MORE ABOUT THIS MAP

Our Earth is a dynamic planet, as clearly illustrated on the main map by its topography, over 1500 volcanoes, 44,000 earthquakes, and 170 impact craters. These features largely reflect the movements of Earth’s major tectonic plates and many smaller plates or fragments of plates (including *microplates*). Volcanic eruptions and earthquakes are awe-inspiring displays of the powerful forces of nature and can be extraordinarily destructive. On average, about 60 of Earth's 550 historically active volcanoes are in eruption each year. In 2004 alone, over 160 earthquakes were magnitude 6.0 or above, some of which caused casualties and substantial damage.

THE DYNAMIC EARTH

As the main map shows, earthquakes and volcanoes are not randomly scattered over Earth's surface. Instead, most are concentrated along the edges of certain continents, along island chains, or along oceanic ridge crests. Although geologists have long known this, it has been only in the past 40 years that a concept has emerged to satisfactorily link these observations. This unifying concept, called *plate tectonics* (see Kious and Tilling, 1996), is now widely accepted and has revolutionized the earth sciences. Table 4 lists some notable milestones and pioneers in the development of the plate tectonics theory.

Earth’s outermost layer (the relatively stiff and rocky *lithosphere*) is a mosaic of large tectonic plates that move relative to one another at speeds measured in tens of millimeters per year—or about the same rate as our fingernails grow. Plates are cold, dense, and strong enough to resist most large deformation. They average about 80 km thick, but are generally thicker under continents than under oceans. Plates are composed of Earth's relatively thin surface rind (the *crust*) and the topmost 75 km of its 2900-km-thick *mantle*. Over 50 separate plates are recognized by some specialists (for example, Bird, 2003), but the 15 that we name cover more than 95 percent of Earth's surface.

Plates move on a viscous, slowly flowing layer of hotter, softer mantle (the *asthenosphere*). Plate movement represents the top of a large-scale circulation system (*convection*)—driven by Earth's escaping heat that extends deep into the mantle. Mantle flow is like the sluggish movement in a pot of thick soup boiling on a stove. Such flow transports the plates horizontally on Earth’s surface. Where plates grind against each other, stresses can build up and be relieved intermittently when rocks break or slide along *faults*, causing earthquakes. Near some plate boundaries, molten rock (*magma*) can rise to the surface from as deep as many tens of kilometers and erupt to form volcanoes. Some plate boundaries cannot be narrowly defined, but instead are diffuse, encompassing broad areas (see interpretive map of plate tectonics).

Most deformation associated with plate movements is concentrated in the boundary zones between shifting plates, explaining why so many earthquakes and volcanoes are found along or near plate boundaries. Nevertheless, active volcanism and large earthquakes also can occur in plate interiors, which are not immune to plate tectonic forces.

FEATURES OF THE MAP

Topography

Earth's topographic features are largely the expression of plate tectonics, modified by erosion. In the oceans, however, scattering of light in seawater prevents "seeing" most of the sea floor from aircraft or orbiting satellites. Radar waves, like light waves, also cannot penetrate deep into seawater, but they have been used successfully to map the ocean surface from satellites. This mapping technique (*satellite radar altimetry*) involves the measurement of small undulations of the sea surface—tens of kilometers across but only a few centimeters to meters in height—produced by slight differences in gravitational attraction of sea-floor mountains and valleys. These small variations in sea-surface height mimic, and are proportional to, the actual topographic features of the sea floor. Satellite-radar data provide global coverage, but resolve only the larger sea-floor features.

The sea-floor topography shown on the main map was produced from satellite-radar mapping of the sea surface, augmented in places by higher resolution [data obtained by] ship-based acoustic techniques. Sea-floor topography is typically "visualized" as computer-generated, colored maps. In reality, however, the deep ocean floor is sunless, totally dark, unless artificially and briefly lit. Land-surface topography is obtained by using similar satellite technology, but here radar mapping from space gives a direct measure of surface features. Shading—as if the topographic images were illuminated by an artificial sun at 20° above the western horizon—helps the visualization of features.

A Mercator map projection is used, both for its familiarity and for ease of transferring information from other Mercator projection maps. This projection exaggerates the relative size of high-latitude areas, and we have omitted coverage beyond 72° N. and 70° S. on the main map. Polar projections in lower corners (65°–90°) complete the coverage of the planet at the equatorial scale of the main map.

Earthquakes

Earthquakes are vibrational motions produced by rupture of rock along faults. The most common measure of earthquake "size," based on the amount of seismic ground motion, is called *magnitude*. This concept was introduced in the mid-1930s by seismologist Charles F. Richter. He measured a seismic-wave characteristic called *amplitude* (the height of the peak seismic wave recorded by standard seismographs at a standard distance from the earthquake source). Because peak amplitudes vary over such an enormous range among earthquakes, the Richter scale is logarithmic: a magnitude-6 earthquake has 10 times the peak amplitude and releases about 30 times more energy than a magnitude-5 earthquake. A magnitude-3 earthquake is about the smallest that can be felt by humans, and the largest ever recorded was 9.5. In general, the larger the magnitude, the larger the rupture area and movement along the fault. Small-magnitude earthquakes occur much more frequently than large-magnitude earthquakes (see earthquake explanation on front).

Map locations of earthquakes (*epicenters*) are determined from the precise arrival times of seismic waves at global seismic stations, the known speeds of those waves, and the principle of triangulation. Our ability to locate earthquake epicenters has greatly improved during the last decade because of sensitive digital seismic instruments and improved data processing. On the main map, modern accurate epicenters show that most earthquakes are closely clustered along plate boundaries. The most demanding test of earthquake-location accuracy is along oceanic plate boundaries that are typically distant from seismic stations on land. Comparison of the new earthquake locations with the similarly improved mapping of oceanic plate boundaries shows that most of these earthquakes occur neatly along transform fault segments. In contrast, spreading ridge crests, linked by these transforms, generate few detectible earthquakes, because plates there are too thin and weak to allow large stresses to build.

A small number of intraplate earthquakes are shown (as hexagons) on the main map despite their pre-1900 dates or failure to meet the precise location criteria of the main data set. These—as shown by notable earthquakes nos. 1, 4, and 5 (table 3)—are important reminders that devastating earthquakes also can happen far from active plate boundaries.

Volcanoes

Volcanoes are shown in four categories on the basis of their most recent known eruption in the past 10,000 years. Because repose intervals between eruptions can be thousands of years, and because the historical record in many parts of the world is only a few hundred years, we have made only minor graphical distinction between the map symbols for the first three categories. Thus, any one of them might erupt within our lifetimes. Remember, though, that most of Earth’s volcanism occurs along the midocean ridge crests, where countless submarine eruptions take place each year—sight unseen—deep on the ocean floor.

Impact Craters

Discoveries during the past decade allow us to show 30 more impact craters than we did on the 1994 edition of the map (Simkin and others, 1994). Still, the evidence of other impact craters has been destroyed or hidden by post-impact geologic processes; the presently known craters simply serve as a reminder of this cataclysmic process, particularly early in the history of the Earth-Moon system (see inset VI and timeline).

Plate Motions

Divergent plate speeds, measured largely from separations of magnetic stripes at oceanic ridge crests, and then integrated into plate motion models, are shown on the main map with white numerals. Convergent plate motions (stubby arrows with white numerals) are calculated from the same model and independently measured by using Global Positioning System (GPS) data. Thin arrows in plate interiors show less accurate “absolute” plate motions (over the deeper mantle).

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