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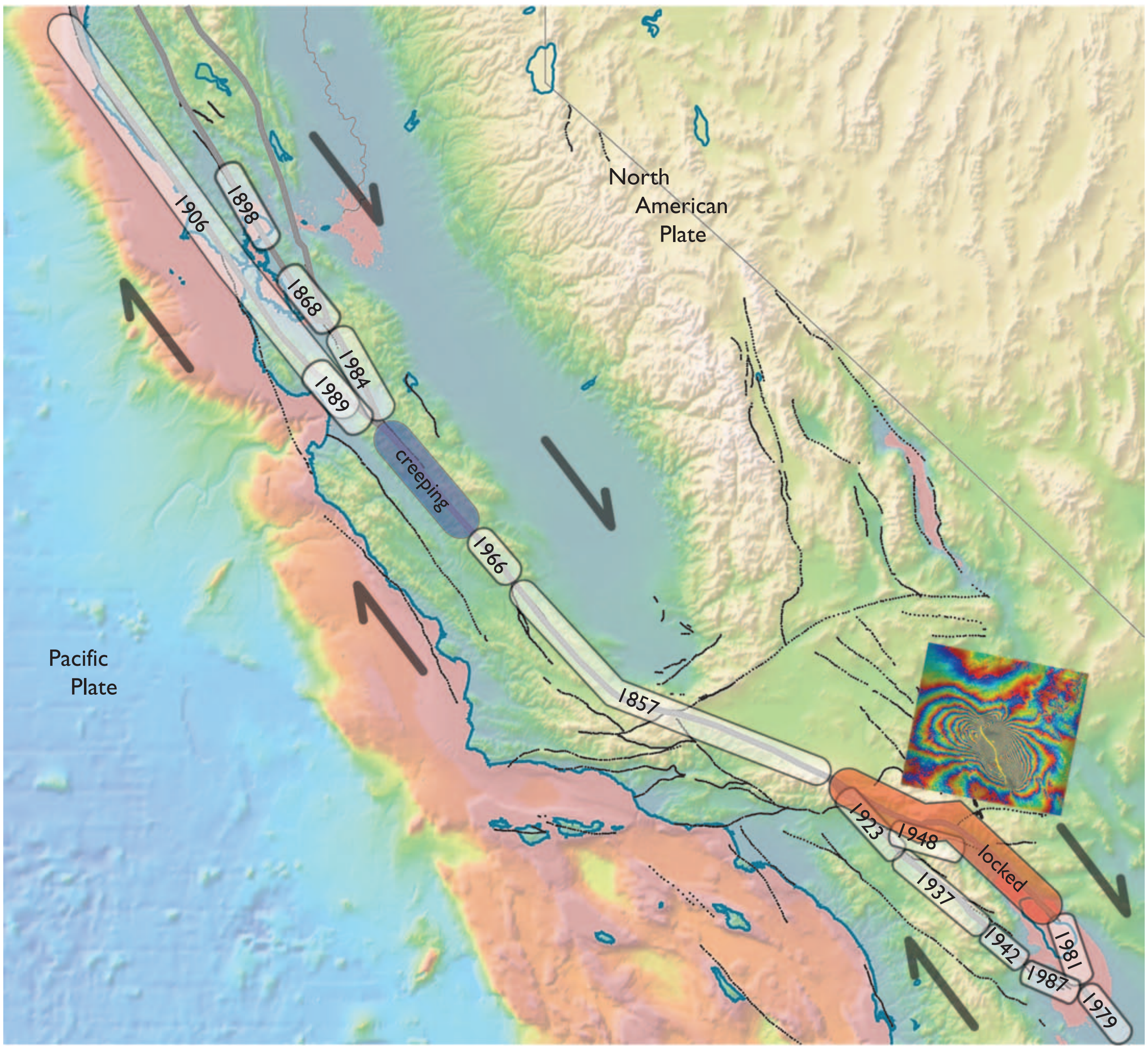
The San Andreas Fault: Adjustments in the Earth's Crust



The sudden release of energy along a major earthquake fault is one of the most destructive forces of Nature. During the 1906 San Francisco earthquake, poorly constructed buildings collapsed in a matter of seconds killing thousands of occupants. This was followed by fires that destroyed 28,000 buildings and left more than half of the residents of the city (225,000) homeless.

Destructive earthquakes, such as the 1906 event, almost always occur along the boundaries of the tectonic plates, which are well mapped globally. While most plate boundaries

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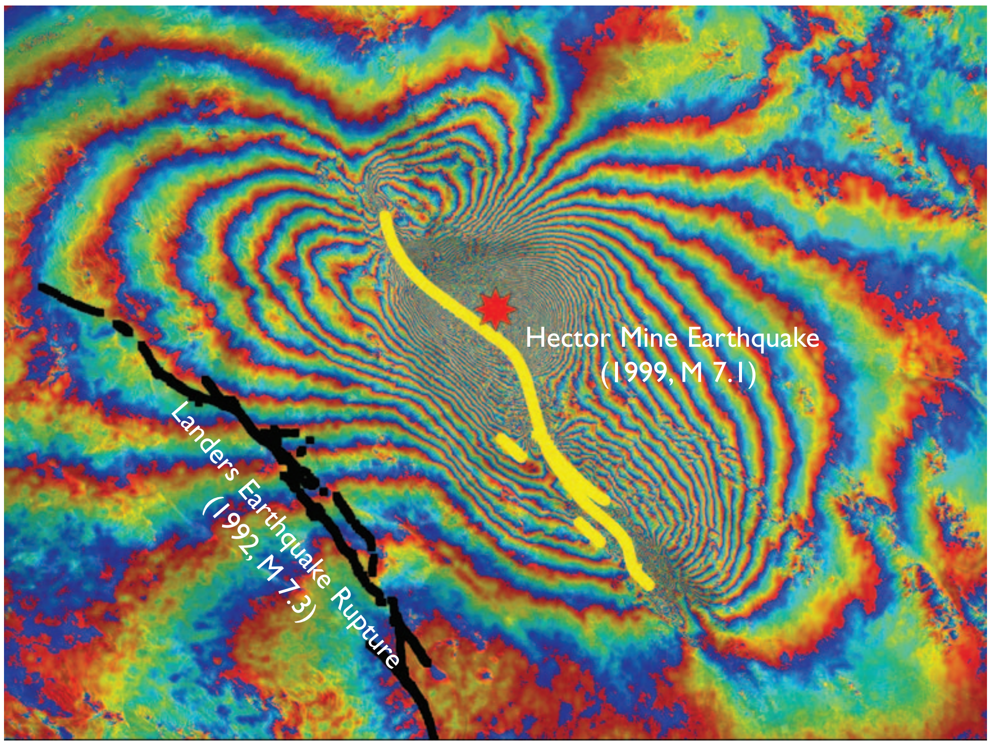

Radar interferogram. Since space-based geodetic measurements have become available, there has not been a major earthquake on the San Andreas Fault. However, two major earthquakes have occurred in the Mojave Desert in 1992 (Landers) and 1999 (Hector Mine). This radar interferogram shows the ground motion associated with the 1999 Hector Mine earthquake. The ERS-2 radar imaged the land before and after the earthquake. The difference in radar phase between the two acquisitions reveals the rupture in great detail; one color cycle (or 'fringe') represents 28 mm of ground motion. The technique of radar interferometry offers the ability to monitor fault zones on continental scales and it is highly complementary to the 400 continuously operating Global Positioning System receivers that have been deployed along the San Andreas Fault zone. (Data from the Synthetic Aperture Radar (SAR) instrument on the European Space Agency ERS-2 satellite.)

occur in the deep ocean and thus far from cities, a major transform fault (the San Andreas Fault) cuts across the most populated areas in California. Over a period of 500 years or so, every section of the San Andreas Fault will rupture to release tectonic stress, suggesting that that residents need to be prepared for the inevitable.

At depths of greater than 30 km, the ductile nature of the rock results in plates sliding freely past one another. However, shallower fault zones are colder and more brittle and undergo stick-slip behavior. Initially, the shallow surfaces of the fault remain locked because of friction and surface imperfections; this interseismic period can last hundreds of years. Eventually the growing stress exceeds the strength of the rocks and the fault ruptures causing a co-seismic slip event. Recently scientists have discovered that slip can either be fast and destructive or slow and largely unnoticeable. Fast ruptures generate elastic waves that propagate outward and destroy buildings. Slow ruptures, which have only recently been detected using the Global Positioning System (GPS), can release the tectonic stress over several days. Of course, it is important to monitor all faults in populated areas to establish the rate of stress buildup and release. Following the co-seismic event, the fault continues to slip generating aftershocks and dissipating the stress concentrations at the margins of the rupture. This post-seismic deformation can lasts for tens of years. Some scientists believe there is also a short period of concentrated deformation just prior to a major earthquake, although this period of 'pre-seismic deformation' is poorly documented.

Over geologic timescales (millions of years), the earthquake cycle is constantly repeated resulting in nearly continuous motion. In terms of global plate tectonics, earthquakes are relatively unimportant since they are just minor squeaks along the plate boundaries. However on human timescales, the earthquake cycle is highly irregular and only partially observed on a single fault segment. A full understanding of the process will require observations over many cycles by many generations of people or by observing many active fault systems in various stages of their earthquake

Opposite: The major sections of the San Andreas Fault zone. These sections undergo repeated earthquake activity except along the creeping section where the plates slide smoothly at all depths. Recent major earthquakes are dominated by the 1857 Fort Tejon Earthquake and the 1906 San Francisco Earthquake. The southernmost locked section of the San Andreas Fault has not experienced a major earthquake in at least 300 years. The next event along this section could release more than 7 m of accumulated slip; typically large California earthquakes have a maximum slip of 6 m.

Images taken from Knob Hill after the earthquake in San Francisco, California on April 18, 1906. This view is from the corner of Van Ness Street and Washington Street. (Photo credit: W. C. Mendenhall, 685 and US Geological Survey.)

Right: Fault trace 2 miles north of the Skinner Ranch at Olema, looking north (left). (Plate 10, US Geological Survey Folio 193; Plate 3-A, US Geological Survey Bulletin 324. G. K. Gilbert, 2933.)

Far right: A fence offset 2.6 m (8.5 ft) by a main fault one half mile northwest of Woodville, looking northeast (right). The fault fracture accompanying the earthquake is inconspicuous, although the horizontal displacement is considerable. Marin County, California. (Photograph submitted by G.K. Gilbert from the Earth Science Photographs from the US Geological Survey Library, by Joseph K. McGregor and Carl Abston, US Geological Survey Digital Data Series DDS-21, 1995.)

Modern reconstruction of the 1906 fence on the same site and in the same position. Note the displacement of approximately 7.6 m (25 ft) by 2006. (Photograph courtesy Tammi Grant.)

cycle. Modern space-based geodetic measurements such as GPS and radar interferometry have recorded all but the pre-seismic element of the earthquake cycle. With these new tools, scientists are beginning to understand the earthquake process and may someday be able to provide useful earthquake forecasts or at least assess the danger of individual faults.