U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2010–1083-L

Seismicity of the Earth 1900–2012
Sumatra and Vicinity

Compiled by Gavin P. Hayes,[1] Melissa Bernardino,[2] Fransiska Dannemann,[3] Gregory Smoczyk,[1] Richard Briggs,[1] Harley M. Benz,[1] Kevin P. Furlong,[4] and Antonio Villaseñor[5]
2013

[1]U.S. Geological Survey
[2]Department of Geological Sciences, University of Colorado Boulder, Colo., USA
[3]Department of Geological Sciences, Indiana University, Bloomington, Ind., USA
[4]Department of Geosciences, Pennsylvania State University, State College, Penn., USA
[5]Institute of Earth Sciences, Consejo Superior de Investigaciones Científicas, (CSIC), Barcelona, Spain

TECTONIC SUMMARY

The plate boundary southwest of Sumatra, Indonesia, is part of a long tectonic collision zone that extends over 8,000 km from Papua, New Guinea, in the east, to the Himalayan front in the west. The Sumatra-Andaman part of the collision zone forms a subduction-zone megathrust boundary, the Sunda Arc (Sunda-Java trench), which accommodates convergence between the Indo-Australia and Sunda plates. This convergence is responsible for the intense seismicity and volcanism in Sumatra. Plate-boundary related deformation is also not restricted to the subduction zone and overriding plate; the subducting Indo-Australia plate actually comprises two somewhat independent plates (India plate and Australia plate), with small amounts of motion relative to one another, that are joined along a broad, actively deforming region producing seismicity up to several hundred kilometers west of the trench. This deformation is exemplified by the recent April 2012 earthquake sequence, which includes the April 11, 2012 M 8.6, and M 8.2 strike-slip events and their subsequent aftershocks.

The relative motion between the Indo-Australia and Sunda plates is rapid, decreasing from roughly 63 mm/yr near the southern tip of Sumatra (Australia plate relative to Sunda plate) to 44 mm/yr north of Andaman Islands (India relative to Sunda) and rotating counterclockwise to the northwest, so that relative motion near Jakarta is nearly trench-normal but becomes nearly trench parallel near Burma. As a result of the rotation of relative plate motion along the strike of the arc and the interaction of multiple tectonic plates, several interrelated tectonic elements compose the Sumatra-Andaman part of the plate boundary. Most strain accumulation and release occurs along the Sunda megathrust of the main subduction zone, where lithosphere of the subducting Indo-Australia plate is in contact with the overlying Sunda plate down to a depth of 60 km. Strain release associated with deformation within the subducting slab is evidenced by deeper earthquakes that extend to depths of less than 300 km on Sumatra and 150 km or less along the Andaman Islands. The increasingly oblique convergence between these two plates moving northwest along the arc is accommodated by crustal seismicity along a series of transform and normal faults. The Sumatra Fault, a major transform structure that bisects Sumatra, accommodates the northwest-increasing lateral component of relative plate motion. East of the Andaman Islands, back-arc spreading in the Andaman Sea produces a zone of distributed normal and strike-slip faulting. Similar to the Sumatra Fault, the Sagaing Fault near Burma also accommodates the strike-slip component of oblique plate motion.

Paleoseismic studies using coral reefs as a proxy for relative land level changes associated with earthquake displacement suggest that the Sunda arc has repeatedly ruptured during relatively large events in the past, with records extending as far back as the 10th century. In northern Simeulue Island, the southern terminus of the 2004 megathrust earthquake rupture area, a cluster of megathrust earthquakes occurred over a 56-year period between A.D. 1390 and 1455 resulting in uplift substantially greater than that caused by the 2004 event. Studies that look at large sheeted deposits of sand on land interpreted as the transport of debris from a tsunami wave also indicate that this region has gone through significant tsunamis in the past, albeit infrequently.

Prior to 2004, the most recent megathrust earthquakes along the Sunda Arc were in 1797 (M 8.7–8.9), 1833 (M 8.9–9.1), and 1861 (M 8.5). Since 2004, much of the Sunda megathrust between the northern Andaman Islands and Enggano Island, a distance of more than 2,000 km, has ruptured in a series of large subduction zone earthquakes—most rupturing the plate boundary south of Banda Aceh. The great M 9.1 earthquake of December 26, 2004, which produced a devastating tsunami, ruptured much of the boundary between Burma and Simeulue Island offshore Banda Aceh. Immediately to the south of the great 2004 earthquake, the M 8.6 Nias Island earthquake of March 28, 2005, ruptured a 400-km section between Simeulue and Batu Islands. Farther south in the Mentawai Islands, two earthquakes on September 12, 2007 of M 8.5 and M 7.9 occurred in the southern portion of the estimated 1797 and 1833 rupture zone, which extends from approximately Enggano Island to the northern portion of Siberut Island. Smaller earthquakes have also been locally important: a M 7.6 rupture within the subducting plate caused considerable damage in Padang in 2009, and a M 7.8 rupture on October 25, 2010, occurred on the shallow portion of the megathrust to the west of the Mentawai Islands, and caused a substantial tsunami on the west coast of those islands.

In addition to the current seismic hazards along this portion of the Sunda arc, this region is also recognized as having one of the highest volcanic activity levels in the world. One of the most dramatic eruptions in human history was the Krakatau eruption on August 27–27, 1883, a volcano just to the southeast of the island of Sumatra, which resulted in over 35,000 casualties.

Subduction and seismicity along the plate boundary adjacent to Java is fundamentally different from that of the Sumatran-Andaman section. Relative motion along the Java arc is trench-normal (approximately 65–70 mm/yr) and does not exhibit the same strain partitioning and back-arc strike-slip faulting that are observed along the Sumatra margin. Neither has the Java subduction zone hosted similar large magnitude megathrust events to those of its neighbor, at least in documented history. Although this region is not as seismically active as the Sumatra region, the Java arc has hosted low-to intermediate-magnitude extensional earthquakes and deep-focus (300–700 km) events and exhibits a similar if not higher volcanic hazard. This part of the arc has also hosted two large, shallow tsunami earthquakes in the recent past which resulted in high tsunami run-ups along the southern Java coast.

DATA SOURCES

The earthquakes portrayed on the main map (above) are taken from two sources: (1) the Centennial earthquake catalog (Engdahl and Villaseñor, 2002), and annual supplements for the interval 1900–2007, where the magnitude floor is 5.5 globally, and (2) the NEIC PDE Catalog M4.0 and larger from 1973 to July 19, 2012.

1900–2001 Centennial catalog M=5.5–9.5(Engdahl and Villaseñor, 2002)
2002–2012 NEIC catalog M=5.5–9.2
1964–2001 EHDB catalog M=4.0–5.4 (Engdahl, written commun.)
2002–2012 NEIC catalog M<5.5

The nucleation points of great earthquakes (M≥8.3) are designated with a label showing the year of occurrence. Their rupture areas are shown as pale reddish polygons.

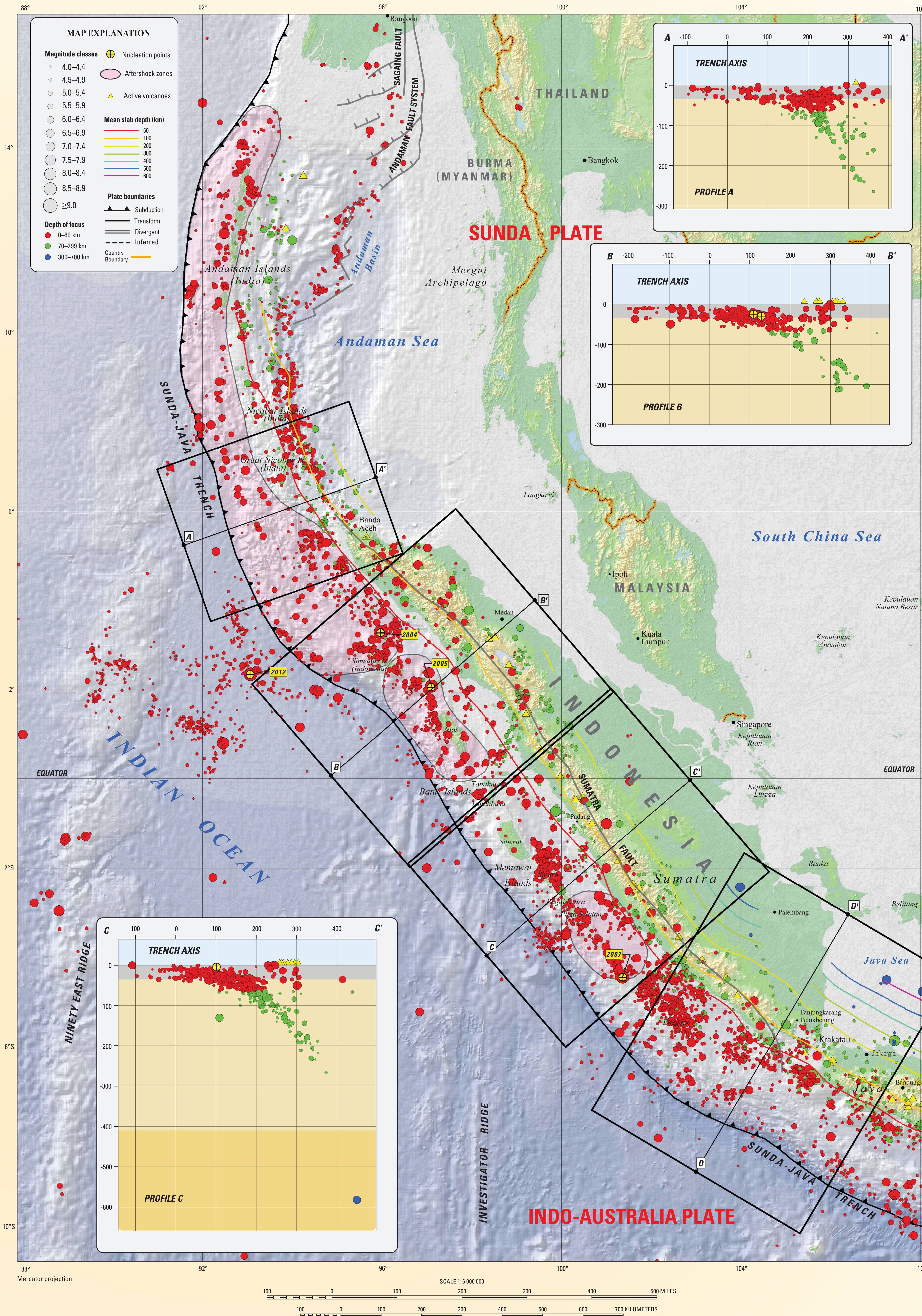
The Seismic Hazard and Relative Plate Motion panel displays the generalized seismic hazard of the region (Giardini and others, 1999) and representative relative plate-motion vectors using the Morvel model (DeMets and others, 2010).

Pre-instrumental seismicity was obtained from the NOAA National Geeophysical Data Center (2010) database of significant earthquakes; locations are approximate, based on macro-seismic reports and field investigations. We selected earthquakes with associated reports of moderate to major damage, 10 or more deaths, a estimated magnitude of 7.5 or greater (if known), Modified Mercalli Intensities X, or tsunami generation.

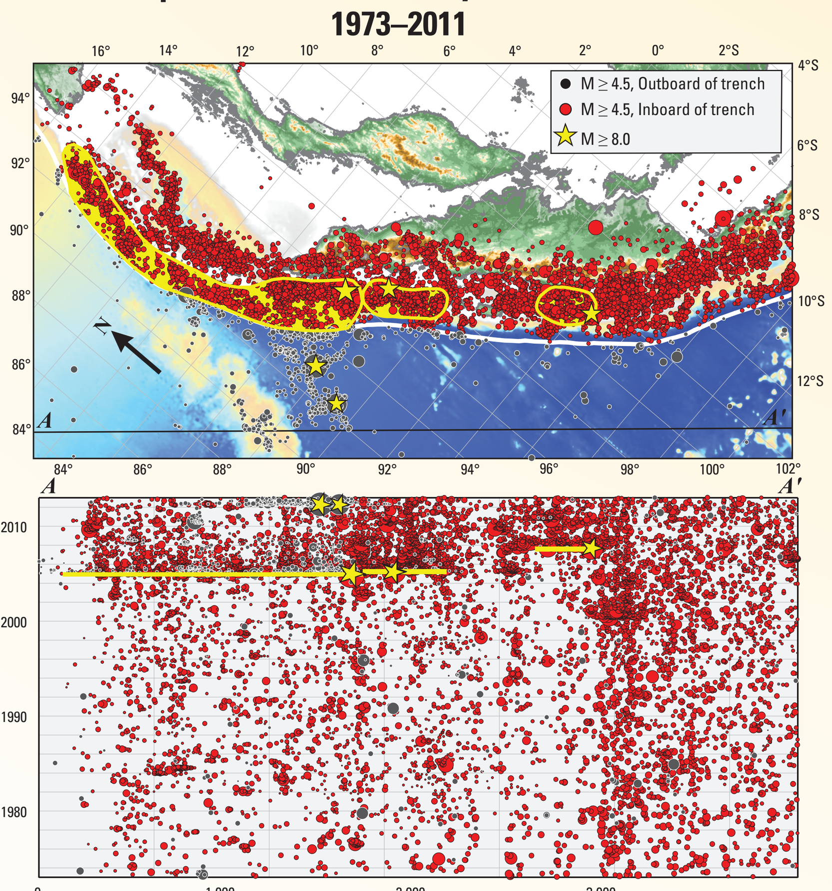
Base map data sources include GEBCO 2008 shaded relief, Volcanoes of the World dataset (Siebert and Simkin, 2002), plate boundaries (Bird, 2003), and geographic information from Digital Chart of the World (1992), and ESRI (2002). Slab contours are from Hayes and Wald (2010).

REFERENCES

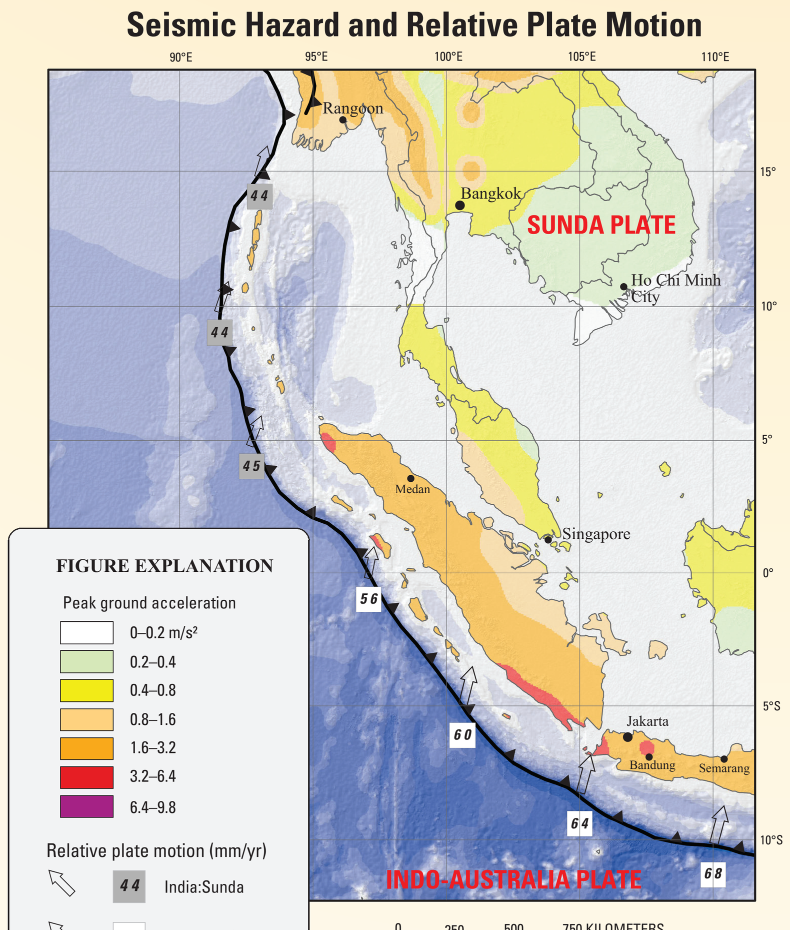
Abercrombie, R.E., Antoloi, M., Felzer, K., and Ekström, G., 2001, The 1994 Java tsunami earthquake—Slip over a subducting seamount: Journal of Geophysical Research, v. 106, p. 6595—6607.
Ammon, C.J., Kanamori, Hiroo, Lay, T., and Velasco, A.A., 2006, The 17 July Java tsunamic earthquake: Geophysical Research Letters, 33, L24308, doi: 10.1029/2006GL028005.
Bird, Peter, 2003, An updated digital model of plate boundaries: Geochemistry Geophysics Geosystems, v. 4, no. 3, 52 p.
DeMets, Charles, Gordon, R.G., and Argus, D.F., 2010, Geologically current plate motions: Geophysical Journal International, v. 181, p. 1—80, doi: 10.1111/j.1365-246X.2009.04491.x.
Digital Chart of the World, 1992: Accessed March 9, 1996, at *http://earth-info.nga.mil/publications/specs/printed/89009/89009_DCW.pdf.*
Engdahl, E.R., and Villaseñor, Antonio, 2002, Global seismicity 1900–1999, *in* Lee, W.H.K., Kanamori, Hiroo, Jennings, P.C., and Kisslinger, Carl, eds., International Handbook of Earthquake and Engineering Seismology, v. 81(A), chap. 41, p. 1–26.
ESRI, 2002, ESRI data and maps: Redlands, Calif., ESRI, *http://www.esri.com/data/data-maps*.
GEBCO, 2008, The GEBCO_08_Grid, ver. 20091120: GEBCO. Accessed July 5, 2012, at *http://www.gebco.net*.
Giardini, Domenico, Grünthal, Gottfried, Shedlock, K.M., Zhang, Peizhen, and Global Seismic Hazards Program, 1999, Global Seismic Hazards Map: Accessed on Jan. 9, 2007, at *http://www.seismo.ethz.ch/static/GSHAP/*.
Hayes, Gavin, and Wald, David, 2010, Slab models for subduction zones: U.S. Geological Survey Earthquake Hazards Program. Accessed on Feb. 23, 2010 at *http://earthquake.usgs.gov/research/data/slab*.
Malod, J.A., Karta, K., Beslier, M.O., and Zen, M.T., Jr., 1995, From normal to oblique subduction—Tectonic relationships between Java and Sumatra: Journal of Southeast Asian earth Sciences, v. 12, p. 85–93.
National Oceanic and Atmospheric Administration (NOAA), 2010: National Geophysical data Center (NGDC): National Oceanic and Atmospheric Administration. Accessed on Mar. 31, 2010, at *http://www.ngdc.noaa.gov/ngdc.html*.
Siebert, Lee, and Simkin, Thomas, 2002, Volcanoes of the world—An illustrated catalog of Holocene volcanoes and their eruptions: Smithsonian Institution, Global Volcanism Program Digital Information Series, GVP-3. Accessed on Jan. 9, 2007, at *http://www.volcano.si.edu/world.*
Spence, W., 1986, The 1977 Sumba earthquake series—Evidence for slab pull force acting at a subduction zone: Journal of Geophysical Research, v. 91, no. 87, p. 7225–7239.
Tarr, A.C., Villaseñor, Antonio, Furlong, K.P., Rhea, Susan, and Benz, H.M., 2010, Seismicity of the Earth 1900–2007: U.S. Geological Survey Scientific Investigations Map 3064, scale 1:25,000,000.



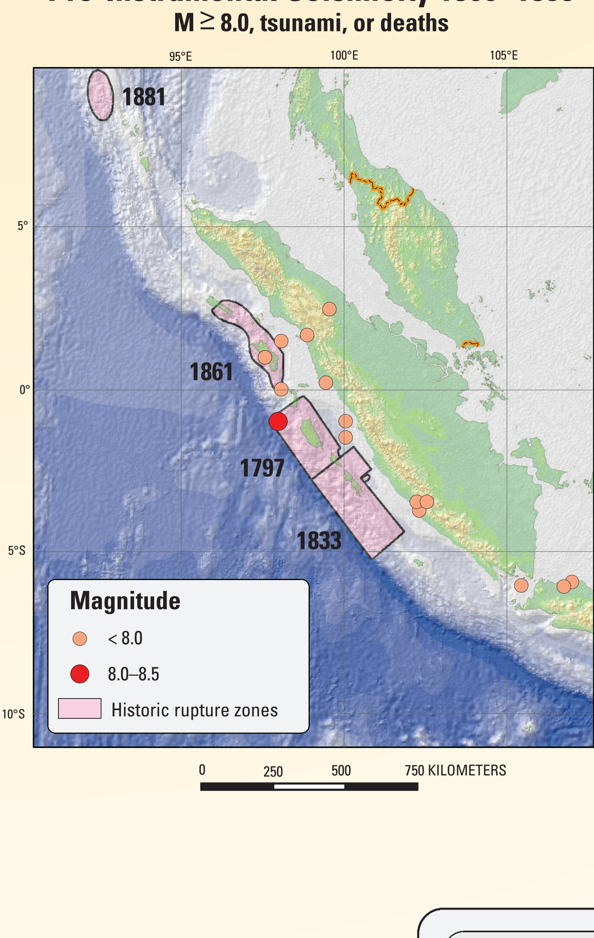
Time-Space Plot of Seismicity in the Sumatra Arc 1973–2011

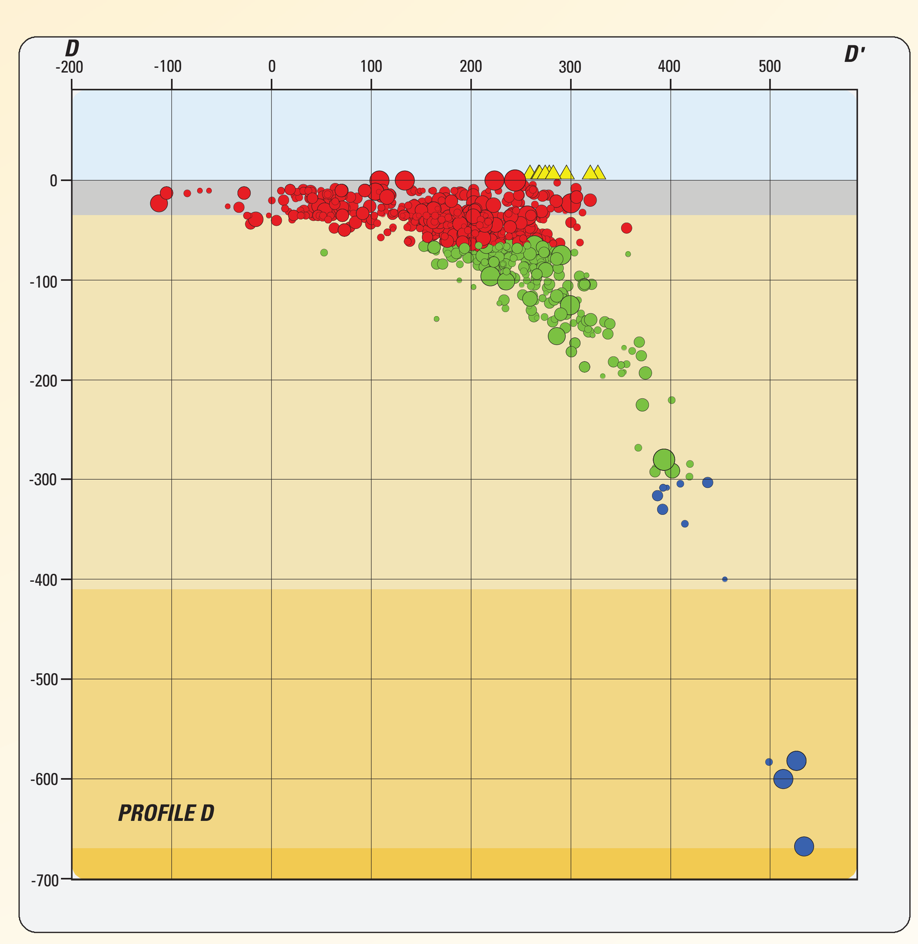


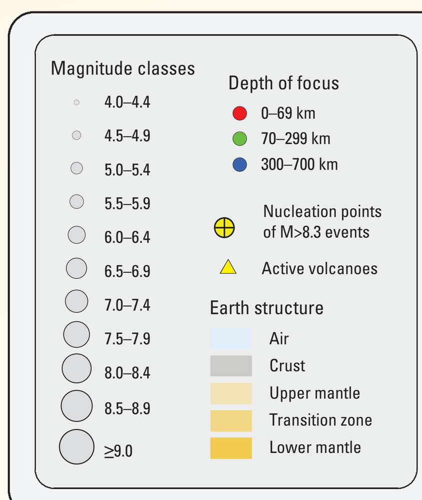
Seismic Hazard and Relative Plate Motion



Pre-Instrumental Seismicity 1500–1899
M ≥ 8.0, tsunami, or deaths

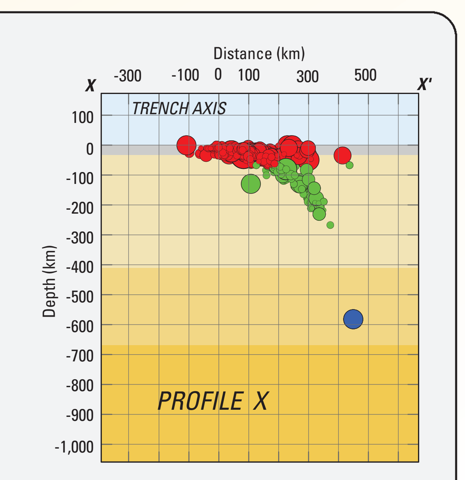






DEPTH PROFILE EXPLANATION

Profiles of earthquake and volcano locations are constructed from the mapped data. Locations of the profile intersections with the surface are drawn in the map and labeled to coincide with the profile label. Box defines extent of earthquakes included in the profile. Length of the profile graphic is the same as in the map. Distance in kilometers from the trench axis is indicated in the X direction, depth in kilometers is indicated in the Y direction. There is no vertical exaggeration. See Explanation at side for color key. Not all earth layers, earthquake depths or magnitudes, are visible in every profile.



Suggested citation:
Hayes, G.P., Bernardino, Melissa, Dannemann, Fransiska, Smoczyk, Gregory, Briggs, Richard, Benz, H.M., Furlong, K.P., and Villaseñor, Antonio, 2013, Seismicity of the Earth 1900–2012 Sumatra and vicinity: U.S. Geological Survey Open-File Report 2010–1083-L, scale 1:6,000,000, *http://pubs.usgs.gov/of/2010/1083/l/*

Publishing support provided by:
Denver Publishing Service Center

Manuscript approved on July 12, 2013

Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also contains copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

This and other USGS information products are available at *http://store.usgs.gov/*.
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit *http://www.usgs.gov/*.
1-888-ASK-USGS

This report is available at:
http://pubs.usgs.gov/of/2010/1083/l/

For more information concerning this publication, contact:
Center Director, USGS Geologic Hazards Science Center
Box 25046, Mail Stop 966
Denver, CO 80225
(303) 273-8579

Or visit Geologic Hazards Science Center Web site at:
http://geohazards.cr.usgs.gov/