II. Sea Floor Disappears as Plates Sink Along Deep Ocean Trenches

Subduction zones occur where a plate created by sea-floor spreading comes together or converges with another plate by sinking (or *subducting*) beneath it. A deep trench typically forms on the ocean floor where the subducting plate bends downward toward the deep mantle (figs. 1–3). More than 75 percent of all earthquakes occur in subduction zones, by slip between plates and rupture within descending plates (called *slabs*), forming inclined zones to depths as great as 690 km below the surface. Huge amounts of oceanic crust (~20 km^3/yr, or ~3 km^2/yr of sea-floor area) are consumed along trenches during subduction. As slabs sink deep into hotter mantle, they warm, lose most of their stored water, and eventually soften to a state incapable of producing either volcanoes or earthquakes.

Subduction earthquakes have caused untold damage throughout human history, killing over 400,000 people in the past 40 years alone. This figure includes the effects of large shallow earthquakes that displace the sea floor, generating high-speed ocean waves (called *tsunamis*) that can travel great distances, devastating coastal communities (see fig. 4 and table 3).

The process of volcano building begins with the initially cold slab descending into the hotter mantle, warming and dehydrating as the water it contains is "sweated out." These low-density fluids can then migrate upward, triggering partial melting of the hot, weak mantle above. Because this melted material (or *magma*) is less dense than the surrounding solid mantle, it rises buoyantly (or "floats"). Some of the magma accumulates in near-surface magma chambers, and some migrates to Earth's surface where it erupts and forms chains of volcanoes—called *island arcs* in oceans or *volcanic arcs* on land—that typically parallel the nearby trench (see schematic cross section, on front, and fig. 3).

Subduction-zone eruptions can be either explosive, producing airborne and ground-hugging fragmental deposits, or non-explosive, producing lava flows. Arc volcanoes built from both fragmental materials and lava flows are typically steep-sided cones called *stratovolcanoes* (fig. 5). Volcanic arcs contain nearly 80 percent of historically active land volcanoes, including those producing some of Earth's most destructive eruptions (see table 2). Some island arcs, such as those north of New Zealand, have localized plate divergence behind them (*back-arc spreading*) that resembles spreading at midocean divergent plate boundaries.

During subduction, sediments and crustal rocks on the upper part of the downgoing slab can be scraped off and added (or *accreted*) to the upper plate. The sinking plate can mechanically erode the bottom of the upper plate. Some of the eroded material also can be added to the bottom of the overriding plate at greater depth (*underplating*). When oceanic lithosphere sinks beneath a continent, mountains are formed by the combined processes of accretion, thickening (by squeezing), underplating, and volcanism. South America's lofty, 8,000-km-long Andes mountain chain formed by such processes, producing Earth's highest volcanoes (see table 2).

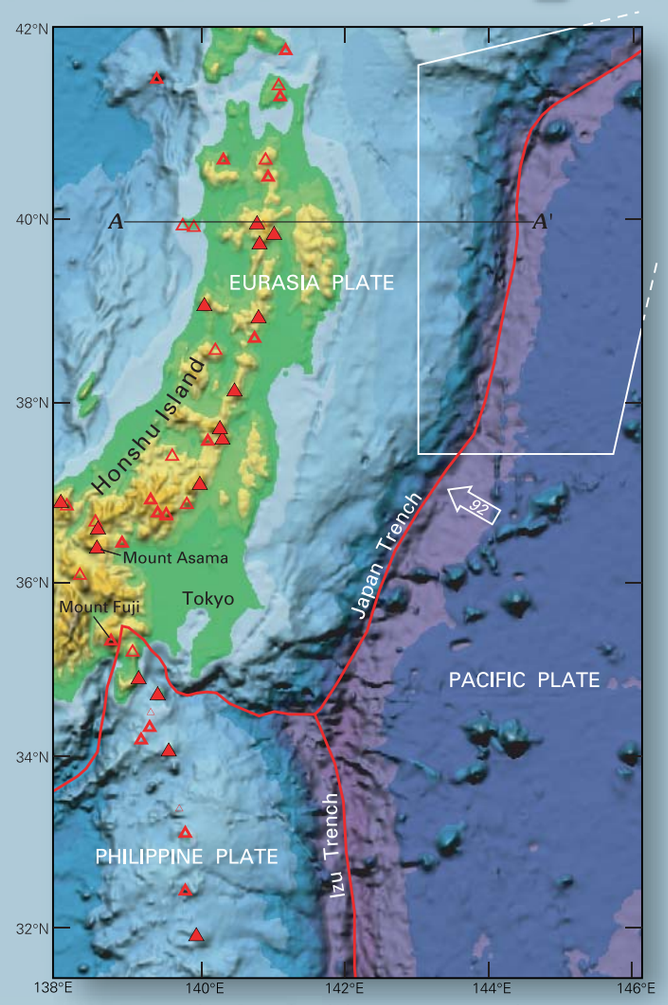

Figure 1.—Japan's subduction zones are the most closely studied in the world. Here, the Pacific plate sinks beneath Honshu Island, forming a deep trench, island-arc volcanoes, and a triple junction where it meets the Philippine plate. See main map for explanation of symbols. The approximate area of figure 2 is shown by the white outline.

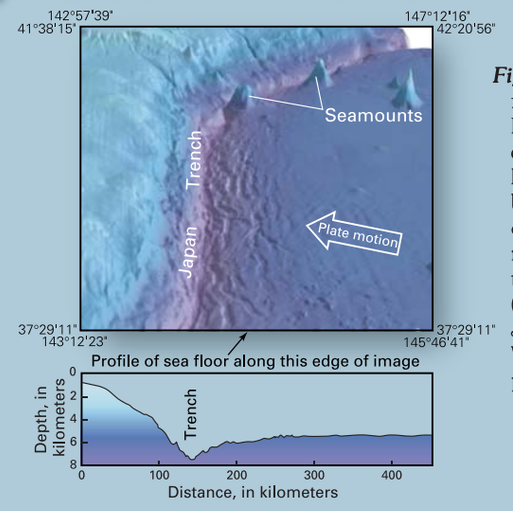

Figure 2.—Oblique view showing faulting of the sea floor where the Pacific plate bends and starts its descent, forming the Japan Trench, here over 7 km deep (see profile below image). Bending breaks the top of the slab, producing valleys and ridges that are roughly parallel to the trench. Image by Joel E. Robinson (USGS) from data collected by the Japan Hydrographic Department. Vertical exaggeration: image, ~10x; profile, ~20x.

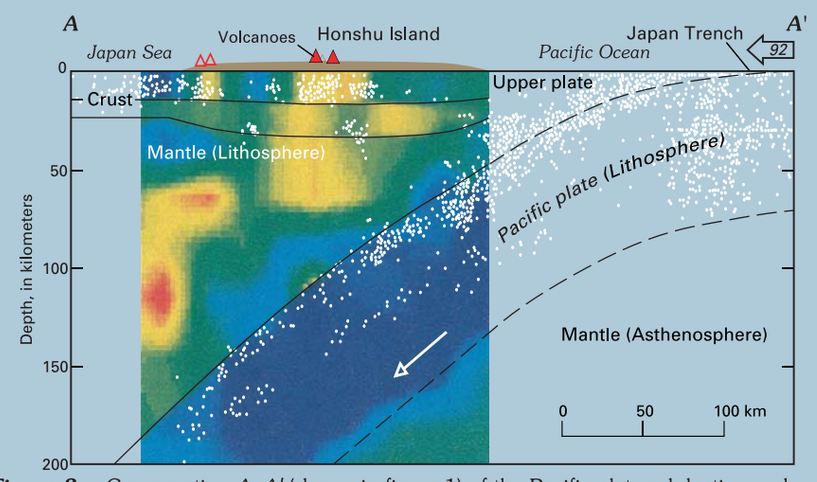

Figure 3.—Cross section *A–A'* (shown in figure 1) of the Pacific plate subducting under Japan. The color part of this figure is a computer image showing variations in seismic wave speeds. Seismic waves pass rapidly through the relatively cold Pacific plate (dark-blue areas) and pass more slowly through the surrounding, hotter mantle (light-blue to reddish areas). Earthquakes (white dots) occur within the cold, strong slab as well as within the overriding plate. Shallow crust under the active volcanoes is hot (yellow areas) and seismically active because rising magma weakens and promotes fracturing of the overlying rock. Modified from Zhao and others (1992). See main map for explanation of symbols.

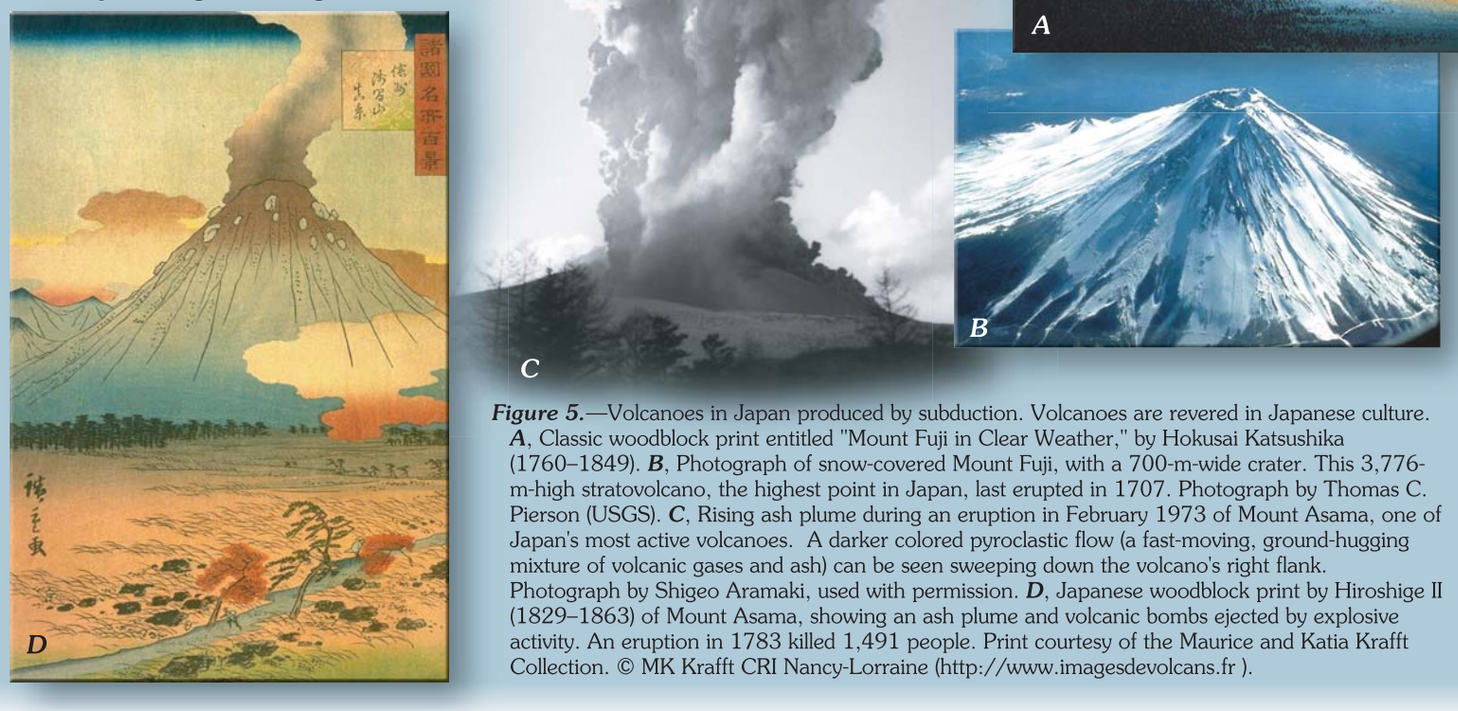

Figure 5.—Volcanoes in Japan produced by subduction. Volcanoes are revered in Japanese culture. ***A***, Classic woodblock print entitled "Mount Fuji in Clear Weather," by Hokusai Katsushika (1760–1849). ***B***, Photograph of snow-covered Mount Fuji, with a 700-m-wide crater. This 3,776-m-high stratovolcano, the highest point in Japan, last erupted in 1707. Photograph by Thomas C. Pierson (USGS). ***C***, Rising ash plume during an eruption in February 1973 of Mount Asama, one of Japan's most active volcanoes. A darker colored pyroclastic flow (a fast-moving, ground-hugging mixture of volcanic gases and ash) can be seen sweeping down the volcano's right flank. Photograph by Shigeo Aramaki, used with permission. ***D***, Japanese woodblock print by Hiroshige II (1829–1863) of Mount Asama, showing an ash plume and volcanic bombs ejected by explosive activity. An eruption in 1783 killed 1,491 people. Print courtesy of the Maurice and Katia Krafft Collection. © MK Krafft CRI Nancy-Lorraine (http://www.imagesdevolcans.fr).

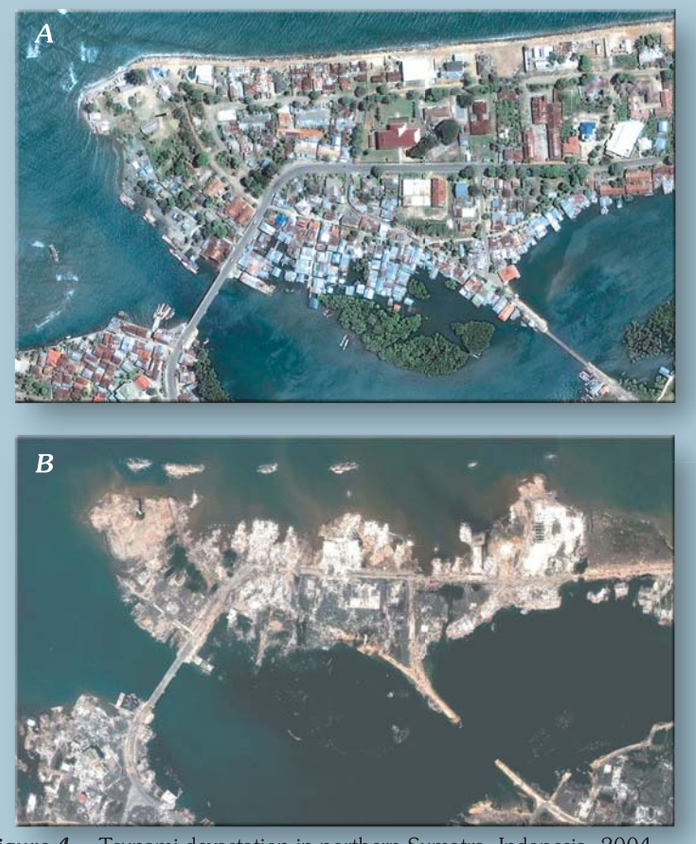

Figure 4.—Tsunami devastation in northern Sumatra, Indonesia, 2004. ***A***, Satellite image of Lohkngar (coastal Banda Aceh) before the December 26, 2004, earthquake that triggered deadly tsunamis (see table 3). ***B***, Same scene 2 days after the tsunamis struck; most buildings have been washed away, and the shoreline itself has been heavily eroded, in places entirely missing. QuickBird images acquired and processed by DigitalGlobe.

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