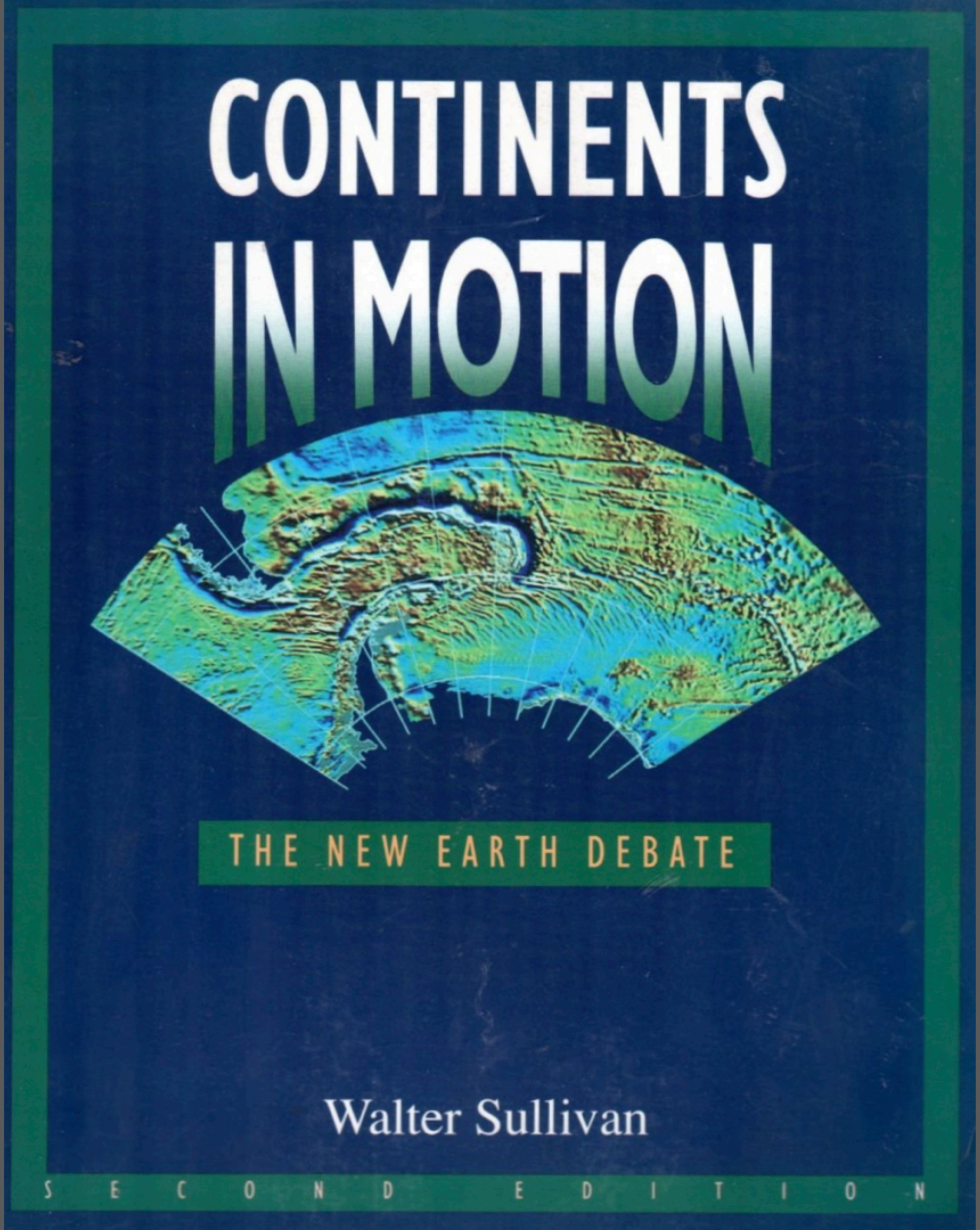
A Perspective on Revolutions, Revisions, Rights, and Responsibilities in the Geosciences

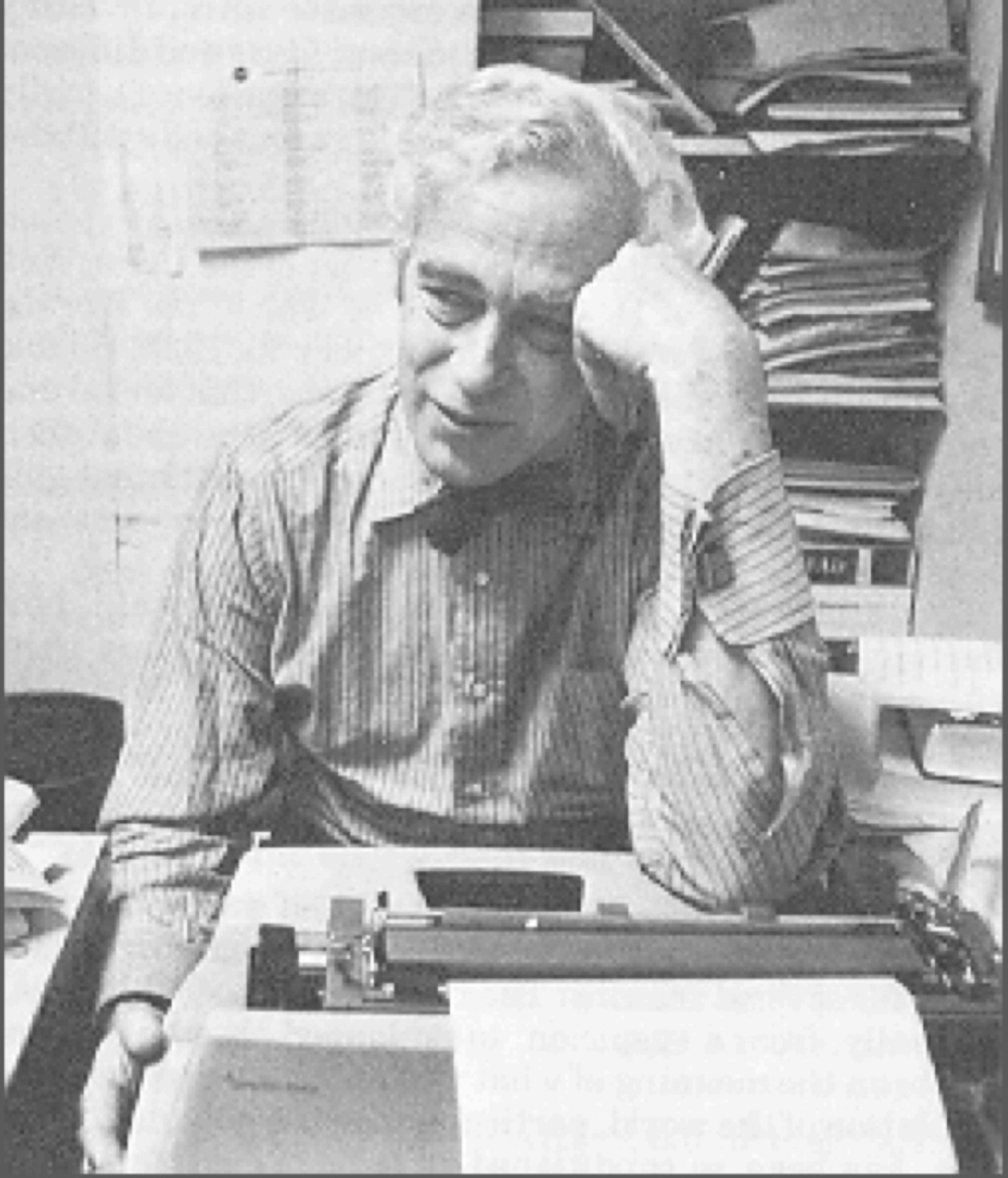
https://CroninProjects.org/October2024/

Kimberly, Australia, from Planet Snapshots, www.planet.com

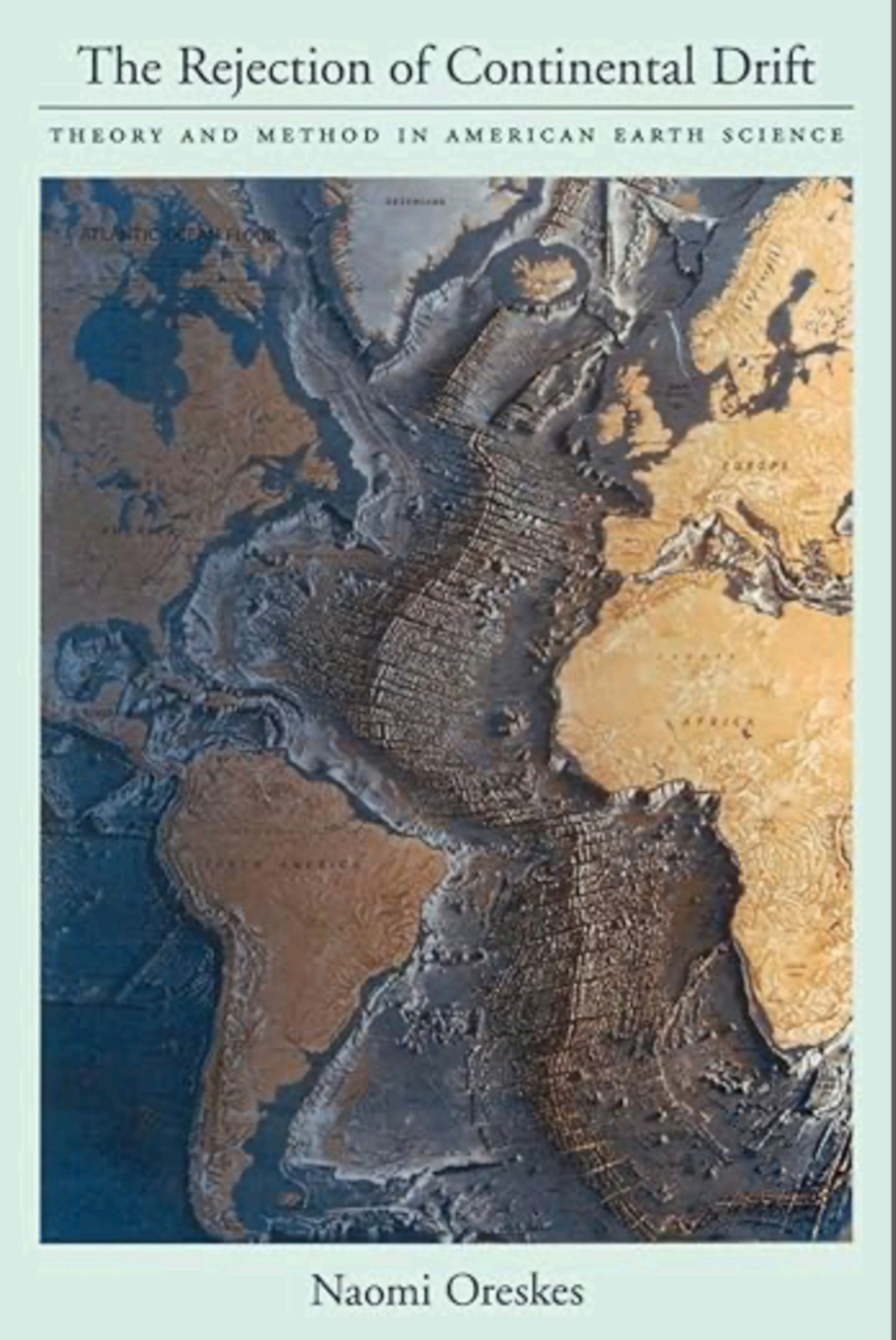
A Current View of Plate Tectonics (Lithospheric Kinematics) Six Decades After the Revolution

https://CroninProjects.org/October2024/Revolution1





Walter Sullivan


The Rejection of Continental Drift
THEORY AND METHOD IN AMERICAN EARTH SCIENCE
Naomi Oreskes

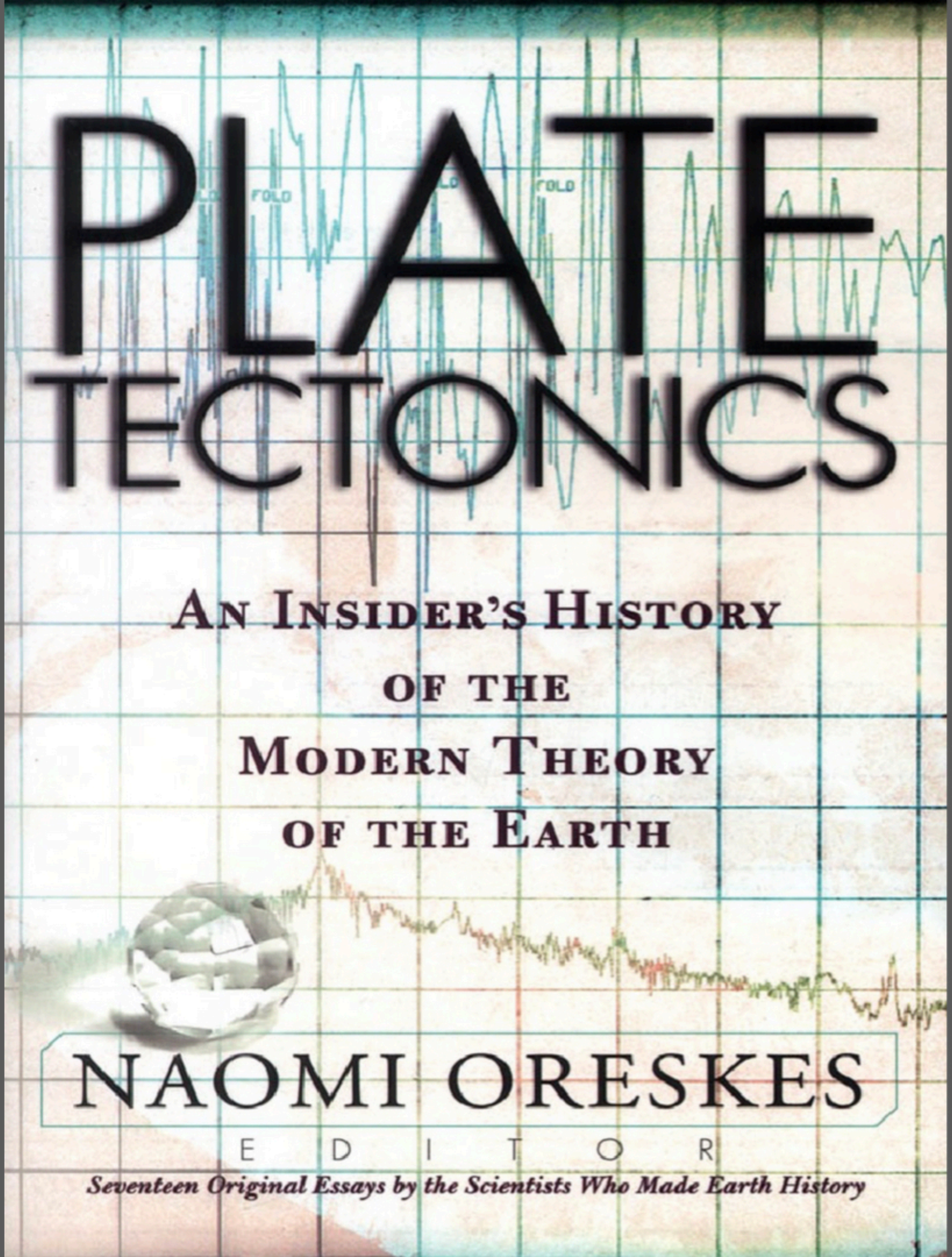
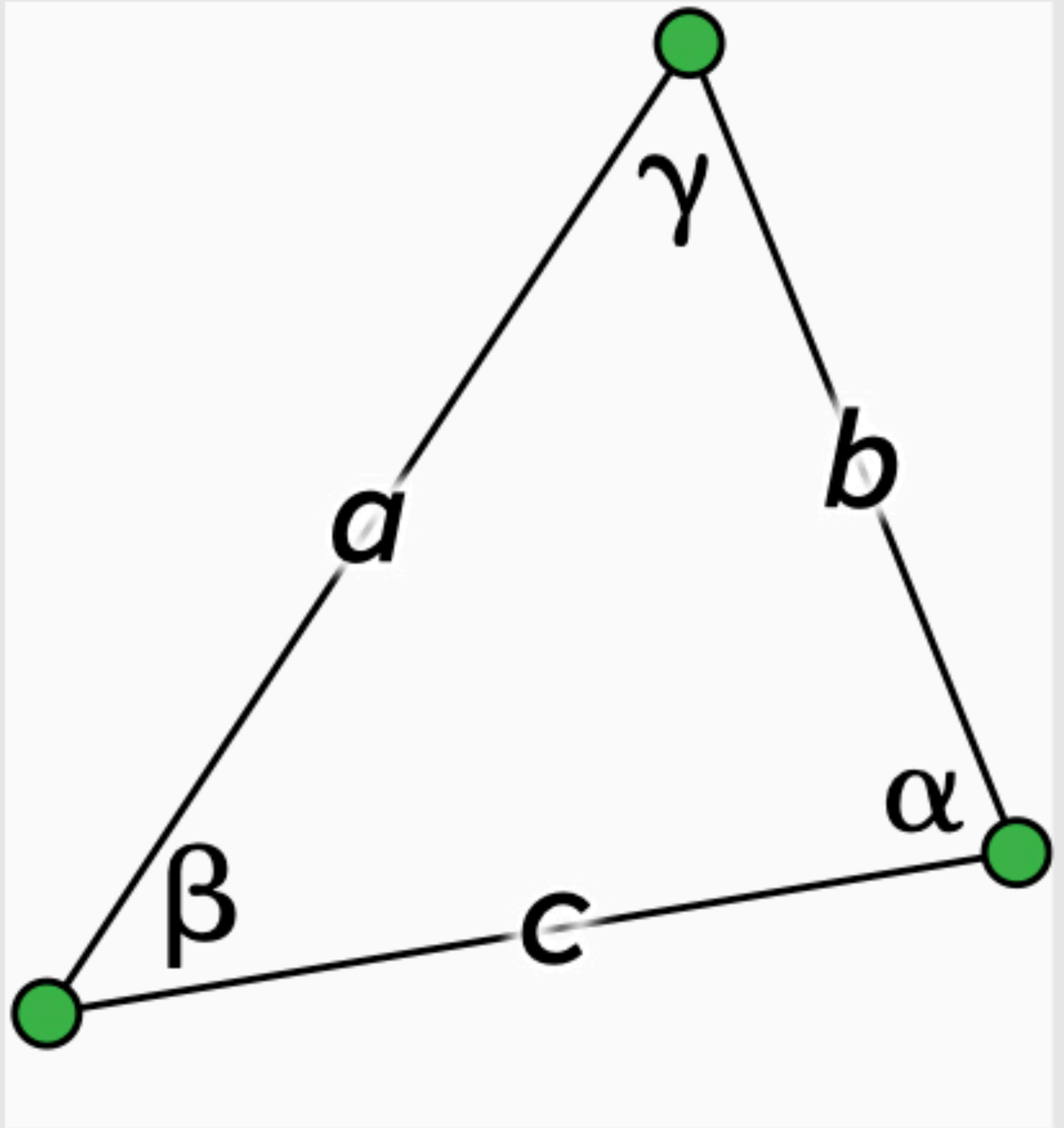
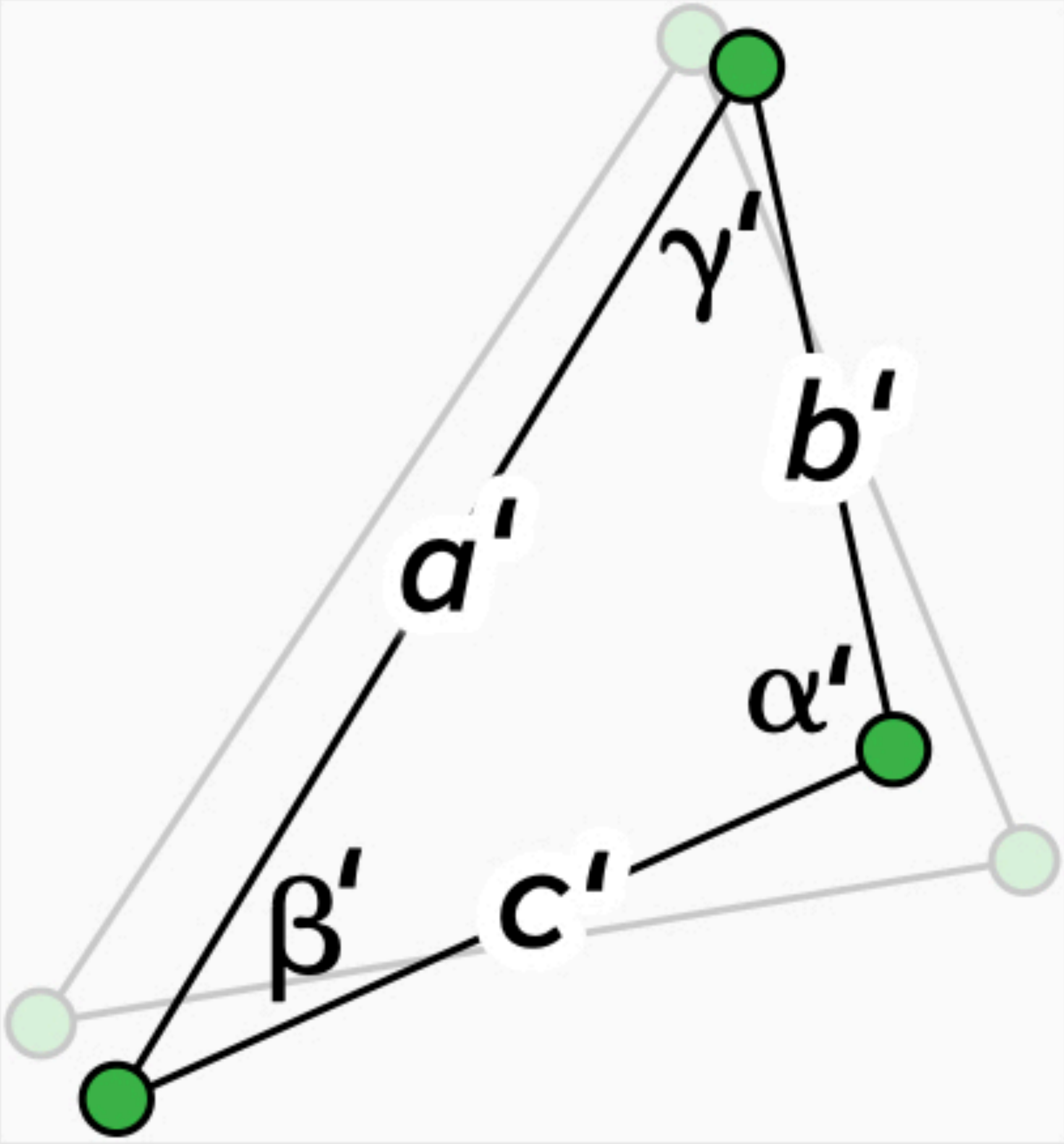


PLATE TECTONICS
AN INSIDER'S HISTORY OF THE MODERN THEORY OF THE EARTH
NAOMI ORESKES
EDITOR
Seventeen Original Essays by the Scientists Who Made Earth History

Explaining terms…

Points in a **rigid** **body** maintain their initial angular and distance relationships with one another over time.

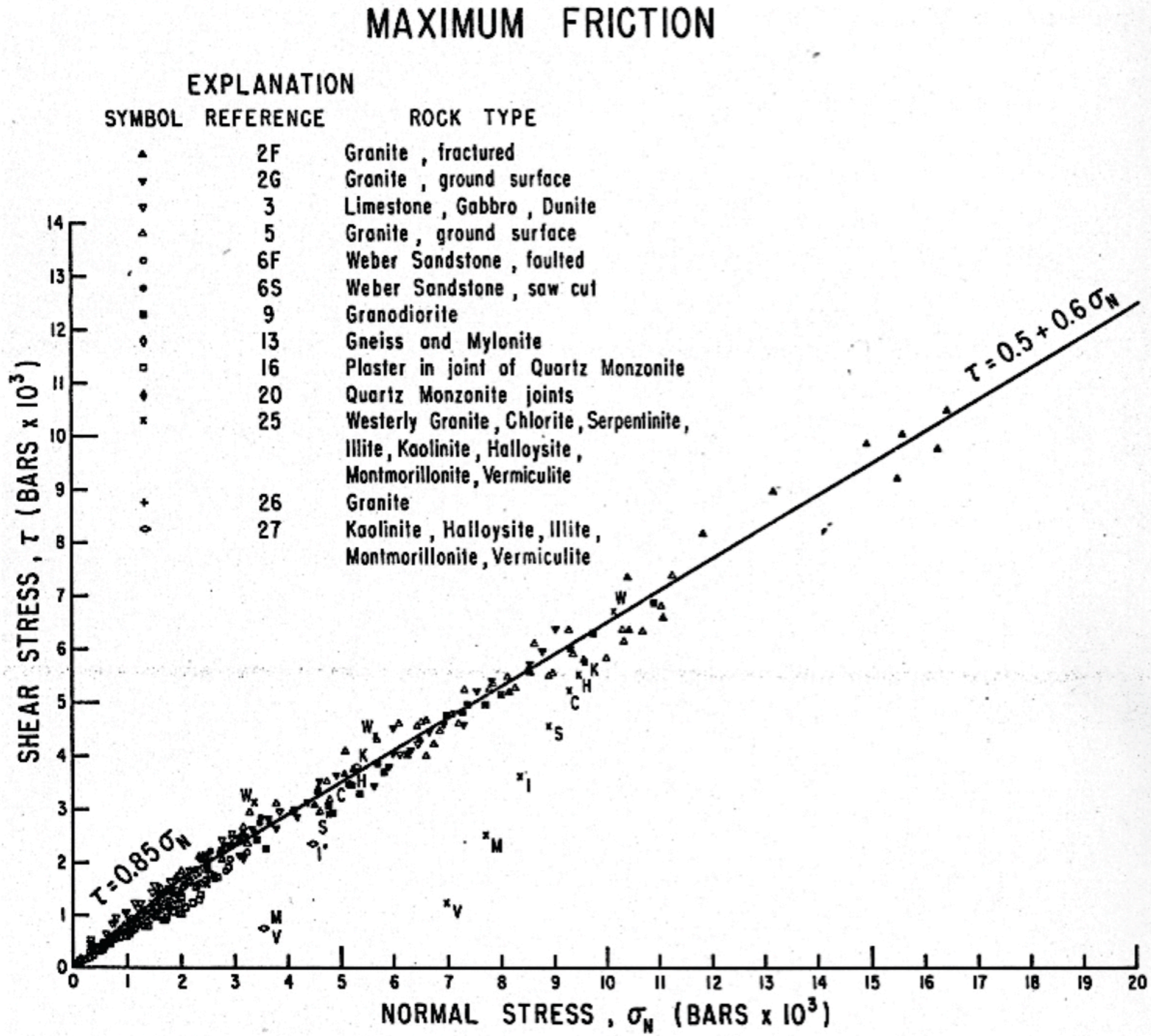




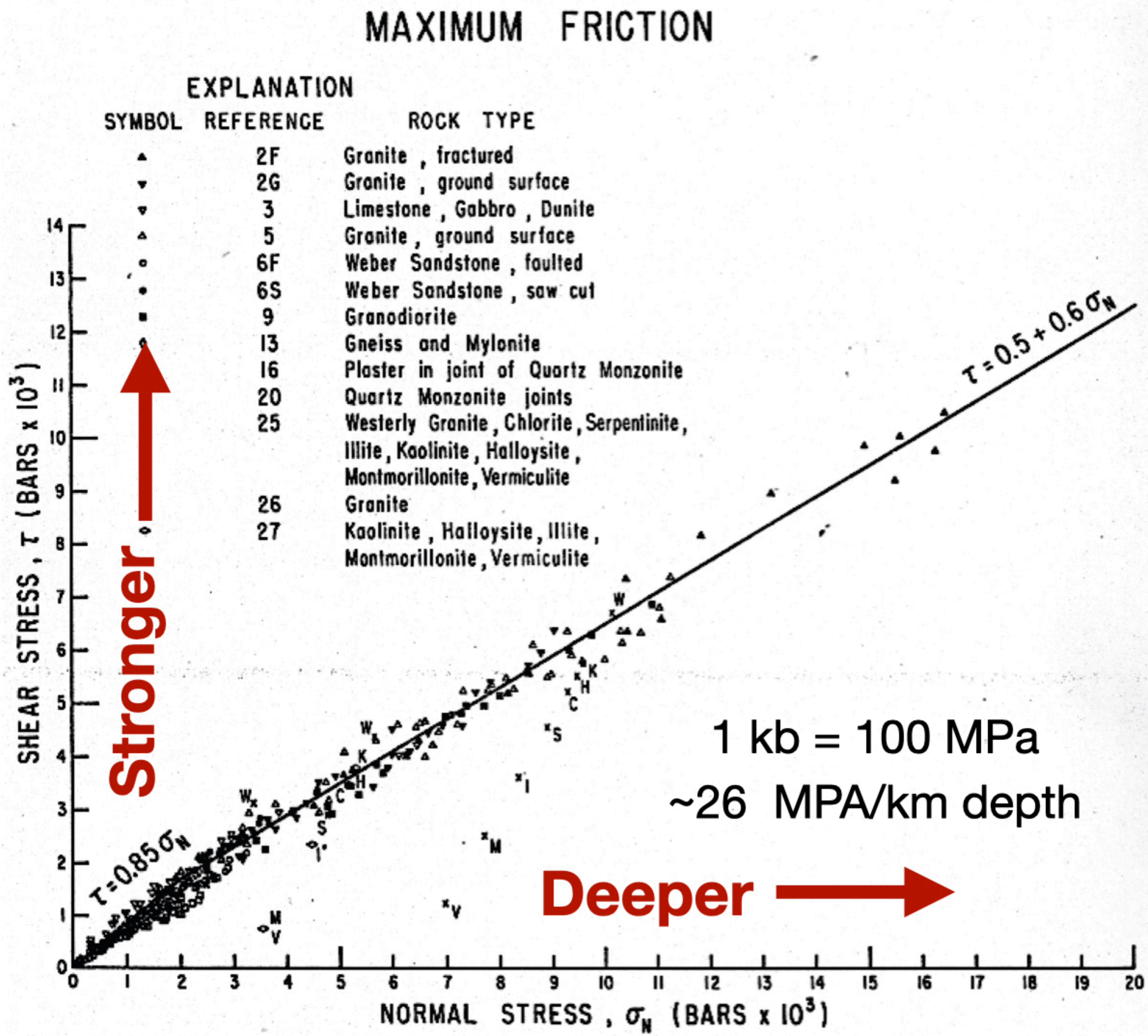
Points in a **deforming** **body** do ***not*** maintain their initial angular and distance relationships to one another over time.

The Global Geoscience Tribes in Early 1957

Tribe	Crust is…	Ocean Basin Age	Exemplars
Fixists	entire crust (and mantle) is rigid	ocean basins are old	AAPG, Birch, Jeffries



Jim Byerlee and a triaxial rig



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Expanding Earthers	continental crust is rigid-elastic	ocean basins are young	S. Warren Carey

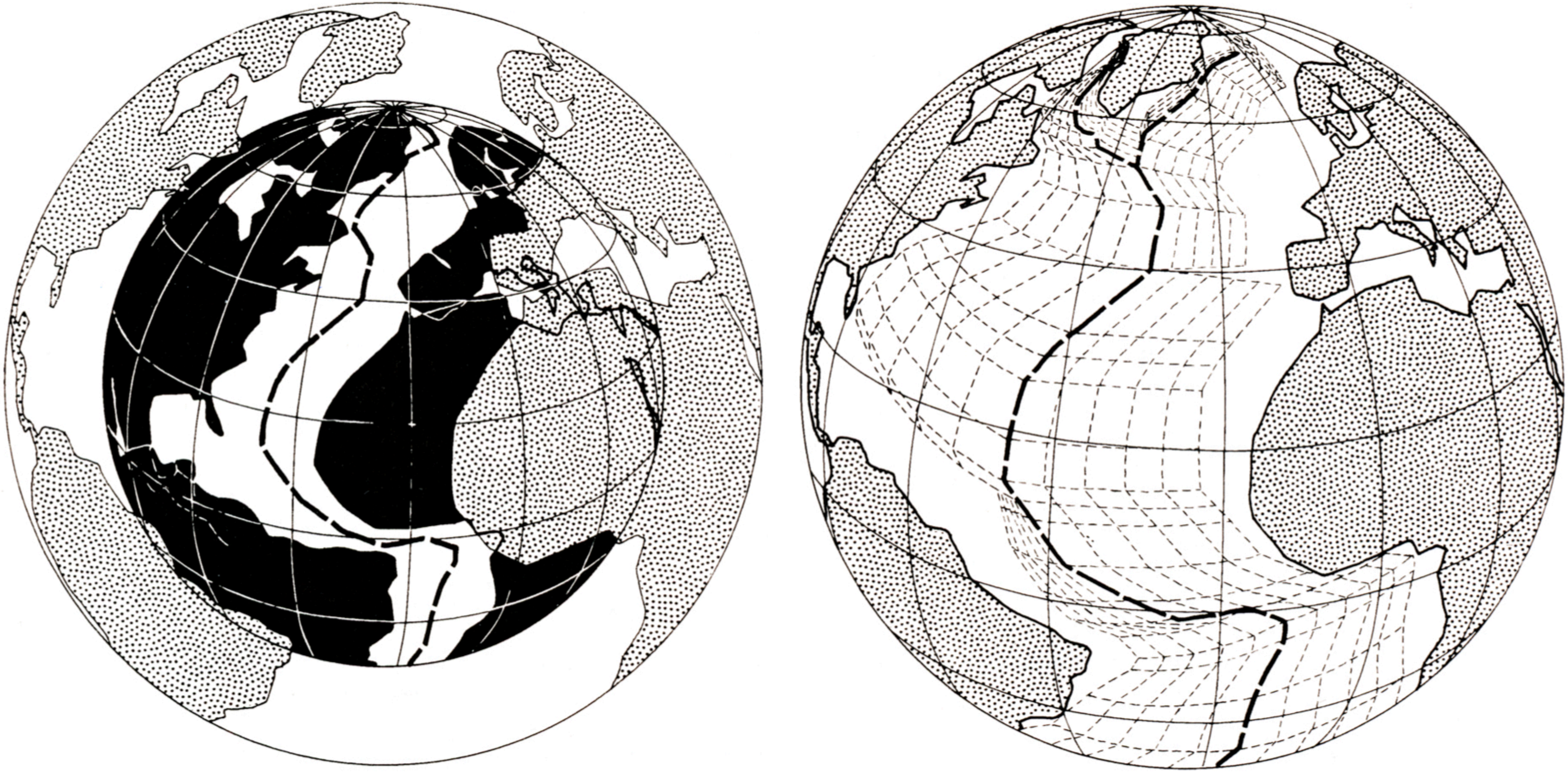

Figure 111*—Perry's computer output from program to shrink the Earth step by step while maintaining the areas of the continents.*

S. Warren Carey, 2000

The Global Geoscience Tribes in Early 1957

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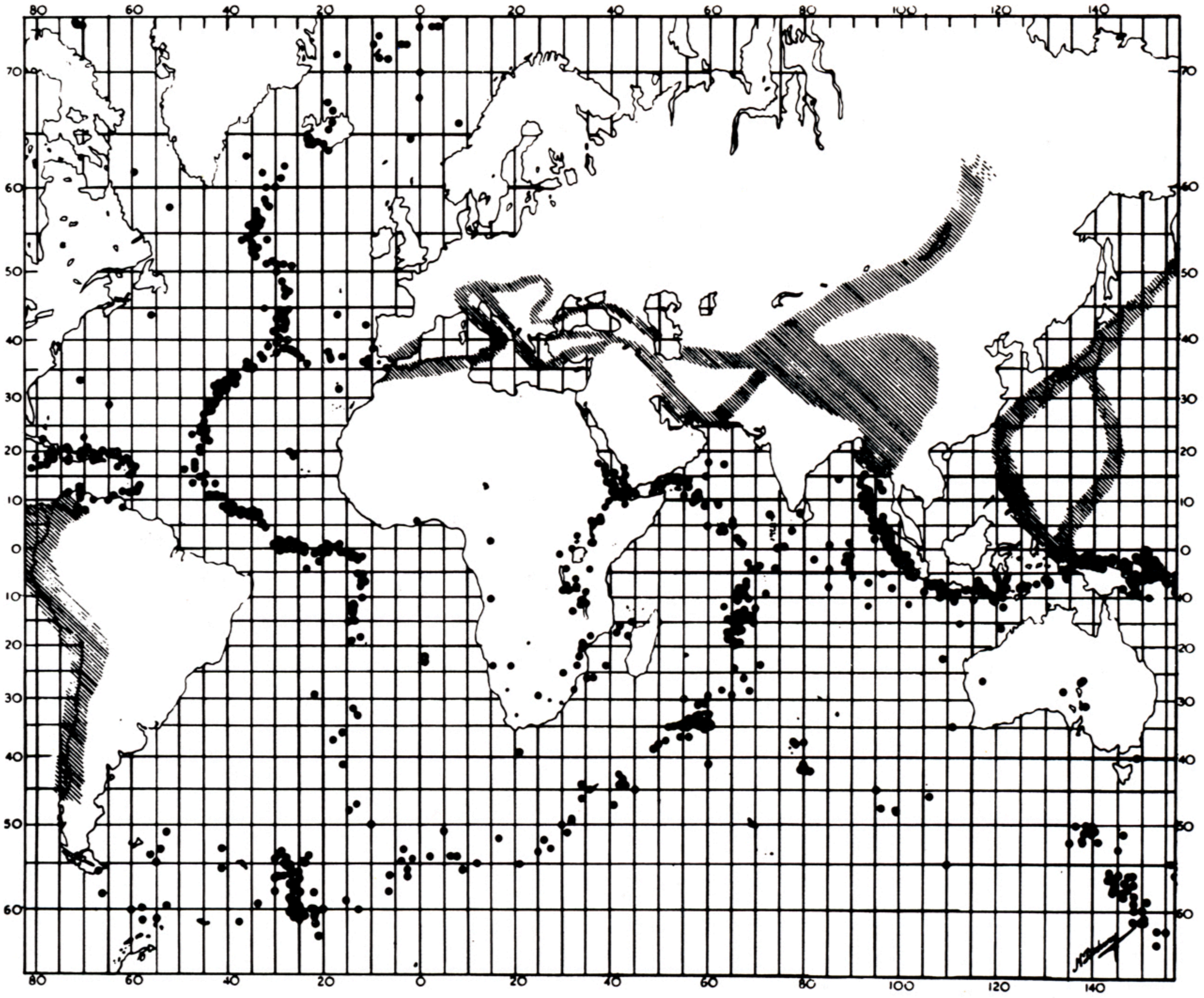
Expanding Earthers	continental crust is rigid-elastic	ocean basins are young	S. Warren Carey
Contracting Earthers	continental crust is rigid-elastic	ocean basins are old	Byerly, Jeffries

Contraction of the earth

Most theories of the origin of the earth assume that it has cooled from a molten mass. It is now solid, that is, possesses rigidity, at least as deep as its core at depth 2,900 kilometers, as is shown by the free transmission of shear waves to this depth. (The radius of the earth is about 6,370 kilometers.) Cooling of a mass as large as the earth is a slow process.

... it is apparent that the temperature is considerably higher below the crust than in it, and a failure of strength in rocks below the crust would not be surprising, although it is not known as yet how far the effect of higher temperature toward lowering the strength is counteracted by the effect of the high pressures toward increasing the strength.

Perry Byerly, 1942, Seismology, p. 41 & 43



Jean-Pierre Rothé's map of (almost) global seismicity from 1920 through 1950, published in 1953.

This map was created before there was a global seismograph network, from records that were analyzed manually.

It shows the line of earthquakes along the axis of the mid-ocean ridges — a feature that had not yet been shown in a published global map.

ten years later…

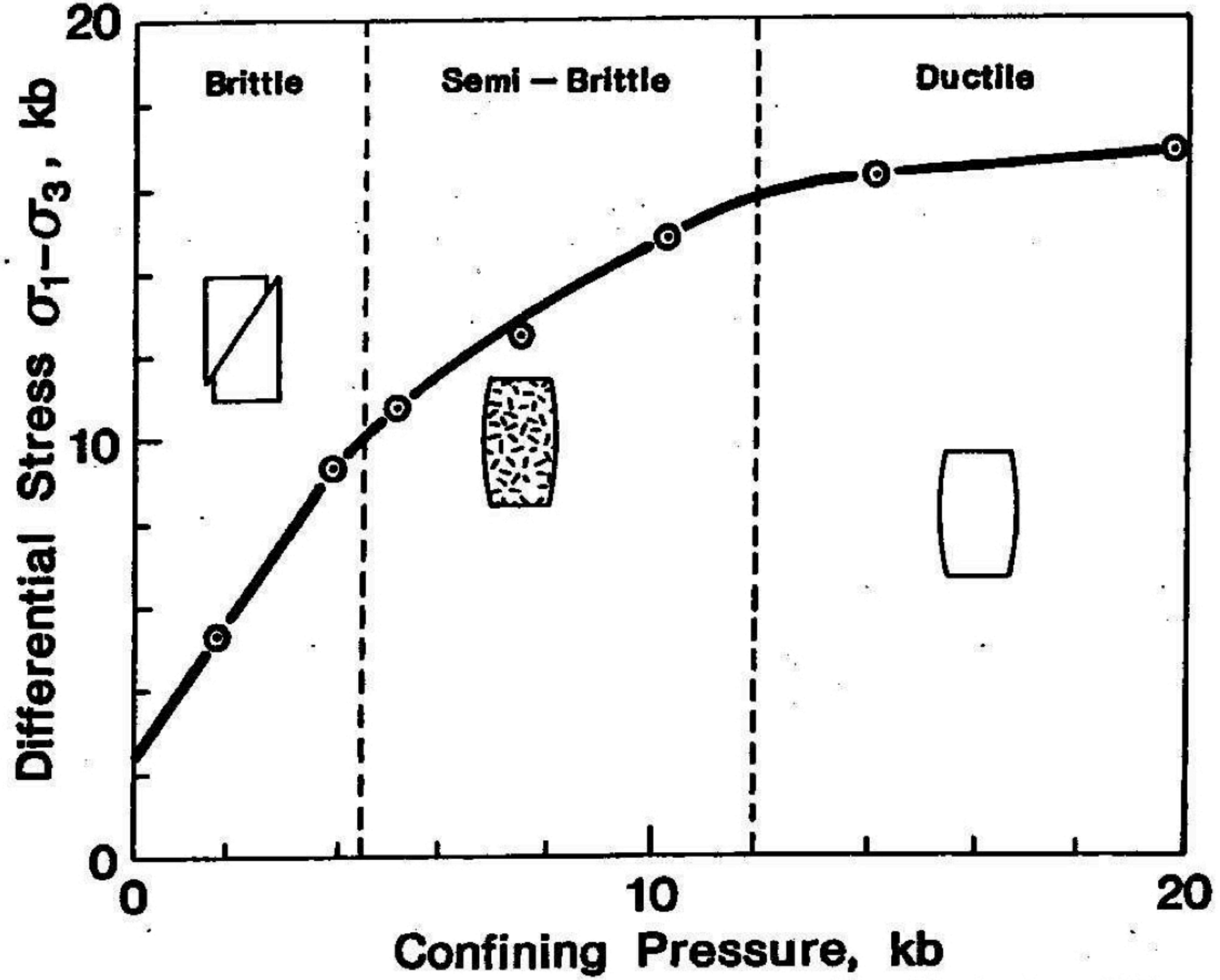
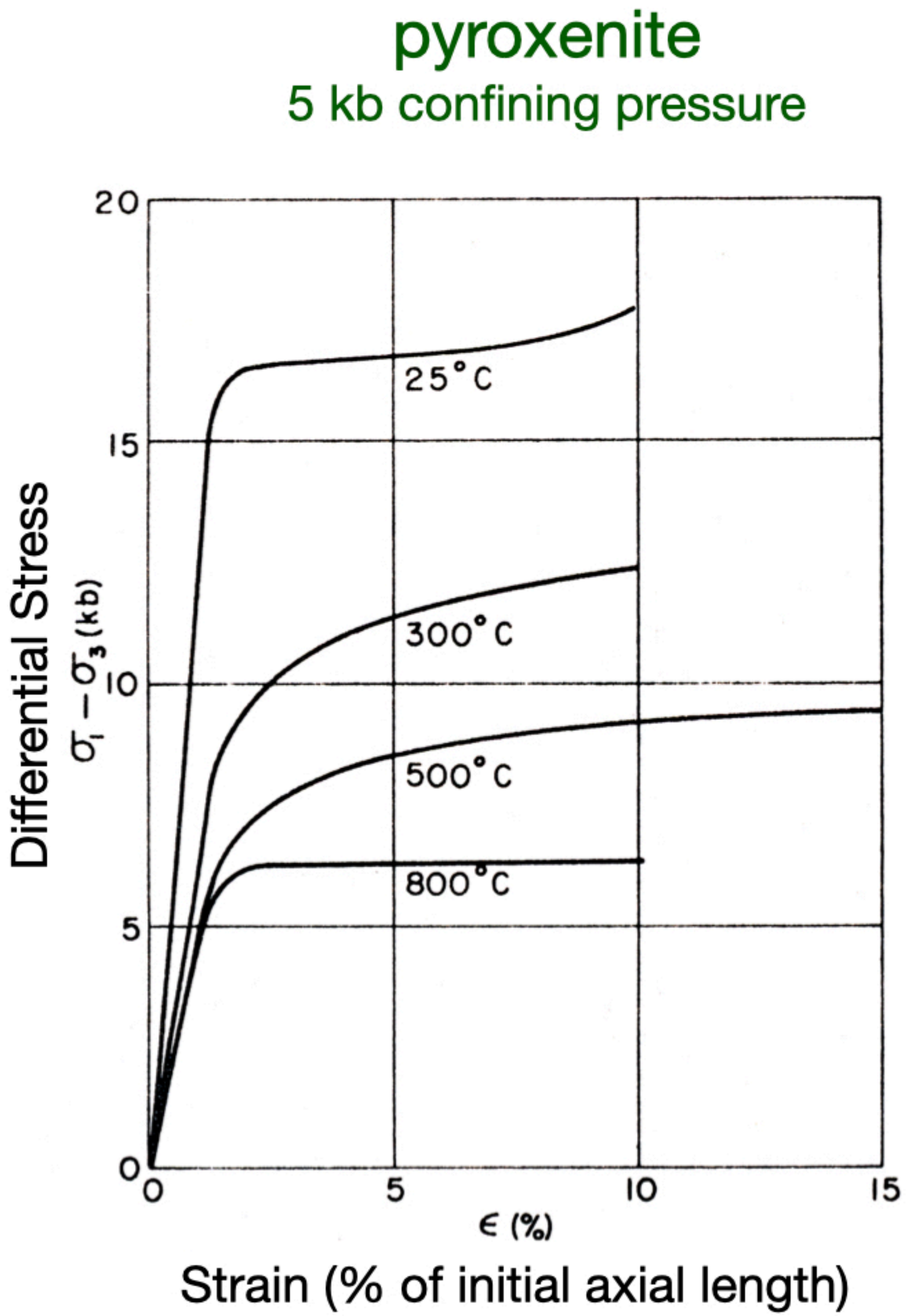
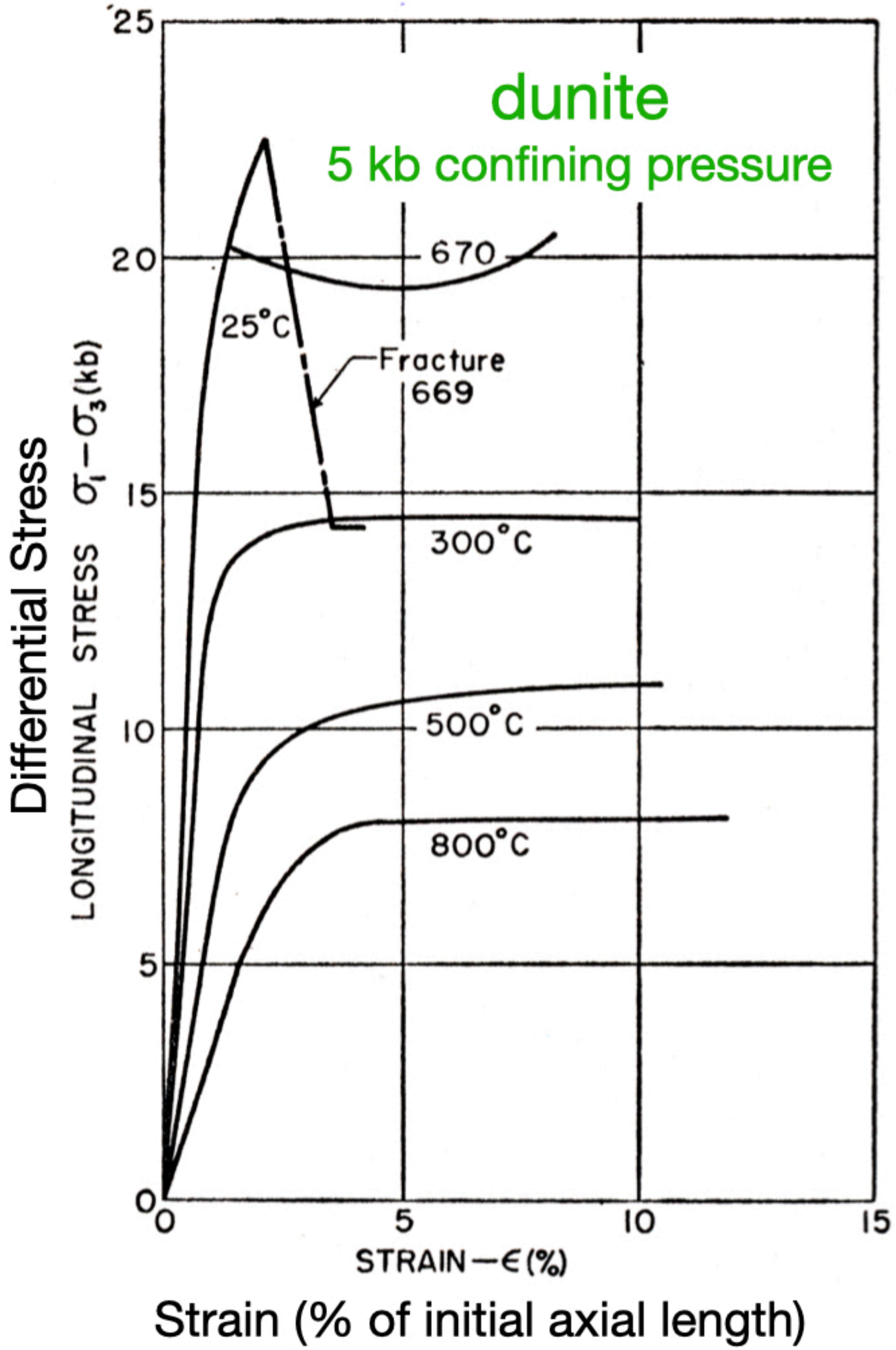


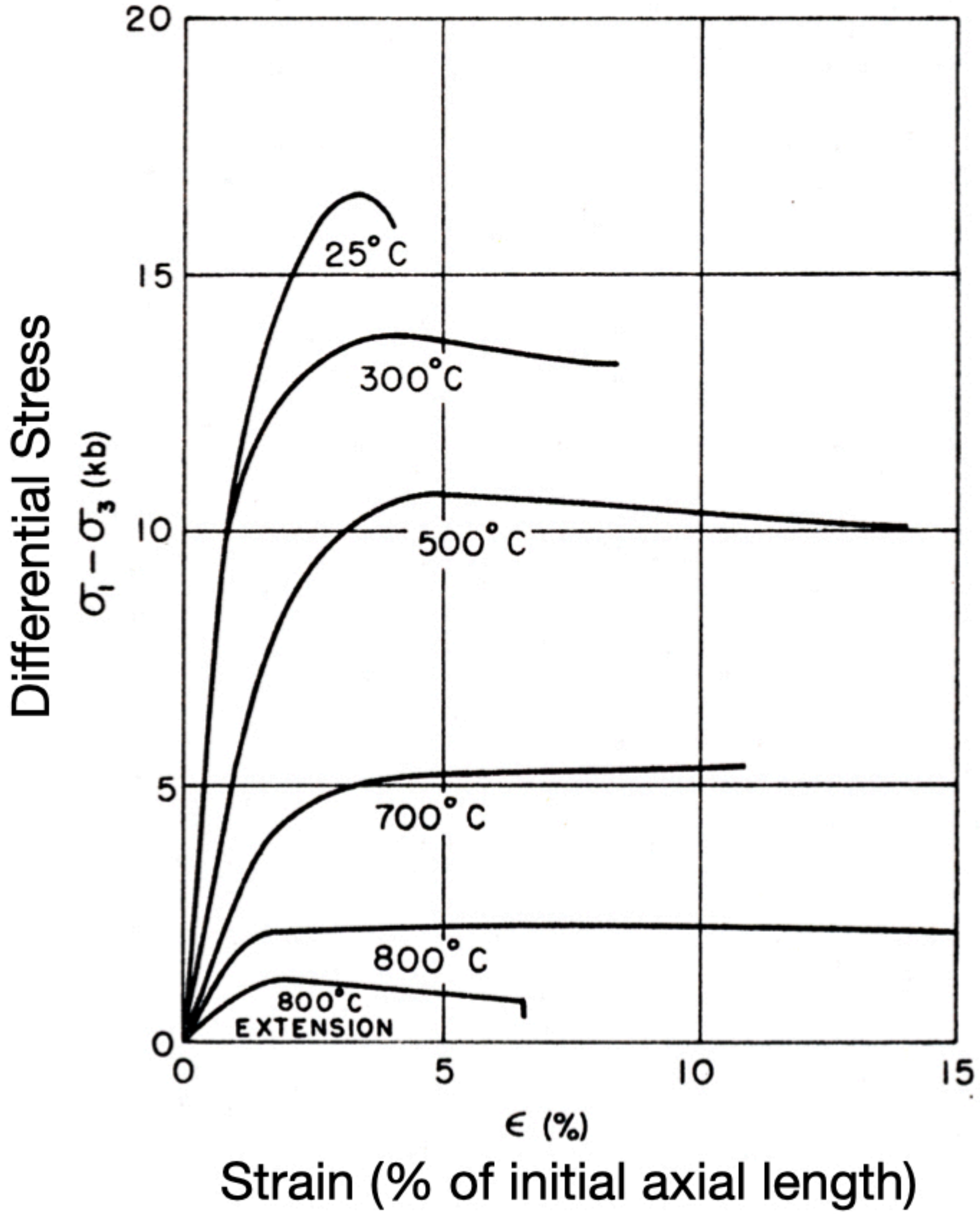
Figure 6-10 Brittle-to-ductile transition of pyroxenite. Effect of confining pressure on the strength of Sleaford Bay clinopyroxenite tested in triaxial compression. *(After Kirby, 1980.)*



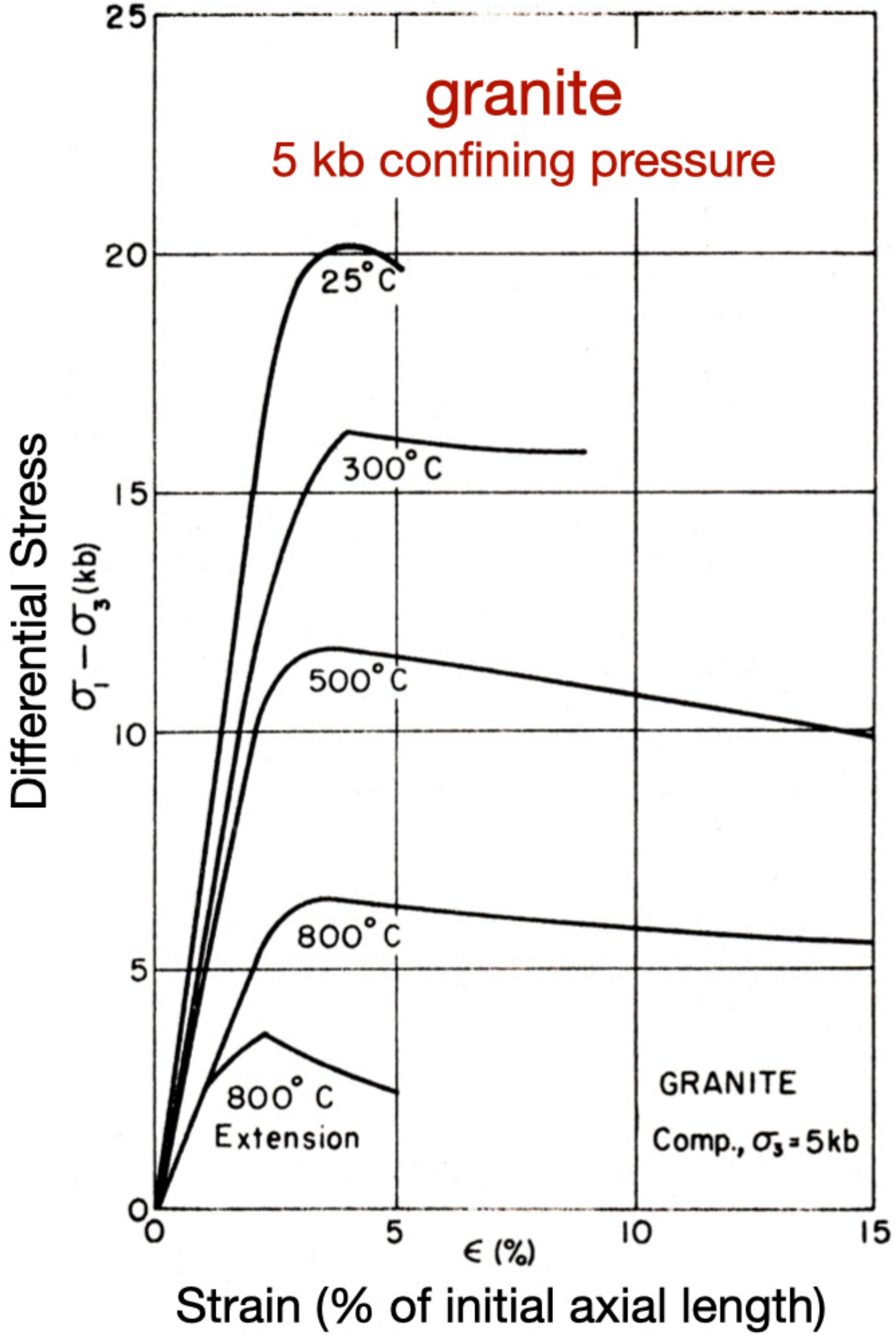


Griggs, Turner, and Heard, 1960

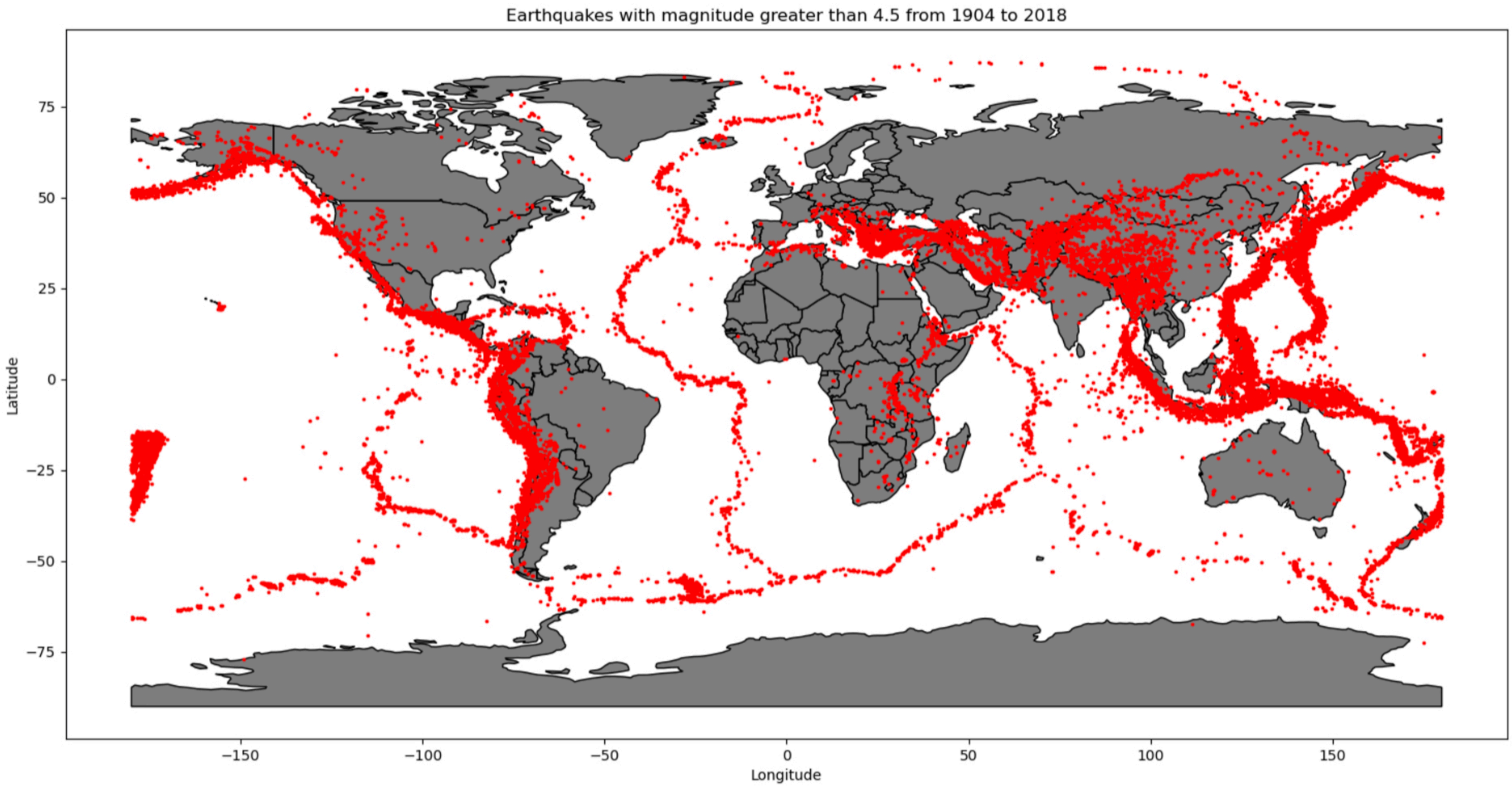
basalt
5 kb confining pressure



granite
5 kb confining pressure



Griggs, Turner, and Heard, 1960



https://github.com/haceru/Earthquakes_1904-2018

The Global Geoscience Tribes in Late 1967

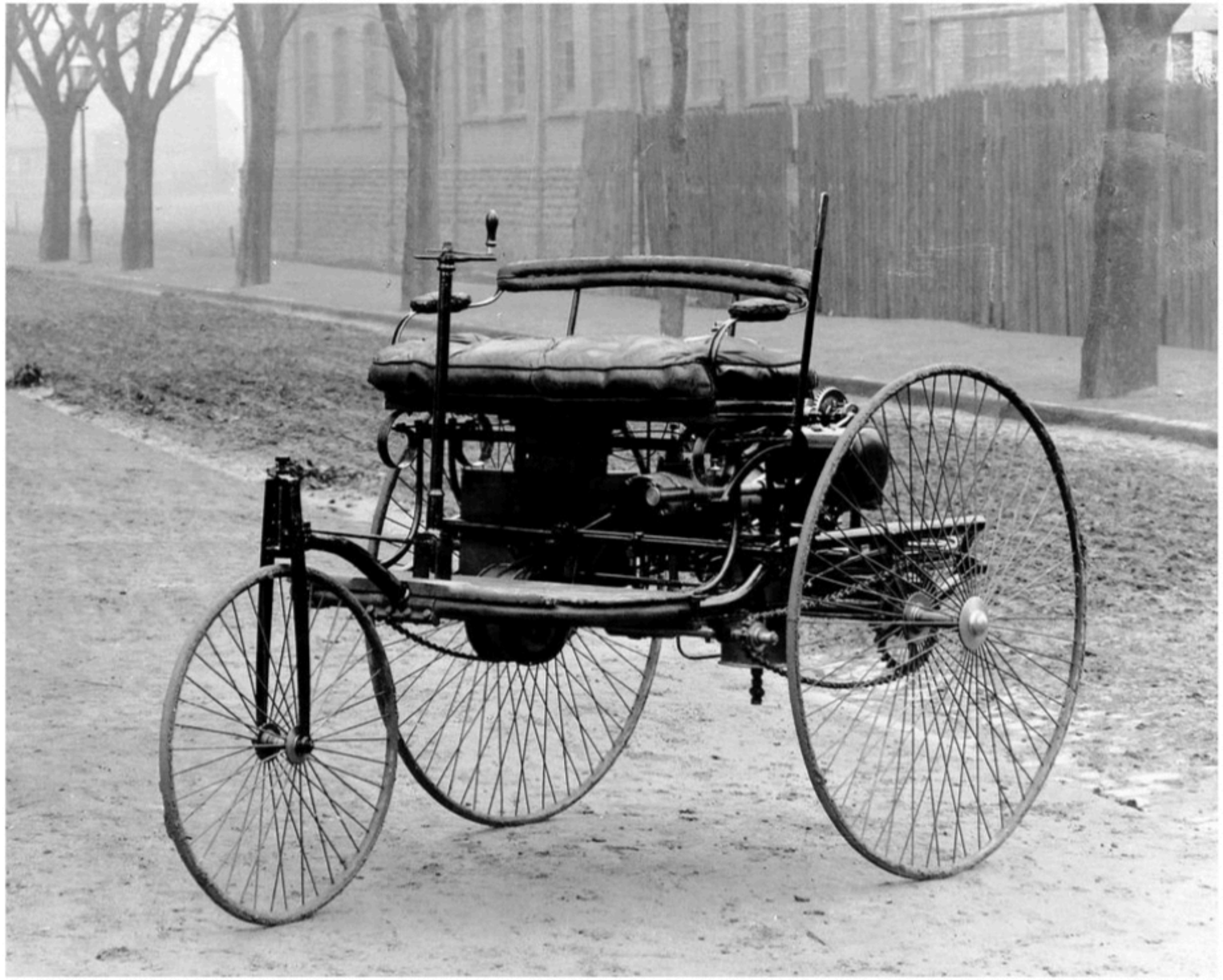
Tribe	Crust is…	Ocean Basin Age	Exemplars
Fixists	entire crust (and mantle) is rigid	ocean basins are old	AAPG
Plate Tectonicists	Crust (continental and oceanic) and rigid-elastic uppermost mantle form lithospheric plates that move across Earth's surface.	Ocean basins are young (<~190 Myr) and change over time through subduction and seafloor spreading.	Bullard, Hess, Wilson, Dietz, Tharp, Mason, Pitman, Opdyke, Morley, Vine, Morgan, McKenzie, LePichon, Cox, Sykes, Heirtzler, Oliver, Isacks

Plate tectonics was a major paradigm shift in the solid-Earth geosciences.

This was a profound revolution that led to great progress in our understanding of Earth.

A revolution in transportation

Irish jaunting car
circa 1865-1903



1885 Benz Motorwagen
gasoline engine, 0.8 hp

A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.

Max Planck
A Scientific Autobiography

The difficulty lies not so much in developing new ideas as in escaping from old ones.

John Maynard Keynes

INCORPORATED RESEARCH INSTITUTIONS FOR SEISMOLOGY

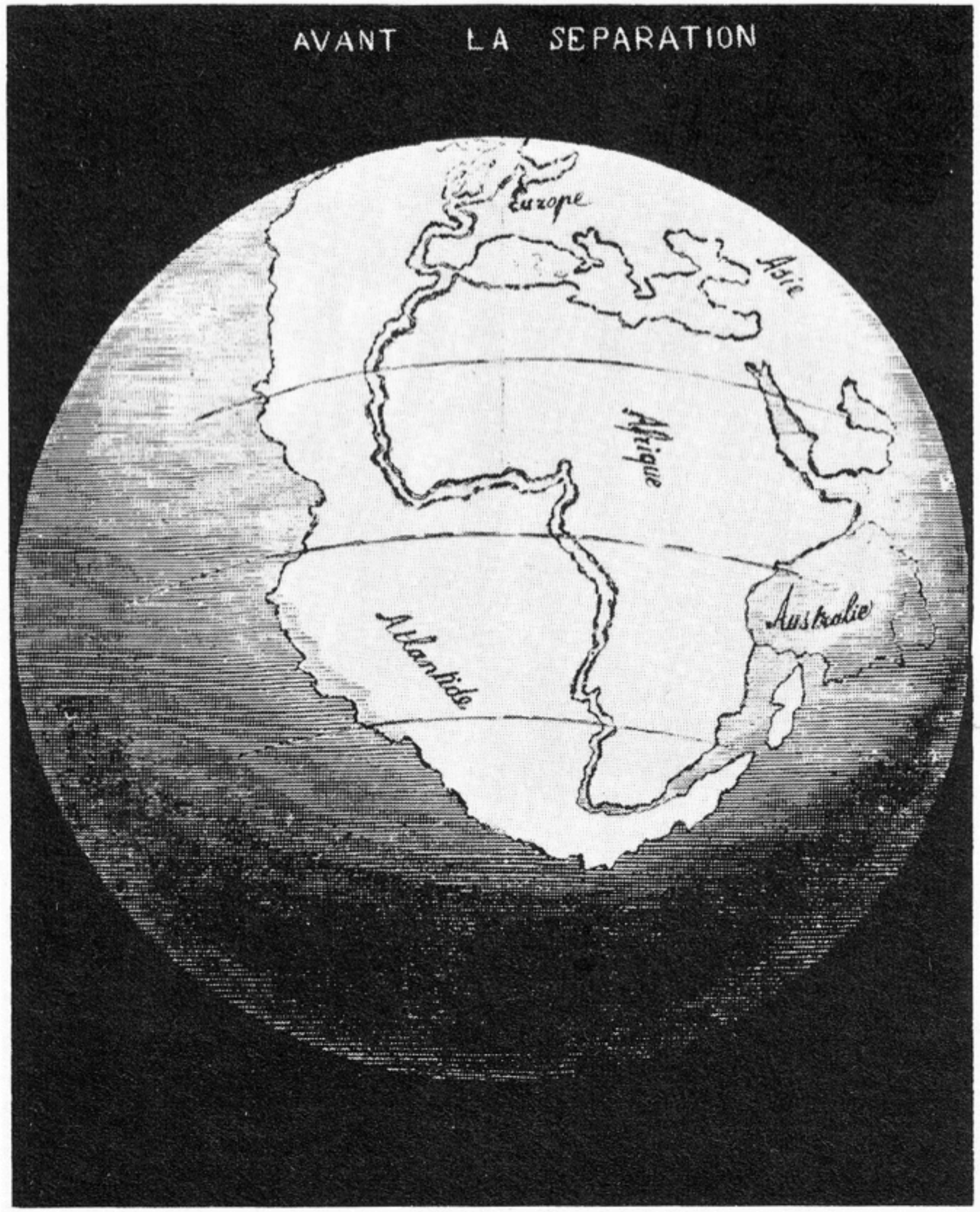
Plate Boundaries

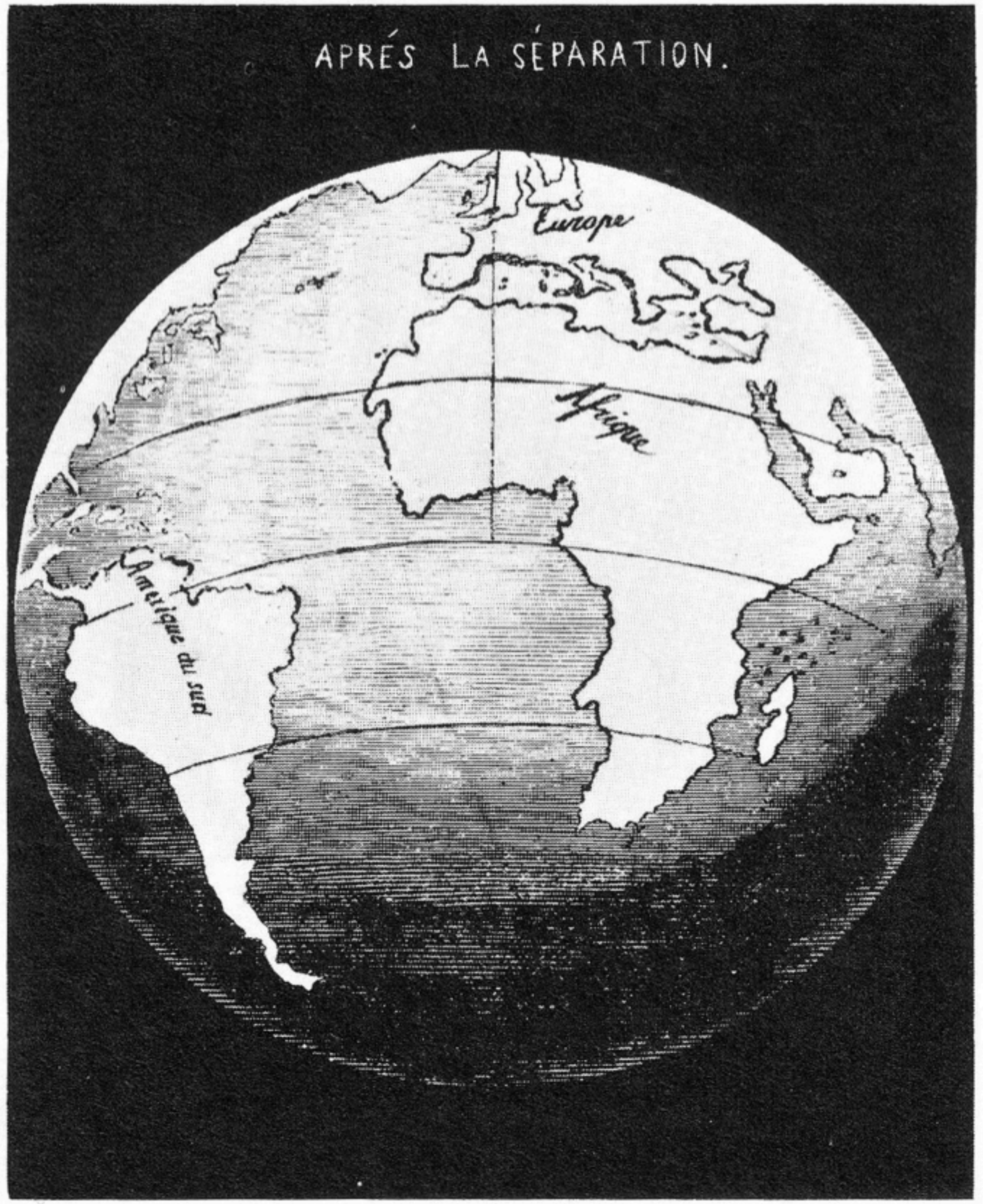
What are the tectonic (lithospheric) plates?

www.iris.edu/earthquake

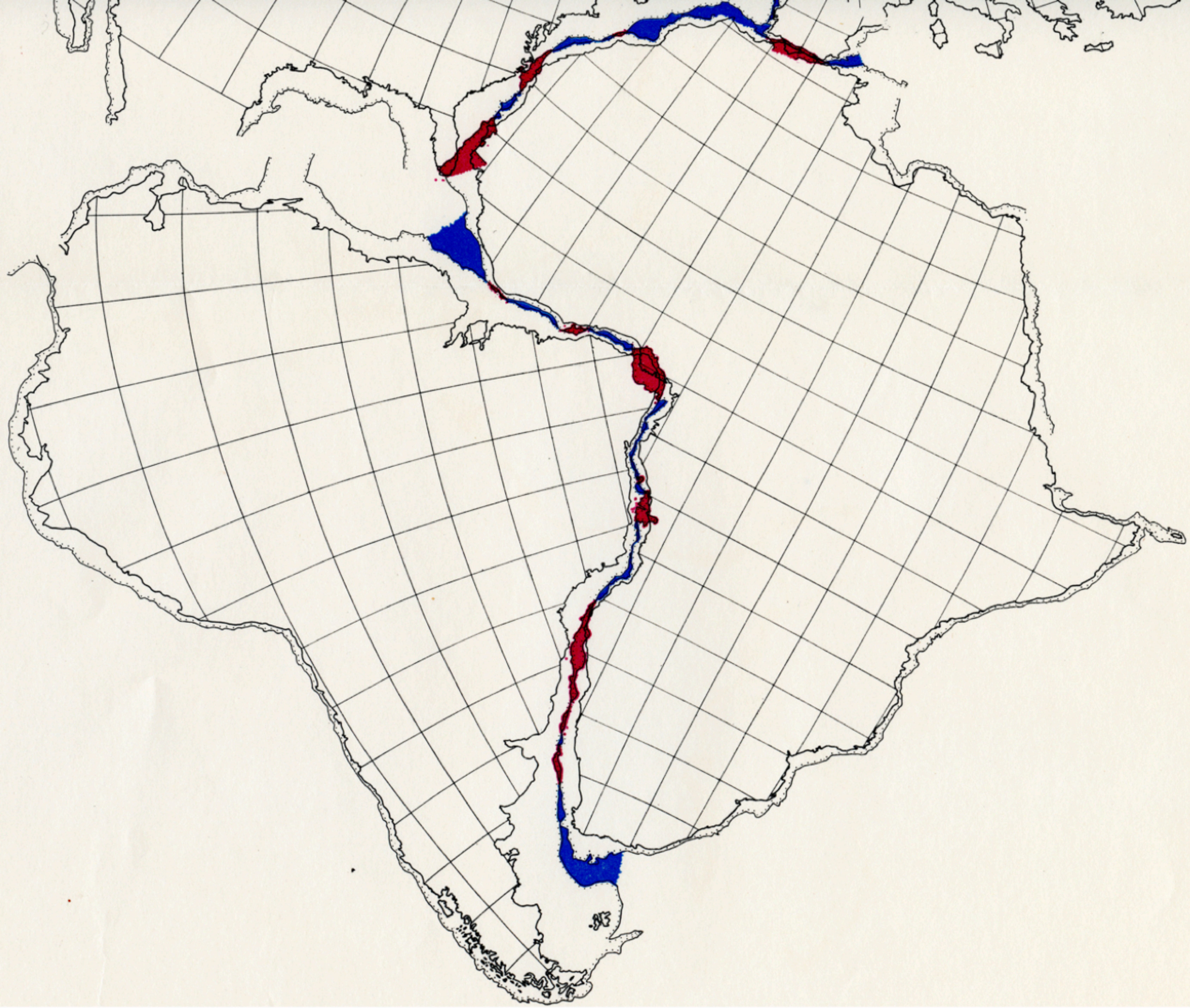
Plate tectonics was clearly defined as a **kinematic** theory, one that is concerned with geometry. It is not a **dynamic** theory: one that is concerned with the driving forces.

Dan McKenzie, 2001





Antonio Snider-Pelligrini (1858)

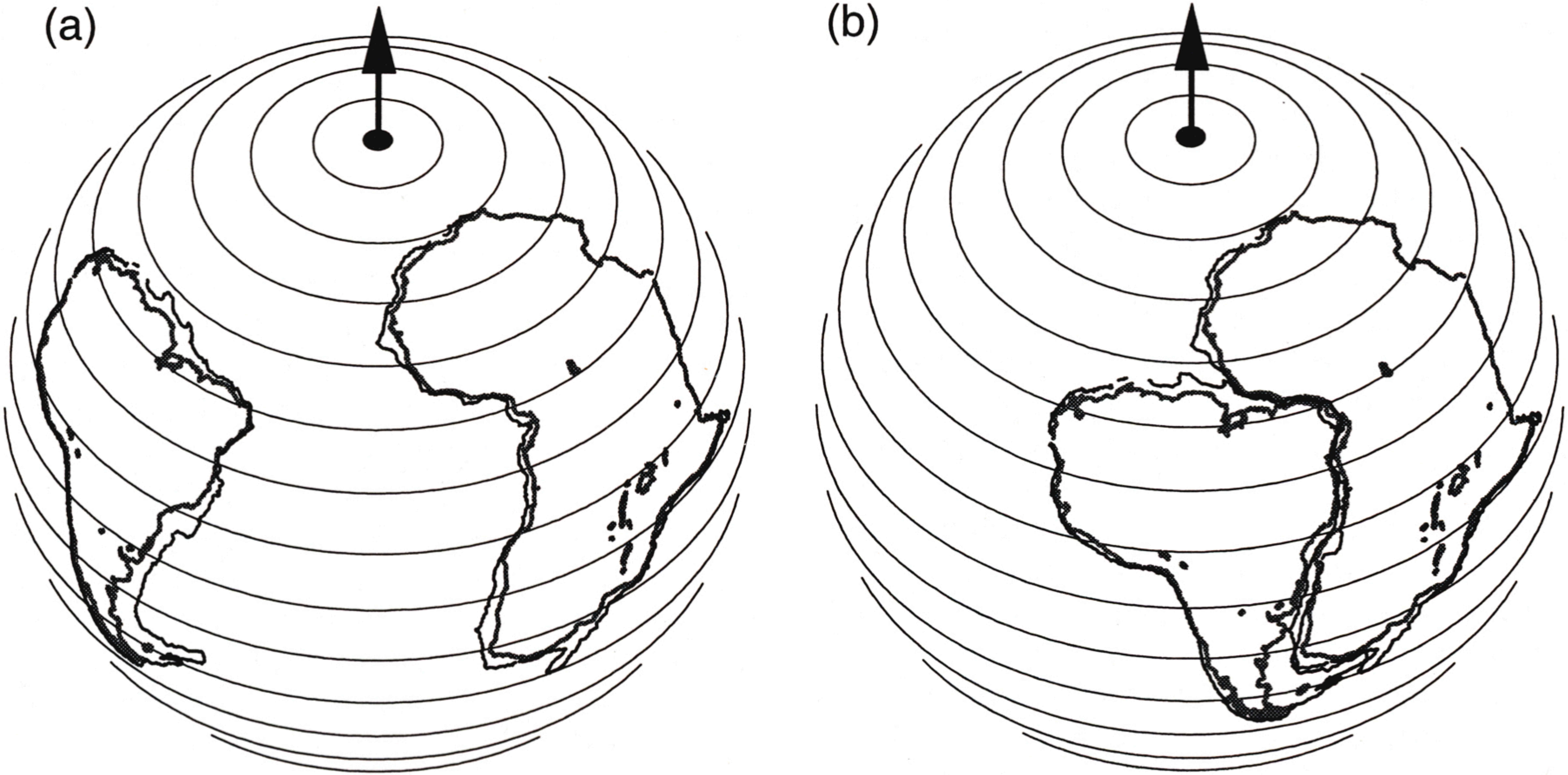


The fit of the continents around the Atlantic.

by Edward Bullard,
J.E. Everett and
A. Gilbert Smith

Philosophical Transactions of the Royal Society, London, no. 1088, 1965

Fit of South America and Africa by rotation around the total-opening Euler axis/pole



McKenzie, 2001, after Bullard et al., 1965

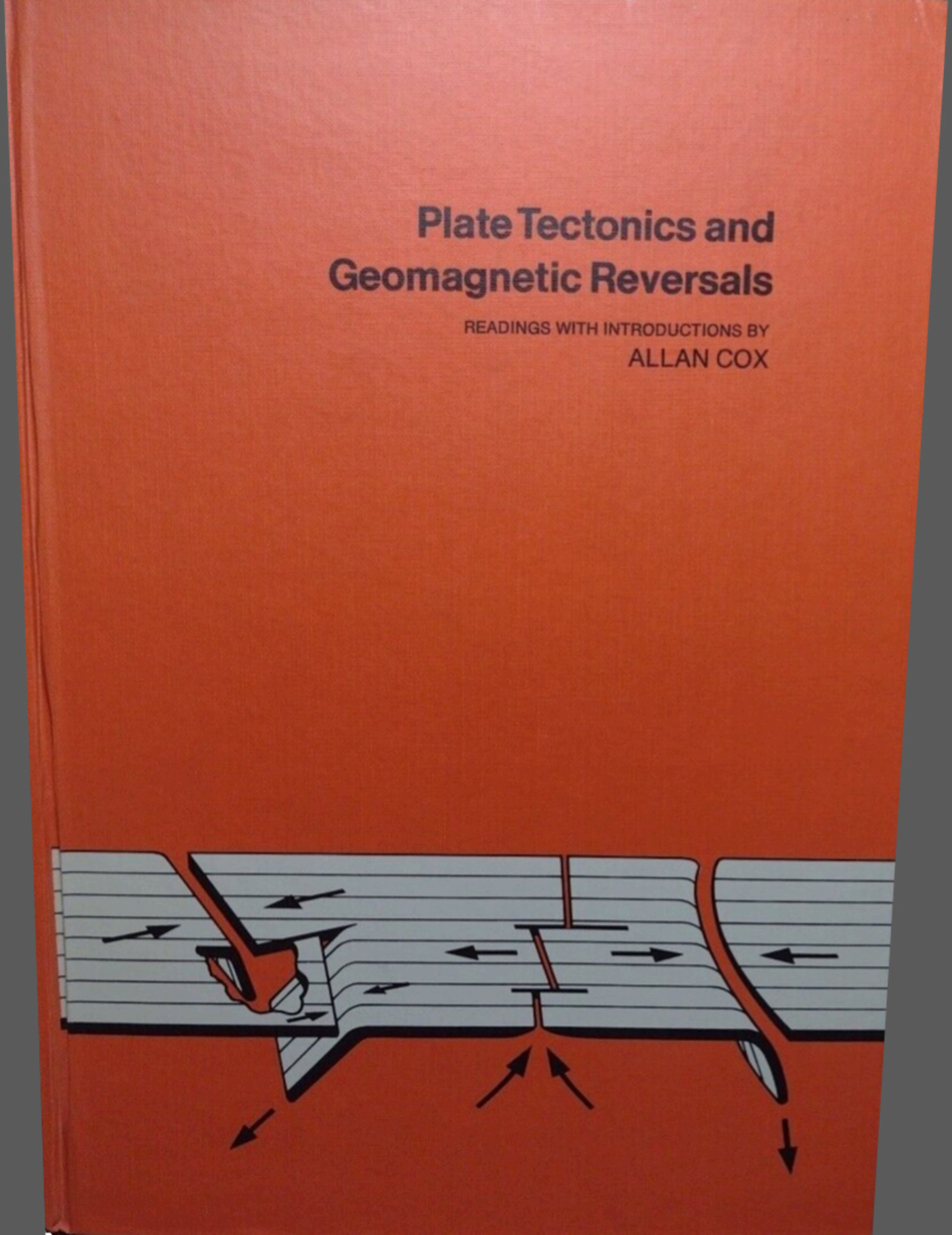
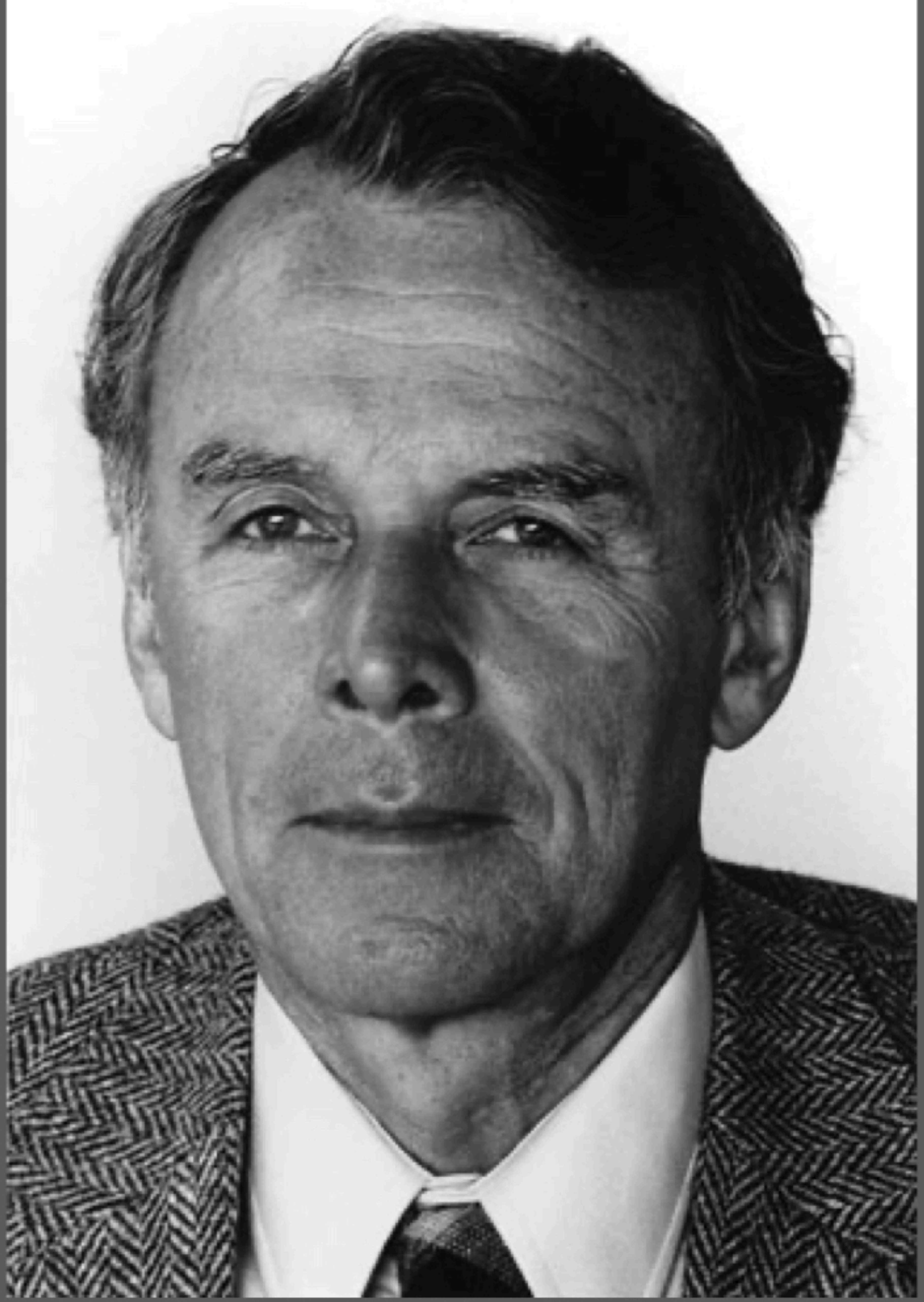


Plate Tectonics and
Geomagnetic Reversals
READINGS WITH INTRODUCTIONS BY
ALLAN COX



Allan Cox

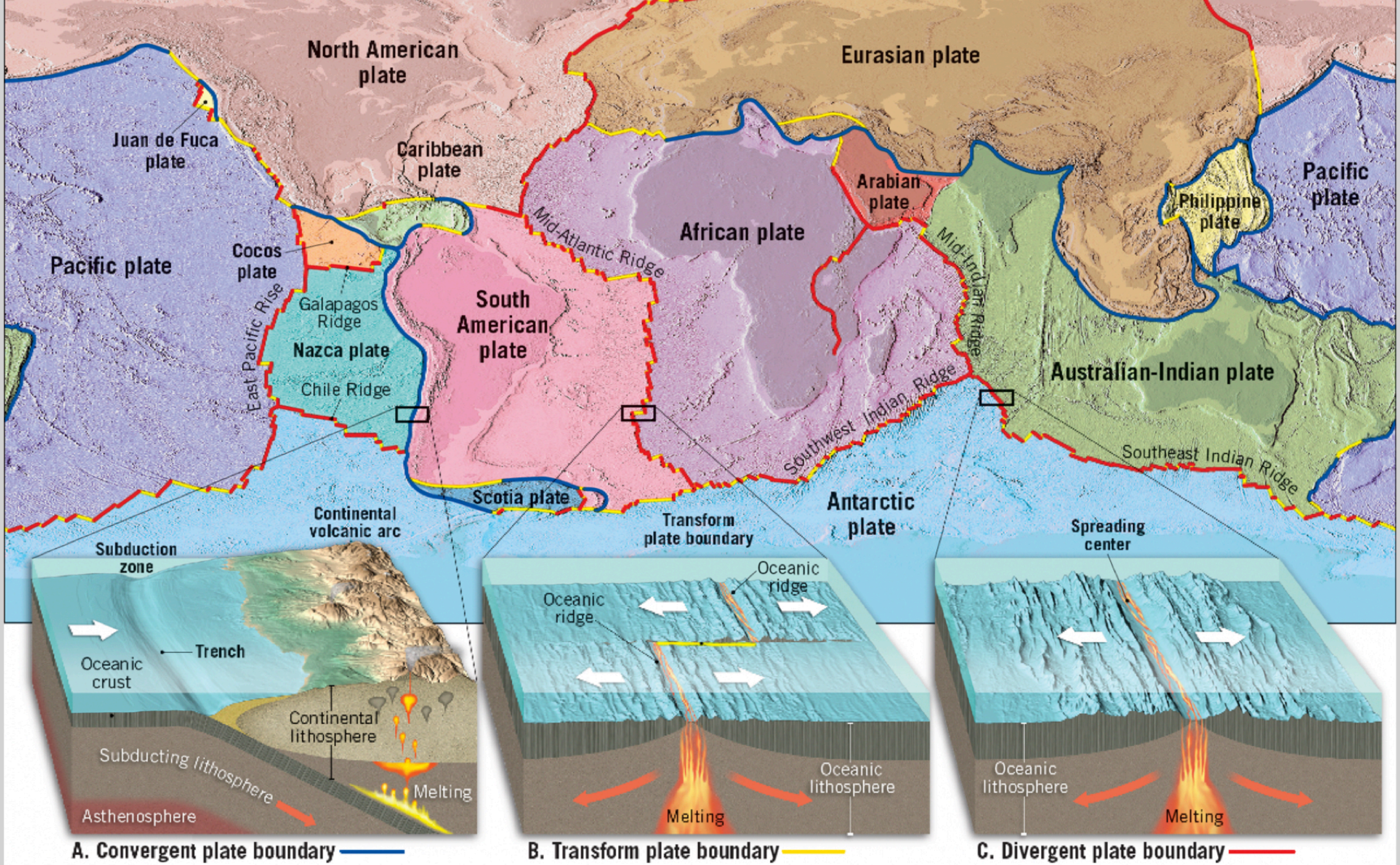
Postulate 1: [Lithospheric] plates are internally rigid but are uncoupled from each other. At their boundaries two plates may pull apart or slip one beneath the other, but within the plates there is no deformation.

Postulate 2: The pole of relative motion between a pair of plates remains fixed relative to the two plates for long periods of time.

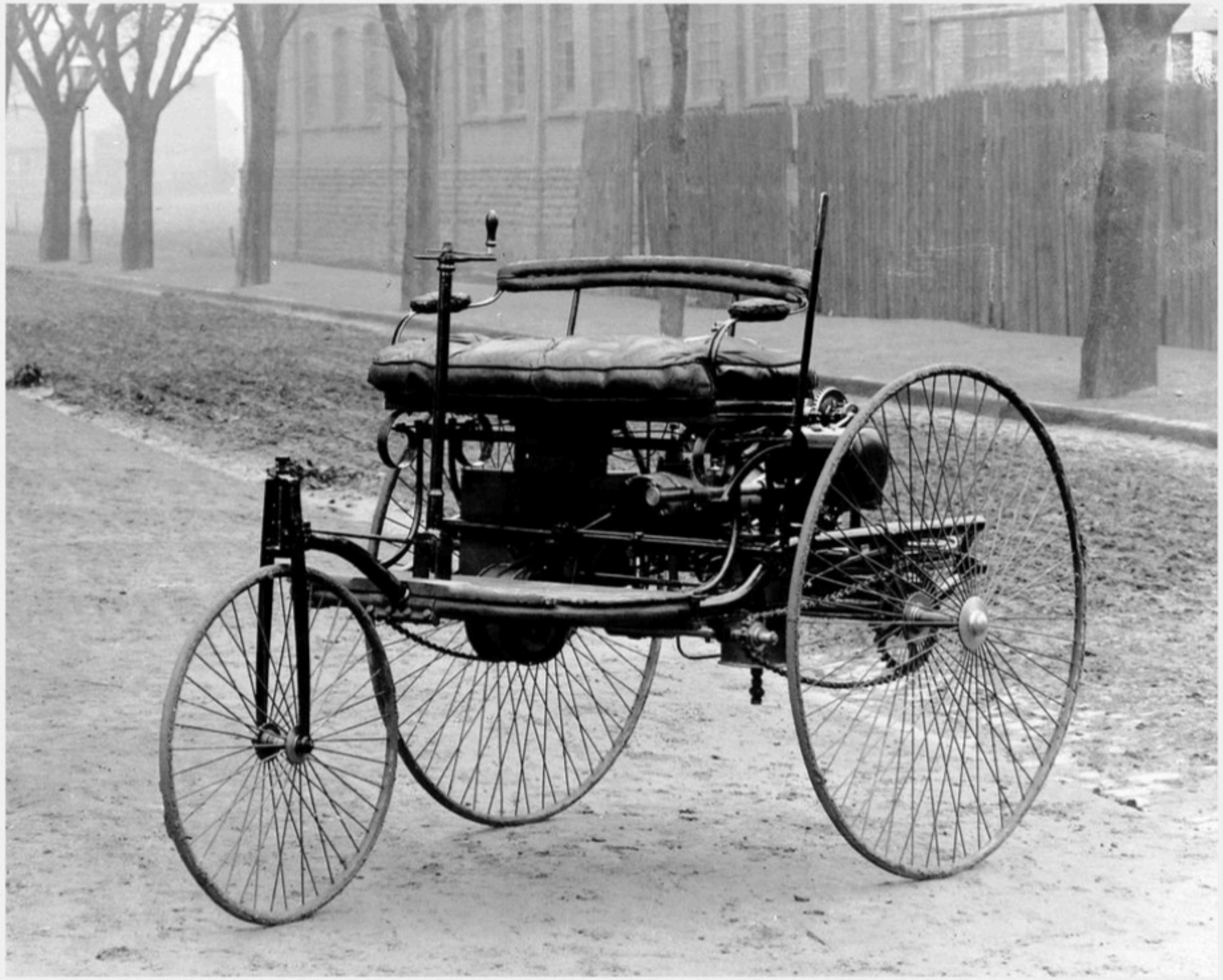
Allan Cox, 1973

For me, the central idea is the rigidity of plate interiors. It is this property that allows the surface motions of the Earth to be described by so few parameters.

Dan McKenzie, 2001



North American plate
Eurasian plate
Juan de Fuca plate
Caribbean plate
Pacific plate
Arabian plate
Philippine plate
Pacific plate
African plate
Cocos plate
Mid-Atlantic Ridge
Mid-Indian Ridge
Galapagos Ridge
South American plate
East Pacific Rise
Nazca plate
Australian-Indian plate
Chile Ridge
Southwest Indian Ridge
Southeast Indian Ridge
Scotia plate
Antarctic plate
Continental volcanic arc
Transform plate boundary
Spreading center
Subduction zone
Oceanic ridge
Oceanic ridge
Trench
Oceanic crust
Continental lithosphere
Subducting lithosphere
Melting
Asthenosphere
Oceanic lithosphere
Melting
Oceanic lithosphere
Melting
A. Convergent plate boundary
B. Transform plate boundary
C. Divergent plate boundary

First Generation	Current Generation
	
1885 Benz Motorwagen gasoline engine, 0.8 hp	**2024 Honda Prologue EV** electric engine, 288 hp


Nevada
Utah
Arizona
Calif.
GPS velocity vectors relative to the NAM14 reference frame
20 mm/yr
Zeng, 2022

We now know that there are places on Earth where the crust of the plate interior is deforming.

Other places, the crust of the plate interior is essentially rigid.

Postulate 1 is not universally valid.

Postulate 1: [Lithospheric] plates are internally rigid but are uncoupled from each other. At their boundaries two plates may pull apart or slip one beneath the other, but within the plates there is no deformation.

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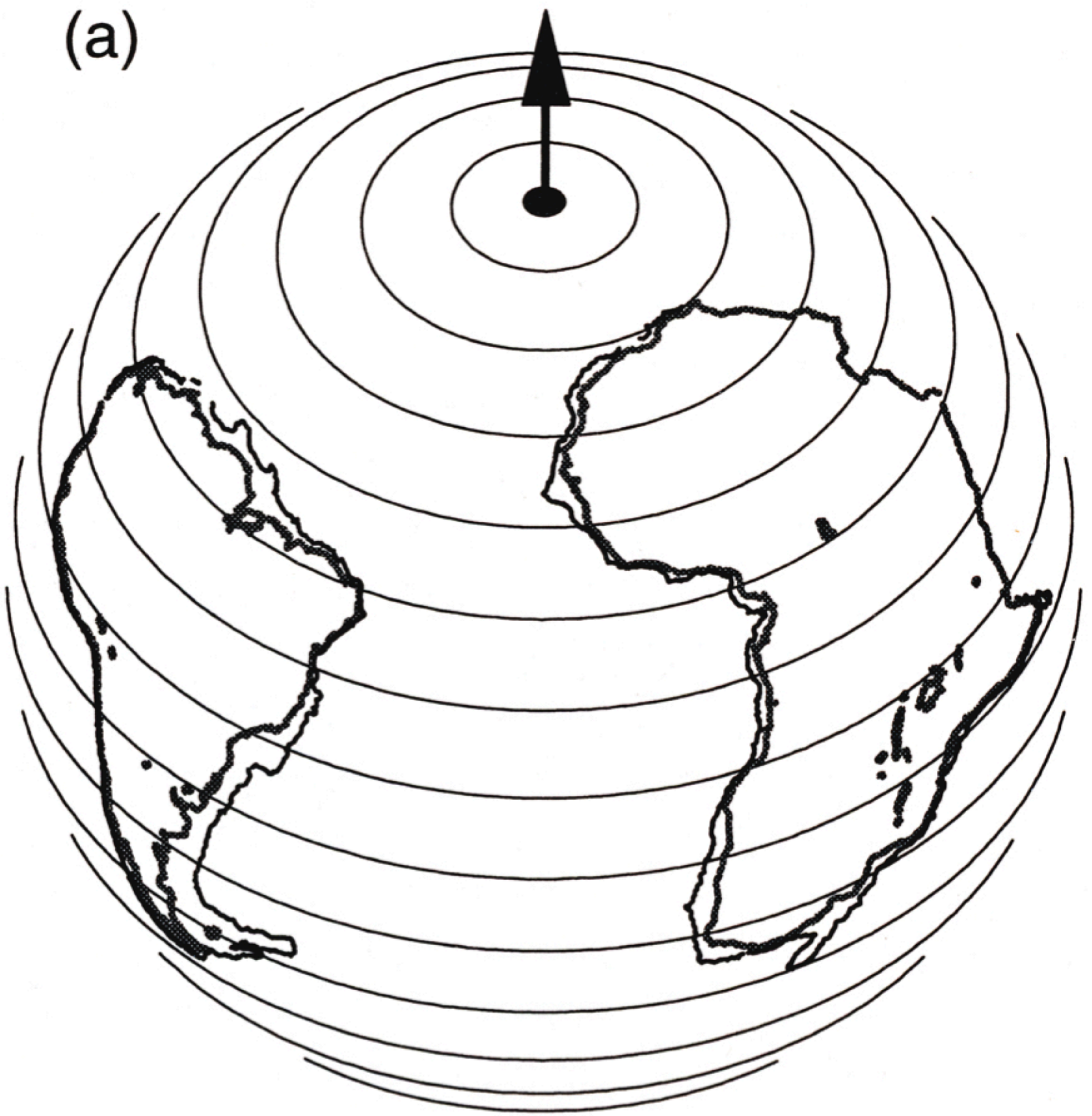

McKenzie, 2001, after Bullard et al., 1965

It seems to me unlikely that plate tectonics will require changes. It is a precisely formulated theory that provides an accurate description of the large-scale tectonics of the earth.

Dan McKenzie, 2001

We have known since ~1969 that the pole of relative motion between a pair of plates **cannot remain fixed** relative to the two plates.

Allan Cox called this **the three-plate problem**. (More about this later.)

Postulate 1: [Lithospheric] plates are internally rigid but are uncoupled from each other. At their boundaries two plates may pull apart or slip one beneath the other, but within the plates there is no deformation.

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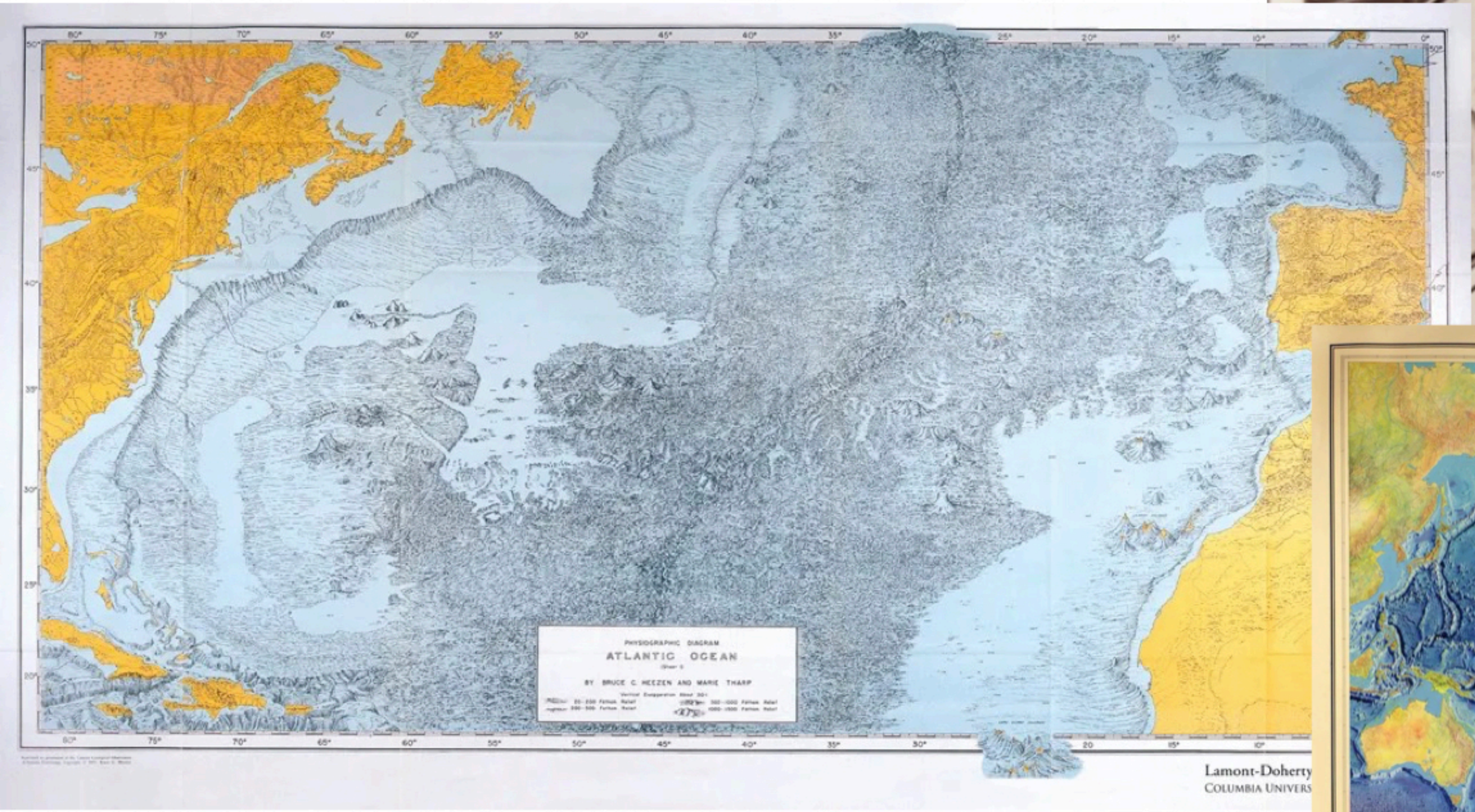
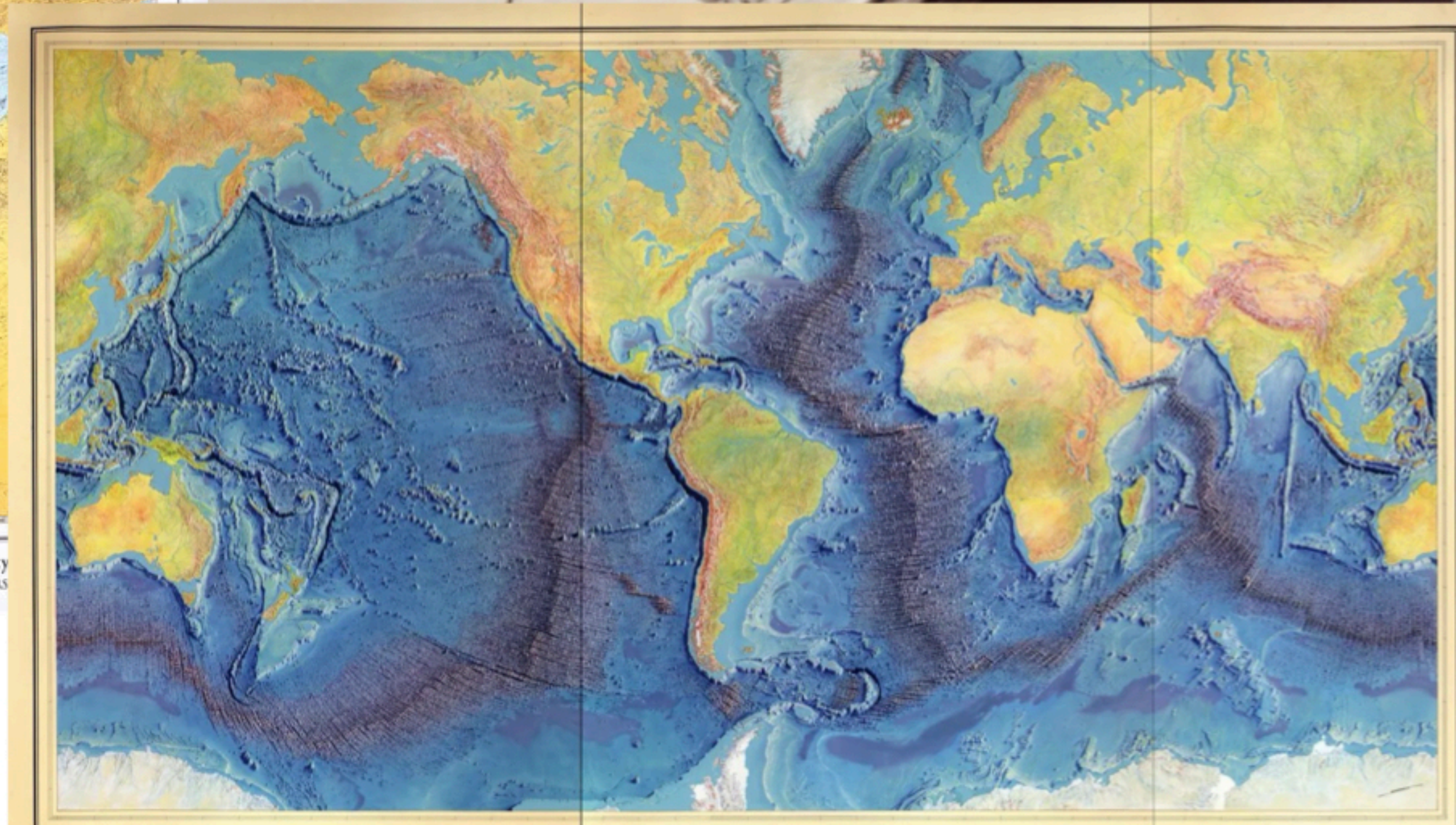
Allan Cox, 1973


Jonathan Kritz

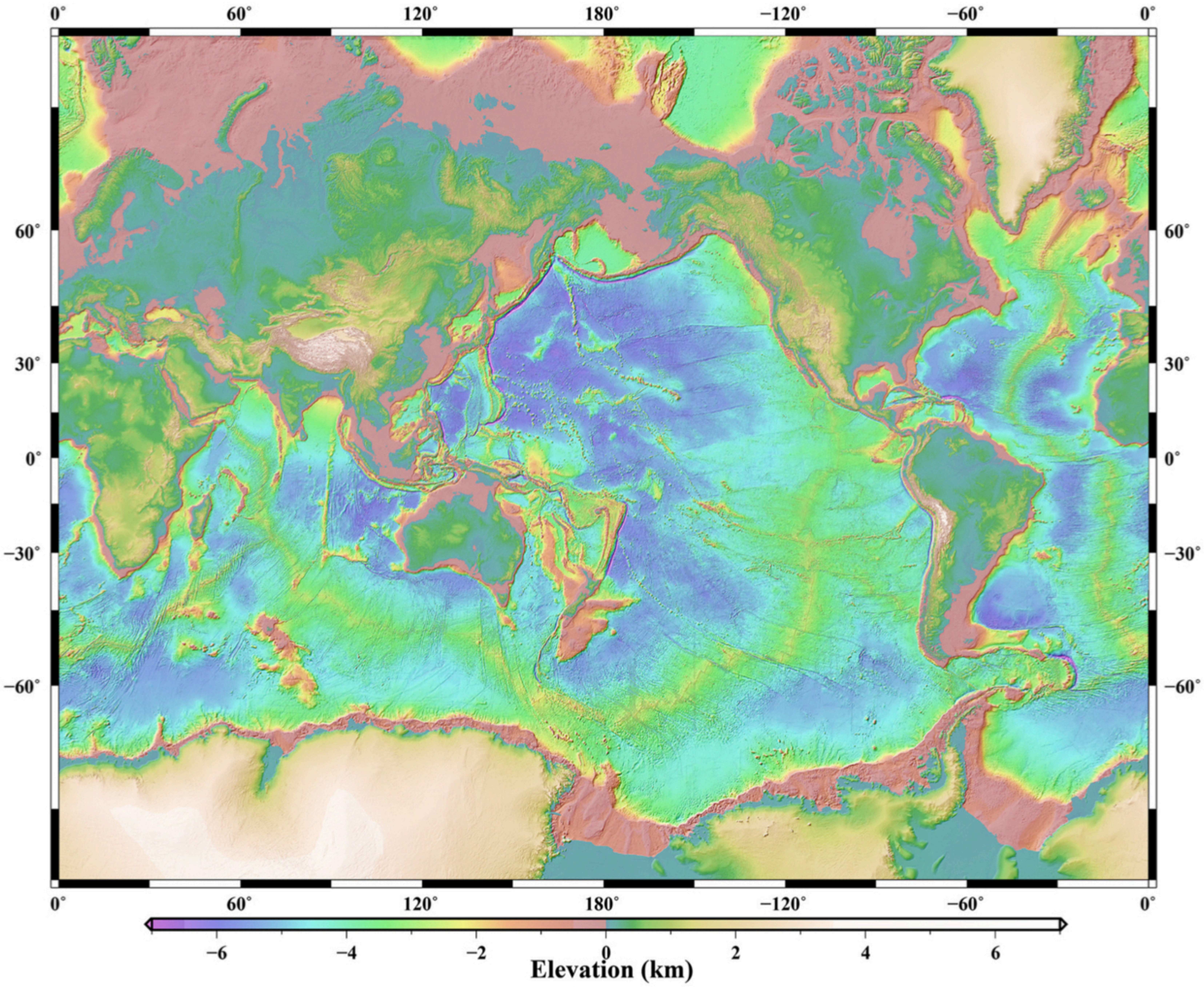
Marie Tharp created the first physiographic maps of the world's oceans, discovered the Axial rift valleys, and was the first to correlate earthquake epicenters with the axial rift.



1957



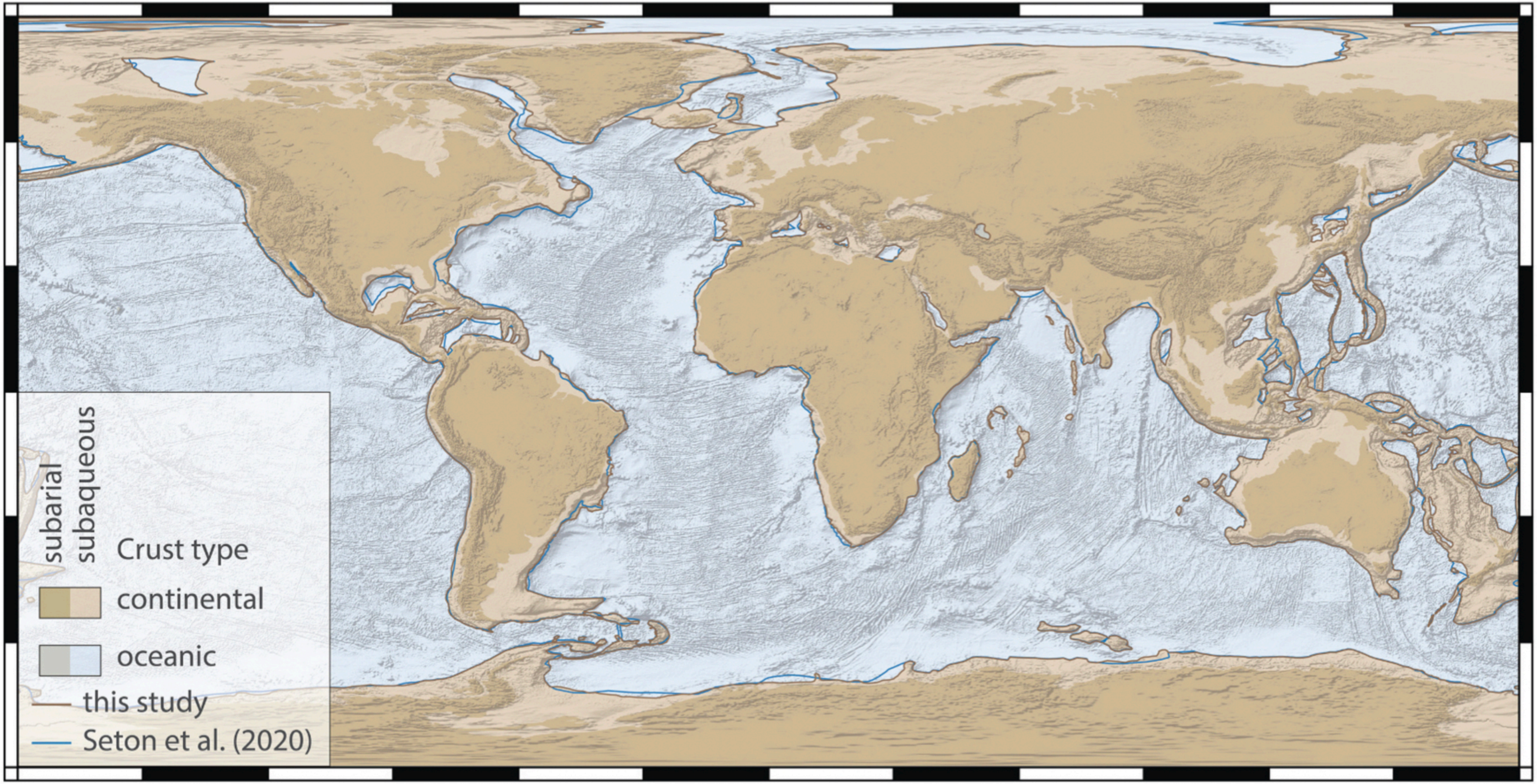
1977



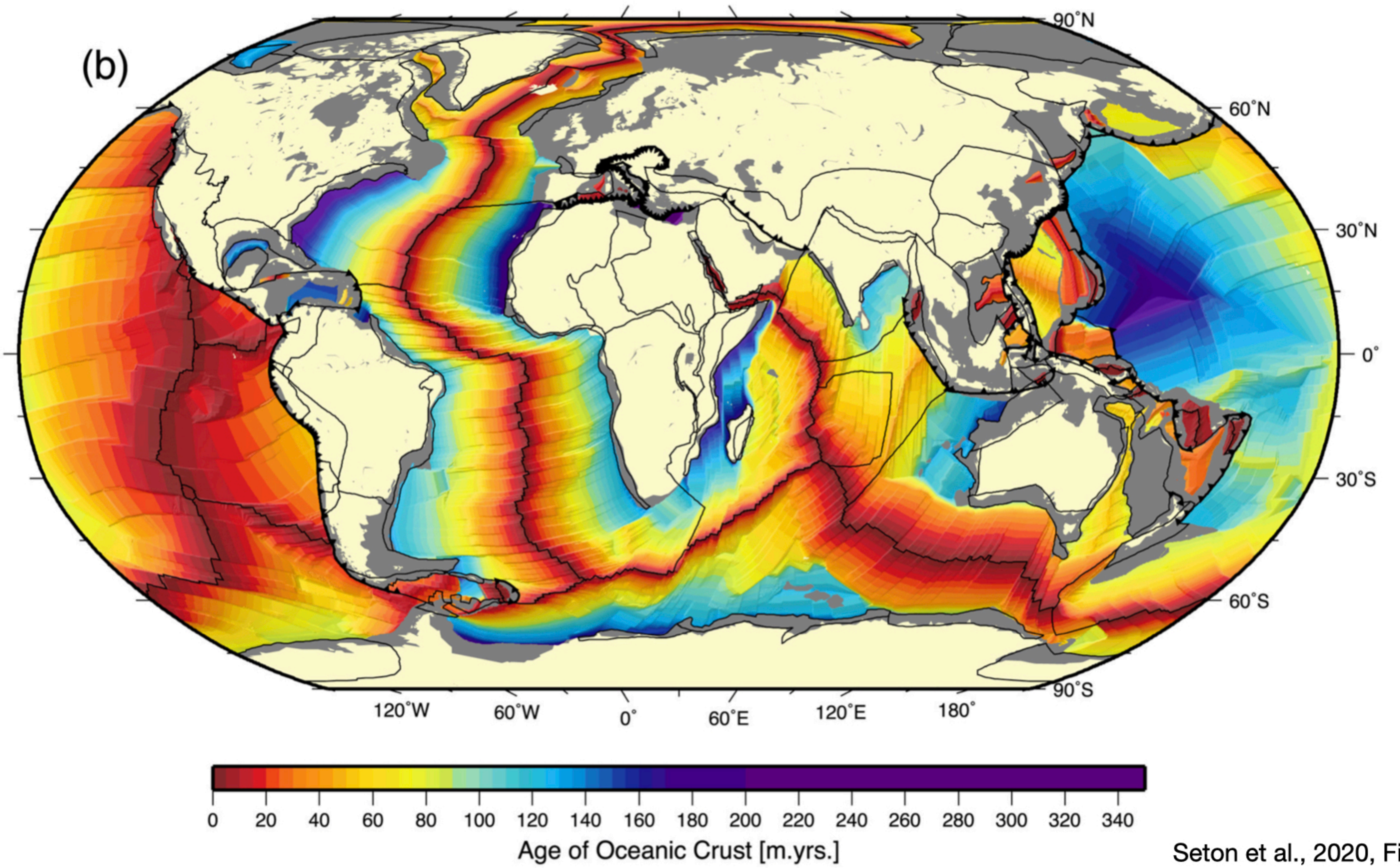
SRTM15Plus map of Earth's topography and bathymetry

Incorporates results from Shuttle Radar Altimetry, satellite laser altimetry, shipborne sonar and multibeam surveys, and land surveys.

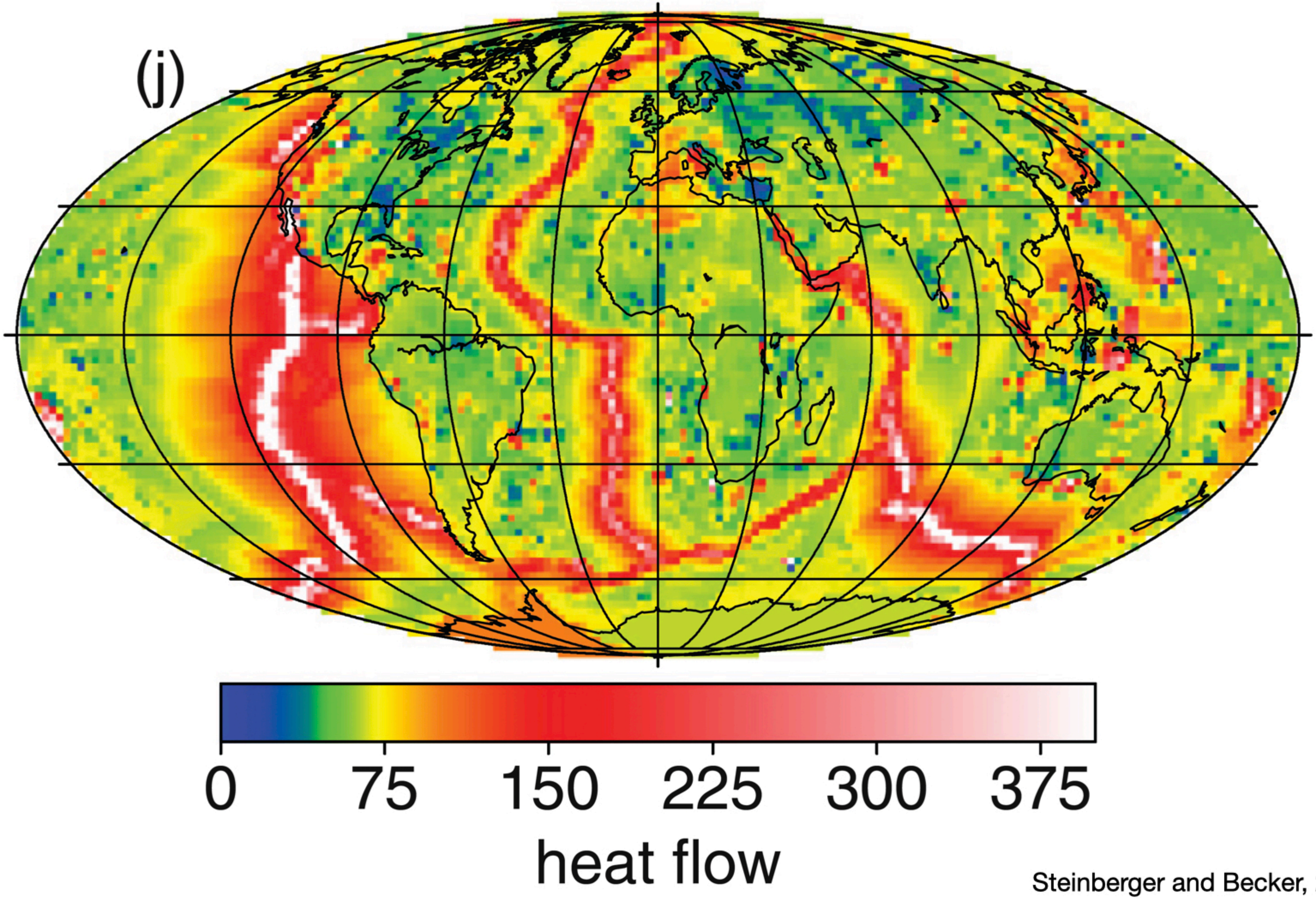
Tozer et al., 2019, Fig. 4



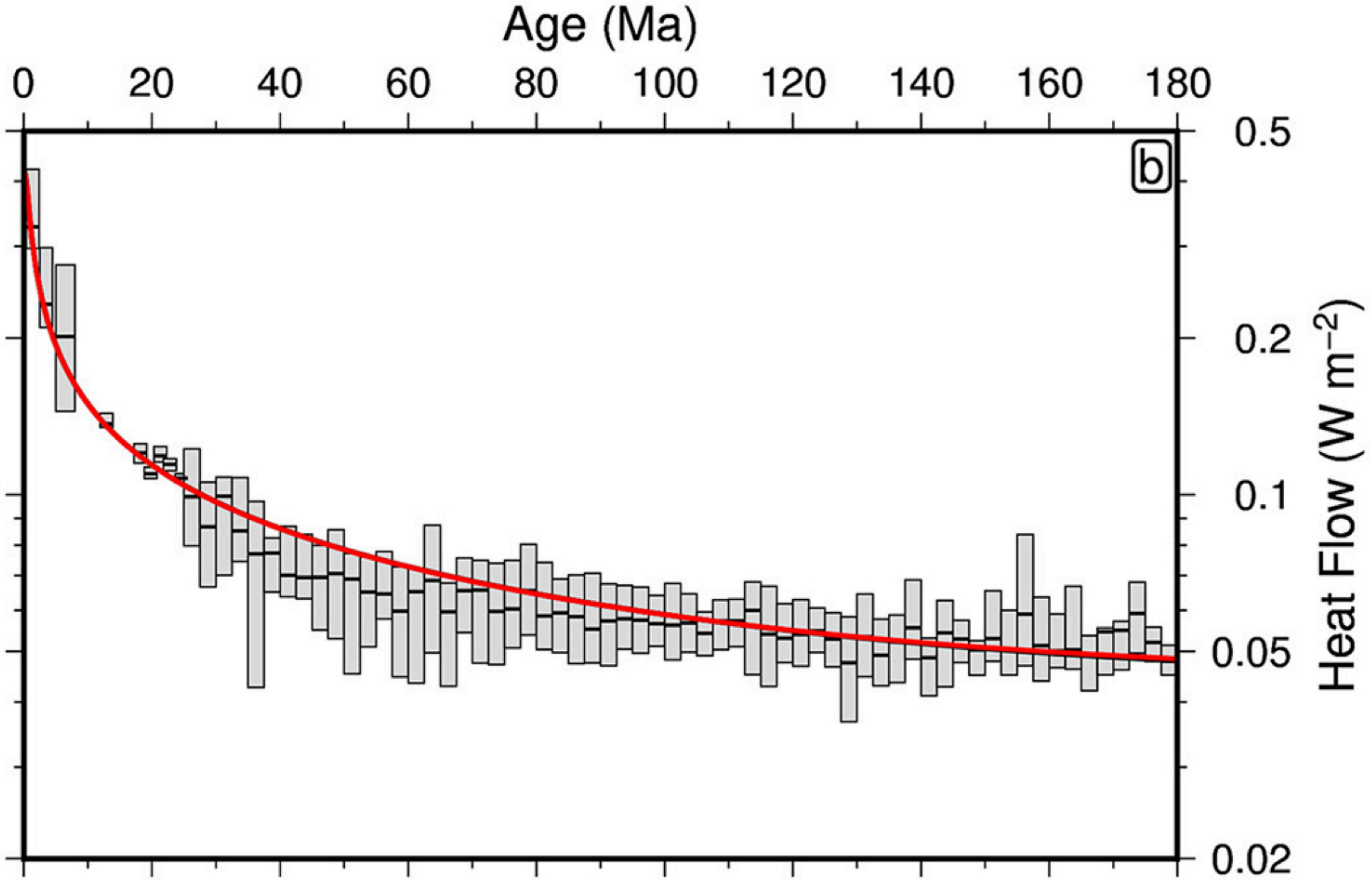
Hasterok et al., 2022, Fig. 4



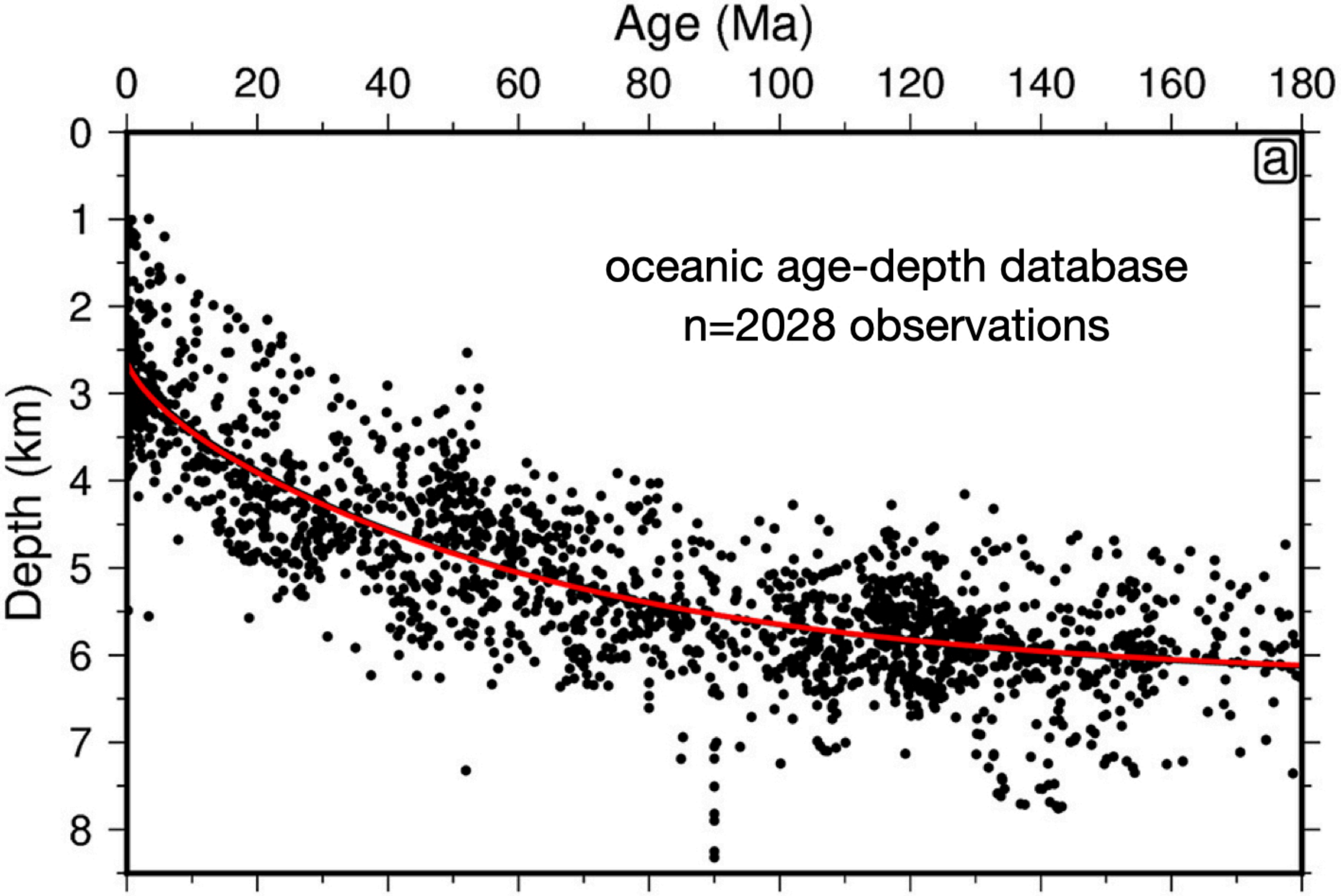
Seton et al., 2020, Fig . 1b



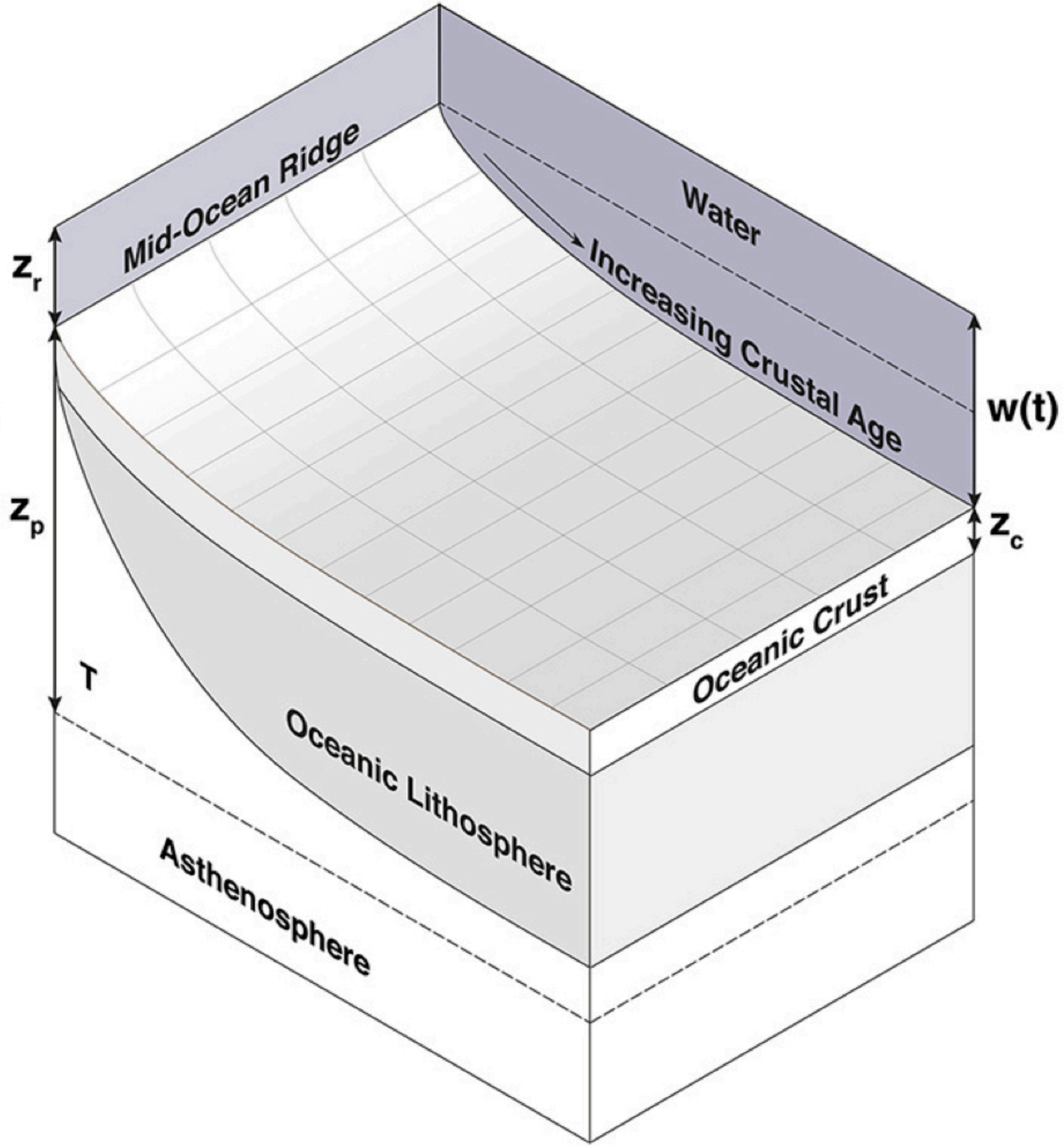
Steinberger and Becker, 2016, Fig . 1



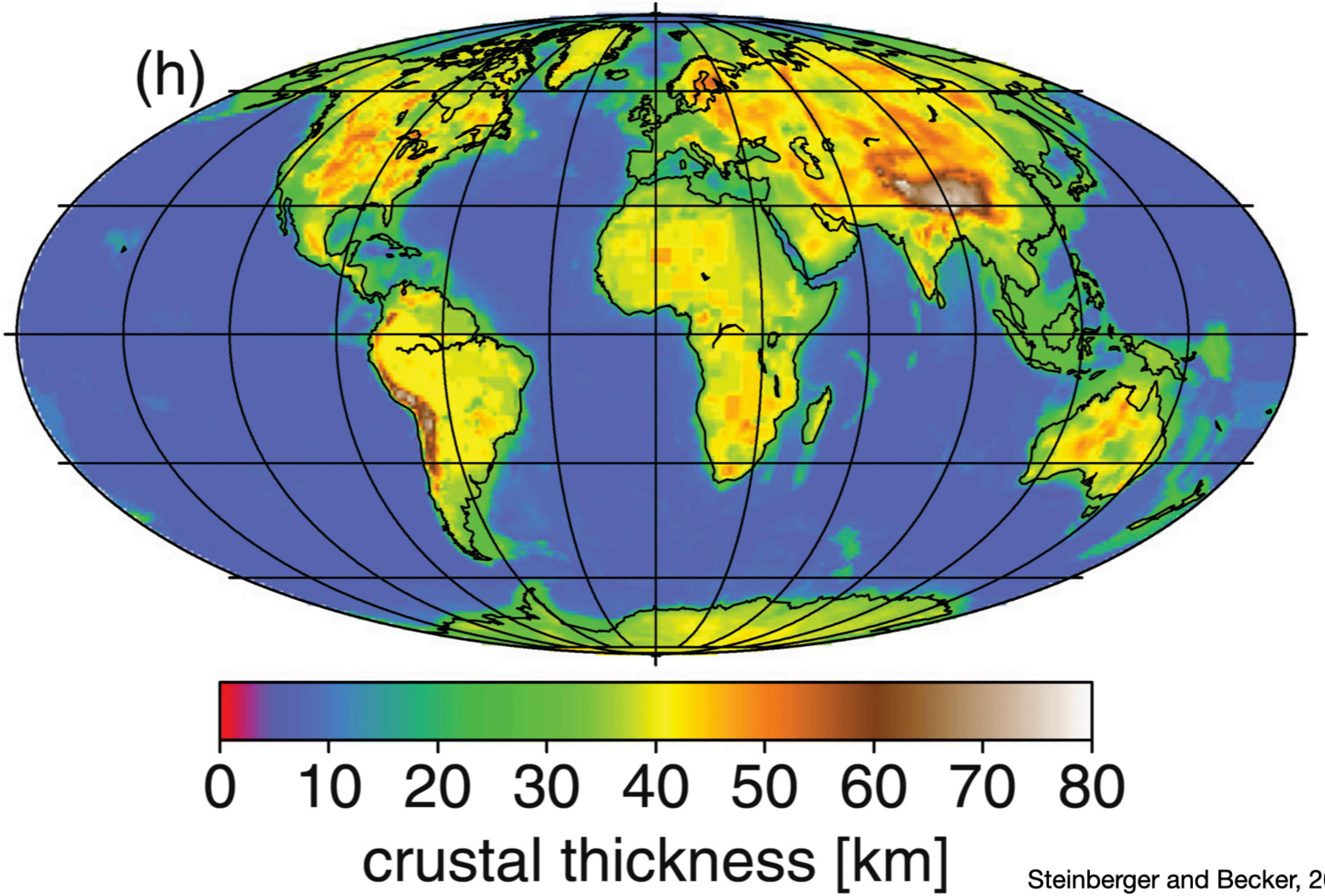
Richards et al., 2018, Fig . 8b



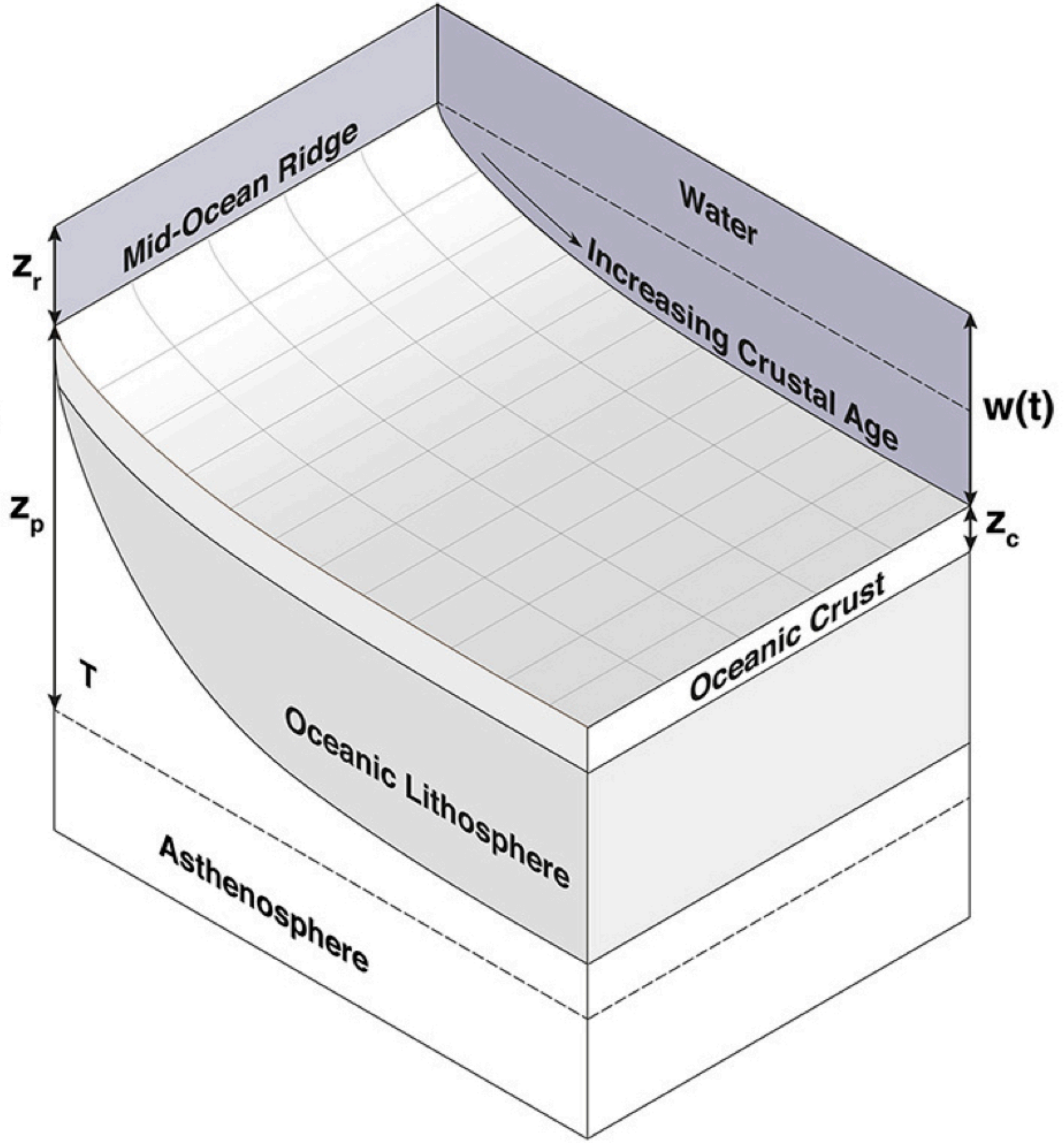
Richards et al., 2018, Fig . 8a



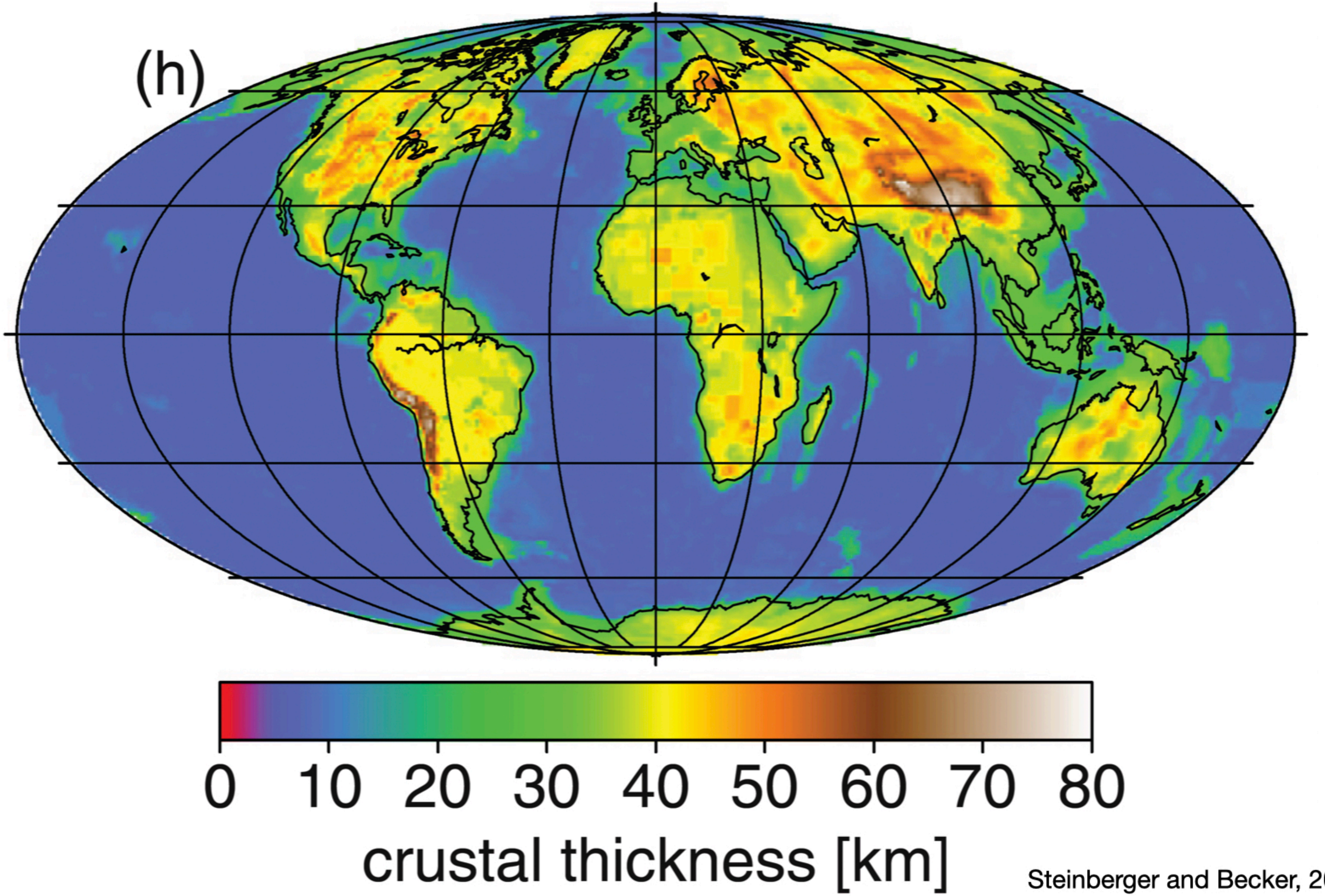
Richards et al., 2018, Fig . 1c



Steinberger and Becker, 2016, Fig . 1

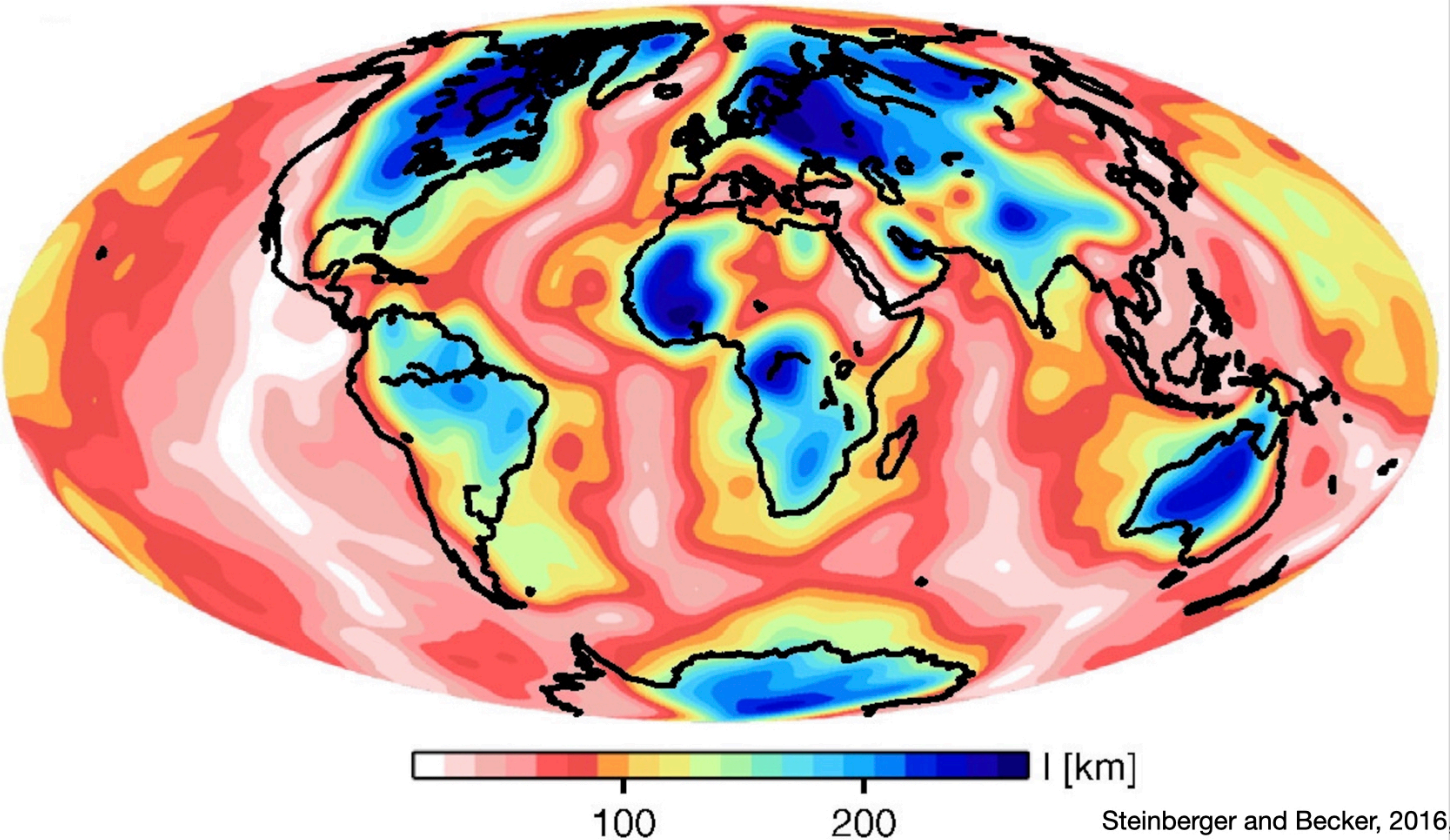


Richards et al., 2018, Fig . 1c

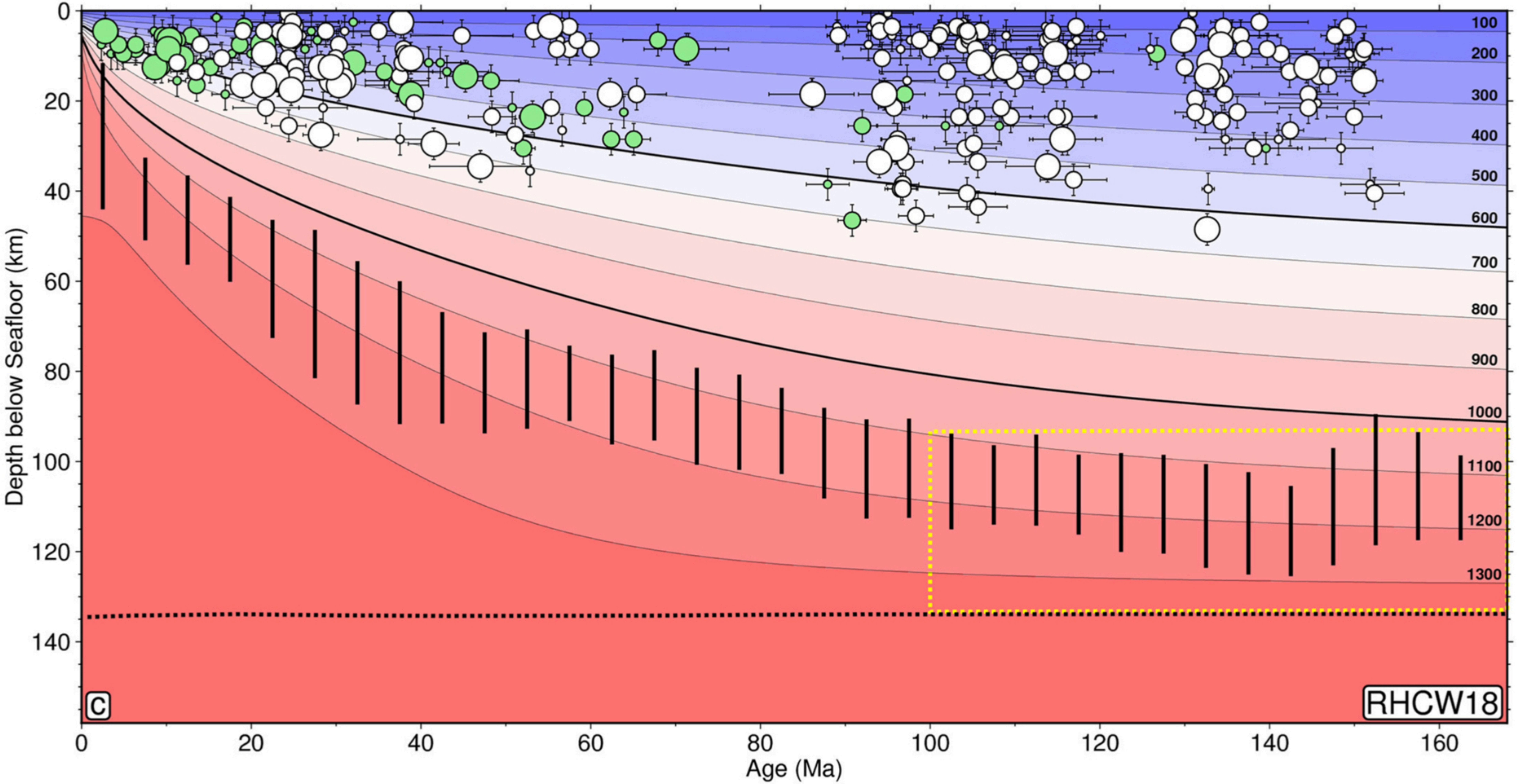


Steinberger and Becker, 2016, Fig . 1

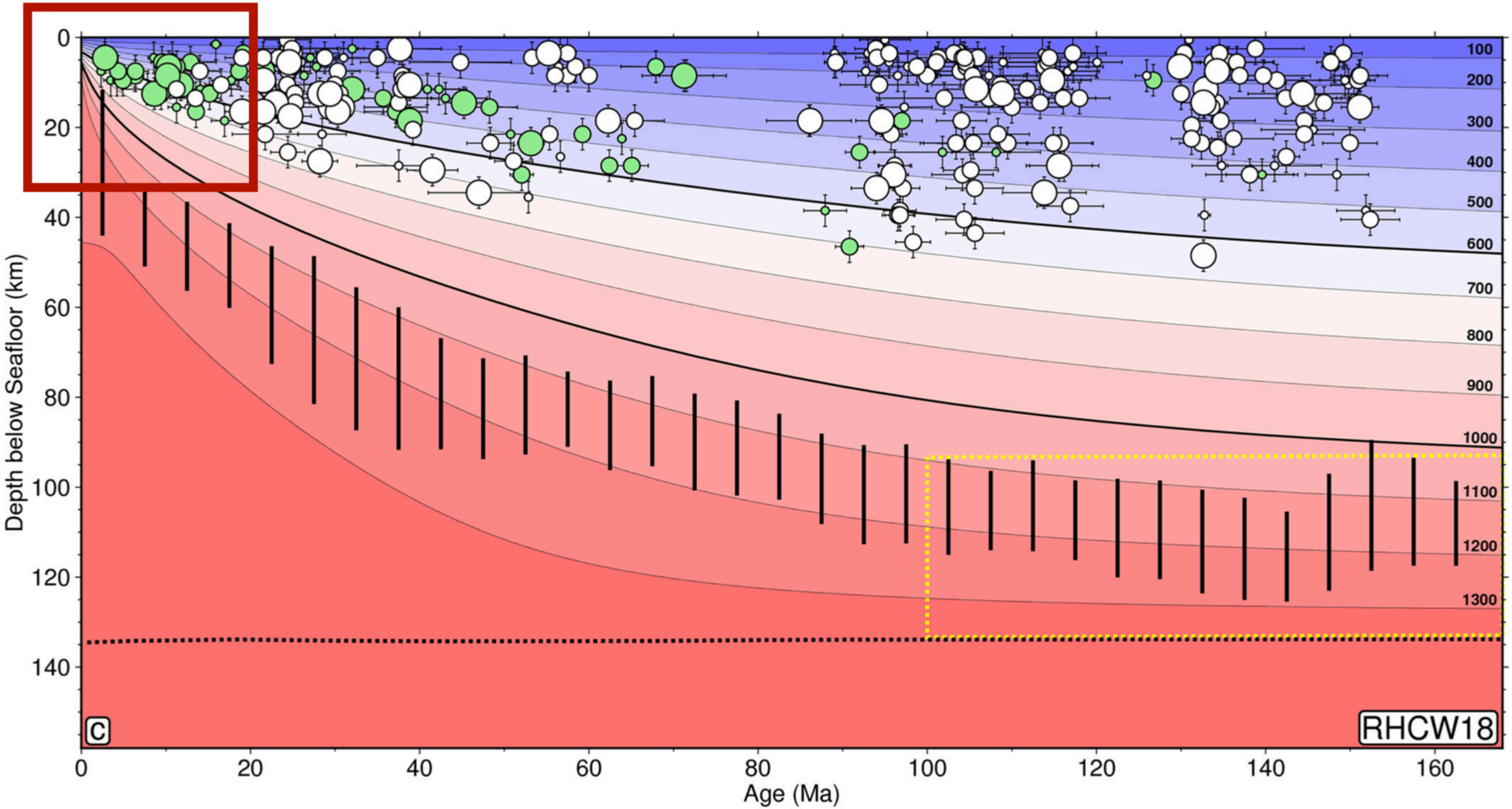
Mean Tomographically Determined Lithospheric Thickness Model



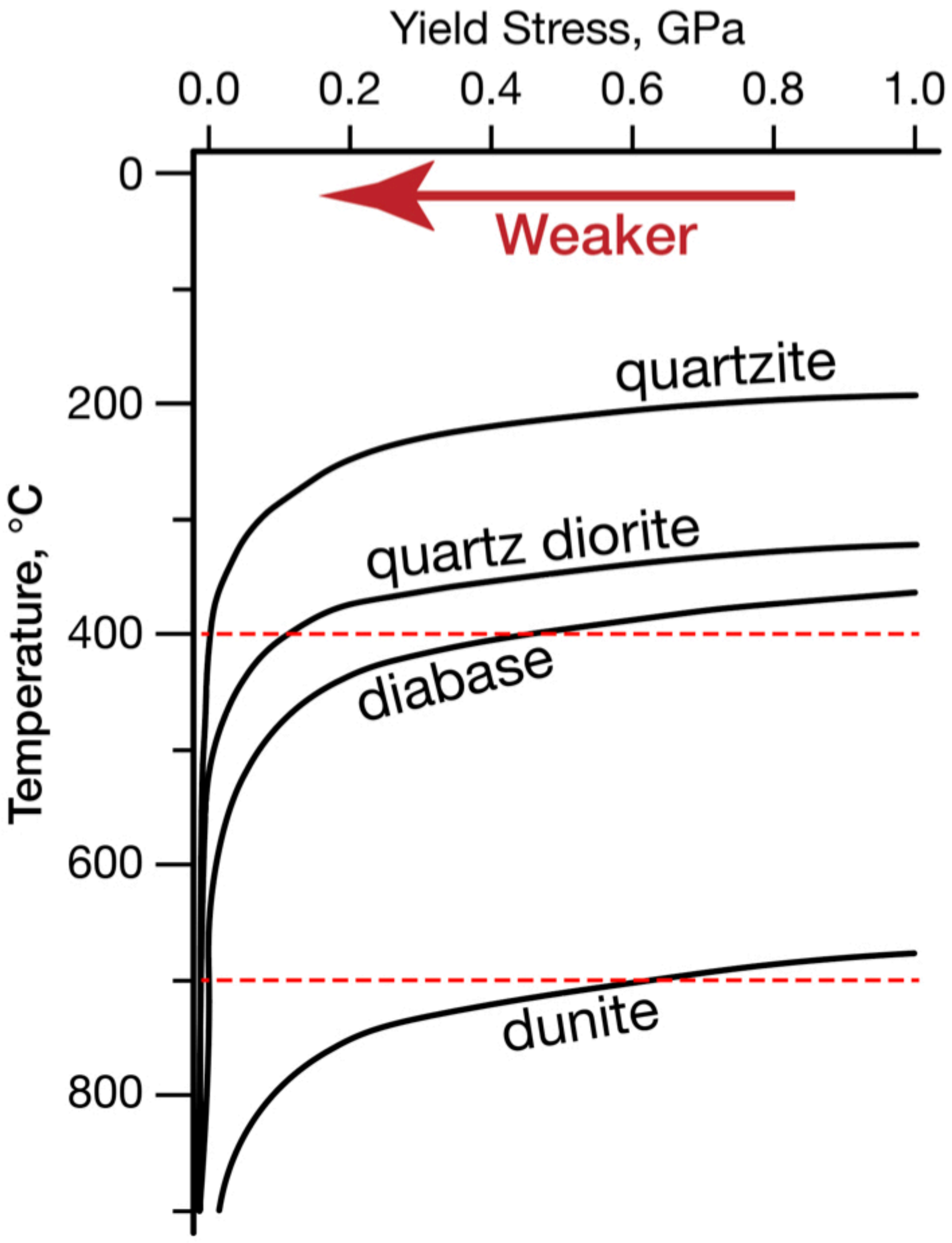
Steinberger and Becker, 2016, Fig . 7



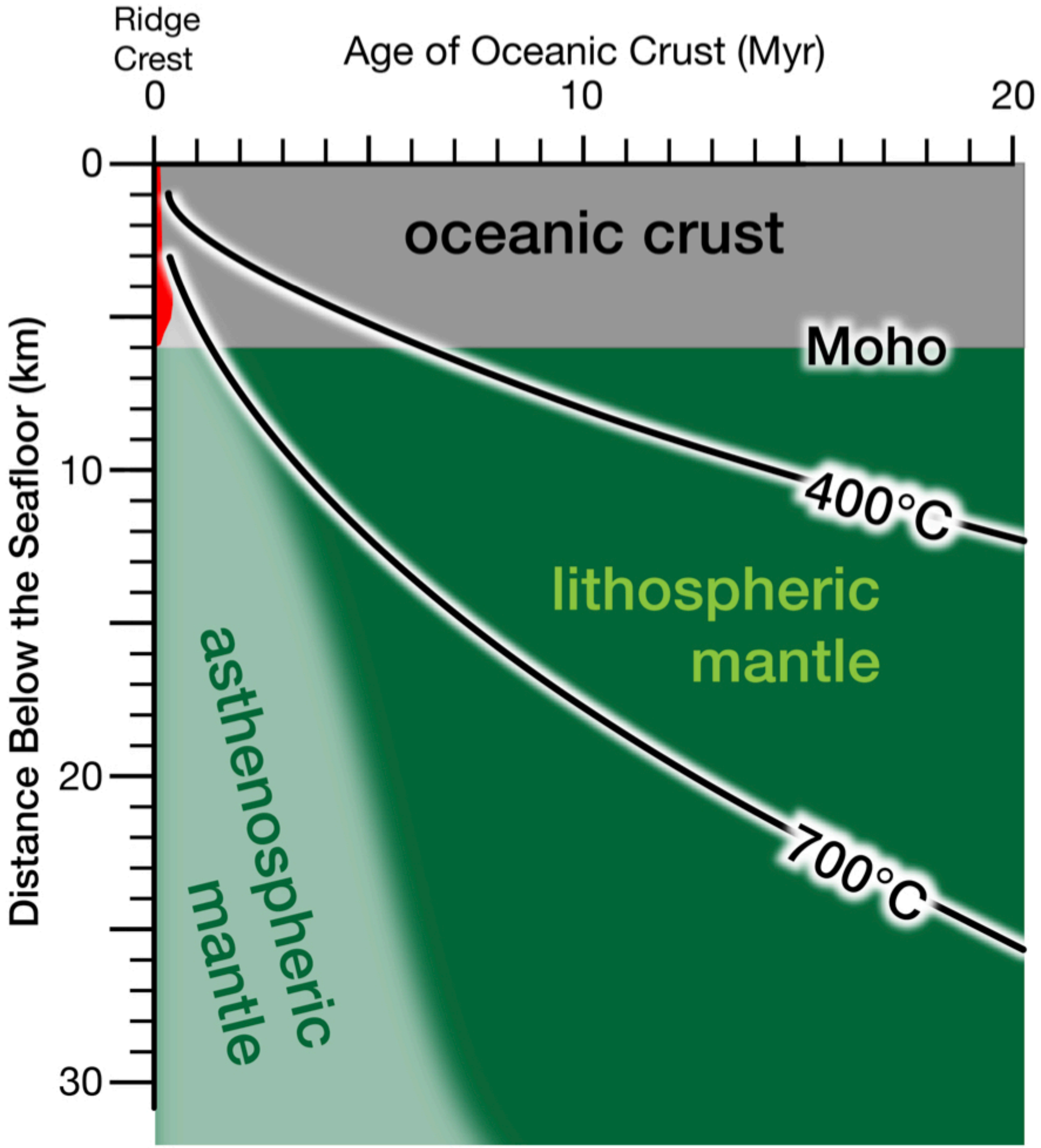
Richards et al., 2018, Fig . 9



Richards et al., 2018, Fig . 9



after Bohannon & Parsons, 1995, and Kirby, 1985



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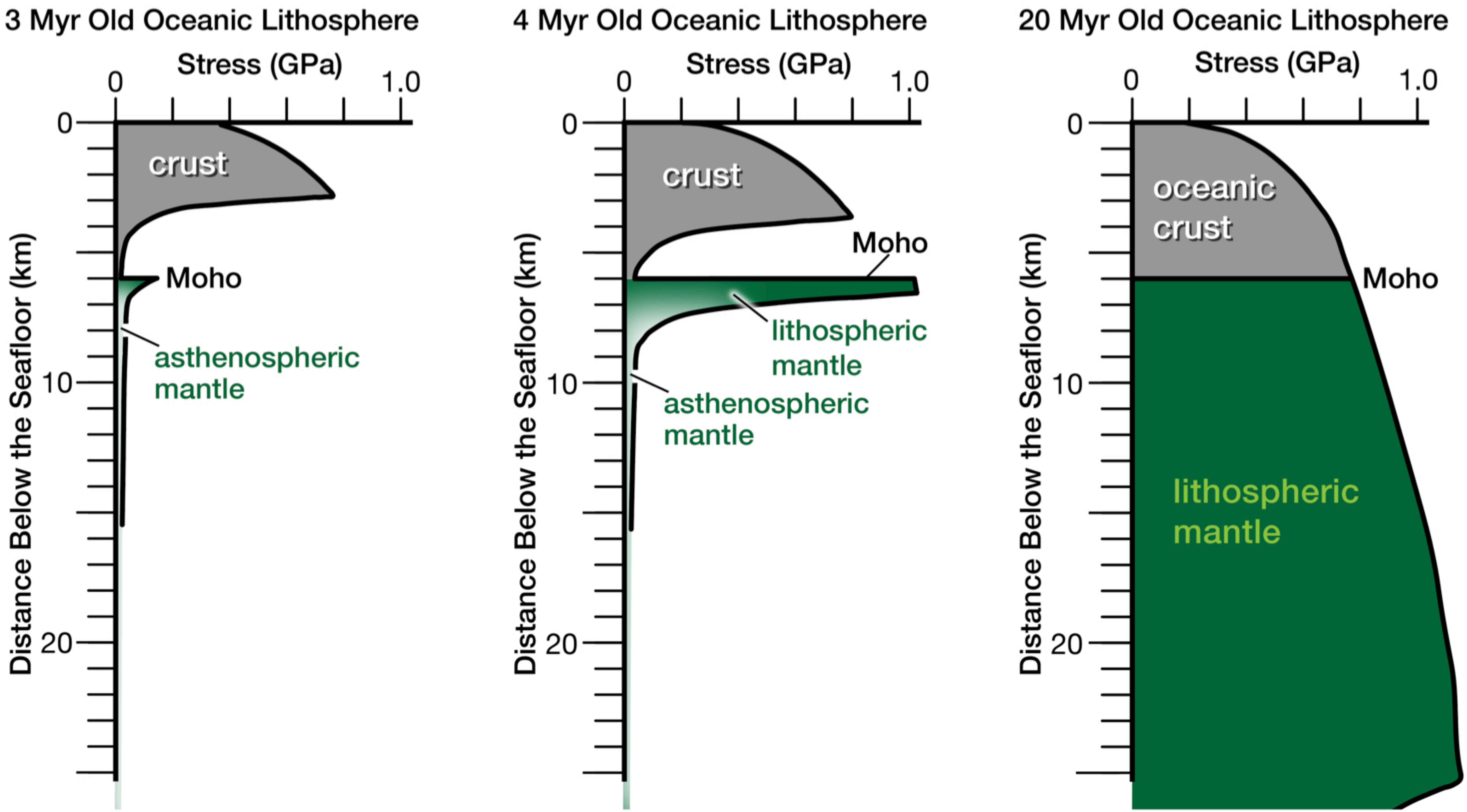
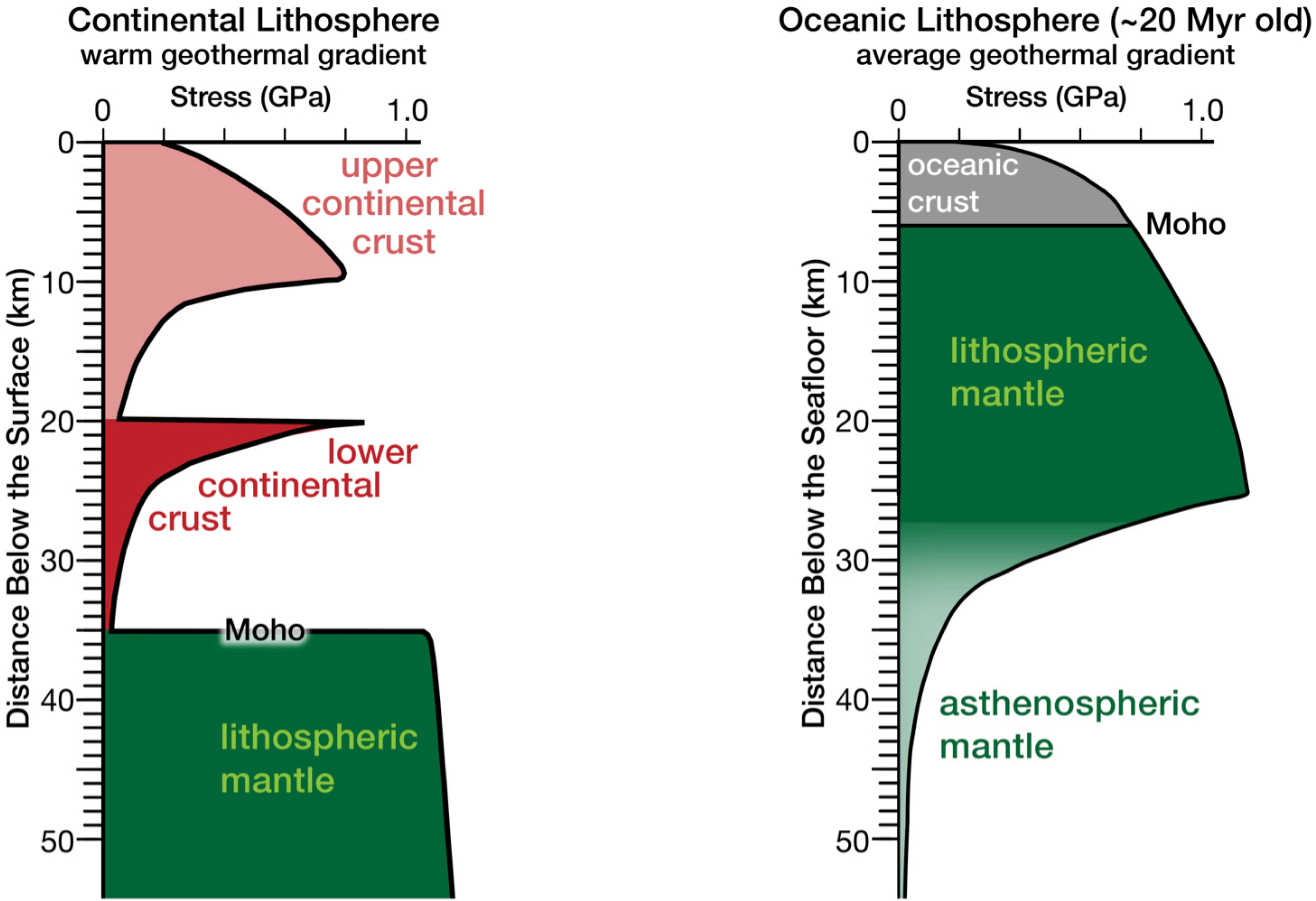


after Bohannon & Parsons, 1995, and Kirby, 1985



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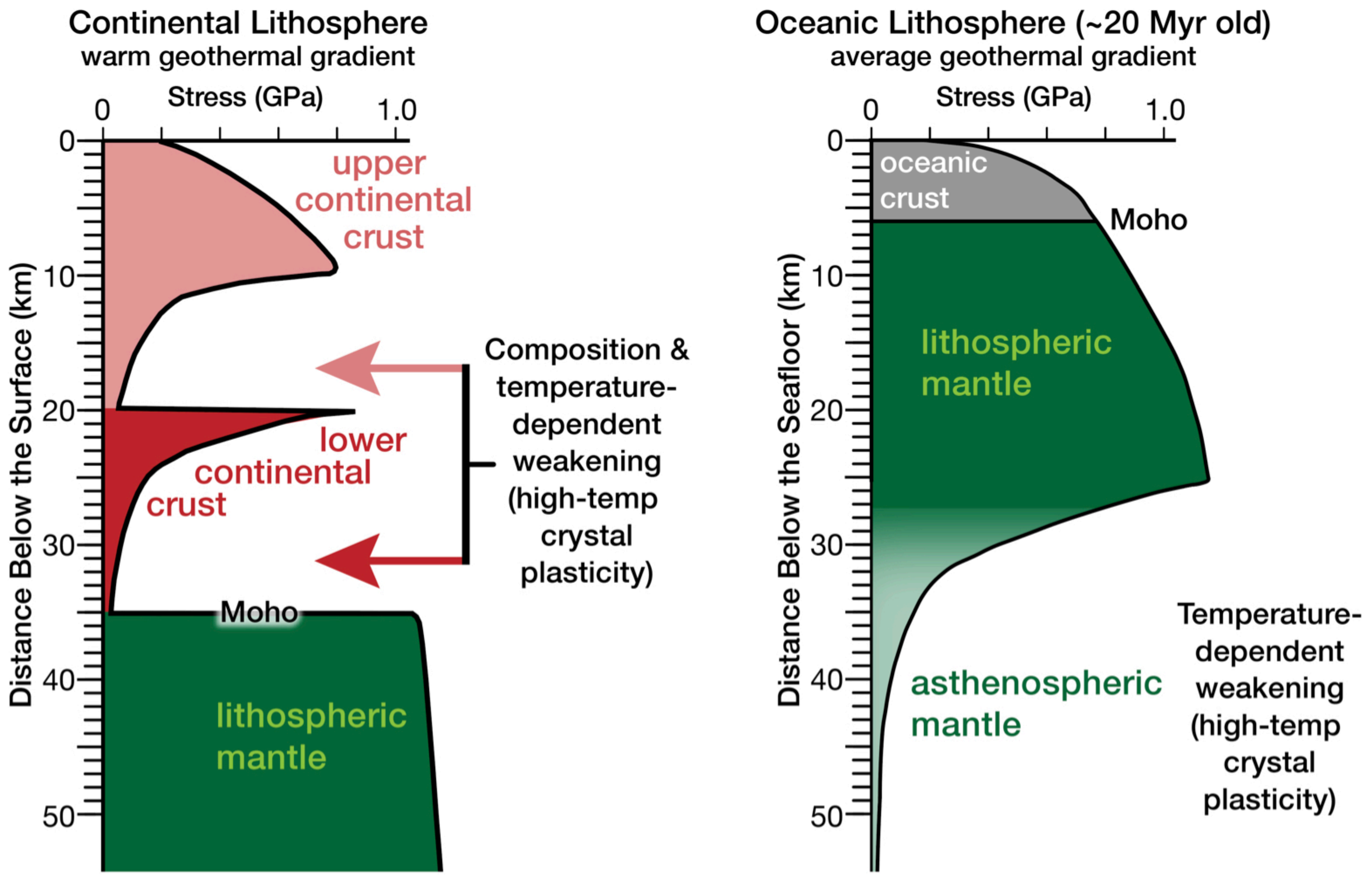
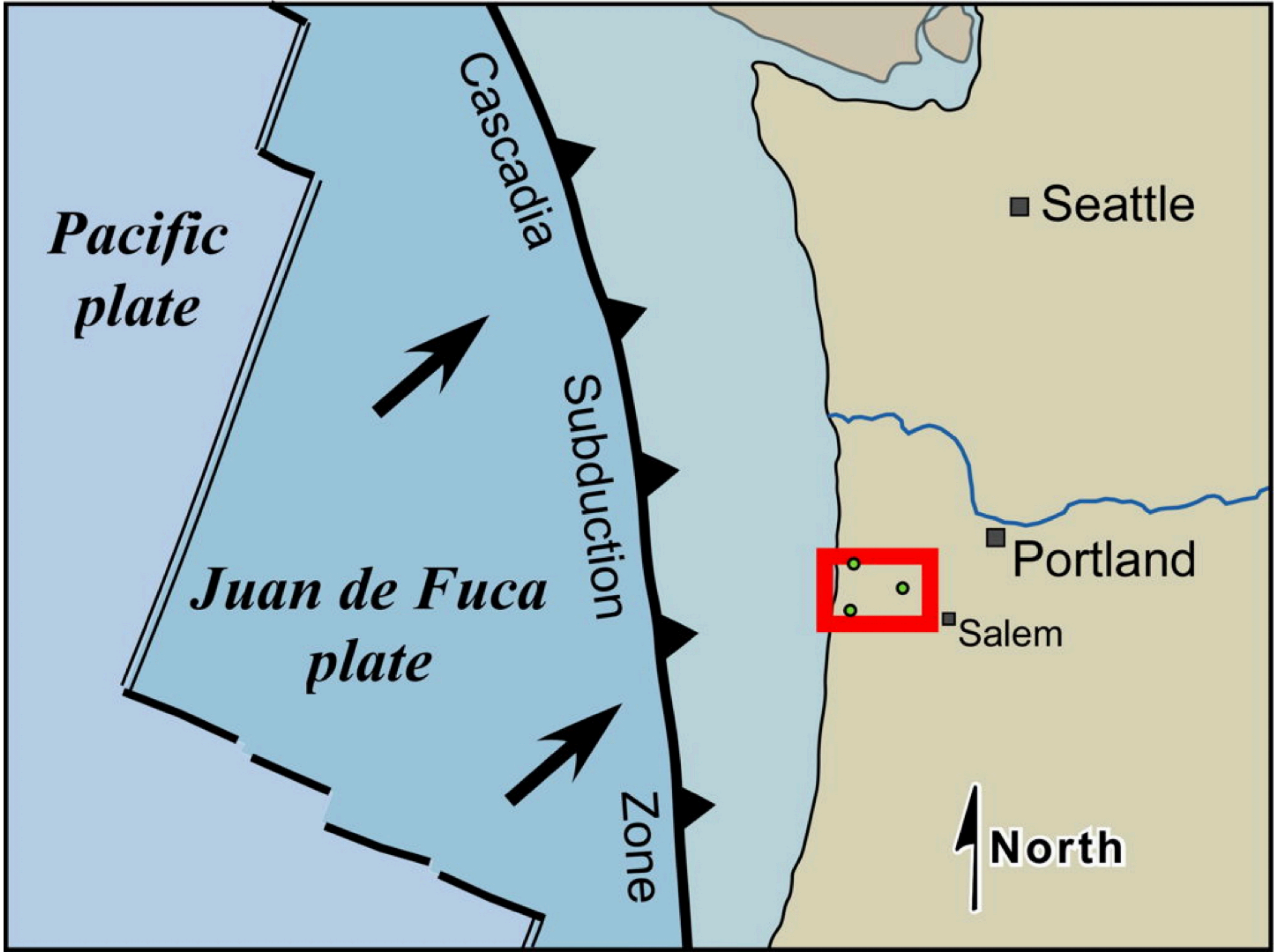
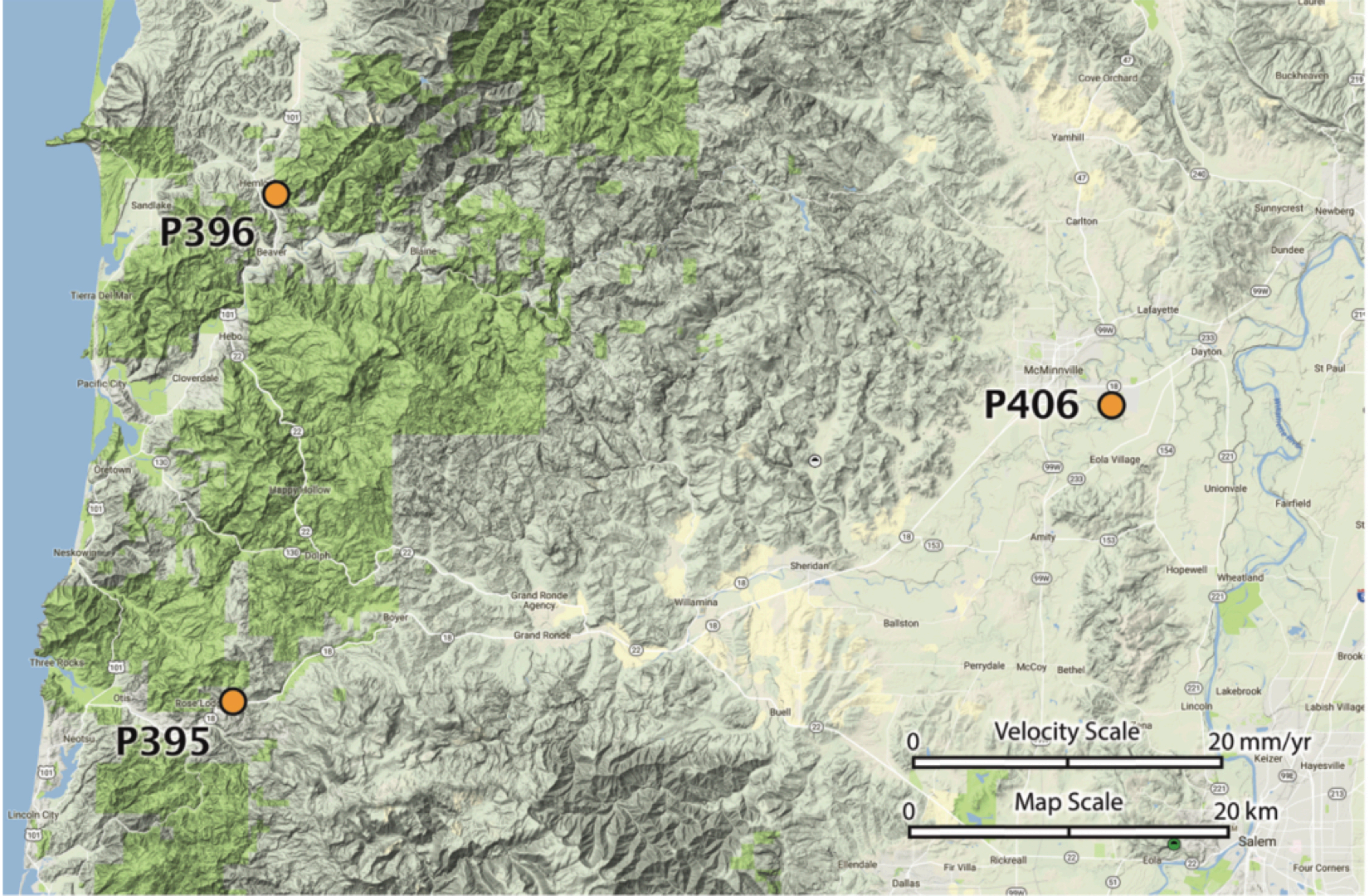


after Bohannon & Parsons, 1995, and Kirby, 1985

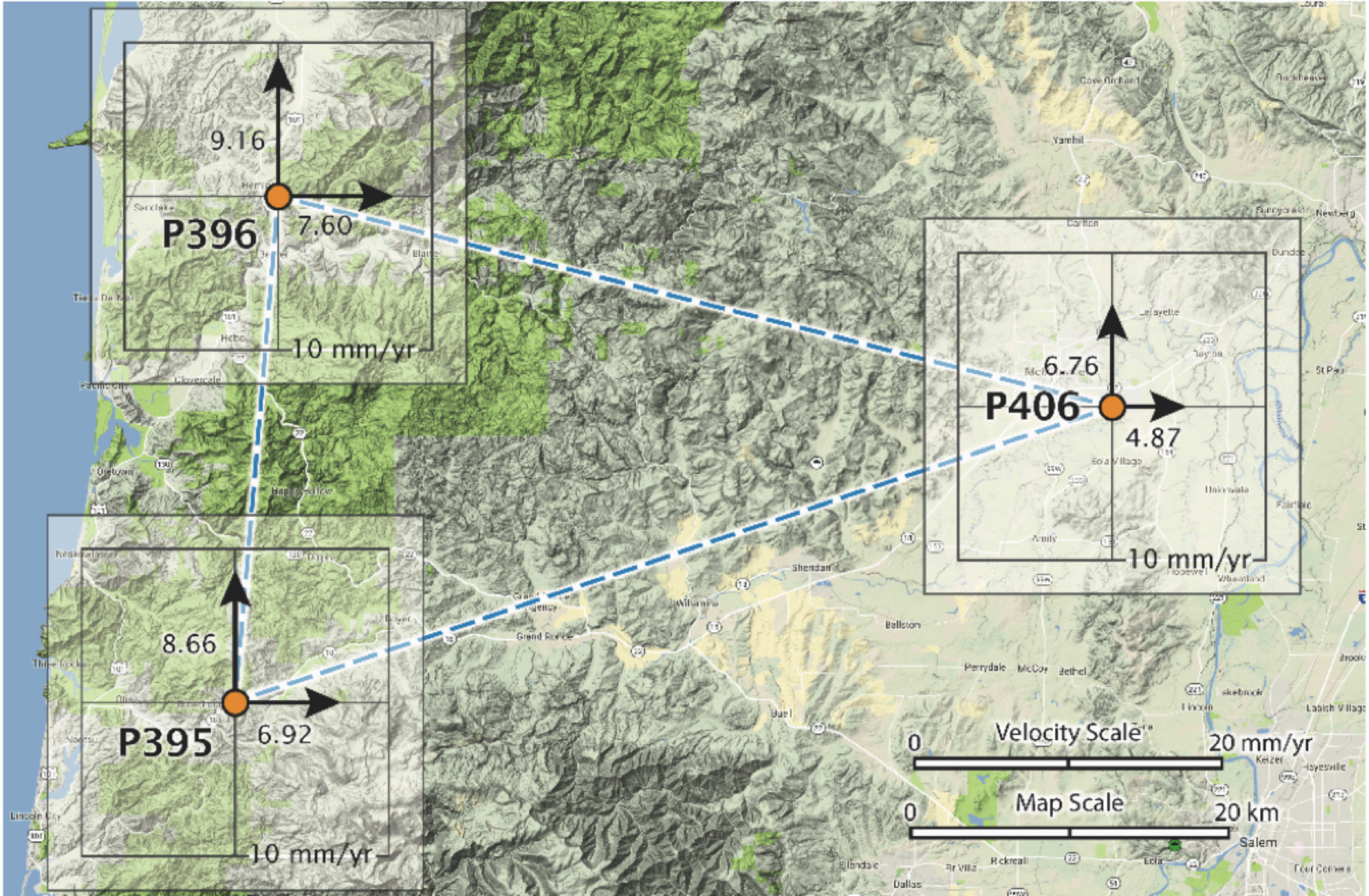
Reprise

Using site velocities from 3 GPS stations to measure crustal strain


Pacific plate
Cascadia Subduction Zone
Juan de Fuca plate
Seattle
Portland
Salem
North


P396
P406
P395
Velocity Scale
0
20 mm/yr
Map Scale
0
20 km
Sandlake
Beaver
Blaine
Tierra Del Mar
Hebo
Pacific City
Cloverdale
Oretown
Neskowin
Dolph
Grand Ronde Agency
Grand Ronde
Boyer
Willamina
Sheridan
Three Rocks
Otis
Neotsu
Lincoln City
Buell
Ballston
Perrydale
McCoy
Bethel
Yamhill
Cove Orchard
Carlton
Lafayette
Dayton
McMinnville
Eola Village
Amity
Hopewell
Wheatland
Unionvale
Fairfield
Newberg
Dundee
Sunnycrest
Buckheaven
St Paul
Lakebrook
Lincoln
Keizer
Hayesville
Salem
Four Corners
Rickreall
Ellendale
Fir Villa
Dallas
Eola
Labish Village


P396
P406
P395
Velocity Scale
0
20 mm/yr
Map Scale
0
20 km


9.16
P396
7.60
10 mm/yr
6.76
P406
4.87
10 mm/yr
8.66
P395
6.92
10 mm/yr
0
Velocity Scale
20 mm/yr
0
Map Scale
20 km

Input Data File for

GPS-strain-calculator-InputCSV-20240918.nb

(a Mathematica notebook)

RecNo	Station	Long	Lat	RefFrame	E-vel	N-vel	E-uncert	N-uncert	Sources
1	P395	-123.85753	45.02228	NAM14	7.021	10.76	0.203	0.177	http://geod
2	P396	-123.82289	45.30951	NAM14	7.269	10.74	0.249	0.175	http://geod
3	P404	-123.39033	45.15853	NAM14	5.137	9.406	0.146	0.214	http://geod

Data Sources for Station P395

http://geodesy.unr.edu/NGLStationPages/stations/P395.sta

https://www.unavco.org/instrumentation/networks/status/nota/overview/P395

GPS-strain-calculator-InputCSV-20240918.nb

Code to determine the 2-D (horizontal) instantaneous or infinitesimal strain from velocity or displacement data from 3 adjacent-and-non-colinear GNSS stations

Coded in *Mathematica* 8 by Vince Cronin with help from Phil Resor, circa 2012. Note that this version uses the formula employed by Corné Kreemer to compute the second invariant of the strain-rate tensor (e.g., Kreemer et al., 2014).

This version is coded in Mathematica (Wolfram) 14.1, and was revised 18 September 2024.

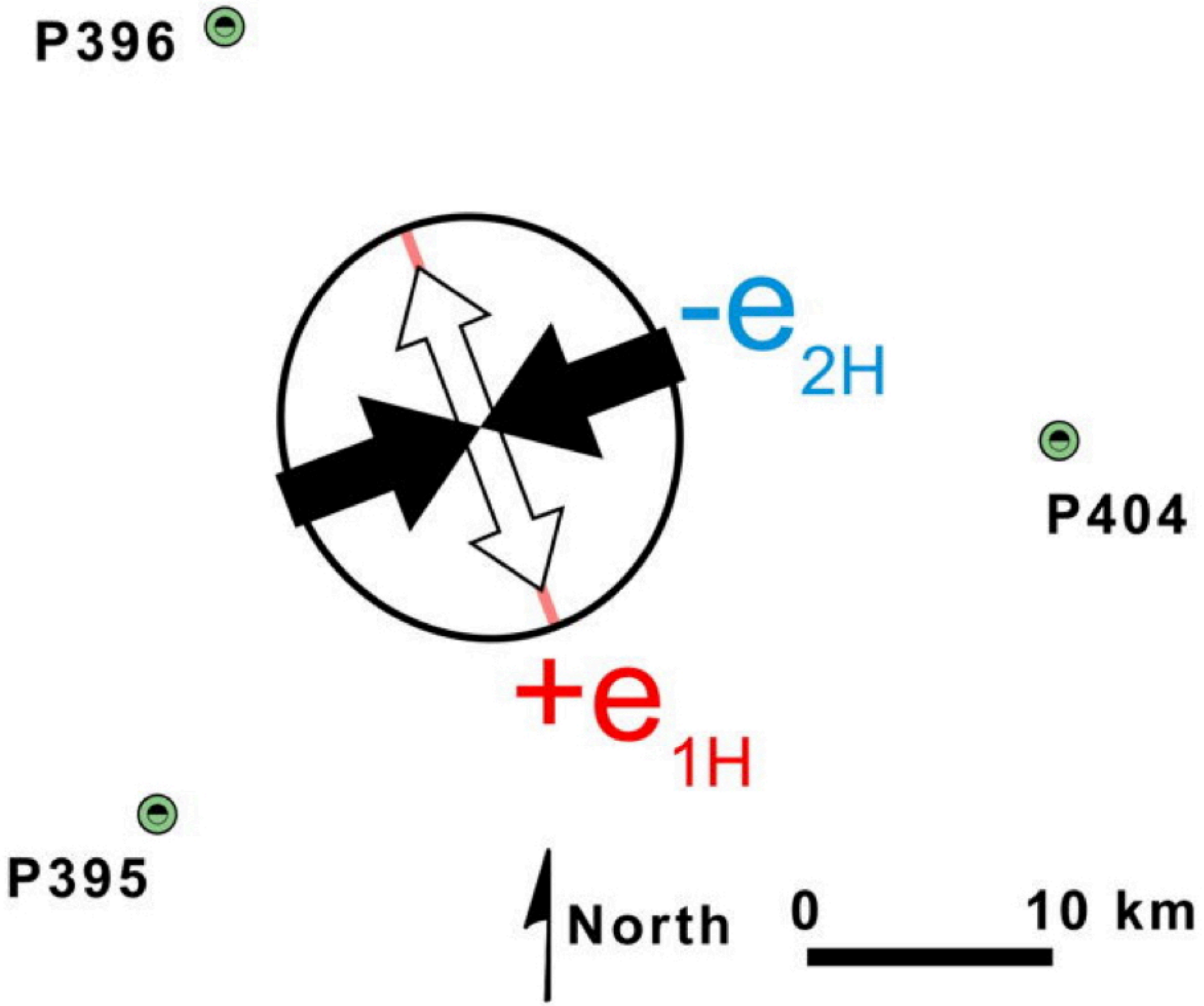
About the input data set

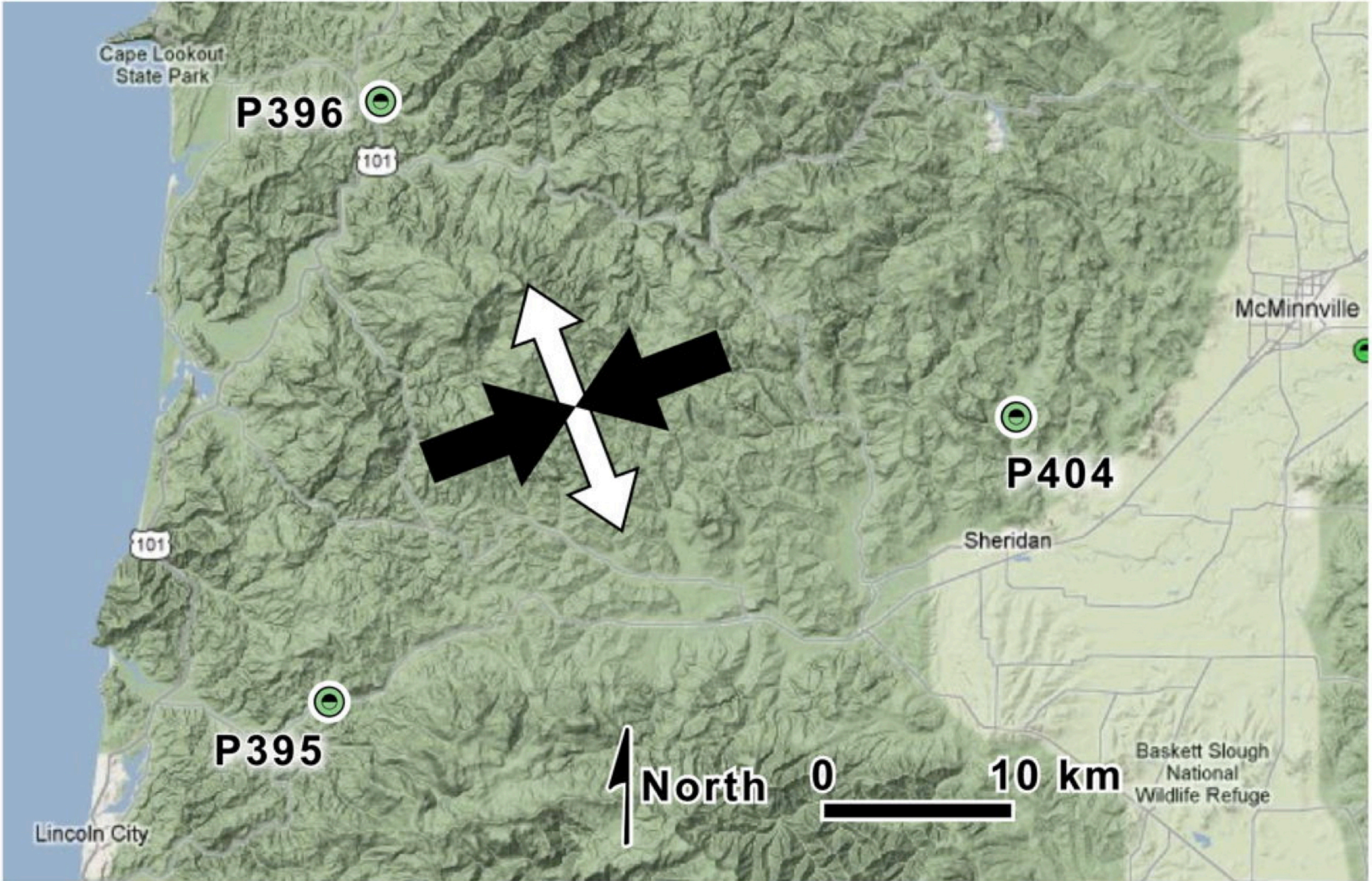
GPS site location and velocity data can be obtained from the Nevada Geodetic Laboratory at the University of Nevada-Reno (http://geodesy.unr.edu/NGLStationPages/gpsnetmap/GPSNetMap_MAG.html). Resources include geodetic data from the MAGNET and NOTA networks, as well as other networks worldwide. As of late 2021, ***this is the current-best resource for obtaining high-quality GPS data worldwide.***

(Data from the Network of the Americas -- the old Plate Boundary Observatory GPS network and a Caribbean network operated by UNAVCO -- are available online through the good work of UNAVCO via http://www.unavco.org/instrumentation/networks/status/pbo/gps)

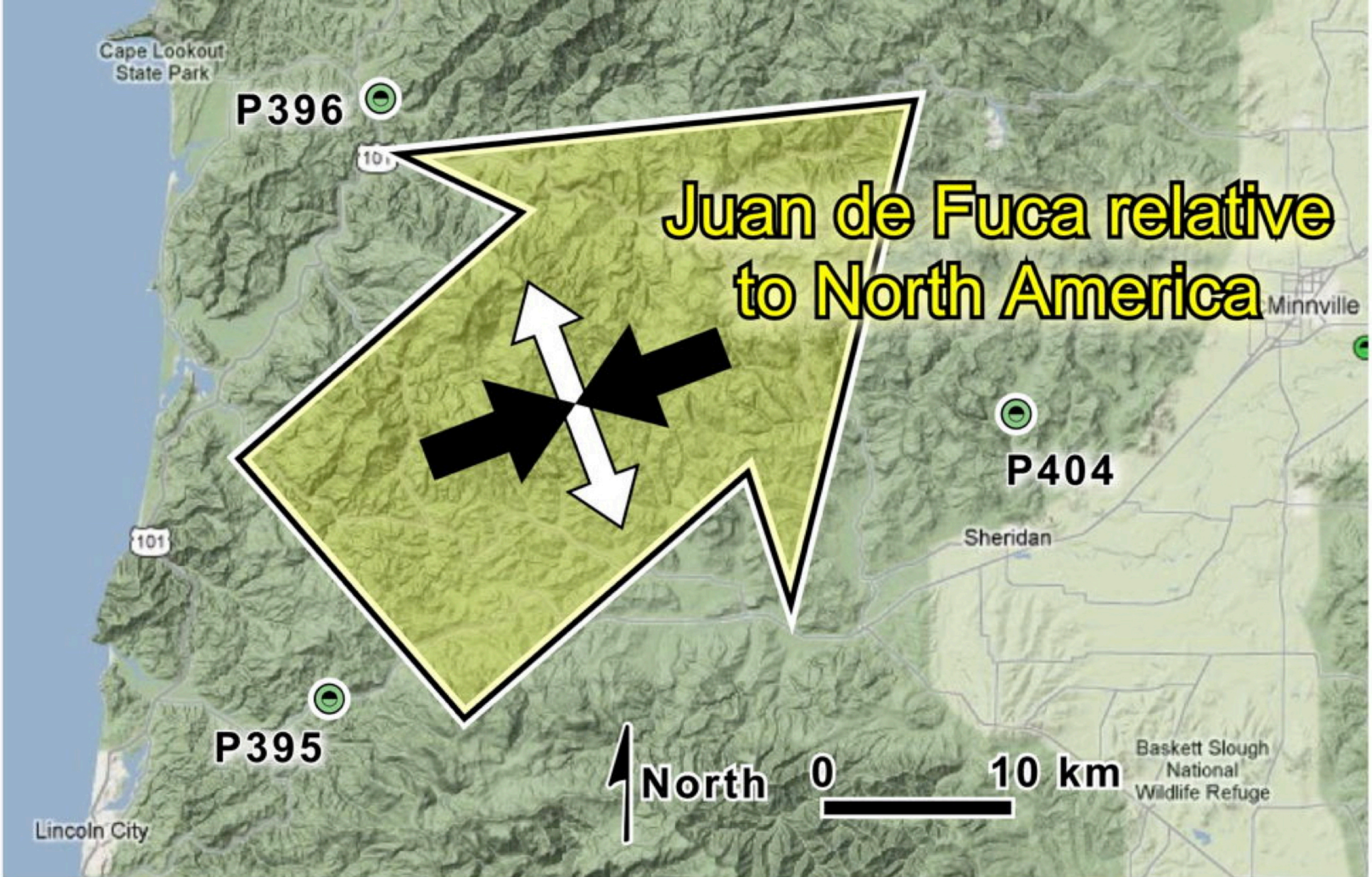
This version of the GPS strain calculator was written to analyze velocity data derived from a comma-separated-value (CSV) file. The input dataset can be created in a text editor, saved as a text file, then substitute ".csv" for ".txt" to make it recognizable as a CSV file.

Each line (record) of the CSV input data file for this strain calculator has 10 items, corresponding to 10 columns in a flat file or matrix:
  column 1: record number in the fullDataSet
  column 2: 4-letter text code for station
  column 3: longitude -- +ve is east, -ve is west
  column 4: latitude -- +ve is north, -ve is south
  column 5: reference frame for GPS site velocity data
  column 6: east velocity in mm/yr -- +ve is toward east, -ve is toward west
  column 7: north velocity in mm/yr -- +ve is toward north, -ve is toward south
  column 8: uncertainty of east velocity in mm/yr
  column 9: uncertainty of north velocity in mm/yr
  column 10: data source

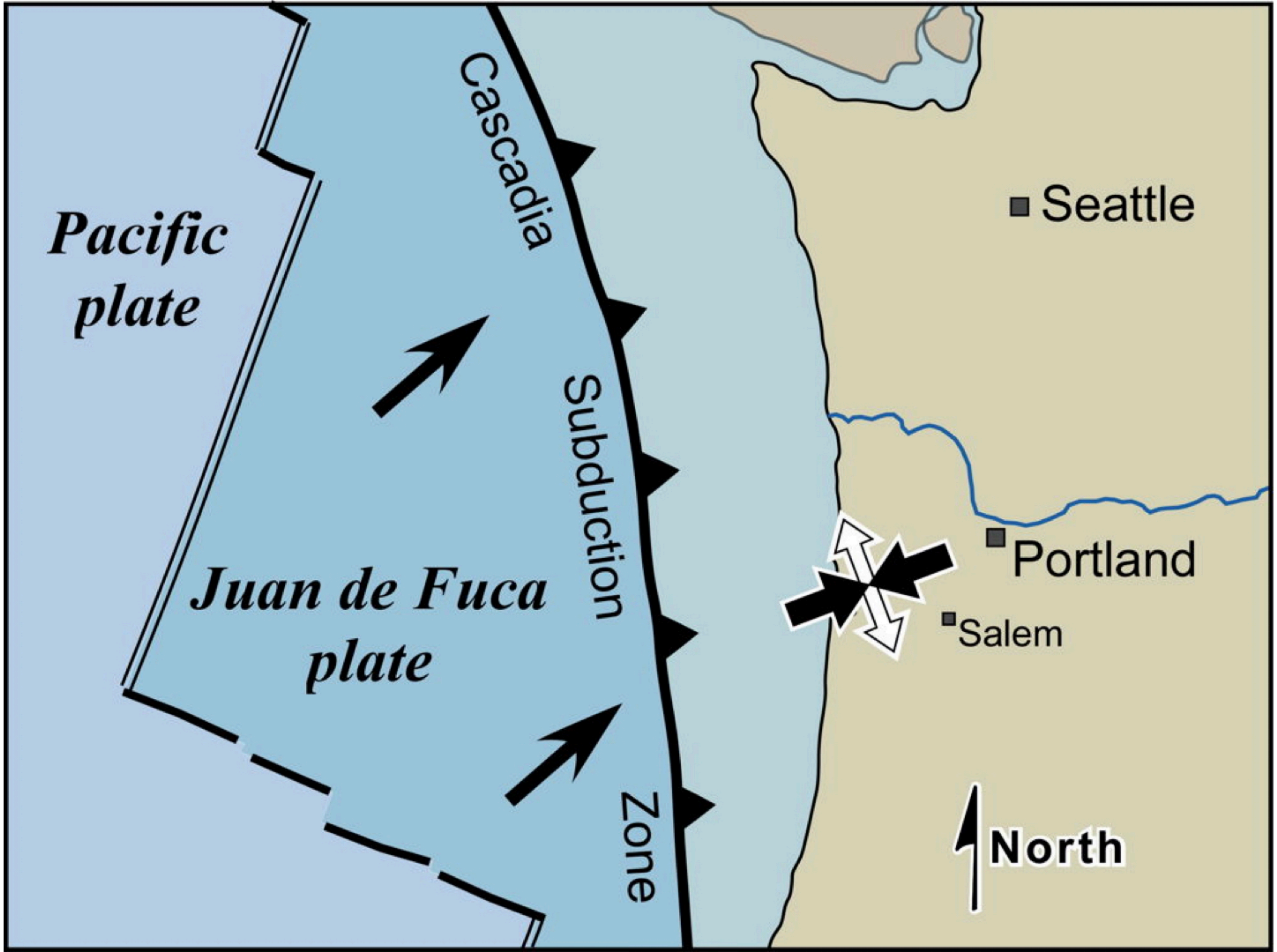

P396
-e2H
P404
+e1H
P395
North
0
10 km



Cape Lookout State Park
P396
101
McMinnville
P404
Sheridan
101
P395
North
0
10 km
Baskett Slough National Wildlife Refuge
Lincoln City

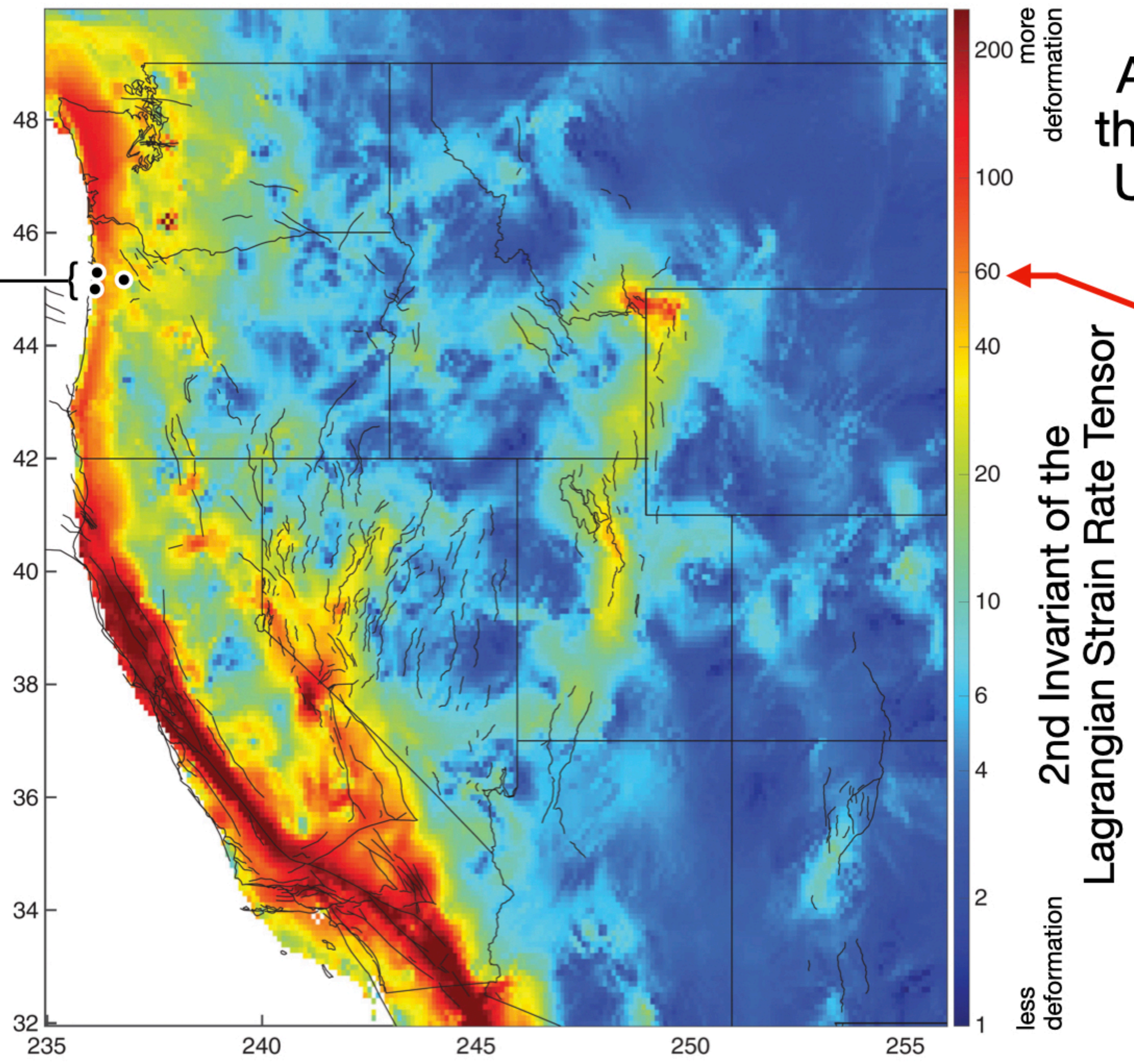


Cape Lookout State Park
P396
101
Juan de Fuca relative to North America
Minnville
P404
Sheridan
101
P395
North
0
10 km
Baskett Slough National Wildlife Refuge
Lincoln City


Pacific plate
Juan de Fuca plate
Cascadia Subduction Zone
Seattle
Portland
Salem
North

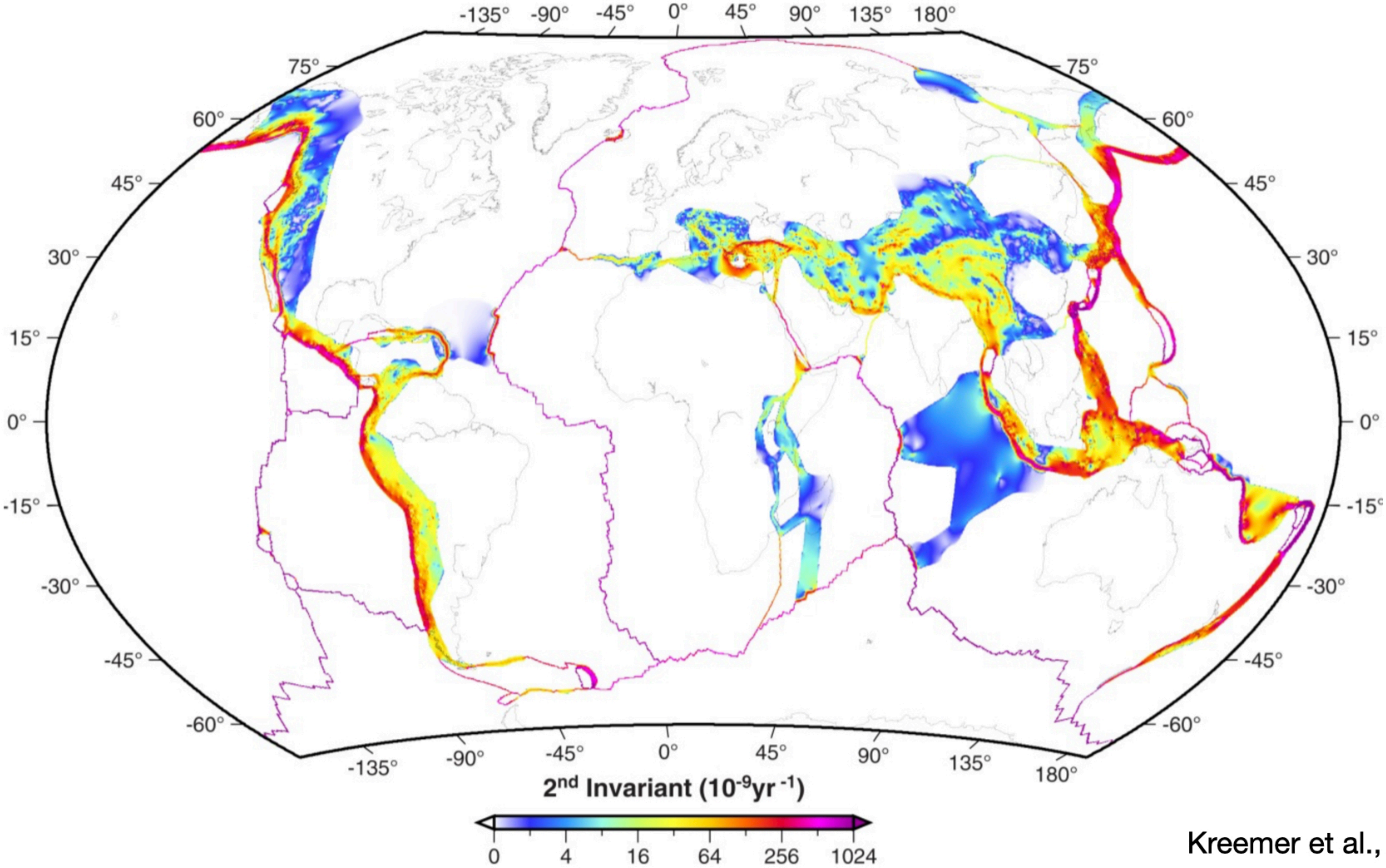
Active deformation of the western continental US from GPS velocity data

GPS Stations P395, P396, and P404

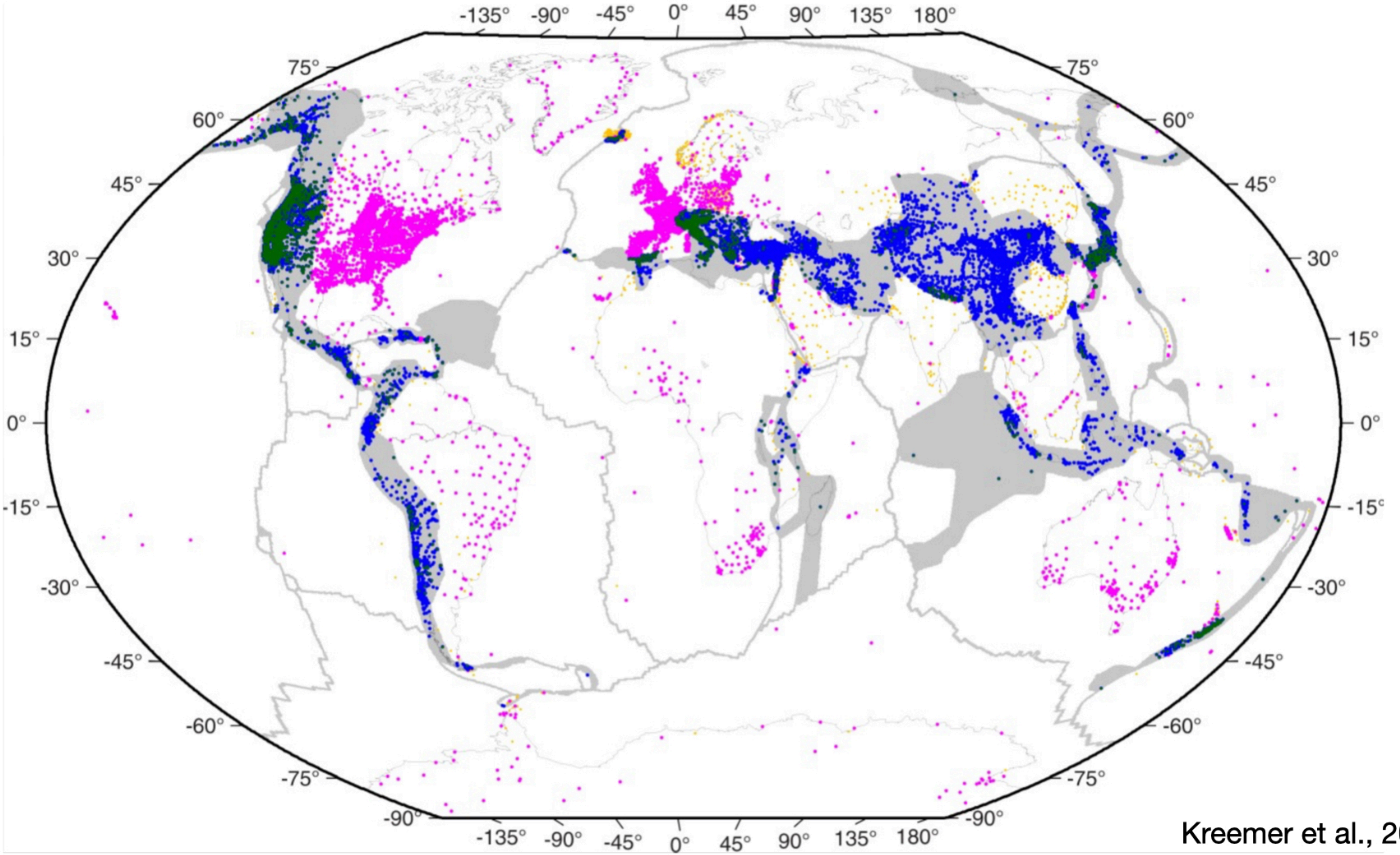


59.12 nano-strain/yr measured using GPS velocities at P395, P396, and P404

Zheng, 2022

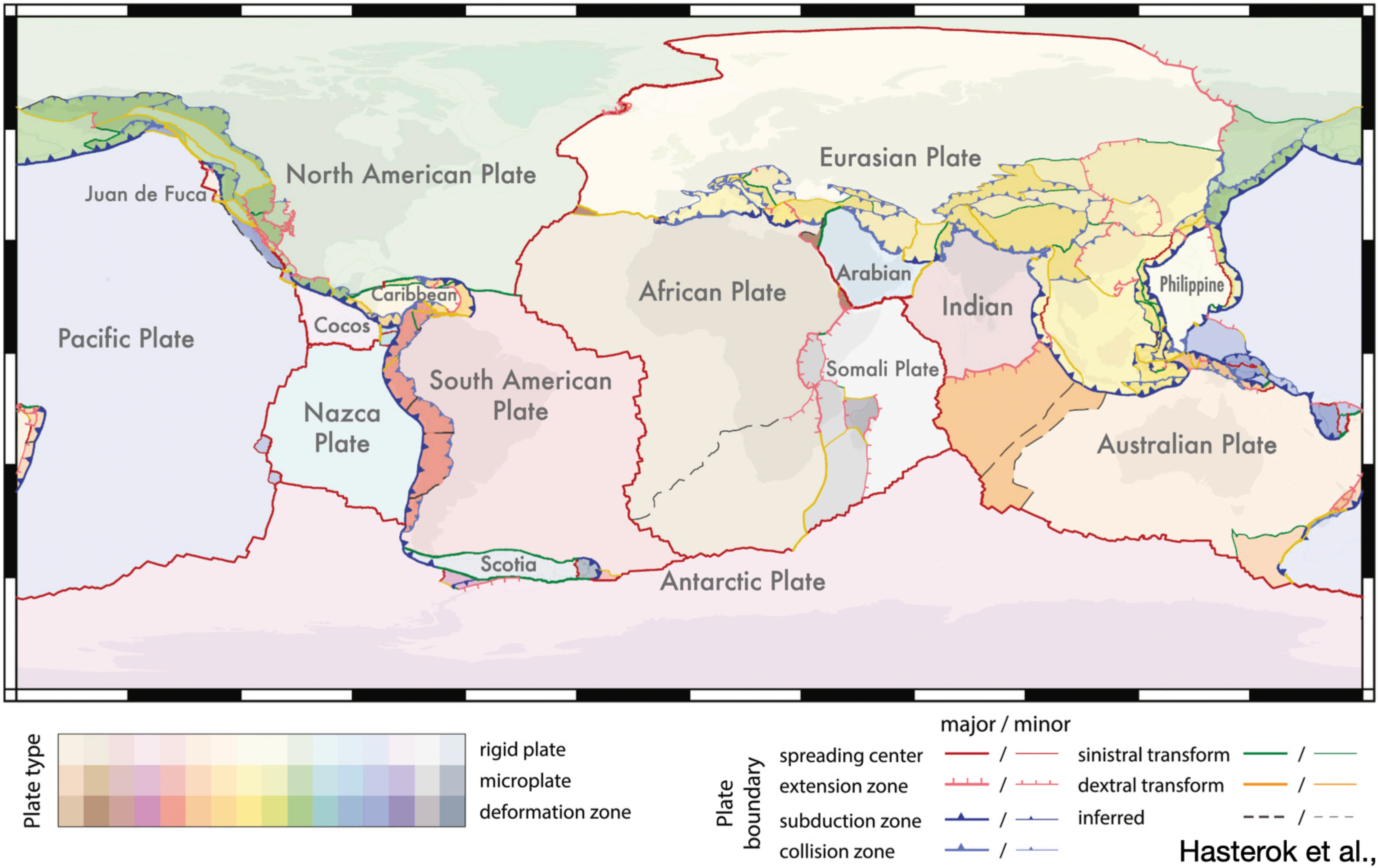


Kreemer et al., 2014

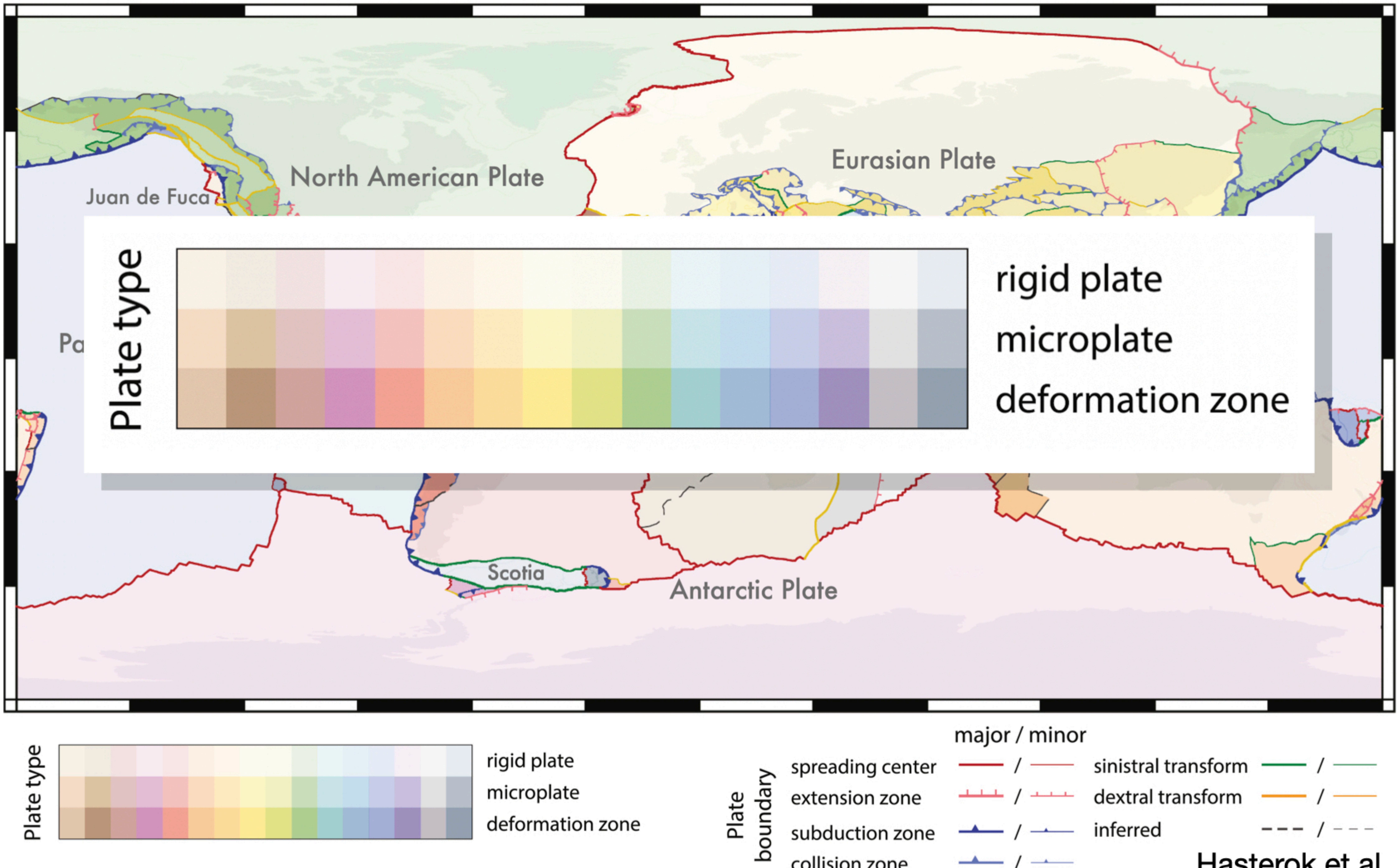


Kreemer et al., 2014

Earth’s surface includes areas that behave as rigid plates, and other areas away from plate boundaries that actively deform. These are “non-plate areas.”



Hasterok et al., 2022



Hasterok et al., 2022


North American Plate
Eurasian Plate
Juan de Fuca
Caribbean
Arabian
African Plate
Philippine
Indian
Cocos
Pacific Plate
Somali Plate
South American Plate
Nazca Plate
Australian Plate
Scotia
Antarctic Plate
Plate type
rigid plate
microplate
deformation zone
Hasterok et al., 2022