It forms a prominent object at several points along the surface of the ground, and is almost the only rock that appears above the soil in that vicinity. The bed is about twenty-five feet thick, and is composed of pebbles and gravel, very round, much water-worn, and chiefly derived from the wear of volcanic or eruptive rocks. Their colors are generally dark; and porphyries, agates, and carnelians are abundant. Their average diameter does not exceed an inch, and many are about the size of beans and peas. They are closely united by a small portion of finer materials. The strata on both sides of the conglomerate consist of alternate beds of soft and friable argillaceous shales, with an occasional layer of gravel and pebbles. Their lithological characters and succession are shown in the following section, enumerating the strata from west to east, or in the order of superposition from above downwards. The measurements which are given are merely approximate, having been determined by the eye, or by pacing in front of the exposed edges in the bluff.

SECTION OF THE STRATA AT NAVY POINT, BENICIA



SECTION OF THE STRATA AT NAVY POINT, BENICIA.

		Feet
1.	Sandstone, fine-grained and soft, with spherical masses of great hardness inclosed--only about 10 feet exposed	10
2.	Sandstone, harder than No. 1, and highly charged with peroxide of iron	15
3.	Sandstone, with layers of small pebbles and coarse grains of quartz. Some hard masses also seen. Ferruginous. Fossils and a shark's tooth	20
4.	Slaty sandstone in thin layers, hardened by the presence of a considerable portion of oxide of iron. Trend S. 75° E.; N. 75° W	6
5.	Slaty sandstone, similar to No. 4	15
6.	Sandstone, fine-grained, soft, regularly bedded	63
7.	Sandstone, soft, in beds separated by thin partings of shale, and traversed by thin seams of gypsum, generally in horizontal layers. The shales and the beds of soft sandstone are much stained by oxide of iron	30
8.	Sandstones and shales, all soft and decomposing; some of the beds consist of fine-grained white sand. The general characters are the same as the previous beds. Thickness of this series, from No. 7 to the point of conglomerate, estimated to be 600 feet	600
9.	h. Conglomerate of gravel and pebbles forming the end of the point	25
10.	g. Decomposed silicious sandstone traversed by nearly horizontal seams of gypsum, and divided in the centre by a thin parting of shale	30
11.	f. Thin layers of sand or sand and clay, forming a kind of shale	1-1/4
12.	e. Decomposed sandstone, containing some hard masses, and traversed by seams of gypsum, partly fibrous	15
13.	d. Thin layers, finely stratified, like No. 11	1-1/4
14.	c. Soft decomposed sandstone	16
15.	b. Soft decomposed sandstone stained by waving lines of peroxide of iron, looking like the grain of wood	6
16.	a. A succession of beds of sandstone and thin partings of shale, all more or less discolored by oxide of iron, and traversed by seams of gypsum in nearly horizontal lines. Thickness about 150 feet	150

These strata are all conformable, and the combined thickness is a little over one thousand feet. The section commences at the low ground on the western side of the point near a quarry, and extends along the beach, under the face of the bluff, to a little cove, where the rocks are no longer exposed. The dip and general appearance of the strata are shown in the appended section; an enlarged view of a portion of the series is presented on the sheet of sections, Chapter XIII. This portion is that lying east of the conglomerate, and it is indicated in the descriptive section by letters which refer to the plate. It includes a thickness of about 175 feet.

The quarry was opened in the thickly-bedded sandstone, containing hard, rounded masses, which, when broken open, revealed a bluish nucleus similar in color to that of the rock at Yerba Buena and other localities near San Francisco. These hard masses seemed, at first, like concretions, but they probably originate in the same manner as the spheriods at Yerba Buena--by decomposition of angular blocks. When these nuclei are broken up, they are found to contain small dark-colored plates and fragments of an earthy character, but apparently the remains of lignites. In some of them, the carbonaceous material is quite apparent; and in the softer and more decayed parts of the rock, I found several specimens in which the organic structure of plants was well exhibited. The small black films in the sandstones of the bay of San Francisco, that have already been described, all lie in planes parallel with the stratification, and are similar to those in the hard masses of this locality; and I consider them, in part, as of vegetable origin. The thickness of this stratum, or series of layers, of compact sandstone, containing the hard nuclei, was not ascertained, and at this time I find it difficult to assert with certainty whether it forms a part of the series exposed along the beach. It is recorded as a part of the section in my note-book, but it is possible that the strata were only seen at the quarry, which is several rods distant from the exposed strata along the beach. I have, however, little doubt of the continuity of the strata, and that they are conformable. This is an important point; for the similarity of the lithological characters of the sandstone to that of San Francisco is, under the circumstances, good evidence of the synchronism of the strata at the two places. In other respects, the strata, as exposed in the section, have little resemblance to those around San Francisco. There is no doubt of the presence of the equivalents of the San Francisco sandstone in the vicinity of Benicia, for a similar rock is quarried in quantities and sent down to be used in the construction of buildings. Many of the stones, when dressed and rubbed down, show a central portion of a dark color identical in its characters with the rock from the quarries of the bay.

The thin seams of gypsum, which occur so abundantly in the strata, are not found in layers parallel with the beds; they are nearly horizontal or curved downwards, thus showing that they are the result of infiltration from above. Such is also the origin of the undulating layers of oxide of iron, which in many of the beds are so numerous and parallel, and at the same time so much bent and plicated, that it at first seems as if the bed was formed of compressed and crumpled shales. The uniform width of the stratum, and the parallelism with the adjoining strata, show, however, that the appearances have not been produced by violence. Fine examples of the deposition of oxide of iron in layers and curved lines were afterwards seen in the horizontal strata along Ocoya or Posé creek.

The fossils which were observed were very few and imperfect; with the exception of a shark's tooth, they are mere, broken casts, all the shells being removed, and the forms left in a matrix of sand and peroxide of iron. As near as can be determined, the genera *Trochus* and *Turritella* represents a species of *Lamna* allied to *L. Elegans*, Agass., which is found in the *Calcaire grossier* in the environs of Paris, and in the London clay at Sheppy. The description, by Professor Agassiz, of the new species, under the name of *L. Ornata*, will be found in Article I of the Appendix. These fossils are regarded as sufficient to establish the Tertiary age of the strata from which they were taken.

It will be seen from the observations recorded in the Itinerary that the strata of Benicia are prolonged towards the south and southeast, on the opposite side of the straits. A conglomerate and similar sandstone to that of Benicia was found south of Mount Diablo, at Livermore's Pass. The strata are believed to have a wide extent in that direction, and to form the greater part of the Contra Costa or Central range. The sandstone and shales of San Francisco have a similar extension towards the south, and it is probable that the stratified rocks at the New Almaden cinnabar mine are of the same age. These strata much resemble those of San Francisco, and are similarly associated with serpentine. A great body of sandstone is found still further south, flanking the San Juan mountains, on the side towards the valley of the Salinas, and I am inclined to include this in the same group. At the last-mentioned point it shows a great thickness, and crops out in great massive beds, many feet in thickness. The strata dip away from the axis of the range at an angle of about forty degrees.

The prolongation of this group of strata is not, however, confined to the southern ranges of the Coast Mountains. The rocks are found developed in the mountains north of the Golden Gate. The outcrops of Angel island, State's prison, and Marin island are on the north, and have already been noticed; but it is probable that the exposures of the beds are greater in the interior. The shore of Saucelito bay, on the west of these localities, is formed of sandstone, similar to that of the other localities in the vicinity, except in color. It is lighter, and more like specimens which have been obtained from Fort Ross, many miles north, on the shore of the Pacific. A block of sandstone, brought down from the vicinity of the coal-beds of Bellingham bay, closely resembles specimens from the quarries about San Francisco, not only in color, but in mineral characters; it is thus rendered probable that the formation is the same, although the evidence presented by mineralogical resemblances can never be regarded as satisfactory.

The wide development of the formation is, however, rendered certain from the evidences presented in the immediate vicinity of San Francisco. The great thickness which the series attains--probably over 2,000 or 3,000 feet--and the even grain of the thick beds of sandstone over large areas, together with the remarkable uniformity of the strata, indicate that they were formed in a wide-spread ocean or sea. The thick beds of shale attest the depth and comparative quiescence of the water. Independently of these considerations, the wide extent of the formation has been made known by observation; it forms a greater part of the hills and mountains around the bay, and, so far as explored, a considerable part of the mass of the Coast Mountains. It is believed to be the most extensive and highly developed sedimentary formation of the California coast, and may appropriately be known as the *San Francisco* or *California sandstone*.

It is greatly to be regretted that, as yet, the evidences of the age of this formation are very few and unsatisfactory. The rocks near San Francisco, so far as I examined them, are singularly devoid of fossils, not a single shell having been observed in them. Masses of similar sandstone containing fossils are, however, thrown up by the surf upon the beach south of Point Lobos, and there is little reason to doubt that they are broken from a submerged outcrop of the formation. The rock, in color and grain, is very similar to the adjoining sandstone of the Point, but it is not quite so hard. It at first appeared possible that these masses were from strata formed out of the comminuted debris of the sandstone, and thus more modern or of recent origin. I am now, however, of the opinion that they are broken from the solid ledges of the San Francisco sandstone, under water, and that the fossils may safely be received in evidence of the age of the formation. The fossils are chiefly *Scutellae*, and represent the period of the Tertiary. They are firmly imbedded in the rock, and lie thickly together, three or more being often found within the thickness of an inch. It was found to be impossible to cleave these masses of sandstone so as to expose fresh surfaces of the fossils. The rock is calcareous and tough, and the lime of the Scutellae has so completely crystallized that the fragments cleave into rhombohedrons, like calc spar. The fossils appear to have determined the form of the fragments of rock, for the latter are generally discoid, and faced on each side by the worn surfaces of the Scutellae. The edges of the fossils also appear on the sides of the specimens, and it is evident that the lime has been less easily abraded by the surf than the granular sandstone. The structure of the fossil is very beautifully shown in several of the specimens, and a figure of one of them is given on Plate IV, fig. 30. I propose for this species the name *Scutella interlineata*, and append a description[3].

These fossils occur in considerable numbers along the beach, and it is probable that a stratum of these interesting relics may be found, in place, along the shore further south.

The block of sandstone from Bellingham bay contains two large Pectens of the age of the Tertiary, and this furnishes additional evidence of the Tertiary age of the San Francisco sandstone. The fossils of Benicia--the *Trochus*, *Turritella*, and shard's tooth, *Lamna ornata*--point to the same conclusion, the only doubt being as to the connexion of the strata. The fossiliferous stratum may e much higher in the series than the rocks about San Francisco. It is not impossible that a portion of the Upper Cretaceous is represented, although there is nothing to indicate it in the lithological characters o the strata. The occurrence of Cretaceous strata in the northern part of the State[4] renders this more probable.[5]

The formation throughout its extent, so far as explored, has been uplifted and thrown into wave-like flexures. A body of the strata in a horizontal position is not known. The dips are generally at angles of from twenty to sixty degrees, and in such direction as to indicate the existence of a series of anticlinals and synclinals. The trends of the strata conform so nearly with the direction of all the principal ridges and headlands as to show that the flexures of the rocks have determined the relief of the region. This direction is nearly northwest and southeast, and is clearly shown on the maps of the Bay by the parallel lines of coast. The promontory extending northwest from Angel Island finds its continuation in this island, and beyond it, in the island of Yerba Buena, indicating the presence of a

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[3]SCUTELLA INTERLINEATA. The specimens are imperfect, but the ambulacral star is apparently central, the petals equal, and closed, or nearly so, at their extremities. The tubercles being mostly worn off in the specimens before me, there are two rows of irregularly pentagonal plates in each inter-ambulacral space, which gradually increase in size toward the margin. A small portion of the surface upon which tubercles still remain shows these to have been sporadic, very numerous and crowded. The ambulacral petals are transversely lineated with impressed lines across their entire width, the thread-like lines connecting the pores of the two inner rows, as well as those of the inner and outer ones. The position of the anus could not be made out; it is probably infra-marginal. The ambulacral furrows of the inferior surface are apparently but little ramified. Diameter of the largest specimen 4-1/10 inches; height at the middle 0.48 inch. This specimen was presented to me by Dr. C. F. Winslow, formerly of San Francisco.

[4]Discovered and announced by Dr. J. B. Trask.

[5]A short paper on the lithological characters and probable age of the San Francisco sandstone was read by the author, with the permission of the War Department, at the meeting of the American Association for the Advancement of Science Providence, 1855. See Proceedings, 9th meeting.

long anticlinal axis. This is rendered more probable by the dip of the strata at the island, and the apparently reverse dip of the beds on the opposite shore at San Francisco. It is probable that the channel between the city and Yerba Buena occupies a synclinal depression. It was not possible to follow out the flexures of the strata from North Point westward to the serpentine ridge of Fort Point, but the dips that were exposed were sufficient to warrant the conclusion that the strata were much flexed and folded between the two places, and indicated that the two principal hills of the city were formed by the summits of flexures. The folded condition of the strata is represented in the little section on page 155, drawn to show the relations of the rocks between the city and the shore of the Pacific. The curved lines show the probable bending of the great mass of the strata.

a, a, a, San Francisco sandstone; *b,* Metamorphosed sandstone; *s,* Serpentine of Fort Point.

Indications of an anticlinal fold of the strata were apparent at Benicia. The strata exposed on the opposite shore of the little bay, or cove, which terminated the section on the east, appeared to dip in a direction opposite to the others. Such foldings were, however, more distinct further south, in the hills west of Mount Diablo.

The most distinct contortions and highly-inclined positions are, however, shown by a class of rocks which have not yet been mentioned. They are, to all appearance, a metamorphosed or changed portion of the sandstone formation. They are found outcropping near the Presidio, south of the Mission, and form the highest elevations of the north shore of the Golden Gate. Lime Point is entirely formed of these rocks, and it is probable that they compose nearly the whole peninsula from Point Cavallos to Point Bonita. At Lime Point they exhibit regular stratification, with the planes nearly vertical, or inclining westward. Portions of the strata are very finely stratified, the layers being not over half an inch thick, and yet they are well defined and apparently very hard. The whole series is enormously thick, and the principal beds are seen to form the crests or culminating points of the principal ridges, and to outcrop in long lines on the surface. Several of the small islands, or large rocks under Lime Point, consist entirely of these metamorphic sediments, and rise above the waves with nearly vertical sides, like steeples. In these islets, and on Lime Point, there are beautiful flexures and folds of the strata, some of them of considerable extent, and others are local, showing many bends and short angles within the space of a square yard, resembling the compressed and crumpled leaves of a book in the number of the thin layers, and their conformity through all the bends. One of the most interesting displays of these plications is found in the sides of Needle rock, a high column rising from the waves near the base of the Point.

The lithological characters of these strata are very interesting. They are hard, flint-like, and jaspery, and occur of various colors. The most common color is a dark reddish-brown, or a chocolate color, but this is often intermixed with yellow and green. Indeed, some of the fragments are beautifully spotted and banded with different colors, and form good specimens of ribbon-jasper, or prase. Quartz, in thin irregular veins, is a common accompaniment of the rock, and traverses it in all directions without any regularity in the trends of the fissures. It appears, in many cases, to form a complete coating around fragments of the rock, so as to isolate them from the adjoining portions. The flat surface of one of the specimens, when viewed at a short distance, appears as if covered by a tangled mass of white cord. It is probable that these flinty strata are similar to those seen by Professor Dana, and described in his report as *prasoid* rocks.[6]

Similar rocks are found along the road south of San Francisco towards San José, and at New Almaden. At the latter place the color is much lighter, and the crooked quartz veins are absent. They are, however, very hard, and show the original alternation of shales and sandstone. In the bank, just behind the smelting works of the quicksilver mine, a slight exposure of the strata shows a very interesting flexure of the beds:

FLEXURE OF THE METAMORPHIC STRATA--NEW ALMADEN

Although the direct transition from the unaltered sandstone and shale to these metamorphic strata has not been observed, there is little doubt they are of the same formation, and that the jaspery condition is due to igneous agencies. The chemical composition of the sandstone and the shales is favorable to such a result. It is regretted that analyses of each, and of the metamorphosed portions cannot be presented.

ERUPTED ROCKS--SERPENTINE

The extensive metamorphism, and the uplifted condition of all the strata, indicate the proximity of igneous rocks. They are not exposed, however, in the vicinity of San Francisco to an extent that the effects which have been produced would lead us to expect. The nearest exposure of the granitic rocks, which is known, is at the Farallones islands, twenty miles out at sea, off the entrance to the Golden Gate, and at Punta de los Reyes, about the same distance up the coast. Granite may, however, occur in the mountains, south of the city, at a nearer point, but this is very doubtful. It may also be found at Point Bonita. It probably forms the principal ridge west of New Almaden, and there is reason to believe that the sandstones and shales and the metamorphosed rocks rest against it. Granite is found in close proximity with the thick strata at San Juan, but the relations of the rocks could not be readily determined. Trappean intrusions and serpentine occur at New Almaden.

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[6]Report on the Geology of the United States Exploring Expedition under the command of Lieutenant Charles Wilkes, U. S. N.

The metamorphosed strata of Lime Point appear to be underlaid on their eastern margin by a dyke, or intrusion of a hard, compact trappean rock, which does not rise far above the tide-level; its presence might, therefore, be easily overlooked. The line of junction between the two formations is also indistinct, but may be traced around the base of the cliff, at a uniform elevation above the water, for a long distance. The position of this rock is indicated upon the map. It appears to have resisted the action of the surf and currents of the channel so well, that the degradation and undermining of the cliff has nearly ceased, it having continued until the softer metamorphic strata were left secure beyond the reach of the waves. The proximity and direct contact of this rock of igneous origin, with a portion of the jaspery strata, indicate that it has caused their metamorphosis. It is, however, difficult to conceive that such extended effects were produced by this rock, which has such a limited exposure at the surface, unless we conclude that it has a broad subterranean extension.

The formation next in importance to the sandstone, in point of extent and development in the vicinity of San Francisco, is the serpentine, or serpentinoid rock, of Fort Point. It forms a high and prominent ridge about midway between the short of the Pacific and the Bay of San Francisco, and extends in a northwest and southeast direction, abutting upon the Golden Gatė and forming Fort Point. The width of the ridge is between one and two miles, but its extension southward is not accurately known. It is partly obscured in that direction by sand, but forms a knob at the Orphan Asylum, near the Mission. It is bounded on both sides by the San Francisco sandstone, and its end, at the Golden Gate, forms a bold bluff facing the Pacific. Fort Point is its extreme northern point, and formerly presented a high bluff with a flat table-like summit, upon which the Mexican fort was built.[7] This has recently been cut away to prepare for the erection of new fortifications. This cutting down of such a large mass of the rock exposed a broad surface of the interior, and permits its structure to be conveniently studied. The rock, in its appearance, is unlike the serpentine of Hoboken, New Jersey, and Staten Island, New York; nor is it like the serpentine of Milford and New Haven, Connecticut; being of a darker color, harder, and filled with distinct crystals of diallage, from one-eighth to one-quarter and half an inch in length. These present brilliant cleavage surfaces when a mass of the rock is broken up. The fracture of some of the dark portions of the rock is sub-conchoidal, the resulting surfaces being smooth, and, in this respect, differing from the serpentines mentioned. Another, and a prominent peculiarity of the rock is its globular character, it being made up of nearly spherical, boulder-like masses, included in a shaly or slaty portion that readily splits up and falls into fragments on exposure to the air. These slaty portions present the common smoothed or furrowed appearance sometimes seen on the surfaces of both igneous and sedimentary rocks where they have been rubbed together, under great pressure, as in the walls of mineral veins. It fills all the space between the masses, and gives them the appearance of having been coated with a soft plastic cement. The color of these globular masses is dark olive-green; they are very hard and compact, and not only contain the crystals of diallage, but in some instances, are traversed in every direction by thin veins of amianthus or chrysotile, with the fibres transverse to the walls. These seams are generally very thin, and, by intersecting, divide the rock into masses not larger than a nut, causing it to exhibit a curious reticulated appearance where the surface is weathered. A similar character was observed in the serpentine at New Almaden.

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[7]According to the notes of Lieutenant Belcher, serpentine is found on the north shore of the Golden Gate, between Point Bonita and Point Diavolo.--Zoology, &c., of Captain Beechey's Voyage.

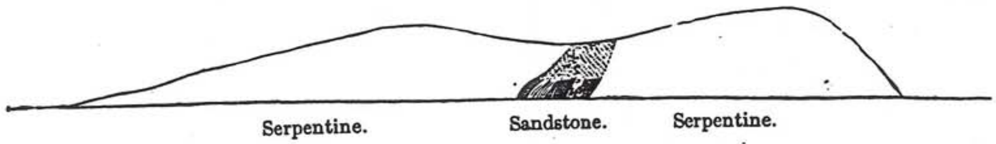
At the Orphan Asylum, the compact portions of the rock, which break with a conchoidal fracture, are also traversed by thin seams or bands of a green mineral, non-crystalline, and about as hard as serpentine. It is delicately shaded in lines parallel with the walls, looking somewhat like a narrow green ribbon, of light color. With the exception of some small nodules, of a white powder, probably arragonite, these were the only minerals observed in connexion with this rock. The slaty portions were light-green in color, and had a greasy feel, like talc, rendering the surface of the rocks at Fort Point very slippery and difficult to climb.

The hard and dark-colored portions of the rock were used in the construction of the Orphan Asylum; but there is nothing to recommend it as a building stone, except, in this instance, its presence upon the spot. It is not well calculated to resist the action of the weather.

It is very probable that the higher portions of Mount Diablo are formed of a similar serpentine. A large quantity of rock was once quarried there and taken away, under the supposition that it contained gold. A fragment of this was obtained; it proves to be a mass of diallage or bronzite in rough crystals, with the usual metalloidal lustre. It closely resembles the bronzite of Bacher Mount, Styria, which occurs with serpentine.

The ridge of compact serpentinoid rock at Fort Point appears to be eruptive, and to be more recent than the sandstone of the bay of San Francisco. It appears probable, also, that the strata of sandstone and shale were much uplifted or disturbed by its intrusion, although the great flexures of the strata, and perhaps the principal metamorphoses, were, in all probability, attendant upon the formation of a granitic axis of considerable extent, but which, in the vicinity of San Francisco and the Golden Gate, is submerged in the waters of the Pacific. That the strata were disturbed by the serpentine, is indicated by the relative positions of the rocks, as seen in the exposures along the shore of the Golden Gate from San Francisco to Point Lobos. These positions are shown on the little section, page 155, which is intended to represent the succession of the formations along the line A, B, upon the map, and the *probable* flexures of the strata. The sandstone is found upon both sides of the serpentine, and appears to rest upon it on the east, and to underlie it on the west. An outcrop of metamorphosed rock is found near the line of junction on the east side, but on the shore near the beach it is not visible. At this point, however, we find a body of sandstone strata, intercalated or imbedded in the serpentine, as represented in the annexed figure.

SANDSTONE AND SHALES IMBEDDED IN SERPENTINE



This mass of strata is between two and three hundred feet thick; the beds dip eastward at an angle of about 75°. The series consists principally of slates and shales, but there are several beds of compact sandstone from two to six feet thick. The relative position of the strata and the serpentine indicates that at the time of its inruption it probably followed the planes of stratification for the greater part of its course. These beds of sandstone and shale are much harder and more compact than the strata of the same formation at a distance from the intrusive rock; but the color and mineral characters are well preserved, and they do not show any signs of change from igneous action.

The line of contact of the serpentine with the outlying beds of sandstone on the west side of the point was not seen, but the character of the surface on that side indicates that the strata dip under the serpentine. The valley through which the little brook, leading from the lake, flows is coincident with the line of junction between the two formations.

Serpentine is found to outcrop, in connexion with sandstone strata, similar to those of San Francisco, in the hills between the southern end of Tomales Bay and the Mission of San Rafael. It is also reported to be an abundant rock throughout the Coast Mountains. Wherever it came under my observation it presented the aspect of an intrusive rock, and I have so regarded it. There is little doubt that the outcrops have undergone great changes, even to a great depth, by the action of percolating water and the atmosphere.

ALLUVIAL AND DRIFT DEPOSITS

Around the shores of the Mission Bay, and near the road leading from the city to the Mission, there are extensive flats of swampy land of alluvial origin. The surface consists of a very thick turf, which, when cut out and dried in the sun, is suitable for fuel. This is underlaid by thick strata of clay, which have been penetrated to the depth of 50 feet or more in several places by boring for Artesian wells. This clay has a dark bluish black color, is very fine, and when first removed exhales a putrescent odor, probably due to the decomposition of leaves and vegetation, which are sometimes found in the borings. Between Fort Point and Point San José there is a narrow, swampy tract, but little elevated above tidewater, which appears to be like that near the Mission, having also a thick layer of turf. This tract is separated from the water of the channel by a narrow dyke, or beach, formed of sand and rounded stones. This has evidently been thrown up by the waves, and piled upon the alluvium. This can be easily seen at low tide, for on the outer side of the sand-beach, and just below the surface of the water at low tide, there is a shore of turf, and an abrupt descent from its margin to deep water. Large masses of the turf are dislodged and thrown up by the waves upon the overlying sand. It is not easy to account for the formation of this peat swamp, which certainly appears to have been much more extensive, and to have required a permanent barrier on its seaward side, as one of the conditions of its formation. A great change in the position of the sea relatively to the land has undoubtedly taken place, for the present action of the sea is directly adverse to the deposition of alluvium, or the formation of a marsh. It is encroaching rapidly upon the margin of this deposit of fine alluvial clay, and it is evident that a formerly existing barrier to the action of the sea has been broken away. What the nature of this barrier was it is difficult to decide. It may not have been a wall-like barrier, like a bar or reef, but the water may have been shoal, and free from swift currents, so that a gently sloping beach of mud, or mud-flats, were formed.

The point of serpentine rock (Fort Point) projects out into the channel, and acts as a natural breakwater to the shore immediately east of it, thus preventing the entire destruction of the alluvial tract. This point is fully exposed to the heavy surf of the Pacific and the violent currents of the channel. It has been much broken down and abraded under these continued influences, consequently the channel has become widened, and the currents have acted with more and more force upon the adjoining shores. The powerful action of the currents and surf are well exhibited to the leeward of the point, where wrecks of vessels lie partly buried in accumulations of sand, pebbles, and even large rocks. The long government wharf, which has been constructed in the cove east of the point, consists of large cribs, filled with rock, placed at intervals, so that the currents could flow between them. These cribs have so modified the action of the currents flowing inland that an immense deposit of sand and boulders is in process of formation on the lee side. The cribs that were constructed beyond the beach, and that were formerly surrounded with water, are now half imbedded in sand. It is probable, therefore, that when the channel was much narrower than now, a sea-wall or beach was formed, leaving a lagoon on the inner side, which became gradually filled up by the wash from the hills. The gradual widening of the channel permitted the sea to encroach and wear down the wall of sand and shingle, throwing a portion of it further inland, until at length it was completely underlaid by the alluvium.

A wide margin of recent or alluvial deposits is found on the shores of the bay opposite to San Francisco. It is most extensive at the mouth of San Antonio Creek. Further south, at the lower end of the bay, there are broad, alluvial meadows, or marshes, and an extensive tract is left bare by the tides. The extension of this alluvian inland, at a higher level, forms the broad and fertile plains of San José. These deposits are bordered by the more dry and sloping plains of coarser soil, formed by the debris and wash from the hills.

On the hills about San Francisco there is a slight formation of drift, either alluvial or composed only of the wash from the hills. It does not show upon the surface in the form of either transported boulders or gravel, but is limited in extent, and occupies the lower parts of the principal depressions. In excavating a tunnel from the small lake on the west slope of the serpentine ridge, a portion of this formation was cut through, and at its junction with the serpentine rock, about 80 feet below the surface, fragments of wood were taken out. They were imbedded in black clay, like sea mud, and were much compressed and flattened out, and partially converted to lignite. Bones were also found in this clay, 18 feet below the surface. One of them appeared to be the rib of an animal not larger than a deer. A fragment of a large bone was also taken from an excavation at the foot of Telegraph Hill. It is about eight inches long and four in diameter, and is nearly triangular in its cross-section.[8]

In boring through the earth outside of the old water-line of the city, at the site of the new custom-house, in order to ascertain the nature of the foundation, several beds of sand, clay, and gravel were found to succeed in regular order for a depth of 60 or 80 feet. This locality is at, or below, tide level, and we thus find that the sandstone strata in the channel are overlaid by drift or detrital deposits of considerable depth. It is between these accumulations of drift, or alluvium, and the rocks, that sheets of water or water-bearing strata are found, and are reached by Artesian borings in various parts of the city.

The sandstone and shales of the hills upon which the city is built are overlaid in many places by a covering of soil, which appears to have been derived from the decomposition of the strata. This soil is found to be a good material for making bricks, and it is extensively used in that manufacture. This fact shows that the rock contains a large per centage of alumina, and the presence of oxide of iron is not only shown by the rusted color of the weathered rock, but by the deep red color of the burned bricks. Wherever this soil has been cultivated it has been found to yield good returns.

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[8]These bones are in the possession of Dr. C. F. Winslow, formerly of San Francisco.

SAND-DUNES

On the Pacific side of the San Francisco peninsula there is an extensive sand-beach, reaching for several miles north and south, and a long distance inland. A wide area is thus covered by loose, dry, sea sand, and it has the aspect and character of a desert. This sand is moved about by the wind and is constantly progressing inland, being thrown into wave-like hills, which move forward and bury shrubs and trees that lie in their path. The extensive formation of blown sand within the city limits has undoubtedly been accumulated by the action of the sea winds upon the sand of the beach, it having been transported from one side of the peninsula to the other.

The sand-hills formerly occupied a wide area in Happy Valley, rising in constant succession, one beyond the other, to various heights, from 20 to 60 feet or more, rendering the region almost impassable for vehicles. Most of these hills are now leveled, and houses have taken their place. Remnants of them may, however, be found along the newly opened streets, where favorable opportunities are presented for the examination of their internal structure. Many interesting exposures of the same character are visible in other parts of the city; and in all the localities, the sections present well-defined lines of stratification, not horizontal, but inclined in various directions, corresponding with the direction of the wind at the time of the deposition of the sand. These lines are very numerous and fine, and appear to be formed partly by thin layers of black iron-sand, which, being heavier than the rest, is not so readily moved; it is frequently seen forming the outer layer of a bank that has been swept by the wind. Blown sand is also found in long drifts and dunes on Point San José. It is in a state of constant progression, passing over the point, under the influence of the wind, and falling into the water on the opposite side. Some large drifts are found at that place, and the grains of sand are unusually coarse. The surface of one of these drifts, when the wind is blowing hard, presents a curious appearance; the sand sweeps along in a constant stream, which does not rise more than one or two feet from the surface, and when the light strikes upon it, it produces a peculiar halo, enveloping the drift. The same peculiar ripple-marks that are so well shown in the beds of streams and on the sand-hills of the Desert, are developed here in the most beautiful manner; they are seen on the broad, rounded surfaces of the hills in all directions.

Most of the hills in the city and its vicinity, where they were partly sheltered from the wind, are, or were, covered with a thick growth of dwarf trees and shrubs, (*chamisal,*) which prevented the wind from acting upon their surfaces and removing the sand.

It is impossible to determine, with any accuracy, the ages that must have elapsed since this sand began to accumulate in Happy Valley. The progress of such hills is not uniform and constant, for, under certain circumstances, they remain stationary for long periods. Whenever the vegetation is removed, or a cutting is made, and the wind is allowed to act upon the surface, or to strike a hill in a new direction, the motion of the sand is rapid, and a large hill is soon carried away and piled up in a protected place, where the sand remains, secure from further violent action.

The Pacific coast presents many favorable opportunities for studying the phenomena of drifting sand and the formation of dunes. Perhaps no point is more favorable than that partly described--the sand-beach, and dunes of the San Francisco peninsula. The sand of the beach is constantly acted on by the wind, and is thrown into hillocks of various forms and magnitude. The observer may, in an hour's time from the city of San Francisco, place himself in the midst of this desert-like expanse, and, having viewed the production of sand-hills and drifts, he may, as he returns, study their internal structure and curvilinear stratification in the numerous sections of the hills along the streets.

ARTESIAN WELLS

Artesian borings for water in the city of San Francisco have become so numerous within three years, that it is almost impossible to ascertain their number and localities. Water appears to be found in all parts of the city around the hills, and generally at a depth of not more than one hundred and fifty feet; but the depth to which the borings extend varies with the locality. In Happy Valley, and towards the Mission, the borings are generally successful at a depth of fifty to seventy-five feet, the water rising to the surface. In that part of the city north of California street, the depth of the wells increases; one at the corner of California and Montgomery streets being eighty-five feet deep, and at Montgomery block one hundred and sixty feet. Another between Clay and Merchant streets, is one hundred and forty-two feet. The depth to which the borings are carried, increases from the base of the hills towards the bay, and many of the wells are bored down through the salt water of the bay.

None of these Artesian borings have been carried downwards into the sandstone strata; they only pierce the superficial drift or alluvium. Several veins or strata of water are generally found; and when the borings first commenced, an overflow was generally obtained.

The formations that are successively passed in boring, are sands and clays, and the water is found to rise from the sandy strata alone. Towards the Mission, a very heavy and thick formation of blue clay is met with, containing roots and leaves partly decomposed, and giving off a disagreeable odor. This clay is over fifty feet thick, and water is found below it. The configuration of the underlying strata of sandstone and shale is highly favorable to the success of Artesian borings in the overlying drift or detrital accumulations. It is possible that water could also be obtained from the slaty layers between the compact sandstone strata; but the drilling of the rock would be attended with great expense, and it is questionable whether the formation is not so compact and dense as to prevent rapid infiltration, or a subterranean flow of water.

Some of the wells in the city are eighteen inches in diameter, and cased with cast-iron pipes; others have a simple and temporary lining of sheet-iron like a stove-pipe. The cost of the wells, complete, with the ordinary lining, is about four dollars per foot.[9]

At the villages of Santa Clara and San José, Artesian borings have been entirely successful. At San José, during the past winter, (1853,) the earth was bored to a depth of seventy-eight feet, through the fine alluvial clay of that valley. At that depth, the auger suddenly dropped into a stratum of water and sand, and, on being withdrawn, the water followed it to the surface and overflowed freely. The column has since been raised several feet by the addition of pipes, and an elevation sufficient to irrigate the surrounding lands is attained. No diminution in the volume of water discharged has yet been observed; but several other wells are about being sunk, which will perhaps reduce the quantity.

Several other wells have been constructed with satisfactory results. One of the borings was remarkably successful; at the depth of about seventy-five feet, a rush of water to the surface took place, and has continued to overflow without diminution. Such is the pressure and force with which

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[9] I am indebted for many of these facts to Mr. Hopkins, who has been engaged in boring wells in San Francisco for two years past. (February, 1854.)

this water rises, that it has been found difficult to control it and prevent it from overflowing the adjoining grounds. Another is reported to have been sunk to the depth of two hundred and twenty-five feet, and to yield seventy-five gallons a minute. The drainage from the different wells forms a brook large enough to drive a saw-mill. The success attending the Artesian borings in that alluvial valley is so general, and the advantages obtained are so great, that they are becoming very numerous. The Artesian wells can also be constructed at an expense that of ordinary wells.