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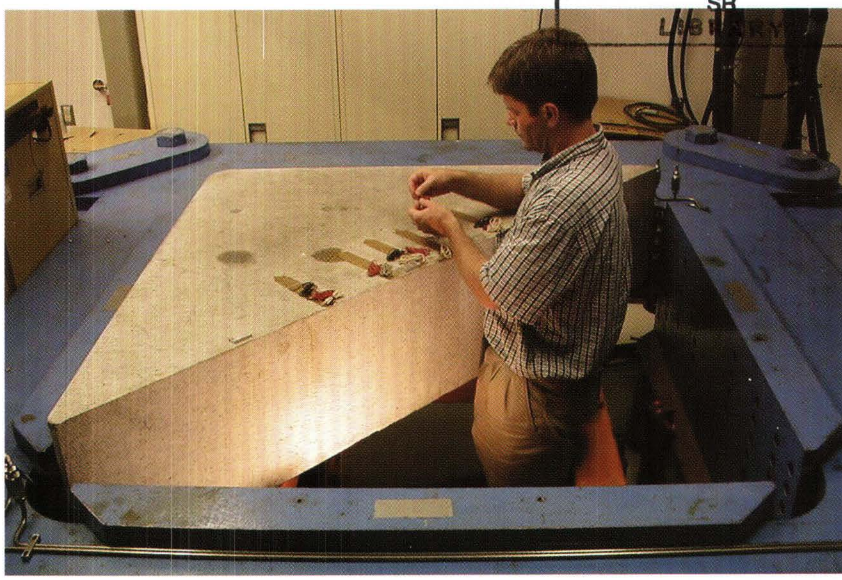
REDUCING EARTHQUAKE LOSSES THROUGHOUT THE UNITED STATES

High-Pressure Rock-Physics Laboratories Investigate Earthquake Processes

An earthquake results from rapid slip on a fault, much like the sudden release of energy stored in a spring. Understanding the timing and magnitude of earthquakes requires knowledge of the mechanical behavior of the Earth's crust as it slowly stores energy and then fails through fault rupture. Because the regions where damaging earthquakes originate are generally too deep and inaccessible to be investigated directly, much of what we know about the properties of rocks and fault-zone materials in earthquake-prone regions comes from laboratory tests in which deep-crustal temperatures and pressures are duplicated. Information gathered from such tests conducted at the U.S. Geological Survey's rock-physics laboratories leads to models of fault behavior that can more accurately determine earthquake hazards and risk.



Laboratory samples, such as this 2,400-pound (1,100 kilogram) granite block containing a 6-foot (2 meter)-long fault surface, are instrumented with sensors to study how earthquakes start and stop. The steel loading frame (blue) is used to force the diagonal fault surface to slide against a matching block (removed here for sensor installation). By obtaining precise information on how a model earthquake propagates along the simulated fault, scientists are learning about the dynamic processes that control energy release and ground shaking during earthquakes. The geometry of this apparatus mimics that of strike-slip faults, such as the San Andreas Fault in California.

These 3-inch (7.6 centimeter)-diameter granite samples originally formed a solid cylinder that was fractured in the laboratory under pressures which simulate tectonic forces deep in the Earth. The uneven fracture surfaces grind against one another as the two halves of the rock are forced to slide along the newly formed fault, producing a layer of finely crushed particles called fault gouge. In natural faults, this gouge layer thickens with repeated earthquakes. At the high pressures and temperatures that occur deep in the Earth, the crushed material will react with ground water to form new minerals whose strengths and frictional properties may differ significantly from those of the original rock. For example, the San Andreas Fault zone in California has slid so far that in some places it now has a gouge zone as much as 2/3 mile (1 kilometer) wide, containing a complex assortment of crushed rock and clay-rich material. Laboratory studies of artificial faults filled with fault gouge show that frictional strength and the tendency for "stick-slip" or earthquake behavior depend on many factors, such as mineralogy and particle size, temperature, fault-slip velocity, and the properties of the ground water that circulates within the rock. This information is then used to model the seismic behavior of natural faults.

A major goal of the rock-physics laboratories in the Earthquake Hazards Program of the U.S. Geological Survey (USGS) is to improve understanding of the physics of earthquake faulting. The nucleation, propagation, arrest, and recurrence of most earthquakes depend on the mechanical behavior of fault rocks and fluids at depths of as much as 25 miles (40 kilometers) in the Earth. This region in which earthquakes occur is called the "seismogenic zone."

The process of strain accumulation and release that leads to major earthquakes typically takes hundreds of years or more, making it difficult to study the full cycle in detail. However, the earthquake cycle can be simulated both on a smaller scale and within a shorter time frame in the laboratory to determine the processes leading up to and controlling sudden slip. This "stick-slip" behavior is the laboratory equivalent of an earthquake.

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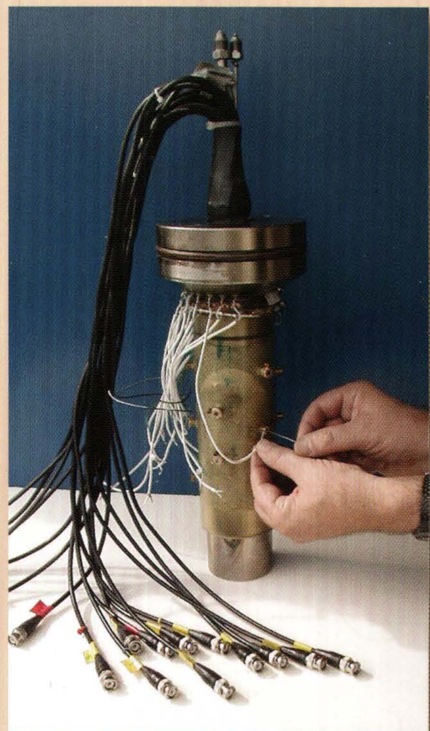
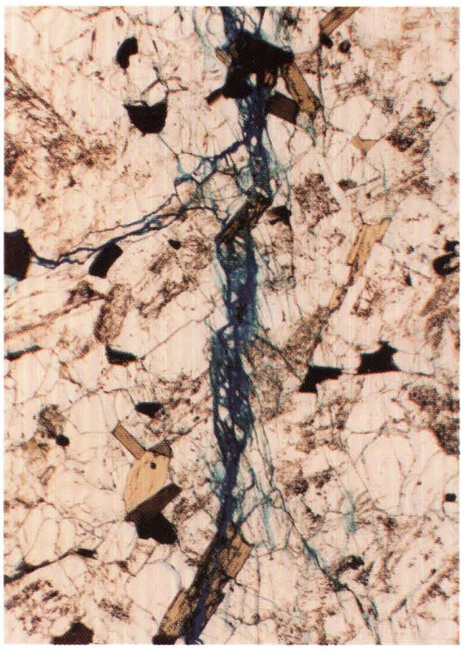


STUDYING FRACTURE PROPAGATION BY MAPPING MICROEARTHQUAKES

◄ Ultrasonic sensors are attached to a granite sample (left) to record the vibrations, known as acoustic emissions, that are produced when mineral grains break during fault formation. The transducer array is a miniature seismic network that is used to locate acoustic-emission events, which can be thought of as microearthquakes.

The acoustic-emission events (microearthquakes) recorded from the sample assembly are plotted in a left-to-right time sequence of images representing a cylindrical granite sample viewed from the side. This time sequence shows the growth of a fracture that begins on the surface of the sample and progresses into the interior of the rock in an expanding arc as the granite fails under high pressure. Such experiments can be used to model large-scale rupture events.

USGS rock-physics laboratories measure rock properties at the high pressures and temperatures that occur in the seismogenic zone, using materials derived from both fault-zone outcrops and drillholes that penetrate faults several miles (kilometers) below the surface. These measurements include the strength and frictional behavior of fault-zone materials, the velocity of seismic waves passing through different rock types, the patterns of microseismicity (indicating small points of failure within a rock) that are observed as rocks are stressed, and the role of water and other fluids as they dissolve and precipitate minerals within fault zones.



Microscopic fractures in rock (filled with blue epoxy in this photograph) that are produced during high-pressure shearing experiments can serve as small-scale analogs of seismogenic faults. This 1/8-inch (4 millimeter)-long fracture in granite has many geometric similarities to larger fault structures. Micromechanical studies are an important part of the broader research effort in USGS rock-physics laboratories to better understand earthquake behavior.

Currently, the USGS plays an active role in scientific fault-zone-drilling projects around the world, including in Japan, Taiwan, and California. For example, the San Andreas Fault Observatory at Depth (SAFOD), a National Science Foundation (NSF)-funded project near Parkfield, California, will penetrate the San Andreas Fault at a depth of 2 miles (3 kilometers), targeting a region where earthquakes occur at regular intervals. Valuable firsthand information about deep-fault-zone properties of this major fault will come from laboratory analysis of the retrieved core samples.

Laboratory studies have made many significant contributions to our understanding of earthquake physics. For example, the "Coulomb failure criterion" provides an important method for predicting whether the stress changes caused by an earthquake will promote the occurrence of new earthquakes on neighboring faults. Laboratory studies of "effective pressure" have shown how increasing pore-fluid pressure can unclamp a fault and induce earthquakes as effectively as raising the applied stresses. Byerlee's law, which states that the range in frictional strength of faults is relatively narrow and independent of rock type, is used to estimate failure stresses in the Earth's crust under different loading conditions and pore-fluid pressures. Laboratory-based "stress corrosion" and "rate and state dependent" models provide a theoretical framework for describing the nucleation process, in which a fault will first move by slow but accelerating creep, ultimately leading to the main dynamic earthquake rupture.

Together, the broad array of laboratory measurements in the USGS rock-physics laboratories improve scientific understanding of the complex dynamic processes that determine the timing and magnitude of earthquakes. These measurements yield the critical information needed for improving the accuracy and predictive power of computer models of earthquakes and fault systems.

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