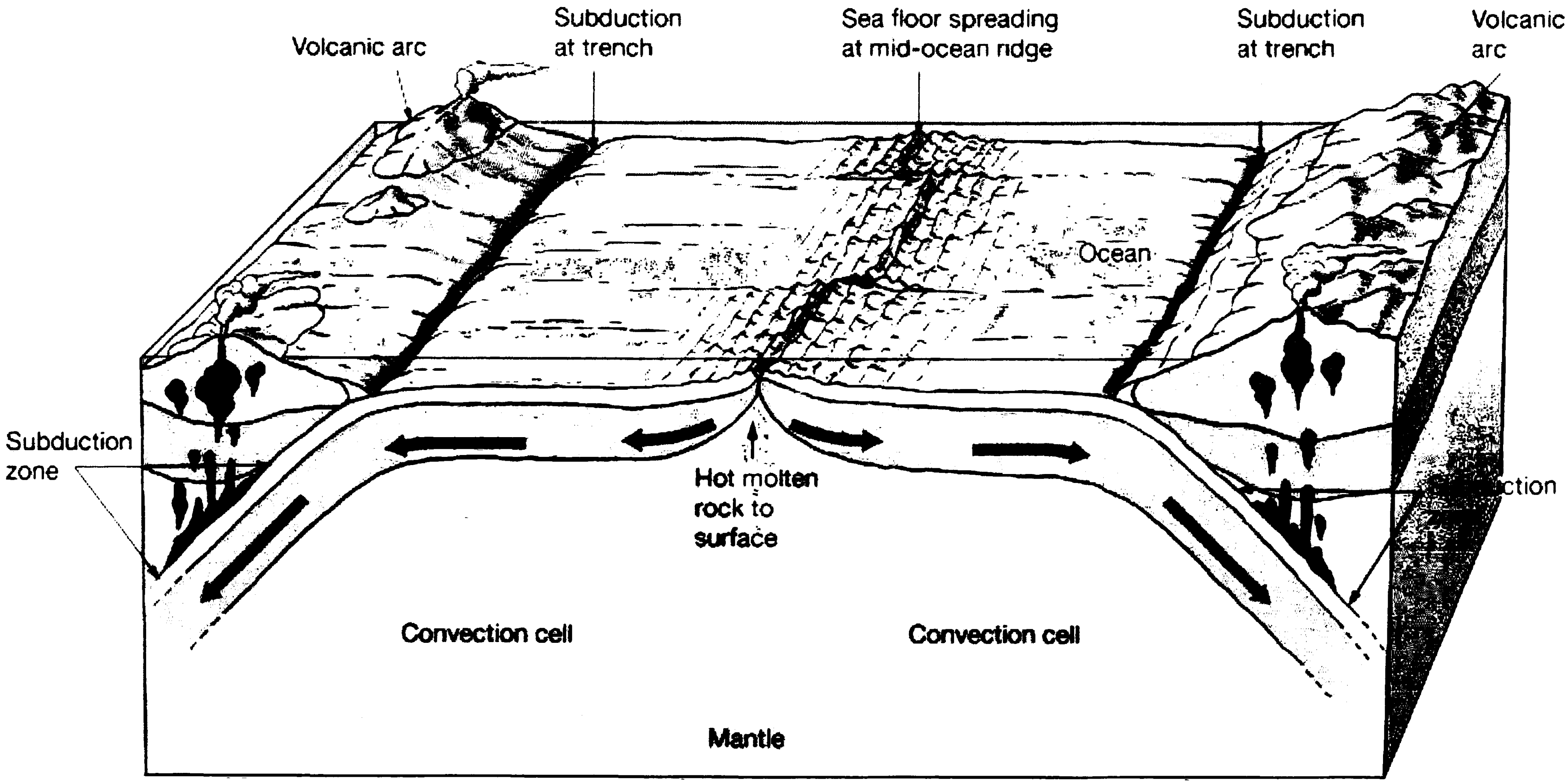
PLATE TECTONIC: OBSERVATIONS

- Display map of beach balls
- Display large topography map with seismicity
- Show schematic diagram of plates/convection

- The theory of plate tectonics is that the lithosphere is divided into a small number of nearly rigid plates which are sliding over the asthenosphere.
- Most of the deformation caused by relative plate motion occurs at the plate boundaries while the interiors of the plates remain relatively undeformed.

(Notes from "The Ocean Basins" Ch 1+2)

- Before going into plate tectonic theory it is instructive to examine some of the primary observations that were used to develop the theory.
(Of course since I believe in plate tectonics, my interpretations of the various maps will be biased.
- After looking at the observations you may decide that plate tectonic theory is flawed or incorrect. It is OK not to believe in plate tectonics but you will have trouble passing this course.)



Volcanic arc
Subduction at trench
Sea floor spreading at mid-ocean ridge
Subduction at trench
Volcanic arc
Ocean
Subduction zone
Hot molten rock to surface
Convection cell
Convection cell
Mantle

(1.5)

Topography (ETOPO5 + Hipsographic Curve)

- Of course the dominant feature of the Earth's topography is the difference in elevation between the continents (~30% of surface area) and oceans (~70% of surface area).

Platform

- The average elevation of the land is only 0.8 km. Land is relatively flat and of low elevation because erosion distroys mountains in relatively short periods of time (10-100 ma).

mountains

- A very small percentage of the earth's surface has an elevation above 3 km. Himalayas, Andes, Zagros, Rockey Mnts., Alps.
- The crust is relatively thick in these areas 50-70 km.
- According to plate tectonic theory these are areas where the plates are converging causing compression and crustal thickening.

Continental margins

- The transition between the land and the deep ocean is the continental margin. There are two varieties of continental margin, passive and active.

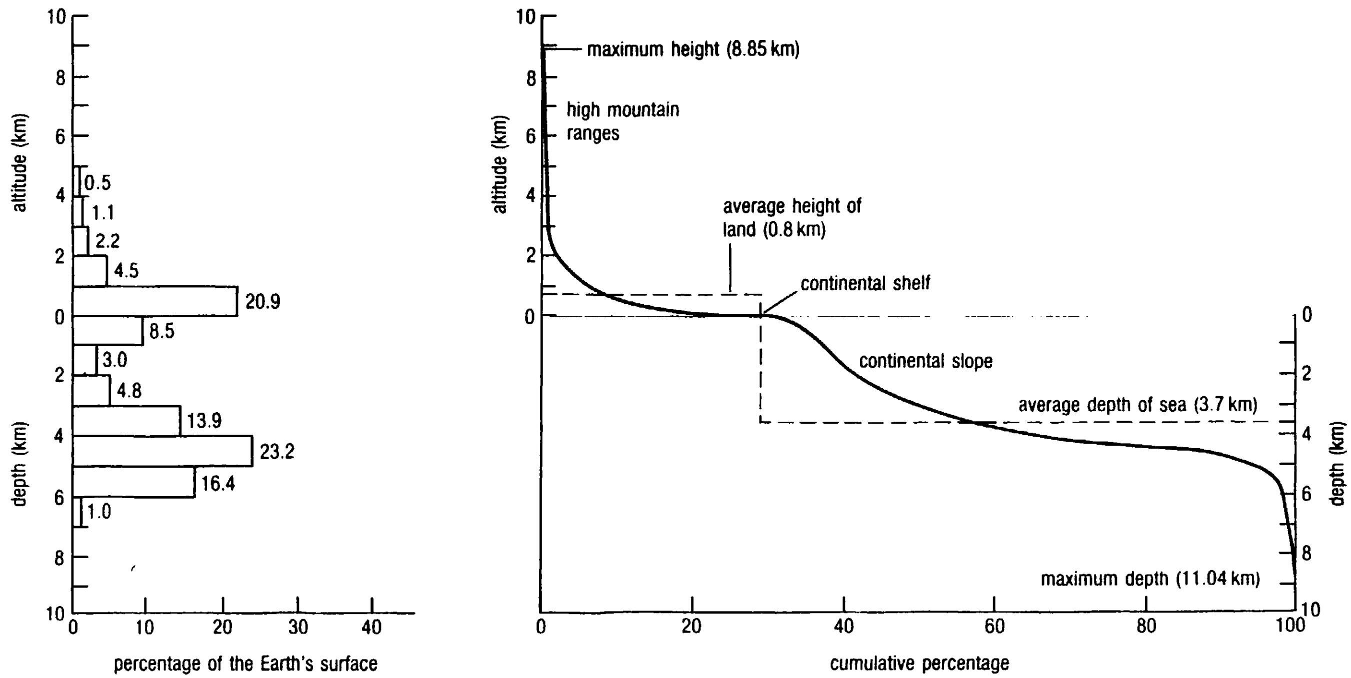
- Passive margins are aseismic. They have shelf break and continental rise extending down to the deep abyssal plain (~5 km).

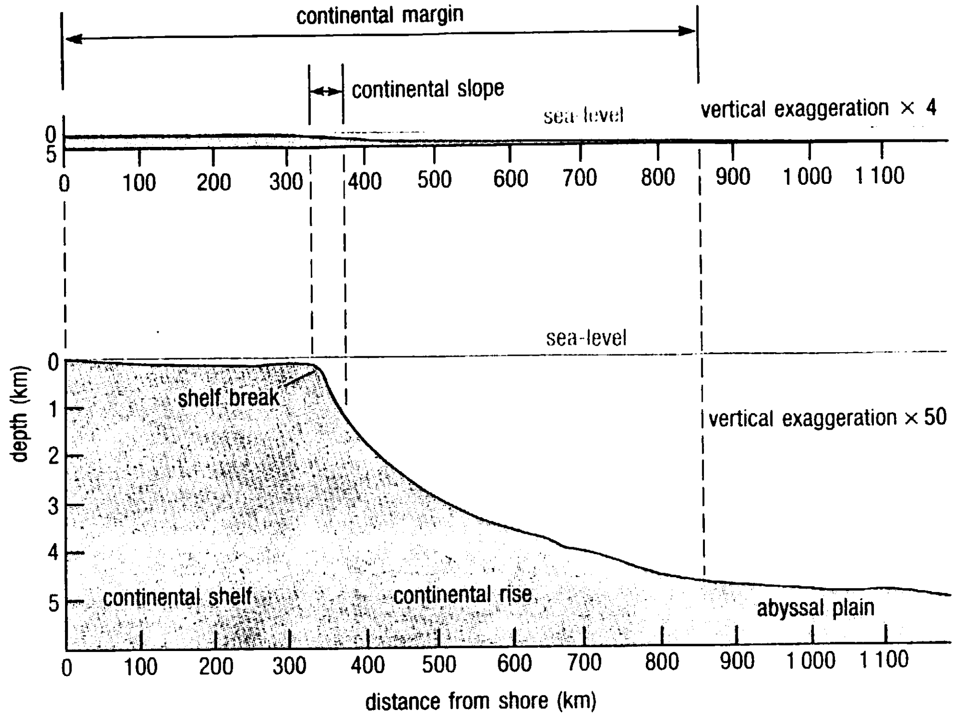
- Active margins have many earthquakes. They have an inner wall, an outer wall and a deep trench axis (5-7 km)

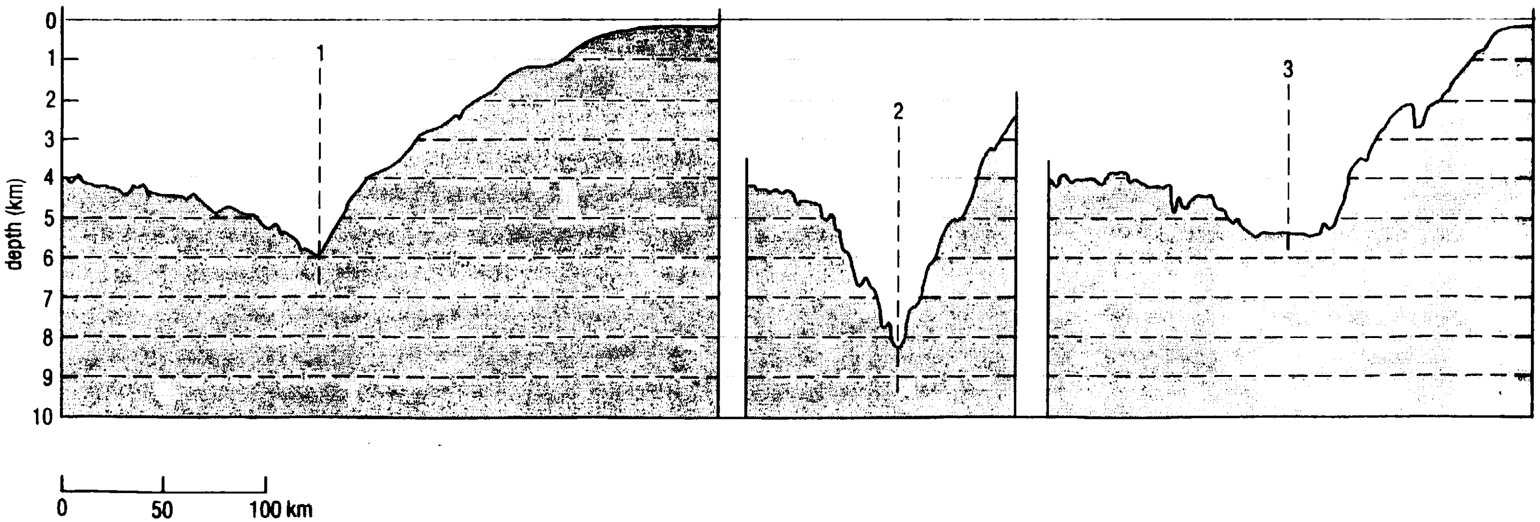
Figure 2.4 The distribution of levels on the Earth's surface.

(a) A histogram showing the actual frequency distribution.

(b) The hypsographic curve: a cumulative frequency curve based on (a). This is *NOT* a profile of the Earth's surface; it is a curve showing the percentages of the Earth's surface that lie above, below, or between any given levels.




continental margin
continental slope
sea-level
vertical exaggeration × 4
sea-level
shelf break
vertical exaggeration × 50
depth (km)
continental shelf
continental rise
abyssal plain
distance from shore (km)


depth (km)
1
2
3
0
50
100 km

Abyssal Plain

- The largest area of the Earth's surface is the abyssal plain. It ranges in depth from about 4.5 km to 5.5 km.
- In many places the abyssal plain is covered by a thin layer of sediments.
- Unsedimented areas have low amplitude, elongate hills called abyssal hills.

Oceanic Ridge

- The second largest area of the seafloor consists of broad oceanic ridges. The centers of the ridges has depths ranging between 2.5 and 4 km. Depth gradually increases away from the ridge axis to a value of 4 - 5 km
- According to plate tectonic theory the deepening of the seafloor away from the ridge axes is due to cooling and contraction of the lithosphere

Ridge Axis

- The axis of symmetry about the oceanic ridge is called the ridge axis.
- There are two types of ridge axes: The ridge axes associated with slow spreading has a deep axial valley and rugged ridge flank typography. The ridge axes associated with fast spreading have a small amplitude axial high with smooth flanking typography.

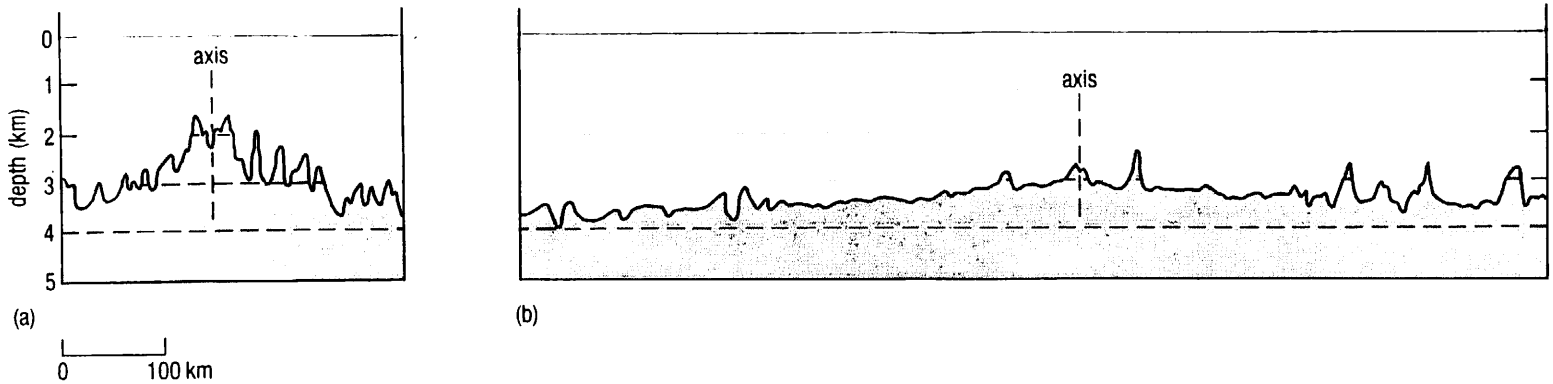


Figure 2.11 Representative east–west topographic (bathymetric) profiles across the Mid-Atlantic Ridge and across the East Pacific Rise (see Question 2.5). The vertical exaggeration is ×50.

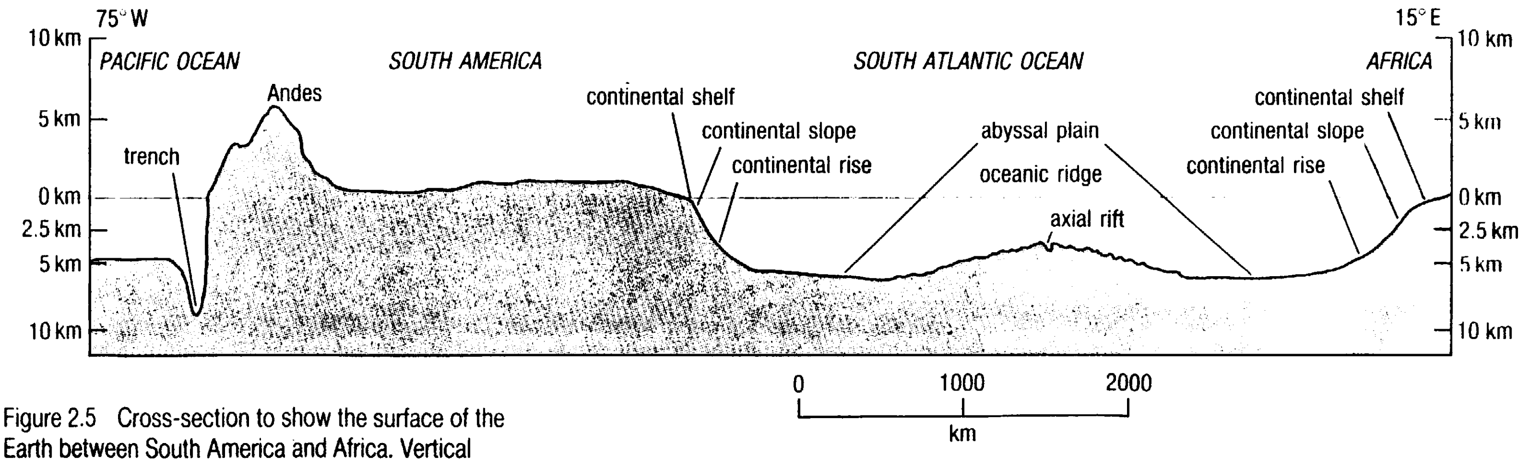
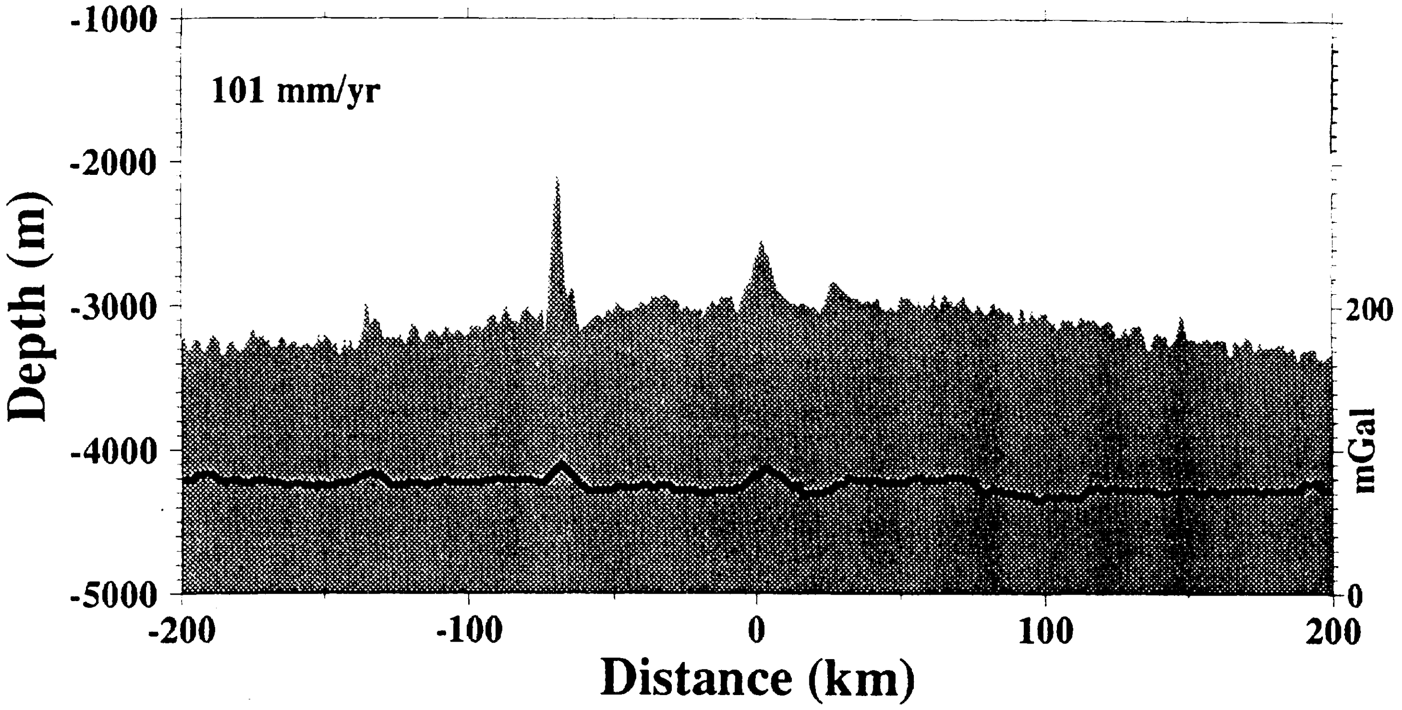


Figure 2.5 Cross-section to show the surface of the Earth between South America and Africa. Vertical exaggeration ×100.

6.2

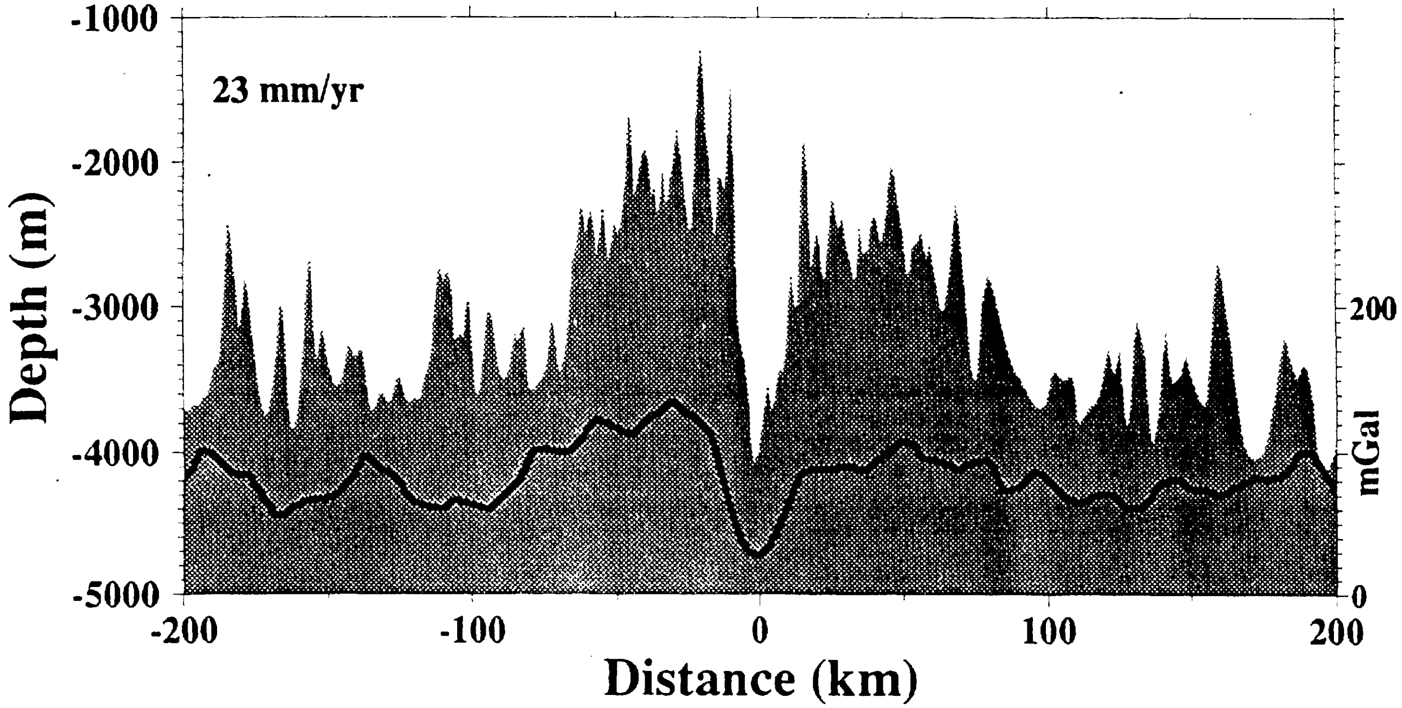
East Pacific Rise

(11.1 N, 256.3 E)



Mid Atlantic Ridge

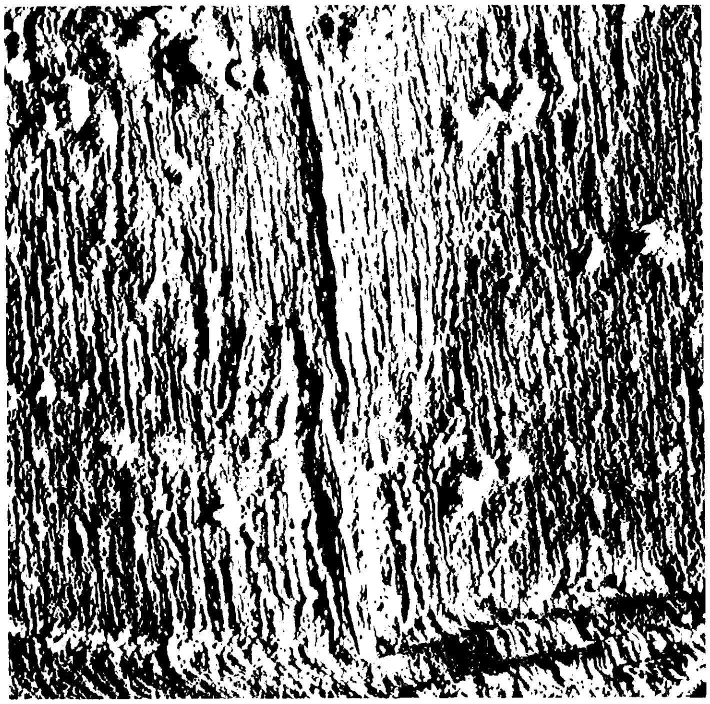
(48.8 N, 331.9 E)



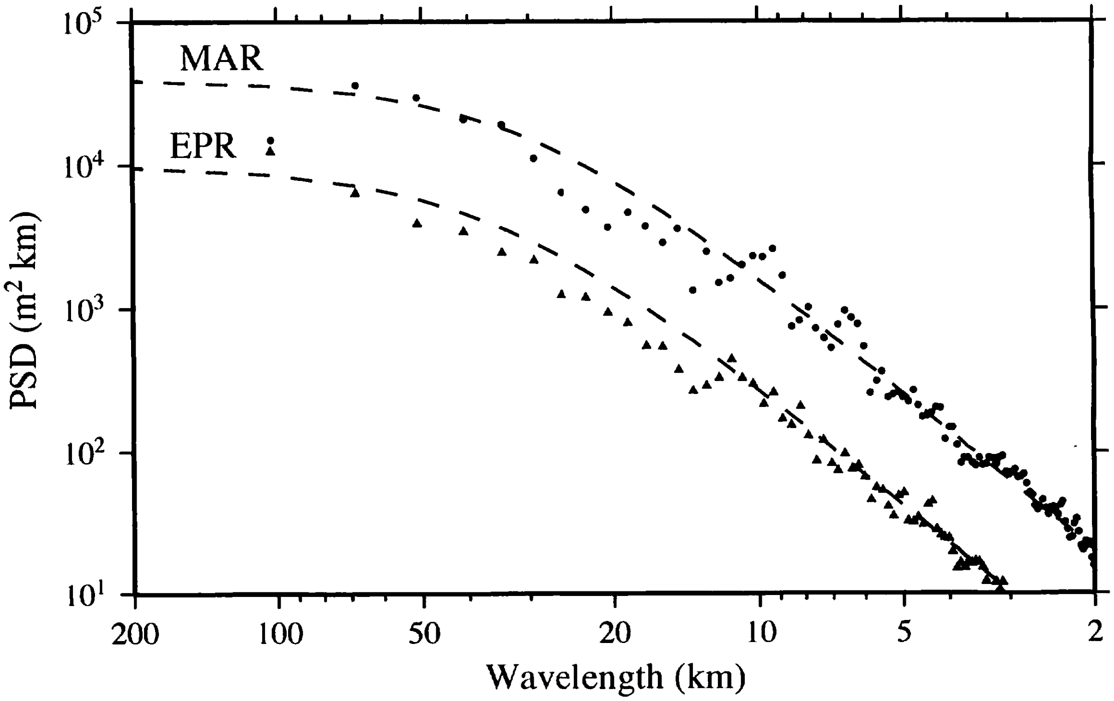
6.3

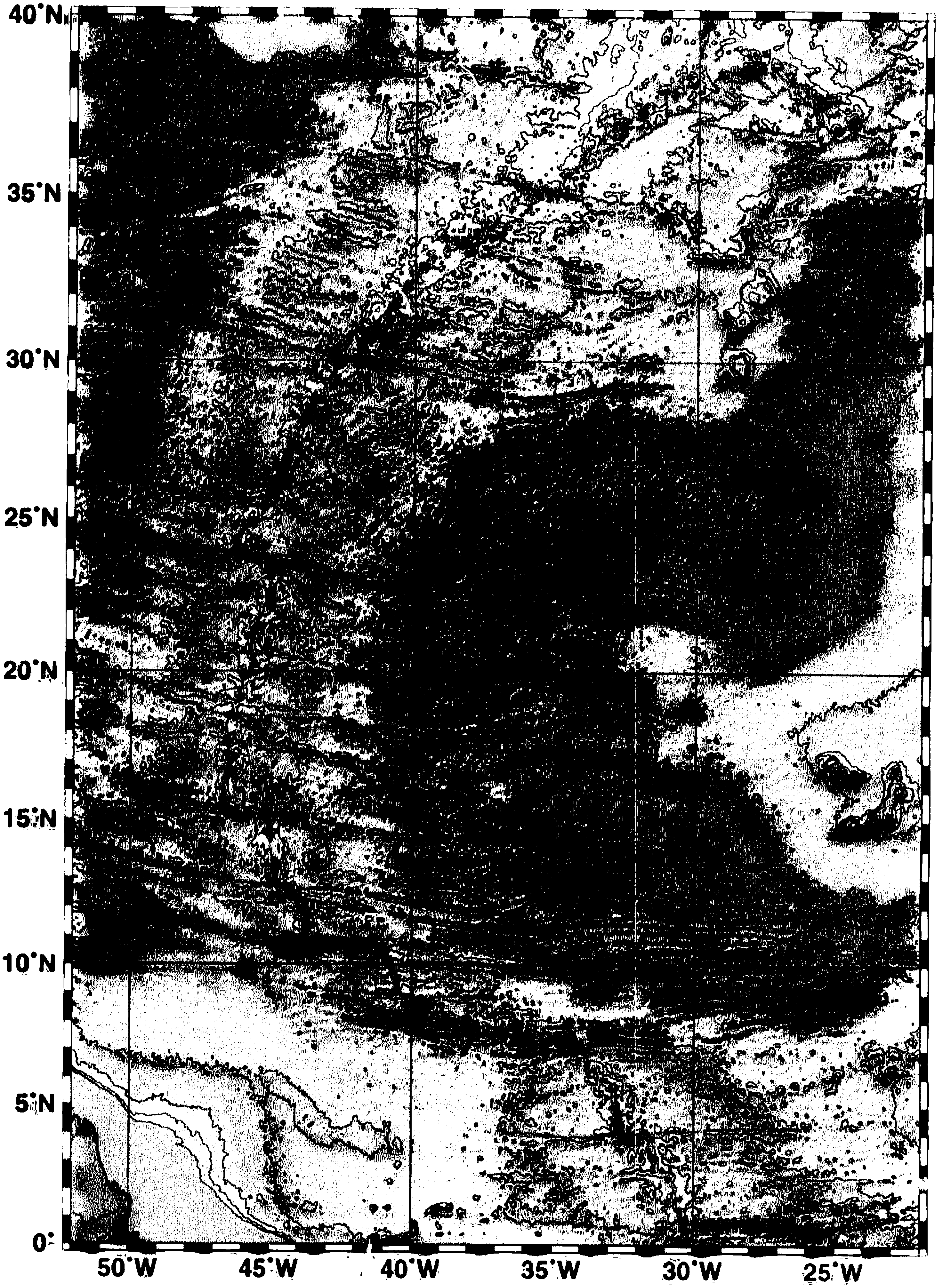
Mid-Atlantic Ridge

East Pacific Rise

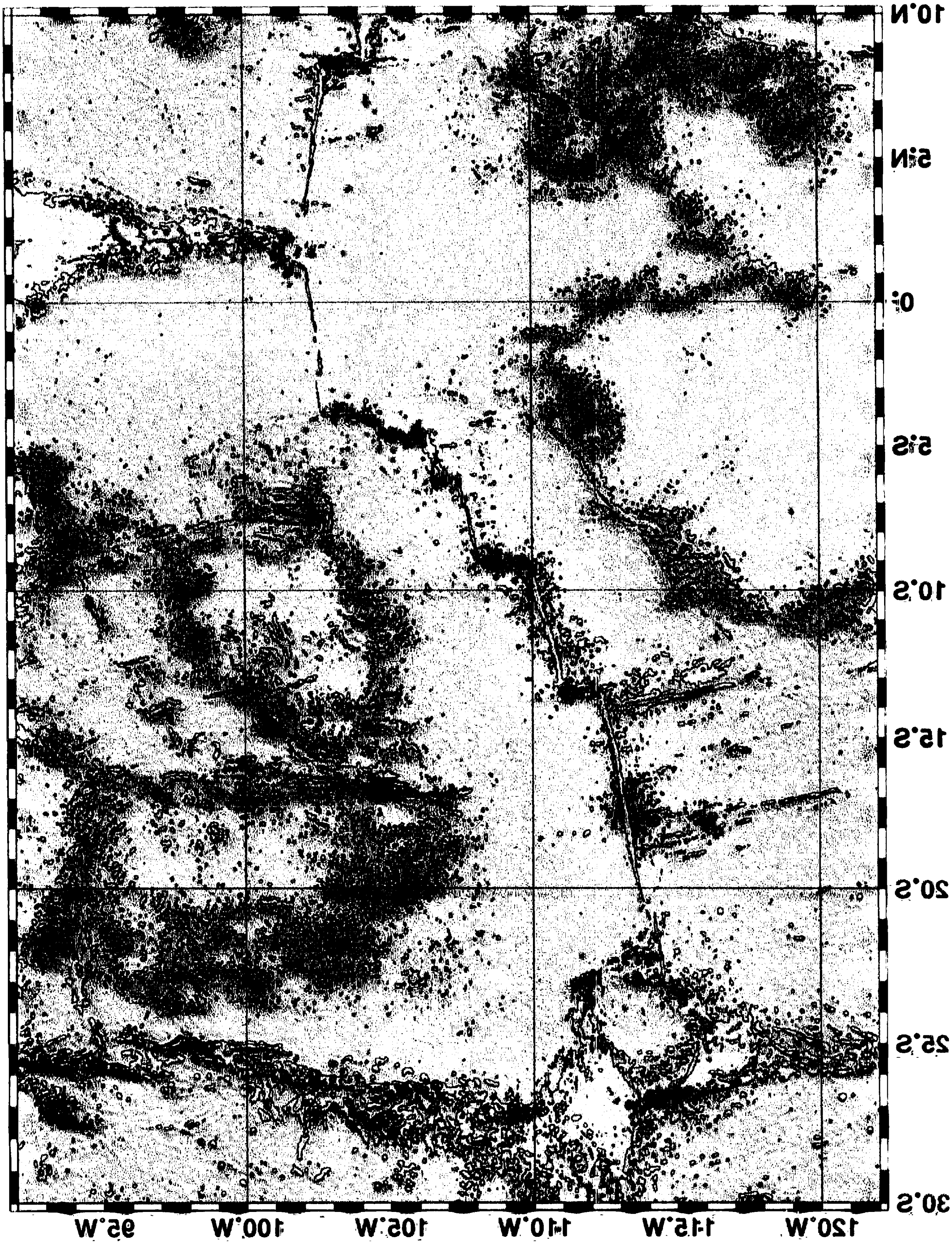


← 200 km →



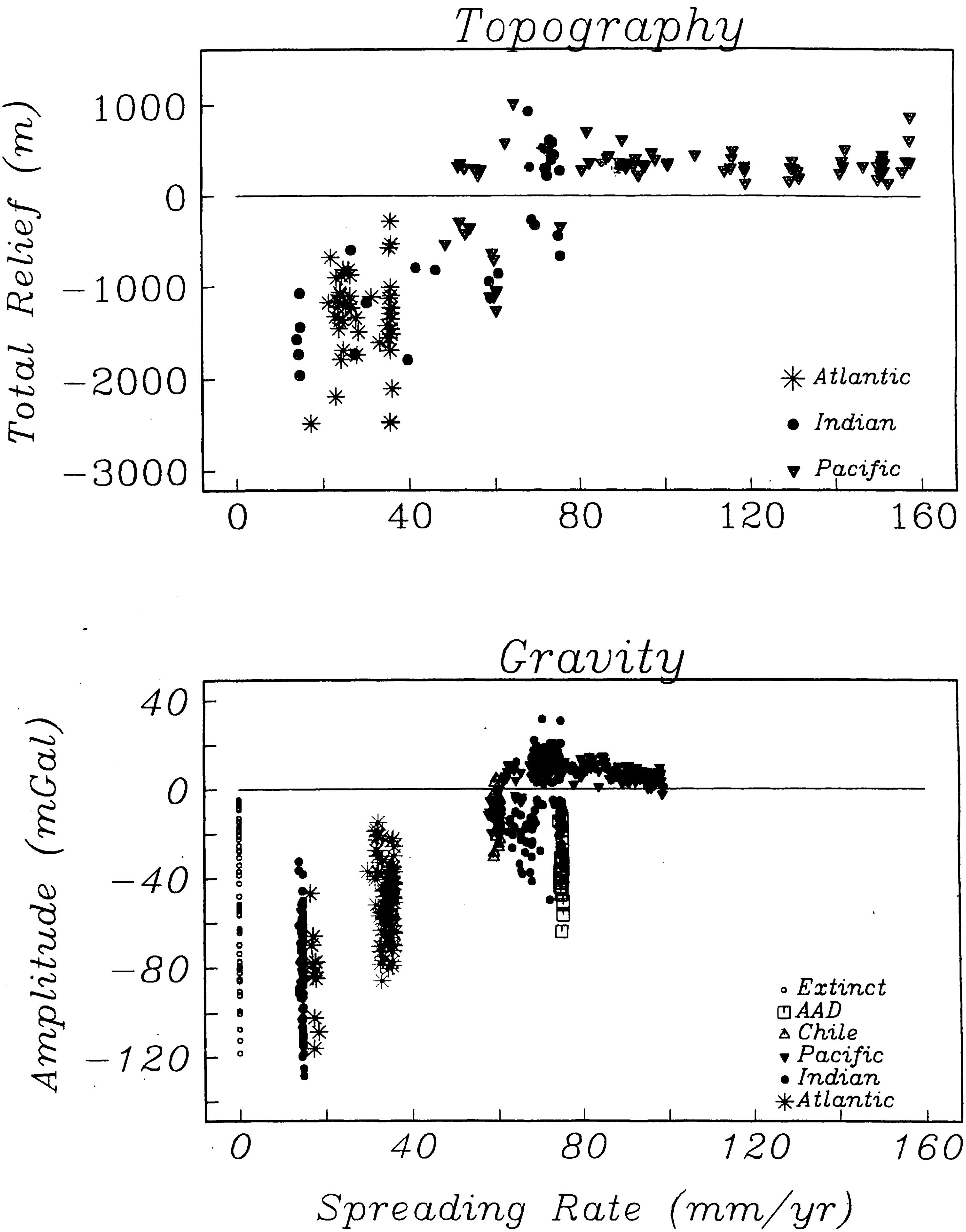


40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
0°
50°W
45°W
40°W
35°W
30°W
25°W

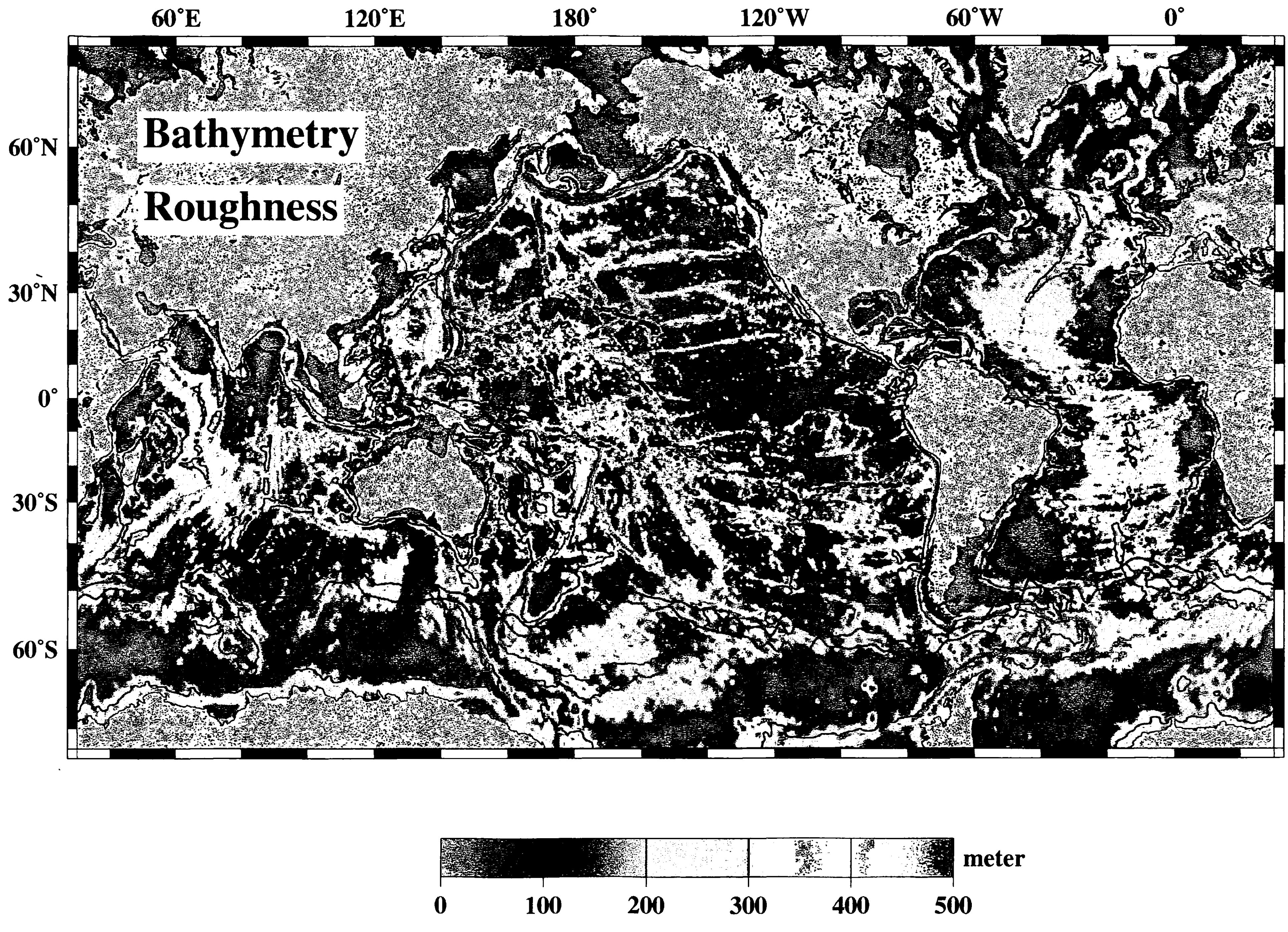


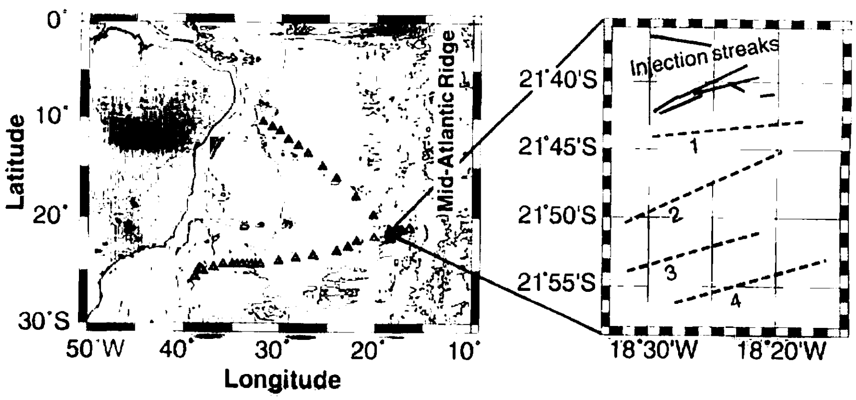
10°N
5°N
0°
5°S
10°S
15°S
20°S
25°S
30°S
95°W
100°W
105°W
110°W
115°W
120°W

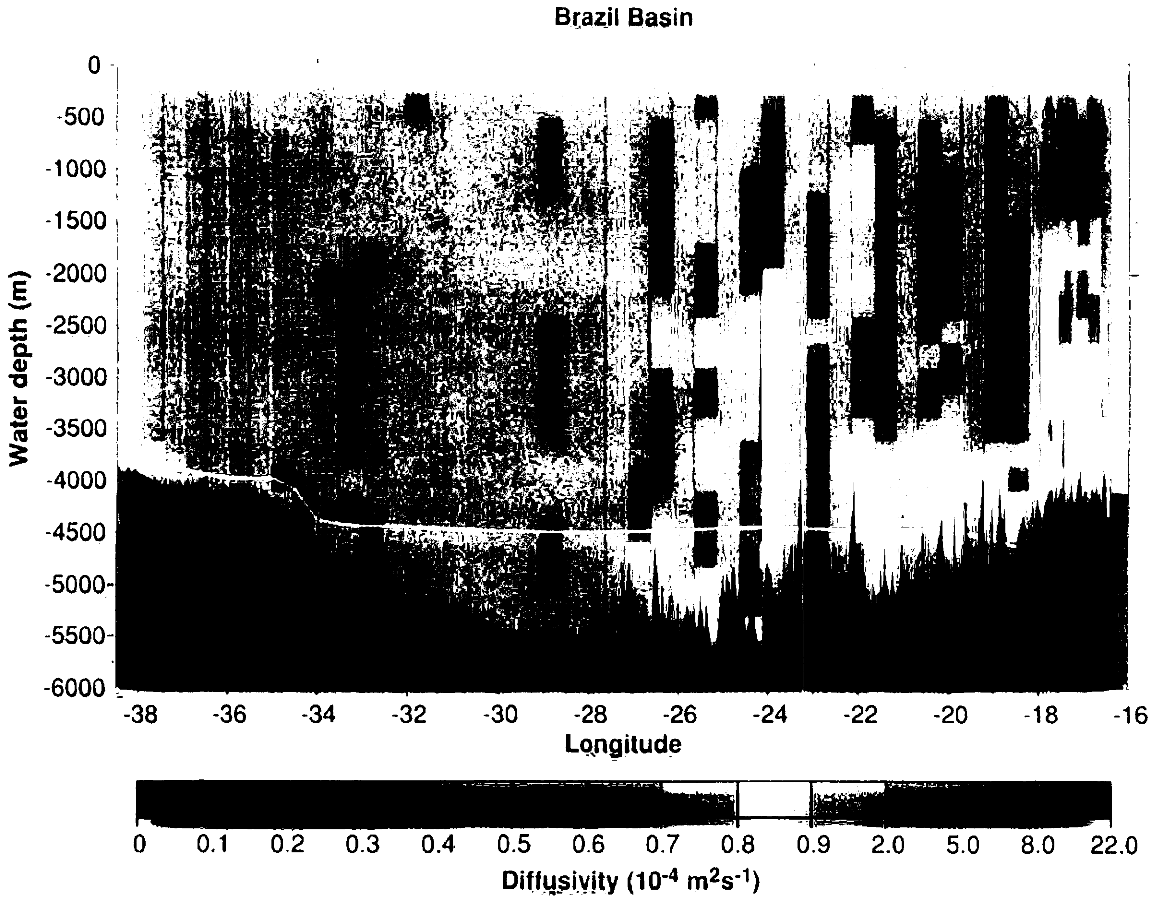
6.4

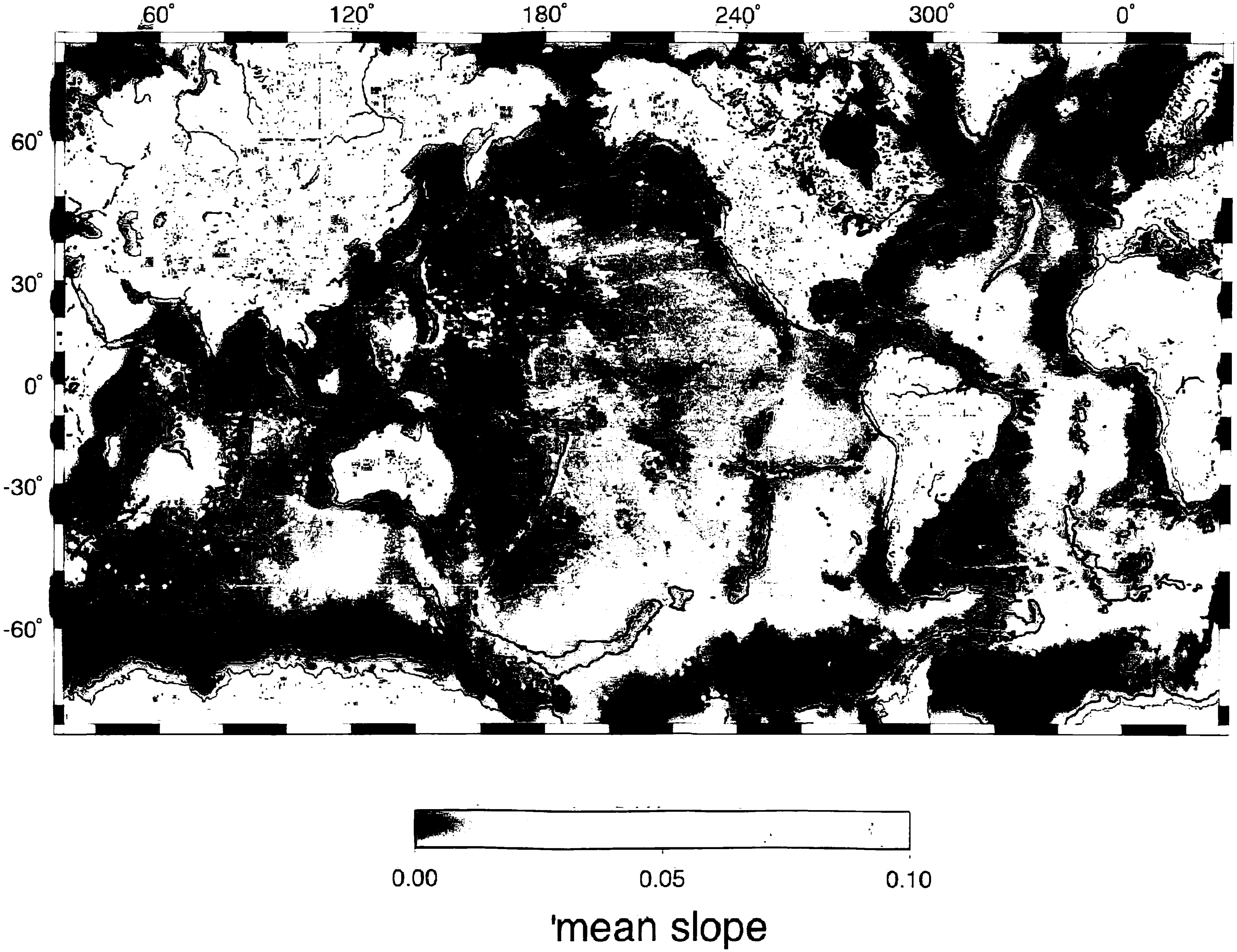


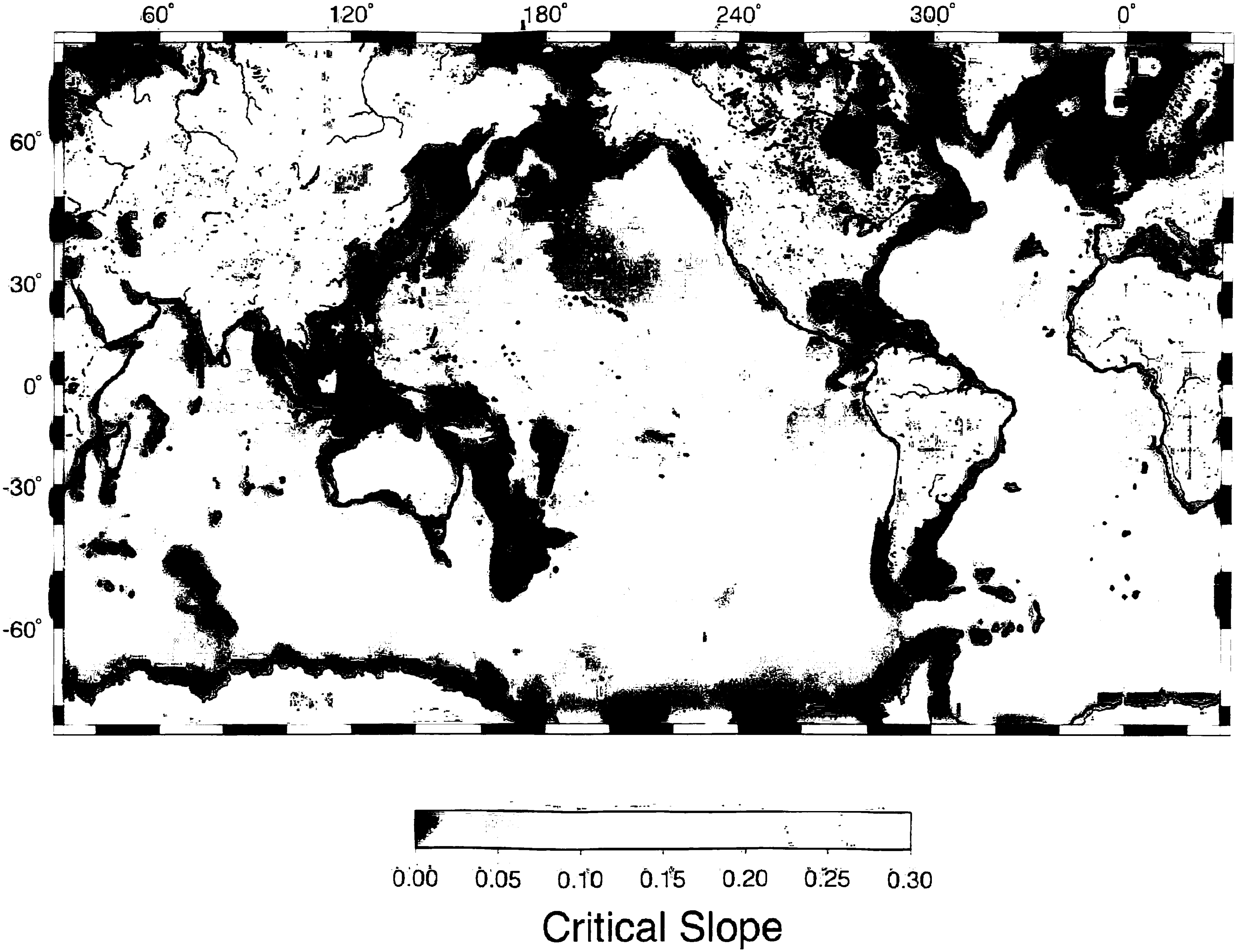
Topography
Total Relief (m)
1000
0
−1000
−2000
−3000
0
40
80
120
160
Atlantic
Indian
Pacific
Gravity
Amplitude (mGal)
40
0
−40
−80
−120
0
40
80
120
160
Extinct
AAD
Chile
Pacific
Indian
Atlantic
Spreading Rate (mm/yr)

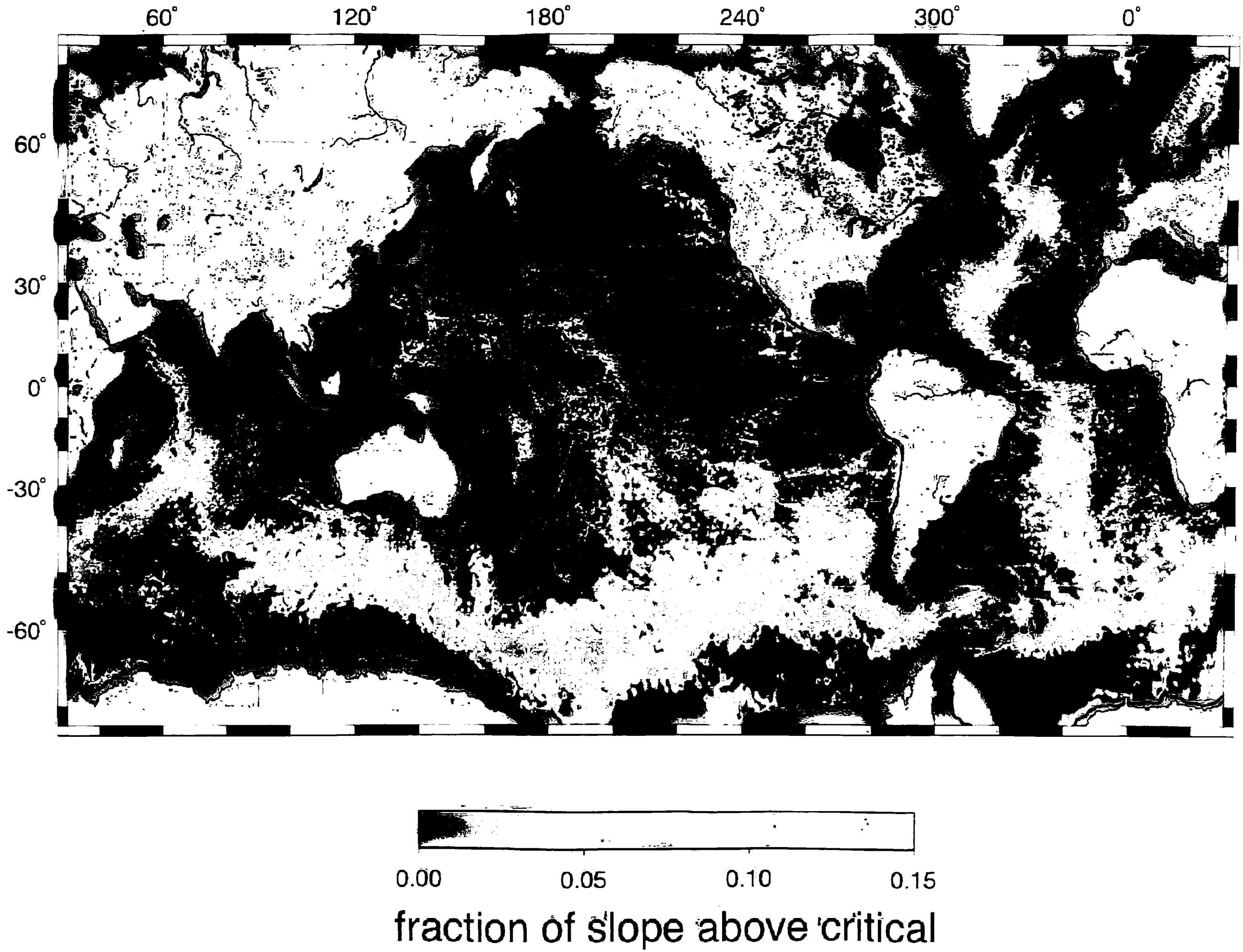

Bathymetry
Roughness
60°E
120°E
180°
120°W
60°W
0°
60°N
30°N
0°
30°S
60°S
0
100
200
300
400
500
meter


0°
10°
20°
30°S
Latitude
50°W
40°
30°
20°
10°
Longitude
Mid-Atlantic Ridge
21°40'S
21°45'S
21°50'S
21°55'S
18°30'W
18°20'W
Injection streaks
1
2
3
4


Brazil Basin
Water depth (m)
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-5500
-6000
-38
-36
-34
-32
-30
-28
-26
-24
-22
-20
-18
-16
Longitude
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2.0
5.0
8.0
22.0
Diffusivity (10^-4 m^2 s^-1)

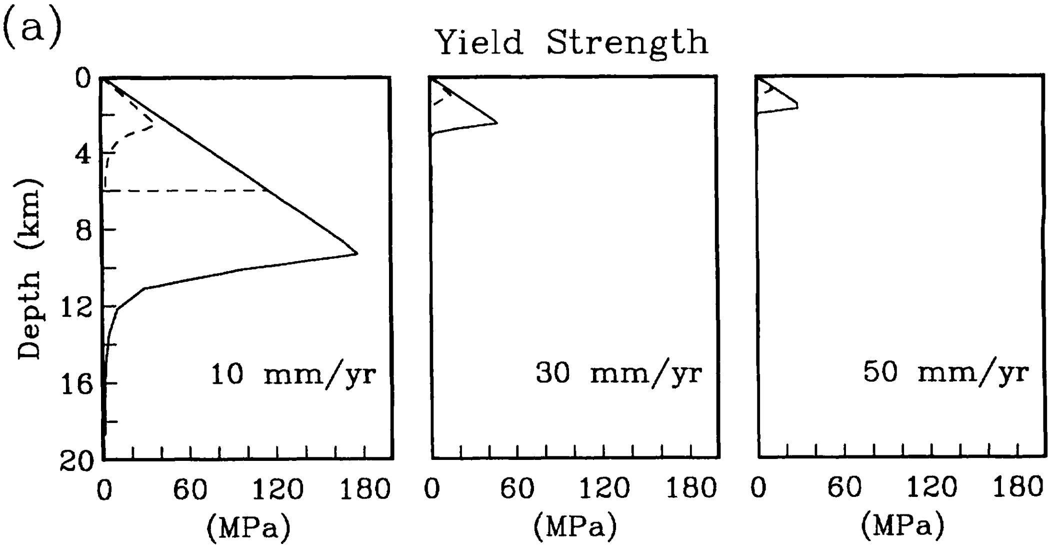

60°
120°
180°
240°
300°
0°
60°
30°
0°
-30°
-60°
0.00
0.05
0.10
'mean slope


60°
120°
180°
240°
300°
0°
60°
30°
0°
-30°
-60°
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Critical Slope


60°
120°
180°
240°
300°
0°
60°
30°
0°
-30°
-60°
0.00
0.05
0.10
0.15
fraction of slope above critical

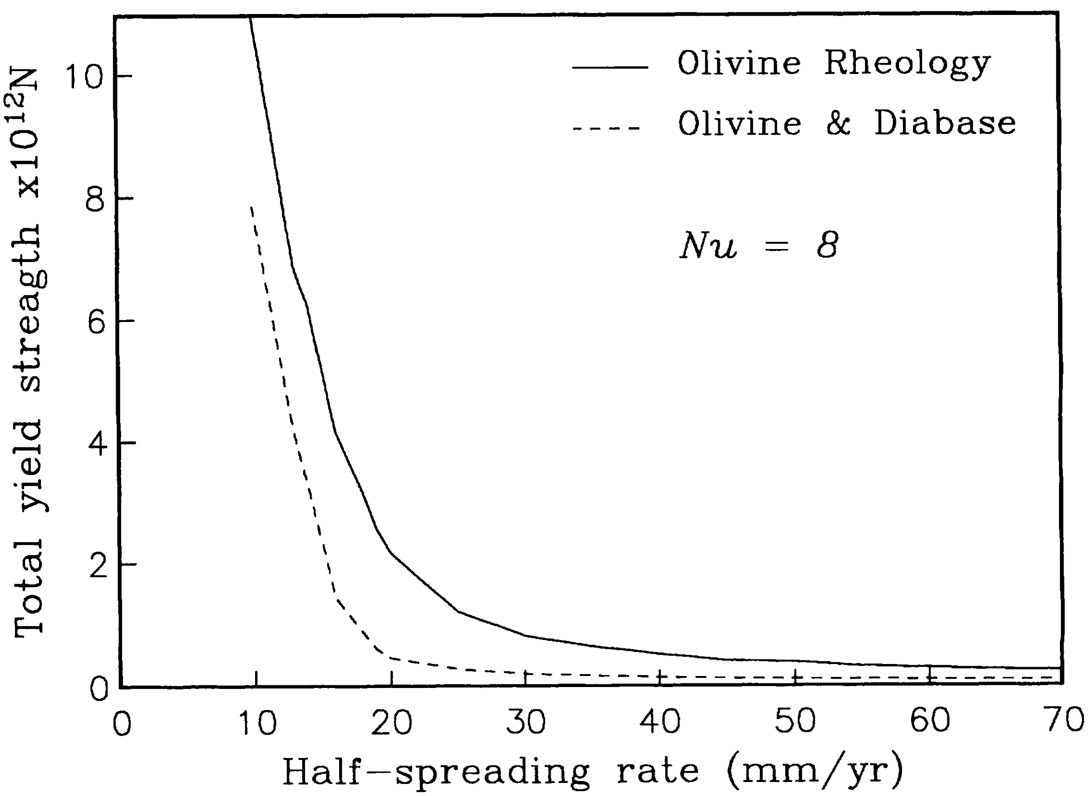
6.6

(a)



Yield Strength
Depth (km)
0
4
8
12
16
20
10 mm/yr
30 mm/yr
50 mm/yr
0 60 120 180
(MPa)

(b)



Olivine Rheology
Olivine & Diabase
Nu = 8
Total yield streagth x10^12N
0
2
4
6
8
10
0 10 20 30 40 50 60 70
Half-spreading rate (mm/yr)

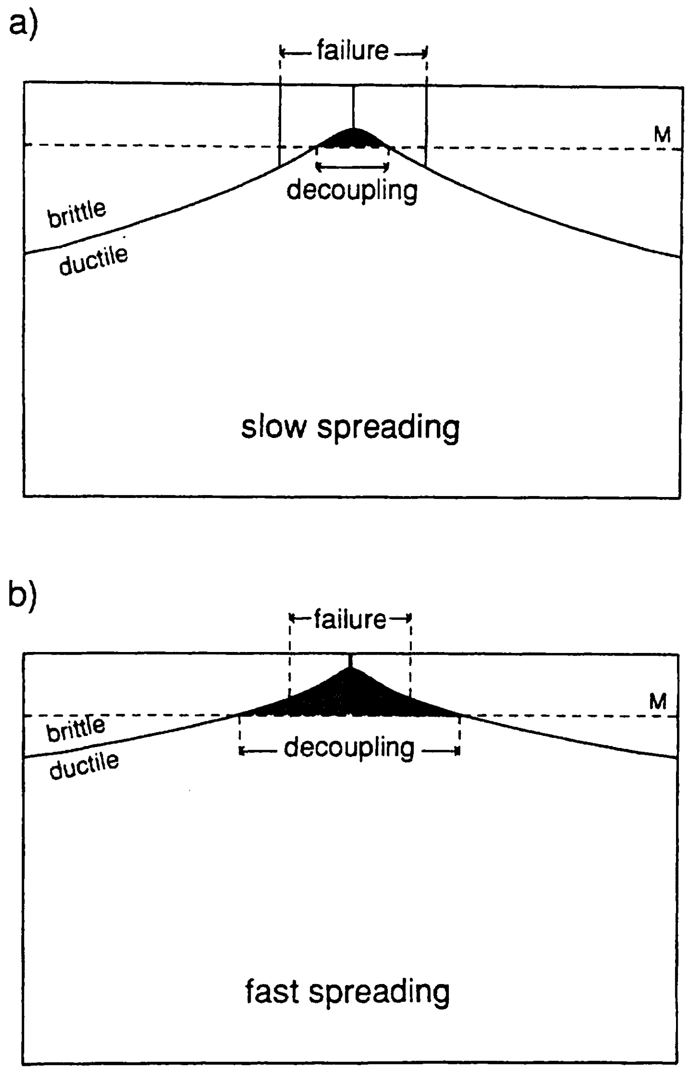


Fig. 5. Geometry of a passive spreading center for two different spreading rates. The oceanic lithosphere is modeled as a brittle plate over a ductile fluid similar to that of Figure 4. (*a*) For a slow spreading rate, the coupling between the viscous flow field and the brittle plate will cause a failure zone. An axial rift valley would be generated as a result of a steady state necking. A small decoupling region will not change this width and the result of an axial rift valley. (*b*) For a fast spreading rate, if there exists a broad decoupling region beneath the ridge axis, it will significantly reduce the coupling between the viscous flow and the plate, therefore, the plate will not "neck". Local isostasy can take place and the isostatic model will produce the smoothed axial topography and the low amplitude gravity anomaly.

Fracture Zones

- Fracture zones are topographic lineations that are perpendicular to the ridge axes and offset the ridge axes in many areas.
- They can also be characterized in terms of spreading rate.

Seamounts

- Seamounts are conical-shaped features that extend from 1 to 8 km above the abyssal plain.
- Islands - mountain above sea level
- Atolls - at sea level with flat top
- Guyots - below sea level with flat top
- Seamounts - below sea level with no flat top

} * Should know for ES-10 exam

Problems with Topography map

A. Land; Antarctica, Africa, China, Soviet Union, Alaska (no longer true - SRTM)

B. Ocean; Islands off Argentina, Poor coverage in oceans, South Pacific Seamounts missing, South Atlantic Ridge-FZ is fantasy.
(improved with Smith and Sandwell, 1997)

C. Bias, Researchers who contoured the ocean seafloor topography believed in plate tectonic theory. They used theory to interpolate over great distances.
(improved with Smith and Sandwell, 1997)

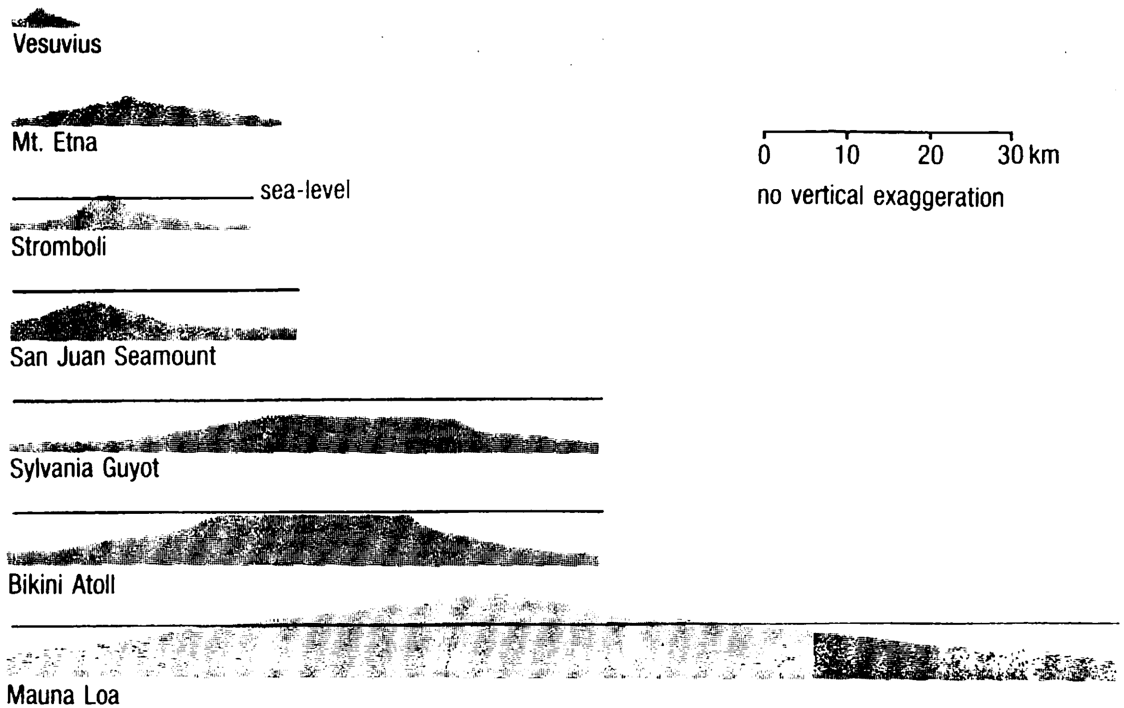


Figure 2.20 Topographic profiles across some on-land volcanoes and seamounts (including guyots).

Seismicity (Earthquake locations red, 0-70 km
green 70-300 blue > 300

- One of the most striking features of the 0-100 km deep global seismicity map is the coincidence of earthquakes with major typographic features.

- High mountians show diffuse earthquake patterns:
  Himalays, Andes
  Plate Tectonic Theory ⇒ compression
- By definition, passive margins have no earthquakes.

- Active margins display earthquakes at all depths 0-700
- Examination of hypocenters reveals Benioff zone
- Deep earthquakes stop at 670 km which is depth of velocity and density increase in the Earth.
- Depth of deepest earthquakes correlates with subduction rate.
- Island arc volcanism occurs along a line landward of the
- trench axis where the Benioff zone reaches a depth of 100 km

- Ridge axis have shallow earthquakes but no deep earthquakes.

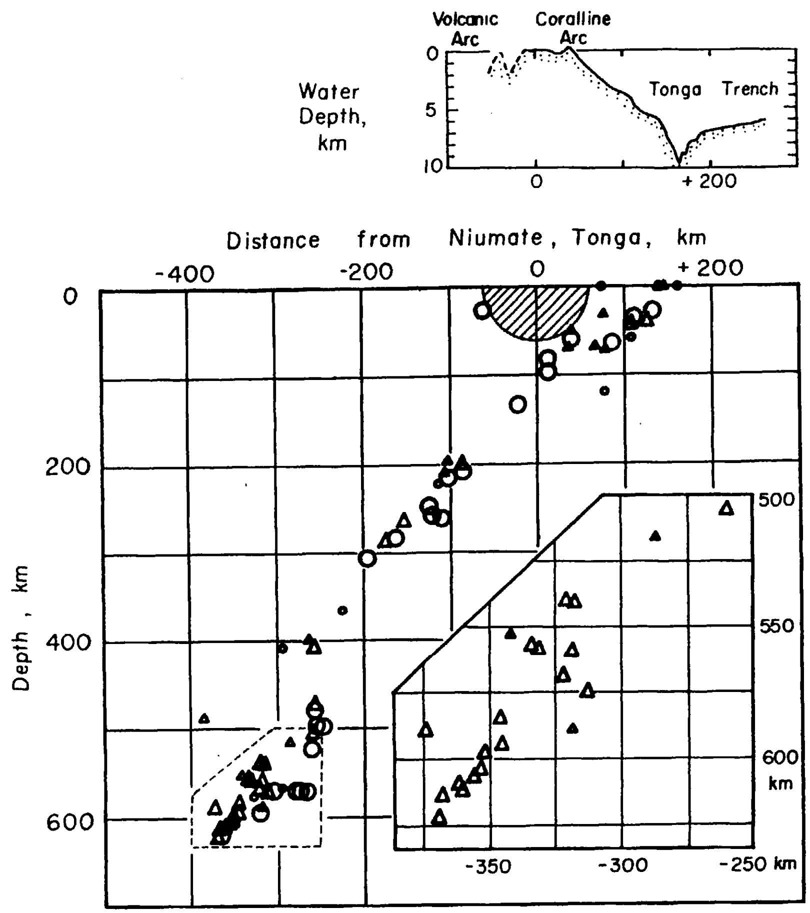


Figure 30-9
Vertical section oriented perpendicular to the Tonga arc. Circles represent earthquakes projected from within 0 to 150 km north of the section; triangles correspond to events projected from within 0 to 150 km south of the section. All shocks occurred during 1965 while the Lamont network of stations in Tonga and Fiji was in operation. Locations are based on data from these stations and from more distant stations. No microearthquakes from a sample of 750 events originated from within the hatched region near the station at Niumate, Tonga (i.e., for S-P times less than 6.5 sec). A vertical exaggeration of about 13:1 was used for the insert showing the topography (after Raitt et al., 1955); the horizontal and vertical scales are equal in the cross section depicting earthquake locations. Lower insert shows enlargement of southern half of section for depths between 500 and 625 km. Note small thickness (less than ~20 km) of seismic zone for wide range of depths

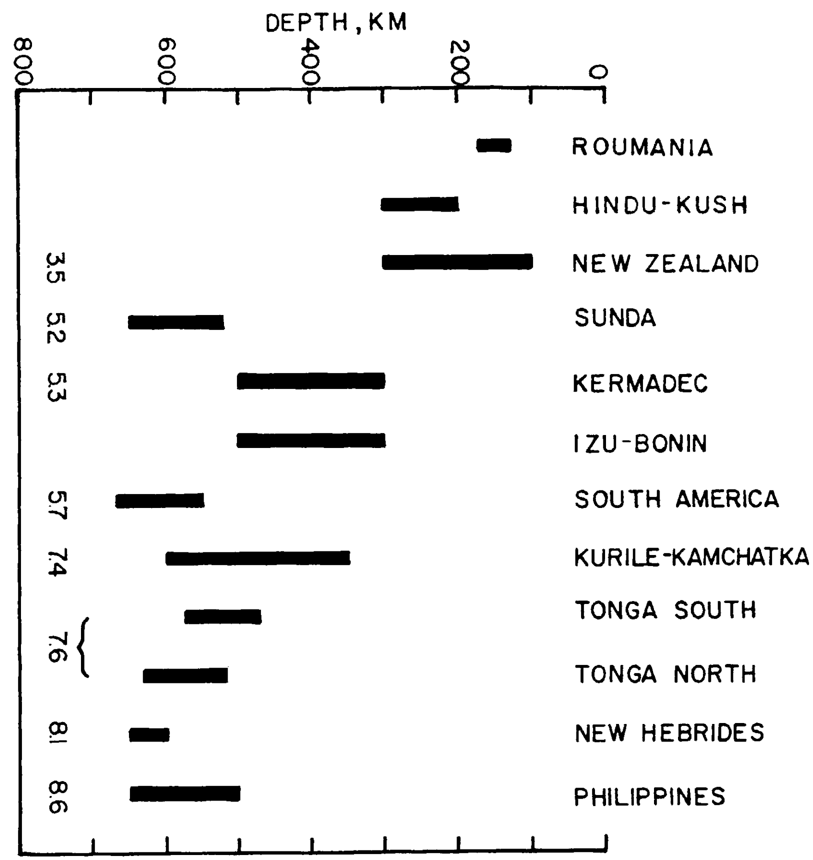


Figure 30-13
Depth range of maxima in the seismic activity (numbers of earthquakes) as a function of depth in island arcs and arc-like structures for which data are sufficiently numerous. The data are from Gutenberg and Richter (1954), Katsumata (1967), Sykes (1966), and listings of earthquakes located by the USCGS in the preliminary determination of epicenters (PDE). The numbers at the bottom of the figure give the rate (in centimeters per year) of convergence for the arc as plotted in Figure 30-2. Note that the maxima occur over a wide range of depths and that the depths appear to correlate, in general, with the calculated slip rate

(10)

High Resolution Subducting Slab Structure beneath Northern Honshu, Japan, Revealed by Double-Difference Tomography

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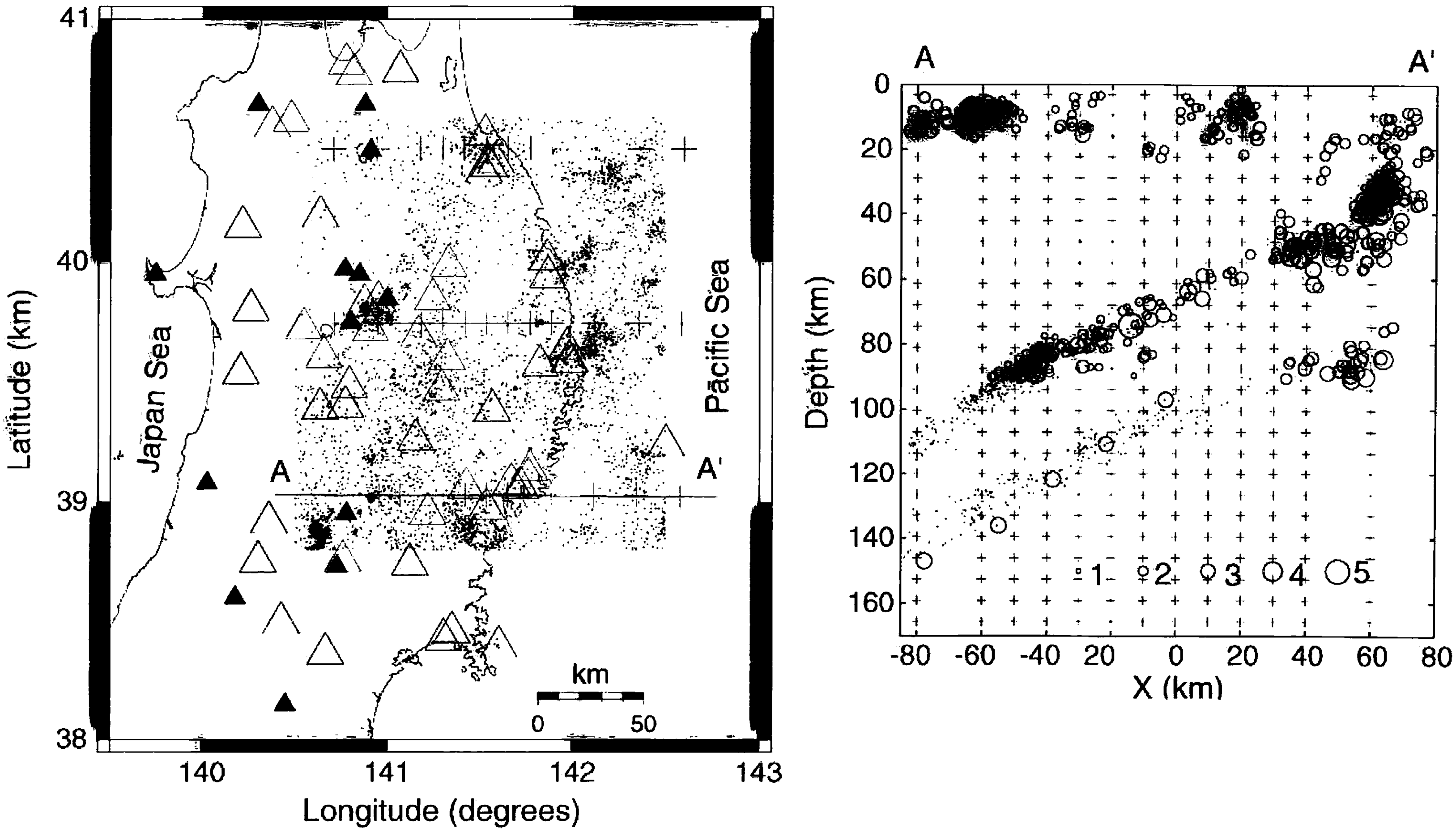

41
40
39
38
Latitude (km)
Japan Sea
Pacific Sea
A
A'
km
0
50
140
141
142
143
Longitude (degrees)
A
A'
Depth (km)
0
20
40
60
80
100
120
140
160
1
2
3
4
5
-80
-60
-40
20
0
20
40
60
80
X (km)

Figure 1

12

Abstract

The high-resolution seismic velocity structure of the subducting slab beneath northern Honshu, Japan has been obtained by double-difference tomography, capitalizing on the existence of two planes of seismicity. The upper plane consists of two distinct regions with relatively high Vp/Vs ratio (1.77-1.85) at 60-85 km depth and low Vp/Vs ratio (1.72-1.77) at 85-110 km depth. These two regions may correspond to the transformations of metabasalt/metagabbro to blueschist and blueschist to eclogite, respectively. The lower plane is associated with very low Vp/Vs ratio (1.6-1.7), in sharp contrast with high Vp/Vs ratio (~1.8-1.85) in the region between the two planes. These features may be explained by forsterite-enstatite-H_2O formation from serpentine dehydration in the lower plane and partial hydration of the region between the two planes.

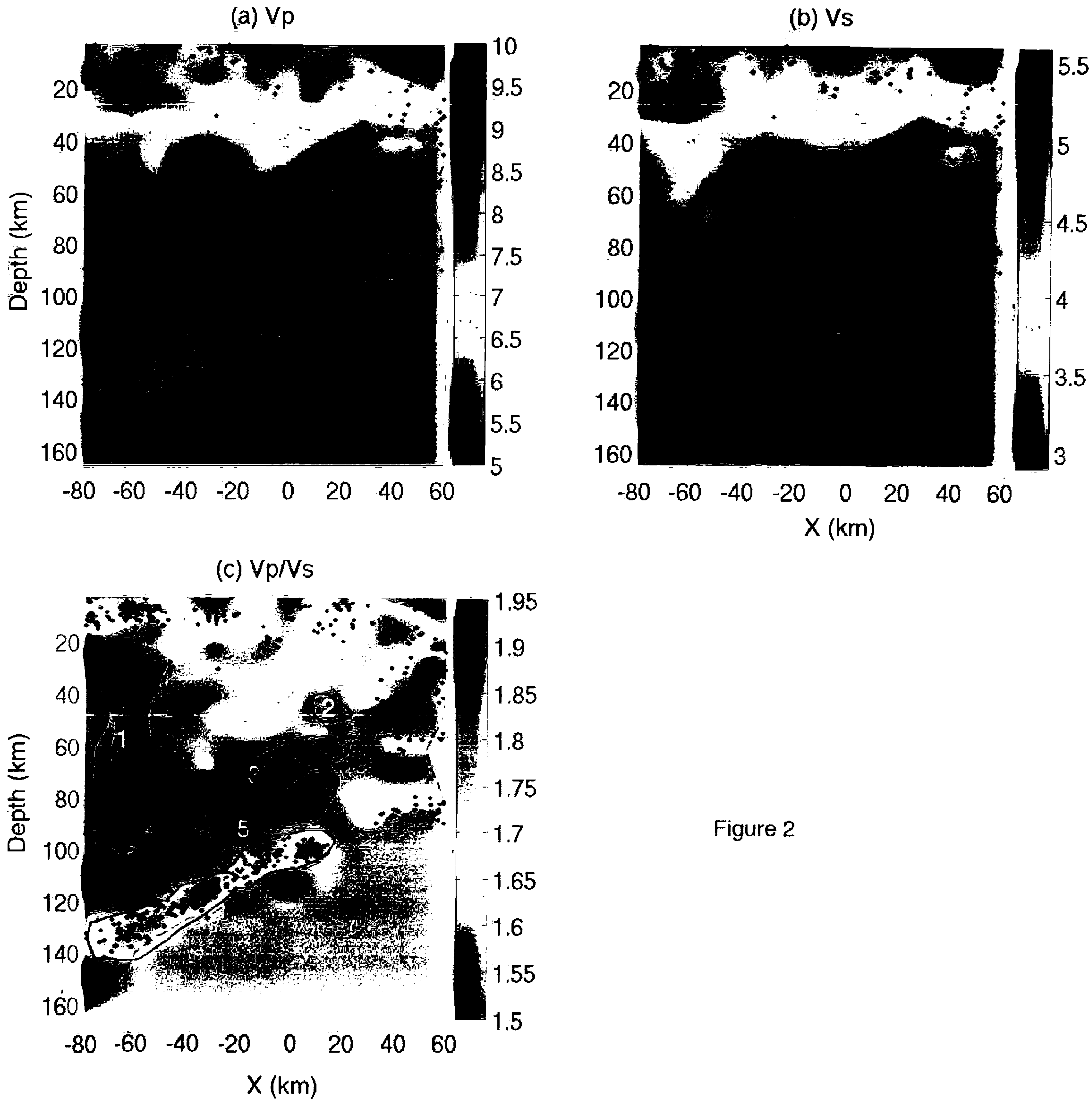
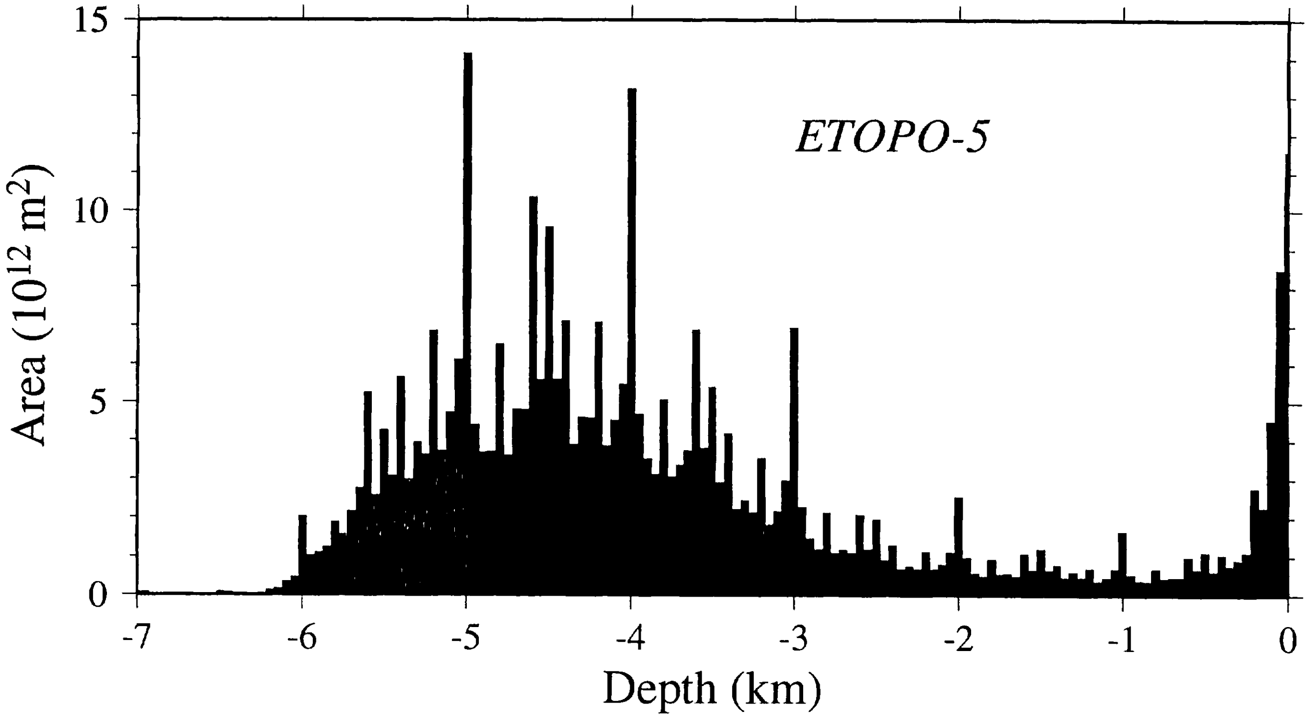

(a) Vp
Depth (km)
20
40
60
80
100
120
140
160
-80 -60 -40 -20 0 20 40 60
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
(b) Vs
X (km)
5.5
5
4.5
4
3.5
3
(c) Vp/Vs
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1
2
3
5

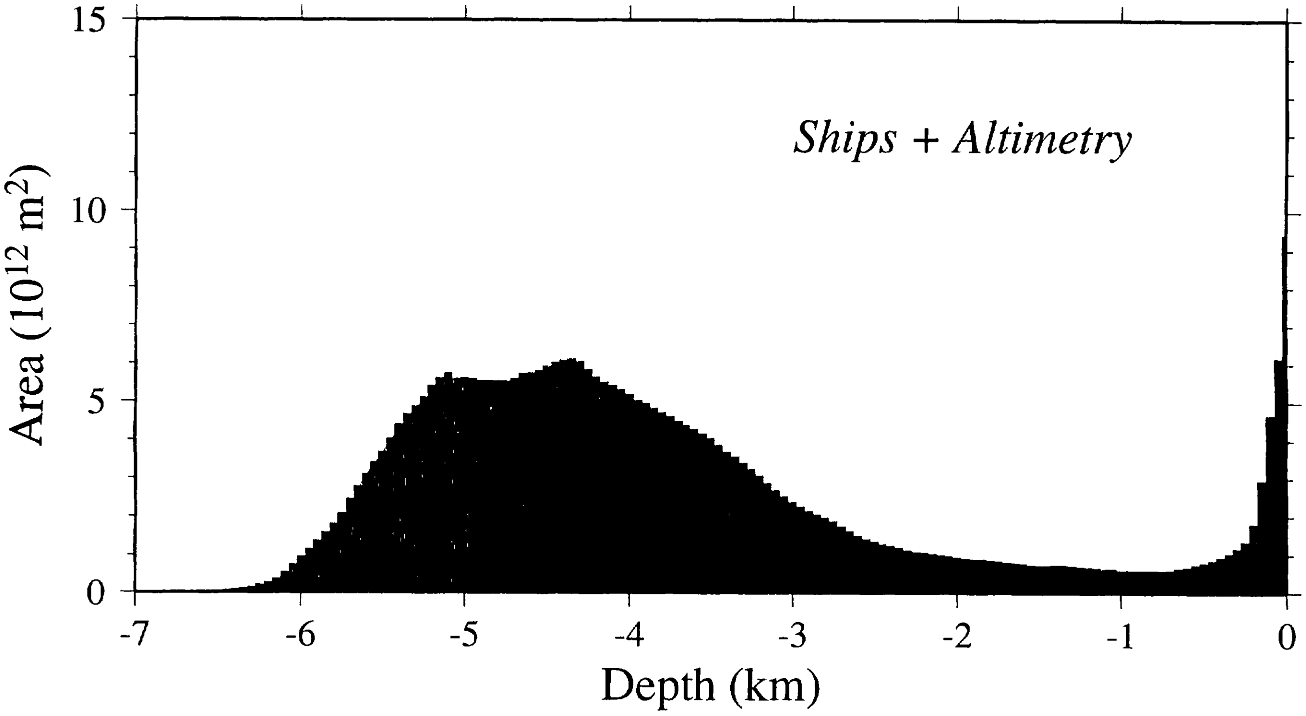
Figure 2

Figure captions

Figure 1. Map view and cross-section of earthquakes used in the inversion. The stations and volcanoes are indicated by open and filled triangles, respectively. The inversion grid used in the double-difference tomography solution is shown as the crosses. In the cross-section, the radii of the circles indicate the earthquake magnitudes.

Figure 2. Vertical slices of (a) Vp, (b) Vs, and (c) Vp/Vs ratio through the Honshu region structure along profile A-A′ (Figure 1). Earthquakes within 25 km of the section are plotted. Structure above the dashed line is meaningful, where the derivative weight sum for each node exceeds 10. Numbered areas in Figure 2c are interpreted as (1) partial melting, (2) serpentine, (3) transformation of metagabbro/metabasalt to blueschist, (4) transformation of blueschist to eclogite, (5) partially hydrated mantle harzburgite, and (6) serpentine dehydration.


ETOPO-5
15
10
5
0
Area (10^{12} m^2)
-7
-6
-5
-4
-3
-2
-1
0
Depth (km)


Ships + Altimetry
15
10
5
0
Area (10^{12} m^2)
-7
-6
-5
-4
-3
-2
-1
0
Depth (km)