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Global tectonic maps

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The original kinematic plate tectonic model proposed that the outer shell (lithosphere) of the Earth is divided into a small number of nearly *rigid* plates that slide over the weak asthenosphere. The plates are the surface thermal boundary layer of upper-mantle or global-scale mantle convection, and the descending slabs are the primary active components of the convective system. The plate boundaries are generally narrow and are characterized by earthquakes and volcanoes. The plates, however, are not really rigid or undeformable, and the plate boundaries need not be localized (Dewey and Bird, 1970; Gordon, 2000; Anderson, 2001, 2002; Steinberger et al., 2004). Not only is the plate-slab system the main driver of plate tectonics and mantle convection, but much of the energy dissipation may be in this part of the system as well, rather than in mantle viscosity (Conrad and Hager, 2001). Plates may be held together by lateral compression—or absence of extension—rather than by strength or rigidity; rocks are strong in compression but have little resistance to extension.

It is useful to assess the global data sets that are most relevant to plate tectonics. Here we have compiled a series of global maps that help to confirm various aspects of plate tectonic theory. Plate boundaries are classified as ridges, transform faults, or subduction zones based on basic observations of topography (Fig. 1) and seismicity (Fig. 2). Remarkably, nearly all seafloor spreading ridges lie at a depth of 2500–3000 m below sea level, which is the level of isostasy for hot thin lithosphere. Depths gradually increase away from the ridges because of cooling and thermal contraction, so old ocean basins are commonly 4500–5000 m deep. Fracture zones and aseismic ridges also show up on these maps. Global seismicity (magnitude >5.1, Figures 2, 6, 7, 8) highlights the plate boundaries and reveals their tectonic style. Shallow normal-faulting earthquakes (<30 km deep) are common along slowly spreading ridges but largely absent along rapidly spreading ridges, where the plates are too thin and weak to retain sufficient elastic energy to generate large earthquakes. Transform faults are characterized by relatively shallow (<30 km) strike-slip earthquakes, and they are common along both rapidly spreading and slowly spreading ridges. The deeper earthquakes (green and blue dots in Fig. 2) occur only in subduction zones where sheets of seismicity (i.e., Benioff zones) are critical evidence that relatively cold lithosphere is subducting back into the mantle. But even convergent boundaries are characterized by shallow extensional earthquakes on the ocean side of the trenches. Some regions (e.g., Africa. Asia, western North America, and the Indian Ocean) have distributed earthquake activity, indicating broad deformational zones. Topography and seismicity provide strong evidence for tectonic activity but little or no information on the rate of plate motion.

Focal mechanisms of earthquakes (Figs. 6, 7, 8) provide information on the orientation and amplitudes of the relative motion vectors associated with rapid plate motions. Marine magnetic anomalies, combined with relative plate motion directions based on satellite altimeter measurements of fracture zone trends, have been used to construct a global age map (Fig. 3) of the relatively young (<180 Ma) oceanic lithosphere. Finally the distribution of off-ridge volcanoes that have been active during

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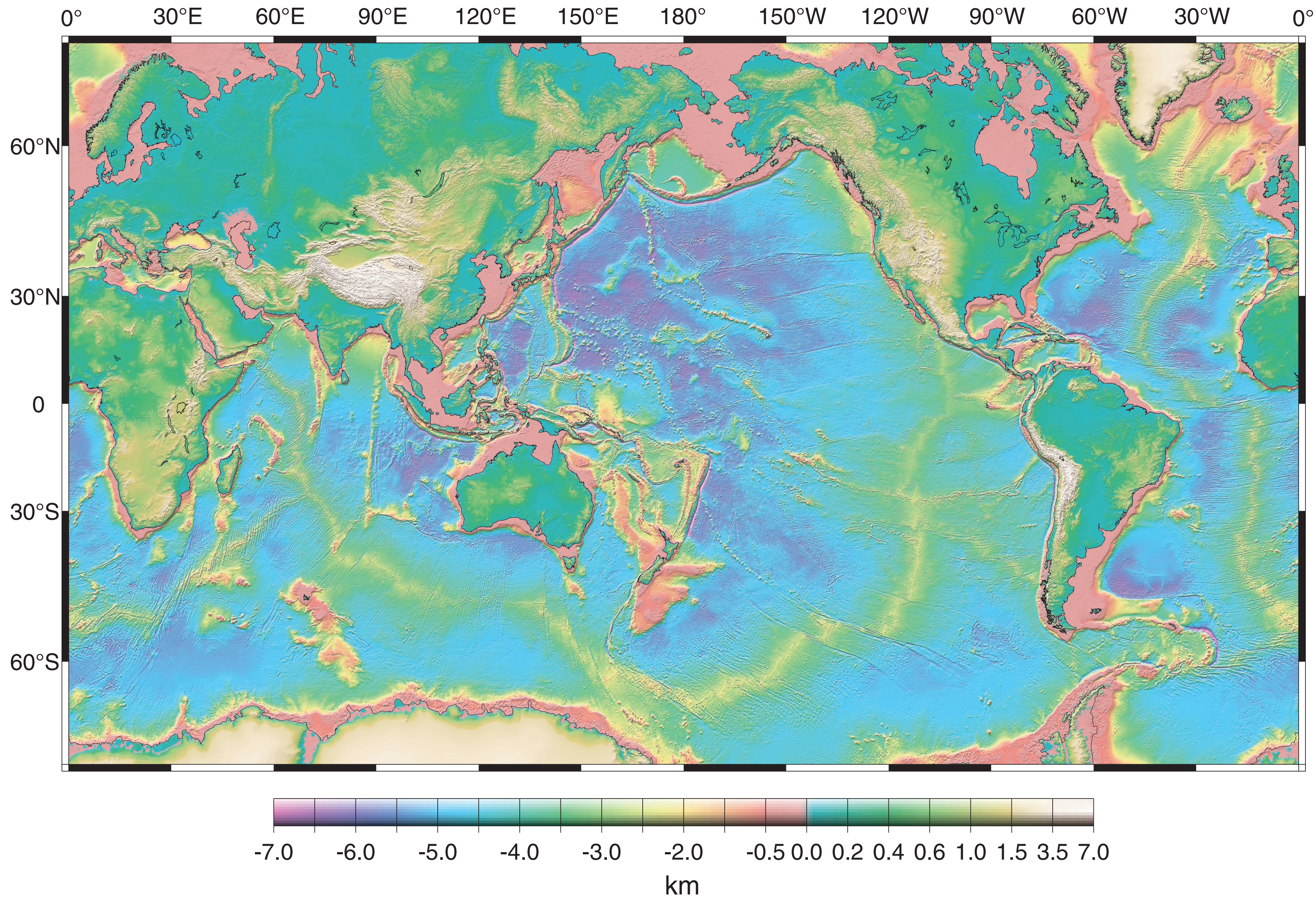

Figure 1. Topography of the Earth based on a global compilation of land data (GTOPO30, http://edcdaac.usgs.gov/gtopo30/README.html) and ocean data from a combination of sparse ship soundings and marine gravity anomalies derived from satellite altimetry (Smith and Sandwell, 1997).

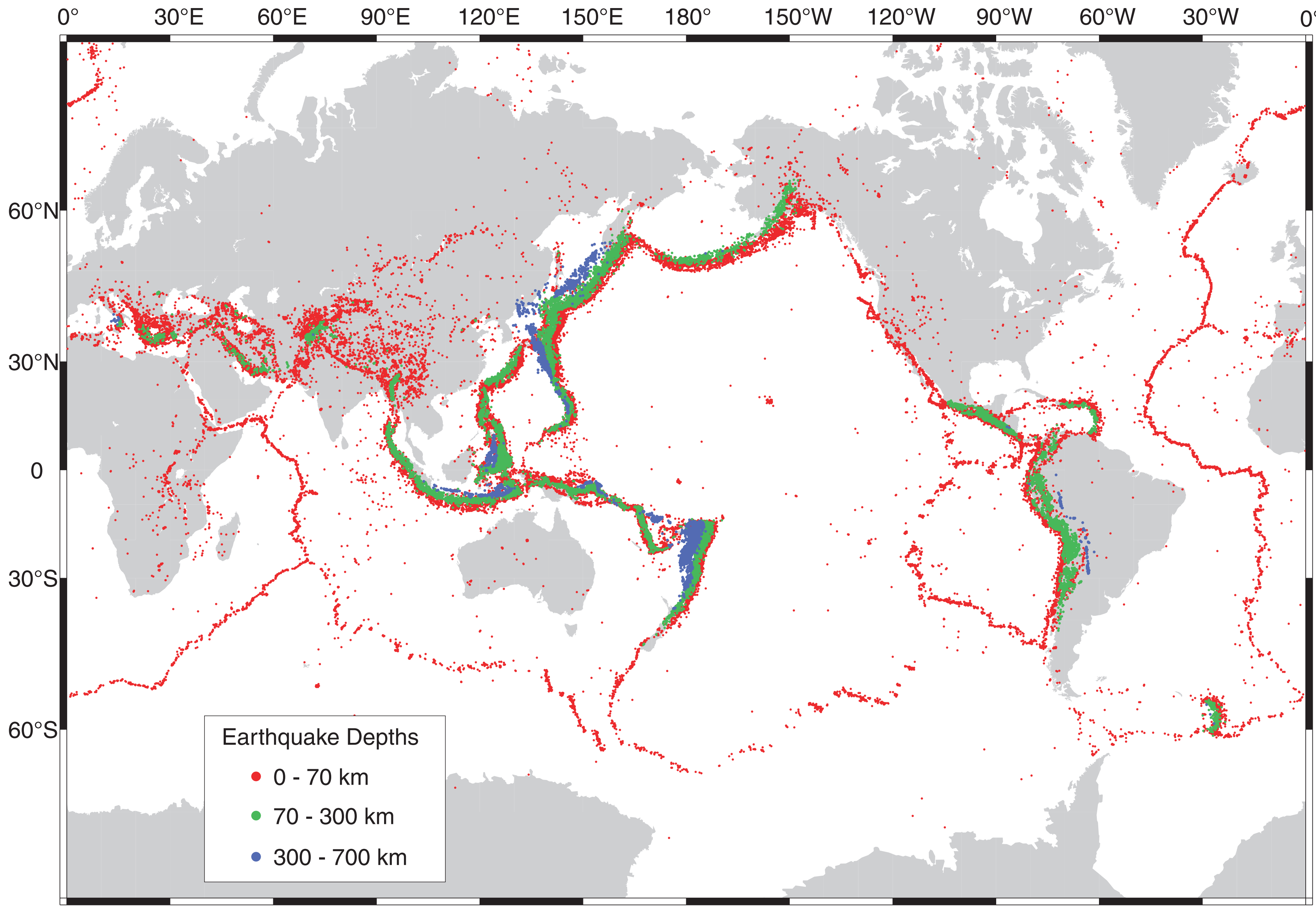

Figure 2. Well-located earthquakes with M >5.1 reveal the global plate boundaries (Engdahl et al., 1998). Shallow earthquakes (0–70 km, red) provide clear definition of the boundaries of the oceanic plates but have a more diffuse distribution on the continents. Intermediate (70–300 km, green) and deep earthquakes (300–700 km, blue) occur in subduction zones and are the primary evidence for lithospheric subduction to at least 670 km.

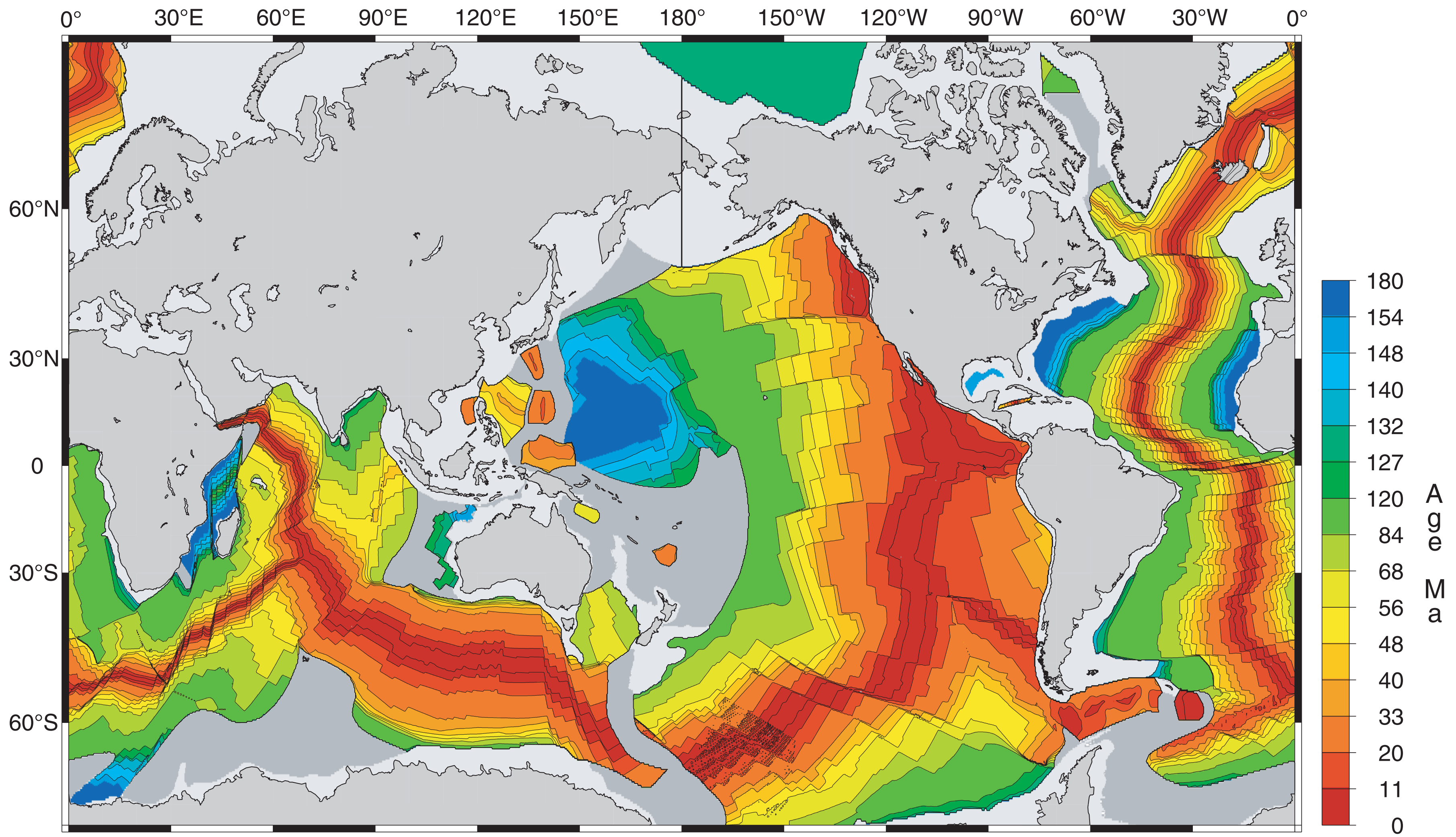

Figure 3. Seafloor age (Müller et al., 1997) based on identified magnetic anomalies and relative plate reconstructions along trends identified in satellite altimeter measurements of marine gravity. Ages in the Cretaceous quiet zone (64–127 Ma) have poor control.

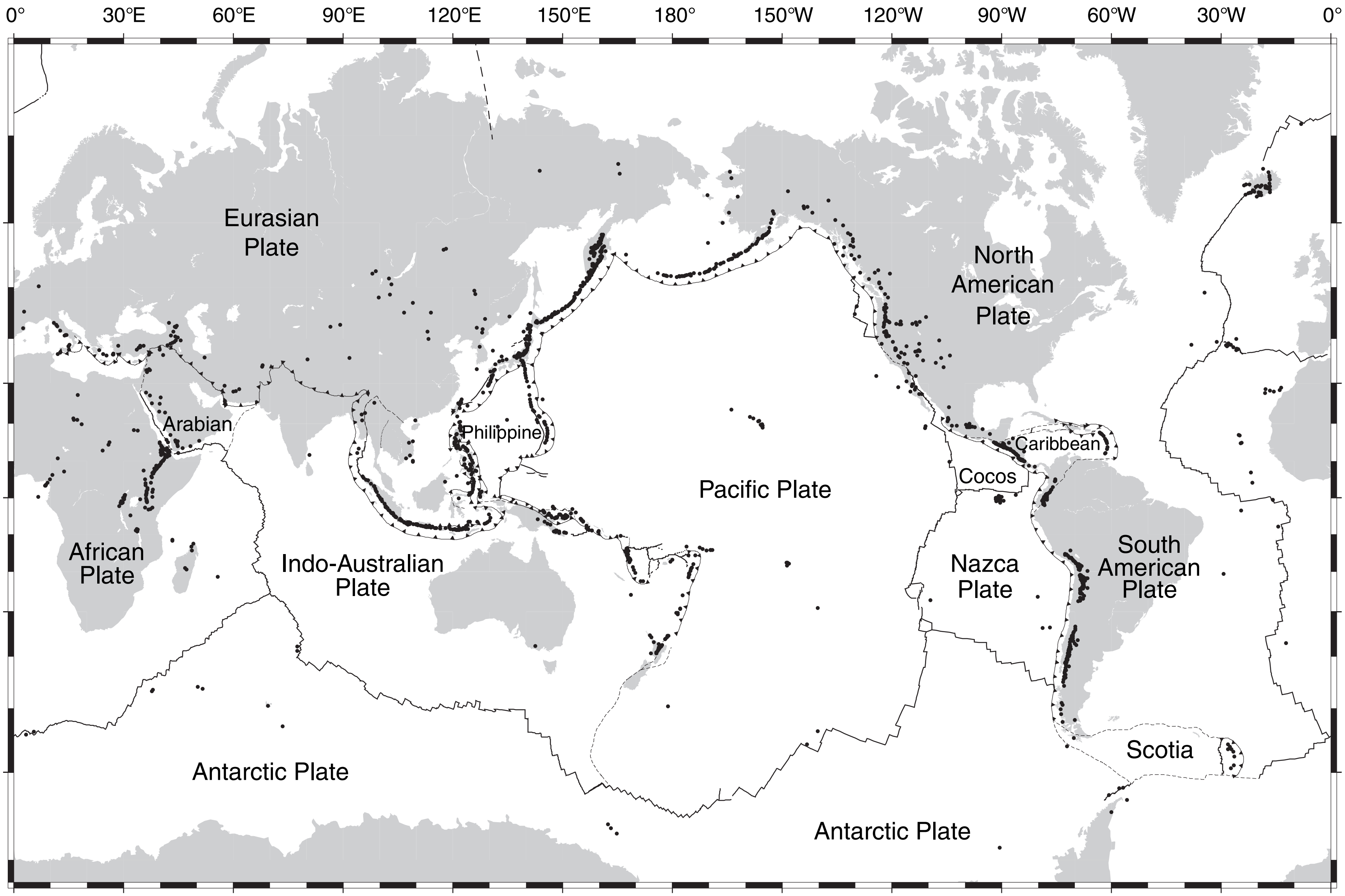

Figure 4. Plates, plate boundaries, and Quaternary volcanoes. The dozen or so tectonic plates are separated by spreading centers (solid lines), transform faults (dashed lines), and subduction or thrust faults (triangular fronts). The majority of active or recently active volcanoes (Siebert and Simkin, 2002) are associated with convergent plate boundaries.

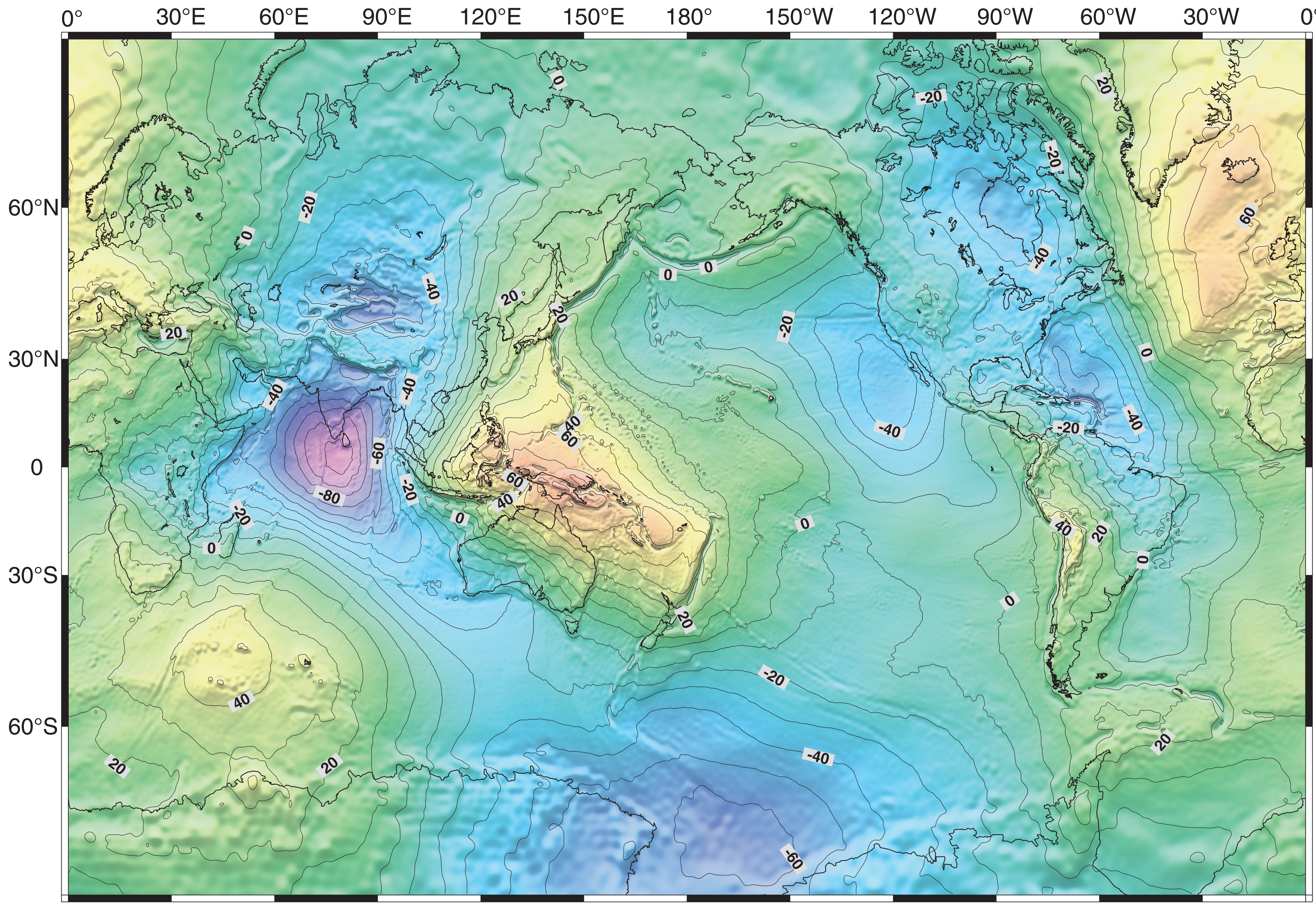

Figure 5. Geoid height (EGM96) above reference ellipsoid WGS84 (Lemoine et al., 1998) based mostly on satellite tracking data and some terrestrial gravity anomaly measurements. Unlike topography, seismicity, and age, shown in the other maps, the geoid is poorly correlated with surface tectonics except in areas where mature lithosphere has subducted.

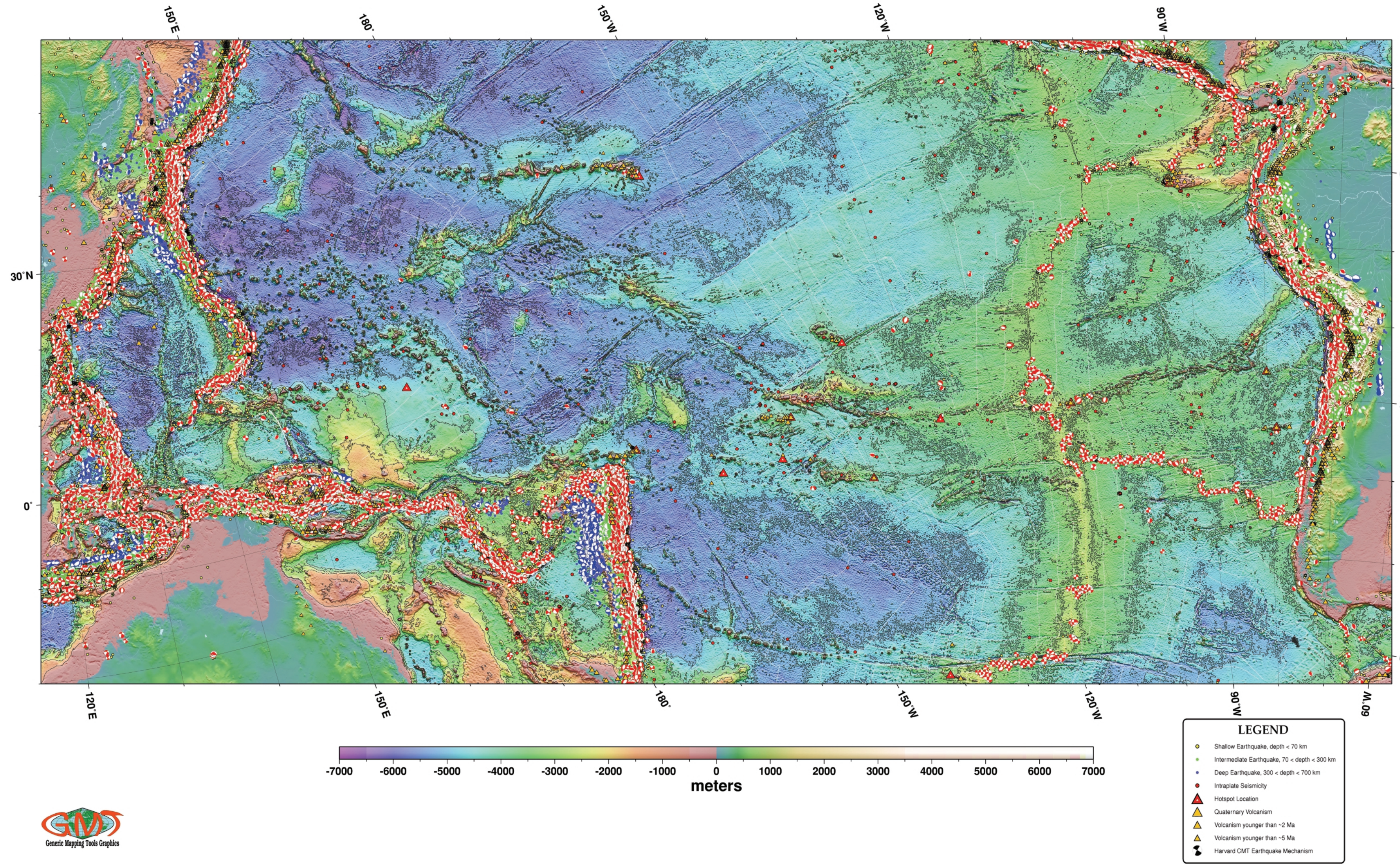

Figure 6. Tectonic map of the central Pacific. This is an oblique Mercator projection oriented such that features that are parallel, or co-polar, to the Hawaiian chain will plot as horizontal lines. Volcanoes are shown as small triangles and "hotspots" as large triangles. Focal mechanisms of earthquakes are from the Harvard catalog (www.seismology.harvard.edu/CMTsearch.html). Solid circles are earthquakes for which the focal mechanisms are unavailable. Note the band of earthquakes and volcanoes in the south Pacific extending from Samoa and the Tonga Trench to Chile. The Louisville seamount chain and the Eltanin fracture zone are at the lower center of the map; portions of it are parallel to the Hawaiian chain.

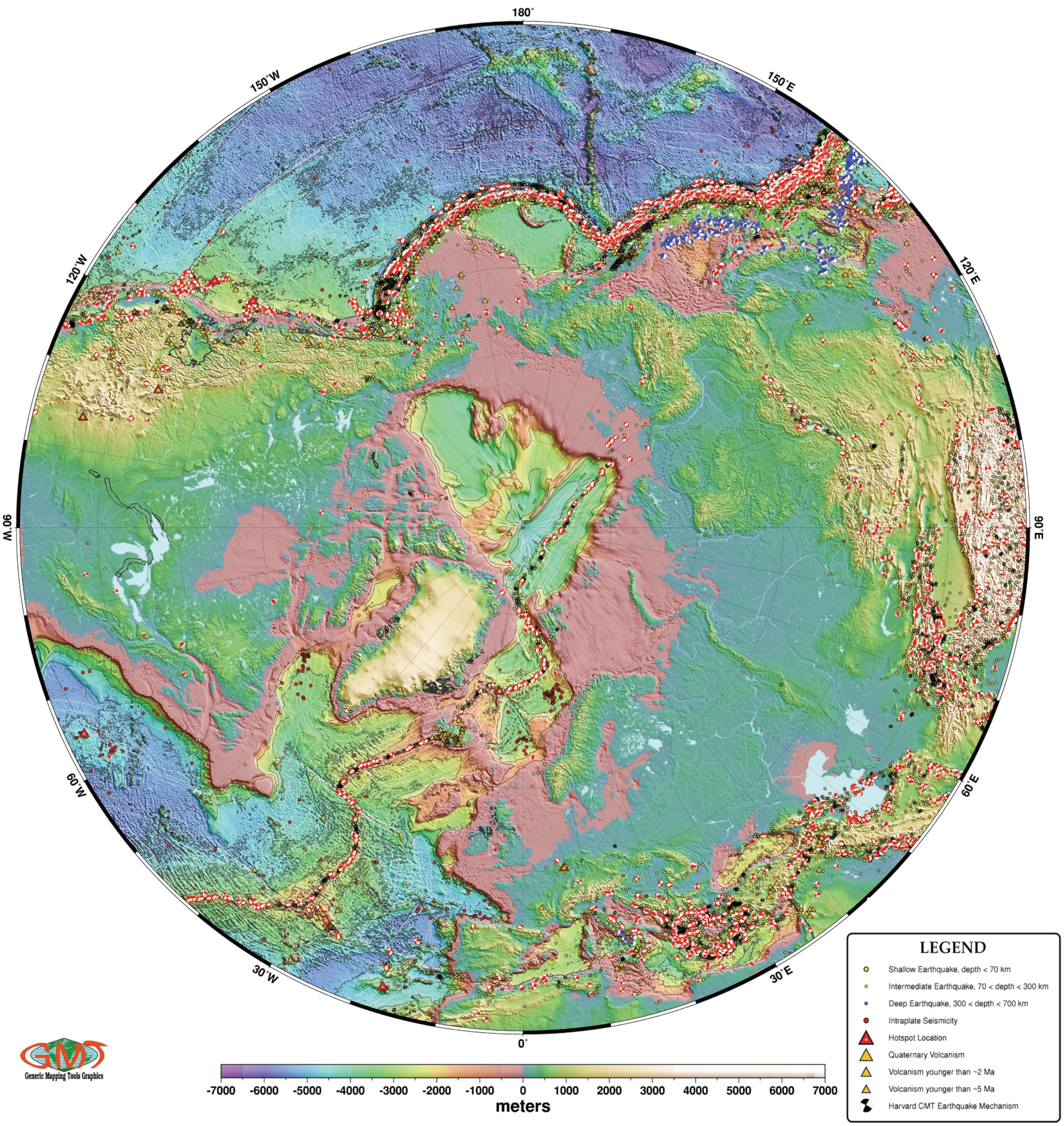

Figure 7. Polar tectonic map, North Polar region. This is a stereographic projection that highlights tectonic patterns in the far northern hemisphere. Note that the seismicity trend that follows the Lomonosov ridge becomes more diffuse as it enters the Siberian continent, but nevertheless indicates the continuation of the North America–Eurasia plate boundary.

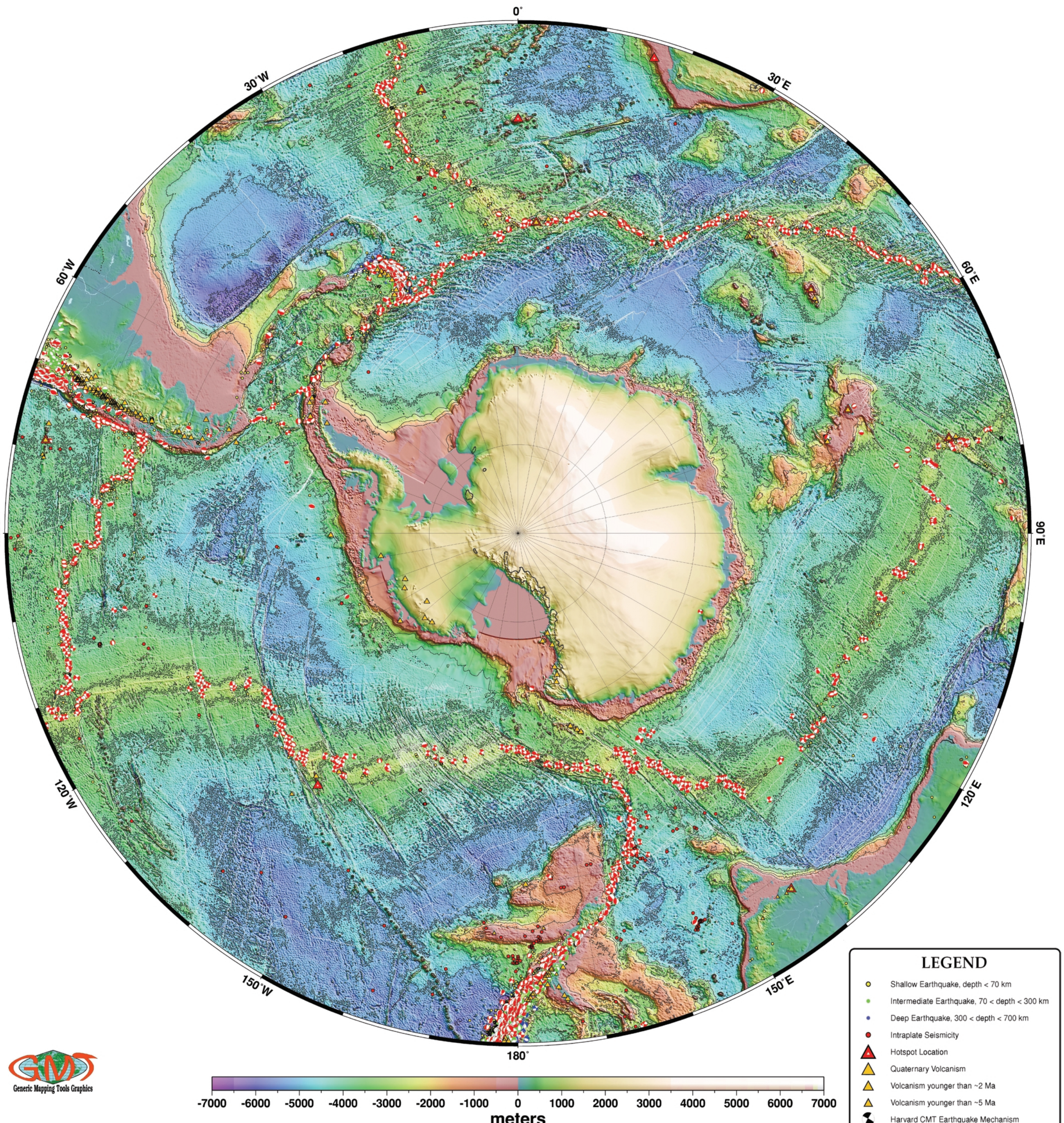

Figure 8. Polar tectonic map, South Polar region. Stereographic projection of the southern hemisphere highlighting the Antarctic continent, which is surrounded by spreading centers.

the Quaternary mainly occur directly behind trenches where wet subducting slabs reach asthenospheric depths and trigger back-arc volcanism (Fig. 4). A few active volcanoes occur in the interiors of the plates and in diffuse extensional plate boundaries. The geoid (Fig. 5) shows little correlation—at long wavelengths—with surface tectonics and primarily reflects mass anomalies deep in the mantle. It is expected that the dynamic topography—the topography not due to crustal and near-surface variations—and the stress state of the lithosphere at long wavelengths will also reflect deep density differences. Insofar as volcanoes correlate with high surface elevations and extensional stress, one expects correlation of volcanoes with deep mantle structure, even if there is no material transfer. Figures 6, 7, and 8 are global tectonic maps that show topography, bathymetry, earthquakes, focal mechanisms, volcanoes, and hotspots. Figure 6 presents these data in oblique perspective about a pole close to the average rotation pole for the Pacific plate since 47 Ma. Figures 7 and 8 allow for a closer examination of the polar regions.

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The data provided in the figures presented here represent decades of data collection by thousands of scientists. The figures were constructed using Generic Mapping Tools (Wessel and Smith, 1995).

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