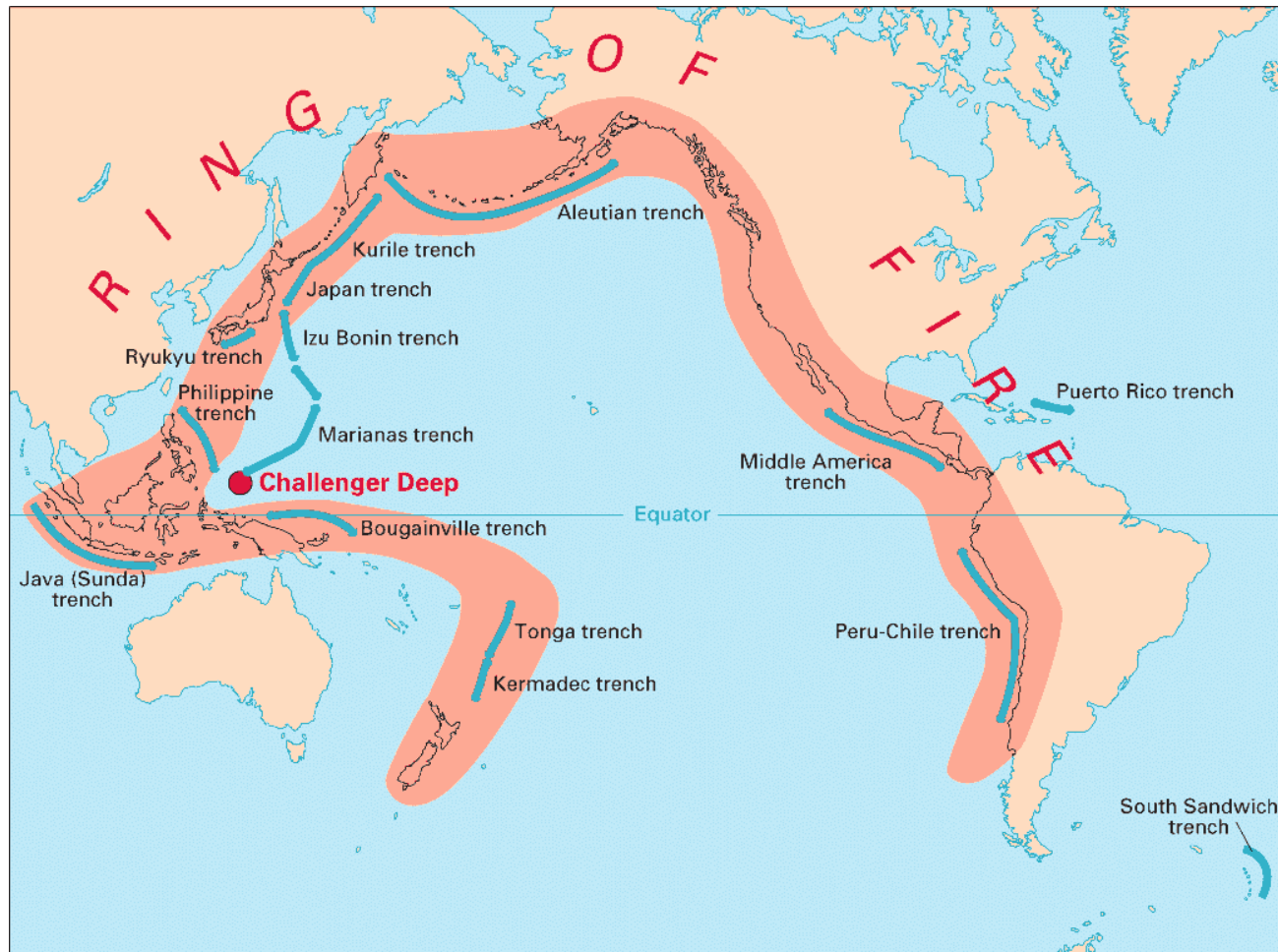


Earthquakes in Latin America

Earthquakes & Earthquake Hazard

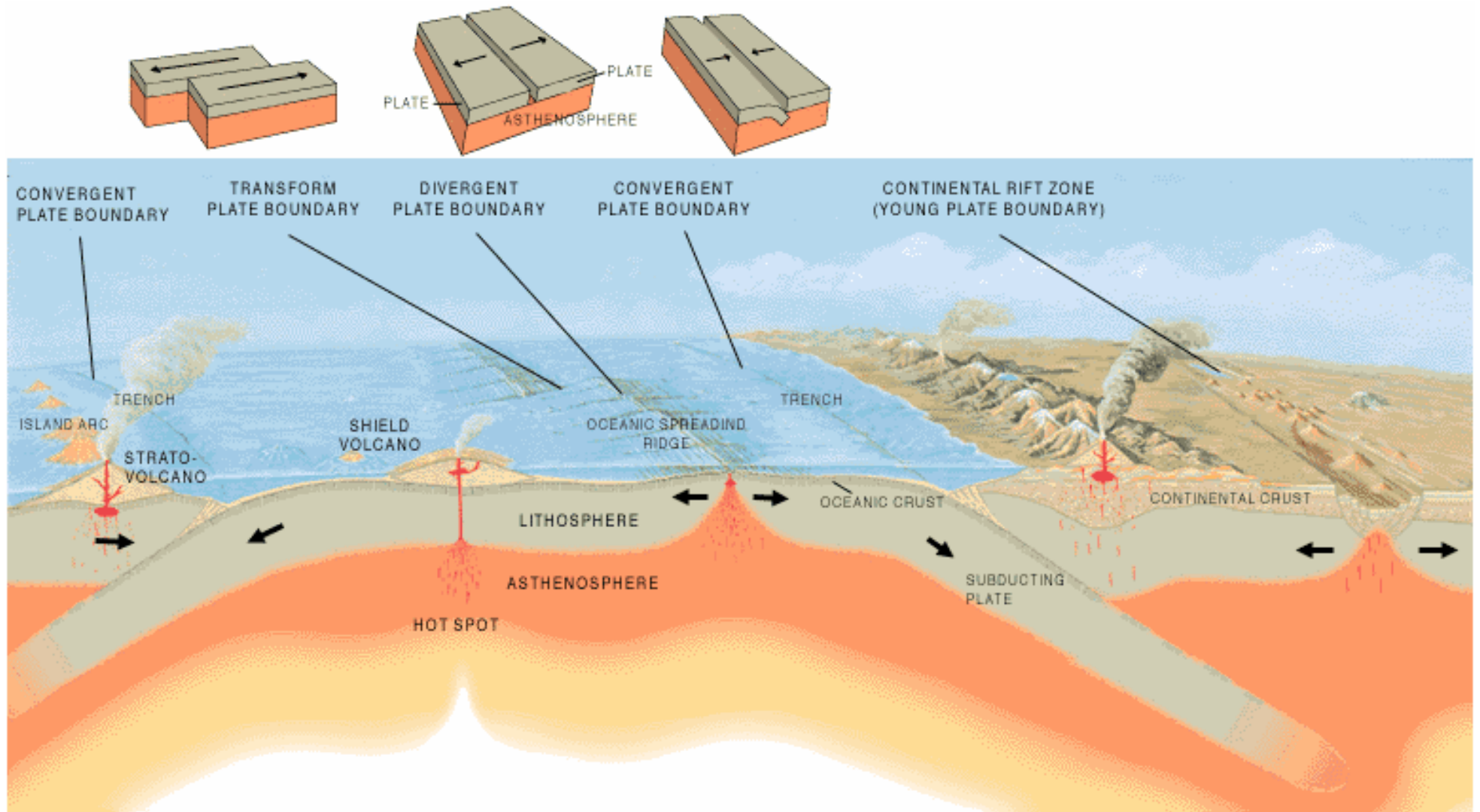
- *Earthquake* is a term used to describe both sudden slip on a fault, and the resulting ground shaking and radiated seismic energy caused by the slip.
- *Earthquake hazard* is anything associated with an earthquake that may affect the normal activities of people. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, and tsunamis.

Circum-Pacific “Ring of Fire”



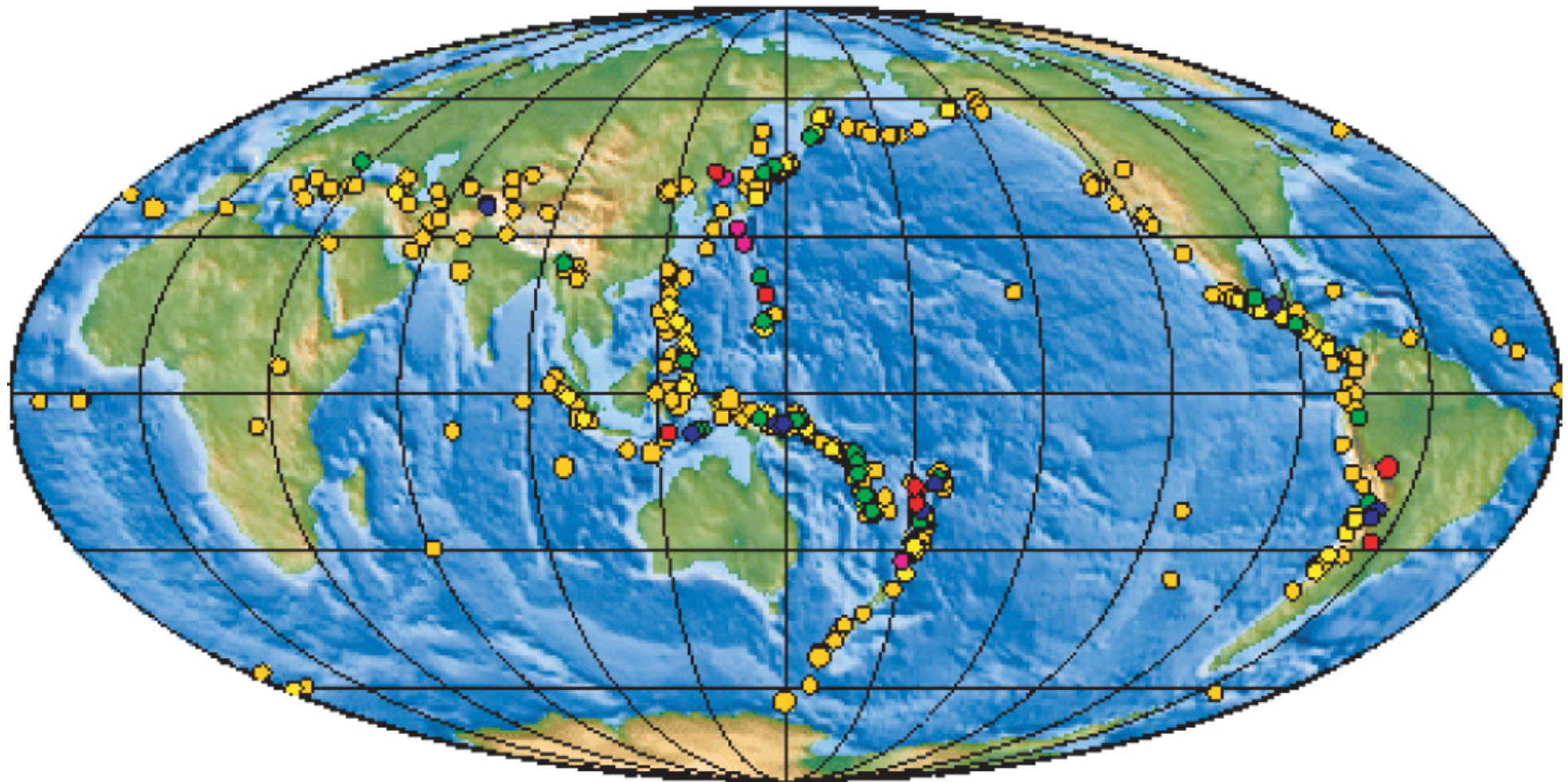
Could also be called Circum-Pacific “Ring of Earthquakes”

Plate Tectonics

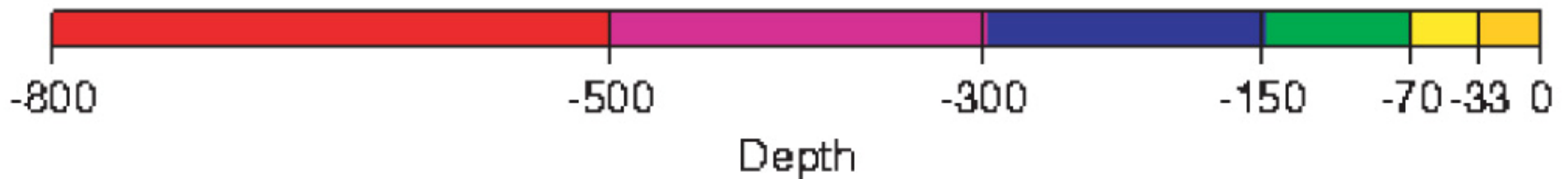


“This Dynamic Earth” <http://pubs.usgs.gov/publications/text/Vigil.html>

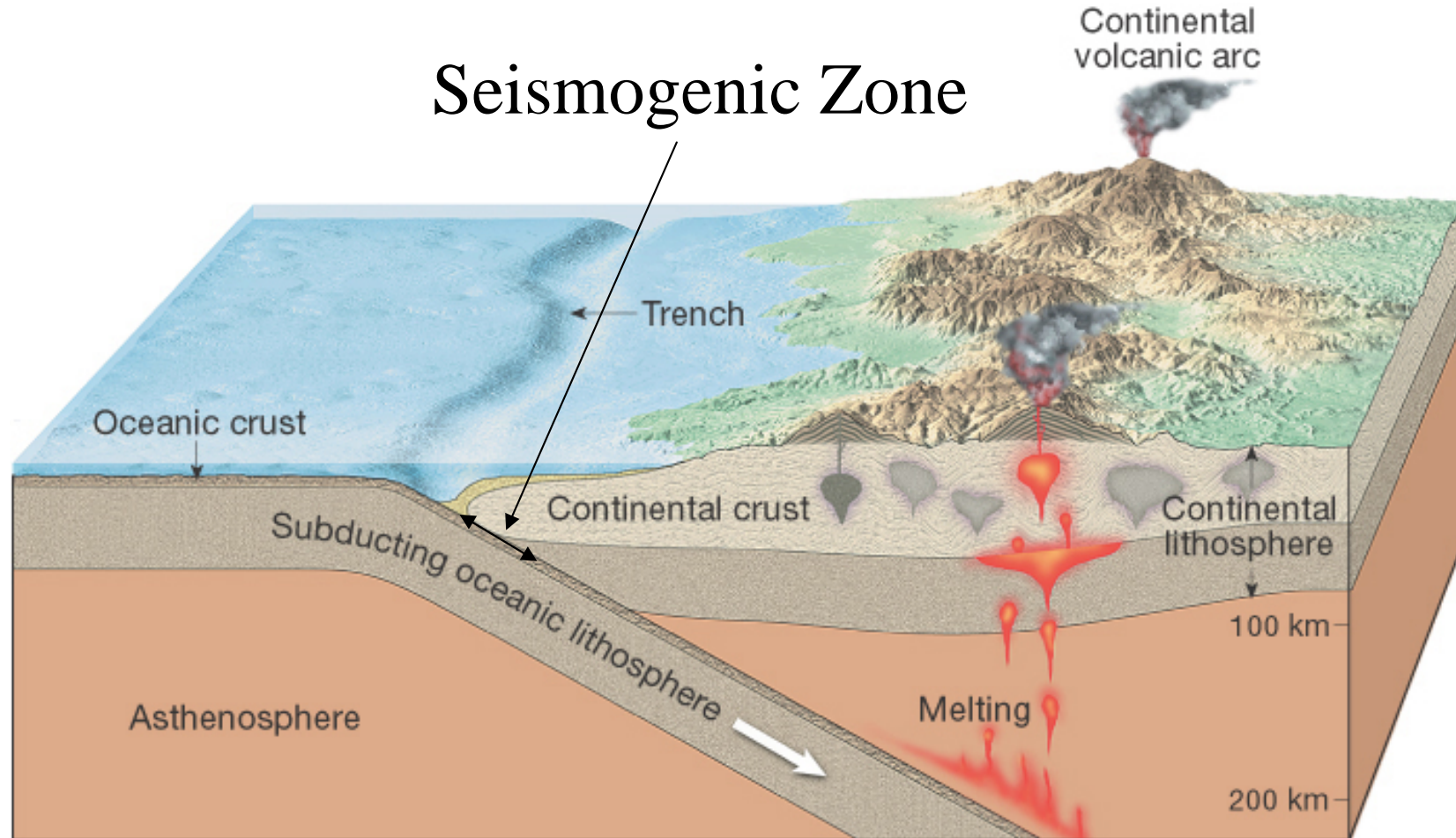
Earthquakes Magnitude 7 and Greater 1975 - Present



USGS National Earthquake Information Center

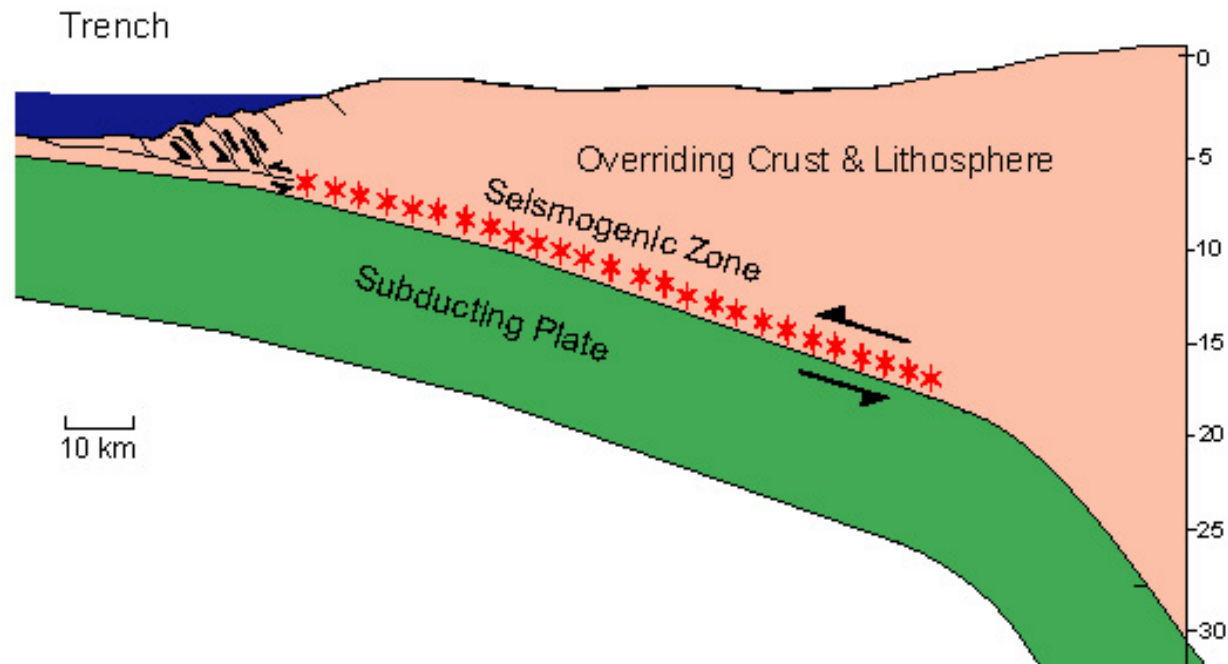


Subduction Zone beneath west Latin America & Lesser Antilles



Earthquakes occur all along the subduction zone but those along the 'Seismogenic zone are most destructive

Seismogenic Zone

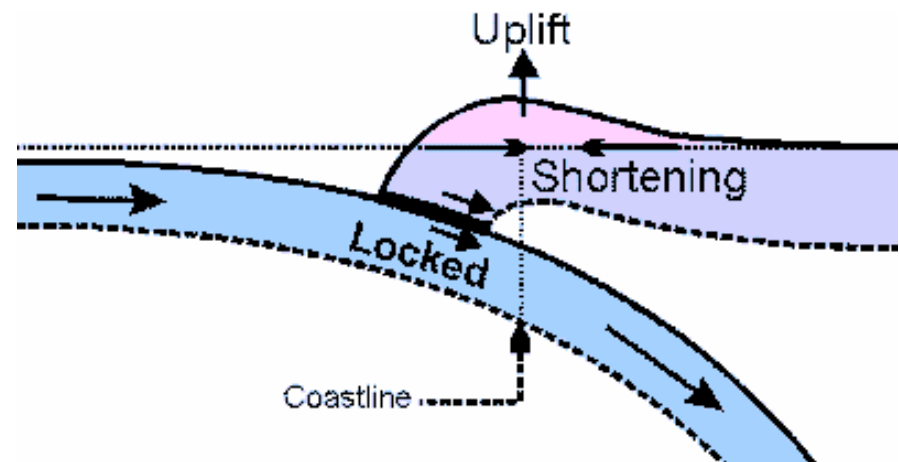


Seismogenic Zone is most dangerous because of the kind of earthquakes and because it is near the surface

Earthquake Cycle in the Seismogenic Zone

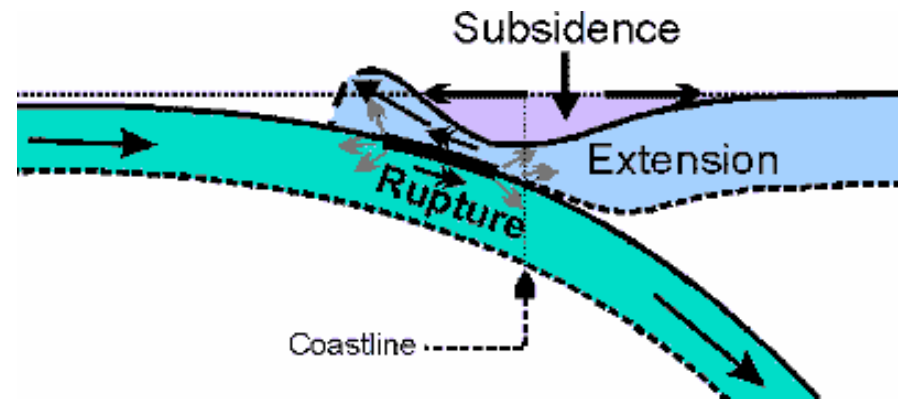
2 stages:

- 1) Interseismic Period
 - 1. **Interseismic Period or Between Earthquakes: (10's to 100's of years)**
 - Plate convergence continues (~8cm/year between Nazca and S. American plates) but the two plates are locked over some width of the subduction plate boundary, resulting in both uplift and horizontal shortening of the overlying plate margin
 - The inland extent of the deformation and the location of the areas of maximum deformation are determined by the extent and the location of the locked zone.



Earthquake Cycle in the Seismogenic Zone (cont'd.)

- **2. Coseismic Period or Earthquake Rupture: (A few minutes)**
 - Once the accumulating stress exceeds the strength of the fault, the locked zone fails and a great earthquake occurs
 - During the rupture, stored elastic strain is released, resulting in subsidence & horizontal extension in those region where slow uplift & horizontal shortening had accumulated.
 - Underwater displacements can cause tsunamis (tidal waves)
 - Once stress is relieved, the cycle begins again.

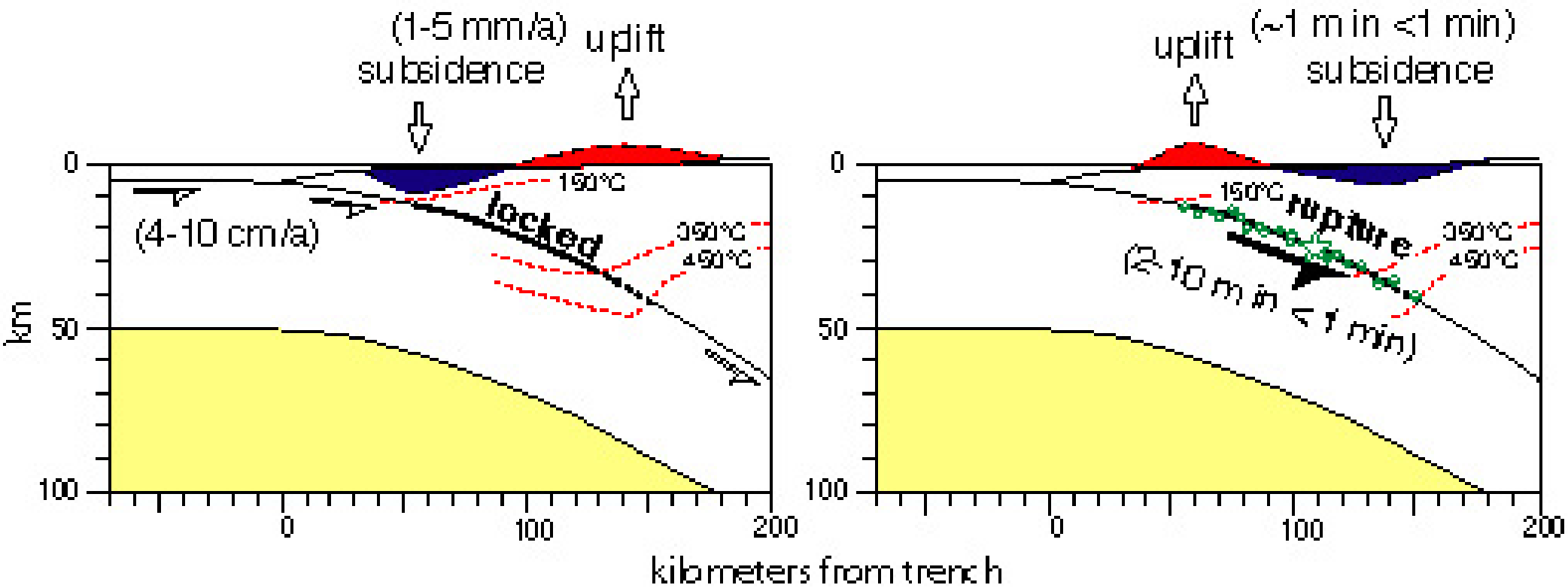


This is a good model for the 1960 Chile earthquake

Earthquake Cycle in the Seismogenic Zone

interseismic (stress build-up)
10's-100's of years

co-seismic (stress release)
seconds to minutes

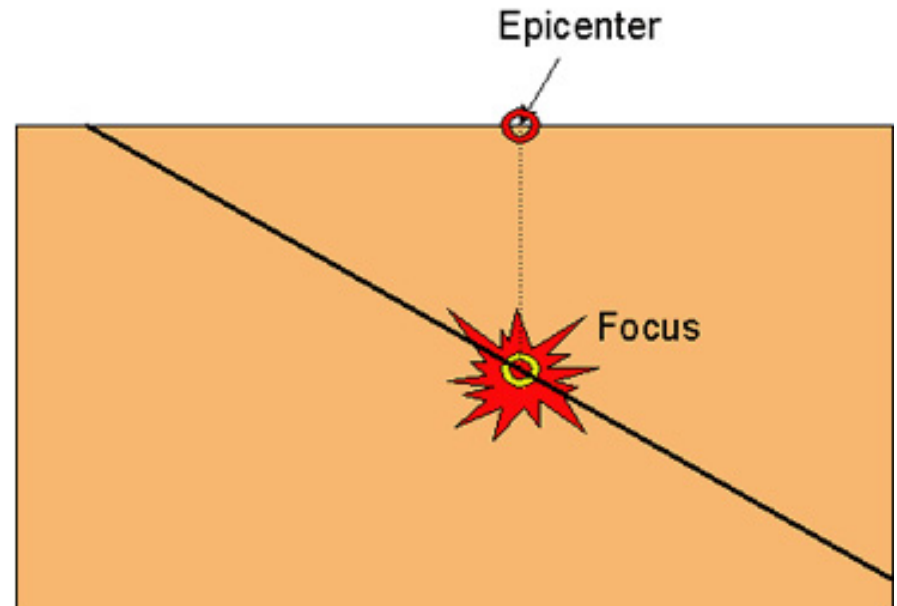


Gutscher & Peacock 2003

Epicerter, Hypocenter, and Focus

The *hypocenter* or *focus* is the location in Earth's interior that ruptures

The *epicenter* is the point on the earth's surface vertically above the hypocenter (or focus).



Earthquake Magnitude

- The magnitude is a number that characterizes the energy released by an earthquake.
- Magnitude is based on measurement of the maximum motion recorded by a seismograph.
- The moment magnitude (M_w) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes.
- The seismic moment is a measure of the size of an earthquake based on the area of fault rupture, the average amount of slip, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting.
- Seismic moment can also be calculated from the amplitude spectra of seismic waves.

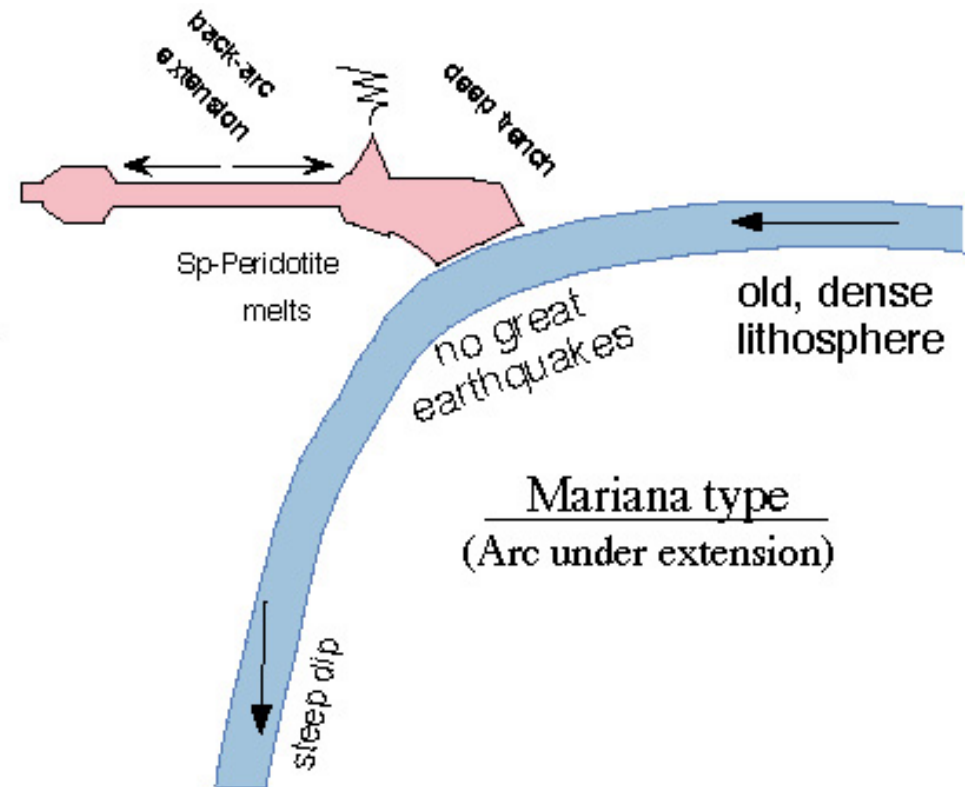
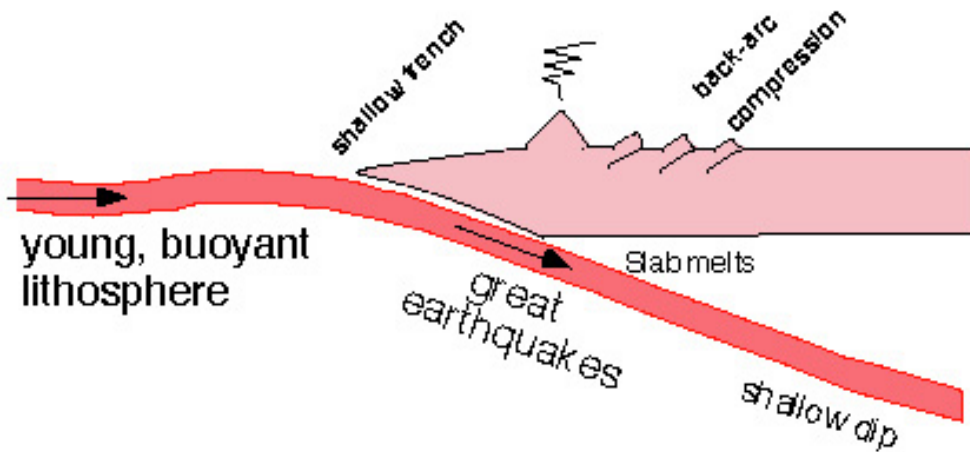
The Deadliest Latin American Earthquakes since 1900:

South America = 10; Central America = 5; Mexico = 1; Caribbean = 1

1) 1970 May 31	Peru	66,000 dead	M=7.8
2) 1939 Jan 25	Chile, Chillan	28,000 dead	M=8.3
3) 1976 Feb 4	Guatemala	23,000 dead	M=7.5
4) 1906 Aug 17	Chile, Santiago	20,000 dead	M=8.6
5) 1985 Sep 19	Mexico, Michoacan	9,500 dead (official) Estimated death toll as high as 30,000.	M= 8.1
6) 1944 Jan 15	Argentina, San Juan	5,000 dead	M=7.8
7) 1949 Aug 5	Ecuador, Ambato	6,000 dead	M=6.8
8) 1972 Dec 23	Nicaragua, Managua	5,000 dead	M=6.2
9) 1960 May 22	Chile	5,000 dead	M=9.5
10) 1931 Mar 31	Nicaragua	2,400 dead	M=5.6
11) 1902 Apr 19	Guatemala	2,000 dead	M=7.5
12) 1907 Jan 14	Jamaica, Kingston	1,600 dead	M=6.5
13) 1946 Nov 10	Peru, Ancash	1,400 dead	M=7.3
14) 1999 Jan 25	Colombia	1,185 dead	M=6.3
15) 1986 Oct 10	El Salvador	1,000+ dead	M=5.5
16) 1987 Mar 6	Colombia-Ecuador	1,000+ dead	M=7.0
17) 1906 Jan 31	Colombia	1,000 dead	M=8.9

Why are Latin American Earthquakes so Strong?

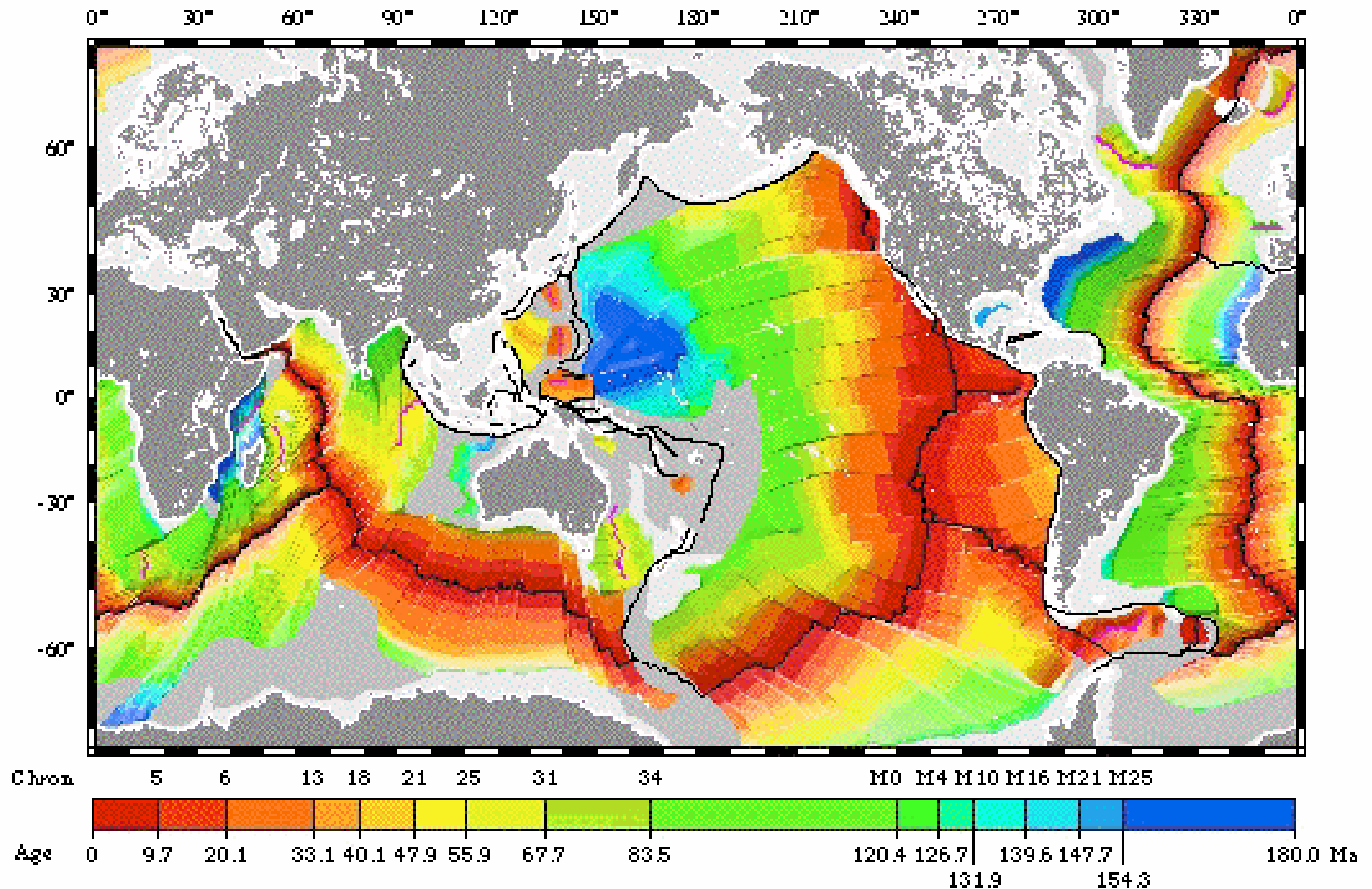
Chilean-type Convergent Margin (Arc under compression)



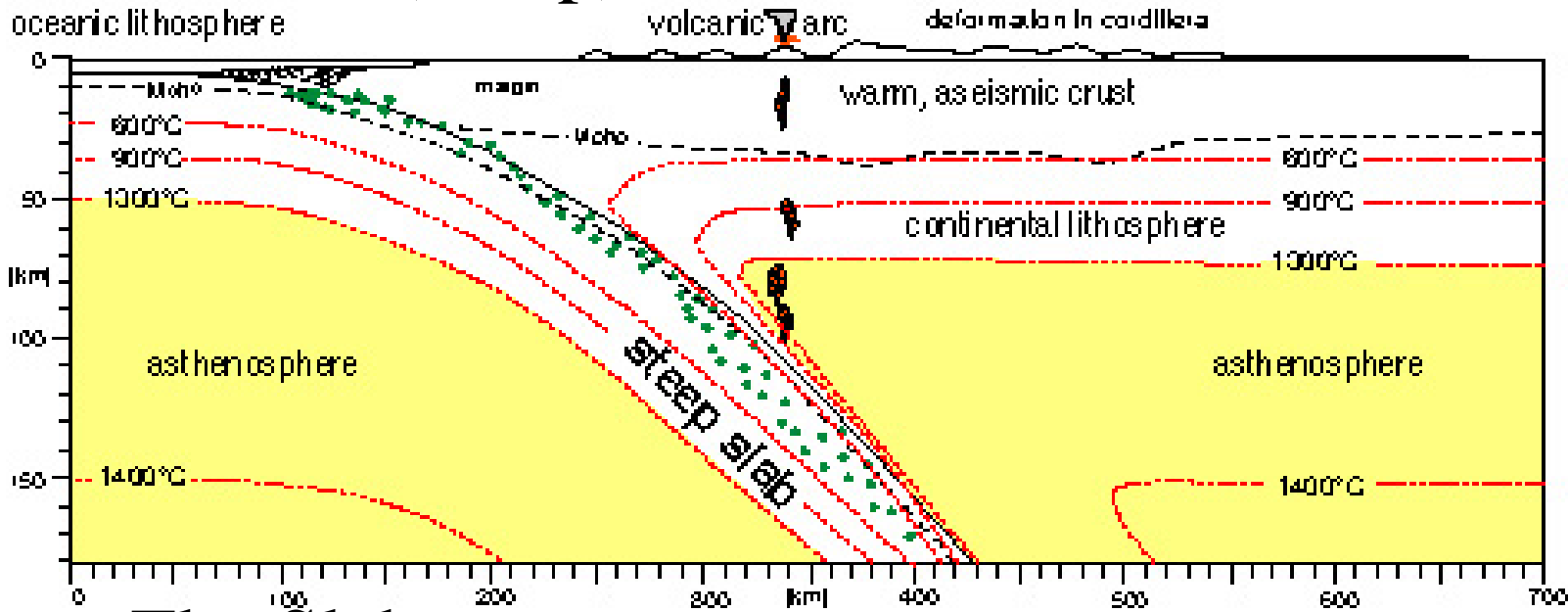
modified after Uyeda and Kanamori, 1979

- 1) Subduction of young, buoyant lithosphere

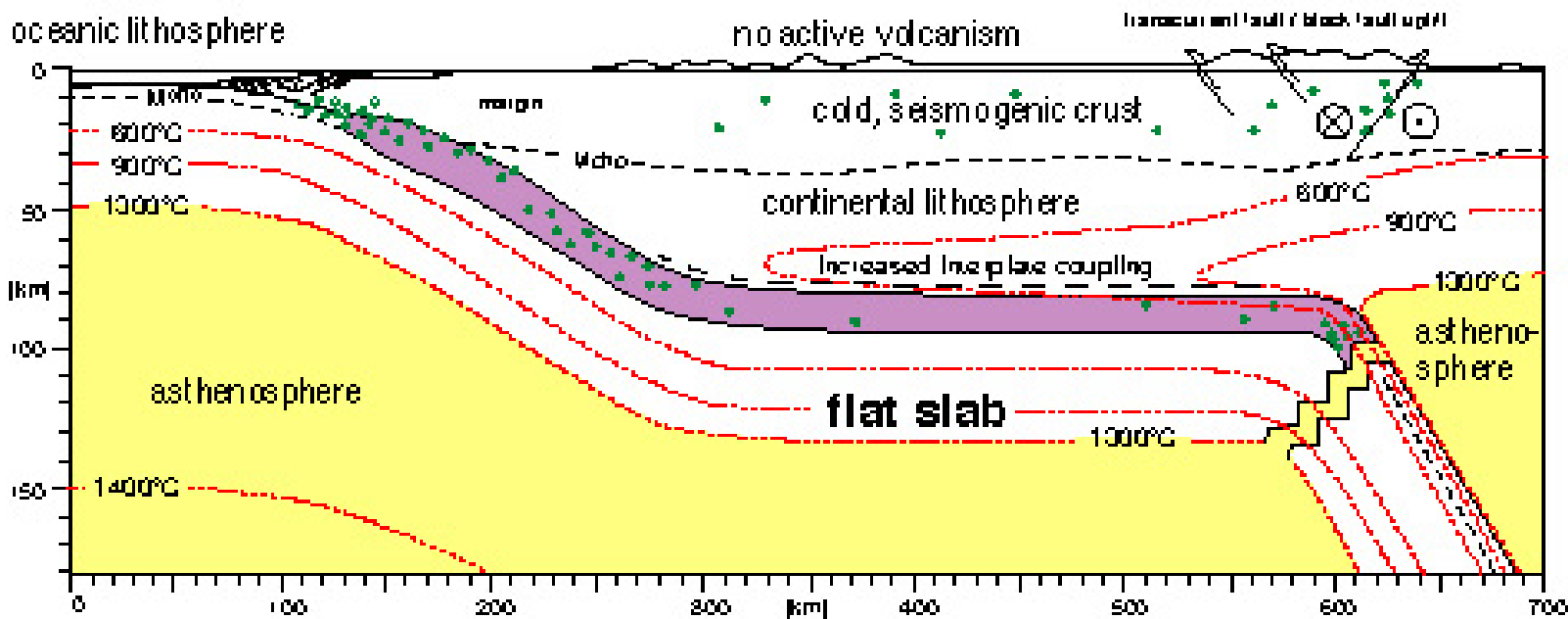
Western America is Subducting Young Oceanic Lithosphere



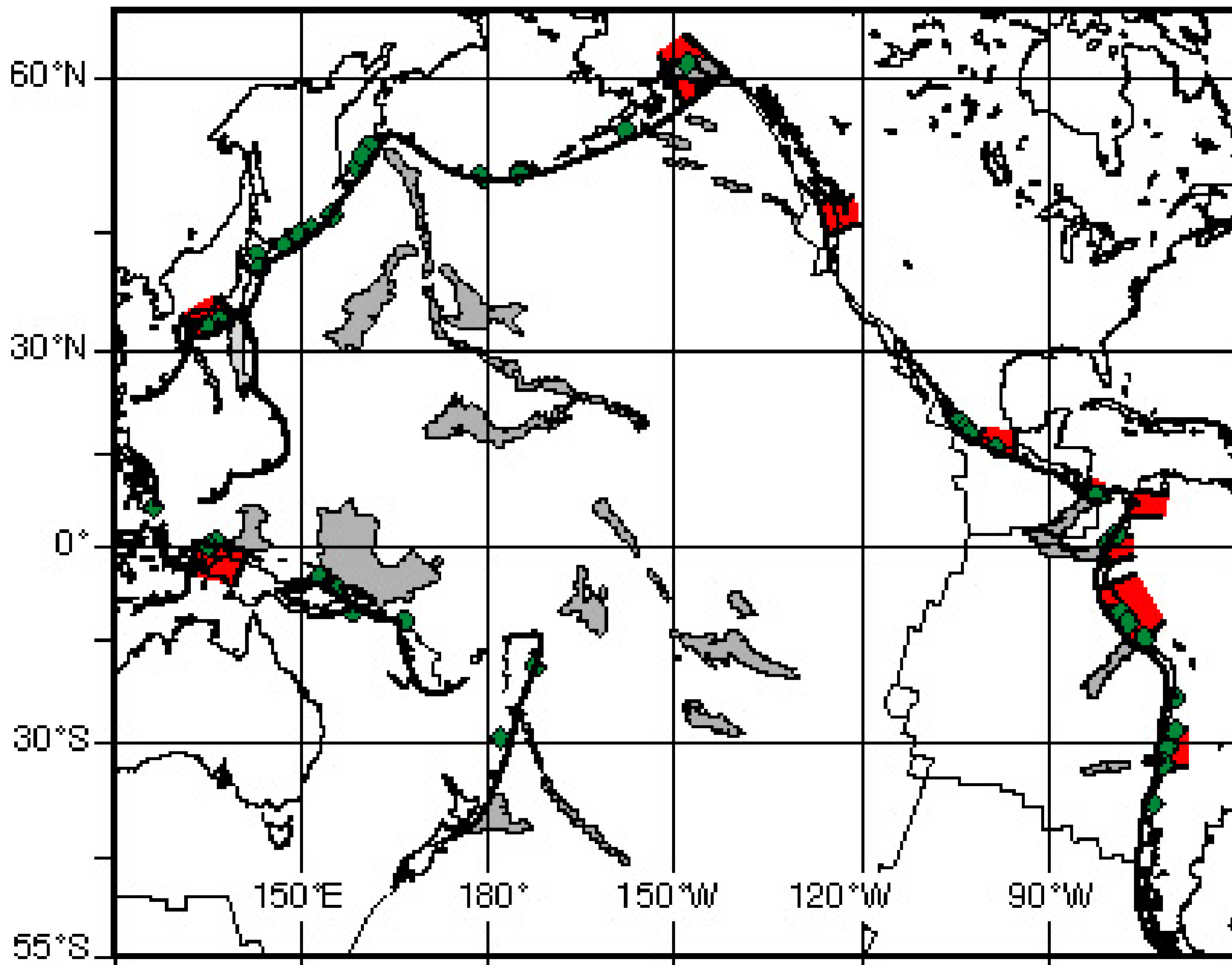
Normal (Steep) Slab



Flat Slab

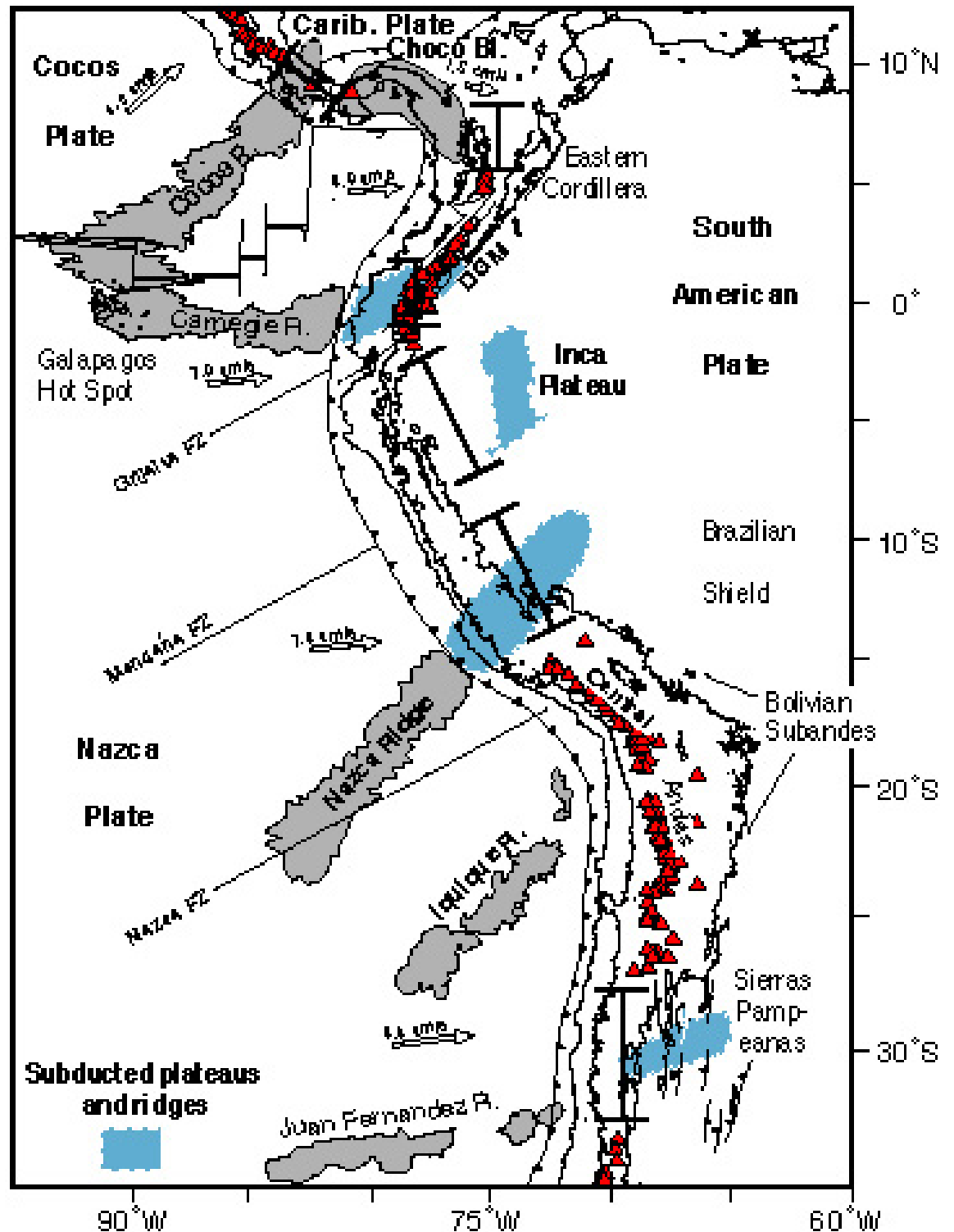


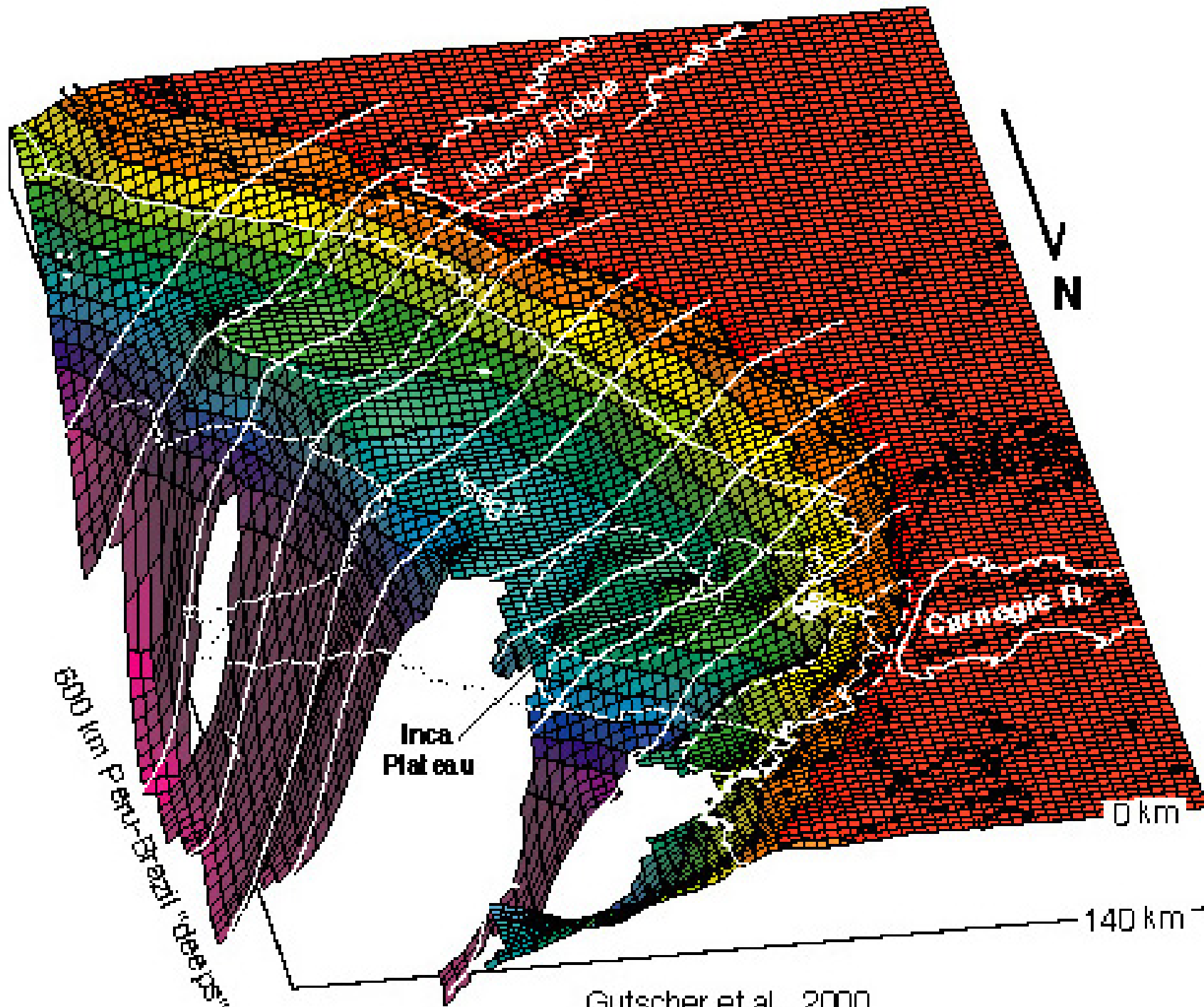
Flat Slab regions allow for more stress to build up between the plates (Gutscher et al., 2000)



Flat slab segments worldwide (red), location of great interplate subduction earthquakes $M > 8$ in the 20th century (green). Nearly 40% occurred in flat slab zones, which represent only 10% of global subduction zones. From Gutscher and Peacock 2003 JGR

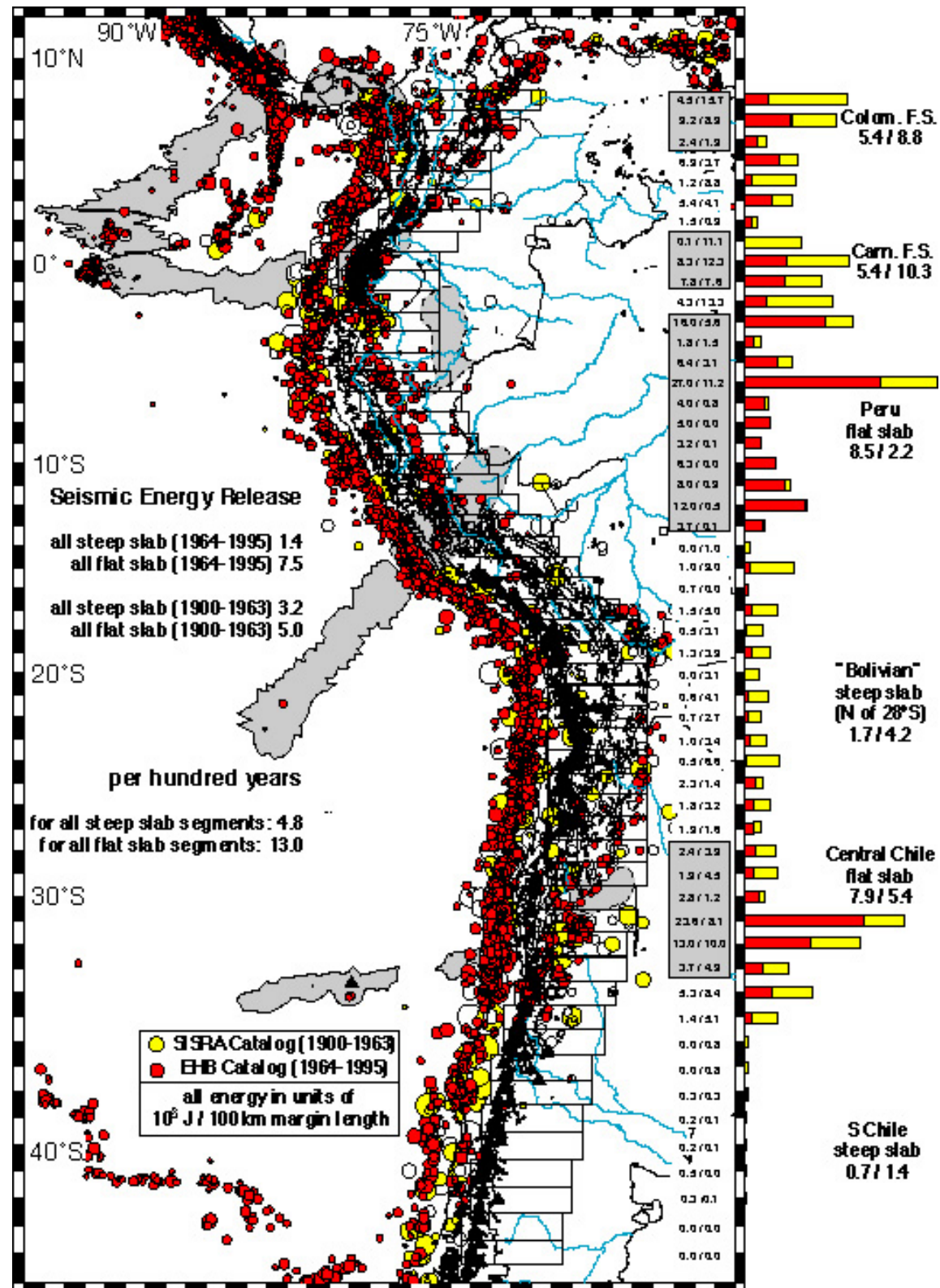
Flat Slab segments in S. America (Gutscher et al., 2000)





Perspective View of S. America Subduction Zone

Greater release
of seismic
energy
associated with
flat slab vs.
steep slab
segments
(Gutscher et al.,
2000)

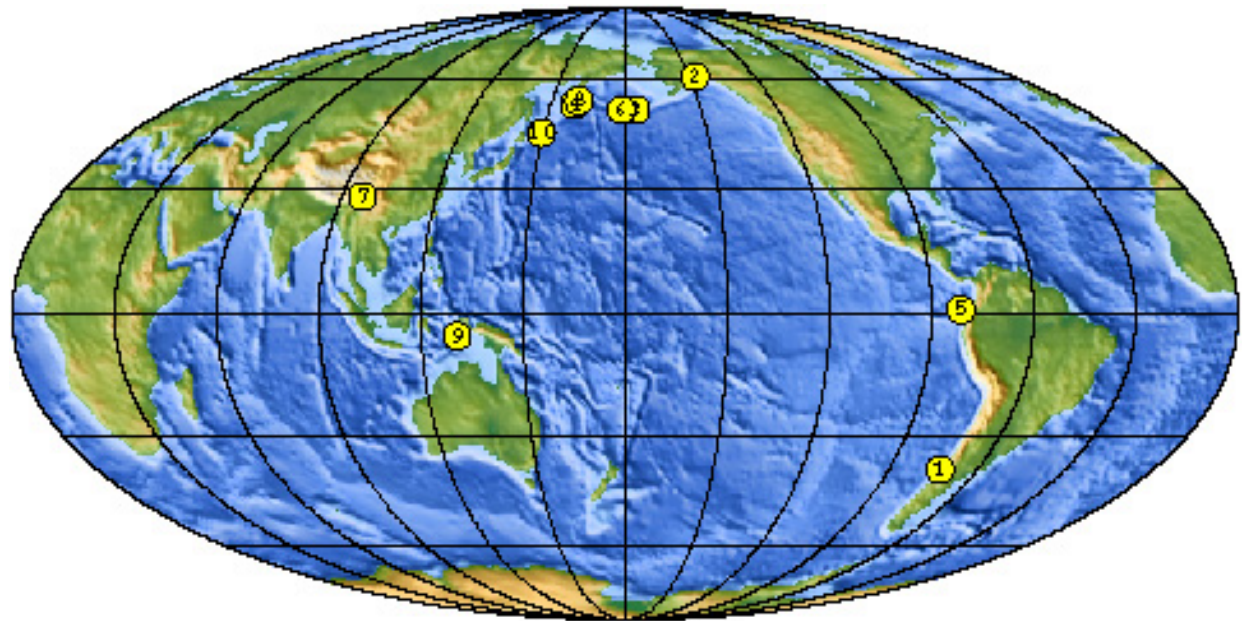


Flat Slab
segments
lack arc
volcanoes



10 Most Powerful Earthquakes since 1900

	Location, year	Magnitude
1.	Chile, 1960	9.5
2.	Alaska, 1964	9.2
3.	Aleutian Islands, 1957	9.1
4.	Kamchatka, 1952	9.0
5.	Ecuador, 1906	8.8
6.	Aleutian Islands, 1965	8.7
7.	India-China, 1950	8.6
8.	Kamchatka, 1923	8.5
9.	Indonesia, 1938	8.5
10.	Kuril Islands, 1963	8.5

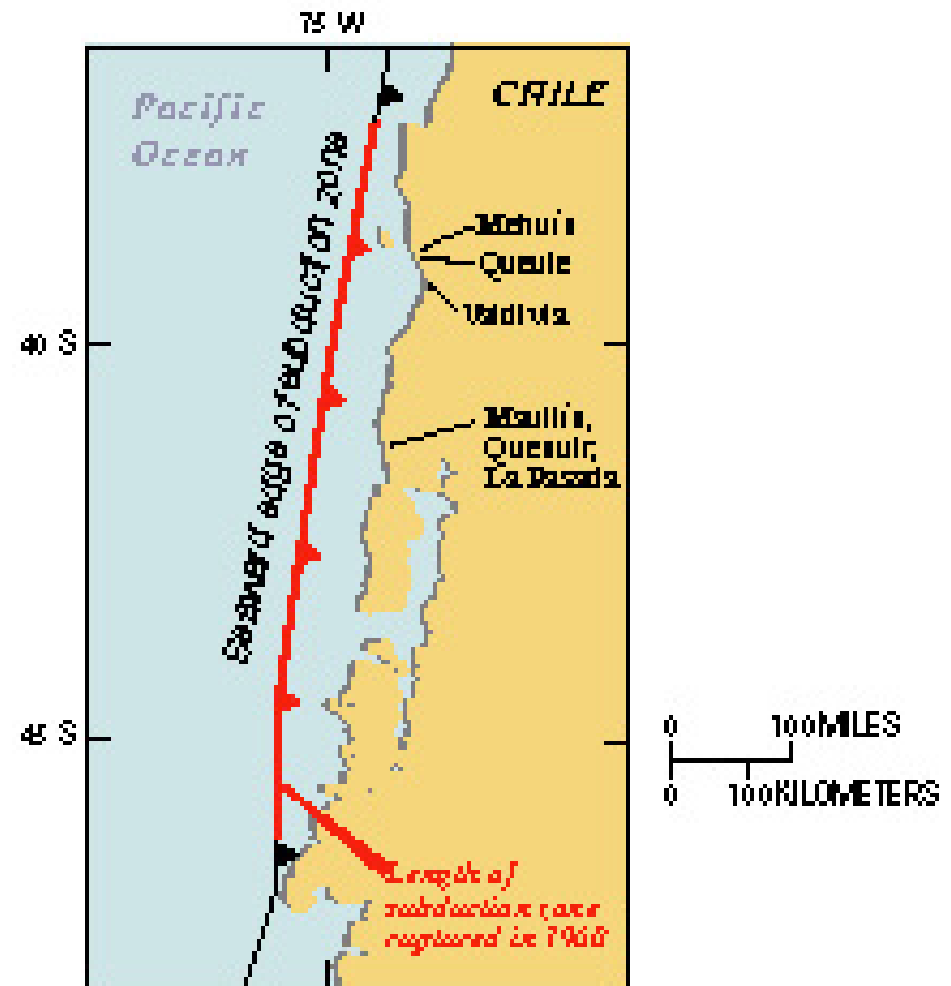


USGS National Earthquake Information Center

http://neic.usgs.gov/neis/eqlists/10maps_world.html

Chile Earthquake of 1960

- Beginning on 21 May 1960, southern Chile was ravaged by a series of earthquakes whose foci lie within a band 1,300 km long, between latitudes 37° and 48° S. The big events had focal depths of ~ 33 km.
- The western margin of the South American Plate moved as much as 60 feet (18.3 m) relative to the subducting Nazca Plate, in an area 600 miles long and more than 100 miles wide.
- More than 2,000 killed, 3,000 injured, 2,000,000 homeless, and \$550 million damage in southern Chile.
- The main shock set up a large tsunami. Although the warning system worked well, the wave caused 61 deaths, injured 282 and did damage amounting to \$20 million on the island of Hawaii. The coasts of California, New Zealand, Australia and Kamchatka were also affected





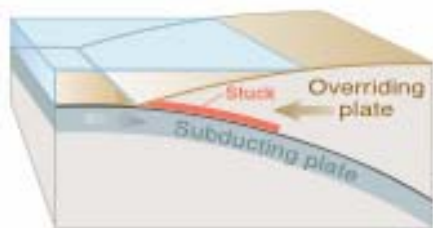
This photo shows earthquake damage to good quality, wood-frame houses in Valdivia, Chile. These houses slid down hill to the right because of solifluction (downslope flow of waterlogged soil).

http://www.ngdc.noaa.gov/seg/hazard/slideset/45/45_slides.html

Earthquake Cycle & Tsunamis

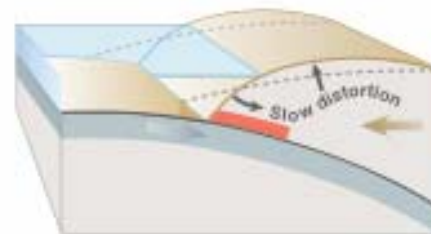
USGS Circular 1187, 1999

TSUNAMI—A SERIES OF WAVES, OR "WAVE TRAINS," USUALLY TRIGGERED BY AN EARTHQUAKE



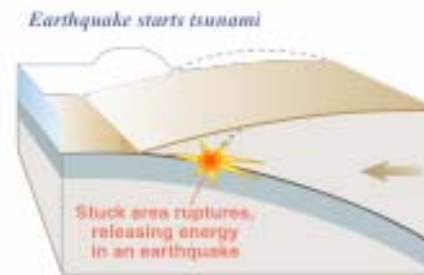
Vertical Slice Through a Subduction Zone

One of the many tectonic plates that make up Earth's outer shell descends, or "subducts," under an adjacent plate. This kind of boundary between plates is called a "subduction zone." When the plates move suddenly in an area where they are usually stuck, an earthquake happens.



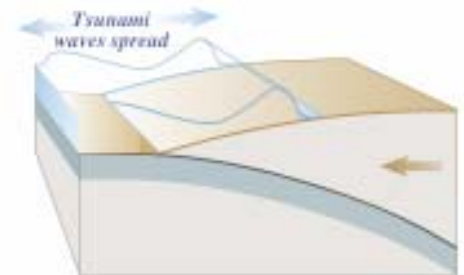
A. Between Earthquakes

Stuck to the subducting plate, the overriding plate gets squeezed. Its leading edge is dragged down, while an area behind bulges upward. This movement goes on for decades or centuries, slowly building up stress.



B. During an Earthquake

An earthquake along a subduction zone happens when the leading edge of the overriding plate breaks free and springs seaward, raising the sea floor and the water above it. This uplift starts a tsunami. Meanwhile, the bulge behind the leading edge collapses, thinning the plate and lowering coastal areas.



C. Minutes Later

Part of the tsunami races toward nearby land, growing taller as it comes in to shore. Another part heads across the ocean toward distant shores.

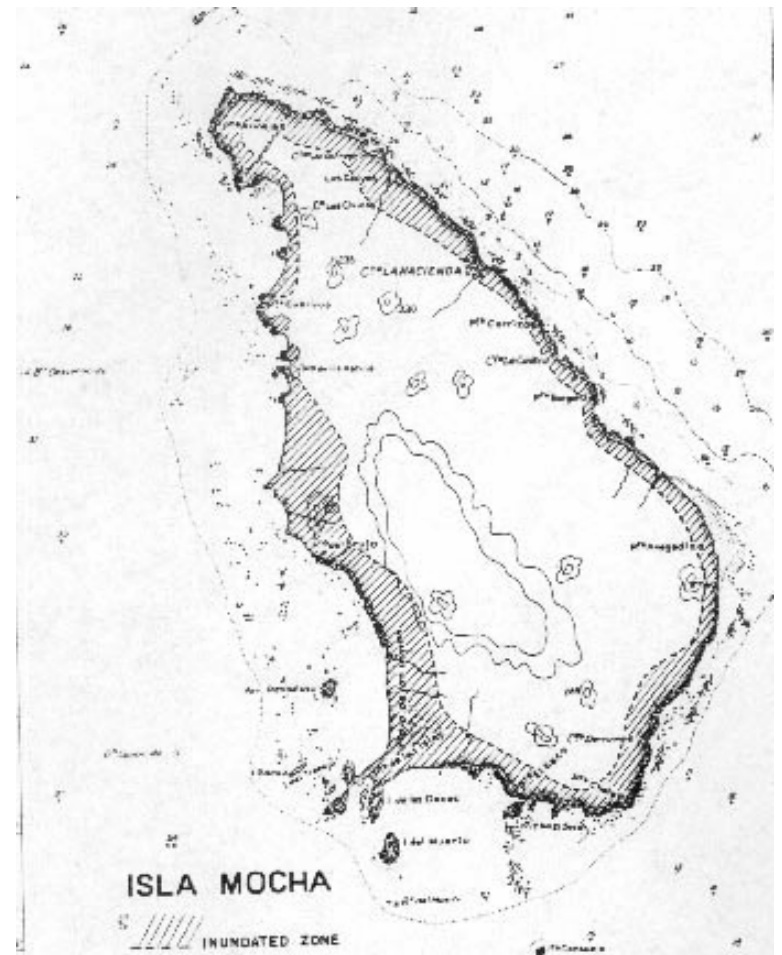
Isla Mocha, Chile

- On Isla Mocha the earthquake was felt with great intensity. The island and adjacent zones were uplifted an estimated 1.7 meters. This is illustrated by rocks that now stick out of the sea but were previously covered with water.

- The sea wave began about 10 minutes after the earthquake, the first evidence being a withdrawal of the water to a distance of about 100 to 200 meters. Three other waves followed, approaching the island from the southwest, affecting the south and west coasts with greatest intensity.

- The first wave was highest and reached an estimated height of 15 meters. The houses of the inhabitants, as well as the building of the lighthouse, dock, etc., were totally wiped away.

- Soundings made inside the 10-meter level show that the post-earthquake depth had been reduced by about 2 m.



Quelue, Chile

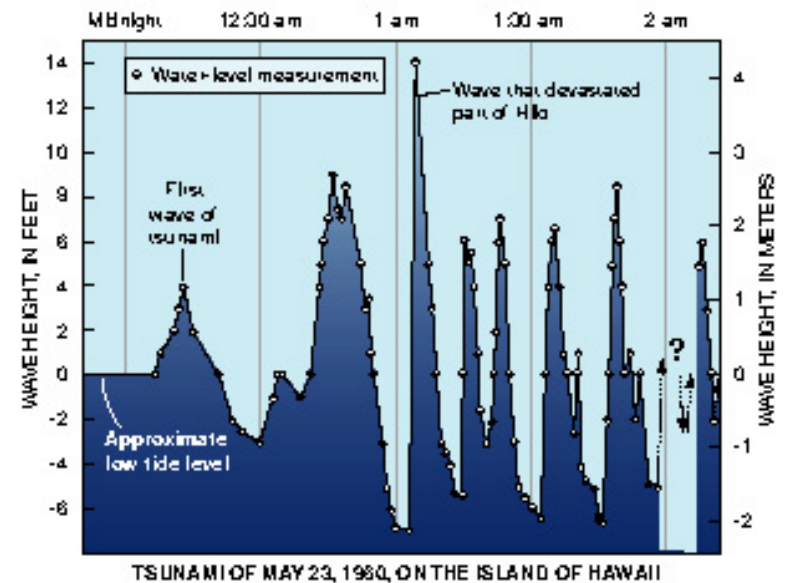
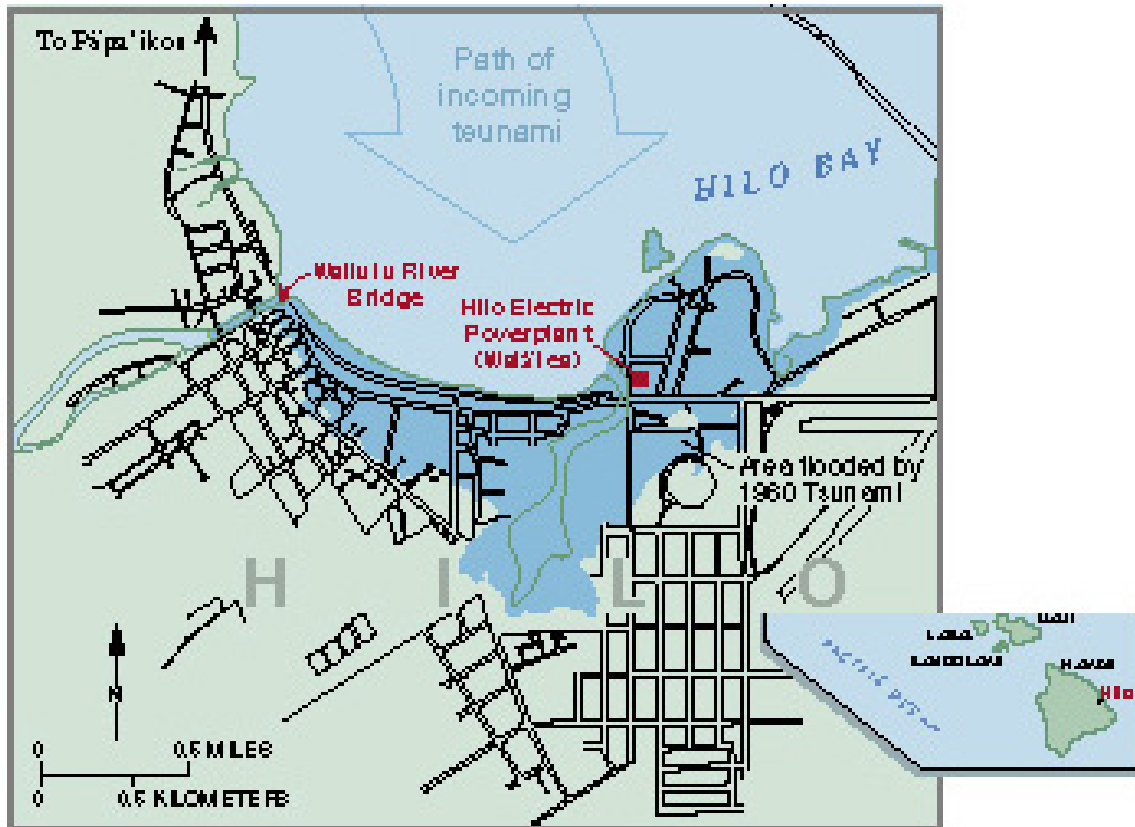


Although a mile from the sea, the town of Quelue was wiped out by a tsunami caused by the 1960 Chile earthquake. Water depths of 13' for the tsunami are estimated. USGS Circular 1187 1999

Corral, Chile (10m wave)



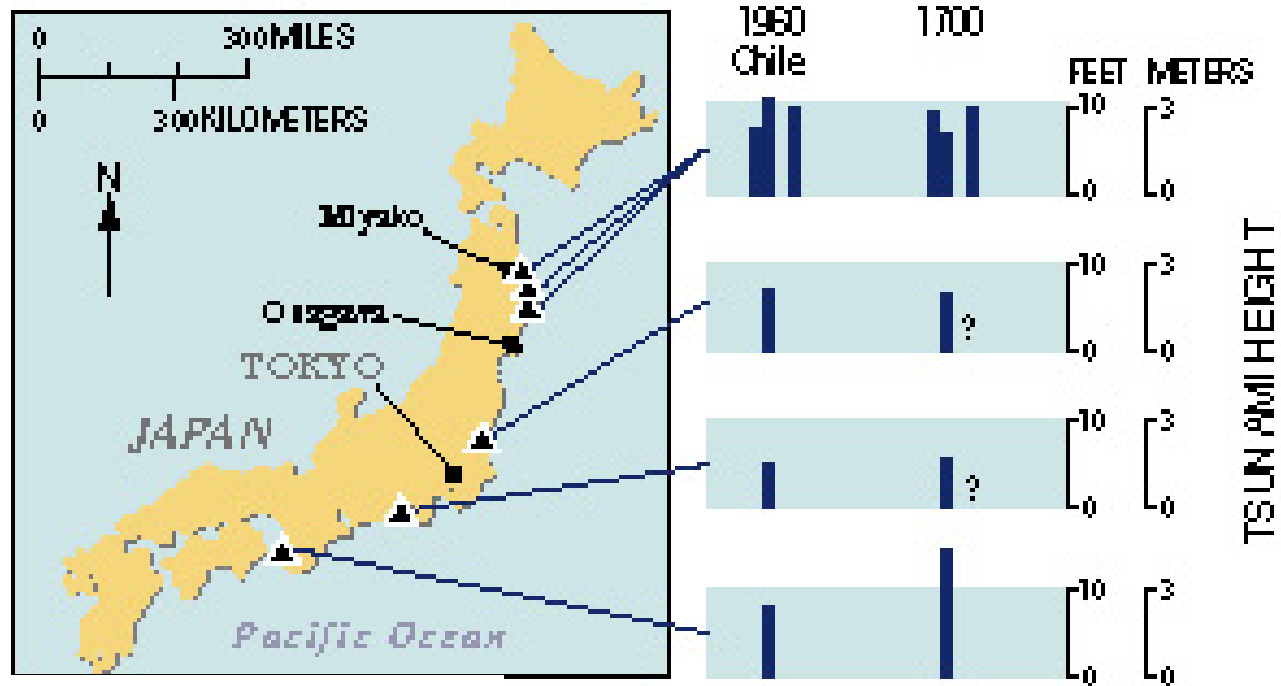
Hilo, Hawaii, was devastated by a tsunami associated with the 1960 Chile earthquake (61 dead)



The 1960 Chile earthquake produced a series of tsunami waves that crossed the Pacific Ocean. This record shows measurements of water levels beneath the Wailuku River Bridge made by seismologist Jerry Eaton and his companions during the first few hours of the tsunami in Hilo, Hawaii.

USGS Circular 1187, 1999

Japan was hit by Tsunamis due to the 1960 Chile quake, too.

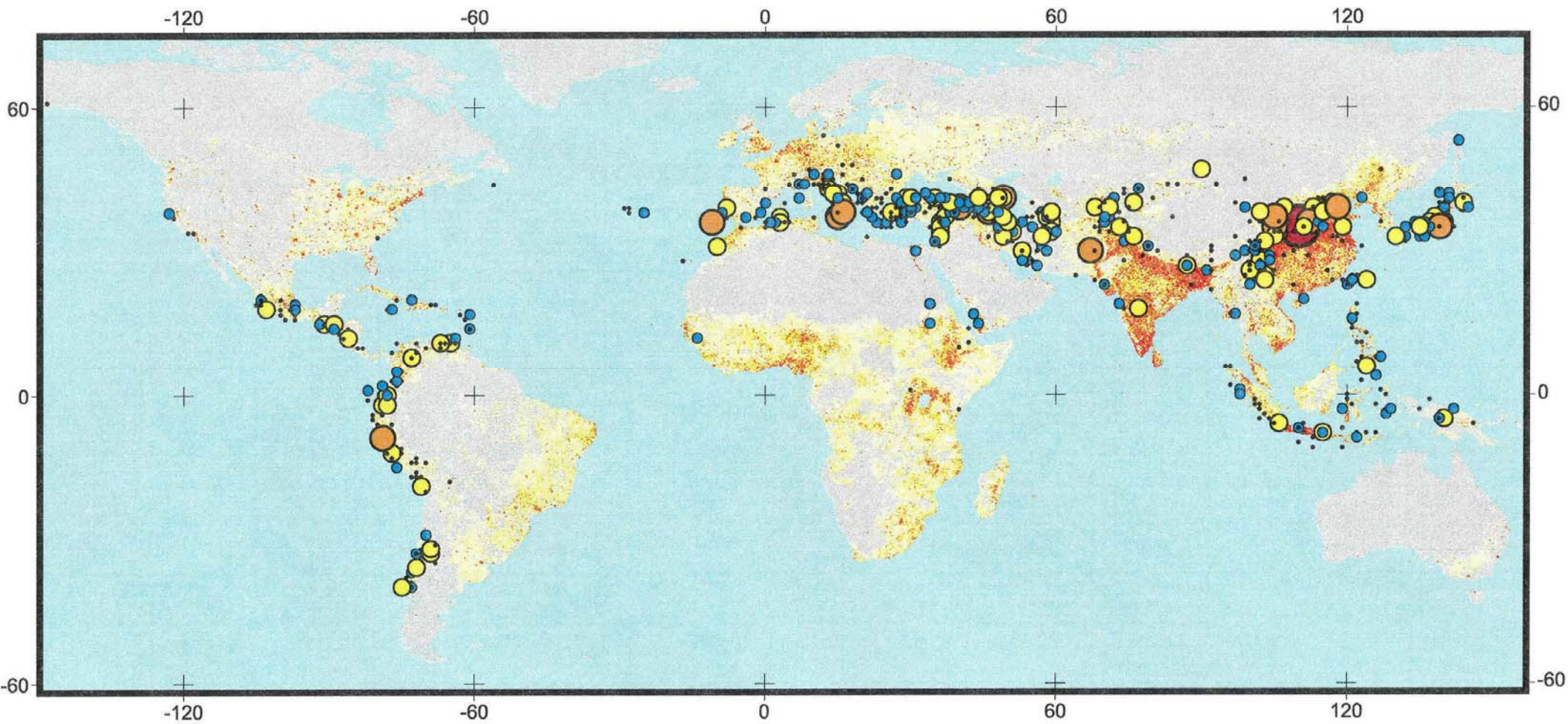


Circular 1187



100 dead, 85 missing, 855 injured, 1,678 homes destroyed).

USGS Circular 1187 1999



LEGEND

Deaths per Earthquake

- 50 - 500
- 500 - 5000
- 5000 - 50000
- 50000 - 500000
- 500000 - 830000

Population Density

- 0 - 2
- 3 - 5
- 6 - 25
- 26 - 50
- 51 - 100
- 101 - 500
- 501 - 2500
- 2501 - 5000
- 5001 - 160000
- No Data

Deadly Earthquakes since 1500
(Utsu, 2002)

Pre-1900 Killer Quakes in LA

Date	Location	Deaths	Magnitude (est)
■ 8/16/1868	Ecuador & Colombia	40,000	7.7
■ 8/13/1868	Chile & Peru	25,000	8.5
■ 3/26/1812	Venezuela	20,000	6.3
■ 2/04/1797	Ecuador	40,000	8.3
■ 6/03/1773	Guatemala	20,000	8.5
■ 5/25/1751	Chile	65	8.5
■ 10/29/1746	Peru	18,000	8.4
■ 1/07/1725	Peru	1500	7.5
■ 2/06/1716	Peru	many	8.8
■ 10/20/1687	Peru	5000	8.2
■ 6/18/1678	Peru	many	7.9
■ 1590	Peru	many	8.2
■ 1/22/1582	Peru	many	8.2
■ 2/08/1570	Chile	2000	8.3
■ 10/28/1562	Chile	many	8.0

1746 Peru Earthquake

- On October 28, 1746, at 10:30 p.m., a massive earthquake struck Lima, the capital of the viceroyalty of Peru, and swamped the nearby port of Callao, shattering areas up and down the coast.
- One account claimed that if "the most astute man attempted to create the perfect calamity, he could not have imagined the horrors inflicted on Lima and Callao."
- The earthquake damaged almost all of Lima's houses. Estimates of the number of dead varied from 1,200 to 6,000, out of a population of 55,000.
- A tsunami killed almost all of Callao's 10,000 inhabitants and leveled most of the buildings.

1746 Earthquake (cont'd.)

- In an anonymous report prepared for the viceroy, the writer observed, "of all [earthquakes] which have happened since their first Conquest, so far at least as hath come to our knowledge, we may with Truth affirm that none ever broke out with such astonishing violence, or hath been attended with so vast a Destruction as that which happened lately in this Capital."

Walker, 2000



Lima and Callao, Peru

Lima

- Lima was founded in 1535 by Pizarro.
- Lima is the political, economic, and cultural center of Peru. Its importance within the nation is so overwhelming that some scholars suggest there are two Perus: Lima and the rest of the country.
- Lima's metropolitan area has a population of 6.4 million, accounting for close to one-third of the nation's total.
- The concentration of wealth and power in Lima is even more intense: The city accounts for more than two-thirds of the nation's gross domestic product.



STS-084-727-53

Aftermath of 1746 Earthquake

- Flexible construction materials began to be used more.
- Grand facades discouraged
- Streets were widened (make these more than twice as wide as walls are tall)
- Multi-storied buildings discouraged and torn down (wealthy did not like this)
- Pressure to knock down the walls around the city to allow the city to grow out, not up

Earthquake near the Coast of Peru

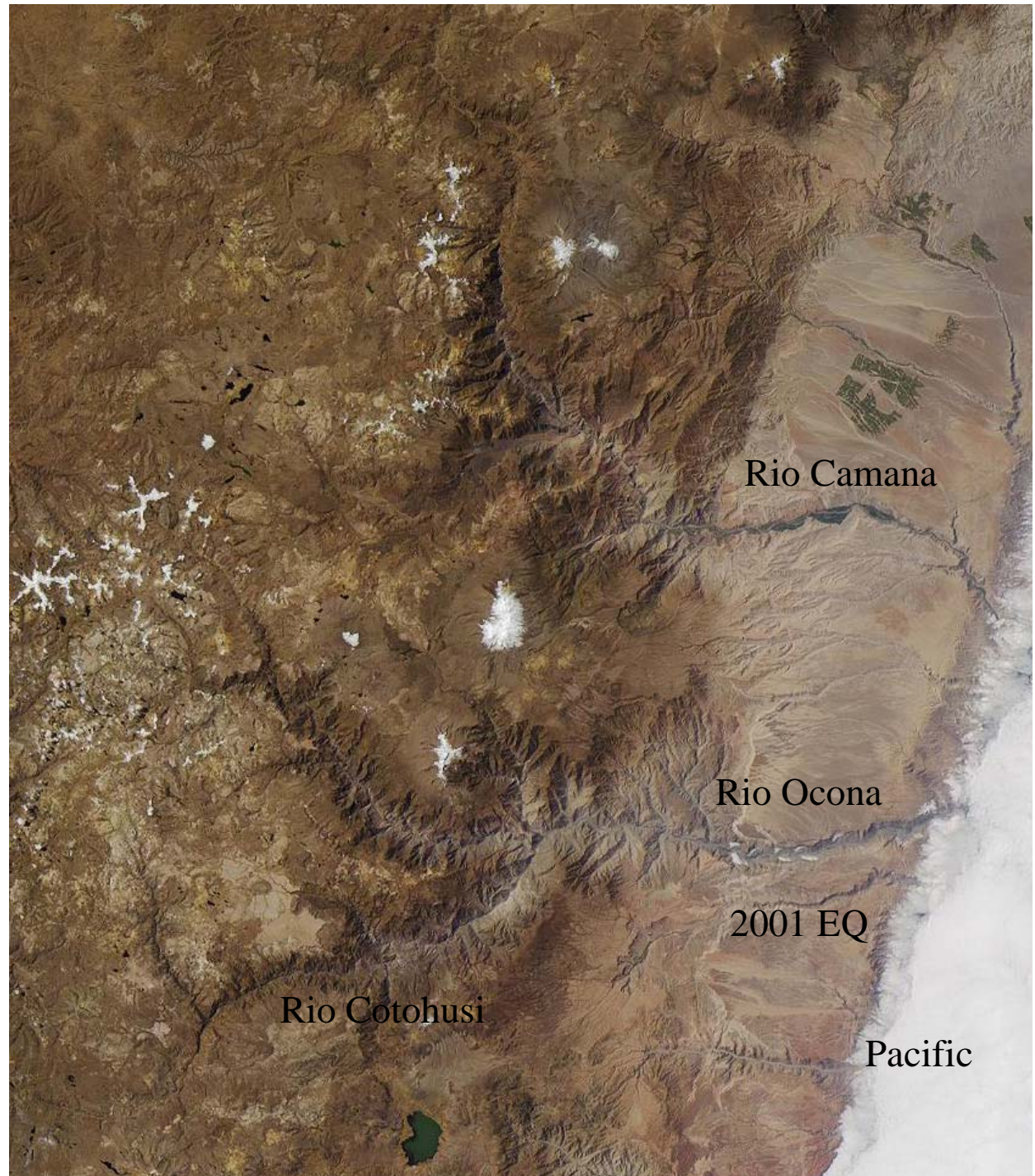
23 June 2001 Magnitude 8.4



A major earthquake occurred about 110 miles (175 km) west of Arequipa or about 370 miles (595 km) southeast of Lima). At least 102 people killed, 1,368 injured and extensive damage in the Arequipa-Camana-Moquega-Tacna areas. At least 20 people killed and some missing from a tsunami in the Camana-Chala area. http://earthquake.usgs.gov/activity/latest/eq_01_06_23/index.html

West is down. Between the canyons, at image center, is the snow-capped peak of the Nudo Coropuna, the highest mountain in the Cordillera Occidental (elevation 6613m). To the west is the smaller Nevado Solimana (6117 meters), part of which has been cut away by a tributary of the Rio Ocona. The Rio Camana's main tributaries are the rivers Andahua and Colca. Colca canyon was once thought to be the deepest in the area, but it is outdone by the canyon of the Rio Cotahuasi (Rio Ocona's main tributary). Reaching a depth of 3354 meters below the top of the plateau, Cotahuasi Canyon is believed to be the deepest of any continental surface on Earth. It is more than twice as deep as Arizona's Grand Canyon. MISR image.

<http://photojournal.jpl.nasa.gov/catalog/PIA03423>

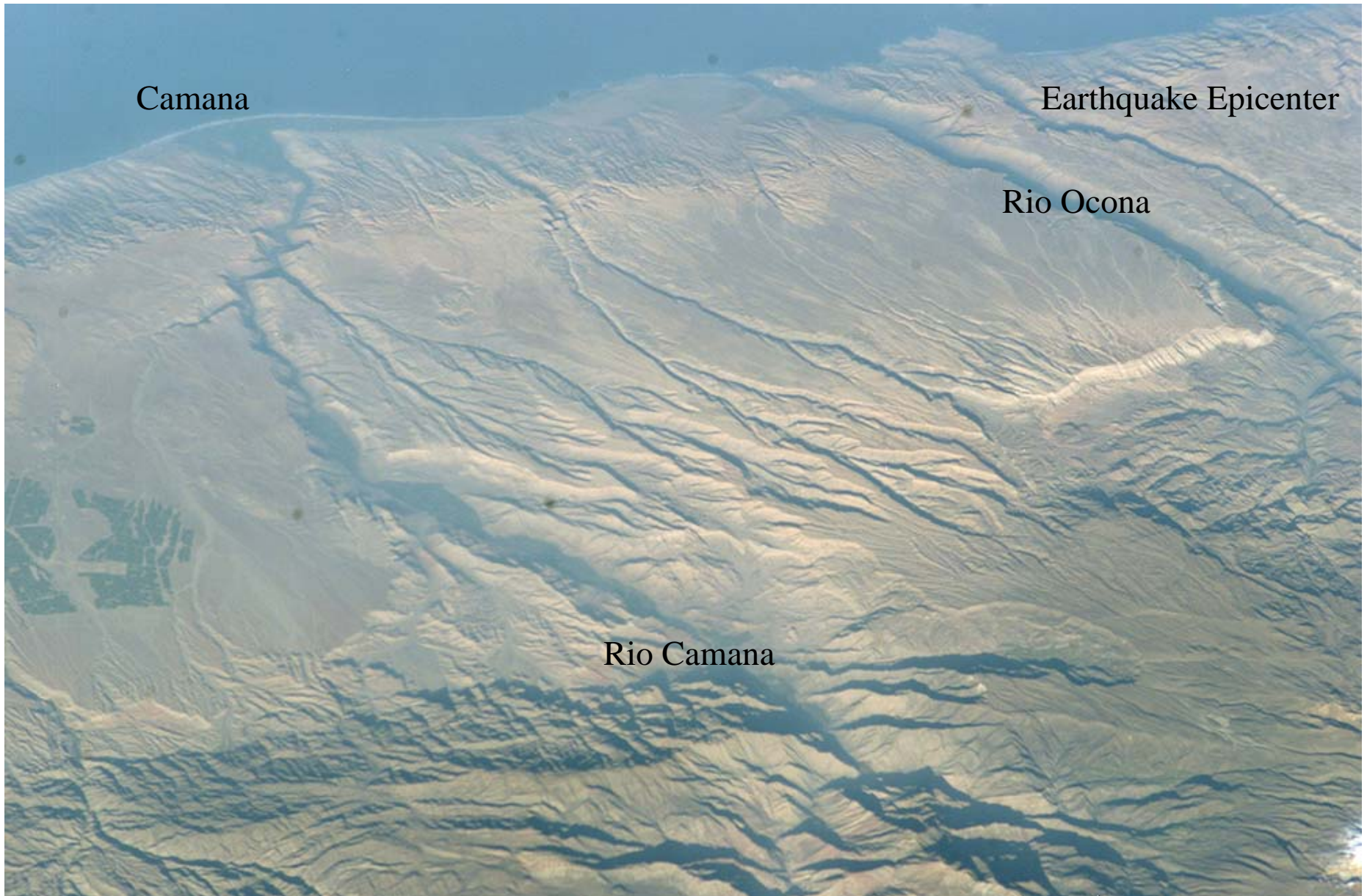


2001 Peru Earthquake



ASTER image

<http://visibleearth.nasa.gov/cgi-bin/viewrecord?8307>



ISS007-E-7388 , taken morning June 13, 2003

2001 Peru Earthquake & Tsunami

A tsunami washed over the low-lying coastal resort region near Camaná, southern Peru, following a strong earthquake on June 23, 2001. After the initial quake, coastal residents witnessed a sudden drawdown of the ocean and knew a tsunami was imminent. They had less than 20 minutes to reach higher ground before the tsunami hit. Waves as high as 8 m came in four destructive surges reaching as far as 1.2 km inland. The dashed line marks the approximate area of tsunami inundation. Thousands of buildings were destroyed, and the combined earthquake and tsunami killed as many as 139 people.

(ISS004-ESC-6128)

