

San Francisco Bay Area Earthquakes ¹

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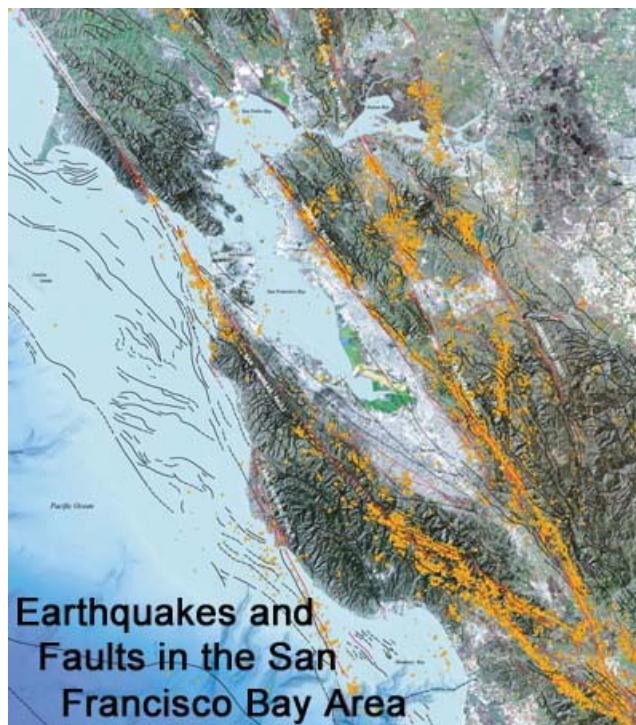
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October, 2006



Introduction: This activity is designed to provide a better understanding of earthquake activity, the locations of faults, and earthquake hazards in the San Francisco bay area. The activity utilizes a satellite image of the bay area on which earthquake epicenters from 1970 - 2003 have been plotted (Sleeter and others, 2004). The map is titled *Earthquakes and Faults in the San Francisco Bay Area (1970 - 2003)* and can be found at: <http://pubs.usgs.gov/sim/2004/2848/>. To order copies of the map (Product Number 116286, Part Number SIM-2848, Scientific Investigations Maps series, \$7 each; \$5 shipping and handling for entire order), call 1-888-ASK-USGS or order online at: <http://store.usgs.gov/>. A reduced-size version of the map is provided in Figure 1. We provide a digital image of the map and an accompanying topographic base map (Figure 2) so that the activity and associated materials are more readily available. The activity can be performed with the reduced-size map (Figure 1, printed in color; can be printed or photocopied enlarged to 11 x 17 inch paper size). However, the landscape features and the epicentral patterns are more visible on the 84 x 117 cm (33" x 46") published map.

* MS Word and PDF versions of this document are located at:
<http://web.ics.purdue.edu/~braile/edumod/bayarea/bayareaNew.doc>, and
<http://web.ics.purdue.edu/~braile/edumod/bayarea/bayareaNew.pdf>.



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Last modified November 19, 2006

The web page for this document is:

<http://web.ics.purdue.edu/~braile/edumod/bayarea/bayareaNew.htm>

Partial funding for this development provided by the National Science Foundation.

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A previous version of this activity using a 1990 USGS color poster (false-color satellite image and epicenters, <http://wrgis.wr.usgs.gov/docs/gump/zulanger/bayarea/landsat.html>) is available at: <http://web.ics.purdue.edu/~braile/edumod/bayarea/bayarea.htm>. A PowerPoint presentation (including images of the map, photos and images of the San Andreas fault zone, and information on the 1906 San Francisco and 1989 Loma Prieta earthquakes) related to the new (2004 map) activity can be found at: <http://web.ics.purdue.edu/~braile/edumod/bayarea/BayAreaEQs.ppt>.

Several attractive and useful digital satellite images of the San Francisco Bay area are available at: <http://www.sfbayquakes.org/>. The images are available for download and printing and can be displayed with or without faults plotted. An example of one of these images is shown in Figure 3.

Additional information on San Francisco Bay area earthquake activity, hazards and earthquake forecasts can be obtained from USGS Fact Sheets (listed below in reference section; also see <http://water.usgs.gov/wid/indexlist.html> for an index of available fact sheets). *Putting Down Roots in Earthquake Country* (San Francisco Bay area version, USGS, 2005) has additional information about earthquakes and earthquake hazards in the San Francisco Bay area. The recent article by Zoback (2006) is also an excellent summary of earthquake activity in the bay area and the 1906 event.

Satellite Image and Earthquake Map: The *Earthquakes and Faults in the San Francisco Bay Area (1970 - 2003)* map (Sleeter and others, USGS, 2004) is shown in Figure 1. The base map is a digital satellite image (Landsat 7 Enhanced Thematic Mapper Plus images) covering an area from about 36.2° to 39° North and about 120.9° to 123.7° West. The original, full-size map is plotted at a scale of 1:300,000. Epicenters of earthquakes that occurred in the area from 1970 to 2003 are also shown. Faults are shown by bold lines. Faults that are interpreted to have been active in the last 700,000 years are indicated by red lines. Information on earthquakes of magnitude 5.0 or greater from 1970 - 2003 is listed a Table. Epicenters for the 22 earthquakes in the Table are numbered on the map. A topographic map of a portion of the area shown in the satellite image is provided in Figure 2 for geographic reference. An additional simplified map of the geography and major faults of the area is shown in Figure 4.

Other Maps: A geologic map of the San Francisco Bay area (Figure 5; Graymer and others, 2006), a map of active faults in the San Francisco Bay area (Figure 6; Graymer and others, 2006), and geophysical maps (<http://geophysics.wr.usgs.gov/gump/zulanger/bayarea/bayarea.html>) including a Teacher's Guide are also available. The geologic and fault maps of the San Francisco Bay area, including interactive versions and files for download, can be found at <http://geomaps.wr.usgs.gov/sfgeo/index.html>. To order copies of the geologic map (Product Number 206043, Part Number SIM-2918, Scientific Investigations Maps series, \$7 each; \$5 shipping and handling for entire order), call 1-888-ASK-USGS or order online at: <http://store.usgs.gov/>. To order copies of the quaternary-active faults map (Product Number 206042, Part Number SIM-2919, Scientific Investigations Maps series, \$7 each; \$5 shipping and handling for entire order), call 1-888-ASK-USGS or order online at: <http://store.usgs.gov/>.

Additional information and teacher resources on the San Francisco Bay area, earthquakes, the San Andreas fault and the 1906 San Francisco earthquake can be found at: <http://1906centennial.org/teachers/resources/>. Very effective ground motion animations for San Francisco Bay area earthquakes (1906 San Francisco and 1989 Loma Prieta events) area available for viewing and download at: <http://earthquake.usgs.gov/regional/nca/1906/simulations/>.

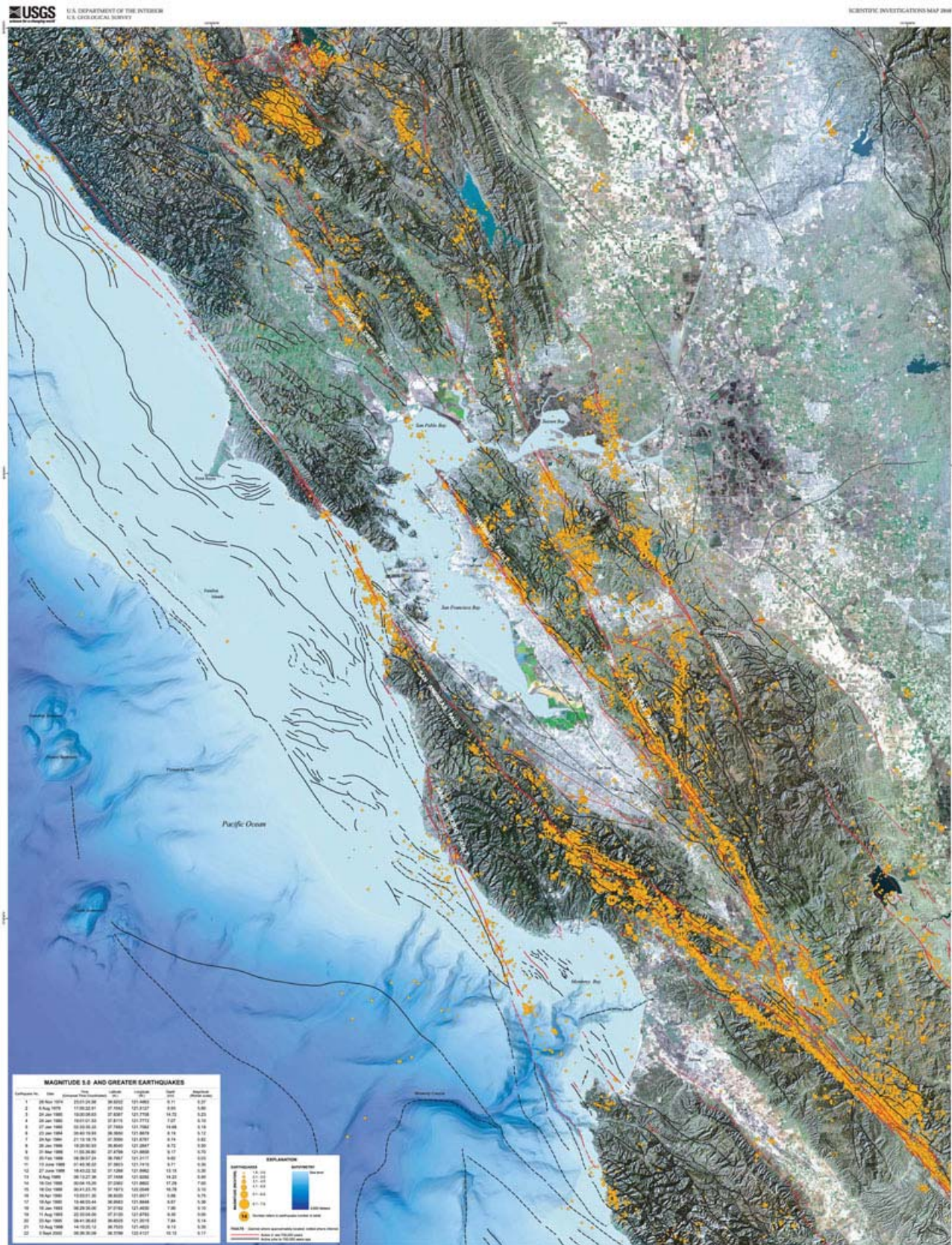


Figure 1. Earthquakes and Faults in the San Francisco Bay Area (1970 - 2003) map (USGS, 2004). The map can be viewed online or downloaded from: <http://pubs.usgs.gov/sim/2004/2848/>. A full size pdf file and smaller jpg files are available.



Figure 2. Topographic map of a portion of the area shown by the earthquake and fault map in Figure 1.

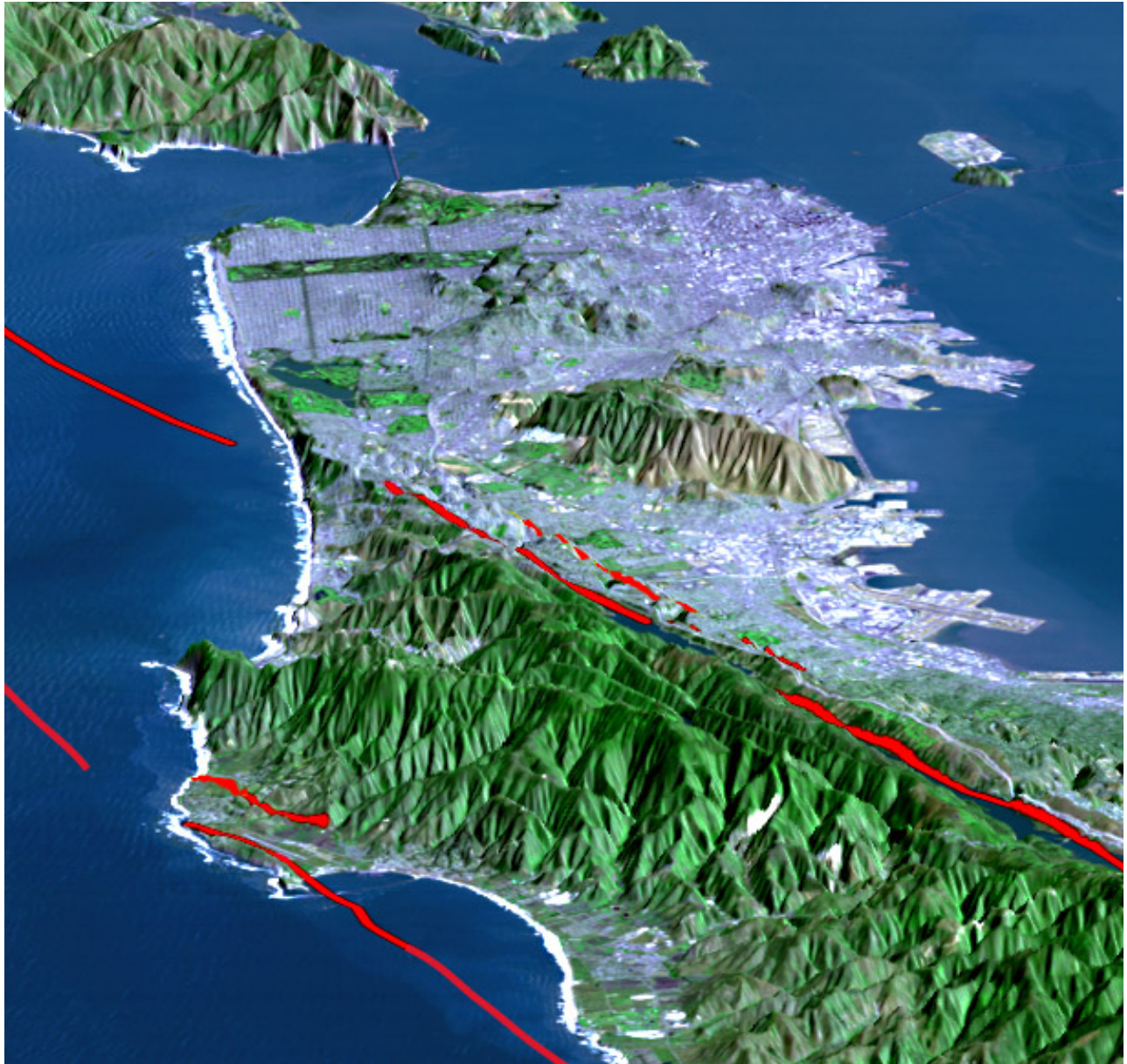


Figure 3. Perspective view digital satellite image of the San Francisco area with young faults (active in the past 700, 000 years) plotted in red. This image and additional satellite images for the San Francisco Bay area are available at: <http://www.sfbayquakes.org/>.

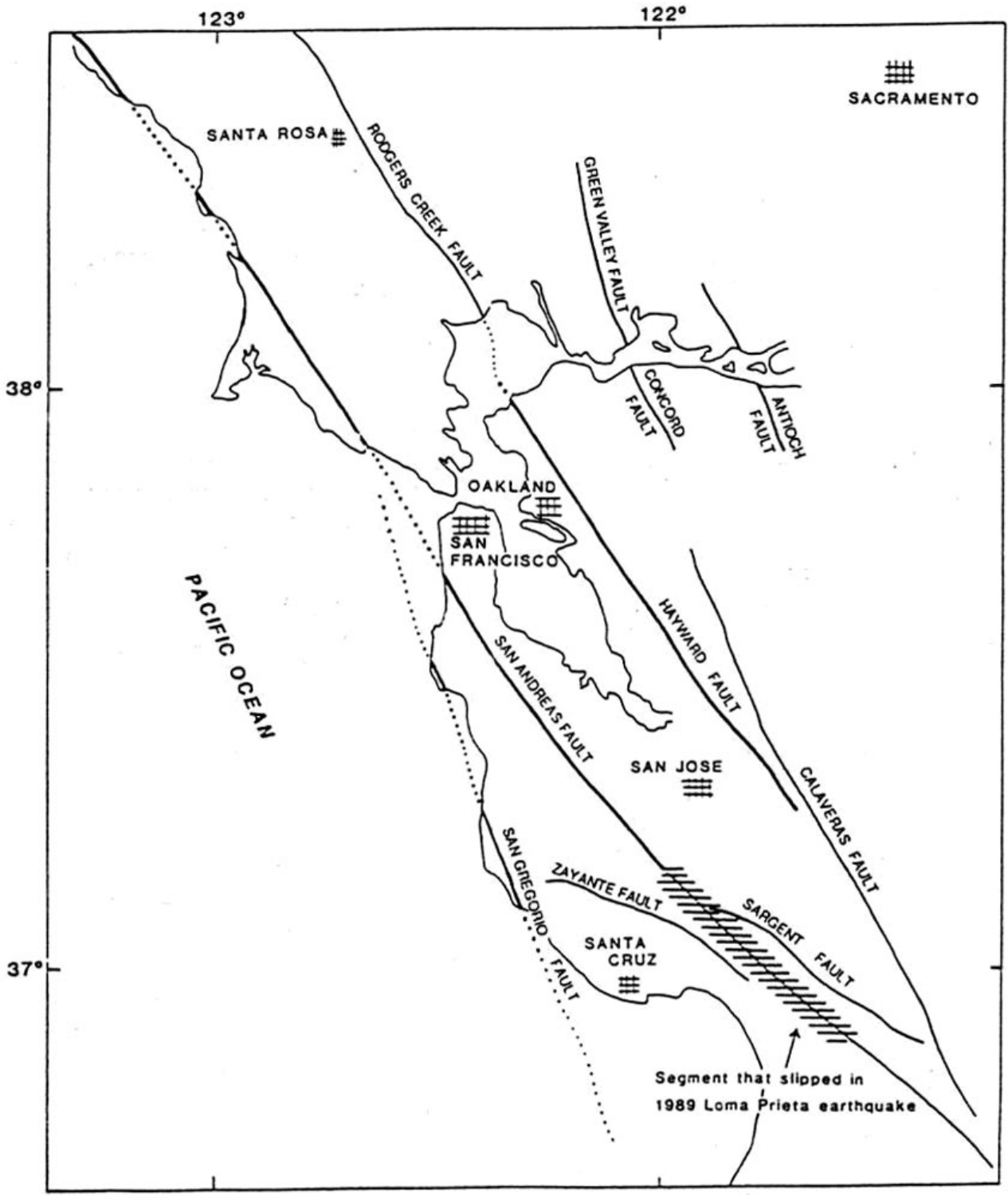


Figure 4. Major faults in the San Francisco Bay area. Map modified from Plafker, George and Galloway, John P., Editors, 1989, *Lessons Learned from the Loma Prieta, California, Earthquake of October 17, 1989*; U.S. Geological Survey Circular 1045, 48 p.

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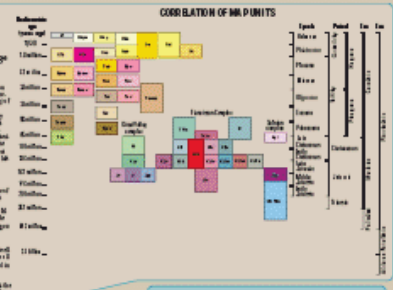
U.S. GEOLOGICAL SURVEY CALIFORNIA DISTRICT OFFICE

DIAGNOSTIC PHYSICIAN CERTIFICATION

What is a geologic map? A geologic map shows the distribution of geologic materials and geologic structures that are visible at the Earth's surface. Geologic maps illustrate the distribution of geologic materials and geologic structures that are visible at the Earth's surface. They are used to determine the geologic history of an area and to assess the potential for natural hazards.

Why make a geologic map? A geologic map is made to show the distribution of geologic materials and geologic structures that are visible at the Earth's surface. It is used to determine the geologic history of an area and to assess the potential for natural hazards. Geologic maps are also used to plan and manage land use and to assess the potential for natural hazards.

Geologic time and the age of rocks Geologic time is the time scale used to describe the Earth's history. It is divided into eons, eras, periods, and epochs. The age of rocks is determined by the geologic time scale. Geologic maps use the geologic time scale to show the distribution of geologic materials and geologic structures that are visible at the Earth's surface.



Geologic materials Geologic materials are the rocks and sediments that make up the Earth's crust. They are formed by various geological processes, including igneous, sedimentary, and metamorphic processes. Geologic maps show the distribution of these materials and the structures that have formed in them.

Rocks from one who also North America was not the same as it is today. All the basement rocks of the San Francisco Bay region have been added to North America, brought by tectonic forces. The rocks in the San Francisco Bay region are a mix of igneous, sedimentary, and metamorphic rocks. They were brought to the region by tectonic forces that have shaped the region's geology.

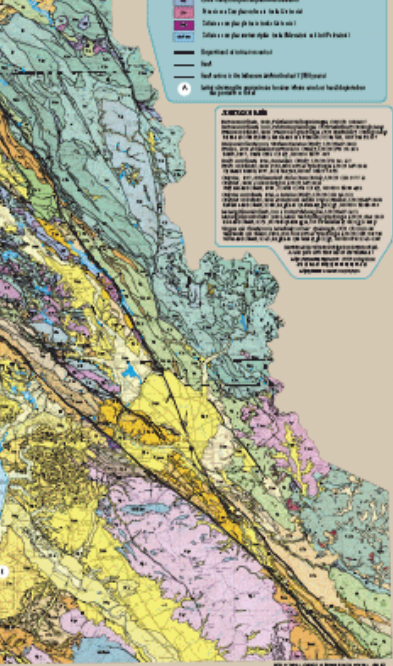
Sliced up Many faultlines up the plate boundary and they do blocks of rocks. The rocks in the San Francisco Bay region are sliced up by faultlines. These faultlines are the result of tectonic forces that have shaped the region's geology. The rocks are divided into blocks by these faultlines, and the blocks move relative to each other.



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Geologic Map of the San Francisco Bay Region

R.W. Graymer, D.C. Metzger, G.J. Sorensen, C.M. Woodworth, E.E. Brown, and K.L. Knudsen

Figure 5. Geologic map of the San Francisco Bay area (Graymer and others, 2006).



Figure 6. Quaternary-active fault map of the San Francisco Bay area (Graymer and others, 2006).

Hands-On Activity for the Classroom: (An efficient and effective strategy for using this activity in the classroom is to obtain about 6 copies of the earthquake map, laminate the maps for durability and marking with water soluble felt pens, and place on tables in the classroom. Divide the students into groups and have them examine and answer the questions and perform the tasks listed below. Each group should submit a written copy of their answers and be asked to respond orally to one or more of the questions during class discussion following the hands-on activity. A useful follow-up discussion or presentation can focus on earthquake hazards and damage. The PowerPoint presentation related to the San Francisco Bay area earthquakes and fault map, <http://web.ics.purdue.edu/~braile/edumod/bayarea/BayAreaEQs.ppt>, contains information, photos and images for this purpose.)

1. Examine the *Earthquakes and Faults in the San Francisco Bay Area (1970 - 2003)* map and the map legend. Note the map scale and sources of data that are displayed on the map.
2. Using the maps in Figure 2 and 4 or a road map or an atlas, find the following geographic localities on the earthquake map: San Francisco, San Jose, Oakland, Santa Rosa, Santa Cruz, Monterey Bay, Point Reyes, San Francisco Bay, the Golden Gate Bridge, and the San Francisco Bay Bridge.
3. Find the following faults on the earthquake map: San Andreas Fault, Hayward Fault, Calaveras Fault, Greenville Fault, Rogers Creek Fault, and San Gregorio Fault. For each fault, using your finger or a pointer, trace each of the fault lines from northwest to southeast to see the extent of the faults.
4. Examine the earthquake epicenters (yellow dots, size of the dot is proportional to the magnitude of the earthquake) and trends or clusters of epicenters visible on the map. Note that there are several young (faults <700,000 years are plotted in red) fault segments with very few earthquakes. What are the possible explanations for this observation?
5. Find the epicenters for the 22 M5+ earthquakes that are listed in the Table of Earthquakes on the map. Summarize the general locations of these larger events (Are they located along a small number of faults? Are they located in one particular area of the map?)
6. Find the epicenters for the 22 M5+ earthquakes that are listed in the Table of Earthquakes on the map. Summarize the general locations of these larger events (Are they located along a small number of faults? Are they located in one particular area of the map?)
7. What topographic or landscape features appear to be correlated with the young faults on the map? Note that there are significant young faults on both sides of the San Francisco Bay and that this area is characterized by low elevations (below sea level of slightly above sea level). This low elevation area, generally, extends somewhat both northwest and southeast of San Francisco Bay. What are the possible geological explanations for this low elevation area?
8. Note that the San Andreas Fault north of about Monterey Bay is seismically relatively quiet. This is a section of the fault that broke in the 1906 M7.8 San Francisco earthquake. North of the map area, the San Andreas extends to near Cape Mendocino making the 1906 fault break about 450 km long. Is a “repeat” of the 1906 earthquake along this section of the fault

- likely? What population centers are likely to be affected by strong shaking from such an event?
9. What other significant faults (length greater than about 20 km, capable of generating M6.5+ earthquakes) are close to population centers?
 10. Scientists know that buildings and other man-made structures built on fill areas or areas of un-compacted sediments are more likely to be damaged in an earthquake because these materials can intensify shaking. Can you identify areas on the map where relatively thick accumulations of these sediments might be?
 11. Where is the plate boundary (on this map) between the Pacific and North American tectonic plates? (Plate tectonic concepts can be demonstrated using the hands-on activities, plate puzzle, <http://web.ics.purdue.edu/~braile/edumod/platepuzz/platepuzz.htm>, and, teaching about plate tectonics and faulting using foam models, <http://web.ics.purdue.edu/~braile/edumod/foammod/foammod.htm>.)
 12. If the Pacific plate moves up the peninsula at an average rate of 4 cm per year toward the northwest, how long will it take for Santa Cruz (at the northern edge of Monterey Bay) to be due west of San Francisco?

Discussion of Earthquake Hazards and Forecasting in the San Francisco Bay

Area: (This section is modified from "San Francisco Bay Area Earthquakes Poster – A Teachers' Guide" developed by the U.S. Geological Survey, 1990. A copy of the text of the Teachers' Guide can be found at: <http://www.seismo.unr.edu/ftp/pub/louie/class/100/sf-class.html>.)

Many people look at this map and the trace of the San Andreas Fault just south of San Francisco and feel comforted by the fact that there are so few earthquakes, when in fact, this area has one of the higher probabilities for a large earthquake. The presence of so many smaller earthquakes south of this section of the fault attests to the fact that the stress is high along the San Andreas.

Scientists know that the Pacific Plate is sliding to the northwest relative to the North American Plate at an average rate of about 4 centimeters per year. The faults in this area are the surface expression of the edges of these two tectonic plates grinding past each other. In fact, the movement along these faults is neither smooth nor constant. The motion of the plates builds up strain (stored elastic energy caused by deformation of the lithosphere due to plate motions) along these faults until the stress becomes too much and the built up pressure is released through an earthquake.

By studying these, and other faults scientists recognize the patterns of earthquakes that relieve the stress in this constantly moving system. The history of earthquakes in the San Francisco area suggests that this area is rocked fairly regularly, on a geologic time scale, with large earthquakes. The seismicity gap, or lack of seismic activity as evidenced along specific segments of the faults on this map, is part of the temporal pattern of strain release for this part of the fault.

Scientists continue to study earthquake patterns. As our understanding of earthquake systems increases, so does our ability to predict the impact on the human environment.

In the early to mid 1980s, scientists began forecasting the Loma Prieta earthquake. Scientists had judged the Santa Cruz Mountain section of the fault as having the highest probability of an earthquake of any segment of the San Andreas Fault that had ruptured in 1906.

In July of 1990, after the Loma Prieta Earthquake, the National Earthquake Prediction Evaluation Council convened a panel of experts to re-evaluate predictions for the San Francisco Bay area. As reported in "The Next Big Earthquake", a publication distributed through regional newspapers in the San Francisco Bay area after the quake (copies of "The Next Big Earthquake" are available from the U.S. Geological Survey's Earth Science Information Center, ESIC, by calling (650) 329-4085), four fault segments in the Bay Area have been identified as having large earthquake potential: "the peninsula segment of the San Andreas fault between Los Gatos and Hillsborough; the Hayward fault between Fremont and San Leandro; the Hayward Fault between San Leandro and San Pablo Bay; and the Rodgers Creek fault between San Pablo Bay and Santa Rosa. The council estimated that the probability is about 25 percent for a large earthquake on each one of these fault segments within 30 years."

The article goes on to say, "More importantly, when the probabilities of earthquakes on all of these segments are combined mathematically, there is a 67 percent chance for at least one earthquake of magnitude 7 or larger in the San Francisco Bay Area between 1990 and 2020. Such an earthquake could strike at any time."

While we cannot predict the exact date and time of an earthquake, nor can we control them, we know enough to mitigate much of the damage that can be caused by an earthquake. Our schools play a critical role in educating people about the potential hazards to human life and property and about appropriate safety precautions in earthquake territory. With this information, our students begin to learn about designing and developing buildings and communities in balance with their natural environment.

References:

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Zoback, M.L., The 1906 earthquake and a century of progress in understanding earthquakes and their hazards, *GSA Today*, volume 16, April/May, p. 4-11, 2006. (Also available online at: <ftp://rock.geosociety.org/pub/GSAToday/gt0604-05.pdf>.)

Earthquake file for the San Francisco Bay area for use with the Seismic Eruption software is located at: <http://web.ics.purdue.edu/~braile/edumod/bayarea/bayarea.hy4>. The file contains earthquake data for events of M1+ from 1973 - 2006.
