Australian National University

Putting plate kinematics to good use

Louis Moresi

louis.moresi@anu.edu.au

What are the rules ?

Plate boundaries: 3 types

Ridges: plates moving apart

Spreading is typically symmetric

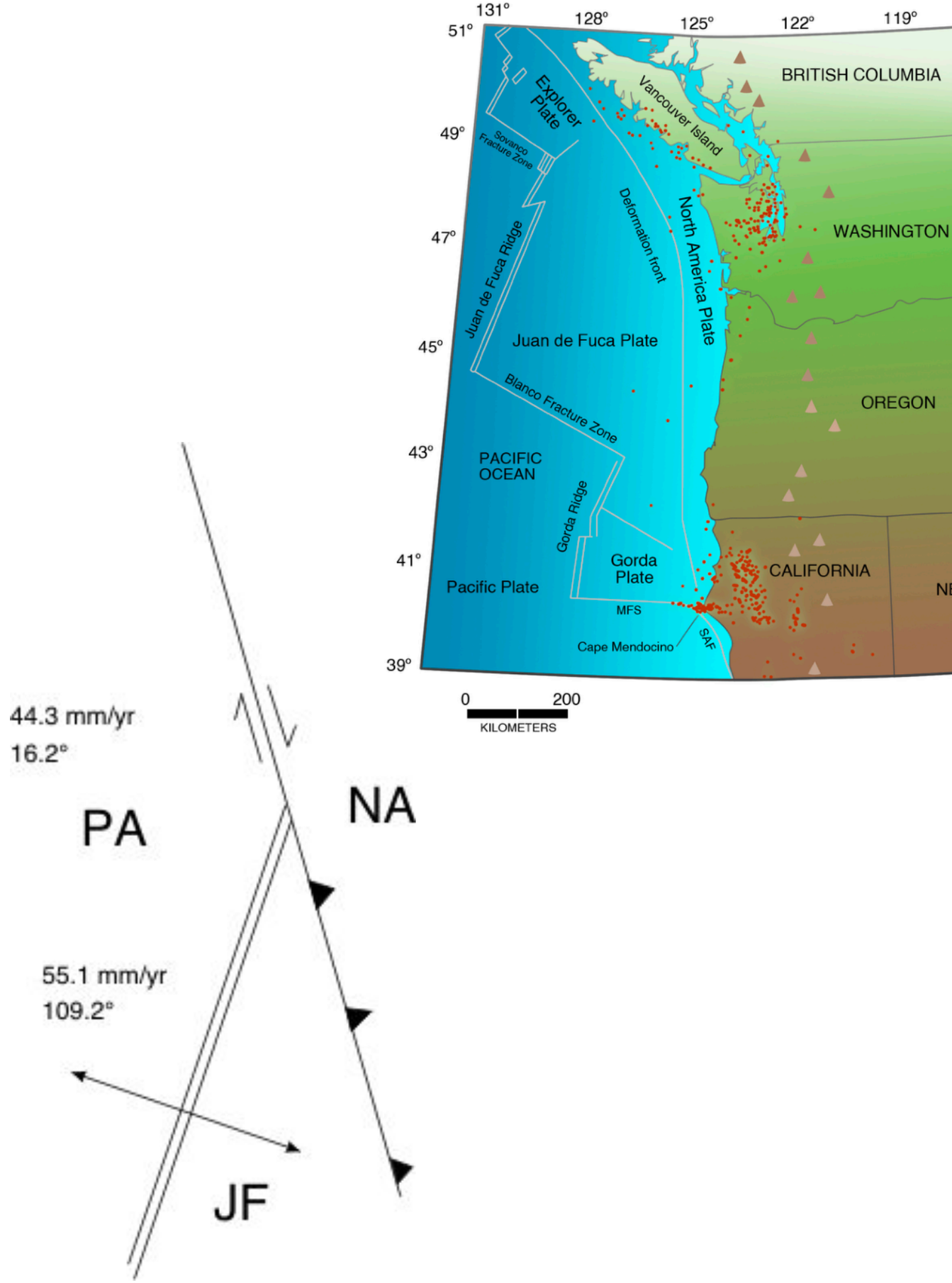
Spreading is typically orthogonal

Trenches: plates converging

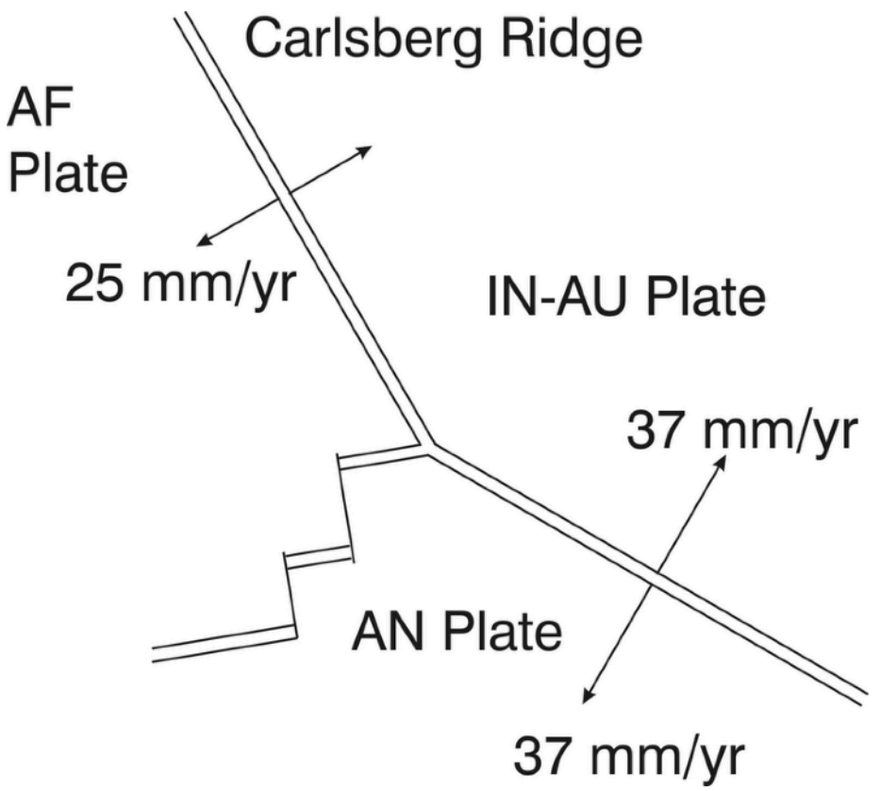
Subduction is highly asymmetric

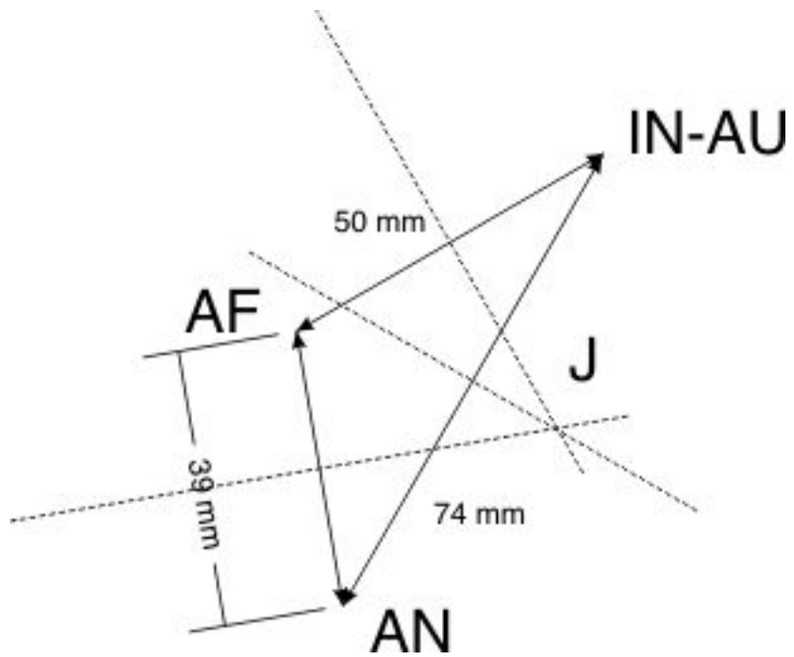
Subduction is not usually orthogonal

Transform faults: motion parallel to boundary



Triple junctions



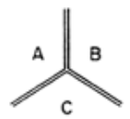
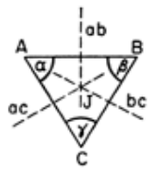
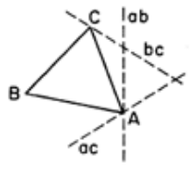
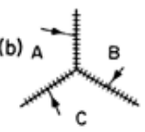
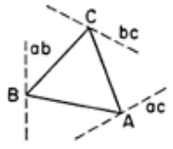
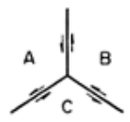
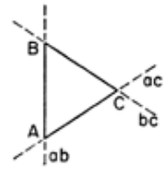
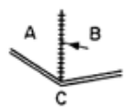
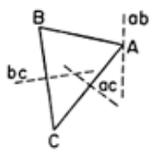
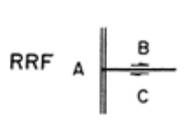
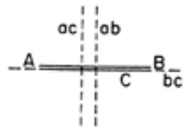
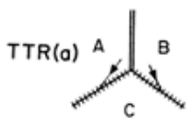
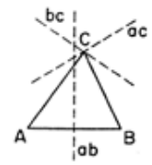
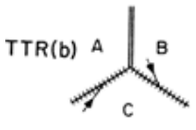
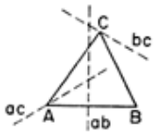


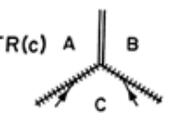
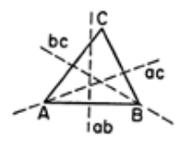
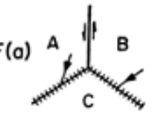
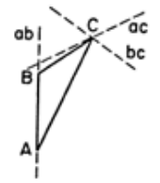
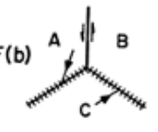
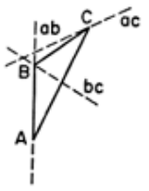
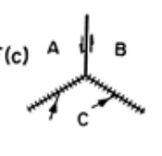
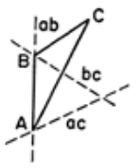
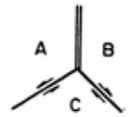
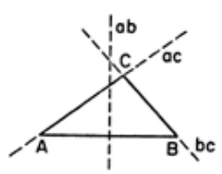
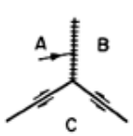
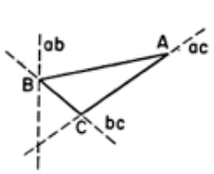
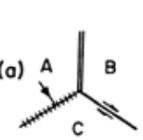
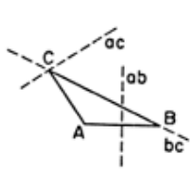
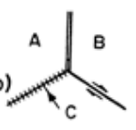
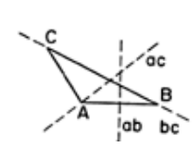
Triple junctions are places where three plates (and three boundaries) meet. E.g. at a ridge-ridge-ridge junction all the plates are separating, and all three are moving relative to the junction itself.

How do we calculate the velocity of the junction (over the "fixed" mantle) ?

Note ${}_A\mathbf{V}_B + {}_B\mathbf{V}_C + {}_C\mathbf{V}_A = 0$

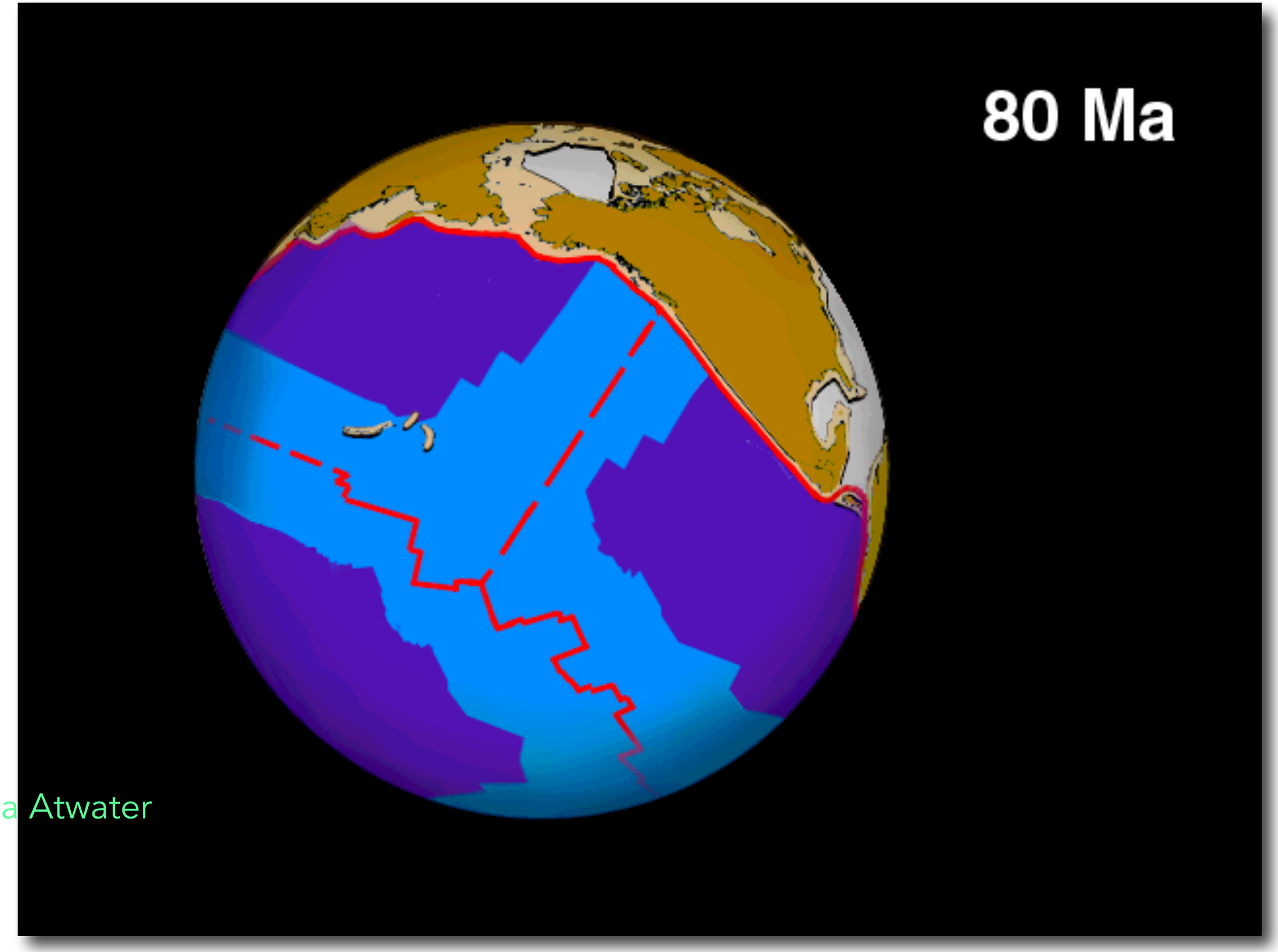
Triple junction rules can be complicated !

Type	Geometry	Velocity triangle	Stability	Examples
RRR			All orientations stable	East Pacific Rise and Galapagos Rift Zone[17,18] Great Magnetic Bight[19,20,22,23]
TTT(a)			Stable if *ab*, *ac* form a straight line, or if *bc* is parallel to the slip vector *CA*	Central Japan[3,21]
TTT(b)			Stable if the complicated general condition for *ab*, *bc* and *ac* to meet at a point is satisfied	
FFF			Unstable	
RRT			*ab* must go through centroid of *ABC*	
RRF			Unstable, evolves to *FFR*	
TTR(a)			Stable if *ab* goes through *C*, or if *ac*, *bc* form a straight line	
TTR(b)			Stable if complicated general conditions are satisfied	

Type	Geometry	Velocity triangle	Stability	Examples
TTR(c)			Stable if the angles between *ab* and *ac*, *bc*, respectively, are equal, or if *ac*, *bc* form a straight line	
TTF(a)			Stable if *ac*, *bc* form a straight line, or if *C* lies on *ab*	Intersection of the Peru–Chile trench and the West Chile Ridge[10]
TTF(b)			Stable if *bc*, *ab* form a straight line, or if *ac* goes through *B*	
TTF(c)			Stable if *ab*, *ac* form a straight line, or if *ab*, *bc* do so	
FFR			Stable if *C* lies on *ab*, or if *ac*, *bc* form a straight line	Owen fracture zone and the Carlsberg Ridge[24,25] West Chile Ridge and the East Pacific Rise[10,26]
FFT			Stable if *ab*, *bc* form a straight line, or if *ac*, *bc* do so	San Andreas fault and Mendocino fracture zone[3,4]
RTF(a)			Stable if *ab* goes through *C*, or if *ac*, *bc* form a straight line	Mouth of the Gulf of California[3,27]
RTF(b)			Stable if *ac*, *ab* cross on *bc*	

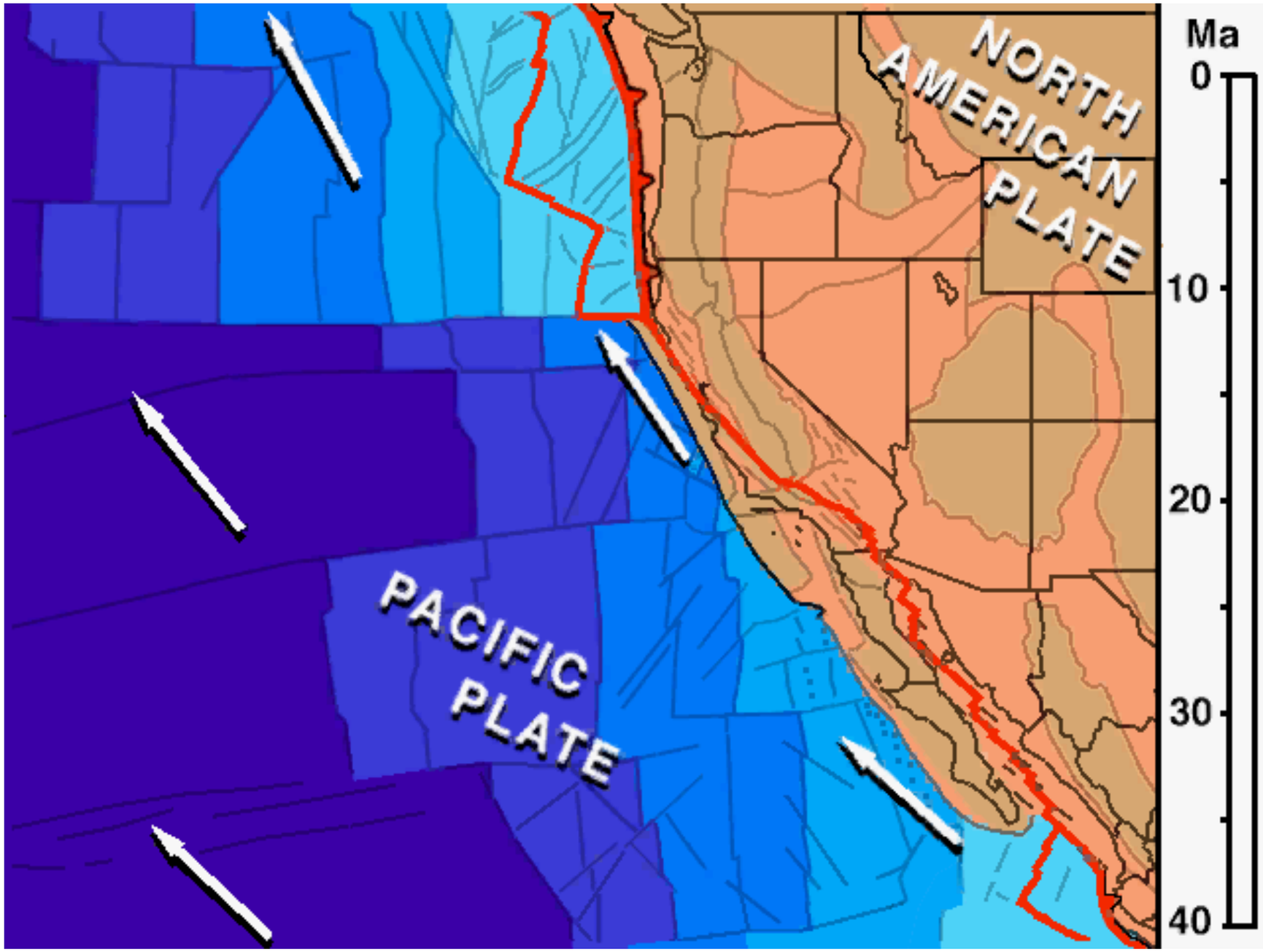
McKenzie & Parker 1967

Reconstructing past plates / boundaries



Tanya Atwater

Reconstructing past reconfigurations



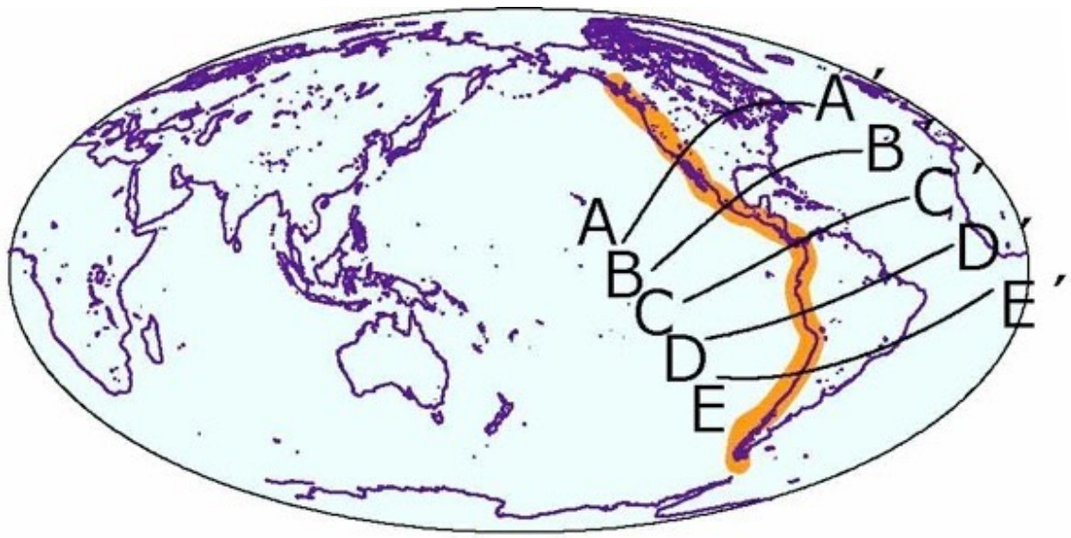
How do we know there was a Farallon plate ?

When does the San Andreas fault system appear ?

The Farallon slab

Still very obvious in tomographic images

- Clearly detached from surface where mid-ocean ridge was subducted



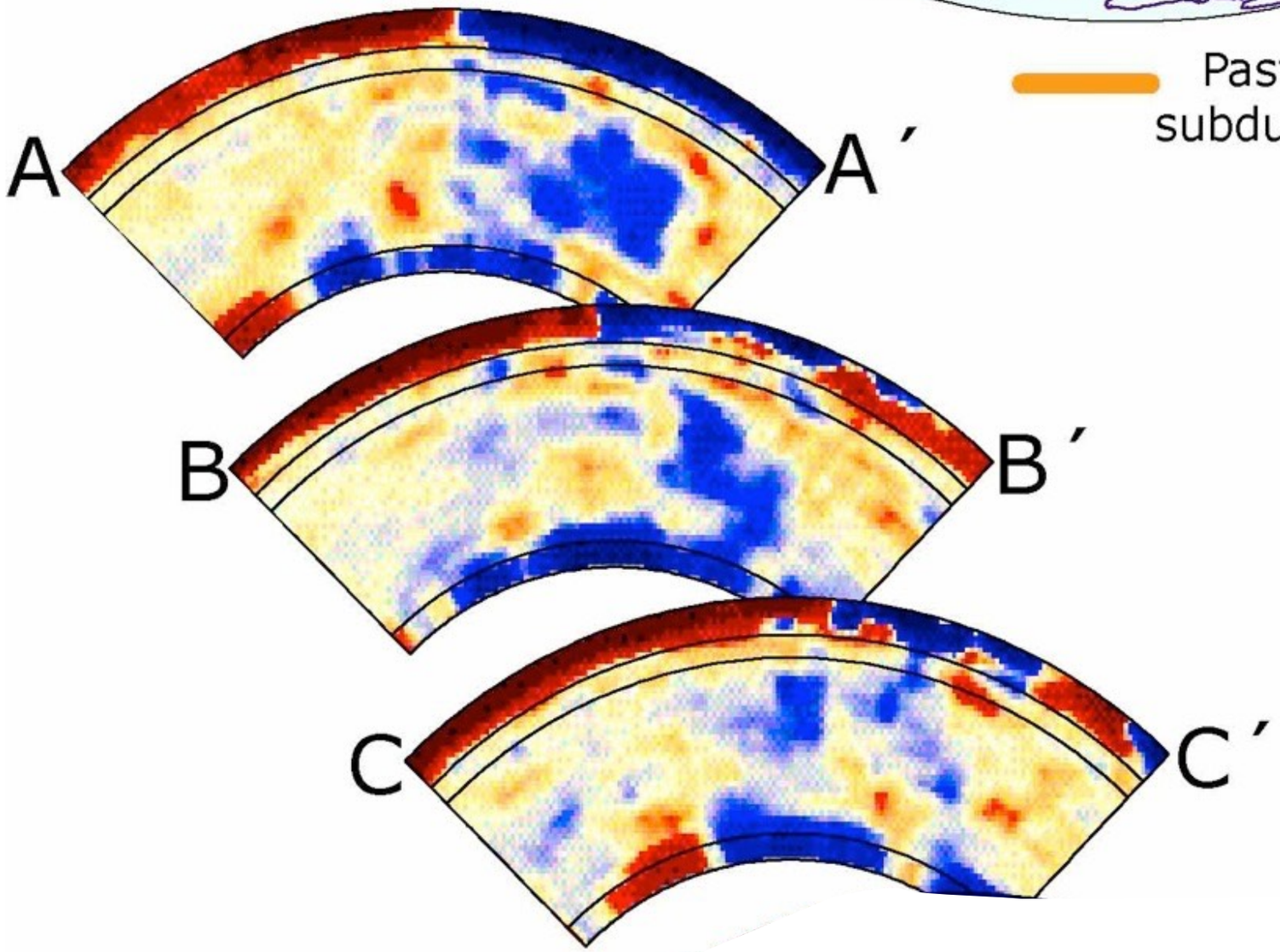
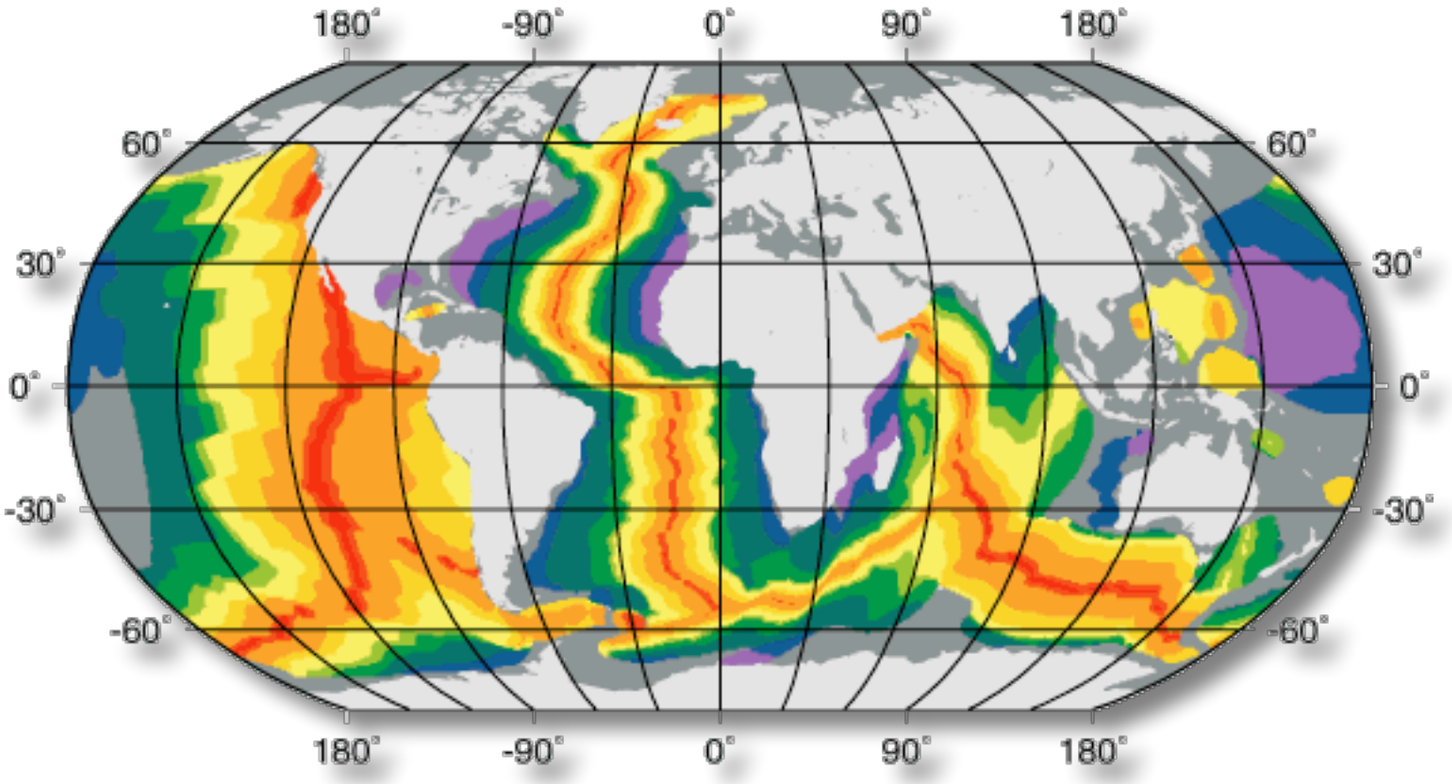


Plate boundary effects in the continent

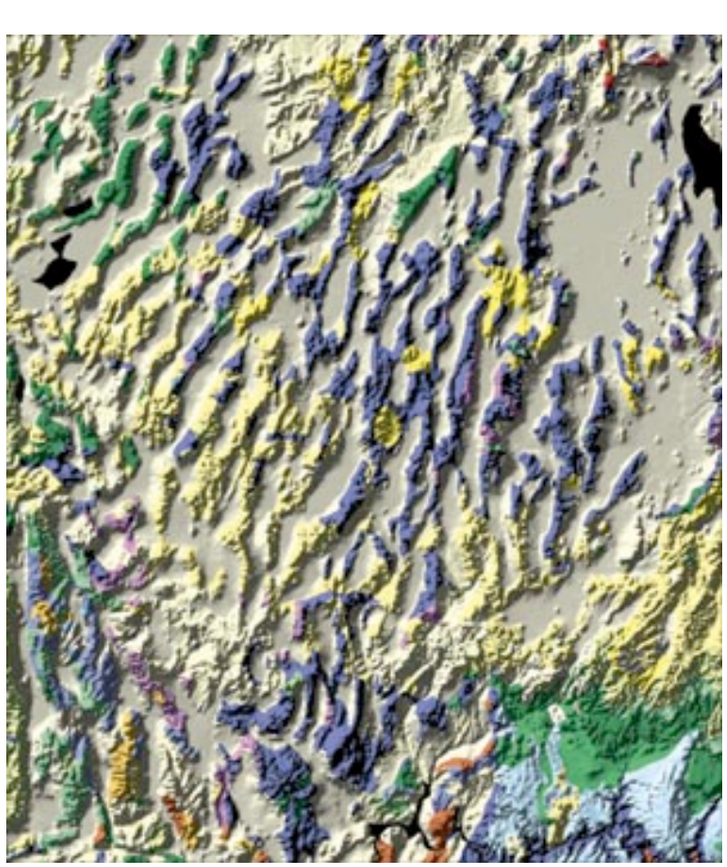


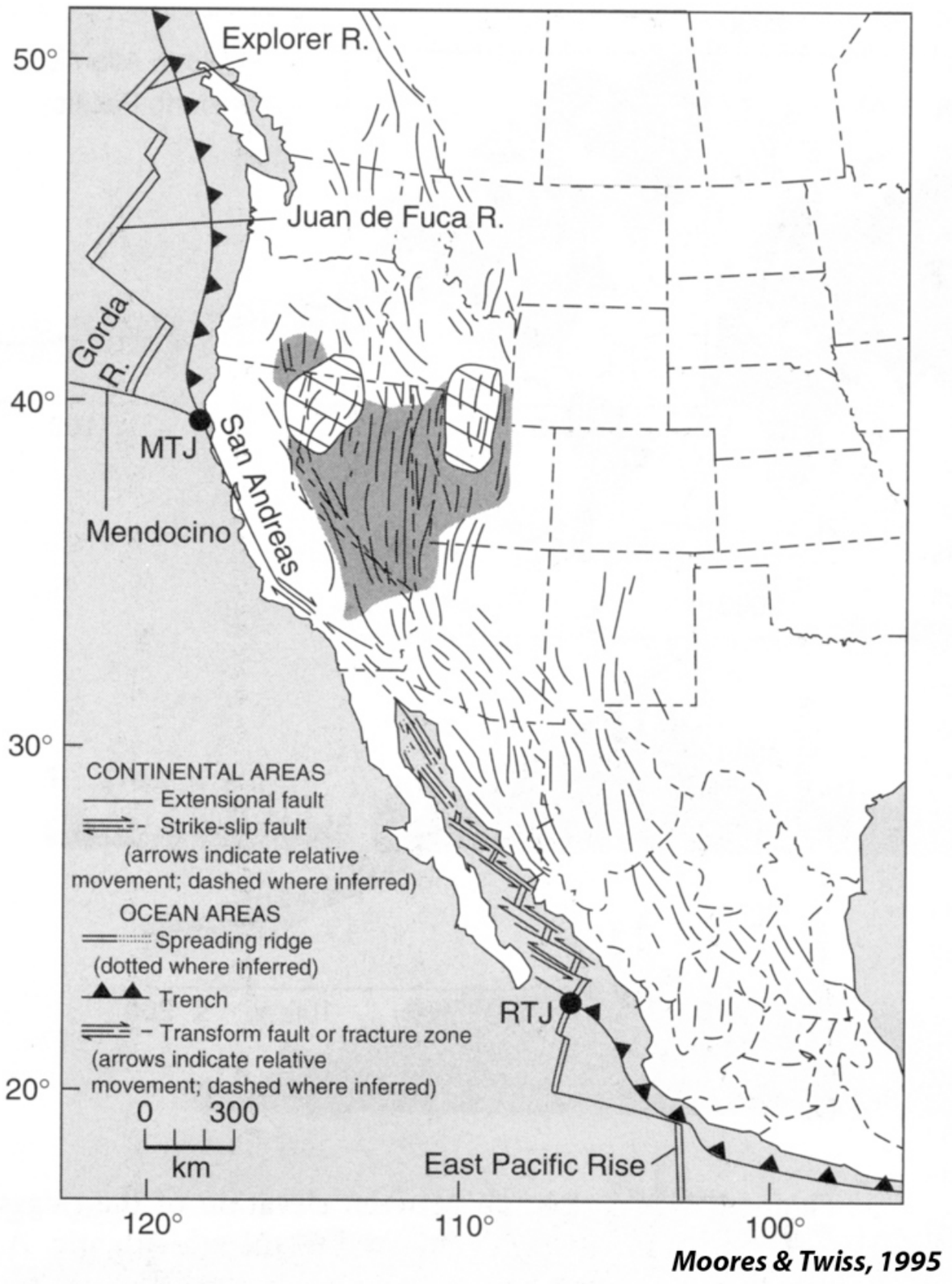
The continental crust records the changes in the plate boundary but a lot more ambiguity than in the sea floor stripes

Basin and range

Extensional tectonics

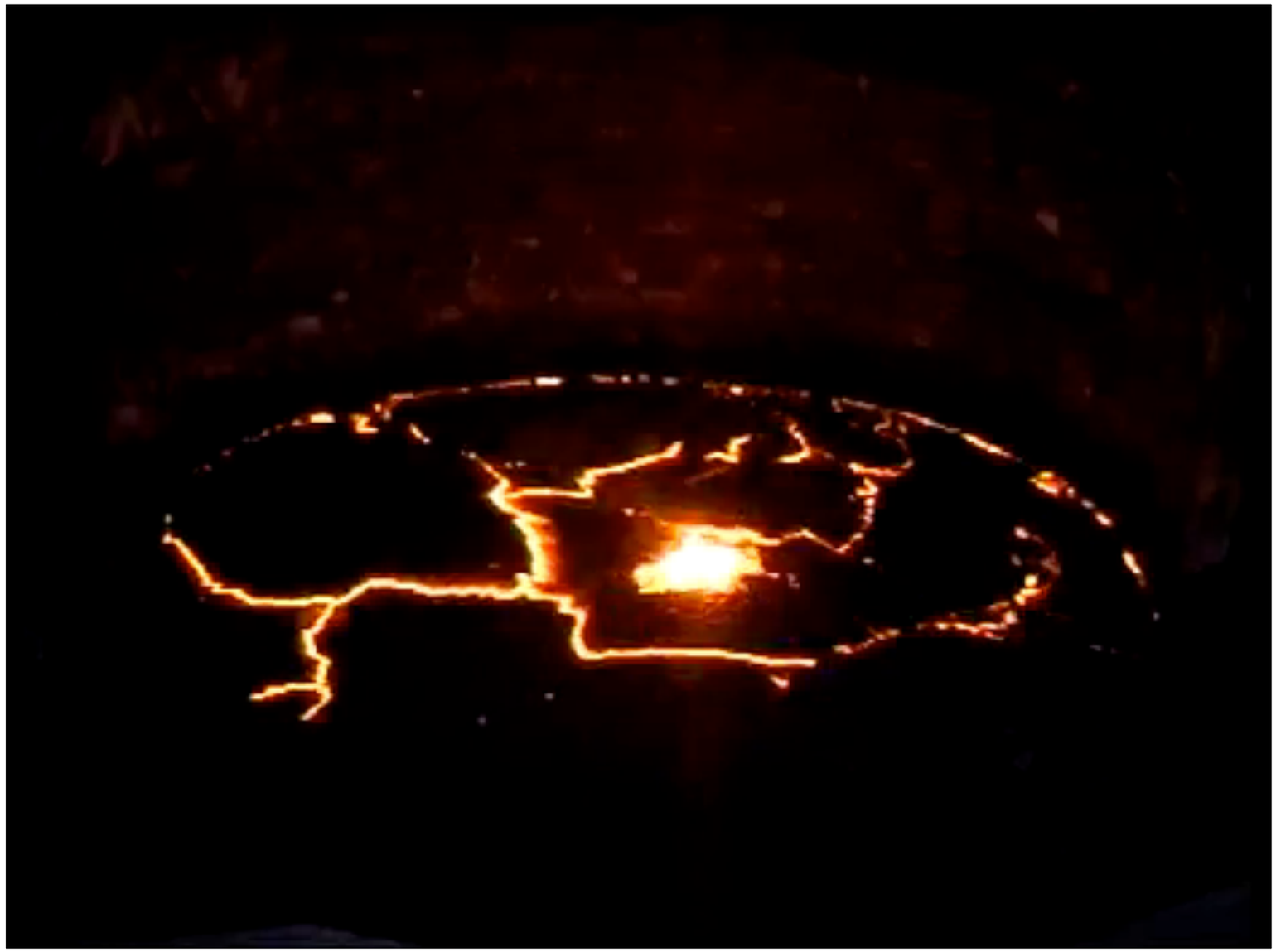
- Change of plate boundary forces
- Coupling to Pacific plate
- Slab detachment / thermal effects





Moores & Twiss, 1995

Lava Lake Tectonics

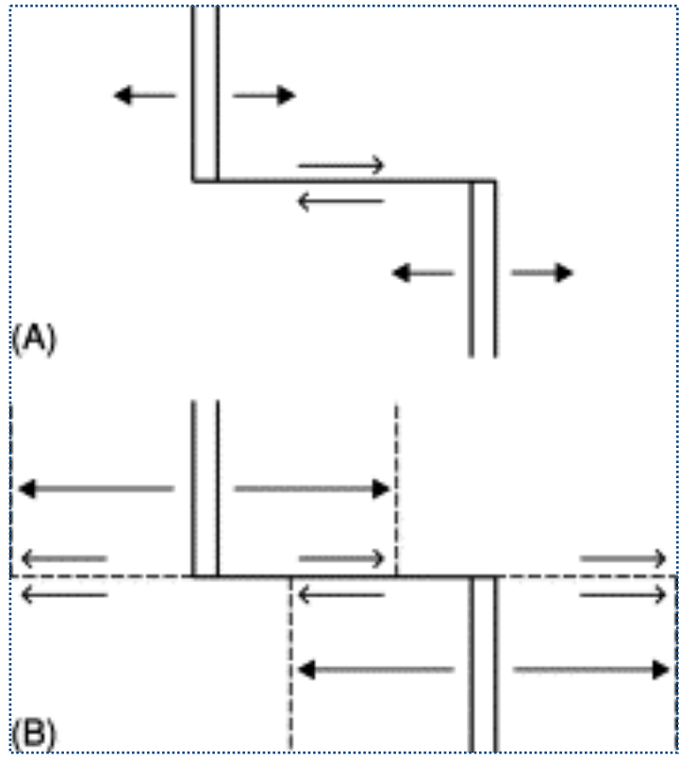


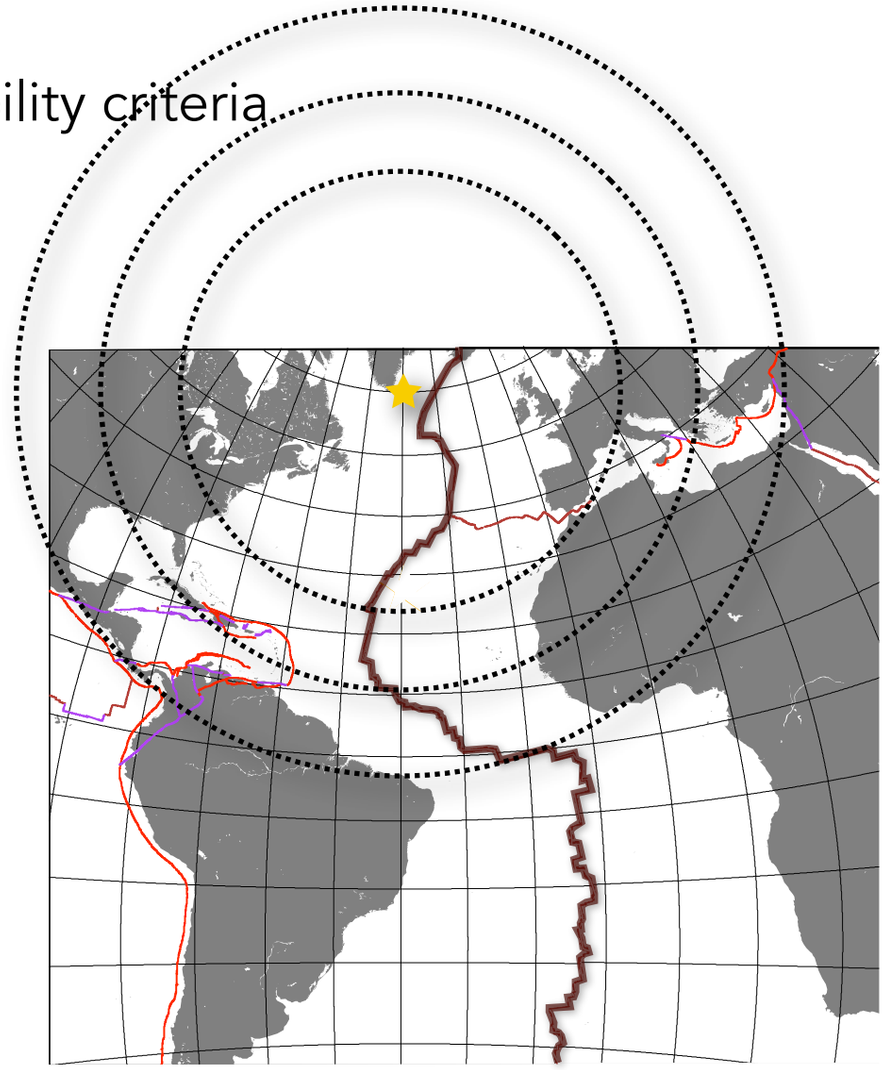
- Note how spreading centres move across the lake as spreading progresses
- Different rates for different plates, rearrangements.

How do we evolve plate boundaries ?

The “rules” of plate kinematics work well for oceanic plate boundaries under most circumstances. To apply them we need to look at:

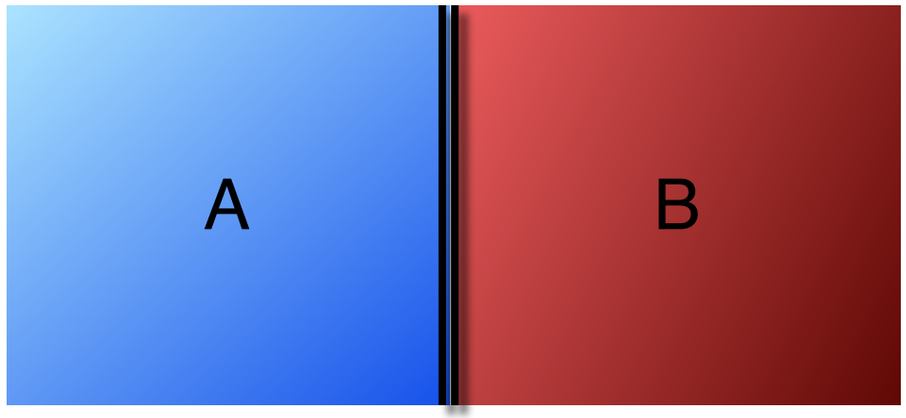
- Relative nature of plate motion
- Addition of plate motion vectors
- Hotspot tracks
- Triple junctions & stability criteria



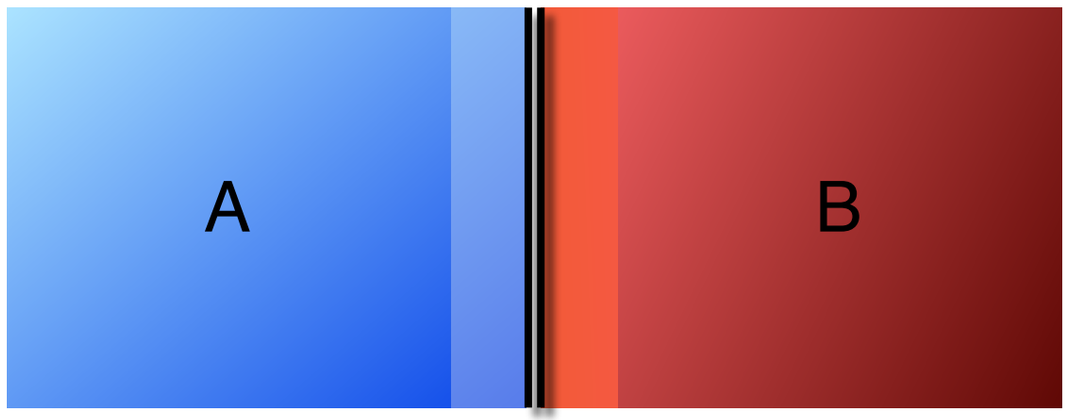


Relative velocities

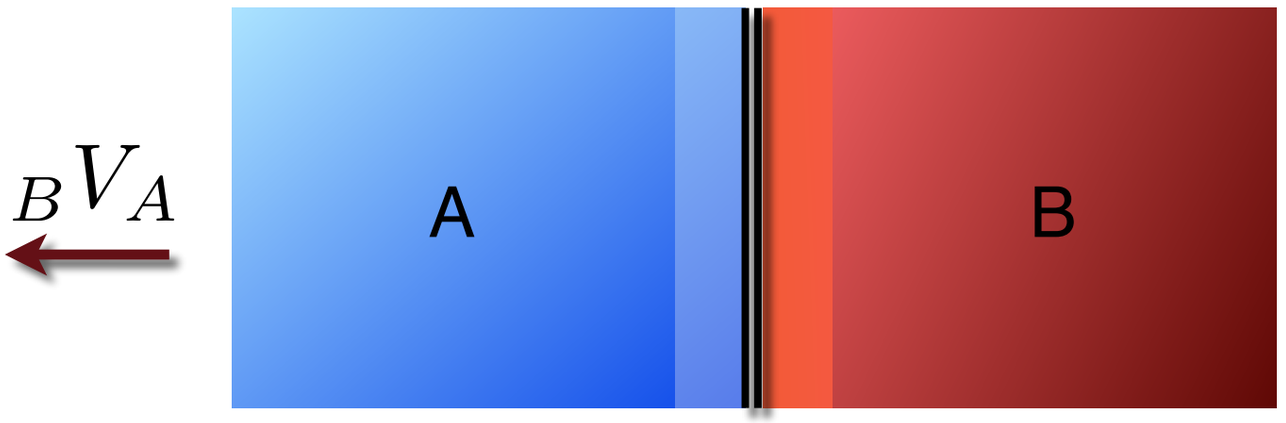
Today



Some time later...



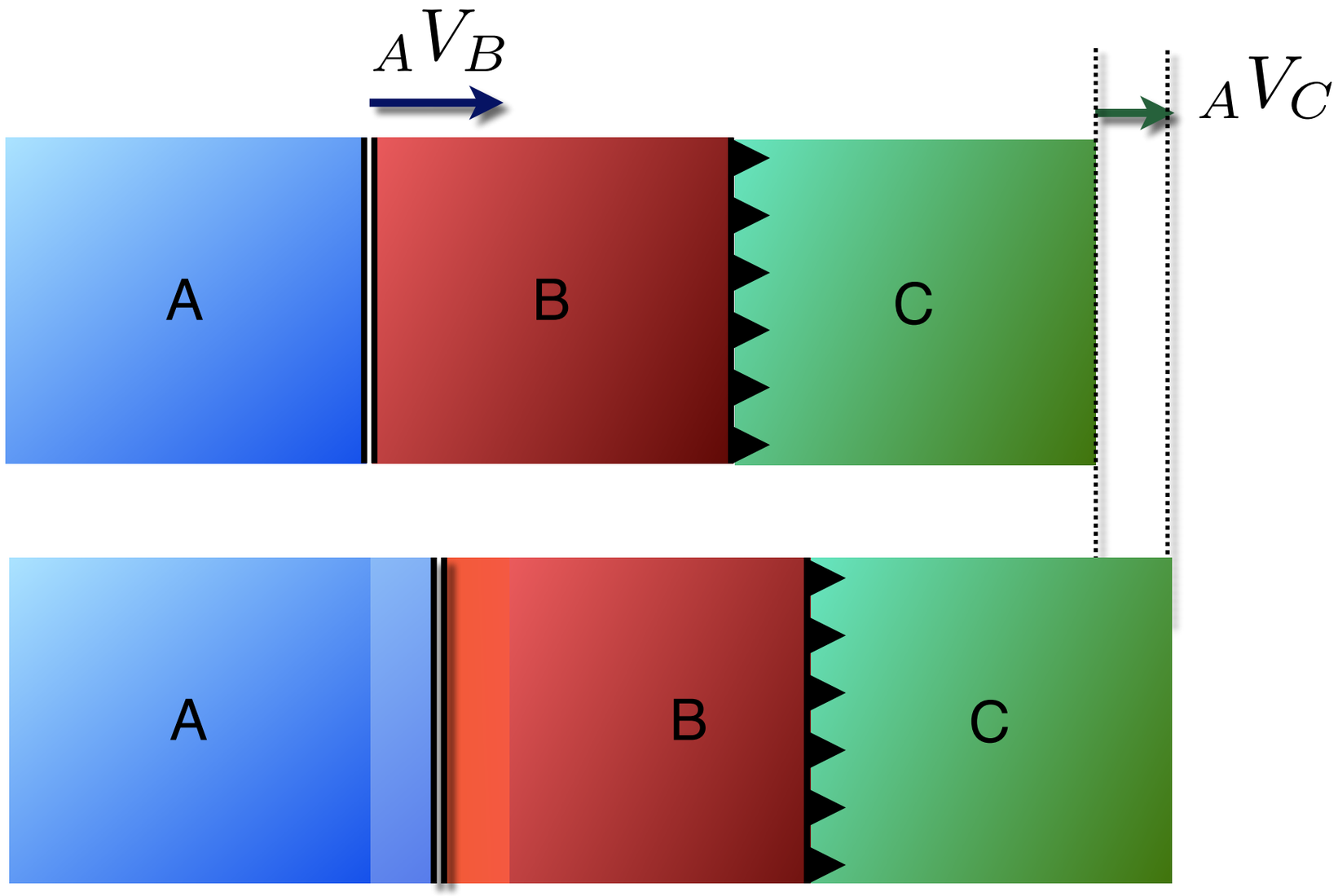
$_AV_B$



$_BV_A$

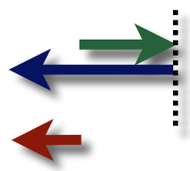
$$_BV_A = -_AV_B$$

Relative velocities



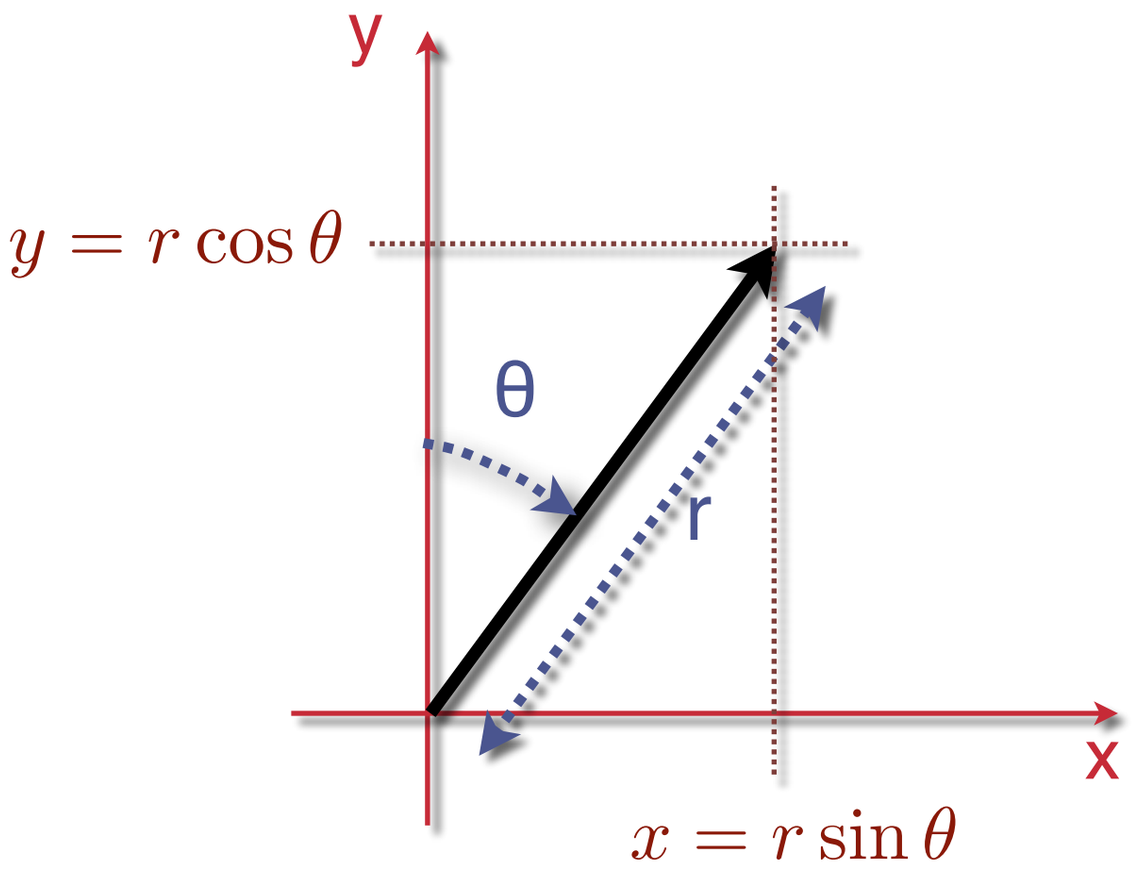
$$_AV_C = {}_AV_B + {}_BV_C$$

$$_BV_C = {}_AV_C - {}_AV_B = {}_AV_C + {}_BV_A$$



Detour — vectors

- Have magnitude and direction
- Examples:
  - Velocity (speed in given direction)
  - Acceleration
  - Displacement (offset and direction)
- Described in terms of
  - Length and Direction (r,θ)
  - Cartesian offset (x,y)



$$\mathbf{d} = (d_1, d_2) = (r\sin\theta, r\cos\theta)$$

Think of giving someone directions by compass bearing *"to get to the pub from here, walk one hundred metres in a roughly north-easterly direction ..."*

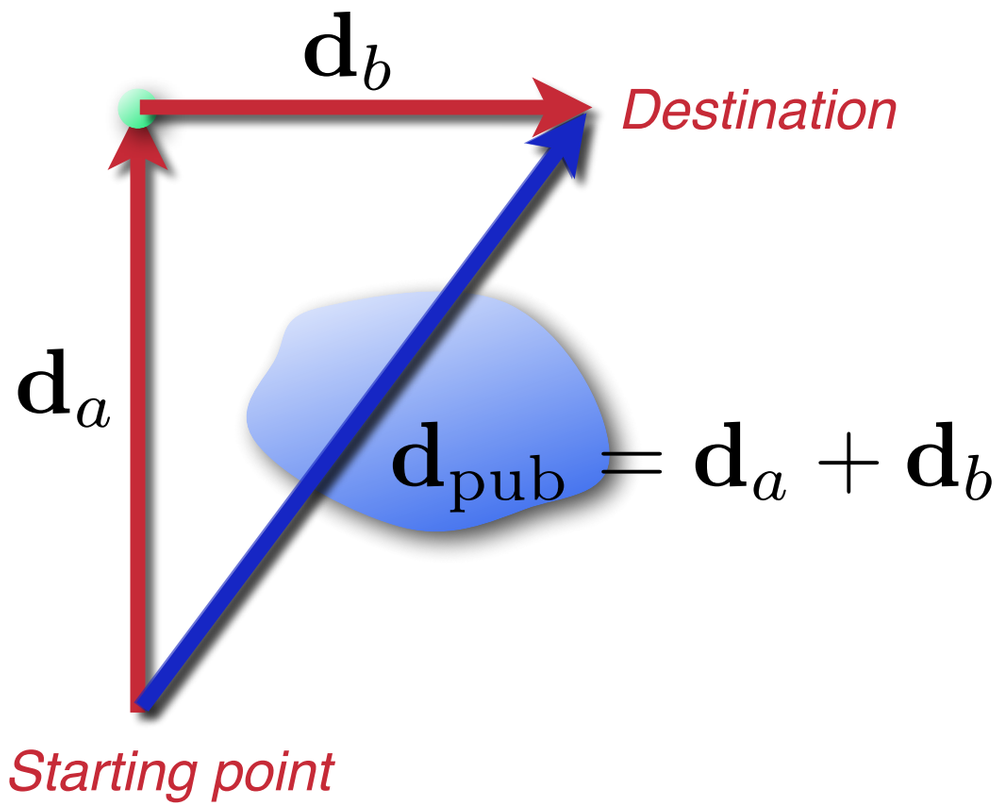
Detour — vector addition

$$\mathbf{d}_a = (0, 80)$$

$$\mathbf{d}_b = (60, 0)$$

$$\mathbf{d}_{\text{pub}} = (60, 80)$$

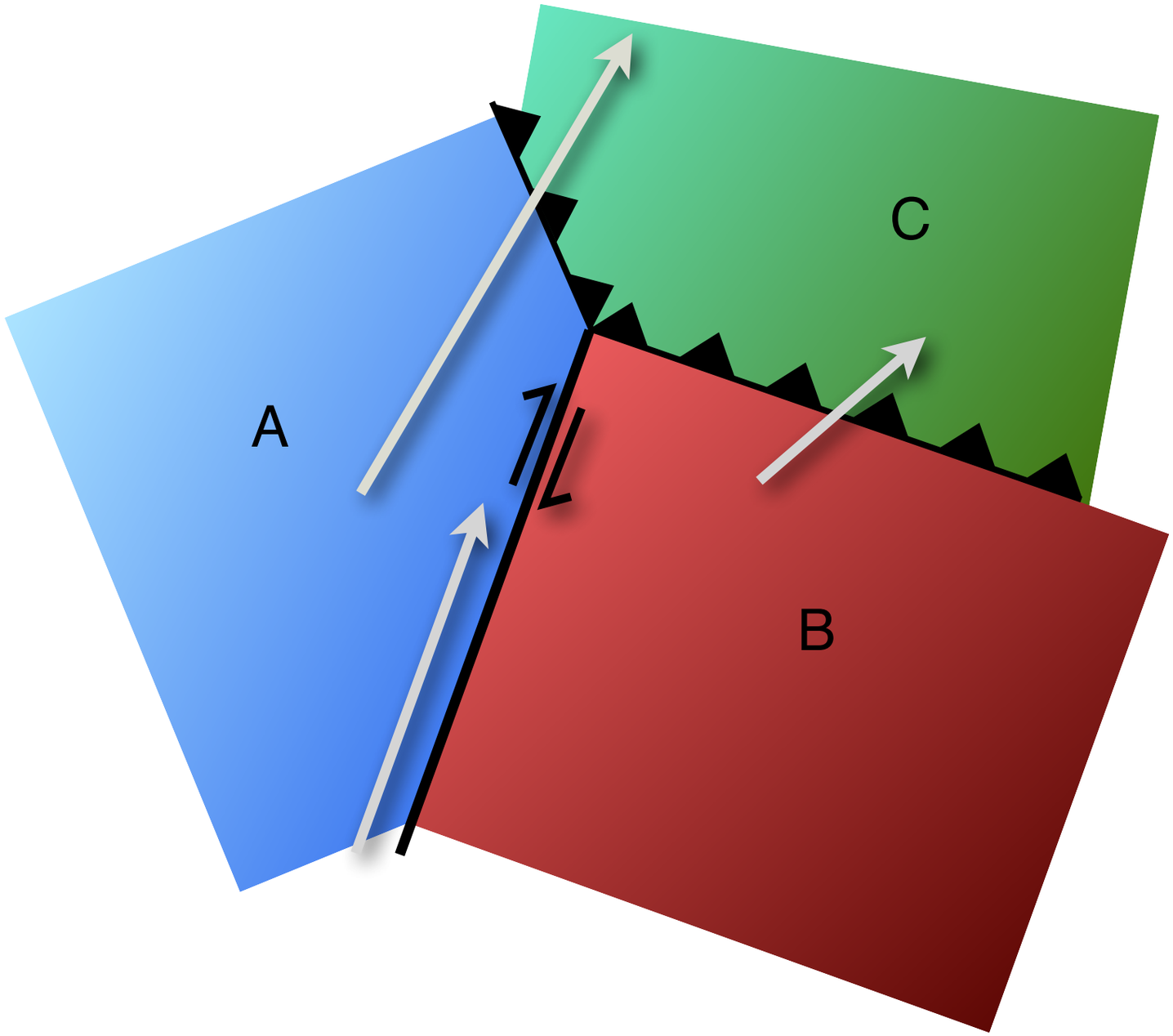
$$|\mathbf{d}_{\text{pub}}| = \sqrt{60^2 + 80^2}$$

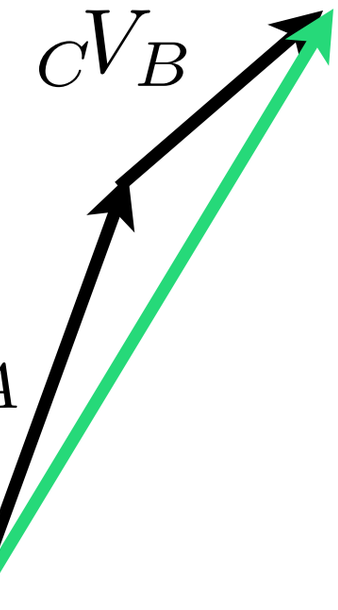


To add vectors we can think again of “adding” compass bearings

“To get to the pub (without falling in the lake) walk 80 metres North and then 60 metres East ... “

Non-orthogonal boundaries





$$_CV_A = {}_CV_B + {}_BV_A$$

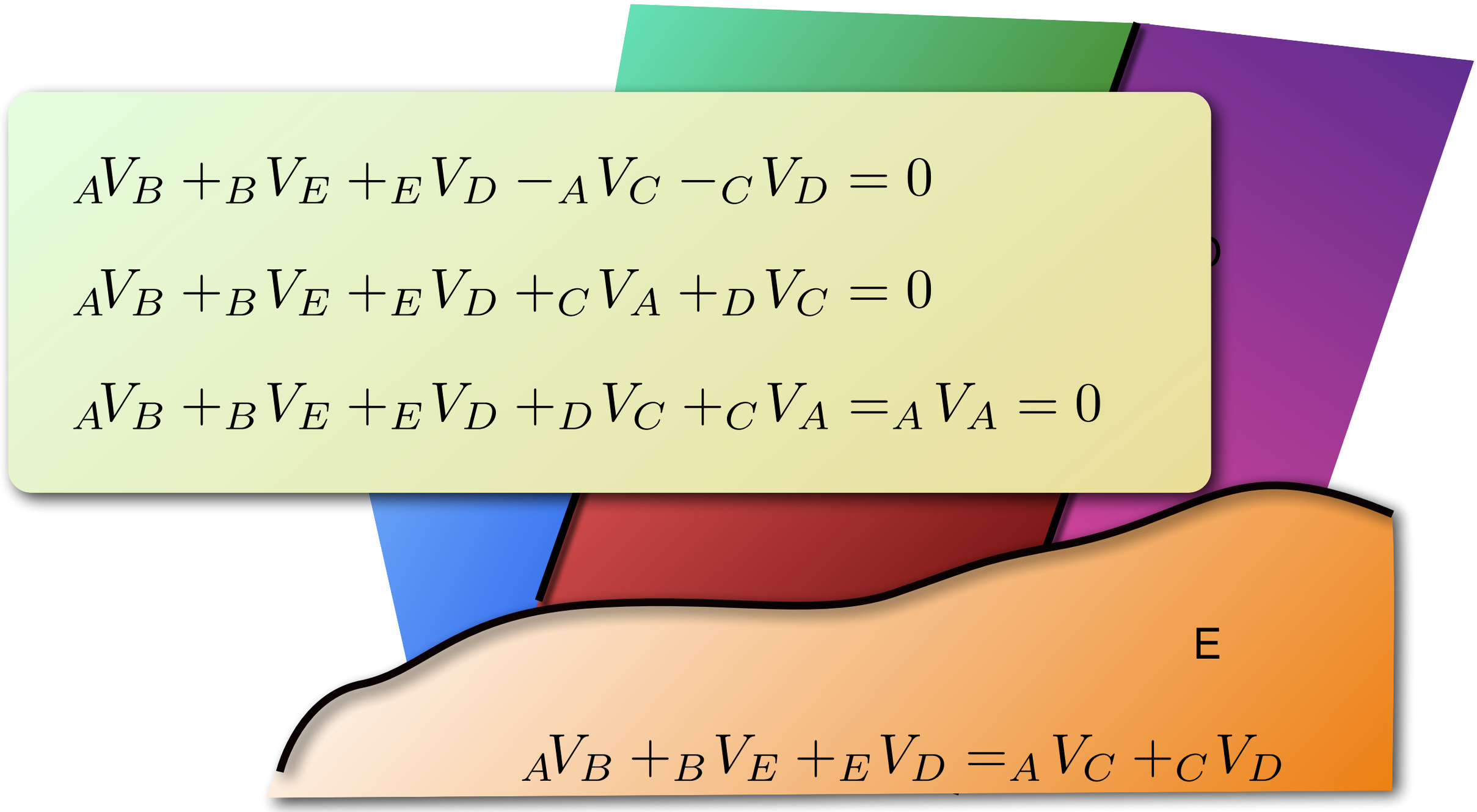
Plate circuits

Generalize the previous example — no matter what the plate boundary types ...

$$ {}_AV_B + {}_BV_E + {}_EV_D - {}_AV_C - {}_CV_D = 0 $$

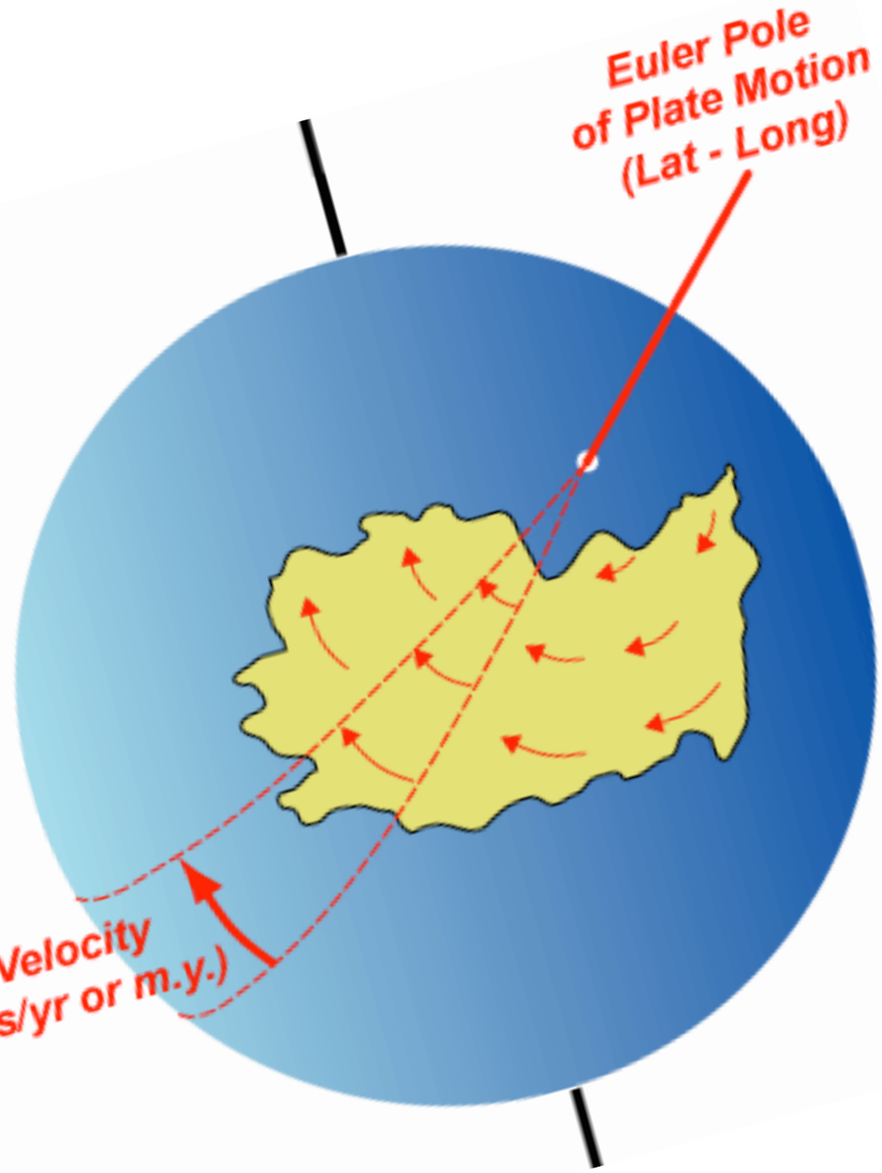
$$ {}_AV_B + {}_BV_E + {}_EV_D + {}_CV_A + {}_DV_C = 0 $$

$$ {}_AV_B + {}_BV_E + {}_EV_D + {}_DV_C + {}_CV_A = {}_AV_A = 0 $$



Motions on a sphere

So far we have looked at everything as though it were happening on a flat Earth ... This is not the case, and on a plate scale, the curvature cannot be ignored.

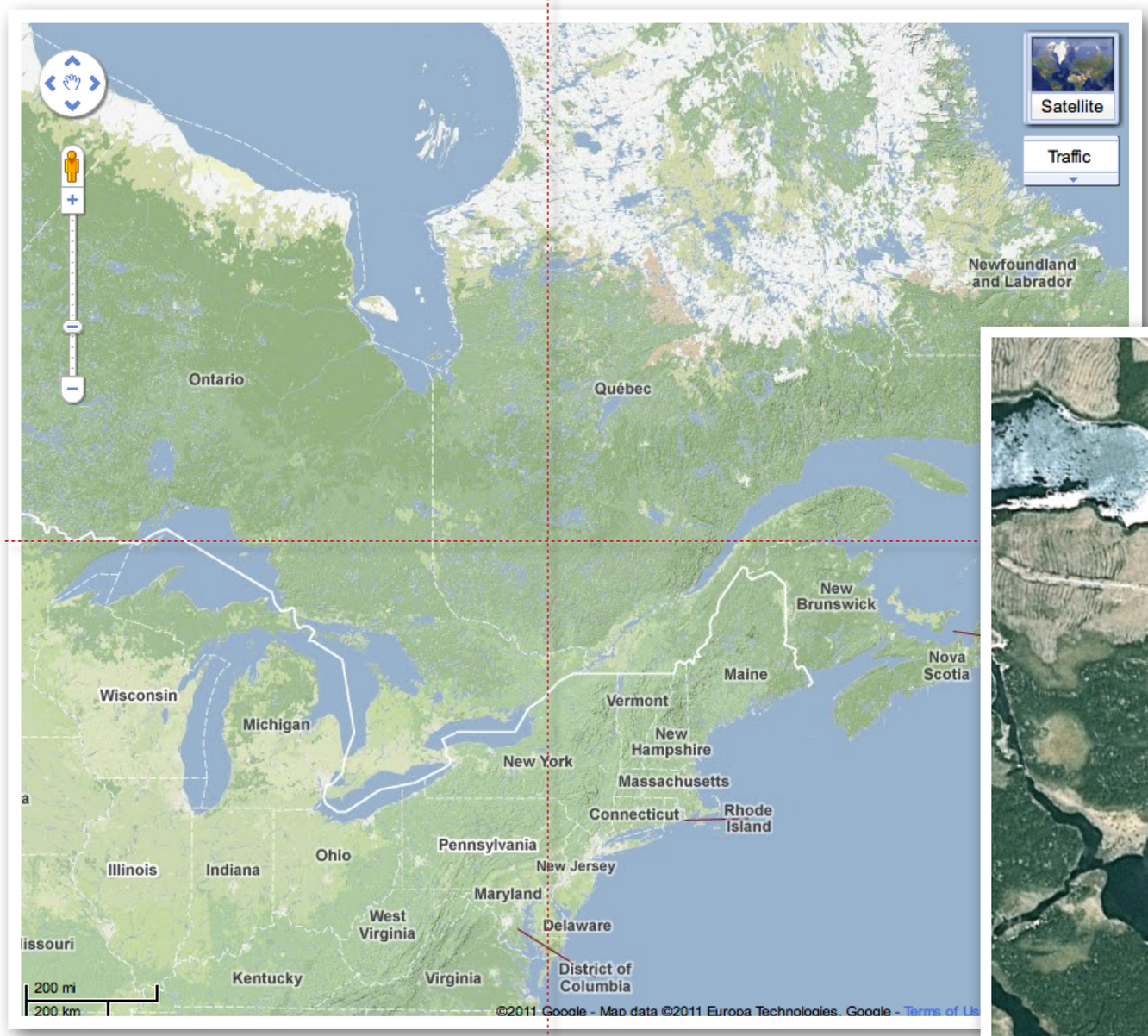


Consequences:

- The (relative) motion of plates is described by rotation pole and angular velocity
- Transform faults lie along small circles relative to this pole
- The velocity (magnitude & direction) of points on a plate varies systematically over the plate

To describe plate motions and do reconstructions we need to understand how to move plates on the surface of a sphere. We also need to understand how to do this quantitatively.

Pacific / North America Rotation Pole



Transform faults v. Fracture zones

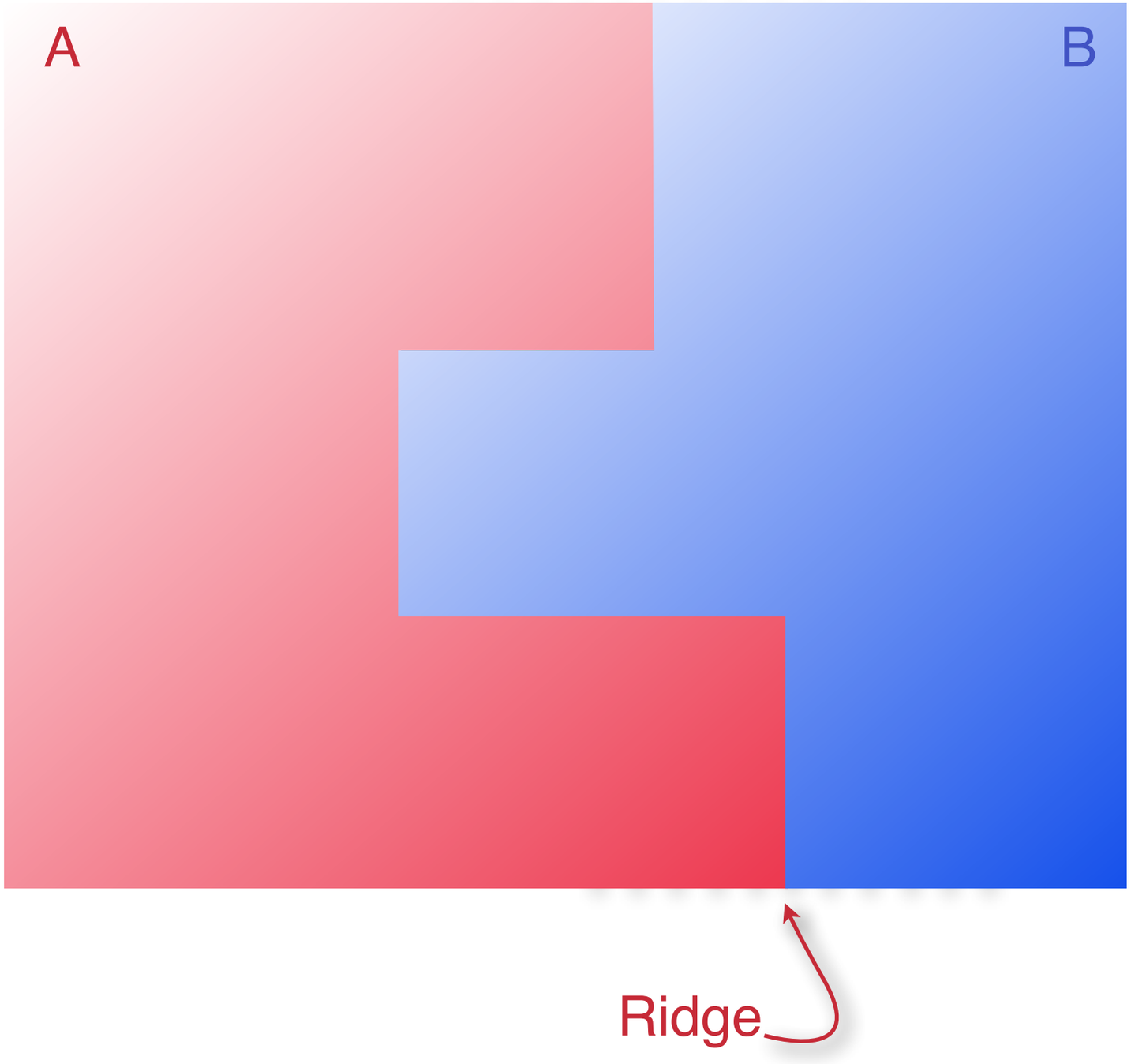
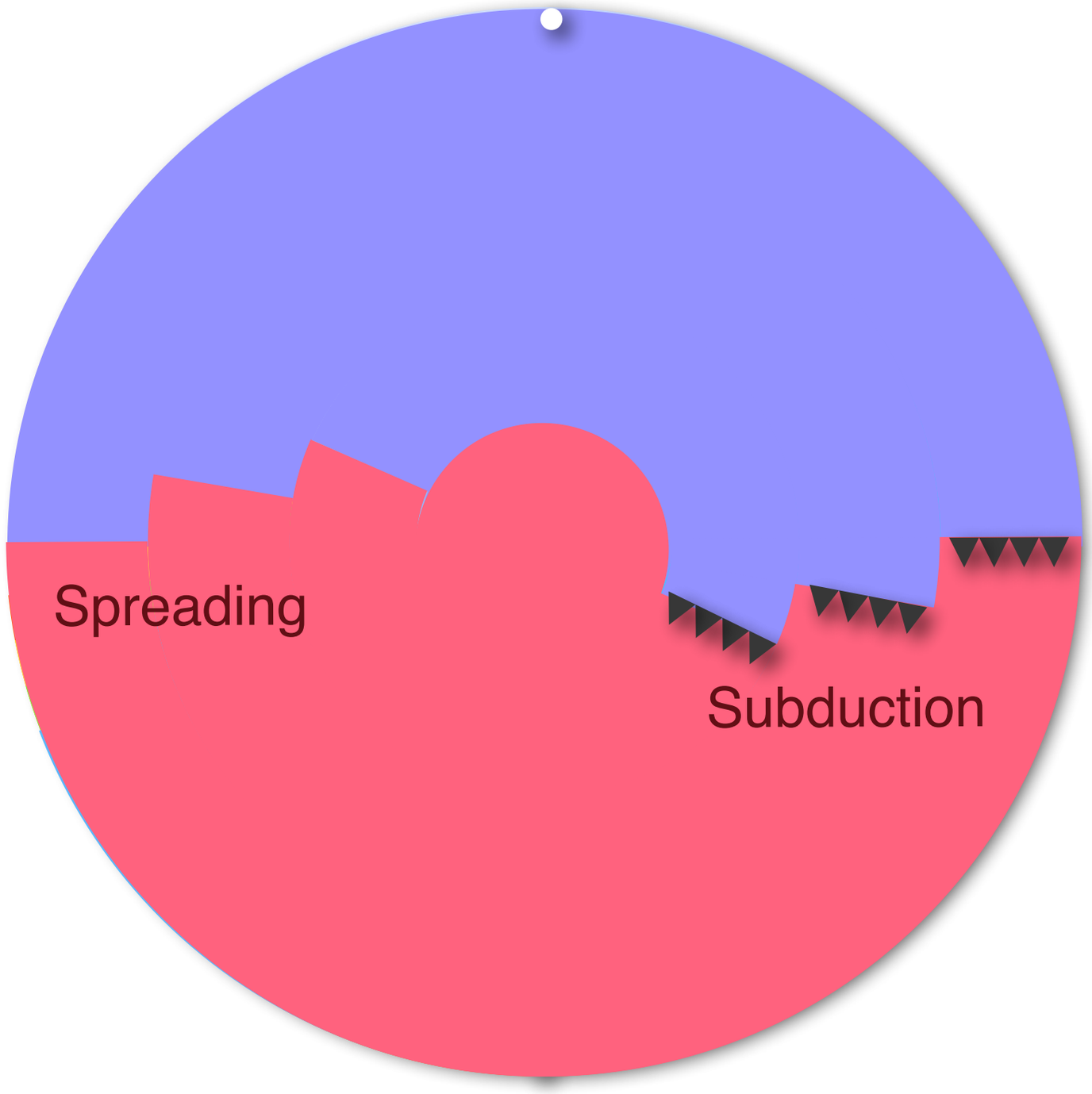
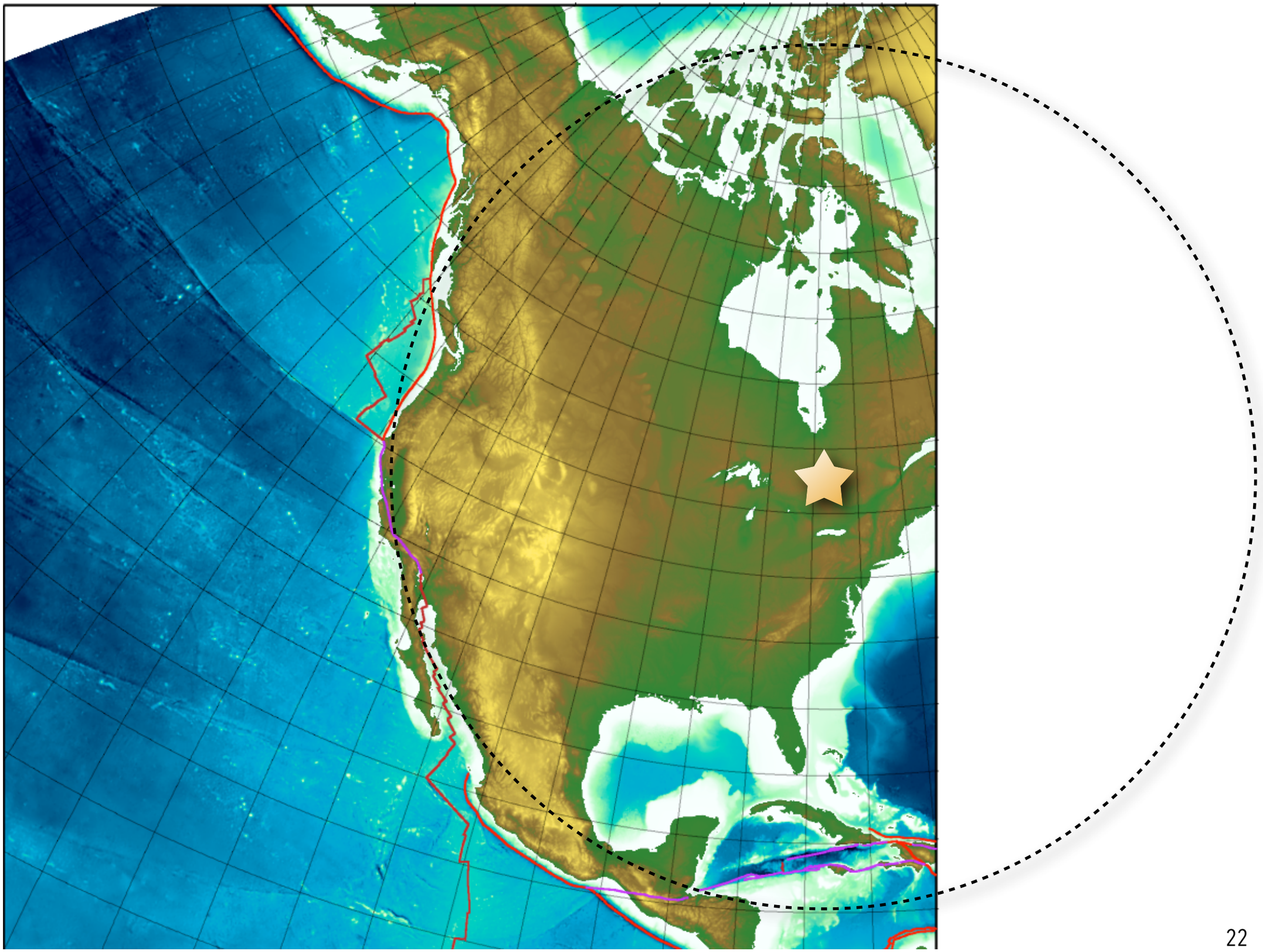


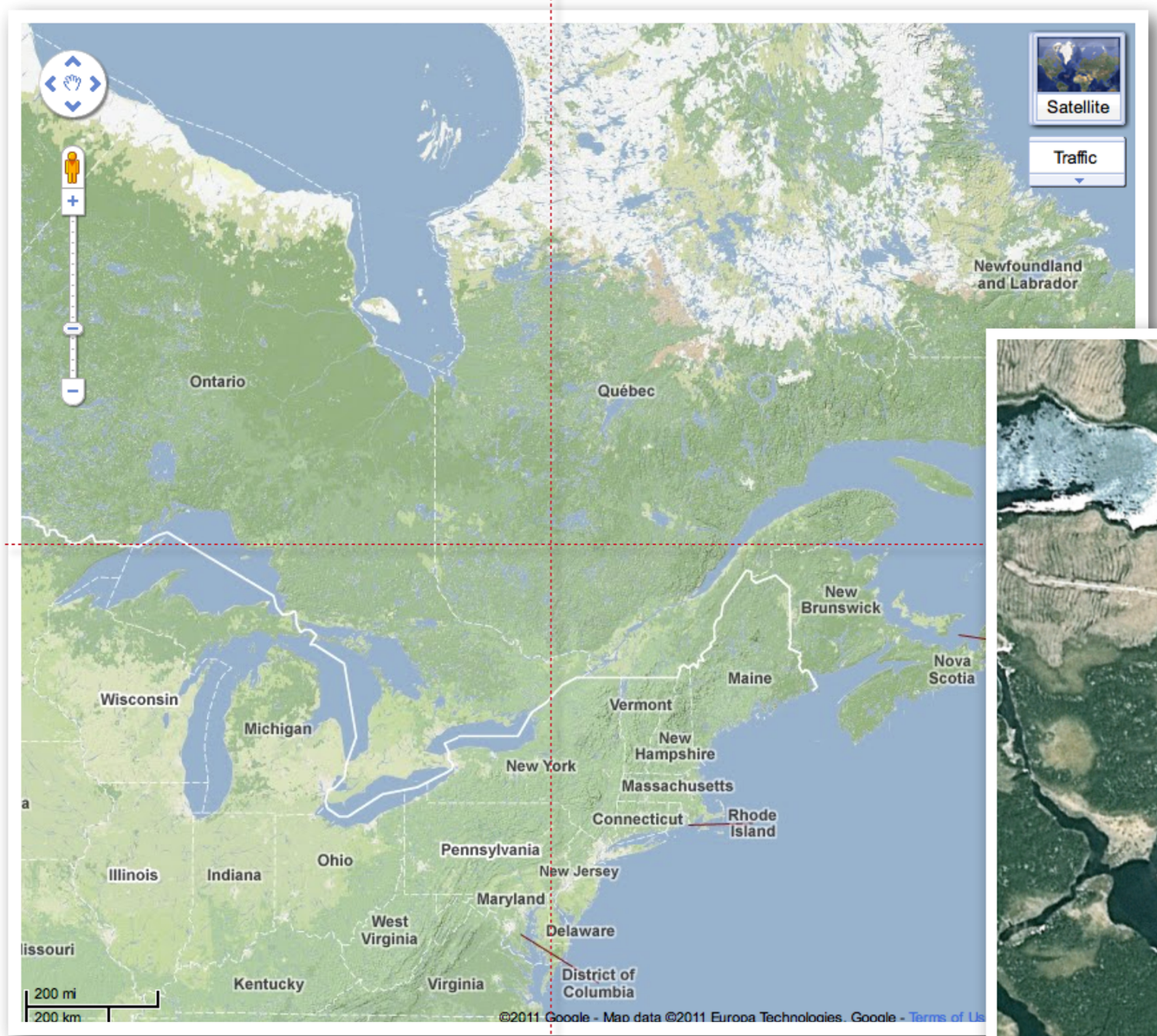
Plate motions on a sphere



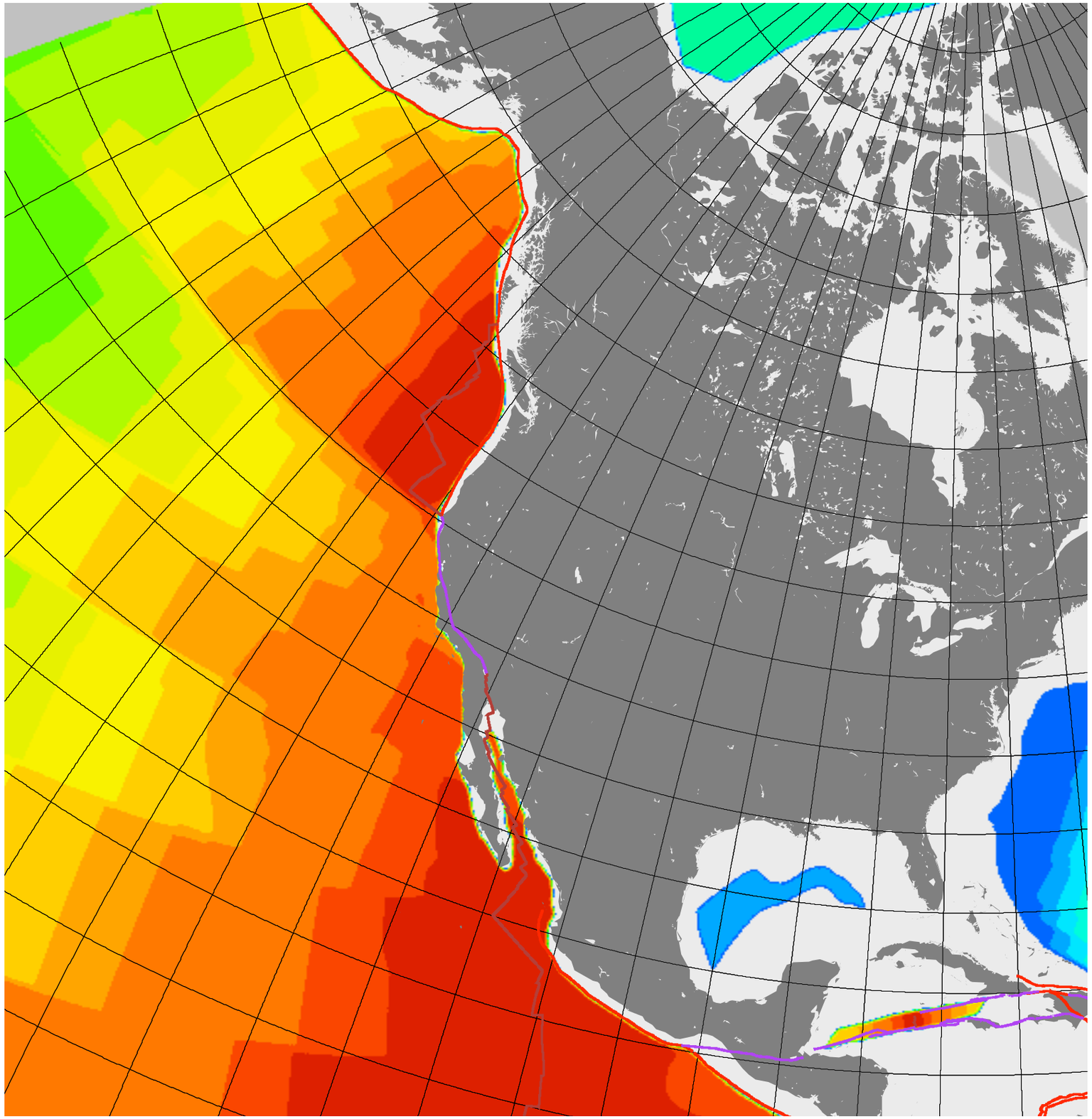
North America / Pacific elevation

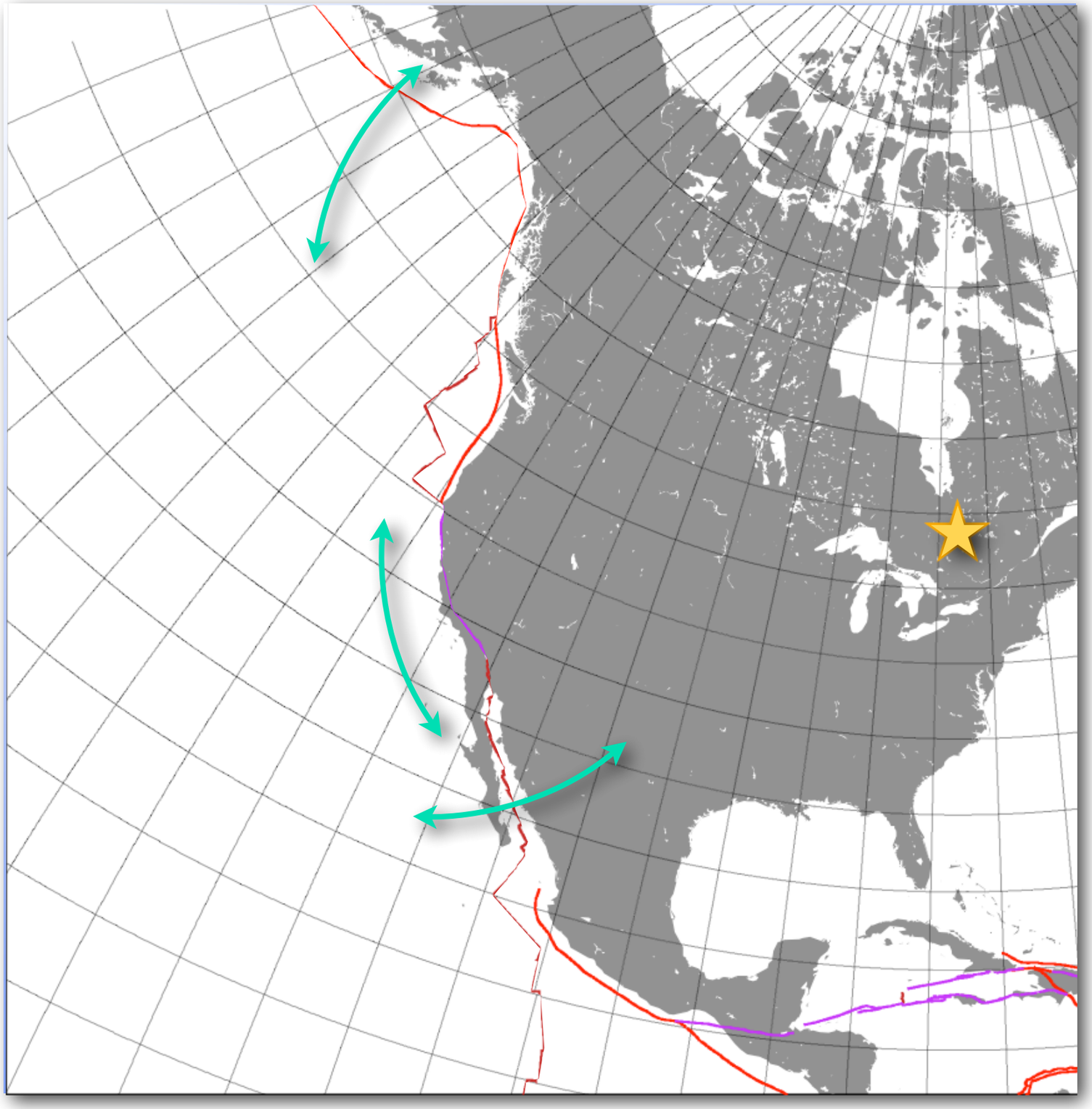


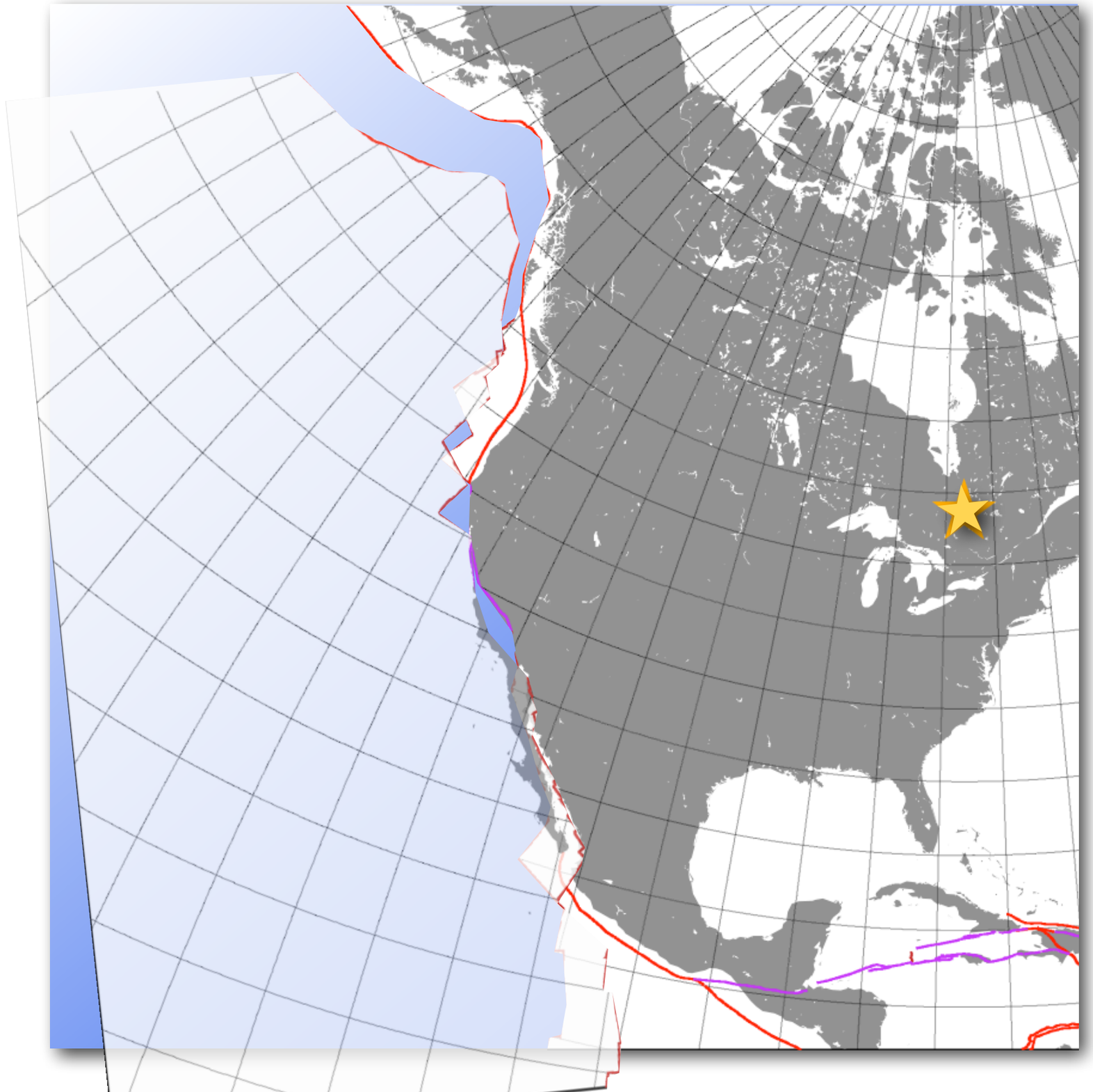
Pacific / North America Rotation Pole

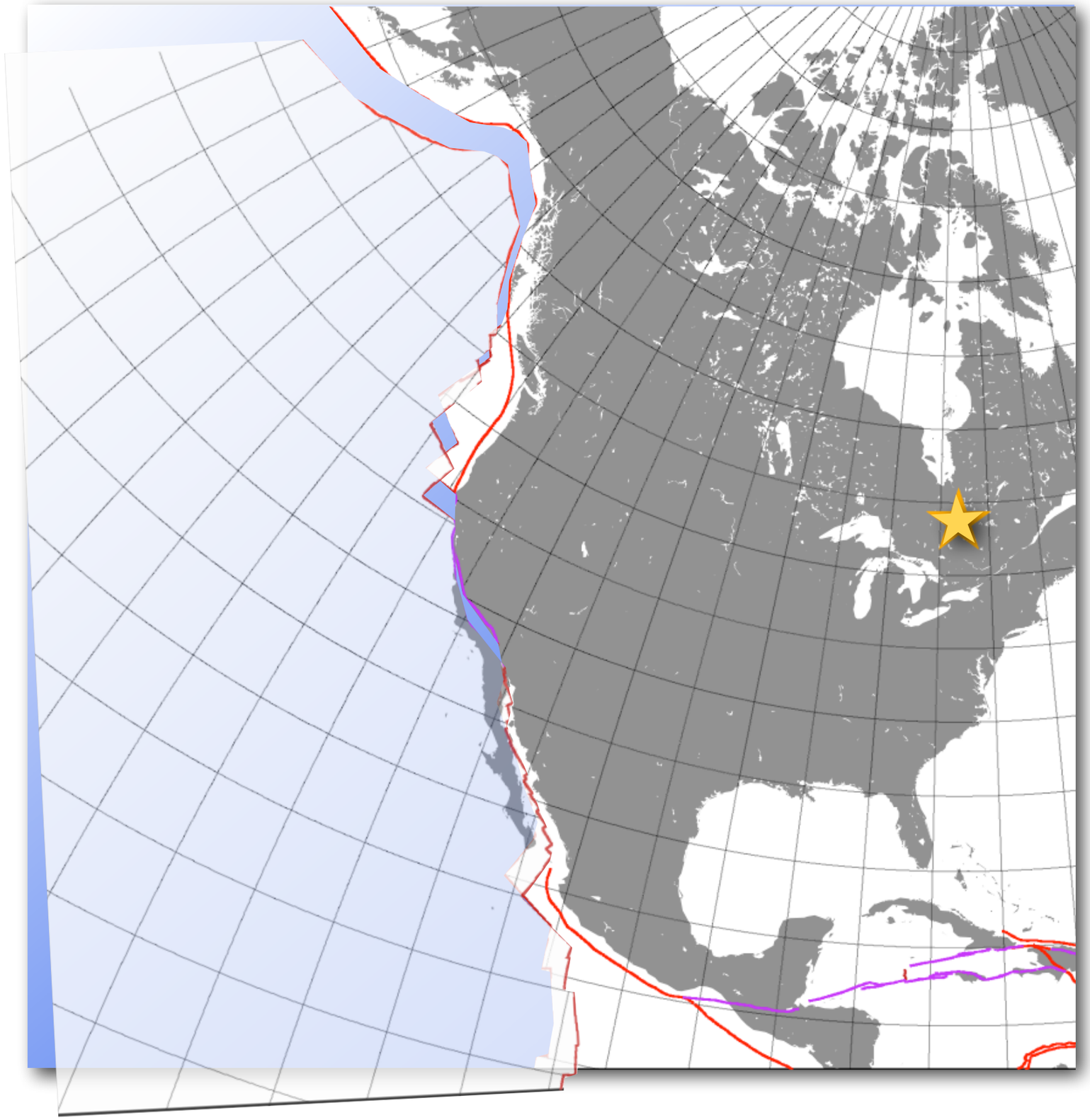


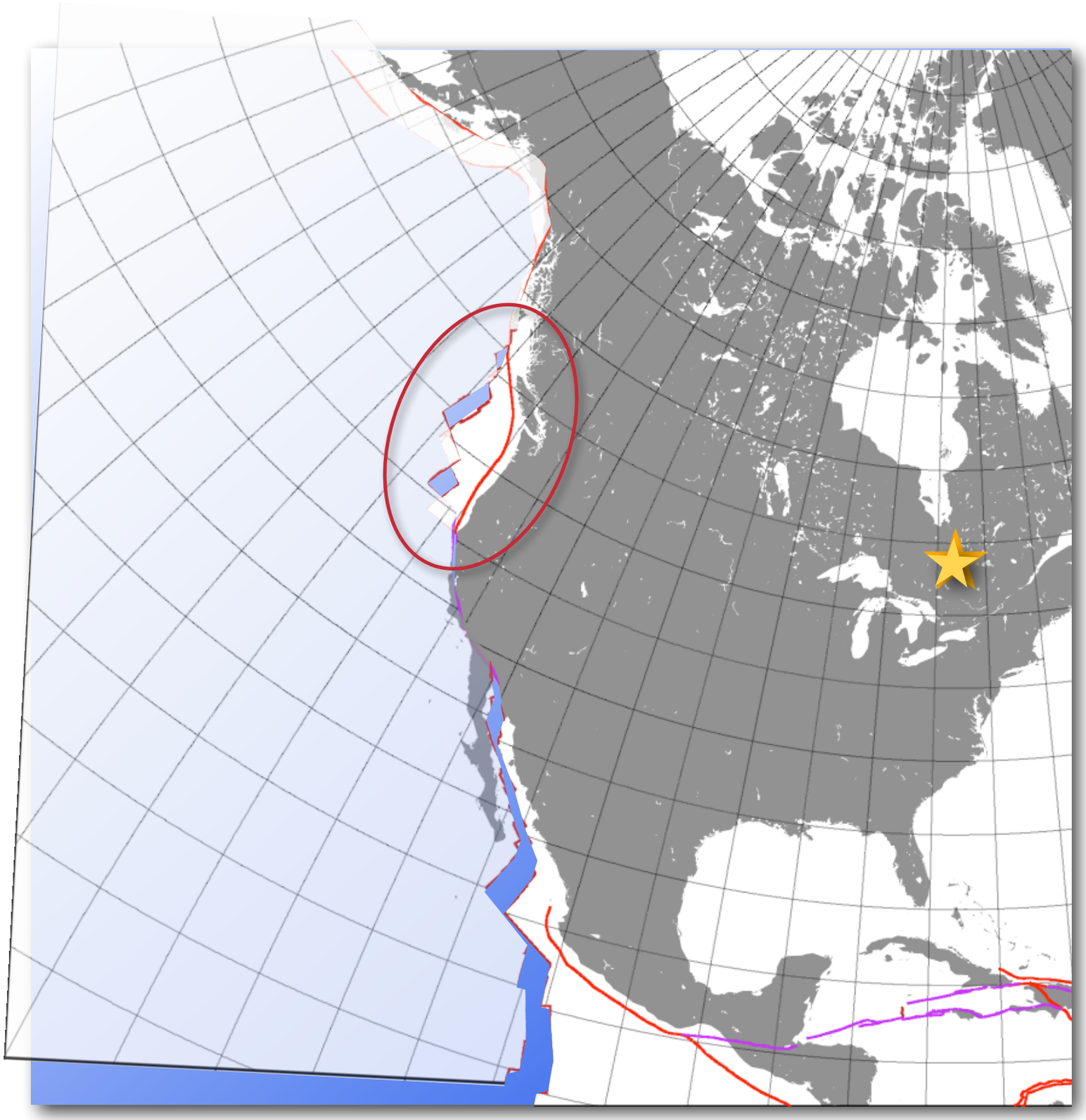
Pacific age grid



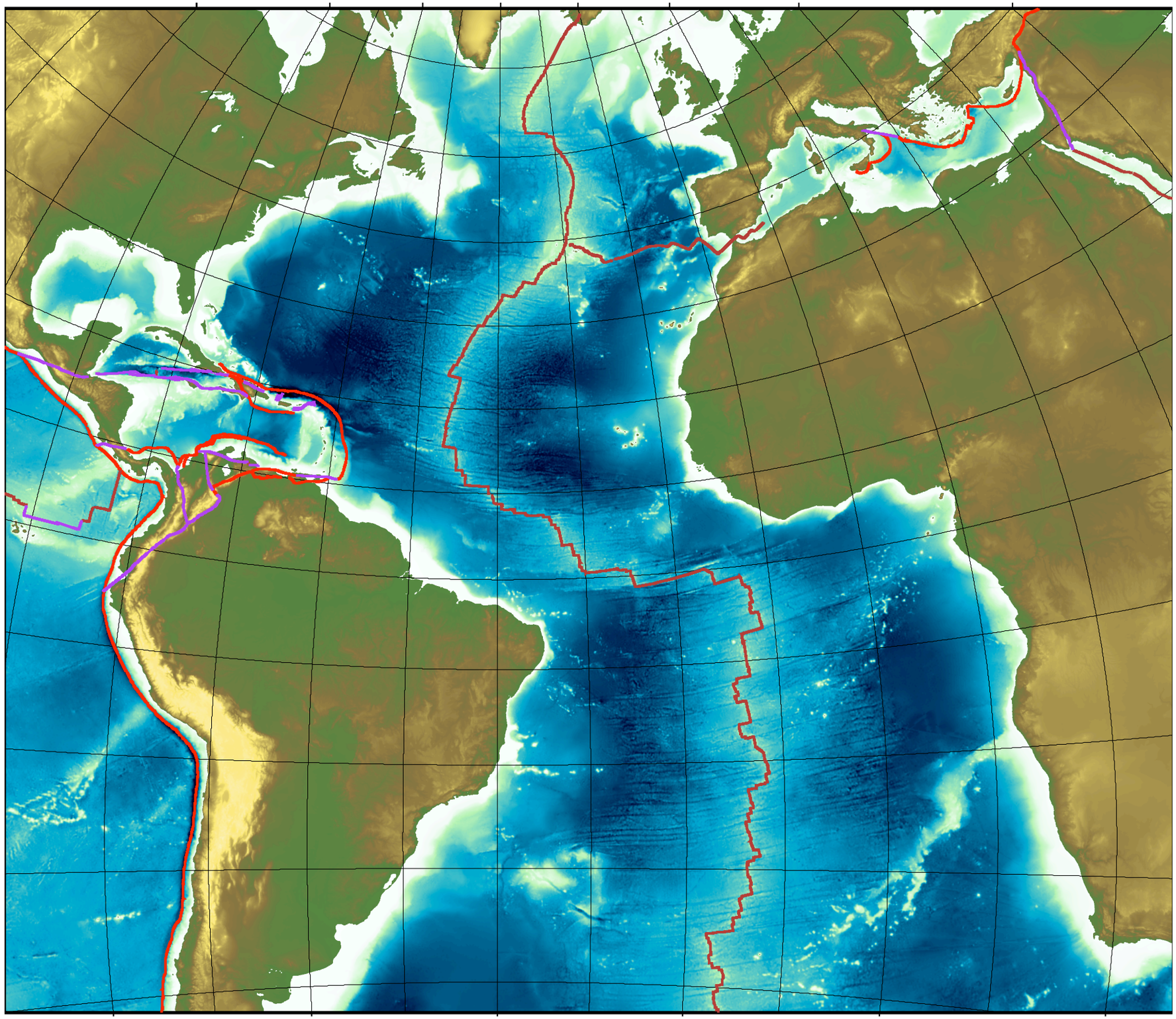




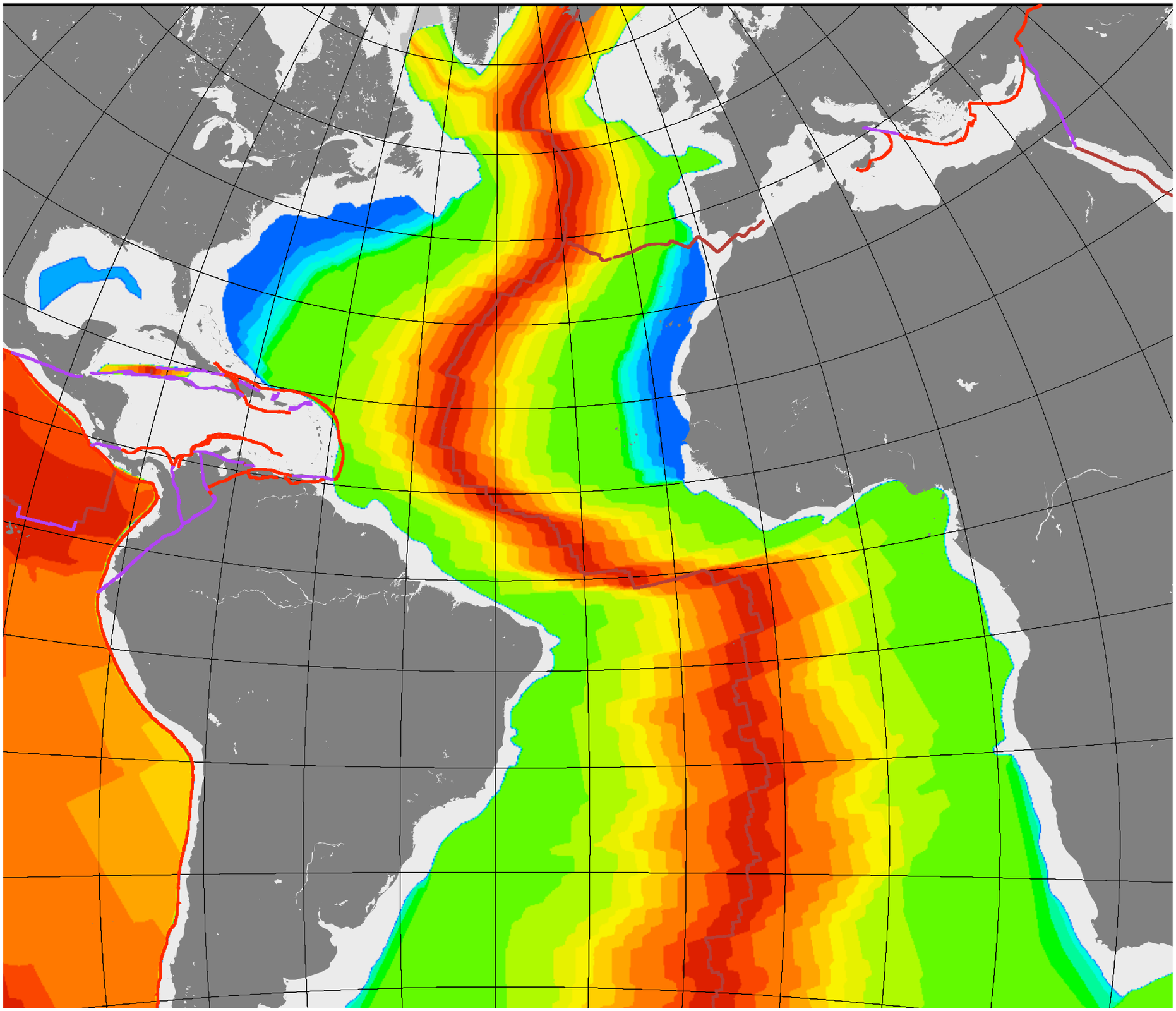


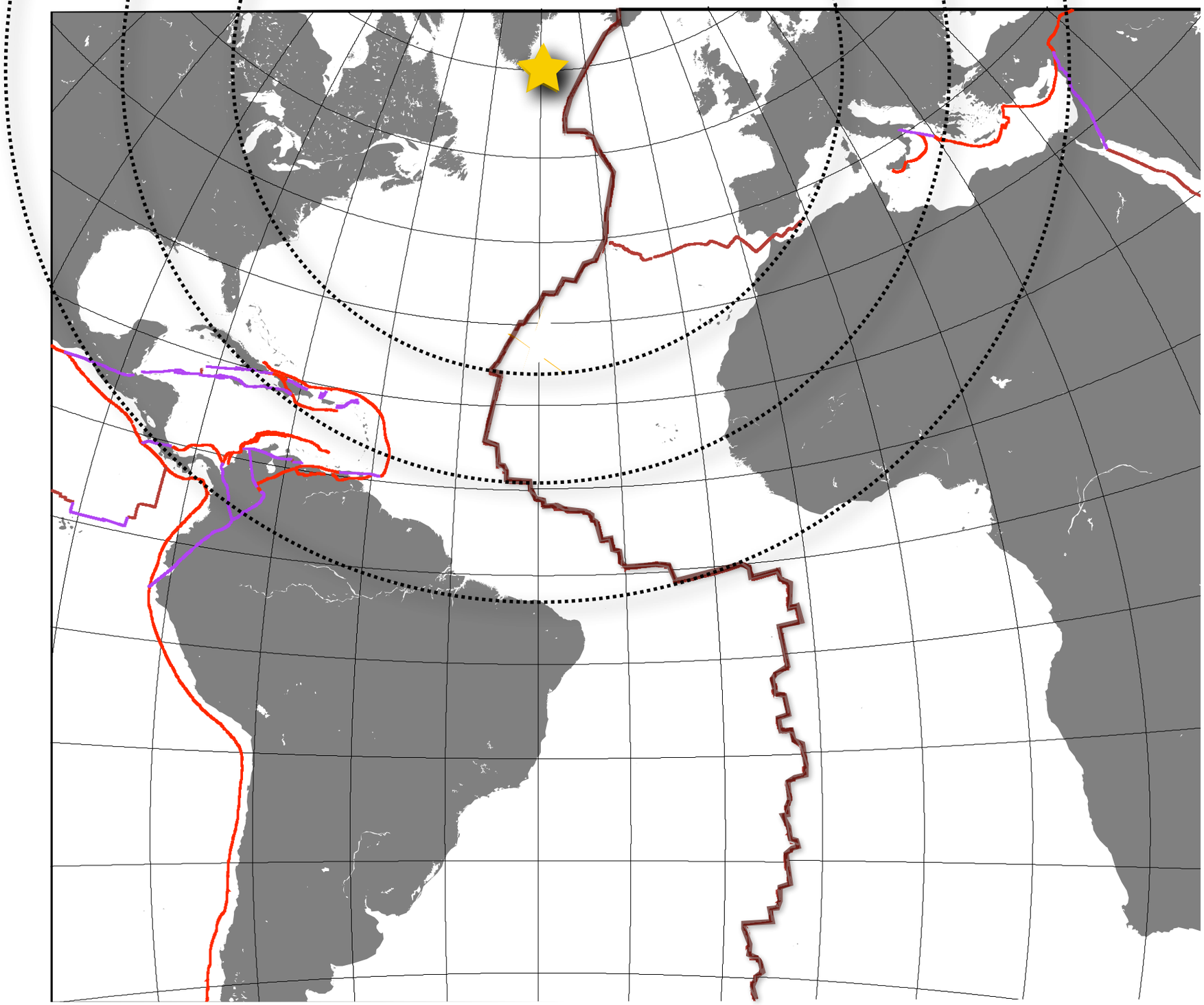


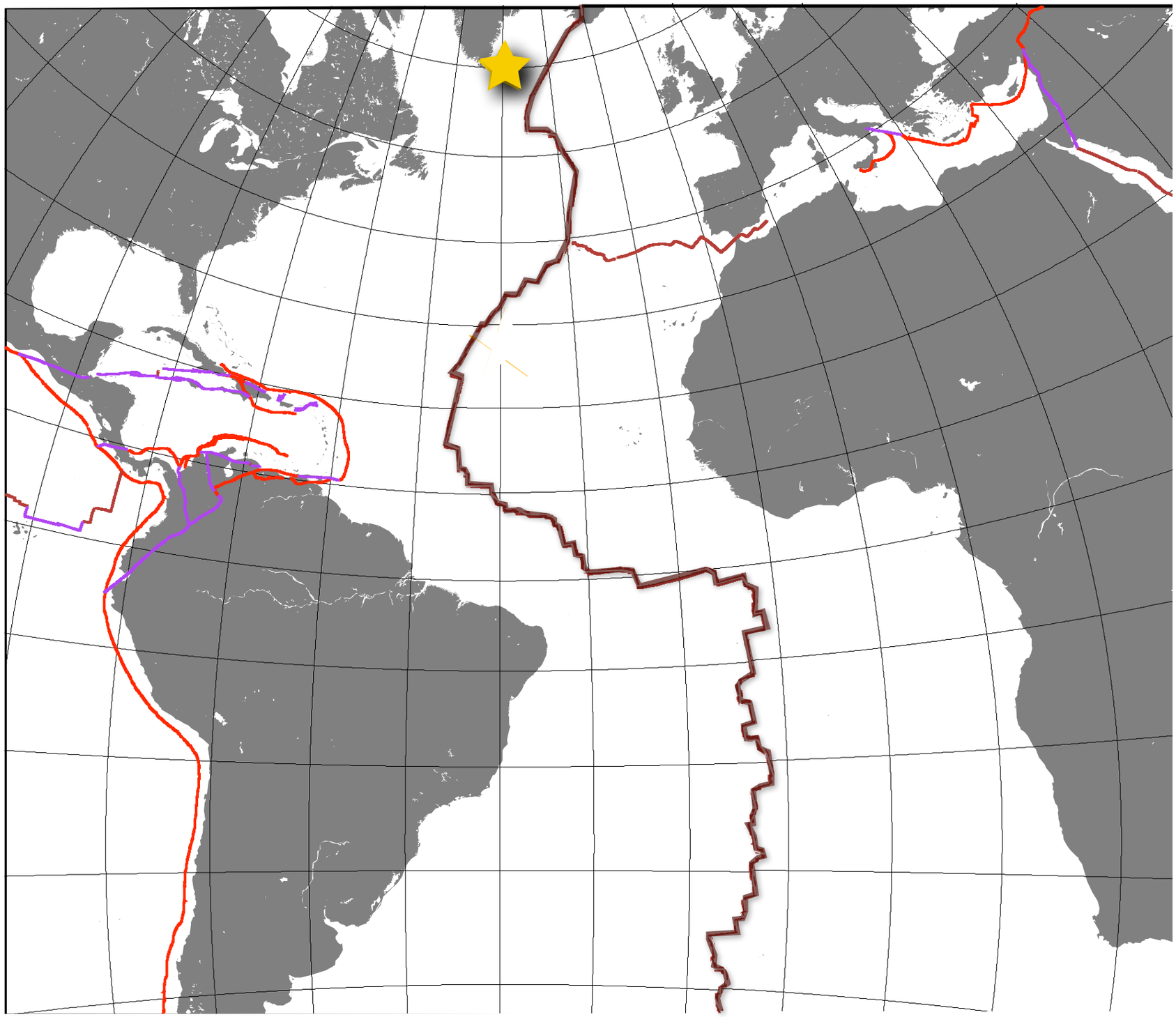
Africa / South America elevation



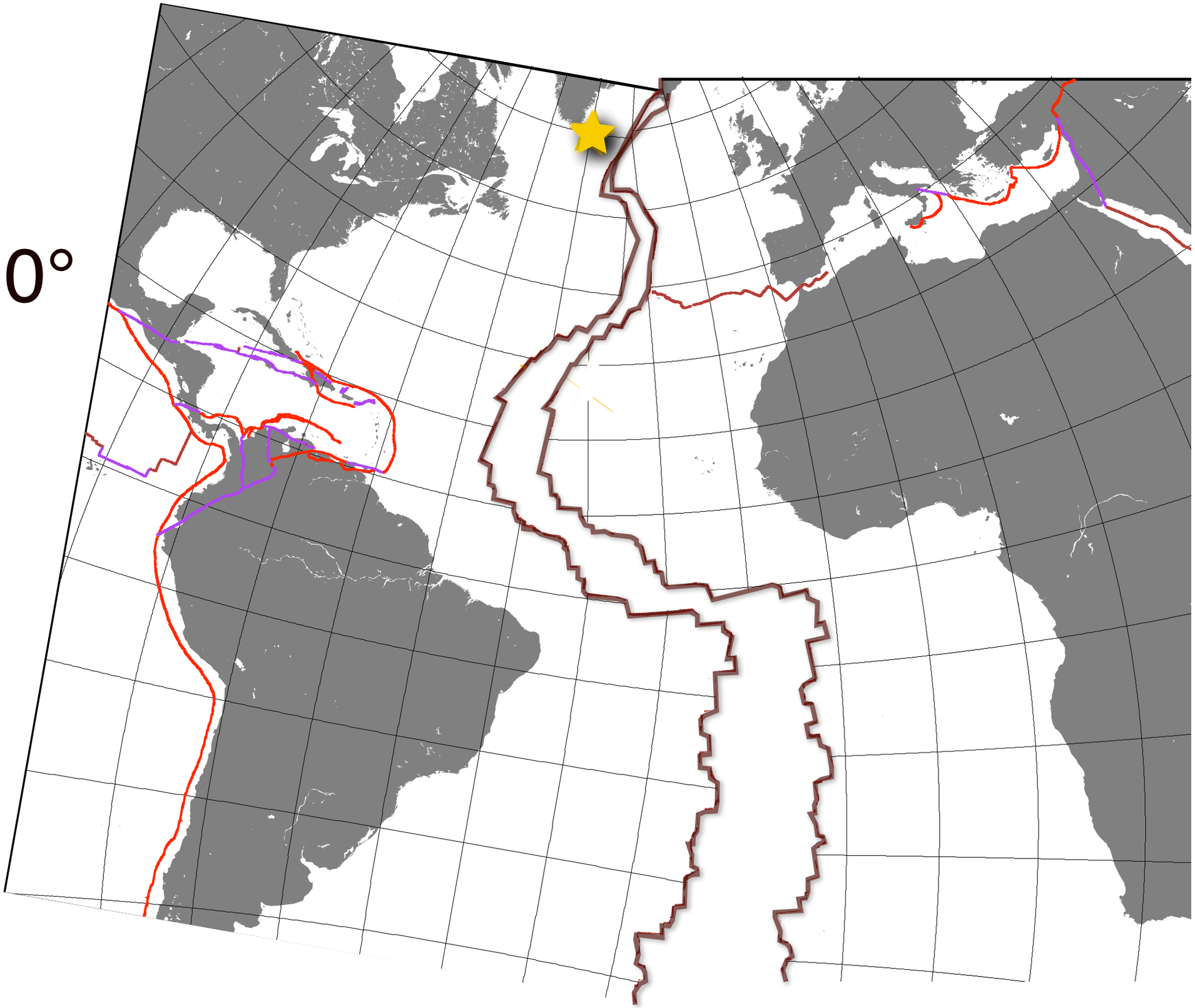
Atlantic age grid



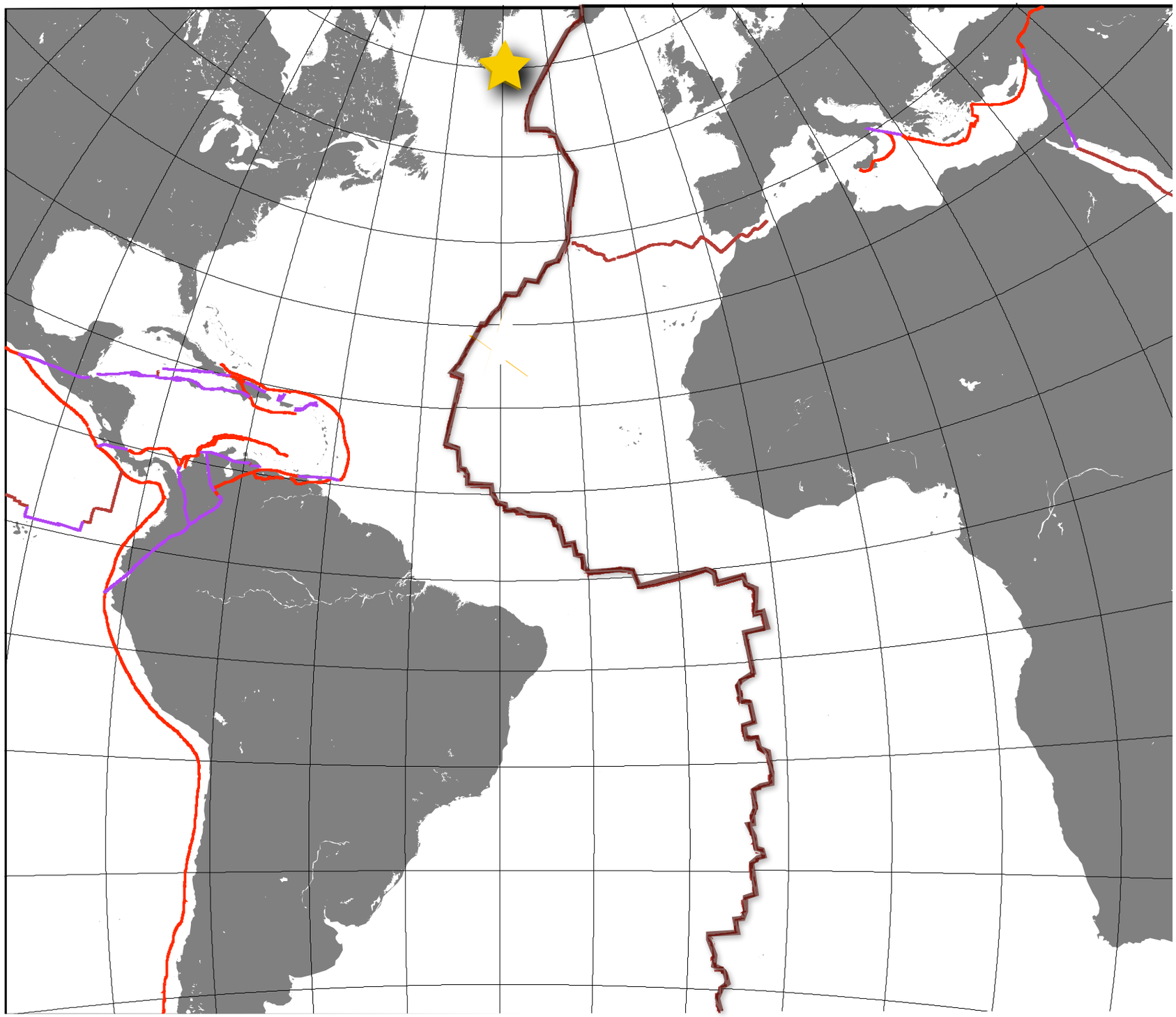




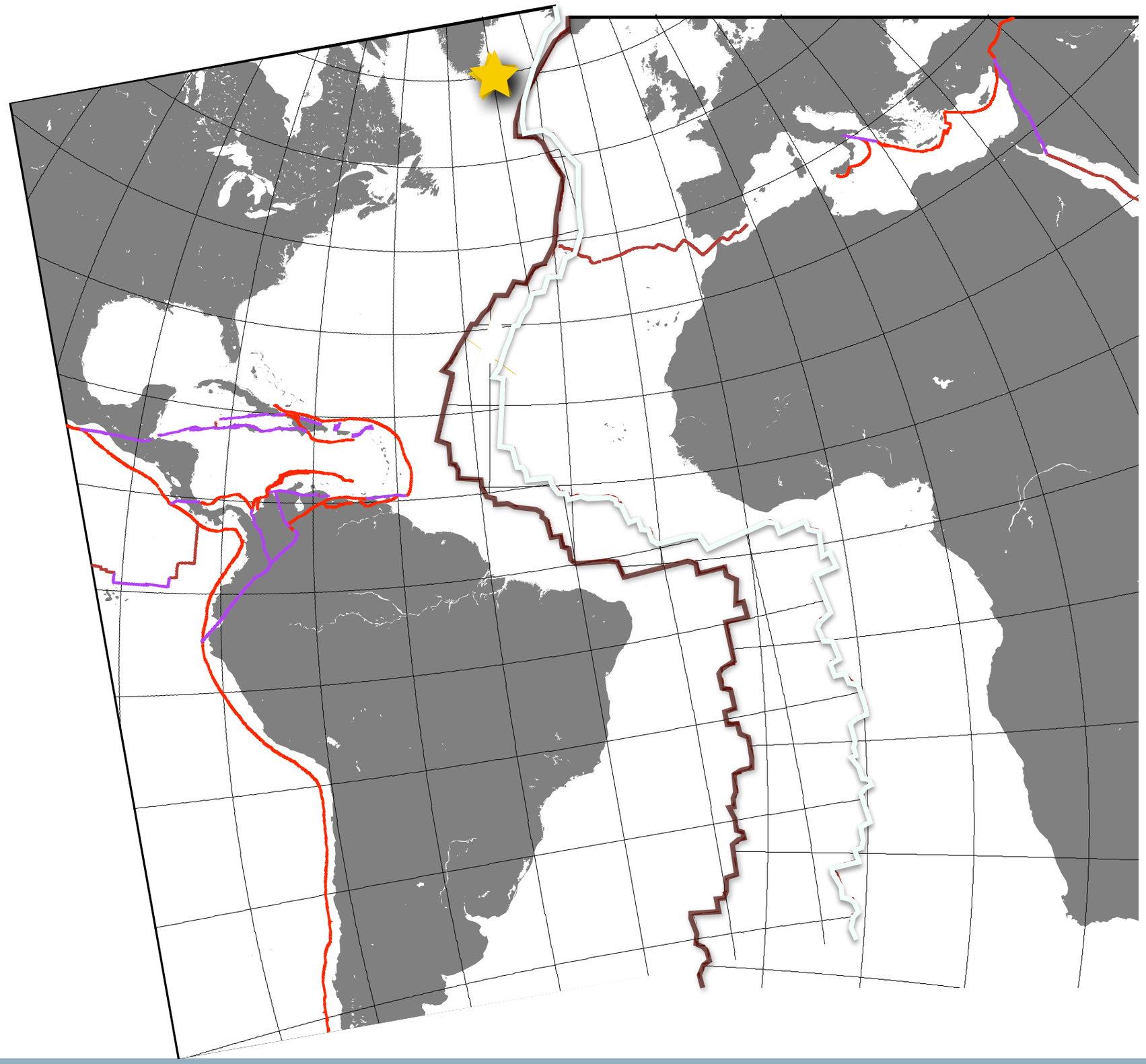
-10°



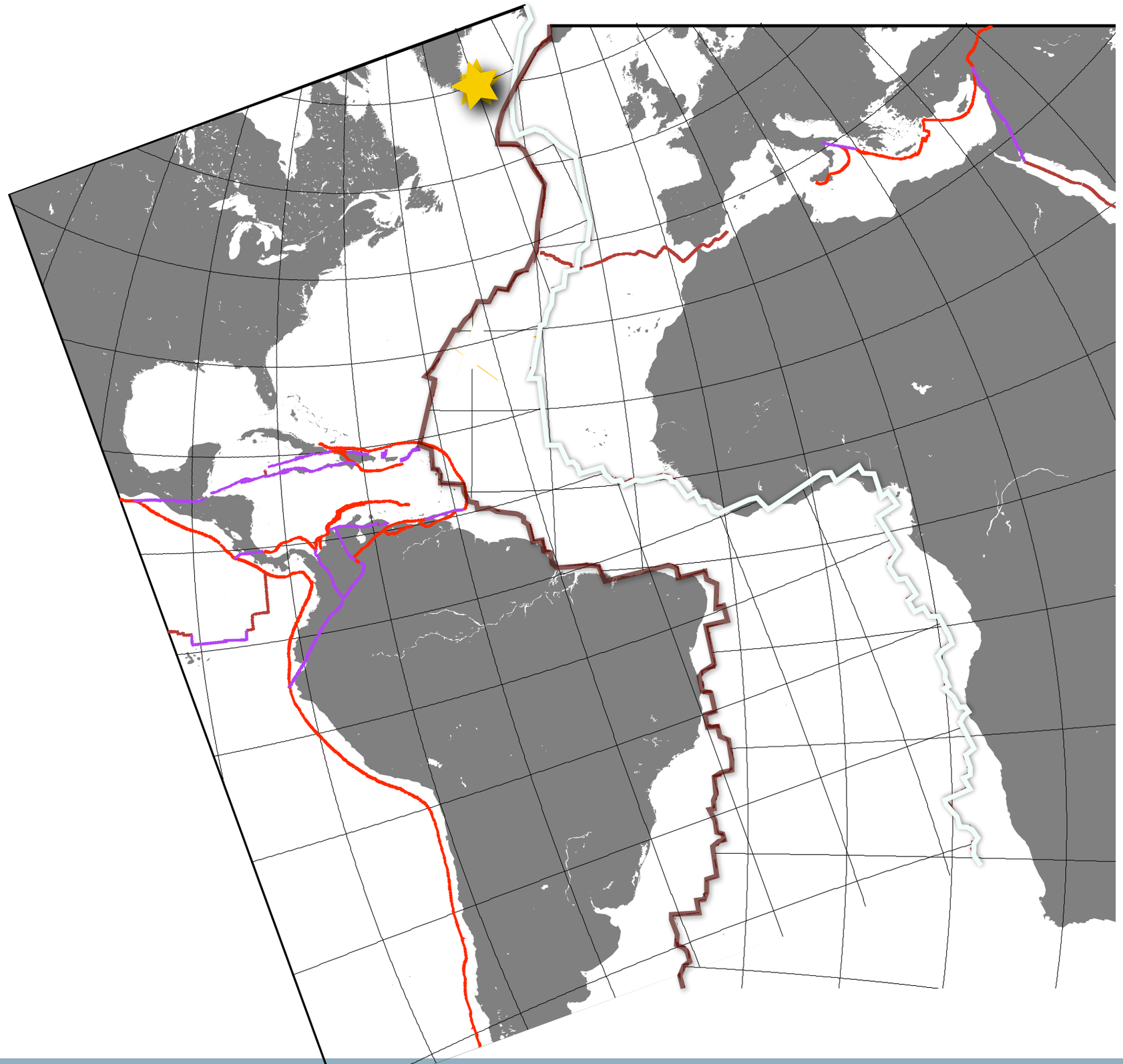
0°



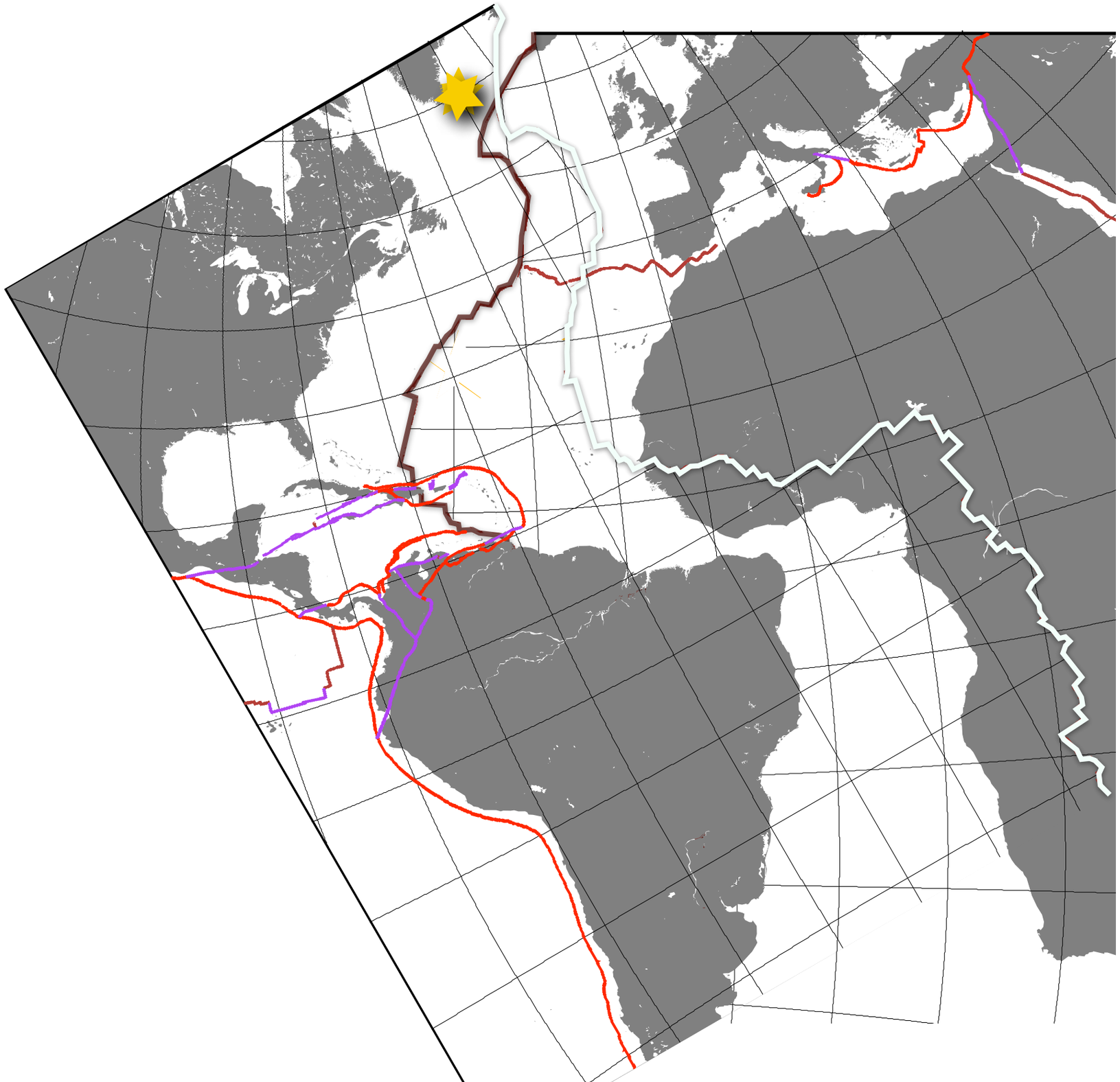
10°



20°



30°



40°