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Seismicity of the Earth 1900–2013
Seismotectonics of South America (Nazca Plate Region)

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TECTONIC SUMMARY

The South American arc extends over 7,000 kilometers (km), from the Chilean margin triple junction offshore of southern Chile, to its intersection with the Panama fracture zone, offshore of the southern coast of Panama in Central America. It marks the plate boundary between the subducting Nazca plate and the South America plate, where the oceanic crust and lithosphere of the Nazca plate begin their descent into the mantle beneath South America. The convergence associated with this subduction process is responsible for the uplift of the Andes Mountains, and for the active volcanic chain present along much of this deformation front. Relative to a fixed South America plate, the Nazca plate moves slightly north of eastwards at a rate varying from approximately 80 millimeters/year (mm/yr) in the south, to approximately 65 mm/yr in the north. Although the rate of subduction varies little along the entire arc, there are complex changes in the geologic processes along the subduction zone that dramatically influence volcanic activity, crustal deformation, earthquake generation and occurrence all along the western edge of South America.

Most of the large earthquakes in South America are constrained to shallow depths of 0–70 km as a result of both crustal and interplate deformation. Crustal earthquakes are caused by deformation and mountain building in the overriding South America plate and generate earthquakes as deep as approximately 50 km. Interplate earthquakes occur due to slip along the dipping interface between the Nazca and the South America plates. Interplate earthquakes in this region are frequent and often large, and occur between depths of approximately 10–60 km. Since 1900, numerous magnitude (M) 8 or larger earthquakes have occurred on this subduction zone interface that were followed by devastating tsunamis, including the 1960 M9.5 earthquake in southern Chile, the largest instrumentally recorded earthquake in the world. Other notable shallow tsunami-generating earthquakes include the 1906 M8.5 earthquake near Esmeraldas, Ecuador, the 1922 M8.5 earthquake near Coquimbo, Chile, the 2001 M8.4 Arequipa, Peru earthquake, the 2007 M8.0 earthquake near Pisco, Peru, and the 2010 M8.8 Maule, Chile earthquake located just north of the 1960 event.

Large intermediate-depth earthquakes (those occurring between depths of approximately 70 and 300 km) are relatively limited in size and spatial extent in South America, and occur within the Nazca plate as a result of internal deformation within the subducting plate. These earthquakes generally cluster beneath northern Chile and southwestern Bolivia, and to a lesser extent beneath northern Peru and southern Ecuador, with depths from 110 to 130 km. Most of these earthquakes occur adjacent to the bend in the coastline between Peru and Chile. The most recent large intermediate-depth earthquake in this region was the 2005 M7.8 Tarapaca, Chile, earthquake.

Earthquakes can also be generated to depths greater than 600 km as a result of continued internal deformation of the subducting Nazca plate. Deep-focus earthquakes in South America are not observed from a depth range of approximately 300–500 km. Instead, deep earthquakes in this region occur at depths of 500–650 km and are concentrated into two zones: one that runs beneath the Peru-Brazil border and another that extends from central Bolivia to central Argentina. These earthquakes generally do not exhibit large magnitudes. An exception to this was the 1994 Bolivian earthquake in northwestern Bolivia. This M8.2 earthquake occurred at a depth of 631 km, which was until recently was the largest deep-focus earthquake instrumentally recorded (superseded in May 2013 by a M8.3 earthquake 610 km beneath the Sea of Okhotsk, Russia), and was felt widely throughout South and North America.

Subduction of the Nazca plate is geometrically complex and influences the geology and seismicity of the western edge of South America. The intermediate-depth regions of the subducting Nazca plate can be segmented into five sections based on their angle of subduction beneath the South America plate. Three segments are characterized by steeply dipping subduction; the other two by near-horizontal subduction. The Nazca plate beneath northern Ecuador, southern Peru to northern Chile, and southern Chile descend into the mantle at angles of 25° to 30°. In contrast, the slab beneath southern Ecuador to central Peru, and under central Chile, is subducting at a shallow angle of approximately 10° or less. In these regions of “flat-slab” subduction, the Nazca plate moves horizontally for several hundred kilometers before continuing its descent into the mantle, and is shadowed by an extended zone of crustal seismicity in the overlying South America plate. Although the South America plate exhibits a chain of active volcanism resulting from the subduction and partial melting of the Nazca oceanic lithosphere along most of the arc, these regions of inferred shallow subduction correlate with an absence of volcanic activity.

The tectonics of the Antarctica triple junction in southern Chile (Chile triple junction), are controlled by the interactions of the Antarctica, South America, and Scotia plates. Immediately south of the Chile triple junction, the Antarctica plate subducts beneath South America at a rate of approximately 16 mm/yr. There have been no moderate-to-large earthquakes associated with this convergence over the past century. Moving south and east through Patagonia, plate motions between the South America and the Scotia plates are predominantly left-lateral, at rates of 5–10 mm/yr. This plate boundary hosted two M7.8 earthquakes in December 1949, near the Chile-Argentina border in Tierra del Fuego. Farther south, the Antarctica plate moves towards the east with respect to the Scotia plate at rates of less than 10 mm/yr, decreasing towards the south. Several M6–6.5 earthquakes have been observed in the Drake Passage region over the past half-century, all with left-lateral strike-slip faulting mechanisms.

DATA SOURCES

The earthquakes portrayed on the main map and the depth profiles are taken from two sources: (a) 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 (b) a catalog of earthquakes having high-quality depth determinations for the period 1964–2002 and a magnitude range of 5.0–5.4 (Engdahl, written commun., 2003)

The nucleation points of great earthquakes larger than M8.3 are designated with a label showing the year of occurrence. Their rupture areas are shown as light gray polygons. Major earthquakes (M7.5–8.2) are labeled with the year of occurrence, whereas earthquakes (M8.0–8.2) are labeled with the year of occurrence and also denoted by a white outline (Tarr and others, 2010).

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 NUVEL-1A model (DeMets and others, 1994.)

Pre-instrumental seismicity was obtained from the National Oceanic and Atmospheric Administration (NOAA) National Geophysical 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, deaths, estimated magnitude of VIII or greater (if known), Modified Mercalli Intensities VIII or greater, or tsunami generation. Base map data sources include GEBCO 2008, Volcanoes of the World dataset (Siebert and Simkin, 2002), plate boundaries (Bird, 2003), Digital Chart of the World (1992), and Esri (2002). Slab contours are from Hayes and others (2012).

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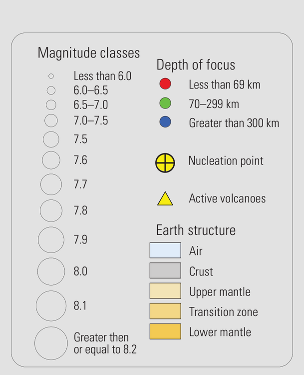
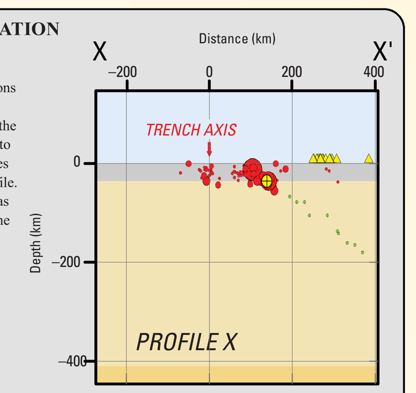
Tarr, A.C., Villaseñor, Antonio, Furlong, K.P., Rhea, Susan, and Benz, H.M., 2010, Seismicity of the Earth 1900–2007: U.S. Geological Survey Scientific Investigations Map 3064, scale 1:25,000,000. [Available at http://pubs.usgs.gov/sim/3064/.]

DEPTH PROFILE EXPLANATION



Profiles of earthquake and volcano locations are constructed from the mapped data. Locations of the profile intersection 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 Y direction. There is no vertical exaggeration. See explanation at side for color key. Not all Earth layers and earthquake depths or magnitude are visible on every profile.

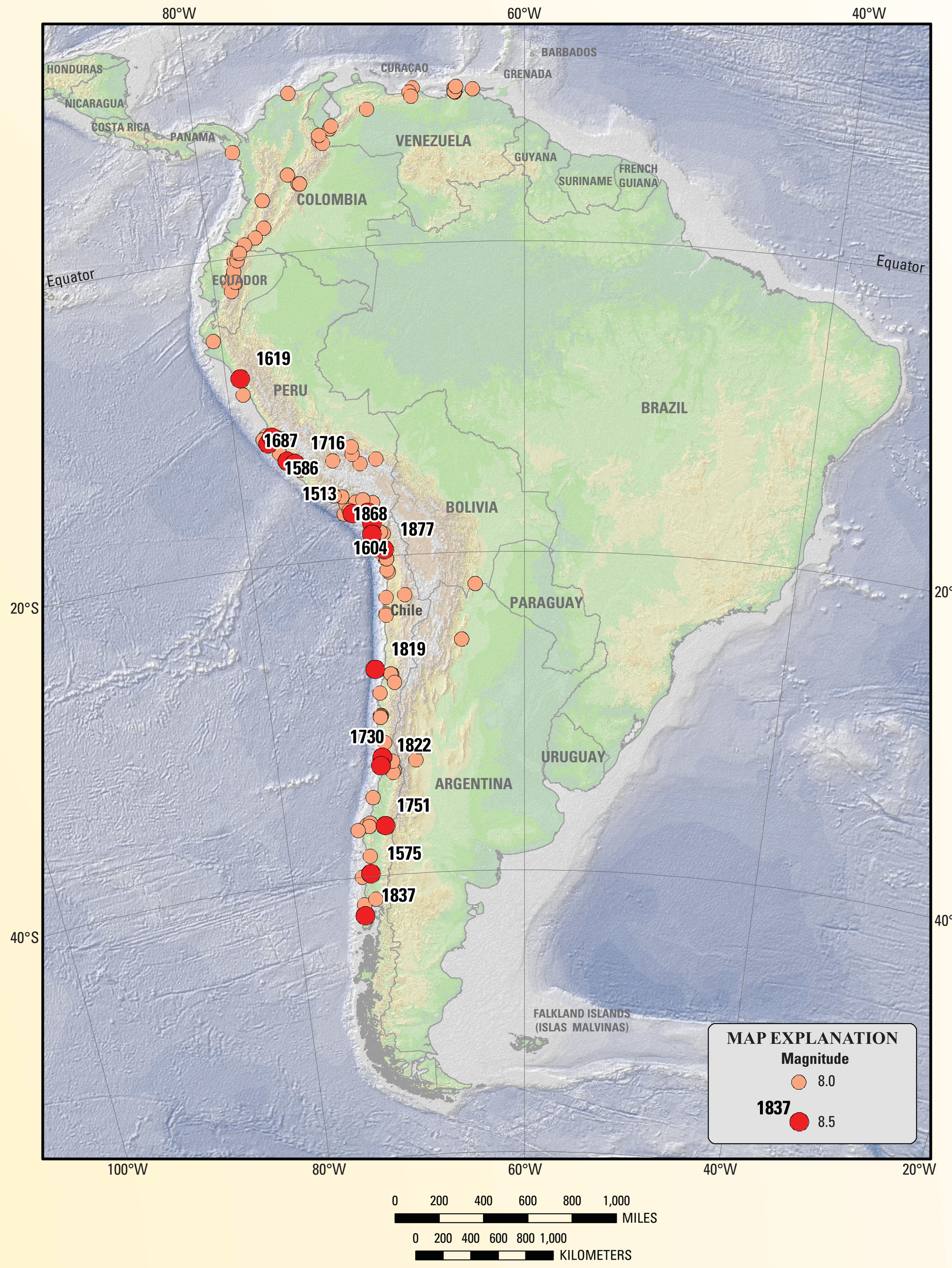


South America Albers Equal Area Projection Scale 1:14,000,000
Digital map database and cartography by Greg Smoczyk

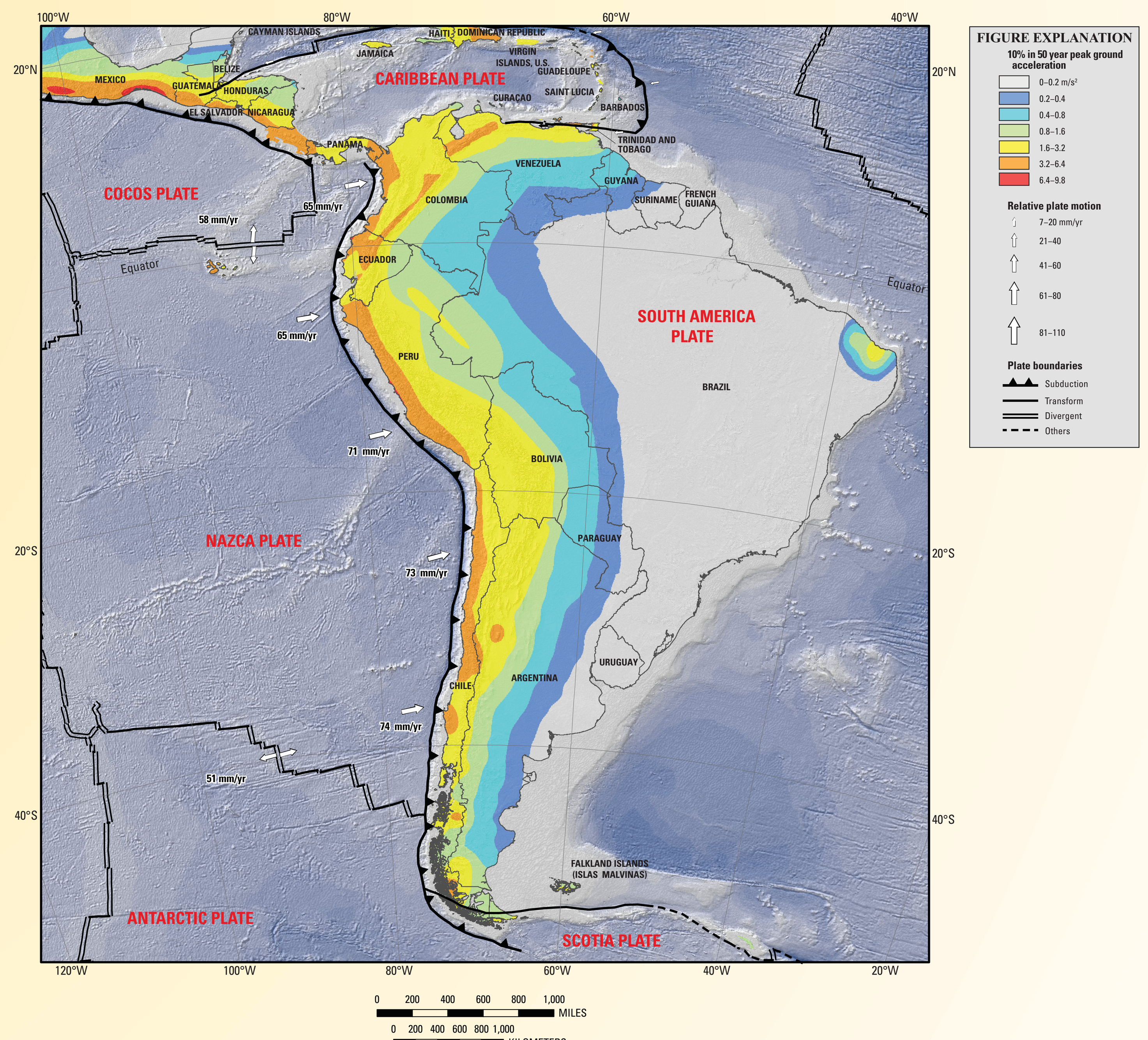
SCALE 1:14,000,000

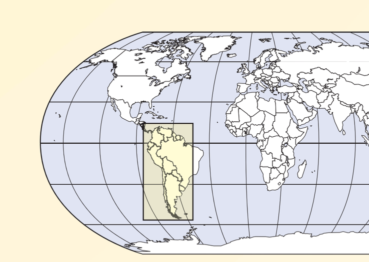
MILES
KILOMETERS

PRE-INSTRUMENTAL SEISMICITY 1500 – 1899
Deaths, tsunami, MMI VIII+, or M≥8
M≥8.5 labeled with year



SEISMIC HAZARD AND RELATIVE PLATE MOTION





MAP LOCATION

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