The Abdus Salam International Centre for Theoretical Physics

2464-22

Earthquake Tectonics and Hazards on the Continents

17 - 28 June 2013

The nature of the hazard: Introduction to earthquakes, their sizes, intensities, and distribution in space and time (continents vs oceans and plate tectonics) Part .2

P. England
University of Oxford
UK

Strada Costiera, 11 - 34151 - Trieste - Italy • Tel. +39 0402240111 • Fax. +39 040224163 • sci_info@ictp.it • www.ictp.it
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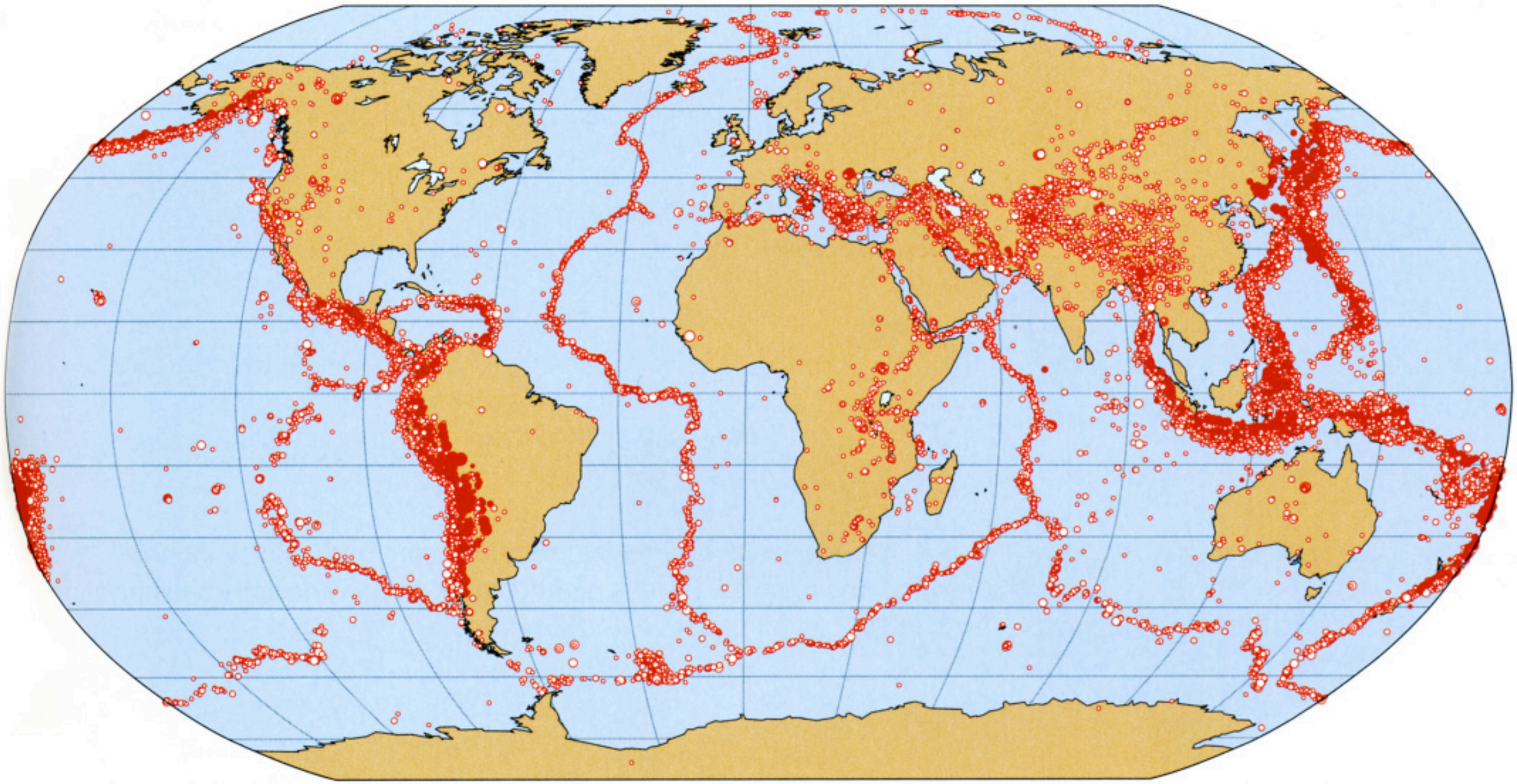
Continental Tectonics

How do the tectonics of continents and oceans differ?

Philip England, ICTP June 2013

Global earthquake epicentres between 1980 and 1996



focal depth: ○ shallow (<70 km) ● intermediate (70–300 km) ● deep (>300 km)

magnitude: ○ 8.0 and above ○ 7.0–7.9 ○ 6.0–6.9 ○ 5.0–5.9 ○ 4.0–4.9

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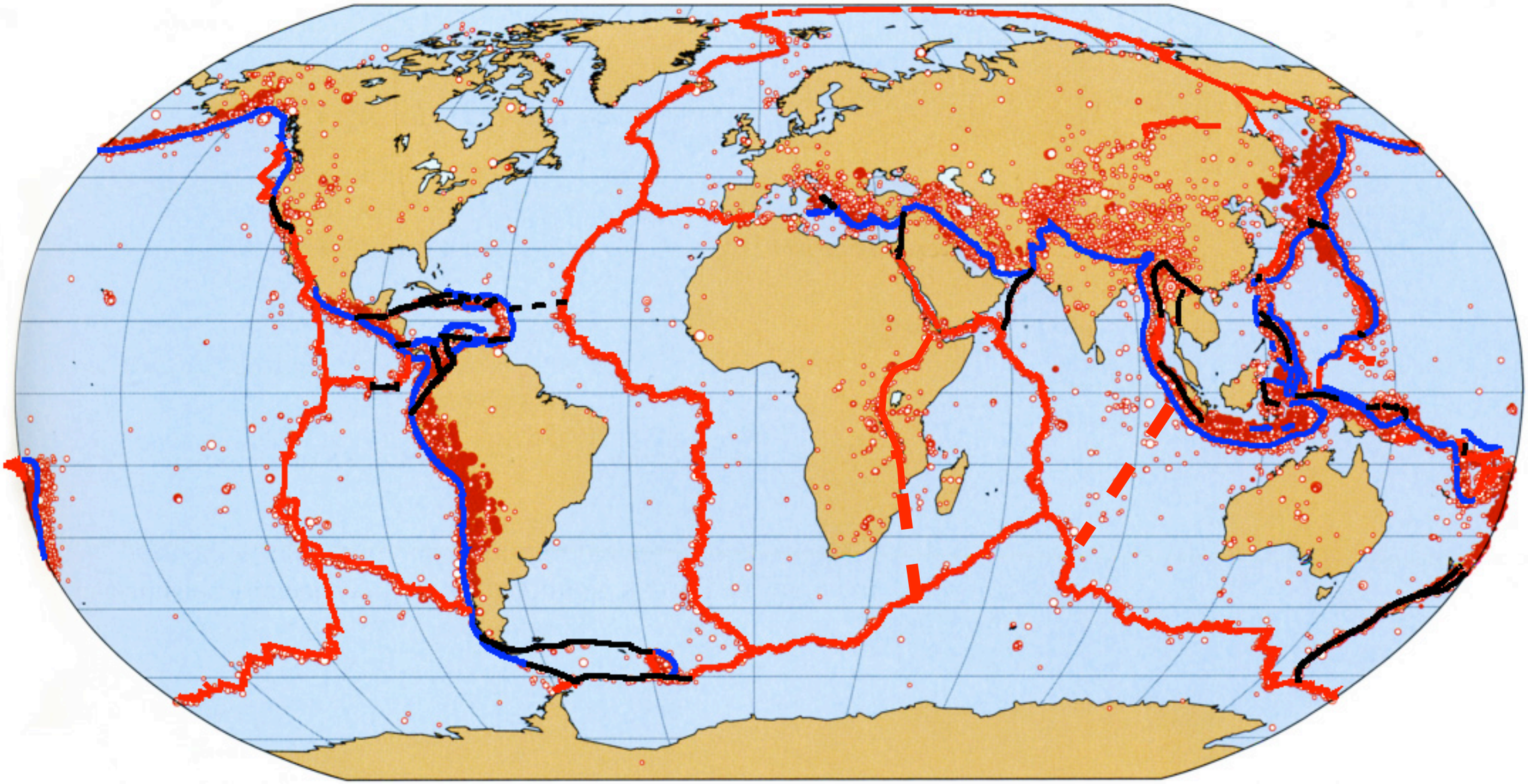

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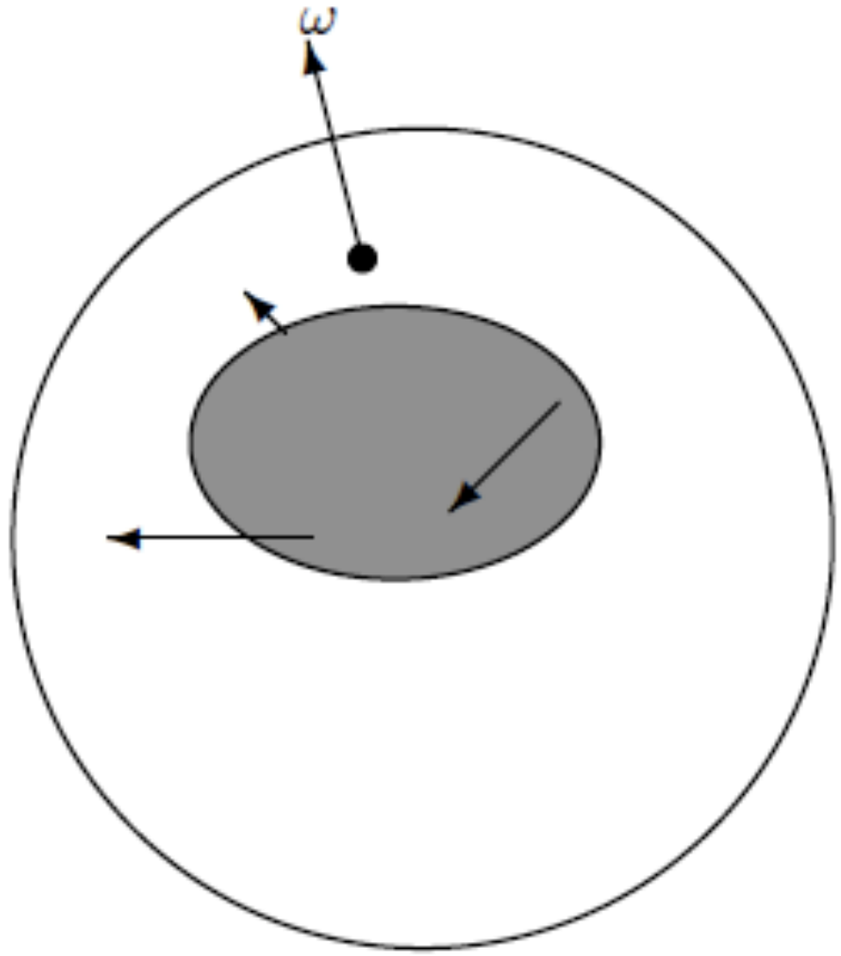
Fundamental Tenet of Plate Tectonics

The surface of the Earth is split into a small number of rigid plates, whose relative motions are taken up in narrow bands around their edges.

Rotation of a rigid body on the surface of a sphere

Euler's fixed-point theorem applied to a rigid shell on the surface of a sphere

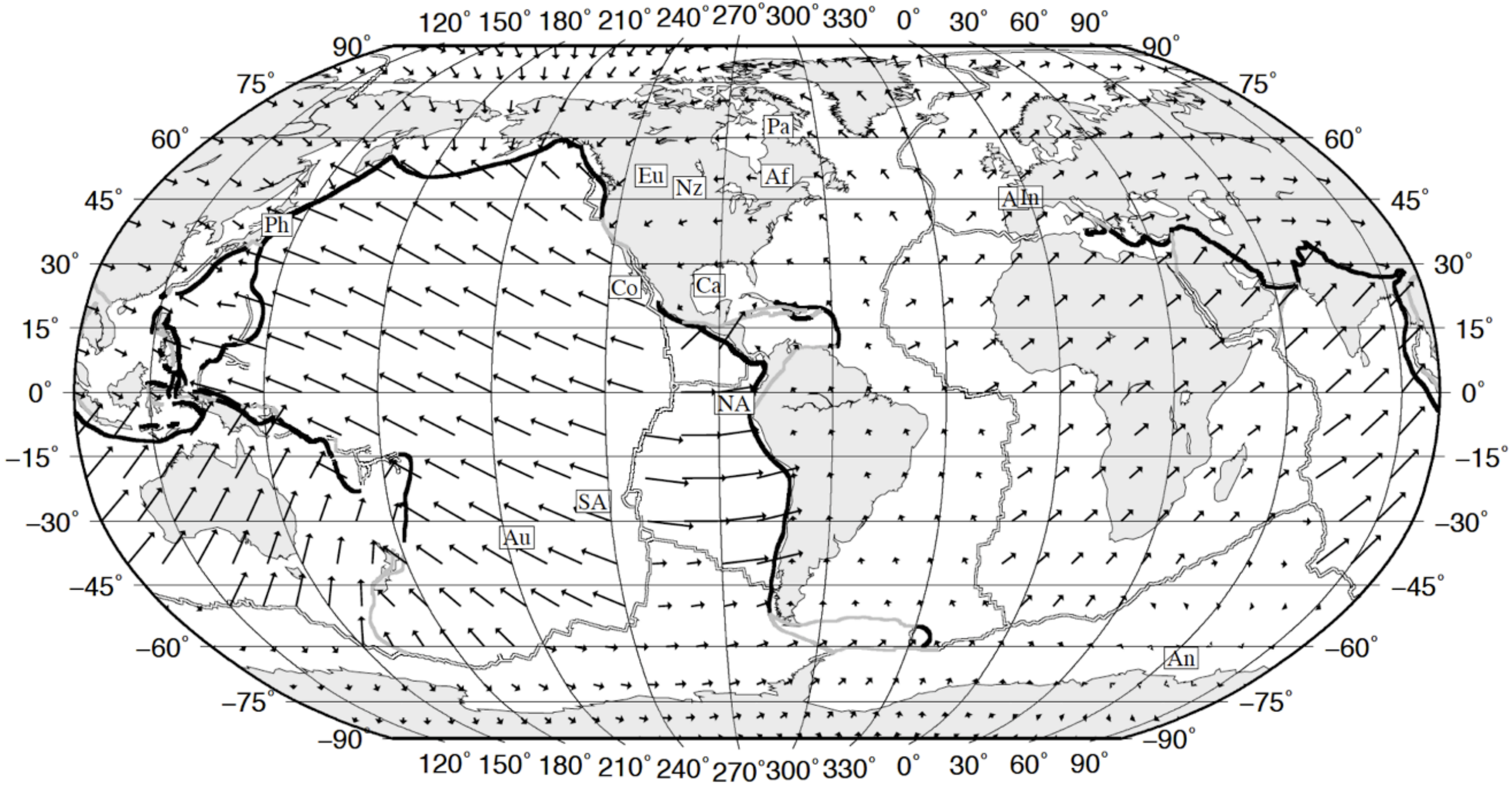


The Governing Equation of Plate Tectonics:

$$\mathbf{v} = \omega \times \mathbf{r}$$

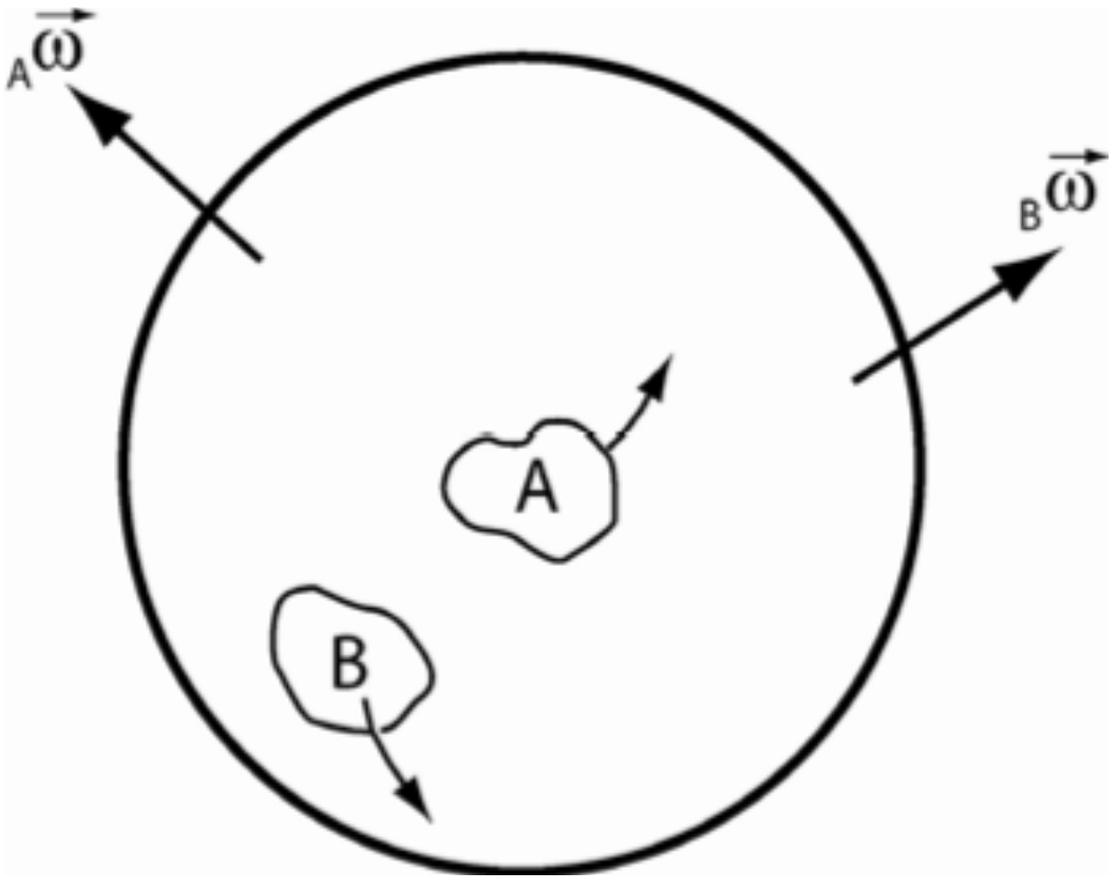
The motion of all parts of the same plate can be described by rotation about a **single axis** passing through the centre of the earth.

Velocities in the No-Net-Rotation Frame of Reference



Boxes show poles for African, Arabian, Australian, Antarctic, Caribbean, Cocos, European, Indian, North American, Nazca, Pacific, Philippine and South American plates.

Relative motions on the surface of a sphere



Angular velocities are vectors, so can be added or subtracted.

Motion of Plate A can be described by rotation about $_A\omega$ and Plate B by $_B\omega$

The relative motion between plate A and B is $_A\omega_B$.

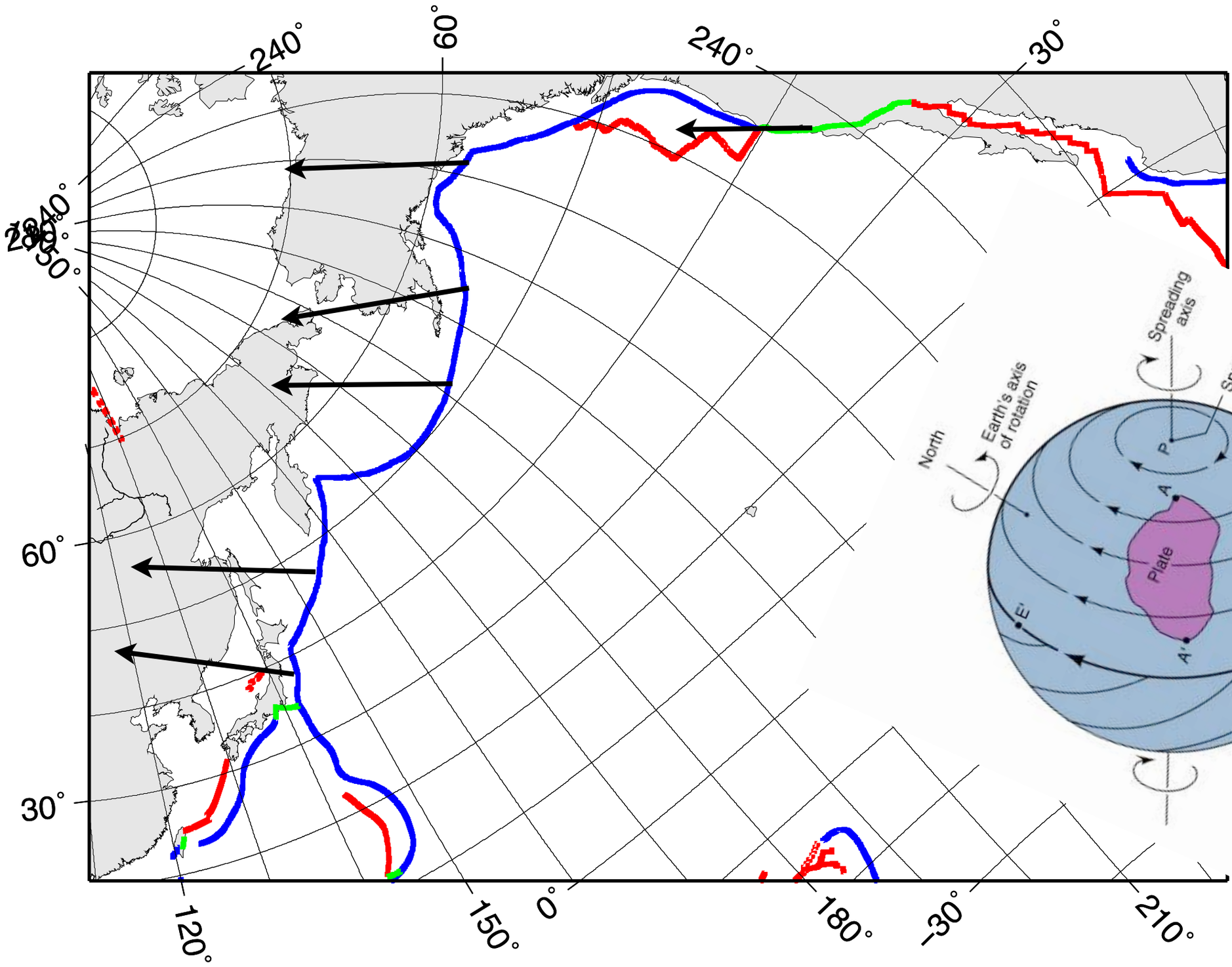
$_A\omega_B = {}_A\omega - {}_B\omega$

Angular velocities are often given by their poles
- longitude,
- latitude

and
- rate of rotation (usually in deg/Myr)

anti-clockwise positive

McKenzie and Parker 1967

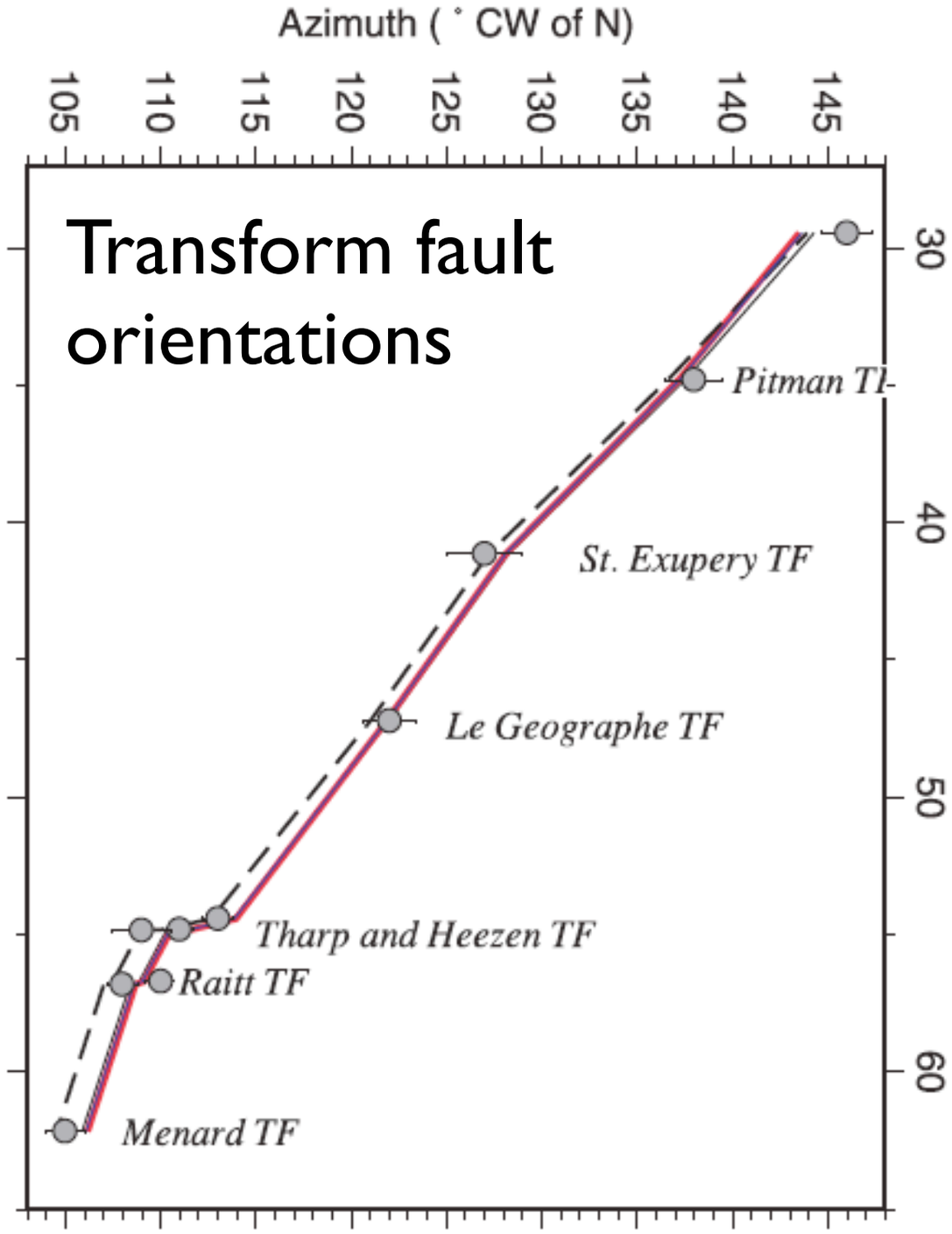


Geologically current plate motions

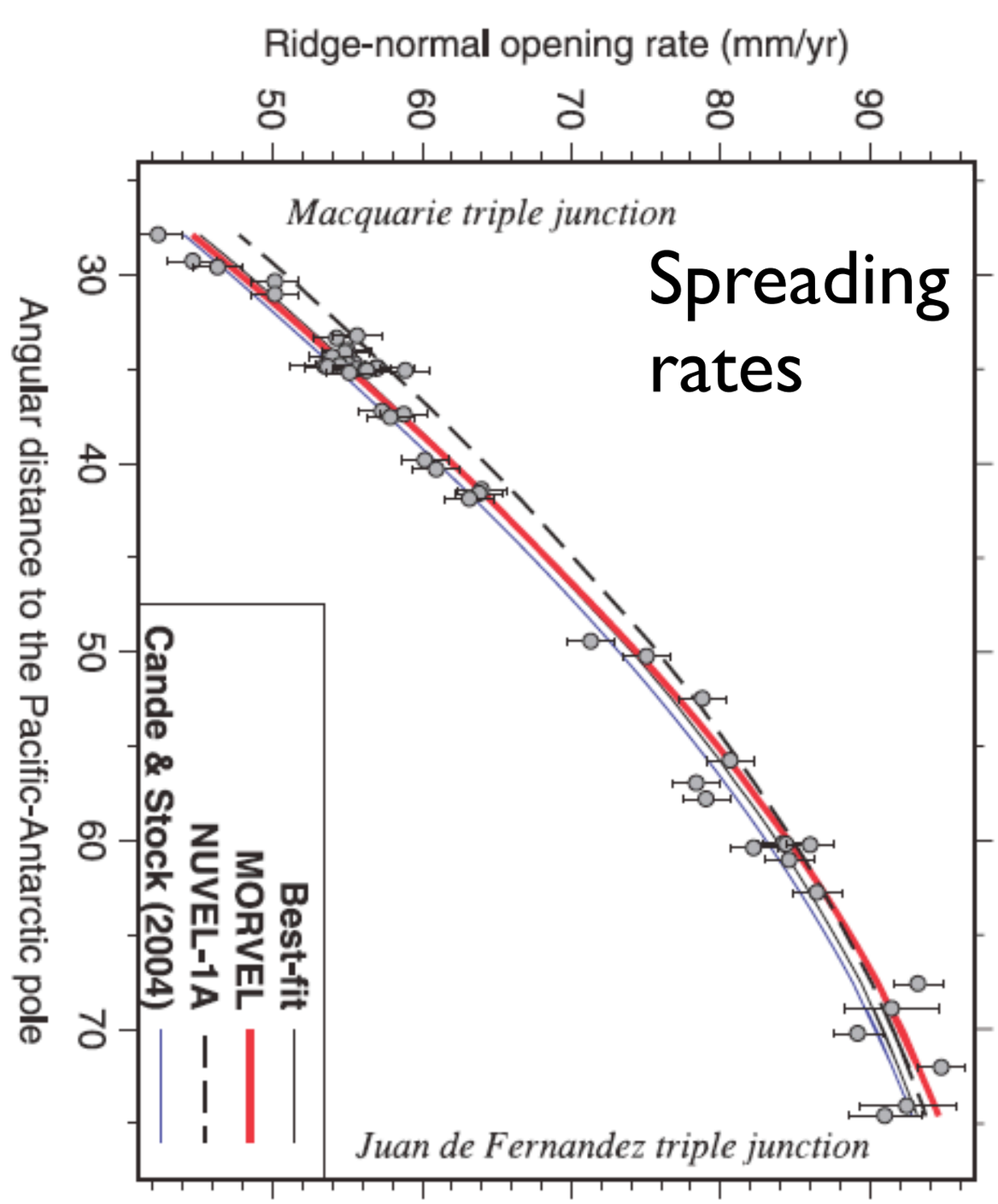
Charles DeMets,[1] Richard G. Gordon[2] and Donald F. Argus[3]

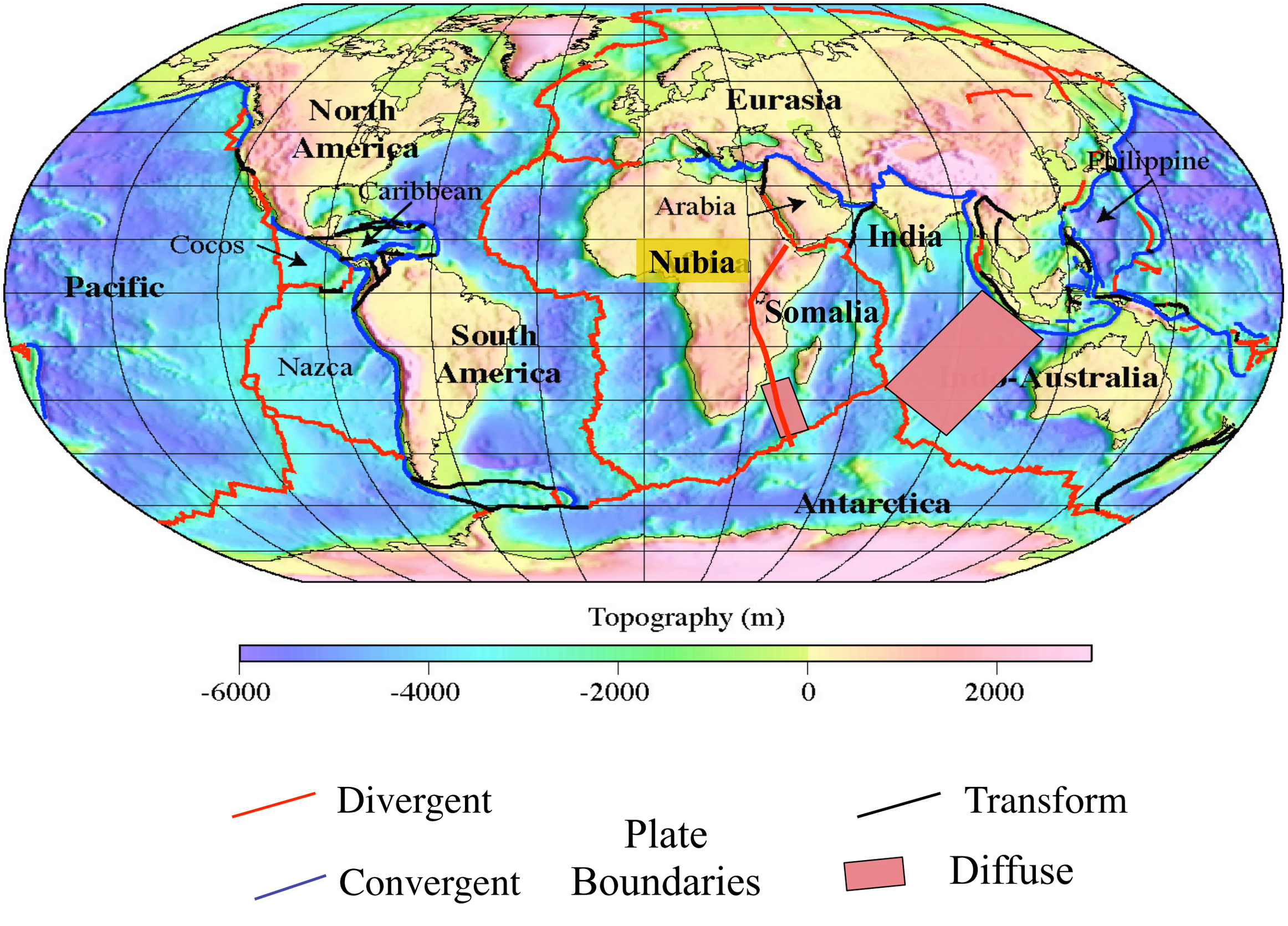
Geophys. J. Int. (2010) **181,** 1–80

Transform fault orientations



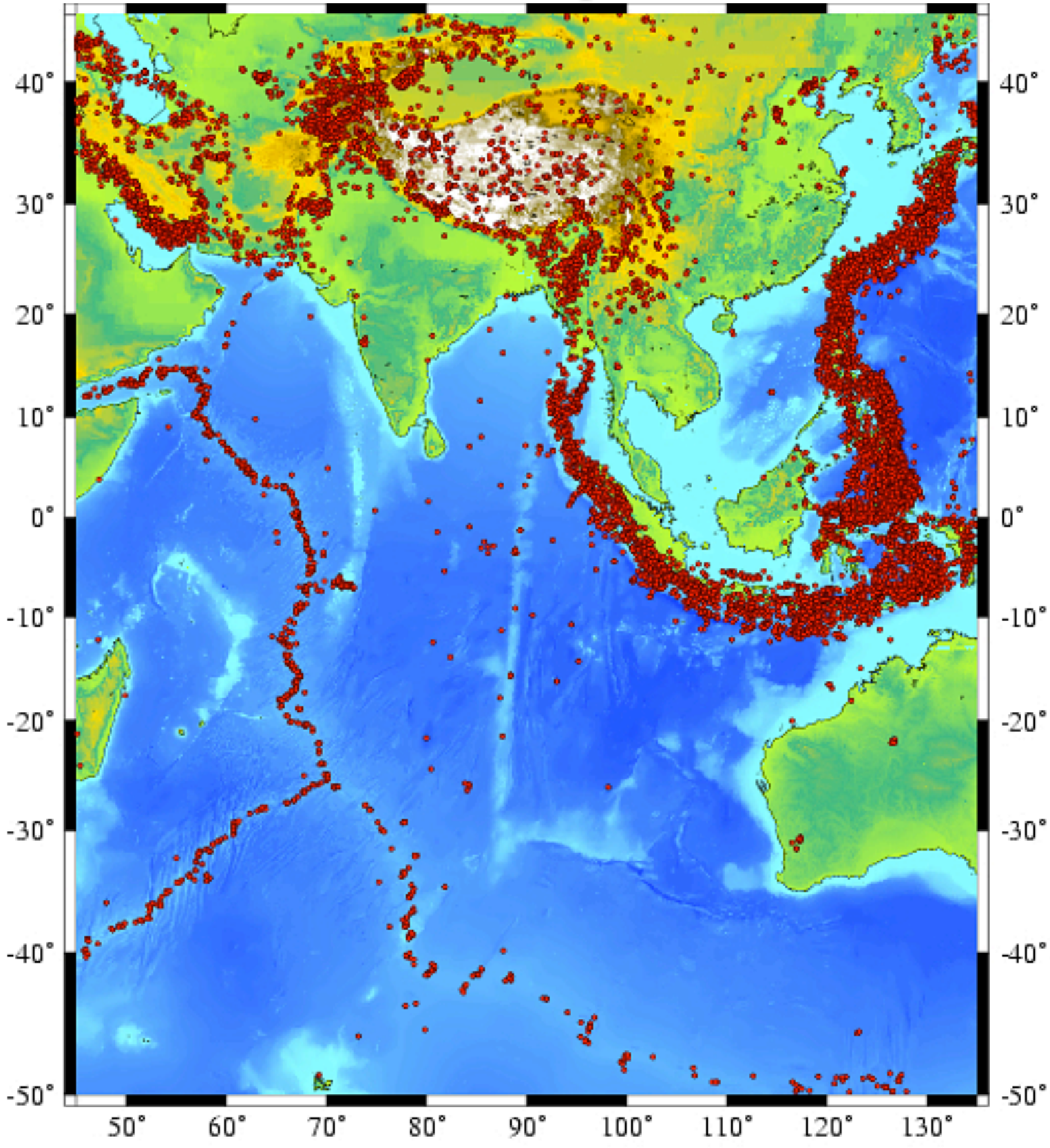
Spreading rates



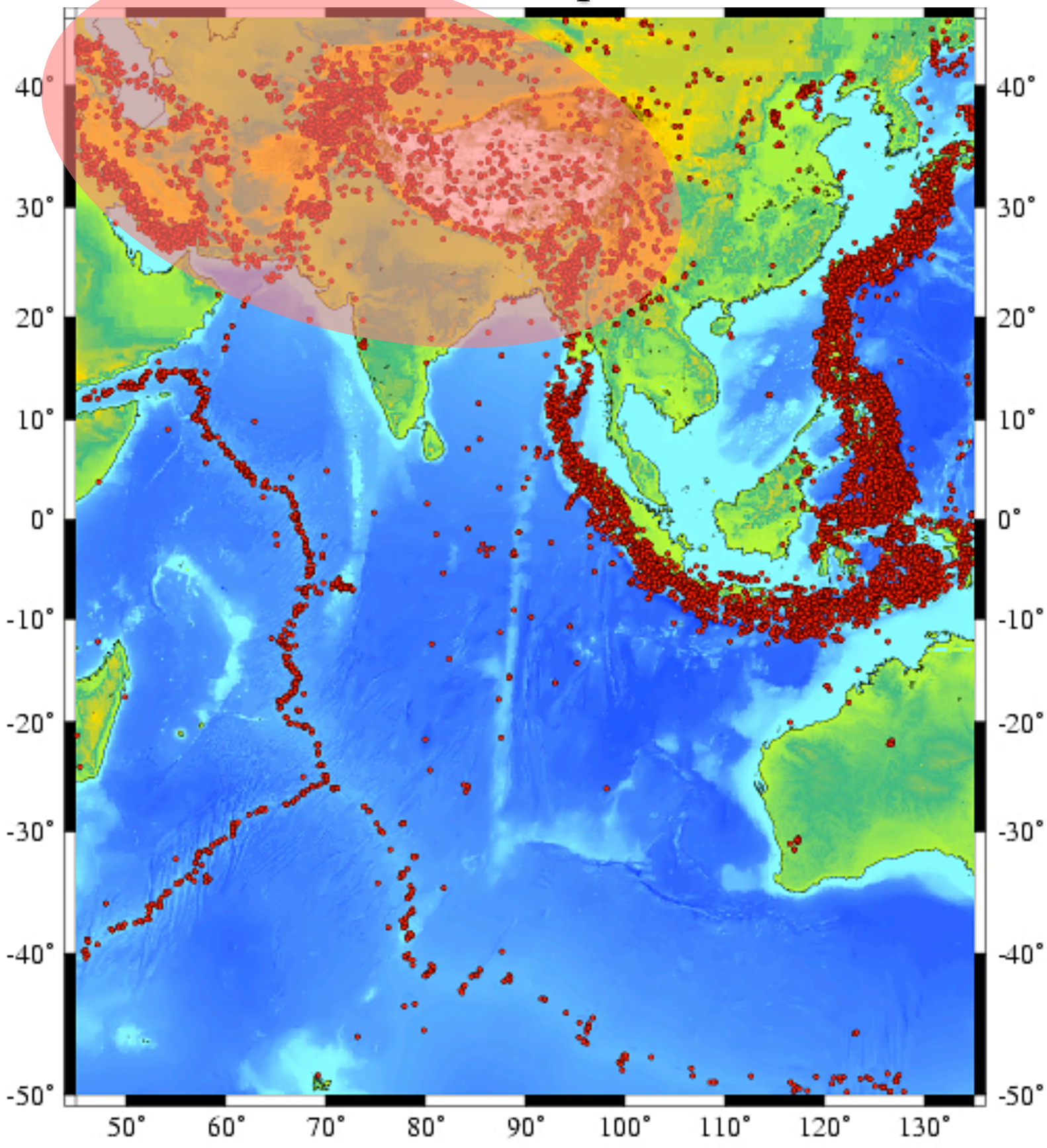

North America
Eurasia
Caribbean
Arabia
Philippine
Cocos
India
Nubia
Pacific
Somalia
South America
Nazca
Australia
Antarctica
Topography (m)
-6000
-4000
-2000
0
2000
Divergent
Transform
Plate Boundaries
Convergent
Diffuse

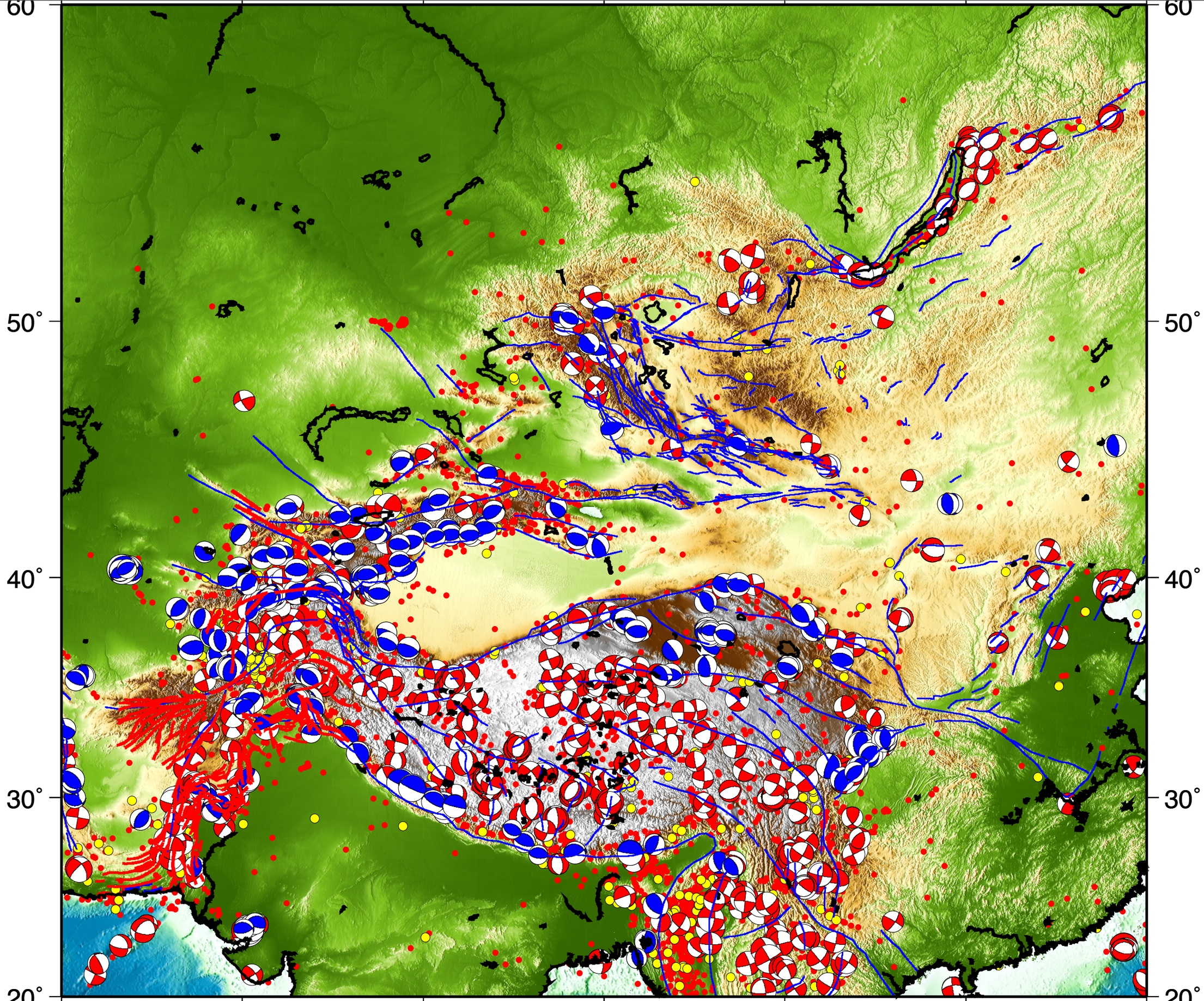
But.....

Epicentres of Shallow Earthquakes M>4 1964-2004



Epicentres of Shallow Earthquakes M>4 1964-2004




60°
50°
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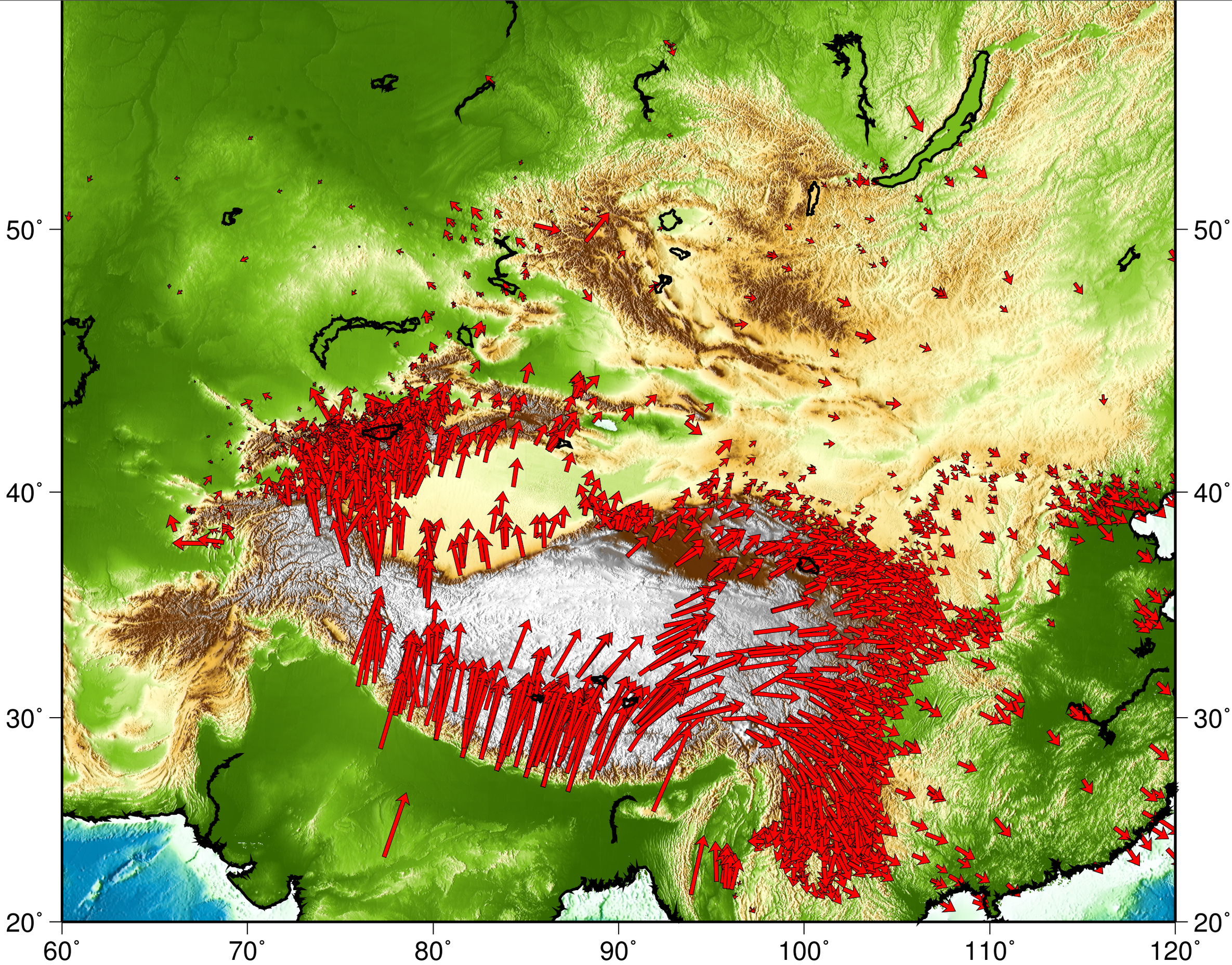
20°
60°
70°
80°
90°
100°
110°
120°


50°
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90°
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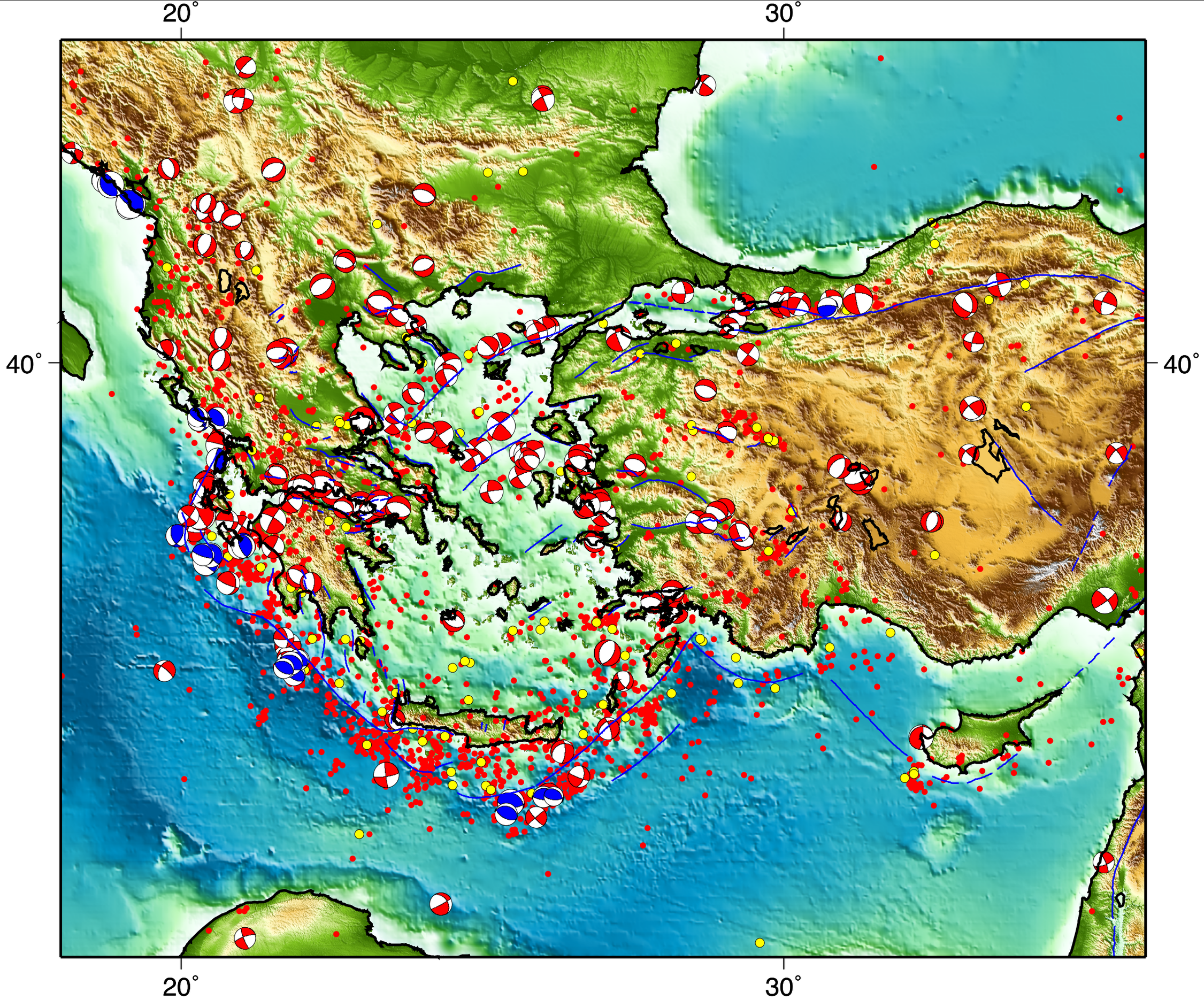
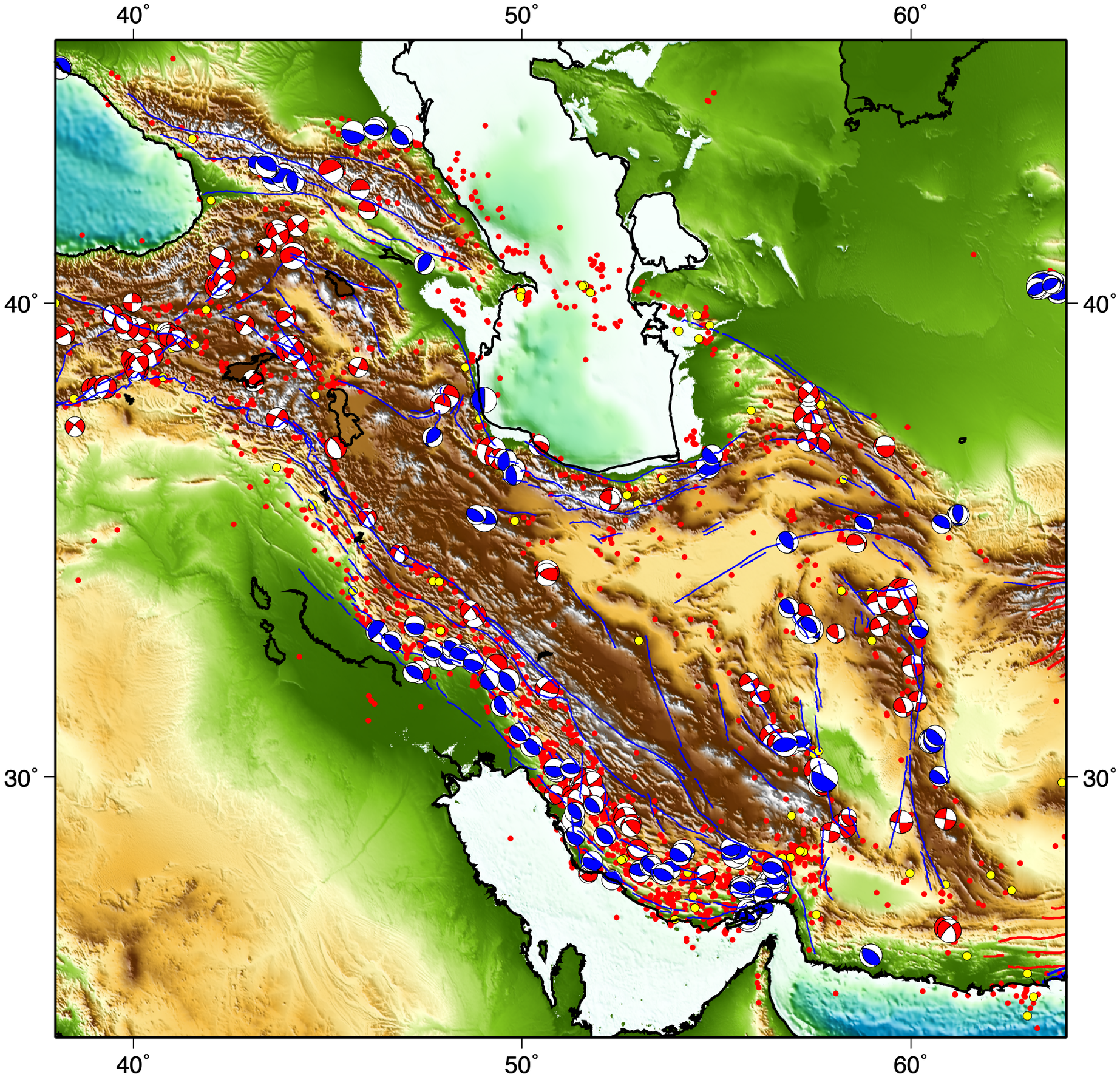
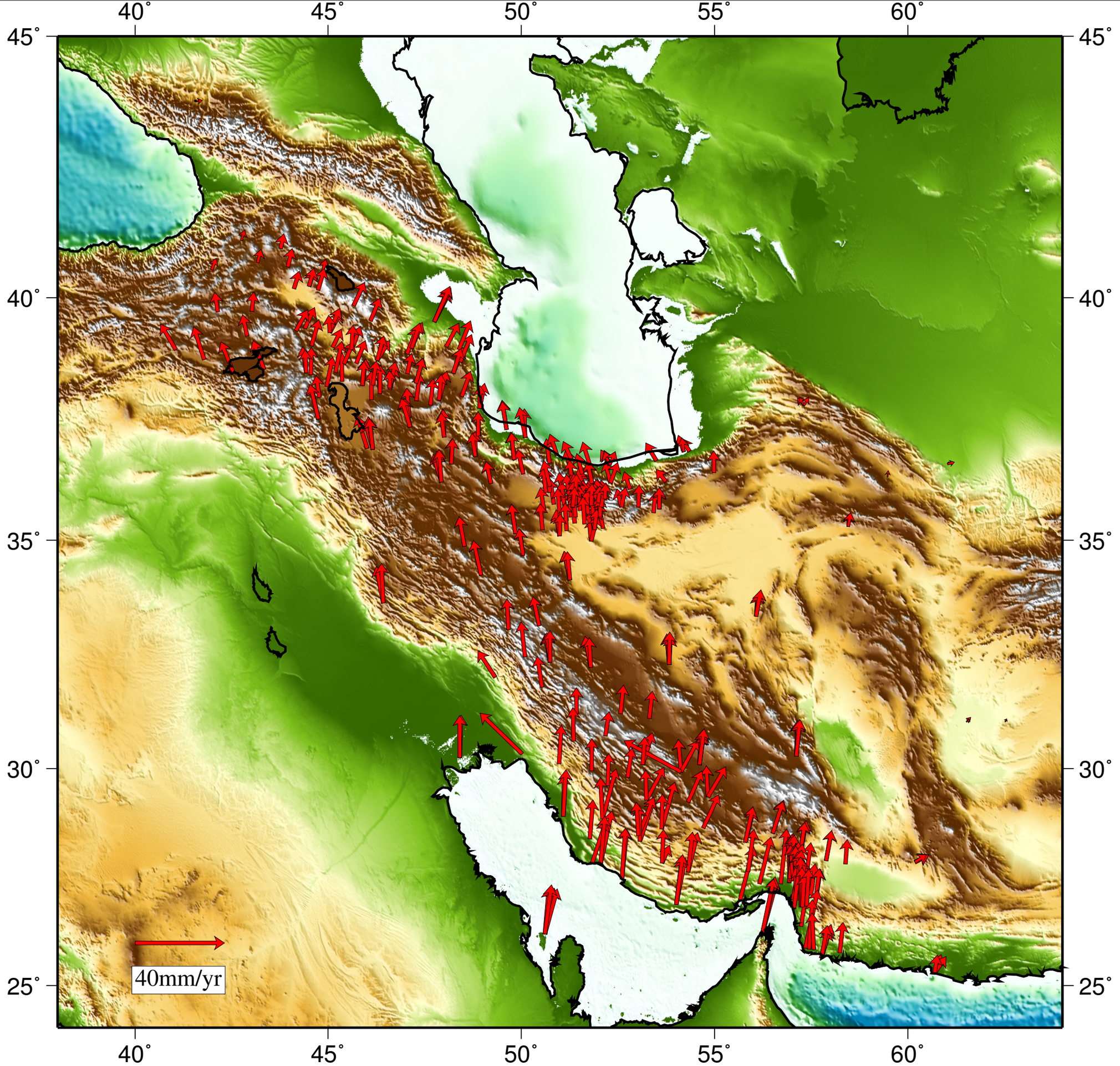
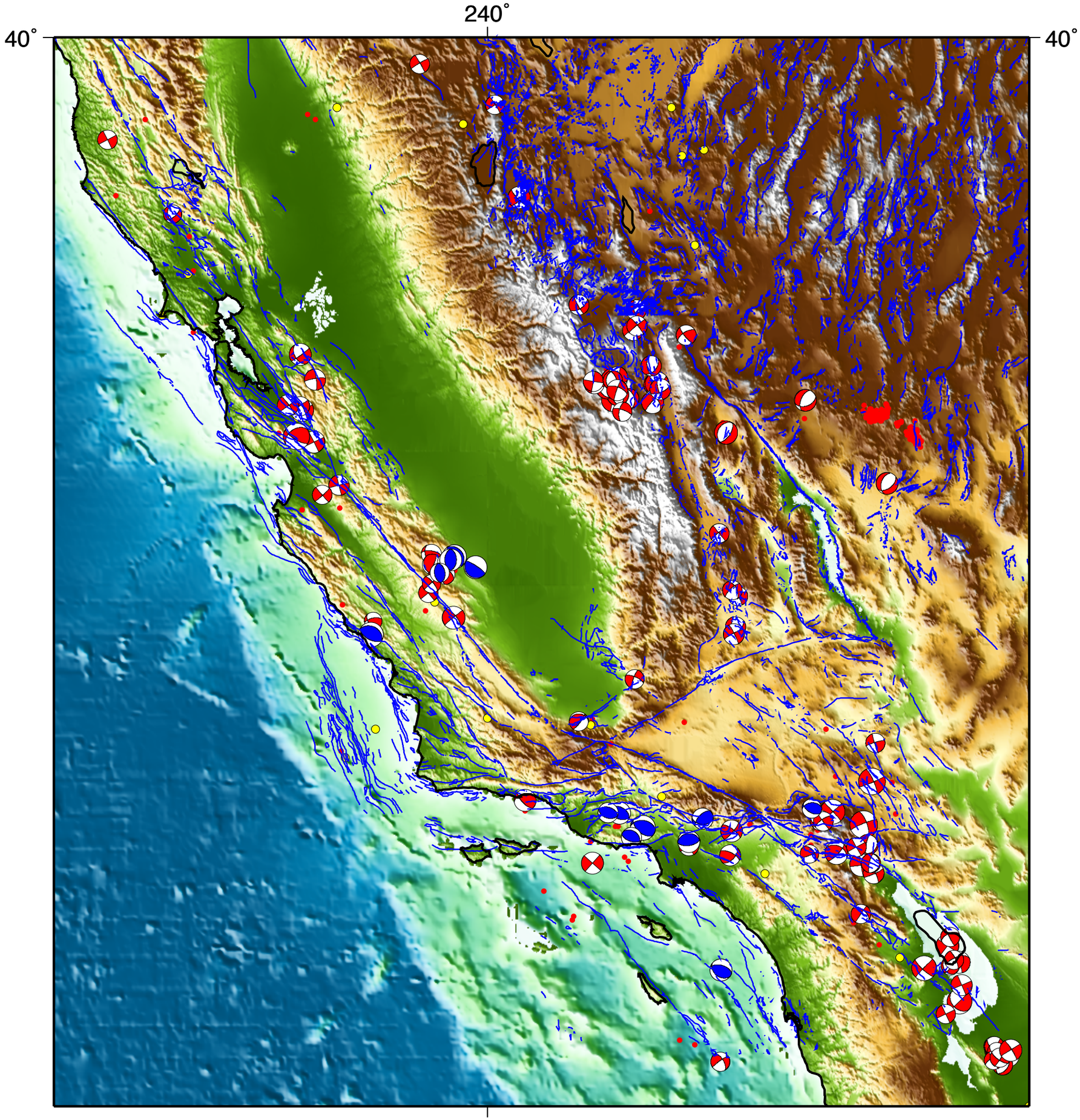
110°
120°


20°
30°
40°
40°
20°
30°

20
25
30
35
40˚
40˚
35˚
35˚
20˚
25˚
30˚
35˚
40mm/yr


40°
50°
60°
40°
40°
30°
30°
40°
50°
60°


40˚
45˚
50˚
55˚
60˚
45˚
40˚
35˚
30˚
25˚
40mm/yr


240°
40°
40°
240°

Morphology of Deforming Zones

- Significant contrasts in elevation occur over length scales of 100s to 1000s of km
- ‘Significant’ means +5/-3 km from sea level or, equivalently, +35/-20 km in crustal thickness
- Seismic activity coincident with regions of significant topographic relief
- Significant (millimetres per year) velocity differences within these zones.

Plate Tectonics on a small scale?

- IF plate tectonics:
- THEN relative motions must be equivalent to rotations about an axis.

Plate Tectonics on a small scale?

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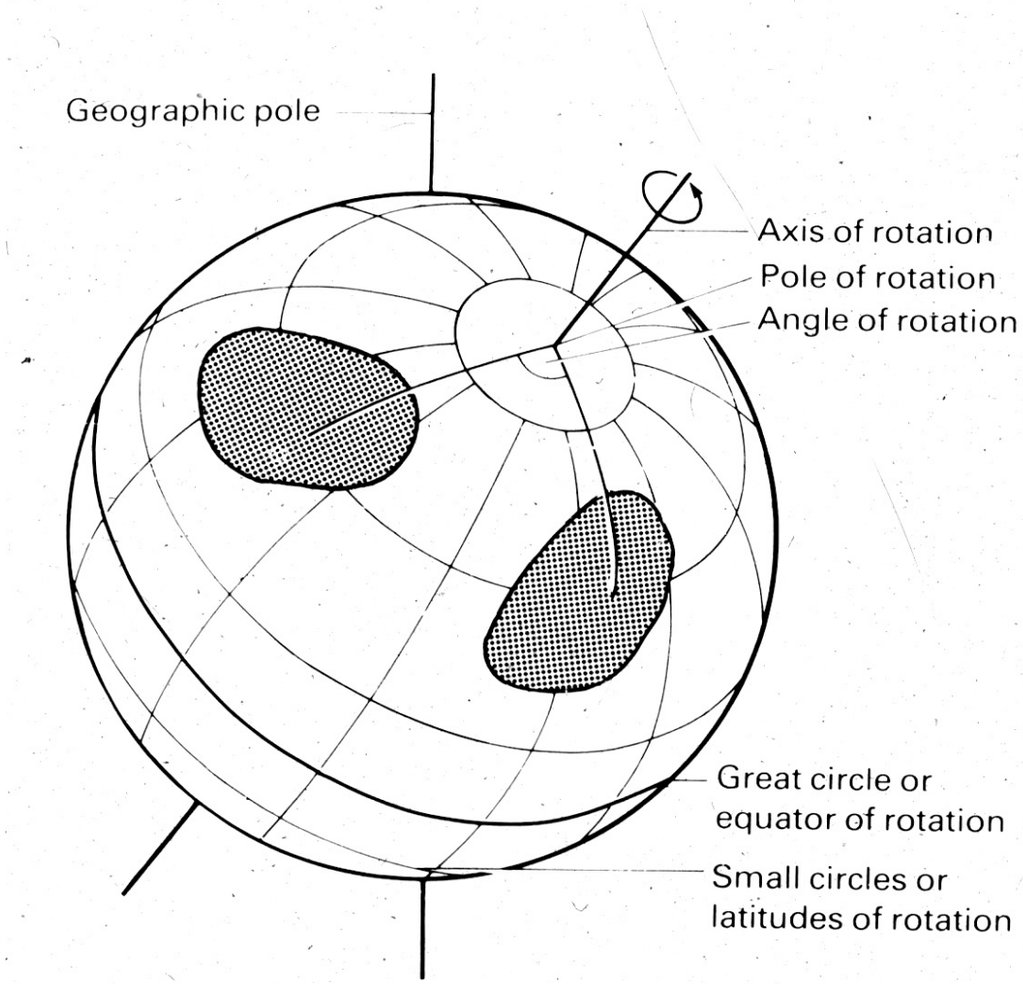
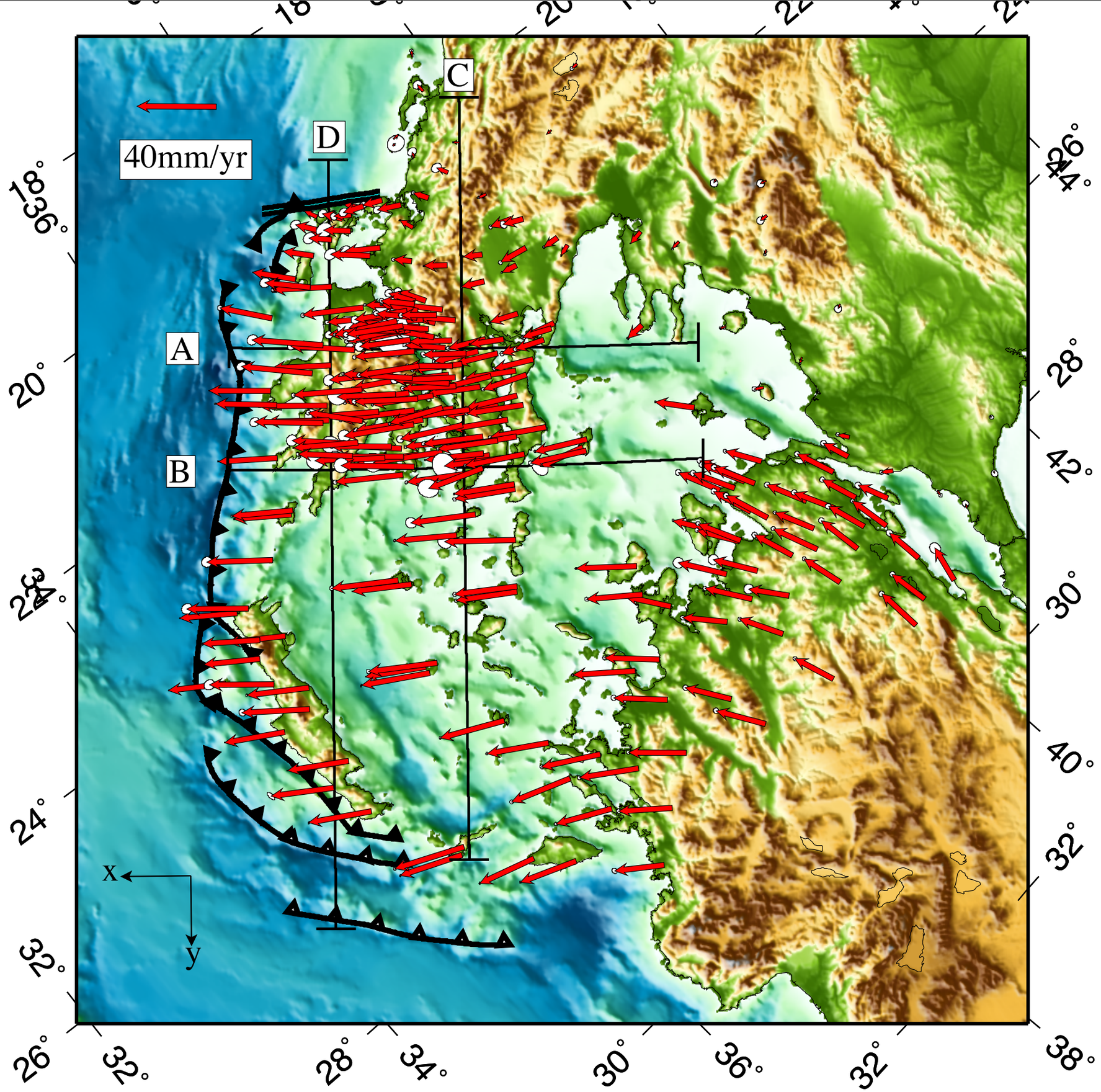
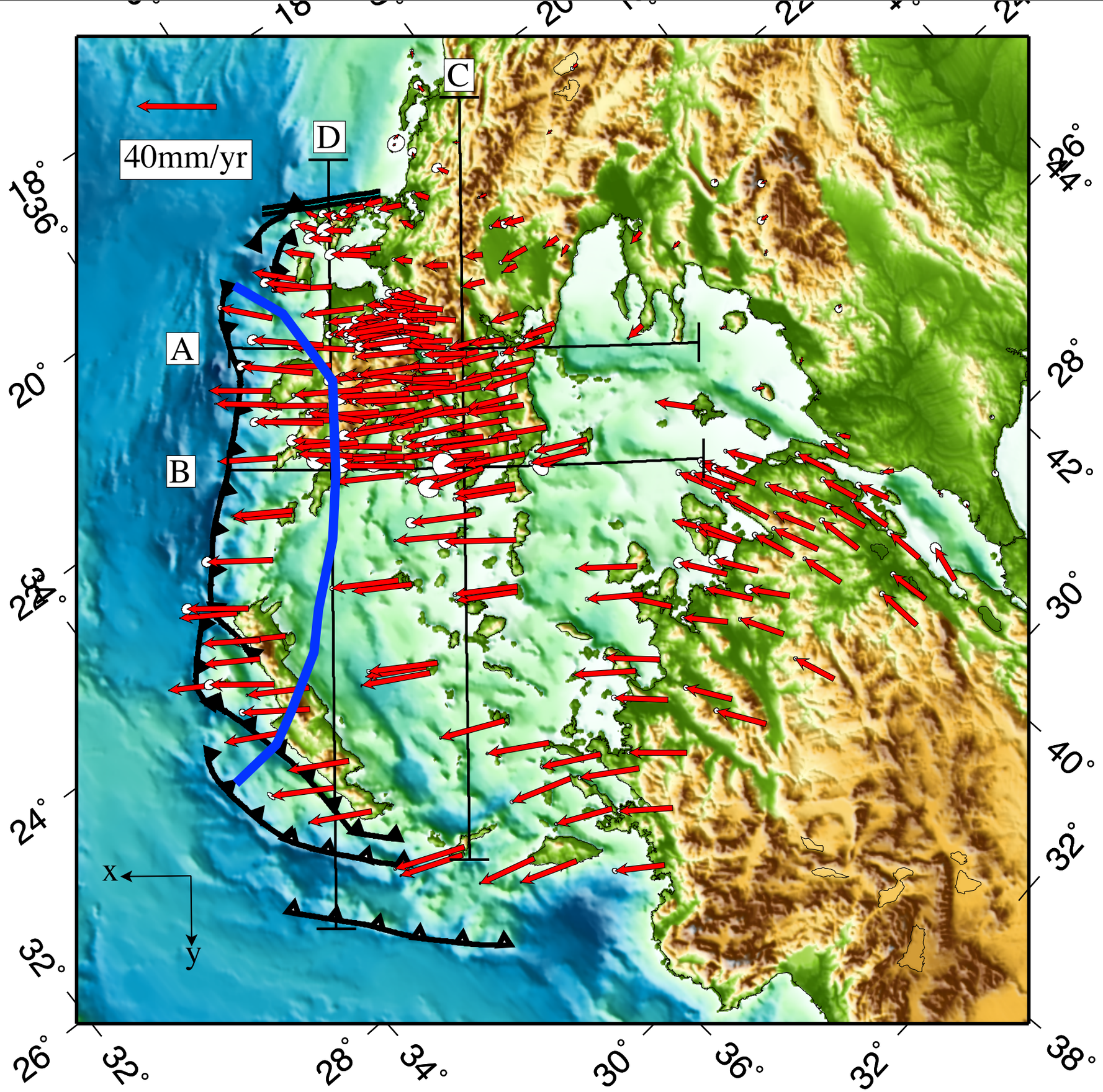


Fig. 3.1 Euler's theorem. Diagram illustrating how the motion of a continent on the Earth can be described by an angle of rotation about a pole of rotation.



Velocities relative to Eurasia: GPS data of Floyd et al., 2010



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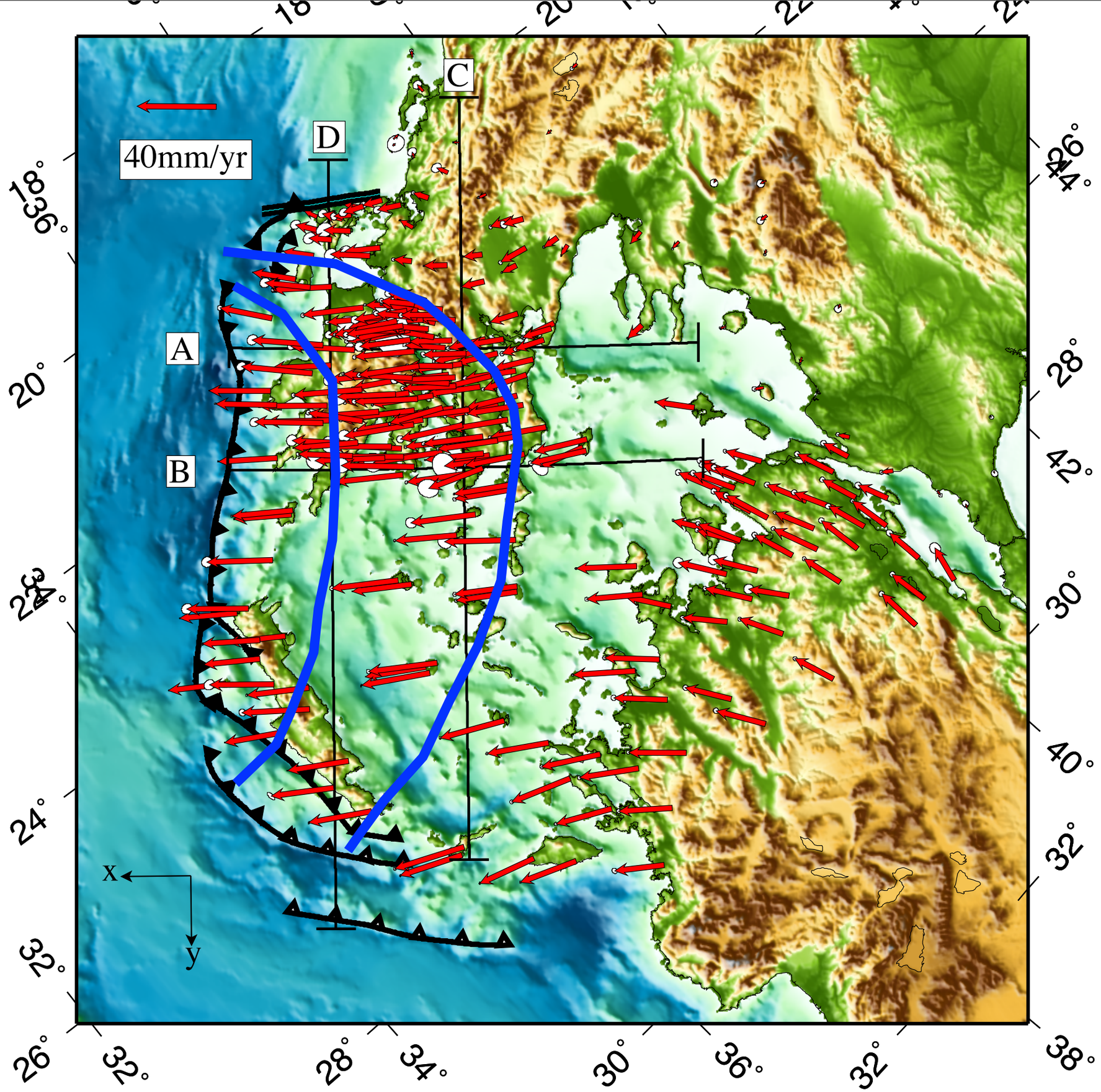

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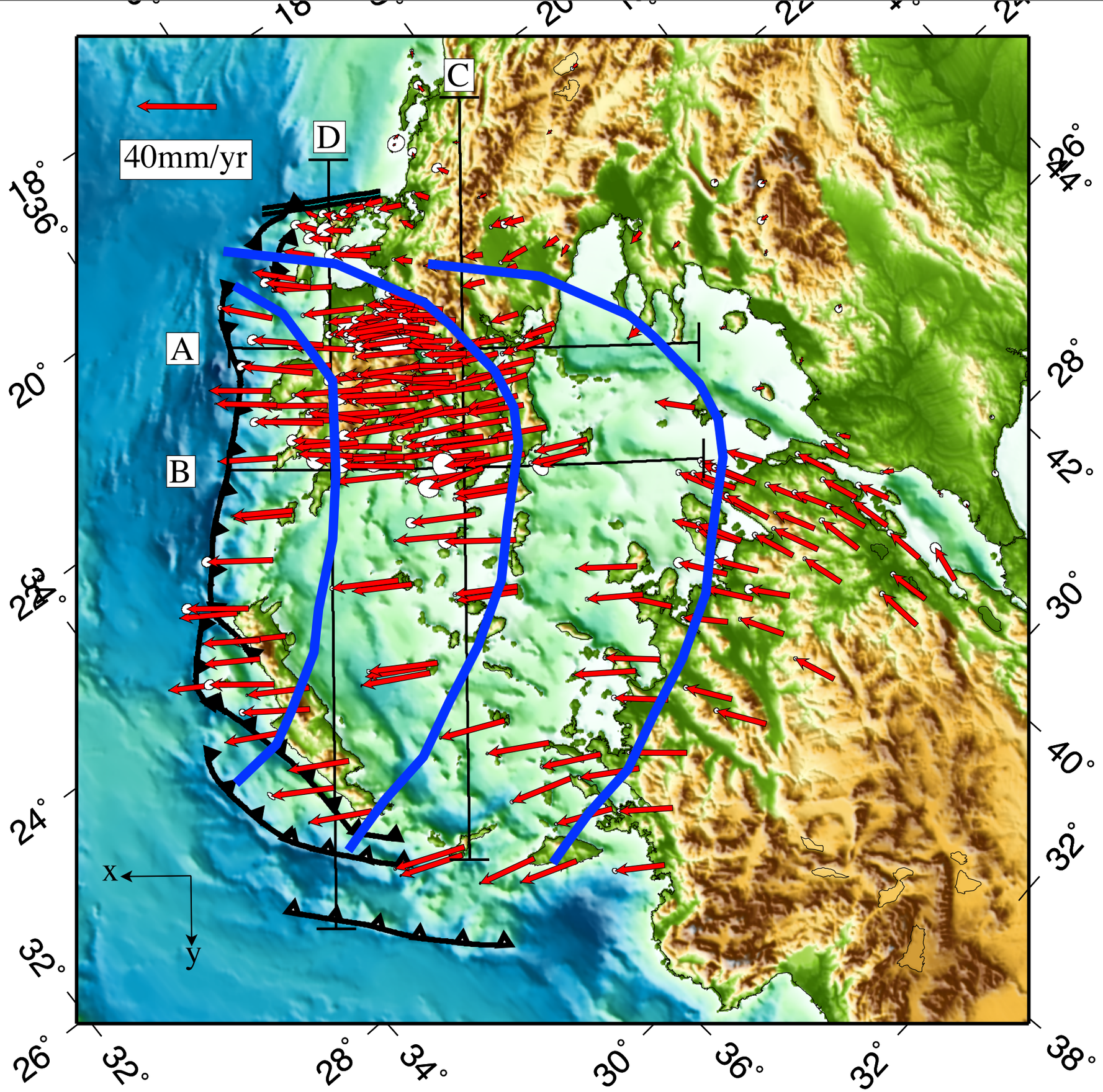

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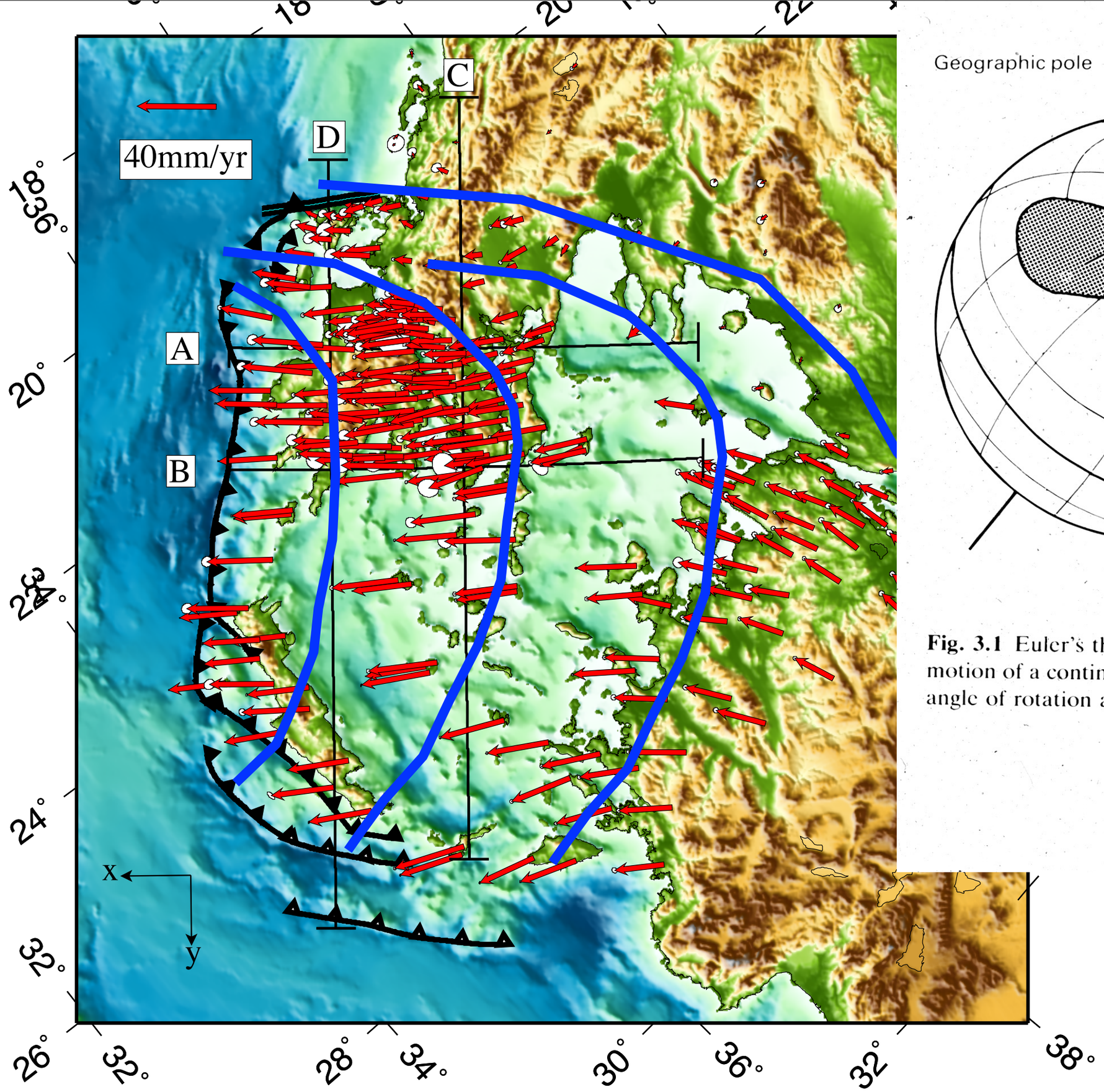

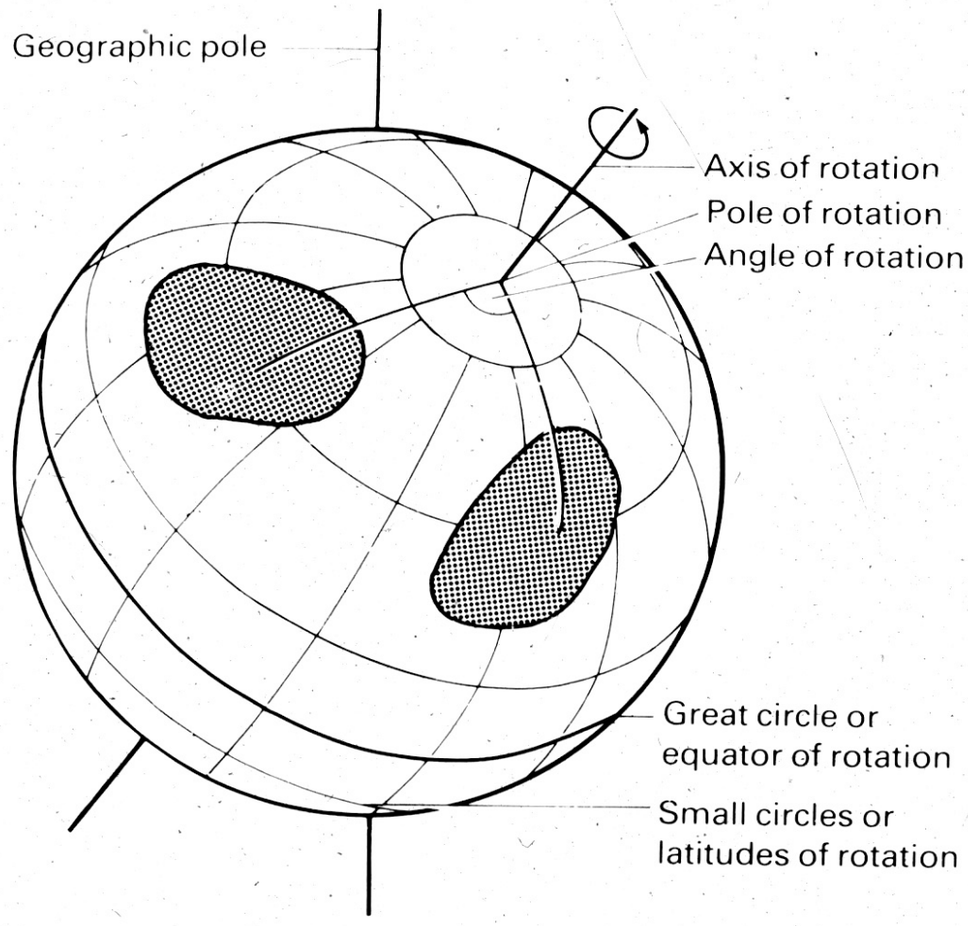

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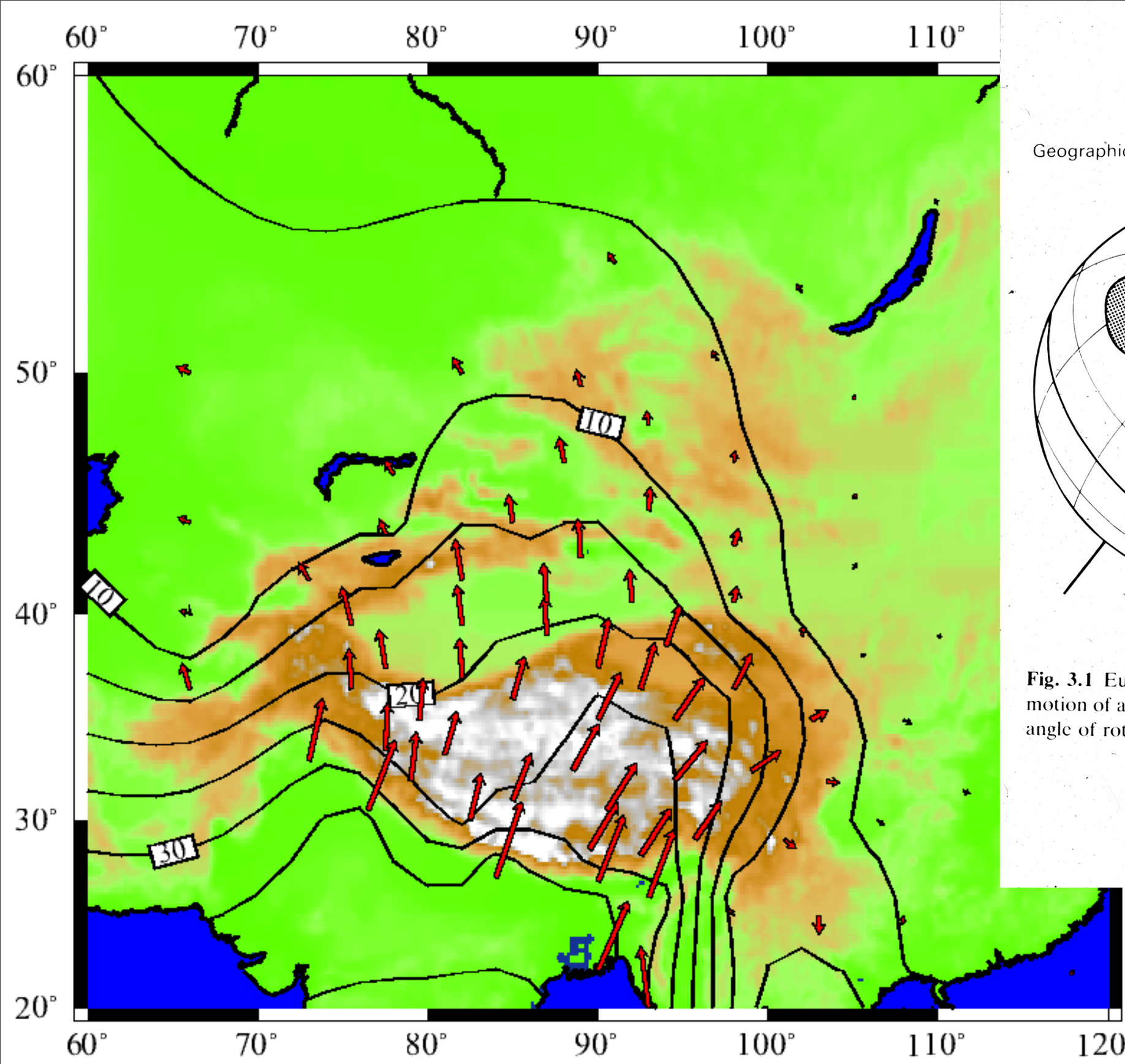


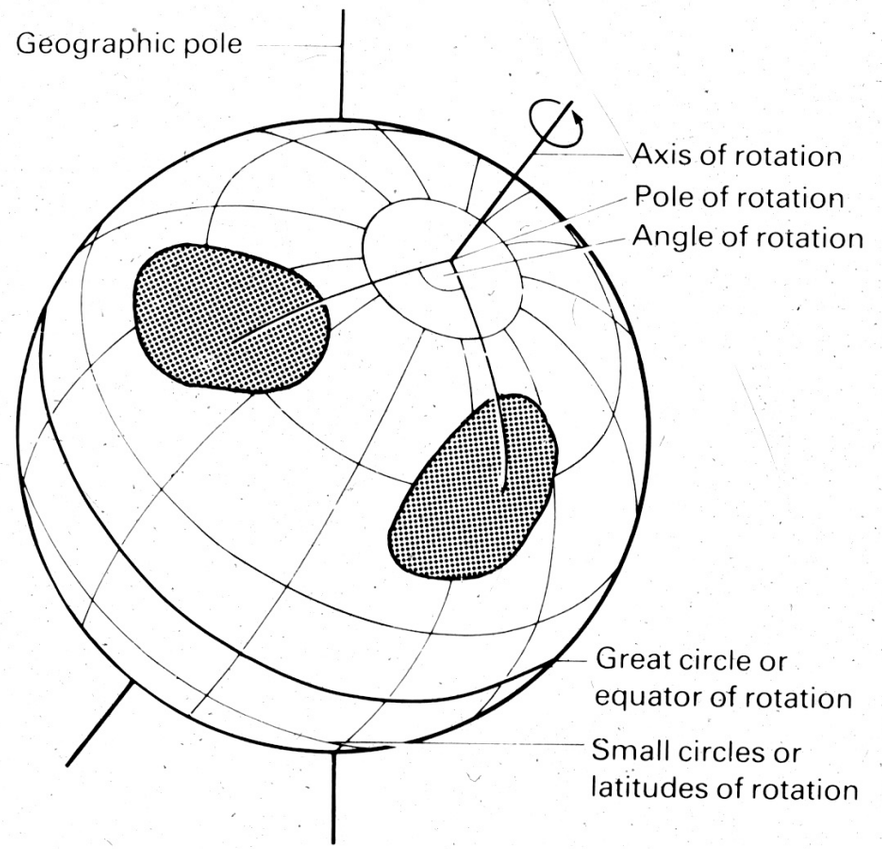
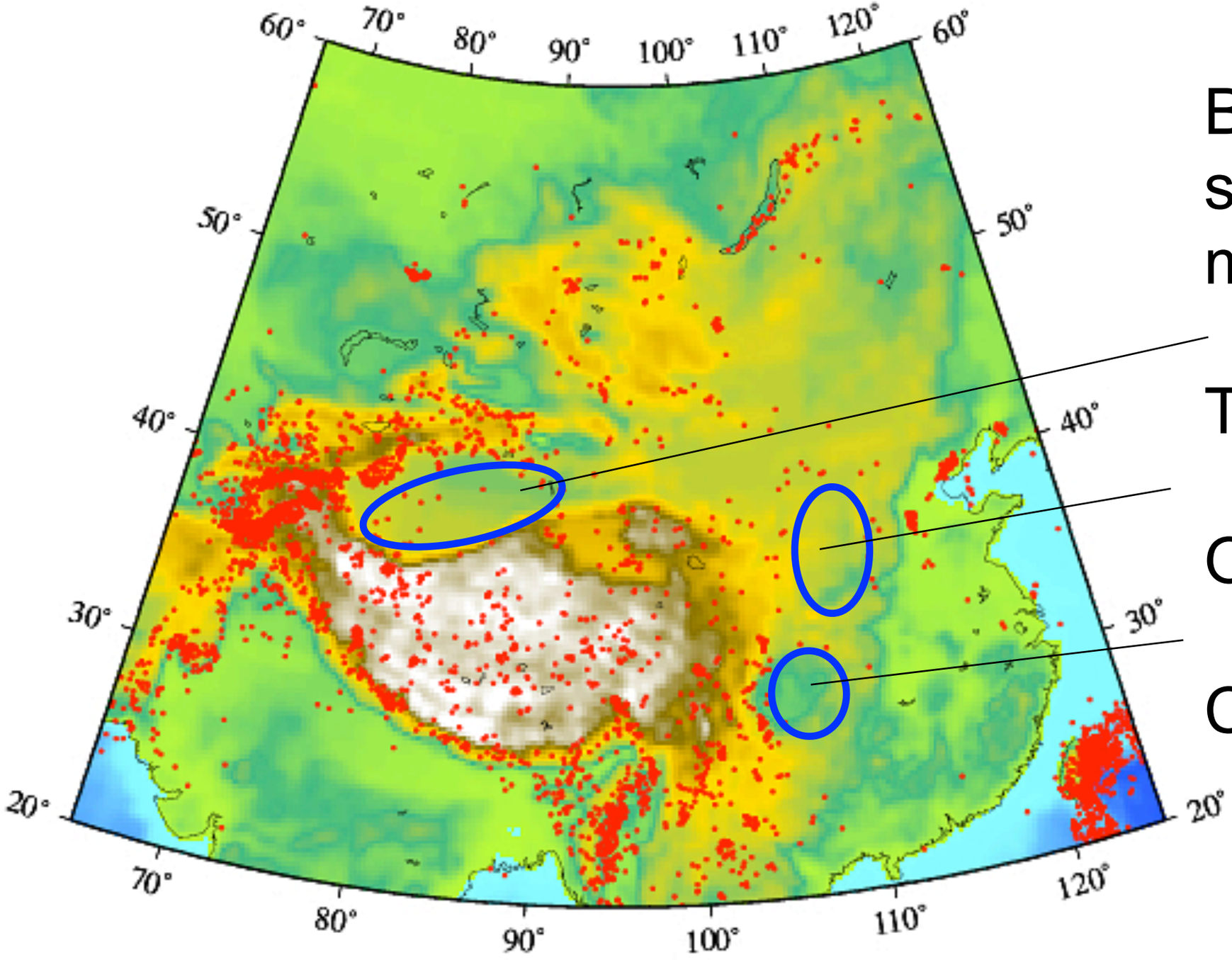


Fig. 3.1 Euler's theorem. Diagram illustrating how the motion of a continent on the Earth can be described by an angle of rotation about a pole of rotation.

Velocities in Asia are perpendicular to contours of their magnitude. England and Molnar, 2005.



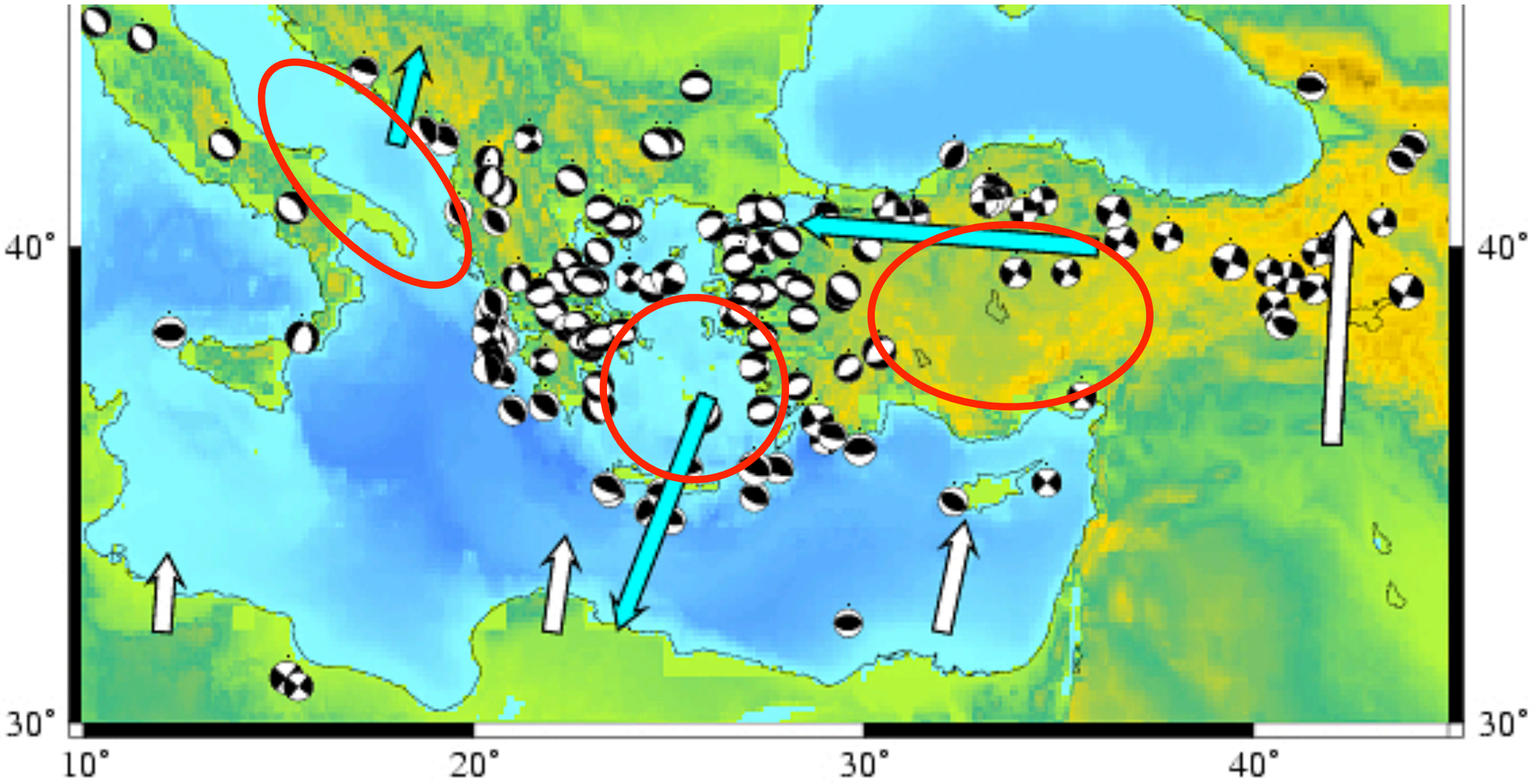
But we find small blocks in many places:

Tarim Basin

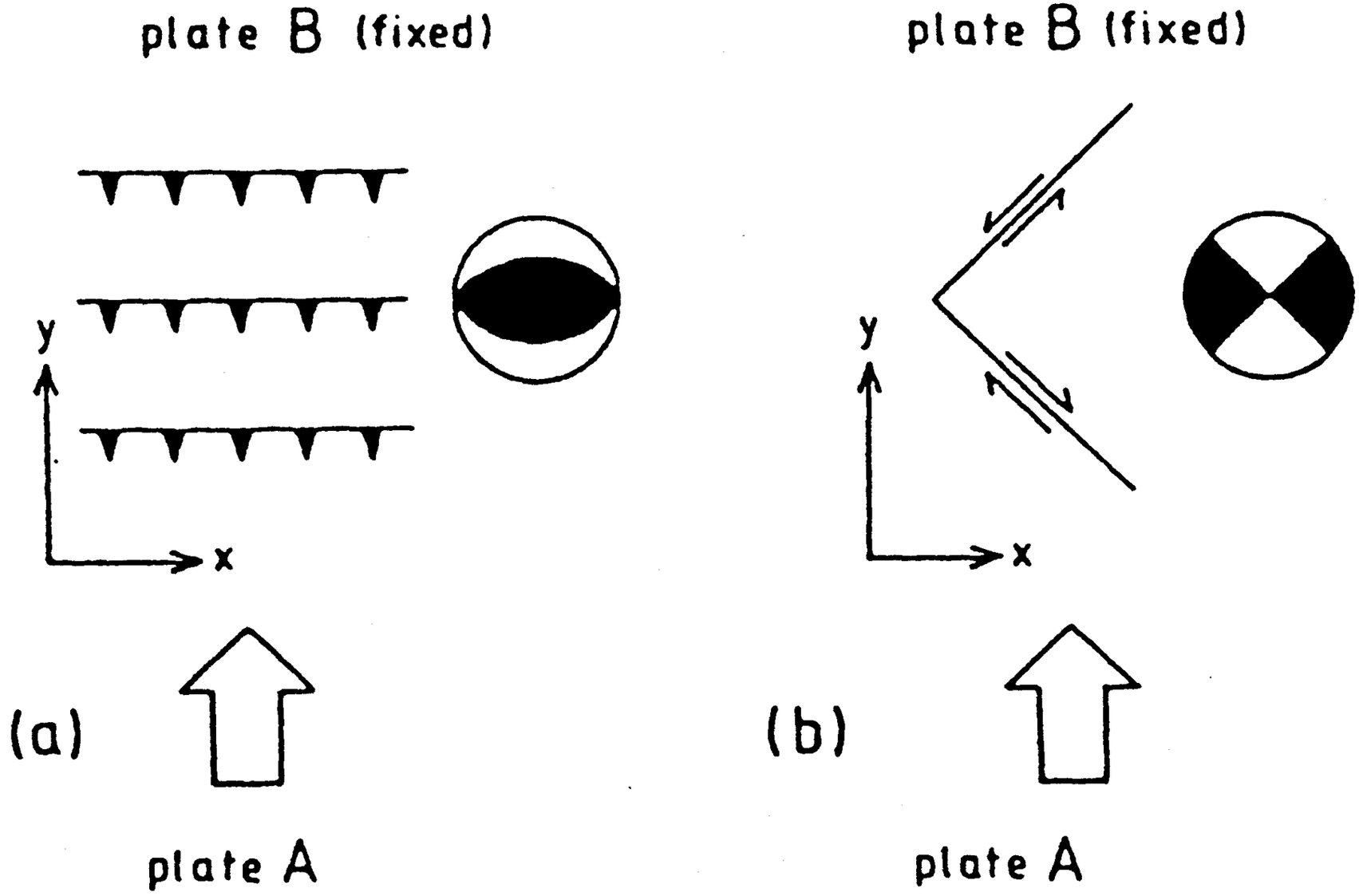
Ordos Block

Chengdu Basin

Jackson and McKenzie 1988, G. J. Int.
‘Microplates’ in E. Mediterranean

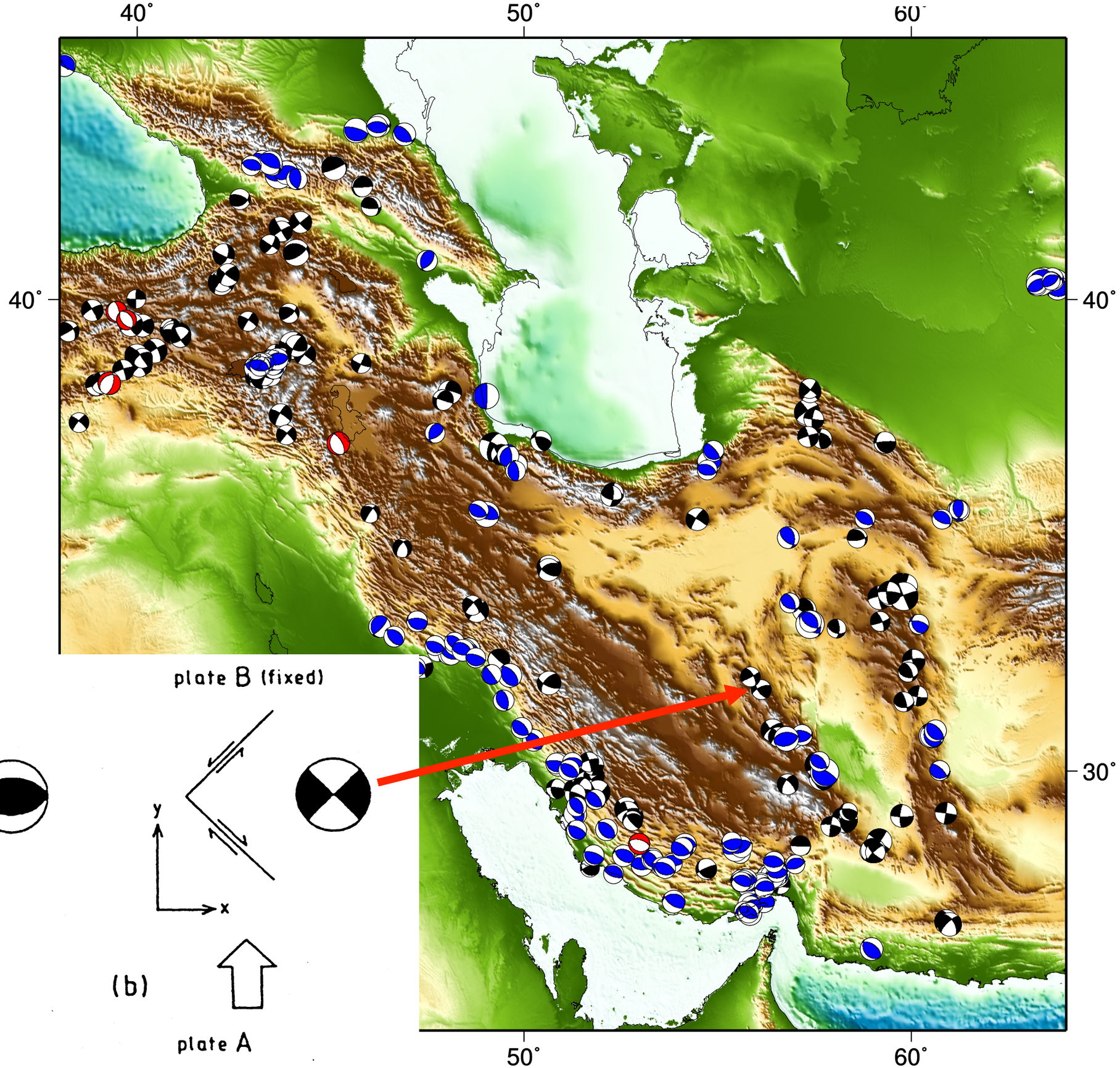


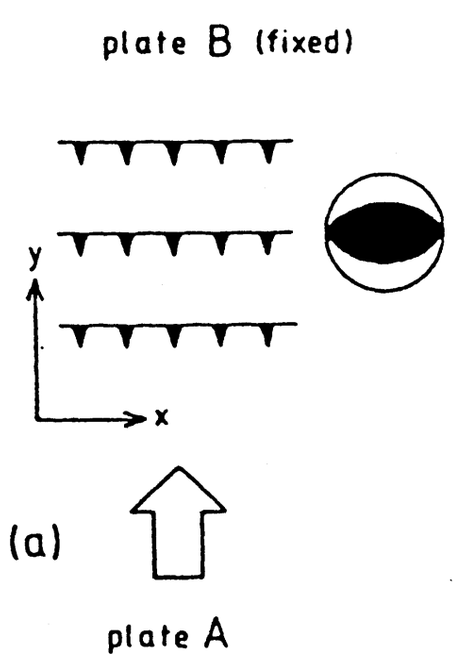
As with Plate Tectonics, we can use the slip vectors of earthquakes to estimate relative motions of ‘micro-plates’. Those motions don’t reveal a simple underlying picture, but that’s OK -- neither do the motions of the major plates. BUT: these micro-plates are small compared with the whole deforming zone.



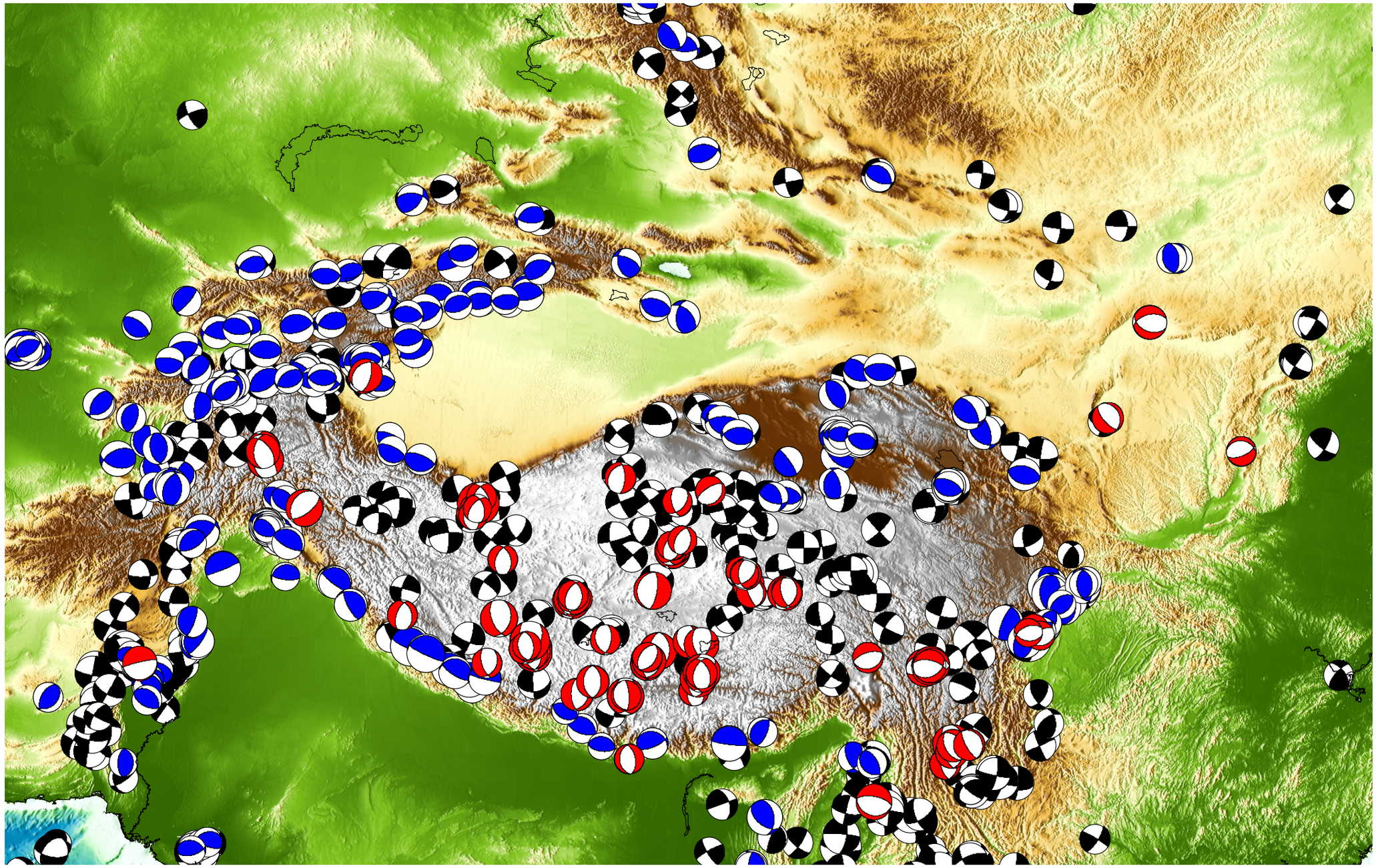
Relative motions of micro-plates do not allow prediction of deformation in diffuse zones around their edges.

England and Jackson
Ann Rev E. P. Sci 1989





Asia Seismicity



Instantaneous strain inconsistent with finite strain

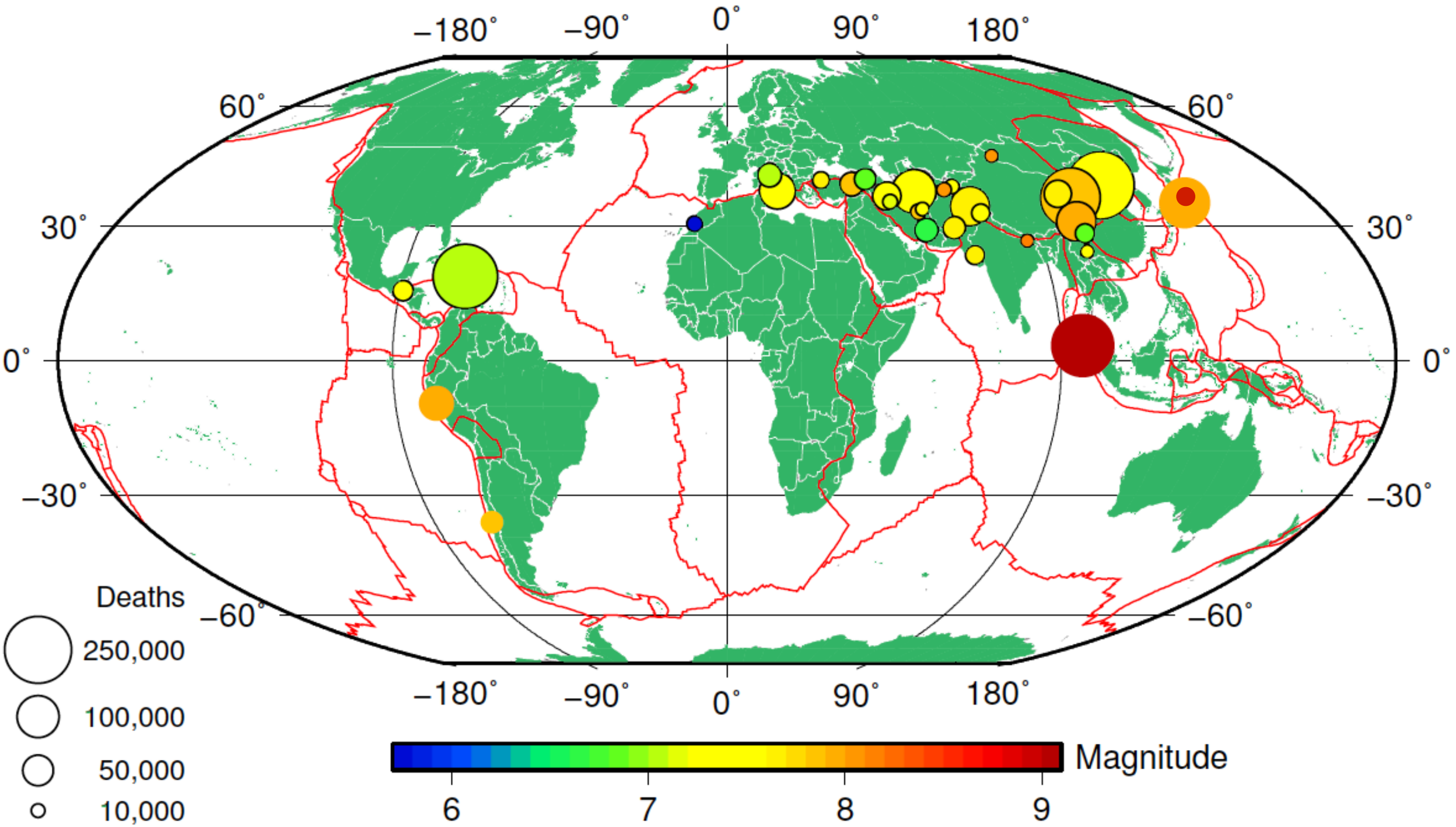
England and Jackson
Ann Rev E. P. Sci 1989

Plate Tectonics is not a useful description of continental deformation

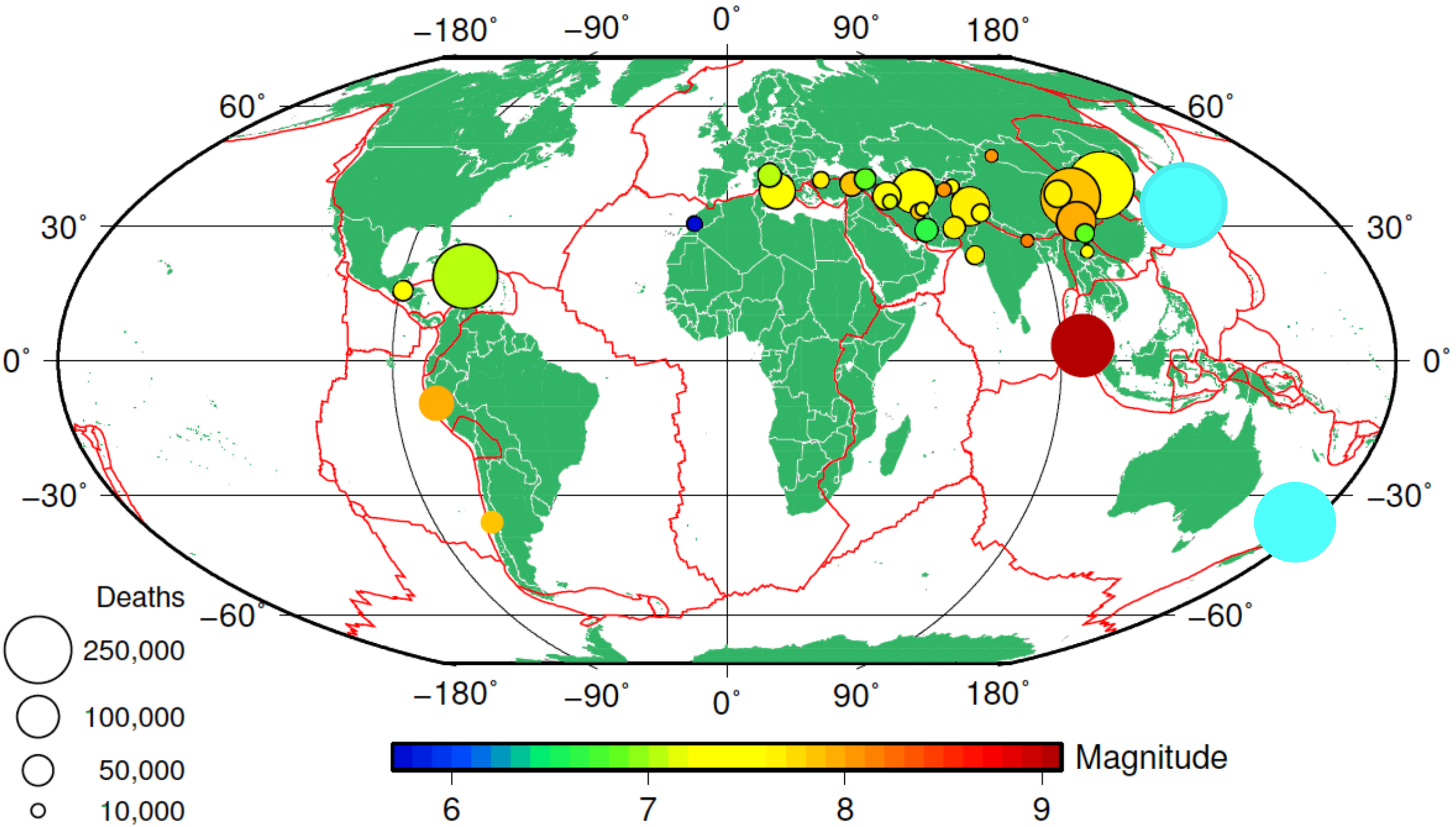
- Micro-plates small compared with whole deforming regions
- Relative motions of micro-plates do not allow prediction of deformation
- Micro-plates aren't plates, anyway, because they have strained
- Active strain rates do not explain finite strain

Why does this matter?

Last 100 Years > 1,000 Deaths



Last 100 Years > 1,000 Deaths



The State of the Art

Sendai 2011

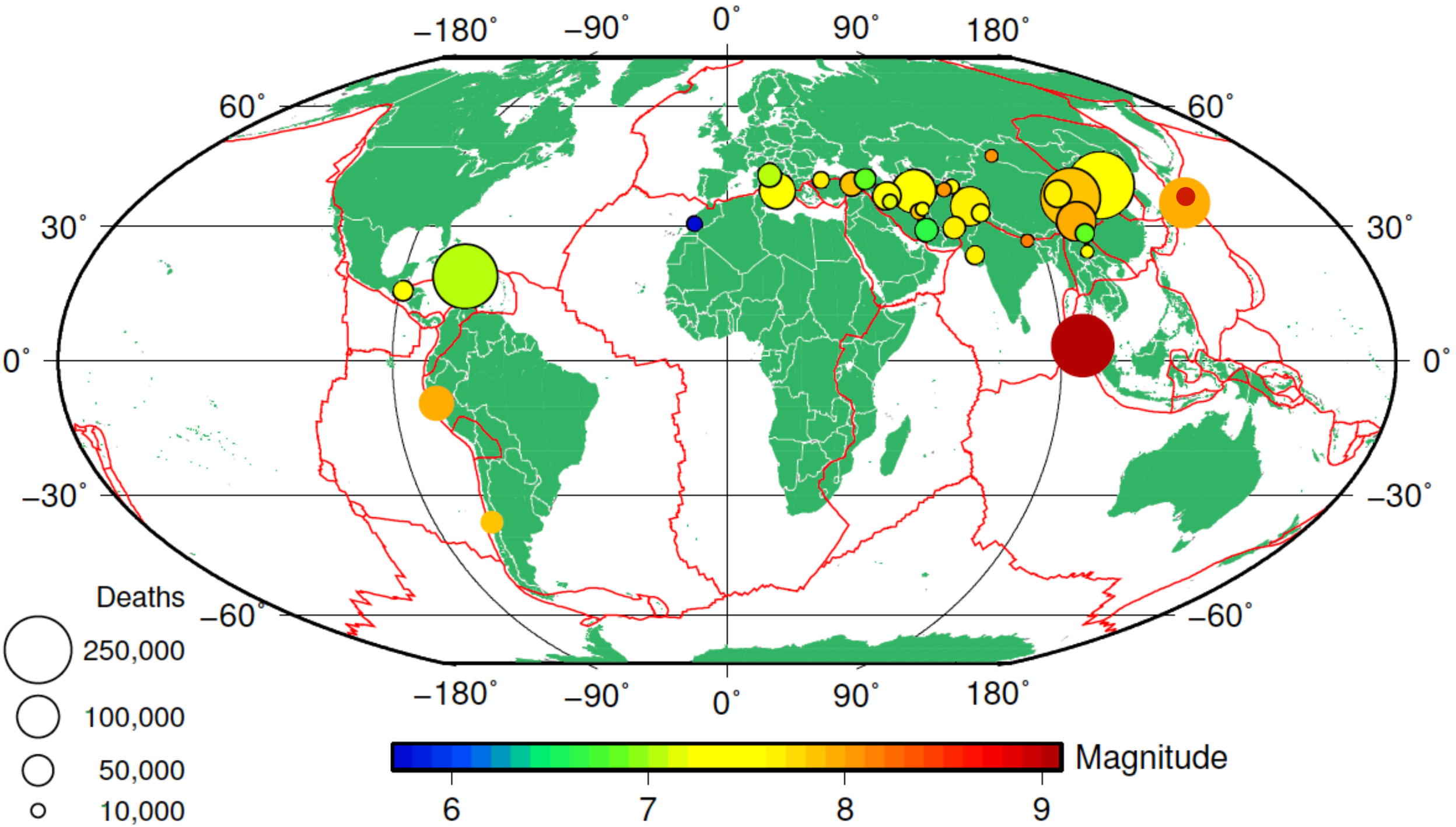
Death rate 0.4% in MVIII+ shaking. (Mostly tsunami.)

The State of the Art

Christchurch 2011

Death rate in MVIII+ shaking 0.1%

Last 100 Years > 1,000 Deaths

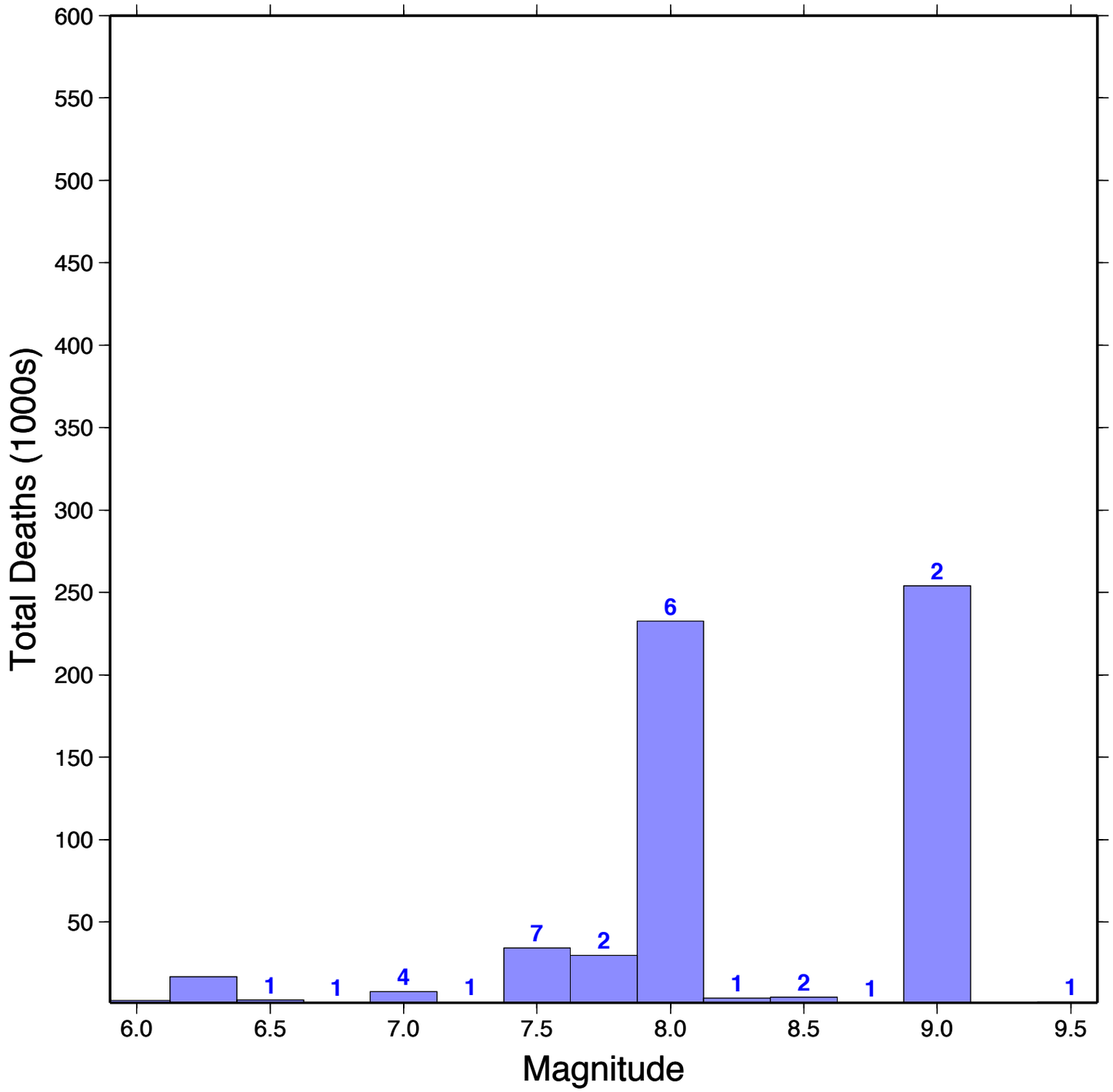


Bam 2003, M6.6: Death rate 30%. >26,000 deaths

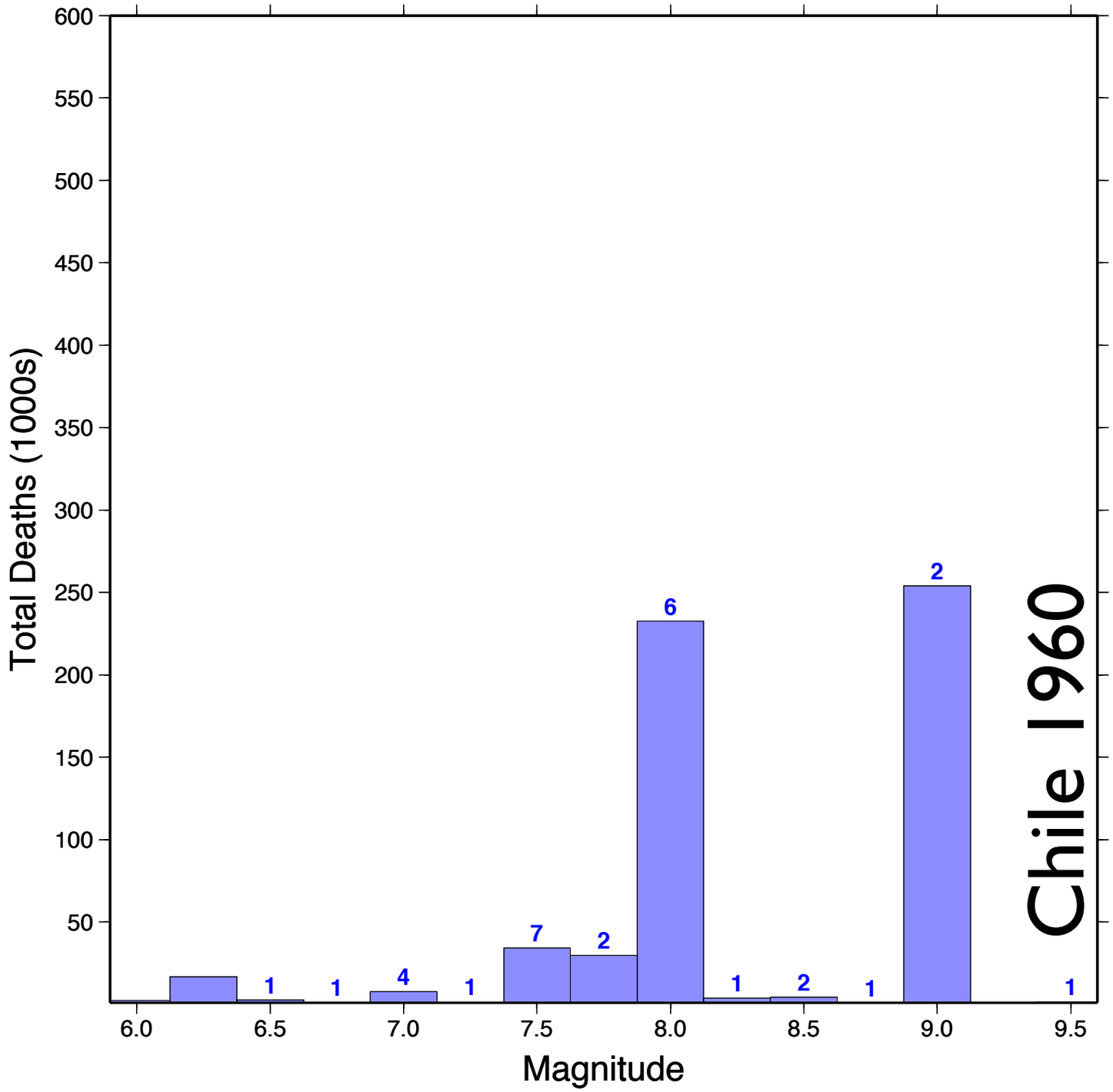
Devastating Earthquakes

1) Plate Boundaries
   Faults of known location
   slip at 10-100 mm/year

Last 100 Years > 1,000 Deaths



Last 100 Years > 1,000 Deaths



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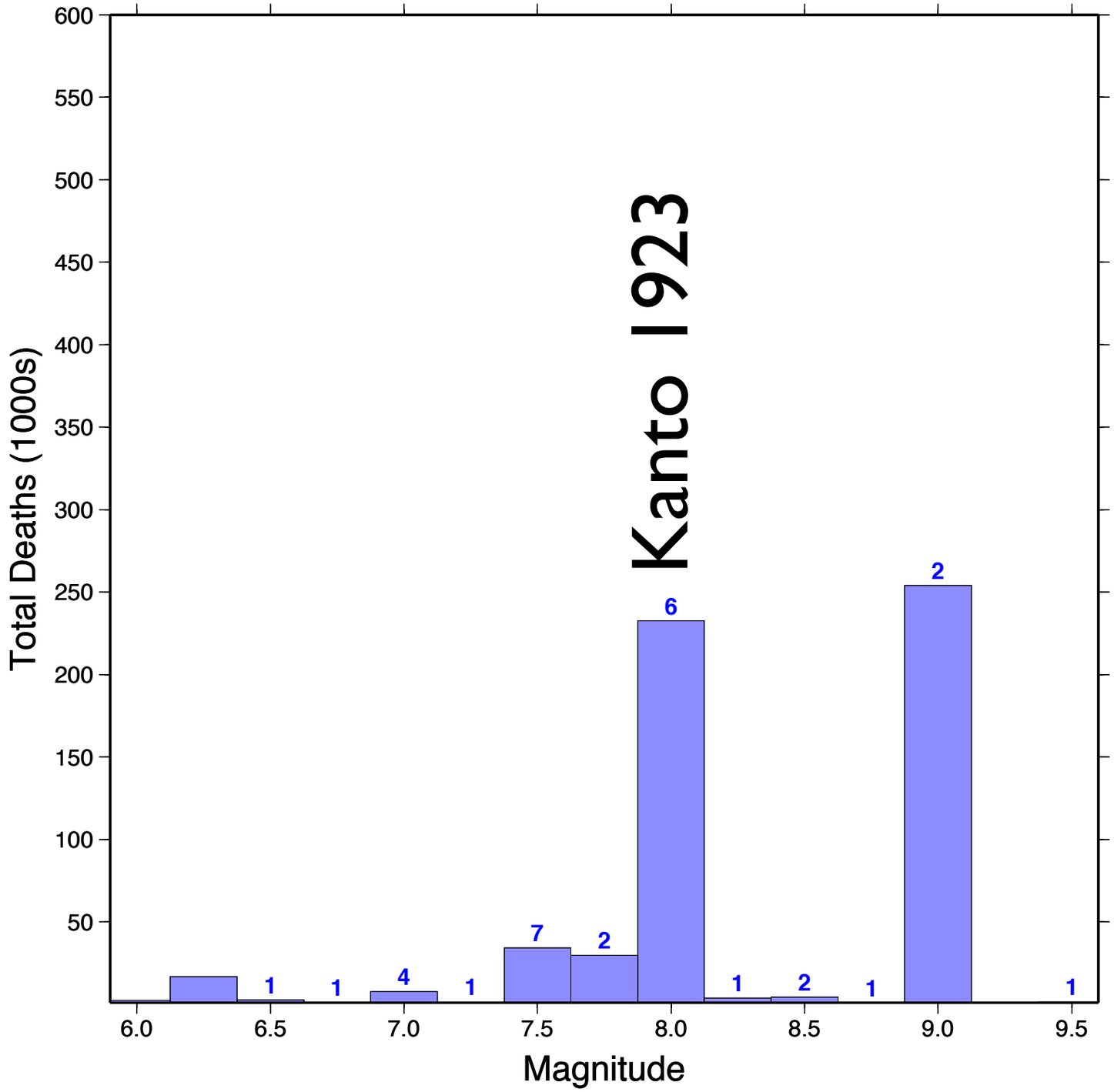

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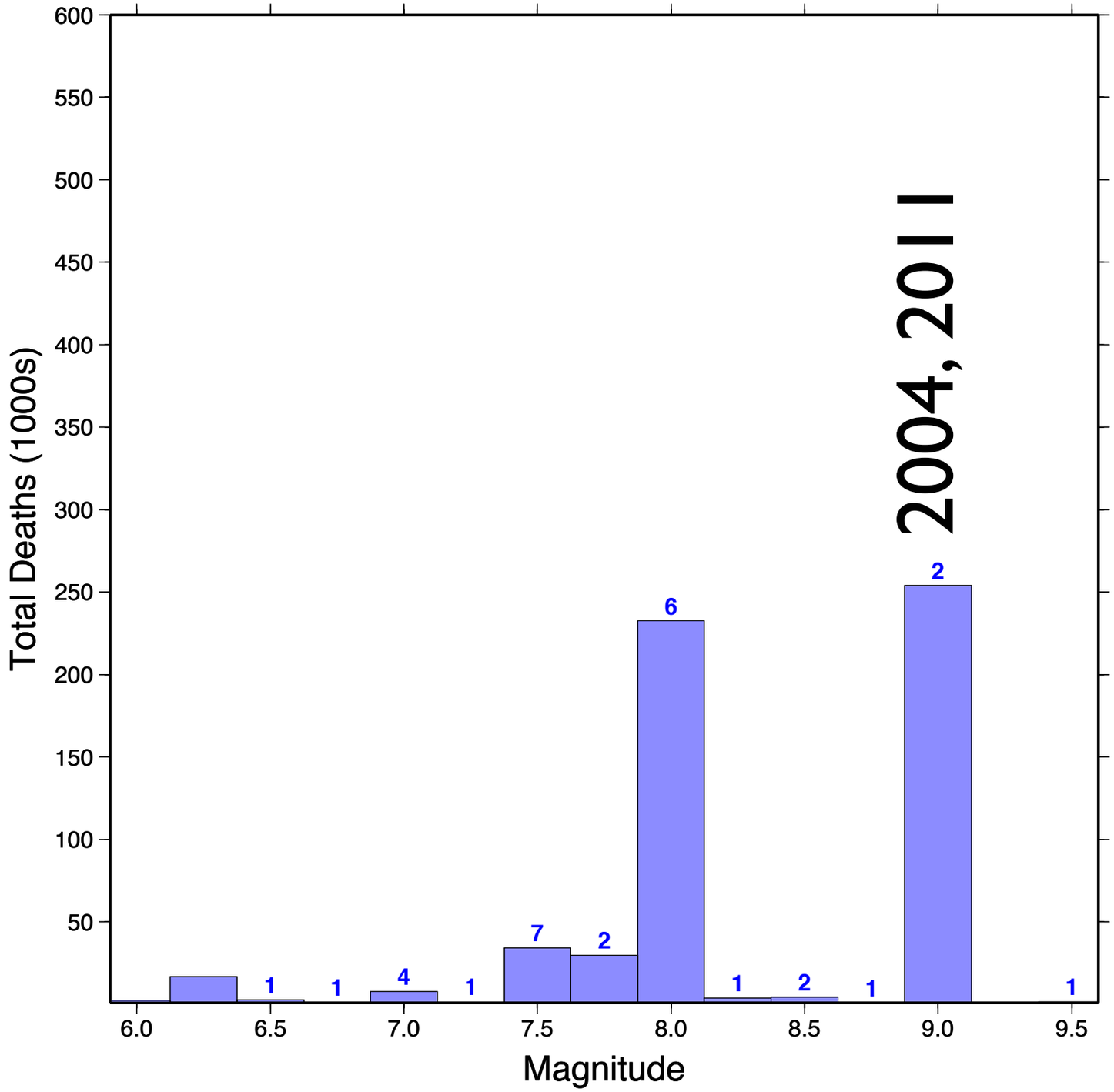
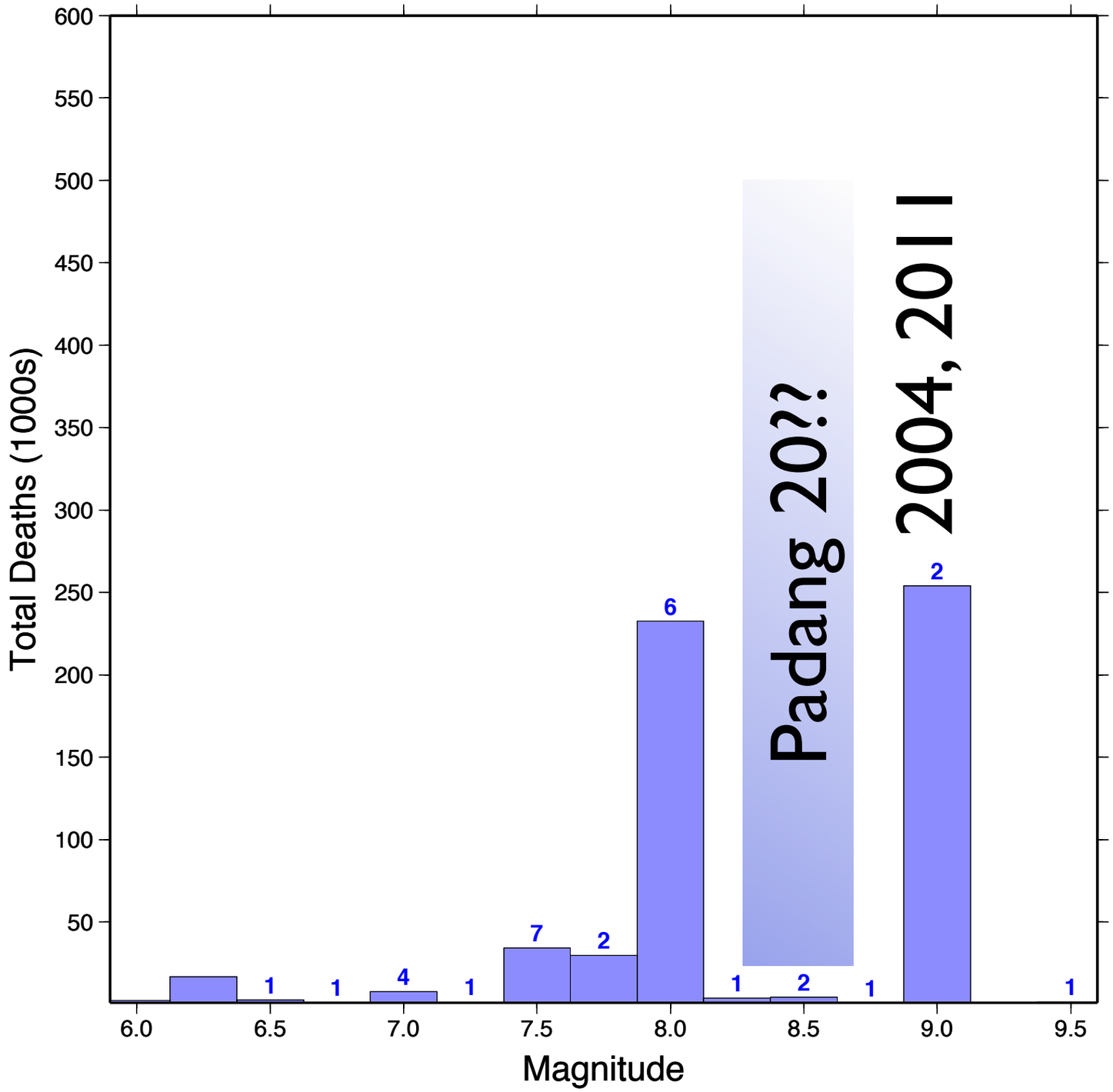


Last 100 Years > 1,000 Deaths

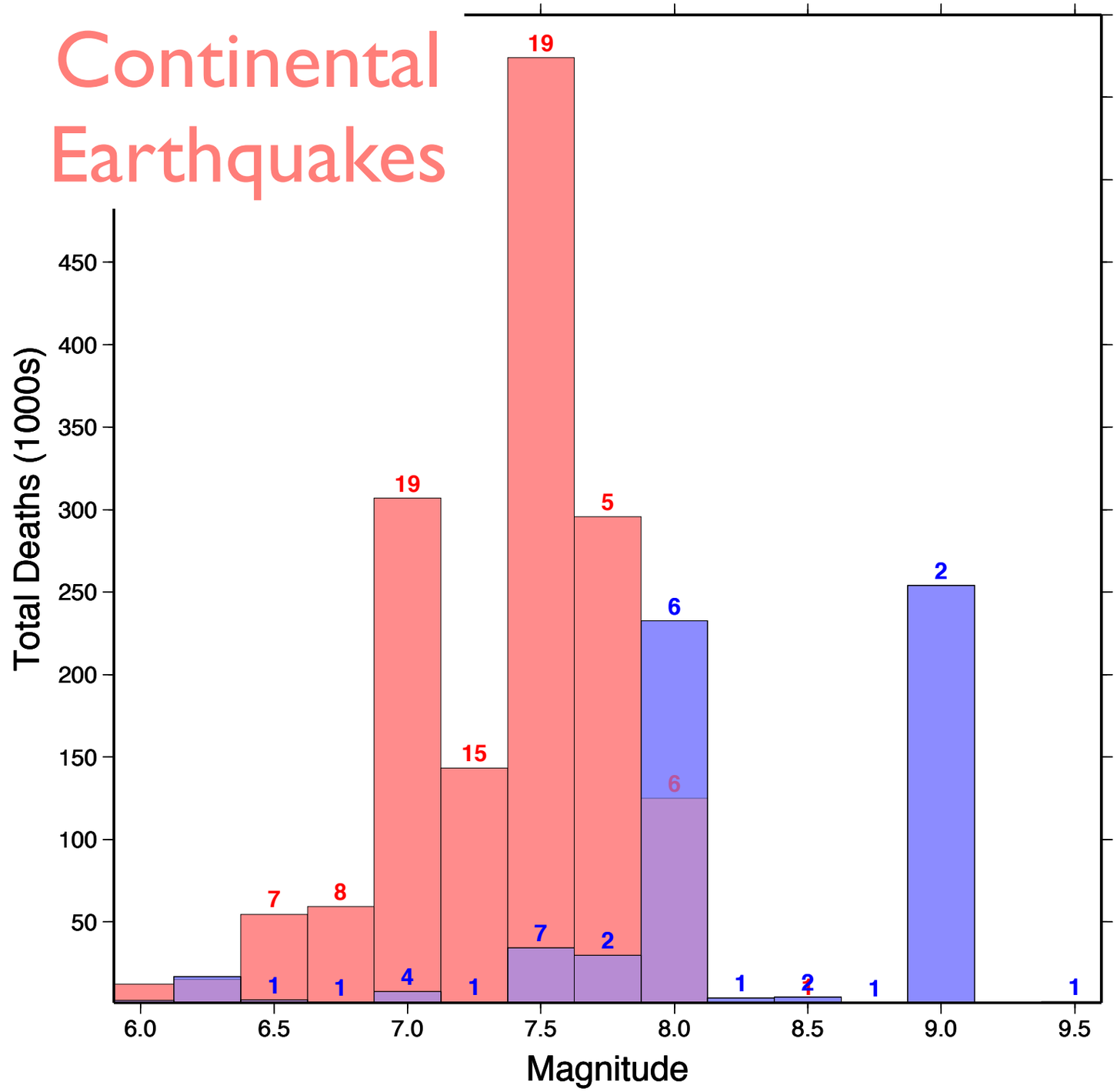


Devastating Earthquakes

1) Plate Boundaries
   Faults of known location
   slip at 10-100 mm/year

2) Continental Interiors
   Fault locations frequently unknown
   Slip at 0.1- 1mm/yr

Last 100 Years > 1,000 Deaths



Continental Interiors

The killers are M ~7 Earthquakes:

- 3 metres of slip
- Slip at 0.1- 1mm/yr
- 1/3,000 1/30,000 yr

At an individual location:

- Earthquakes are extremely rare devastating events.
- Collective memory fades.
- Lack of effective action.