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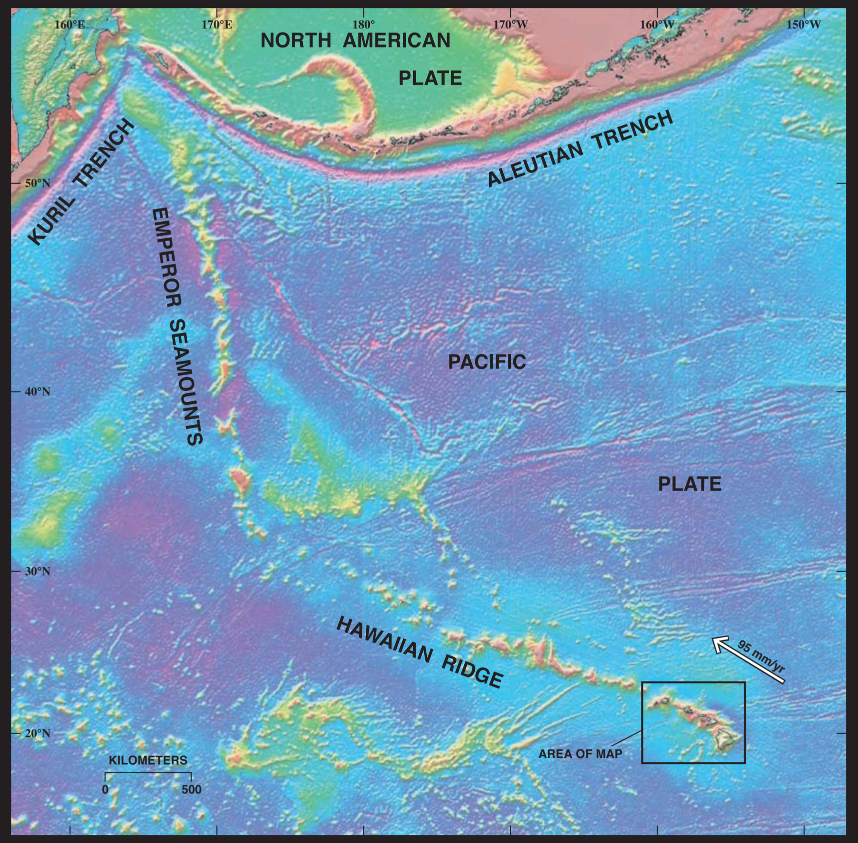


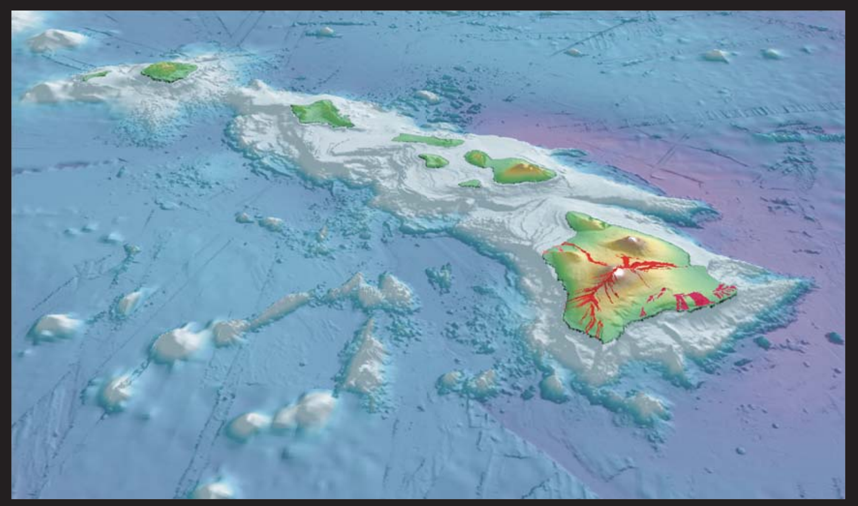
Bathymetry of the northwest Pacific Ocean. The linear Hawaiian Ridge and older Emperor Seamounts are generally accepted to have formed by northwestward motion of the Pacific Plate over a hot spot in the mantle that itself migrated southward in the past; arrow denotes present plate motion. The Hawaiian Islands represent the latest volcanism associated with this hot spot, which has been vigorous enough to build massive volcanoes that breach the sea surface.

The volcanoes of Hawaii

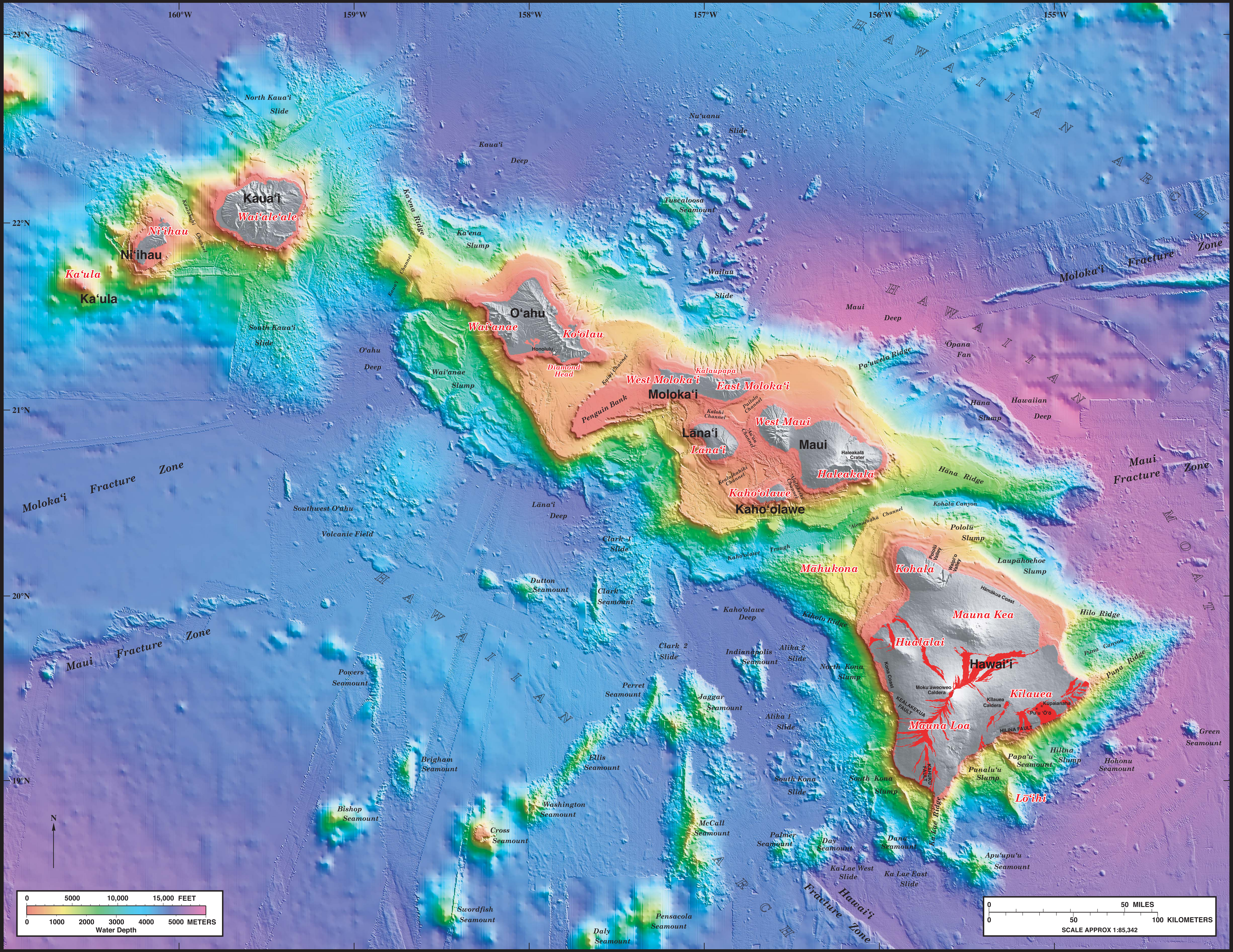
Hawaiian volcanoes typically evolve in four stages as volcanism waxes and wanes: (1) *early alkalic*, when volcanism originates on the deep sea floor; (2) *shield*, when roughly 95 percent of a volcano's volume is emplaced; (3) *post-shield alkalic*, when small-volume eruptions build scattered cones that thinly cap the shield-stage lavas; and (4) *rejuvenated*, when lavas of distinct chemistry erupt following a lengthy period of erosion and volcanic quiescence. During the early alkalic and shield stages, two or more elongate rift zones may develop as flanks of the volcano separate. Mantle-derived magma rises through a vertical conduit and is temporarily stored in a shallow summit reservoir from which magma may erupt within the summit region or be injected laterally into the rift zones. The ongoing activity at Kīlauea's Pu‘u ‘Ō‘ō cone that began in January 1983 is one such rift-zone eruption. The rift zones commonly extend deep underwater, producing submarine eruptions of bulbous pillow lava.

Once a volcano has grown above sea level, subaerial eruptions produce lava flows of jagged, clinkery ‘a‘ā or smooth, ropy pāhoehoe. If the flows reach the ocean they are rapidly quenched by seawater and shatter, producing a steep blanket of unstable volcanic sediment that mantles the upper submarine slopes. Above sea level then, the volcanoes develop the classic shield profile of gentle lava-flow slopes, whereas below sea level slopes are substantially steeper. While the volcanoes grow rapidly during the shield stage, they may also collapse catastrophically, generating giant landslides and tsunami, or fail more gradually, forming slumps. Deformation and seismicity along Kīlauea's south flank indicate that slumping is occurring there today.

Loading of the underlying Pacific Plate by the growing volcanic edifices causes subsidence, forming deep basins at the base of the volcanoes. Once volcanism wanes and lava flows no longer reach the ocean, the volcano continues to submerge, while erosion incises deep river valleys, such as those on the Island of Kaua‘i. The edges of the submarine terraces that ring the islands, thus, mark paleocoastlines that are now as much as 2,000 m underwater, many of which are capped by drowned coral reefs.



3-D perspective view of Hawaii. The Hawaiian Islands (shown in green; white at summits of Mauna Loa [4,170 m high] and Mauna Kea [4,206 m high]) are the tops of massive volcanoes, most of whose bulks lie below the sea surface. Ocean depths are colored from purple (5,750 m deep northeast of the Island of Maui) and blue to light gray (shallowest). Historical lava flows, erupted from the summits and rift zones of Mauna Loa, Kīlauea, and Hualālai volcanoes on the Island of Hawai‘i, are shown in red.



Mercator map projection; image illuminated from the northeast to emphasize sea-floor relief.

NOT TO BE USED FOR NAVIGATION

Hawaii's Volcanoes Revealed

By

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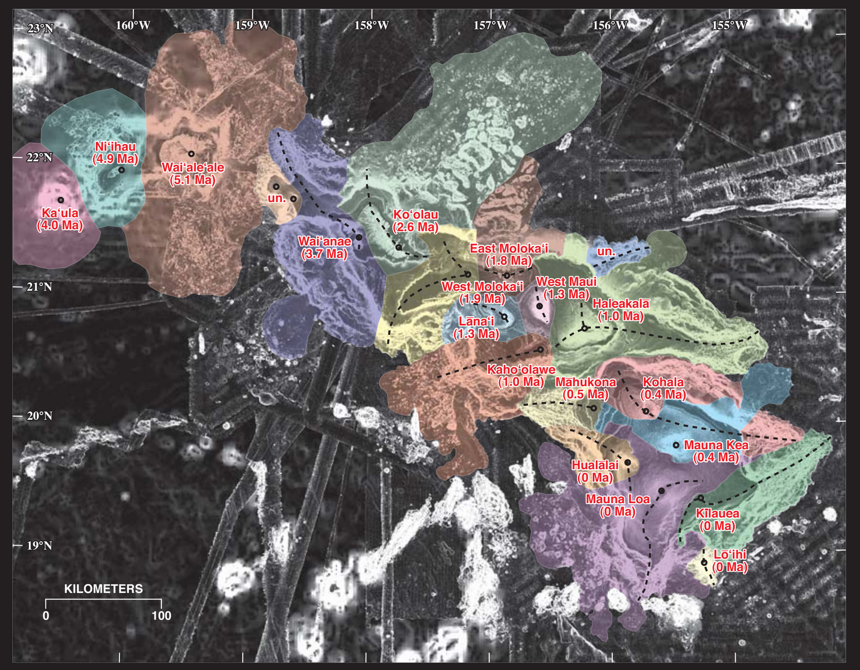

Interpretive map of Hawaii's volcanoes. Transparent pastel colors on a slope map define the approximate extent of each known major Hawaiian shield volcano and its landslide debris; white denotes steep slopes, dark gray denotes flat-lying areas. Circles mark the location of main eruptive centers, presumably overlying summit magma reservoirs; dashed lines mark well-developed rift zones. The westward-increasing ages of shield-stage lavas (given in millions of years [Ma] for each volcano) continues along the Hawaiian Ridge and on through the Emperor Seamounts (76 Ma at the northern end), supporting the plate-motion theory.

Mapping the sea floor around Hawaii

The Japan Marine Science and Technology Center (JAMSTEC) funded and led a four-year collaborative survey of the underwater flanks of Hawaii's shield volcanoes. This exploration, involving scientists from the U.S. Geological Survey (USGS) and other Japanese and U.S. academic and research institutions, utilized manned and unmanned submersibles, rock dredges, and sediment piston cores to directly sample and visually observe the sea floor at specific sites. Ship-based sonar systems were used to more widely map the bathymetry from the sea surface.

The state-of-the-art multibeam sonar systems, mounted on the hull of GPS-navigated research vessels, convert the two-way travel times of individual sonar pings and their echoes into a line of bathymetry values across the ship track. The resulting swaths across the ocean bottom, obtained along numerous overlapping ship tracks, reveal the sea floor in stunning detail. The survey data collected by JAMSTEC form the basis for the bathymetry shown on the map, augmented with bathymetric data from other sources. Bathymetry that is predicted from variations in sea-surface height, observable from satellites, provides the low-resolution (fuzzy) bathymetry in between ship tracks. Subaerial topography is from a USGS 30-m digital elevation model of Hawaii. Historical lava flows are shown in red.

Prominent terraces (shown in orange and yellow) illustrate the larger size of the islands in the past; O‘ahu and the Maui-Nui complex (Maui, Moloka‘i, Lāna‘i, and Kaho‘olawe islands, and Penguin Bank), in particular, are mere vestiges of their former extent. Lō‘ihi, the youngest volcano in the chain, has not yet reached the sea surface. Fields of blocky debris, such as Ko‘olau's Nu‘uanu Slide, were created by catastrophic landslides, which carried large parts of some volcanoes as much as 200 km across the sea floor. Slower-moving, sediment-blanketed slumps, in contrast, typically develop ridges that parallel the paleocoastlines, such as Haleakalā's Hāna Slump. Eruptions along the submarine part of a volcano's rift zone produce a rugged morphology, as at Kīlauea's Puna Ridge. Numerous seamounts of Late Cretaceous age (approximately 80 Ma) are scattered across the deep sea floor and are unrelated to the hot spot that supplies Hawaii's volcanoes.

Submarine bathymetry and subaerial topography data sources:
Japan Marine Science and Technology Center, Yokosuka, Japan
http://www.jamstec.go.jp/
U.S. Geological Survey, Menlo Park, California
http://walrus.wr.usgs.gov/infobank/
Monterey Bay Aquarium Research Institute, Monterey, California
http://www.mbari.org/data/mapping/hawaii/index.htm
University of Hawai‘i, School of Ocean and Earth Science and Technology, Honolulu, Hawaii
http://www.soest.hawaii.edu/HMRG/
National Geophysical Data Center, Boulder, Colorado
http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html
Scripps Institution of Oceanography, San Diego, California
http://sioexplorer.ucsd.edu/
U.S. Army Corps of Engineers, Mobile, Alabama
http://shoals.sam.usace.army.mil/default.htm
Global seafloor topography (predicted bathymetry)
http://topex.ucsd.edu/marine_topo/mar_topo.html

Additional reading:
Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., 1987, Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, 2 v., 1667 p.
Francis, Peter, 1993, Volcanoes—A planetary perspective: Oxford, Clarendon Press, 433 p.
Heliker, Christina, Swanson, D.A., and Takahashi, T.J., eds., 2003, The Pu‘u ‘Ō‘ō-Kūpaianaha eruption of Kīlauea Volcano, Hawai‘i—The first 20 years: U.S. Geological Survey Professional Paper 1676, 206 p.
Macdonald, G.A., Abbott, A.T., and Peterson, F.L., 1983, Volcanoes in the sea—The geology of Hawaii (2d ed.): Honolulu, University of Hawai‘i Press, 517 p.
Rhodes, J.M., and Lockwood, J.P., eds., 1995, Mauna Loa revealed—Structure, composition, history, and hazards: American Geophysical Union Geophysical Monograph 92, 348 p.
Smith, W.H.F., and Sandwell, D.T., 1997, Global seafloor topography from satellite altimetry and ship depth soundings: Science, v. 277, p. 1957-1962.
Takahashi, Eiichi, Lipman, P.W., Garcia, M.O., Naka, Jiro, and Aramaki, Shigeo, eds., 2002, Hawaiian volcanoes—Deep underwater perspectives: American Geophysical Union Geophysical Monograph 128, 418 p.
Tarduno, J.A., Duncan, R.A., Scholl, D.W., Cottrell, R.D., Steinberger, Bernard, Thordarson, Thorvaldur, Kerr, B.C., Neal, C.R., Frey, F.A., Torii, Masayuki, and Carvallo, Claire, 2003, The Emperor Seamounts—Southward motion of the Hawaiian hotspot plume in Earth's mantle: Science, v. 301, p. 1064-1069.

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