

Neotectonics: Watching the earth move

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Recent advances in global positioning system (GPS) technology have made it possible to detect millimeter scale changes in the Earth's surface. Using these systems it has been possible to detect relative motion between the large plates of the outer most rigid layer of Earth. These motions previously had only been inferred from indirect evidence of the plates' motions. A remarkable result from these studies is that the plate motions are nearly continuous and not an episodic process, even on human time scales. Analyses of these motions indicate that much of the motion between plates occurs without producing earthquakes (1). In addition to monitoring interplate motions, GPS arrays are making it possible to study present deformation occurring within mountain belts. The strain rate models obtained from the GPS arrays then can be used to test specific theories of crustal deformation in mountain belts.

The theory of plate tectonics that revolutionized the earth sciences during the 1960s was based primarily on indirect evidence of past crustal movements. Motions of the sea floor crust were inferred from the magnetization of the crust that recorded polarity reversals (of known age) of Earth's magnetic field. The symmetric magnetic patterns suggested that new crust was being created at the mid-ocean ridges and then was spreading away from the ridges. The sea floor-spreading hypothesis was successful in explaining many longstanding problems in the earth sciences and became the basis of a new paradigm of crustal mobility.

In recent years, advancements in technology have made it possible to use GPS for high-precision (mm level) surveying. Using the new GPS surveying it is possible to directly observe the movements of the crustal plates. Perhaps the most startling result to most geologists is that the present-day plate motions agree very well with the plate velocities averaged over millions of years, which suggests that the motion is a nearly continuous process rather than a stick-slip or episodic process. In other words, the plate motions are steady-state. This finding has important implications for earthquake seismology and for understanding the formation and deformation of mountain belts.

Most plate boundary zones accommodate motion along relatively narrow regions of deformation. However, plate boundary zones involving continental lithosphere absorb relative motion by deforming over broad zones that are hundreds to even thousands of kilometers wide (2). An understanding of the forces at work in these zones is important because many of the most damaging earthquakes occur within these zones. At the present, we do not know how much of the relative motion between two tectonic plates is accommodated by earthquakes and how much is taken up by slow creep, either steady or episodic. Understanding the ratio of fast, seismic (earthquake producing) slip to slow aseismic slip is fundamentally important in the quest to assess the danger of active geologic faults.

One of the most exciting developments in the past few years is the ability to measure the deformation of the Earth's surface

over a great area in a continuous fashion. Although repeated surveys using GPS provided valuable data, the use of GPS arrays capable of continuously monitoring a large region provides the resolution needed to monitor short- and long-term displacements that occur during and after earthquakes. In addition to making estimates of the component of aseismic creep between the major earthquakes, we also can now estimate the relative amounts of seismic and aseismic slip associated with a particular earthquake event. Cases now have been documented in which the aseismic slip after an earthquake has accommodated as much or more slip as the quake itself. If this is a common occurrence, then it indicates that as much as half or more of plate boundary slip may be aseismic (3).

Currently several GPS arrays are being deployed across plate boundaries in an effort to monitor slip events. For example, an array being installed across the Cascadia subduction zone offshore Oregon and Washington State is capable of detecting purely creep events (4). These events result from slip on a fault that does not radiate seismic energy detectable by seismometers and hence does not produce traditional earthquakes. These creep events may explain the paradox that many fault zones currently have high strain rates, yet their histories are largely devoid of earthquakes or the quakes that did happen were too small to account for the long-term rate of slip.

The improved precision in GPS also makes it possible to study strain in large regions within a plate and test specific theories of deformation in mountain belts. For example, it has been proposed that the kinematics for Asia are consistent with the response of a slowly creeping fluid under the influence of gravity (5–7). The stress field modeled for a viscous medium with gravitational potential energy differences associated with the present-day topography of Asia (together with the India-Eurasia relative plate motion), predicts the observed spatial variation in deformation through Asia (8, 9). This model is successful over length scales of about twice the lithospheric thickness (≈ 200 km). These proposals can be shown to be consistent with strain rate models determined by using GPS and other deformation indicators. In the case of Asia, the GPS results provide an limit on the magnitude of vertically averaged stresses that are on the order of 100–400 bars. Thus the GPS measurements tell us that deformation over distances greater than 200 km is controlled by the bulk effects of crustal thickness, crustal density, and upper mantle density rather than local, vertical variations in rheology or density.

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Abbreviation: GPS, global positioning system.

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