San Francisco Bay Area Earthquakes

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(modified from "San Francisco Bay Area Earthquakes Poster – A Teachers' Guide" developed by the U.S. Geological Survey, 1990)

Explorations in Earth Science

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 "false color" satellite photo of the bay area on which earthquake epicenters from 1972-1989 have been plotted. The epicenters include the mainshock location and aftershocks of the October 17, 1989, magnitude 7.1, Loma Prieta earthquake. The satellite photo is available as an attractive color poster. To order copies of the poster ($4 each; $5 shipping and handling), call 1-888-ASK-USGS. A reduced-size version of the poster is provided in Figure 1. This activity is a slightly modified version of the U.S. Geological Survey's teacher's guide produced in 1990. We provide a digital image of the poster and an accompanying base map so that the activity and associated materials are more readily available. The activity can be performed with the reduced-size satellite image (Figure 1, printed in color). However, the color-coded surface features and the epicentral patterns are more visible on the 60 x 76 cm (24" x 30") poster. A California highway map (or a copy of the California or San Francisco Bay area map from an atlas) is needed for finding some locations on the satellite image and helps one become familiar with the geography represented in the satellite view.

Satellite Image and Base Map: Figure 1 (or original color poster of bay area) is a Landsat Satellite image that depicts a 50,000 square kilometer area from Lake Berryessa in the upper right of the poster (north) to Monterey on the lower left (south) and from about 30 km out into the Pacific Ocean on the west to Stockton on the east. The image depicts the Bay area as it looks from about 900 km above the earth.

The satellite image was taken using the infrared portion of the electromagnetic spectrum that is not visible to the human eye. The poster uses false-color imaging to enhance

the landforms and surface features. The colors, though brilliant, are not as objects normally appear to the human eye. The color key follows:

Deep red – ground covered by heavy vegetation (Santa Cruz Mountains – coastal mountains north of Santa Cruz)

Light red – cultivated crops (rectangular areas most abundant in the San Joaquin Valley, on the right side of the image)

Shades of green – grass-covered areas (east of the Bay) and marshy areas (northwest shore of San Pablo Bay)

Turquoise Blue – urbanized areas (Note the obvious street grids. Red flecks represent parks and greenways)

Royal Blue – bodies of water (San Francisco Bay, the Pacific Ocean)

The bright yellow circles represent the epicenters of the more than 12,000 earthquakes of magnitude 2 or larger that occurred in the San Francisco Bay area between January 1, 1972 and December 31, 1989. An epicenter is the point of the Earth's surface directly above the focus, or actual location of the earthquake. Note that the extension of the San Andrea Fault north of San Francisco, where it follows the bay to the east of Point Reyes Peninsula (see also Figure 2), has no earthquakes. Of the estimated 430 km that ruptured in the 1906 San Francisco earthquake, this area had the greatest surface displacement.

The magnitude of the earthquakes is depicted by the diameter of the circles—from the smallest (one millimeter on the poster), representing earthquakes of magnitude 2-3, to the largest, an eight-millimeter (on the poster) circle in the Santa Cruz Mountains, representing the 7.1 magnitude Loma Prieta earthquake of October 17, 1989.

The area north and east of the Loma Prieta epicenter circle is heavily dotted with more than 150 smaller circles representing some of the aftershocks of that earthquake.

In areas where earthquakes occur most frequently, a solid yellow cluster or line clearly traces the major Bay Area faults. Note how closely the trace of the computer-generated epicenters compares with the faults shown in Figure 2.

William Bakun, who heads the USGS Bay Area Future Earthquakes Project, said the poster is more than "just another pretty map."

"While this is one of the more visually appealing renditions of the Bay Area," Dr. Bakun said, "it also is an excellent way to comprehend the amount of earthquake activity in the area and where that activity is concentrated. Even seismologists who have studies the area for

years look at this map and are surprised. They see features and relationships that they had not noticed before."

A base map showing faults and selected geographical features is shown in Figure 2 for comparison with the satellite image. Note that the map and the satellite image (Figure 1 or poster) are not at the same scale and do not cover exactly the same area. In fact, although the map is oriented in the traditional manner with "north" toward the top of the map (note North latitude and West longitude tic marks along the edge of the map), the satellite image is "rotated" to be more parallel to the coastline (see north arrow in lower left hand corner of the image or poster).

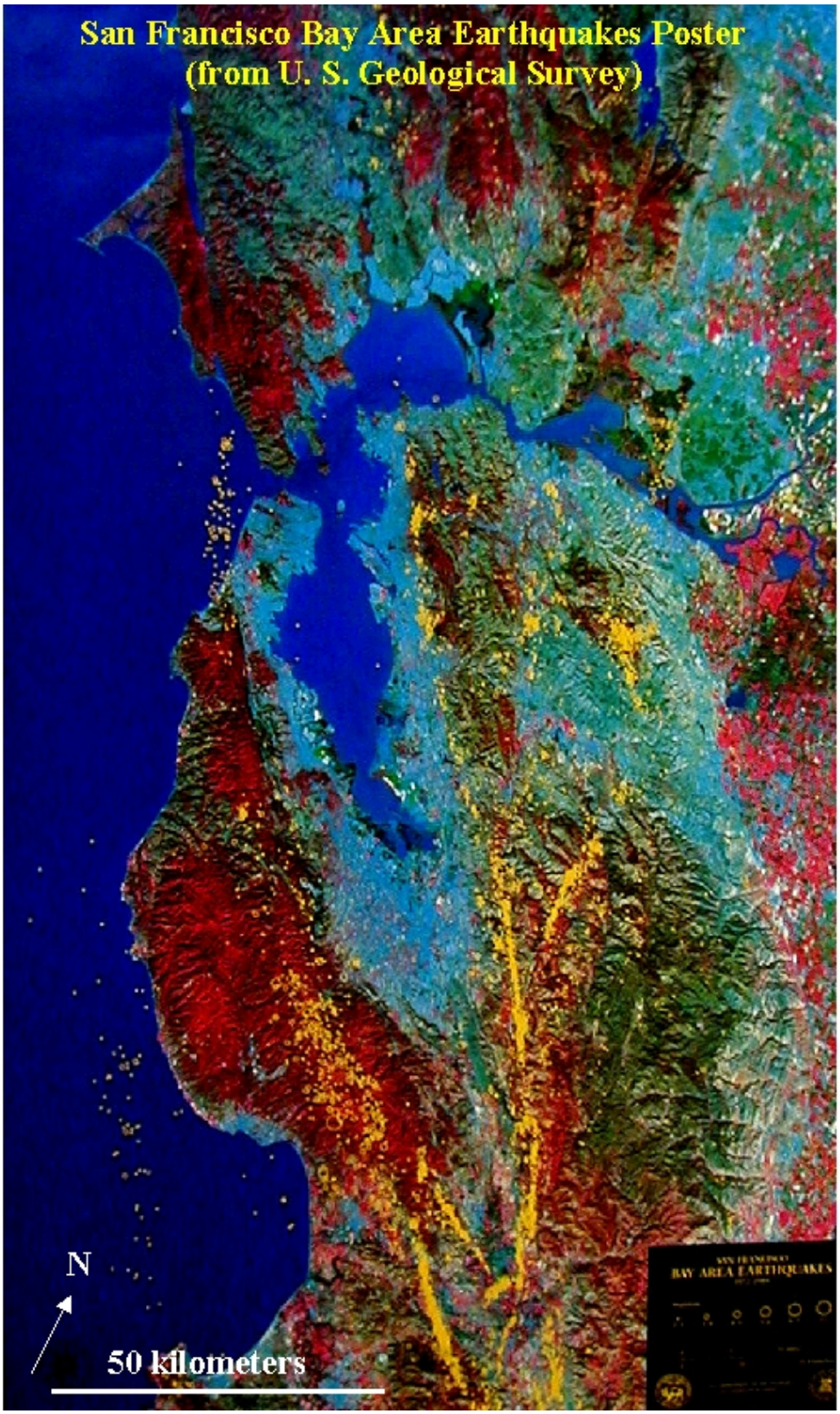

Figure 1. False color satellite image of the San Francisco bay area. Yellow circles are earthquake epicenters from 1972-1989. Circle size is proportional to earthquake magnitude. Modified from U.S. Geological Survey poster "San Francisco Bay Area Earthquakes."

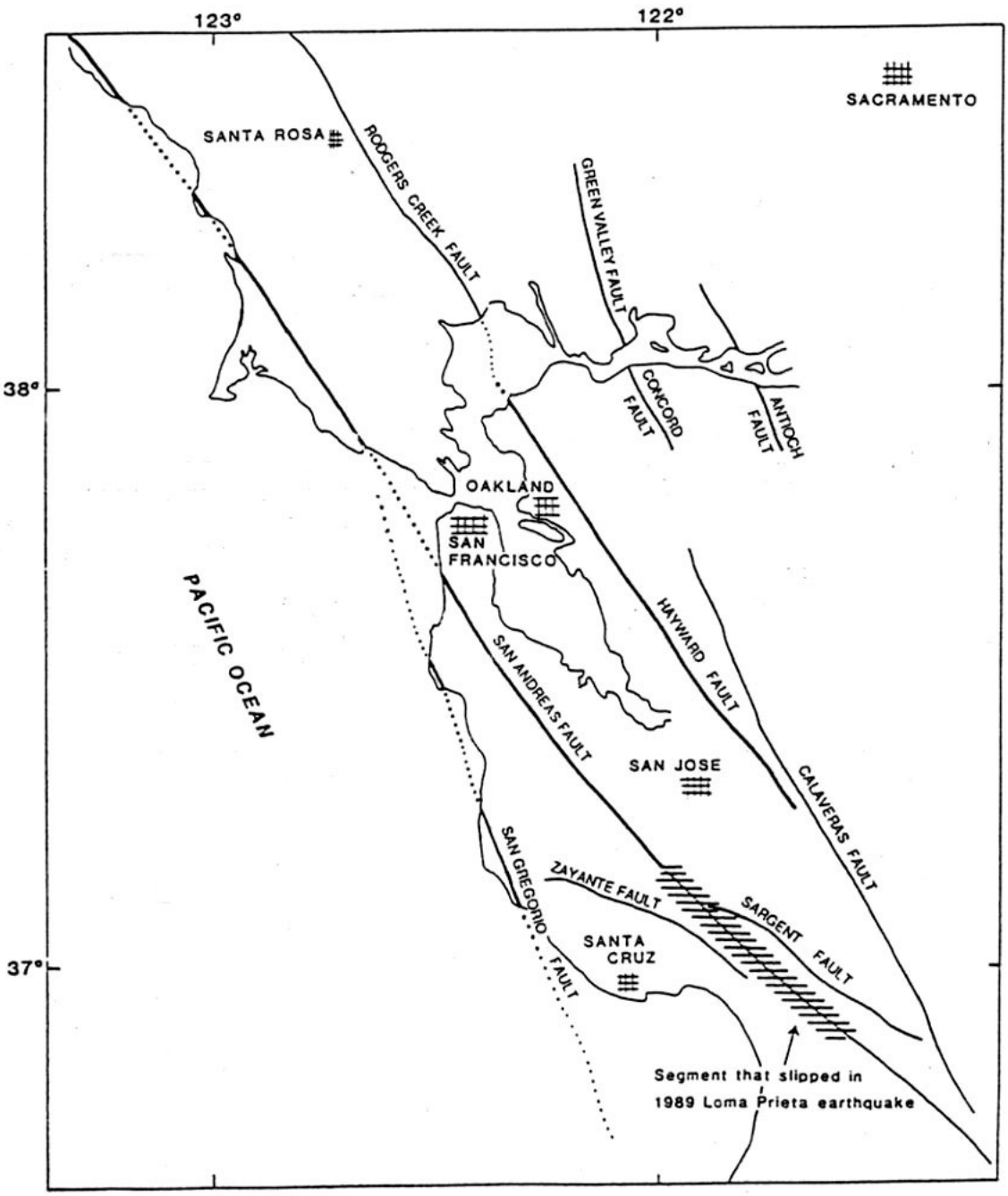

Figure 2. Faults in the San Francisco Bay area. Map modified from Plafker, George and Galloway, John P., Editors, 1989, Lessons Learned from the Loma Prieta, California, Earthquake of October 17, 1989; U.S. Geological Survey Circular 1045, 48 p.

Activities for the Classroom:

1. Using a road map or an atlas, find and mark the following geographic localities on he reference map: Lake Berryessa, Stockton, the Santa Cruz Mountains, the Diablo Range, the Coastal Range, San Joaquin Valley, San Pablo Bay, the Presidio, the Golden Gate Bridge, and the San Francisco Bay Bridge.

2. Find the largest earthquake circle on the map. Can you identify this earthquake?

3. If there were 12,000 earthquakes from January of 1972 to December of 1989, how many earthquakes were there per year and per month, on average?

4. Trace the surface expression of four faults using the clues given by the epicenter circles. Identify the faults using the reference map.

5. Dr. Bakun noted that seismologists were surprised about some of the features that they could see on the poster. Write your own paragraph about interesting features that you see on the poster.

6. Blow up a balloon and predict when it will pop. What variables are you using to make your prediction? Does your prediction mechanism work for multiple balloons? Try this activity with a group of students. What prediction methods can you develop? How accurate is your prediction method with different students blowing up the balloon?

7. Make a hypothesis about the lack of earthquakes on the San Andreas Fault in the northern part of the peninsula. What is the relationship of the lakes along the San Andreas Fault at the northern end of the peninsula and the fault itself?

8. As reported in "The Next Big Earthquake," "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" have been identified as having large earthquake potential. Use a road map or an atlas map of California to find these cities. Using a clear sheet of paper as an overlay on the map, mark the approximate location of these cities. Then, use the epicenter circles to estimate the location of the faults and trace the fault segments that are predicted to have the most earthquake potential in this region.

9. Translate the Spanish place names to English.

10. Scientists know that buildings and other man-made structures built on fill areas or areas of uncompacted sediments are more likely to be damaged in an earthquake because these materials can intensify shaking. Areas that are steep sloped are more likely to experience landslides and mud slides. With this information and information gathered from the

earthquake epicenters on the poster, where would you look for a house if you were moving to the San Francisco Bay area?

11. What supplies would you want to have in your home if you were in an earthquake prone area? What changes would you make in your home if you lived in an earthquake prone area? Would you change or move furniture or belongings?

12. If the Pacific Plate moves up the peninsula at an average rate of 5 cm per year toward the northwest, how long will it take for Santa Cruz to be due west of San Francisco?

Discussion of Earthquake Hazards and Forecasting in the San Francisco Bay Area:

Many people look at this poster 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 5 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 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 on this poster, 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 80s, 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.

Additional and more recent information on San Francisco Bay area earthquake activity, hazards and earthquake forecast can be obtained from USGS Fact Sheets (see http://water.usgs.gov/wid/index-hazards.html for an index of available fact sheets).

Progress Toward a Safer Future Since the 1989 Loma Prieta Earthquake, Fact Sheet 151-99, http://geopubs.wr.usgs.gov/fact-sheet/fs151-99/

Major Quake Likely to Strike Between 2000 and 2030, Fact Sheet 152-99, http://geopubs.wr.usgs.gov/fact-sheet/fs152-99/

When Will the Next Great Quake Strike Northern California?, http://quake.wr.usgs.gov/QUAKES/Fact Sheets/When/