Introduction

This poster shows the distribution of Quaternary-active faults in the San Francisco Bay region and explains what they are, why they are important, and how geologists study them.

Quaternary-active faults are those that have slipped in Quaternary time (the last 1.8 million years). Geologists think that these faults are the most likely source of future great earthquakes, so it is important to know what they are, where they are, and how they work.

The map at the center of this poster shows Quaternary-active faults as differently colored lines on a computer-generated image of the region. This image combines LANDSAT satellite photography, digital elevation data, and digital water-depth data.

This fault map is derived from the ongoing work of the Northern California Quaternary Fault Map Database Task, which is a group of geologists from the U.S. Geological Survey, California Geological Survey, and consulting firms. Their work is to make and compile a modern map database of Quaternary fault information. They are largely funded by the USGS National Earthquake Hazards Program.

What is a fault?

A fault is a break in the rocks that make up the Earth's crust, along which rocks on either side have moved past each other.

Not every crack in the ground is a fault. What defines a fault is the movement of the rock on either side. When that movement is sudden, the released energy causes an earthquake.

Some faults are tiny, but others are part of great fault systems along which rocks have slid past each other for hundreds of miles. These fault systems are the boundaries of the huge plates that make up the Earth's crust. In the San Francisco Bay region, the Quaternary-active faults are part of the boundary between the Pacific and North American plates.

This photo shows a small fault in San Mateo County. Matching layers across the fault shows that it has offset the sandstone (lighter layers) and shale (darker layers) about ten feet.

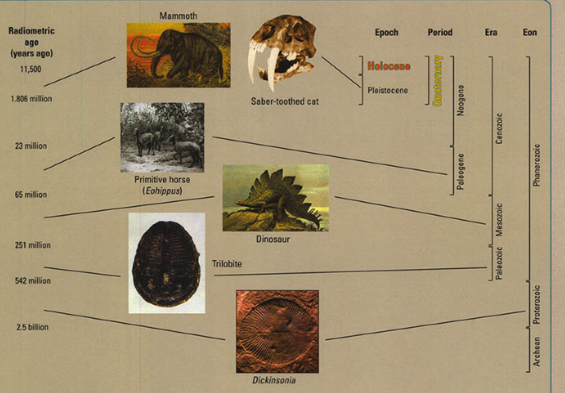
Some major faults can even be seen from space, as shown by this LANDSAT image of the San Andreas Fault in southern California.

What is the Quaternary?

Quaternary time is the current period of geologic time, which began about 1.8 million years ago.

We divide time into years, months, and days, and we give these divisions names, such as 1776, August, and Friday. Similarly, geologists have divided the time of Earth's long history into eons, eras, periods, and epochs of geologic time, and they have given each division a unique name. When they first started using these names, nobody knew how old the Earth was, or how many years ago the time divisions were. Instead, they based the division of time on how the fossils found in rocks changed from the oldest layers to the youngest. The **Quaternary** period is the name for the time in which we live. It spans the two most recent geologic epochs, the **Pleistocene** and the **Holocene**. Fossils from the Holocene epoch are like the animals living today, whereas Pleistocene fossils are much like living animals but with some differences. Many observations show that Pleistocene time was characterized by long periods of arctic conditions that allowed ice and snow to cover vast areas of land and sea, and so it is sometimes called the Ice Age. Animals of that time, such as the mammoth and the saber-toothed cat, were equipped to deal with those conditions. Holocene time is the warmest epoch since the last time of widespread icy conditions.

In the 20th century, following the discovery of radioactivity, geologists developed a tool to assign numeric ages to the divisions of geologic time. By observing the rate of decay of radioactive elements, and then measuring the amounts of both the radioactive elements and their decay products in rocks and minerals, geologists can calculate a numeric age for certain rocks and deposits, including those with bits of charcoal for carbon-dating. By careful study of the relations between the fossil-bearing sedimentary rocks and the rocks that have numeric ages, geologists have calculated the ages of the divisions of geologic time. The beginning of the **Holocene** was about 11,500 years ago, and the beginning of the **Pleistocene** was about 1,800,000 years ago.



Geologists used fossils to divide geologic time. The most primitive fossils are found in the oldest rocks, the rocks of the Archean eon. Younger are the more complex but still simple fossils of the Proterozoic eon, such as *Dickinsonia*. The Paleozoic era marked the first complex organisms, such as the trilobites. The Mesozoic era was the time of dinosaurs. The Cenozoic era is the age of mammals, such as the *Eohippus* (or dawn horse) of the Paleogene period. By Quaternary time, the fossils are of animals that are almost, but not quite, like animals that are alive today, such as the mammoth and the saber-toothed cat of the Pleistocene epoch.

What makes a fault break?

Where the Earth's tectonic plates collide, pull apart, or slide by each other, they form and drive faults.

Although the Earth seems very stable on a human time scale, over geologic time it is a very dynamic system. Rock bodies are continuously being made and destroyed. Mountains are pushed up and ground down. Huge slabs of the Earth's surface are sliding and grinding past one another.

Fossilized fragments of a marine animal called crinoid, or sea lily (left), have been found near the top of Mount Everest (right), evidence of the dynamic forces that drive faults.

The powerful forces that drive this system cause huge slabs of the Earth's crust, called tectonic plates, to grind and push against one another. The rocks along the boundaries of these plates are continuously being squeezed and sheared, causing them to bend and break. California is cut by one such plate boundary, between the Pacific and North American plates, at the San Andreas Fault system. All the Quaternary-active faults in the San Francisco Bay region are part of the San Andreas Fault system.

A map of tectonic plates that make up the Earth's crust (top) and a map of the world's earthquakes, shown as red dots (bottom). Note how most earthquakes occur at plate boundaries, as the plates grind against each other to drive faults and generate earthquakes.

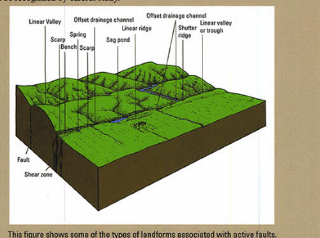
How do geologists find Quaternary-active faults?

Geologists trace faults by following the characteristic effects that young faults have on the landscape.

Some faults, called creeping faults, move very slowly all the time. Structures such as bridges, sidewalks, and buildings on top of these faults will be offset a small amount each year as the faults move. You can try to find a creeping fault by looking for bent or offset curbs and sidewalks. Not every offset curb is a fault, but if you find several offsets that line up, you may have found a creeping fault.

This curb in Hayward is being offset by creep on the Hayward Fault. Notice the change between 1974 and 1993.

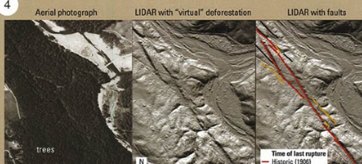
Most faults don't creep, however, so geologists must look for other ways that faults affect the landscape. Usually the evidence is created by repeated earthquakes. Over time, features such as streams, valleys, and ridges may be offset where they cross faults as movement from many earthquakes is accumulated. Active faults also create their own landscape features. For example, if one side of a fault moves up or down, a straight, low ridge called a scarp is created. As faults accumulate offset, the rock along the fault is broken and ground down, and the resulting shattered zone is more easily eroded than the surrounding rock. This type of erosion produces other common fault-related landforms, such as benches, saddles, and linear valleys along the fault. Faults also can disrupt the movement of underground water, forcing it to the surface to form springs and ponds. Finally, faults can be recognized by the effect they produce in the rocks that underlie the landscape, which can be recognized by careful study.



This figure shows some of the types of landforms associated with active faults.

Examples of fault-related landforms in the San Francisco Bay region. Crystal Springs Reservoir fills the linear valley of the San Andreas Fault in San Mateo County. A small scarp deforms the fairway of this golf course along the Hayward Fault in Contra Costa County (also notice the trench across the fault).

The newest tool in the effort to find active faults is Laser Imaging Detection And Ranging (LIDAR), which uses laser light projected from an airplane to make a detailed image of the ground surface, even through trees in a forest.



This figure shows how LIDAR can help reveal active faults. (Left) A regular aerial photograph of an area of trees obscuring part of the San Andreas Fault Zone in Sonoma County. (Center) The same area in a computer rendering of LIDAR data to "virtually" remove the trees and other vegetation. Scarps and other landforms associated with the Quaternary-active fault are now much easier to see. (Right) Fault strands traced onto the LIDAR image.

Learn more about it

Visit our website to see more maps, photos, diagrams, downloads, and information about Quaternary-active faults and other aspects of the geology of the San Francisco Bay region.

http://sfgeo.wr.usgs.gov

How do geologists know when a fault last broke?

Geologists find the age of prehistoric fault rupture where faults cut young deposits.

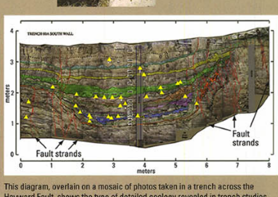
Although the evidence in the landscape that a fault leaves behind can guide geologists to Quaternary-active faults, it cannot tell them just when the fault last lurched in an earthquake. In the San Francisco Bay region, geologists have mapped the extent of ground rupture for only three earthquakes: 1868 (Hayward Fault), 1906 (San Andreas Fault), and 1980 (Greenville/Las Positas Faults). Everywhere else, they have to determine the age of the most recent fault rupture in other ways.

Earthquakes can offset and disrupt the sedimentary layers that naturally accumulate over time from deposition by rivers, streams, wind, and waves. If a layer is not cut or bent by a fault, then the last earthquake on that fault must have occurred before the layer was deposited.

The photo on the left shows a distinct bench along the Warm Springs Fault. Pleistocene fossils found in gravels cut by that fault, like the mammoth tooth shown in the photo on the right, tell geologists that the Warm Springs Fault is Pleistocene or younger.

It commonly is difficult to determine if layers are cut or bent by looking at the ground surface because the surface usually is smoothed out soon after an earthquake by rain, wind, and animal activity. To get a clearer view of young layers, geologists dig trenches across faults where they know that young deposits have accumulated. In some places, the subsurface view of the fault and the young layers reveals distinct evidence of one or more past earthquakes. Trench studies also give geologists a better chance to find the fossils and bits of carbon (for radiometric dating) that might tell them how old the layers of young deposits are.

USGS geologists supervise trench digging across the Hayward Fault.



This diagram, overlain on a mosaic of photos taken in a trench across the Hayward Fault, shows the type of detailed geology revealed in trench studies. The yellow triangles show where carbon was collected for radiometric dating. Colored areas highlight various layers of Holocene sediment. Geologists have found evidence for five earthquakes in this trench.

Do all faults cause earthquakes?

Faults with no Quaternary activity are least likely to cause an earthquake. Holocene-active faults are considered the most active.

There are literally hundreds of faults in the San Francisco Bay region alone. All faults are the result of movement in the Earth's crust, and all but the tiniest probably have generated earthquakes. However, much of that movement and most of those earthquakes occurred far in the Earth's past. Because the pattern of stress in the crust changes over geologic time, faults are formed, move, and then are abandoned.

Geologists focus their studies on Quaternary-active faults, faults that have moved in Quaternary time. Faults that have not moved in the last 1.8 million years are probably abandoned, or at least they cause an earthquake so infrequently as to be less important. On the other hand, faults that have moved in Holocene time (the last 11,500 years) are considered the most active and dangerous faults.

This map of faults (red lines) includes many older faults that are not on the main map to the right. These faults do not show evidence of having broken in Quaternary time, and so they are considered less likely to cause future earthquakes.

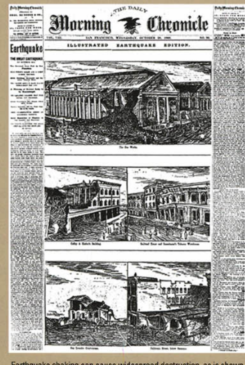
MAP KEY

- Fault that had ground rupture in an earthquake in **historic** time (since 1776). Dotted where concealed by water
- **Holocene-active** fault. Dotted where concealed by overlying rocks, sediments, or water
- **Quaternary-active** fault. Dotted where concealed by overlying rocks, sediments, or water
- (1) Number showing the approximate location where a photograph on this poster was taken

Why do geologists study faults?

Active faults generate earthquakes. Geologists study them to better understand where and when future earthquakes will occur.

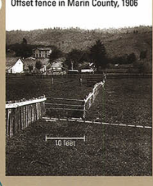
Geologists study faults to better understand where large earthquakes originate. The Earth's plates are constantly moving, but most faults are motionless, locked by friction, until the day when the force on the fault builds up enough to overcome the resistance. When that happens, the rocks on either side of the fault lurch into motion, releasing pent-up energy in an earthquake. Most earthquakes are so small that special instruments are needed to detect them, but a few release huge amounts of energy, causing widespread destruction. During most earthquakes, fault motion stays below the Earth's surface, but in large earthquakes, fault motion may break through to the surface, offsetting rocks and sediments, as well as anything built on the fault, as much as ten feet or more.



Earthquake shaking can cause widespread destruction, as is shown by newspaper drawings made after the 1868 earthquake on the Hayward Fault and photos taken after the 1906 earthquake on the San Andreas Fault.

Knowing the location of active faults is important so that planners and developers can avoid building houses or other structures, which would be destroyed when the fault breaks the Earth's surface, on the faults. Geologists also study the faults to find out how quickly the stress on them is building, as well as when the last large earthquake on them was and how often large earthquakes are caused by them. This information together gives them a general idea of how soon to expect the next Big One on a particular fault. The eventual goal is accurate and precise earthquake prediction, but geologists still haven't developed the tools required to do that.

Geologists also study faults because they can affect the distribution of oil, underground water, and mineral resources. Faults also can serve as conduits for volcanic eruptions. Finally, studying faults can help to better understand how both the Earth's crust and the surface landscape formed.



During earthquakes, faults can offset the ground surface by many feet, as shown by the offset of this fence across the San Andreas Fault after the 1906 earthquake.

Fault offset destroyed this house during the 1906 earthquake.

How not to use this map

This map should not be used to evaluate potential earthquake hazards. It is intended for educational and general-interest purposes only.

More detailed maps and information about earthquake hazards in the region can be obtained online from USGS (http://quake.usgs.gov) and CGS (http://www.consrv.ca.gov/cgs).

Sources of Fault Mapping

- Compressional faults, northeastern San Francisco Bay region—J. Unruh, William Lettis & Associates
- Concord-Green Valley Faults—B. Bryant and C. Wills, CGS
- Faults in Santa Cruz and northern Monterey County—L. Rosenberg, Tierra Geosciences
- Foothills Thrust System, Santa Clara and San Mateo Counties—D. Kennedy, Sanders & Associates
- Hayward Fault—J.J. Lienkaemper, USGS
- Northern and Peninsula segments of the San Andreas Fault—C. Prentice, USGS
- Northern Calaveras Fault—K. Kelson, William Lettis & Associates
- Rodgers Creek Fault—S. Hecker, USGS, and C. Randolph-Loar, Lachel Felice & Associates
- West Napa Fault—K. Hanson, Geomatrix, and J. Wesling, William Lettis & Associates

Base extracted from U.S. Geological Survey Scientific Investigations Map 2848 (Sleeter, B.M., Calzia, J.P., Walter, S.R., Wong, F.L., and Saucedo, G.J., 2004, Earthquakes and faults in the San Francisco Bay area (1970–2003): U.S. Geological Survey Scientific Investigations Map 2848, scale 1:300,000. Available at *http://pubs.usgs.gov/sim/2004/2848*)
Universal Transverse Mercator Projection, Zone 10 North

APPROXIMATE MEAN DECLINATION, 2006 (14½°; TRUE NORTH, MAGNETIC NORTH)

SCALE 1:275 000
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 KILOMETERS

MAP LOCATION (CALIF.)

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Map of Quaternary-active Faults in the San Francisco Bay Region

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