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Putting plate kinematics to good use

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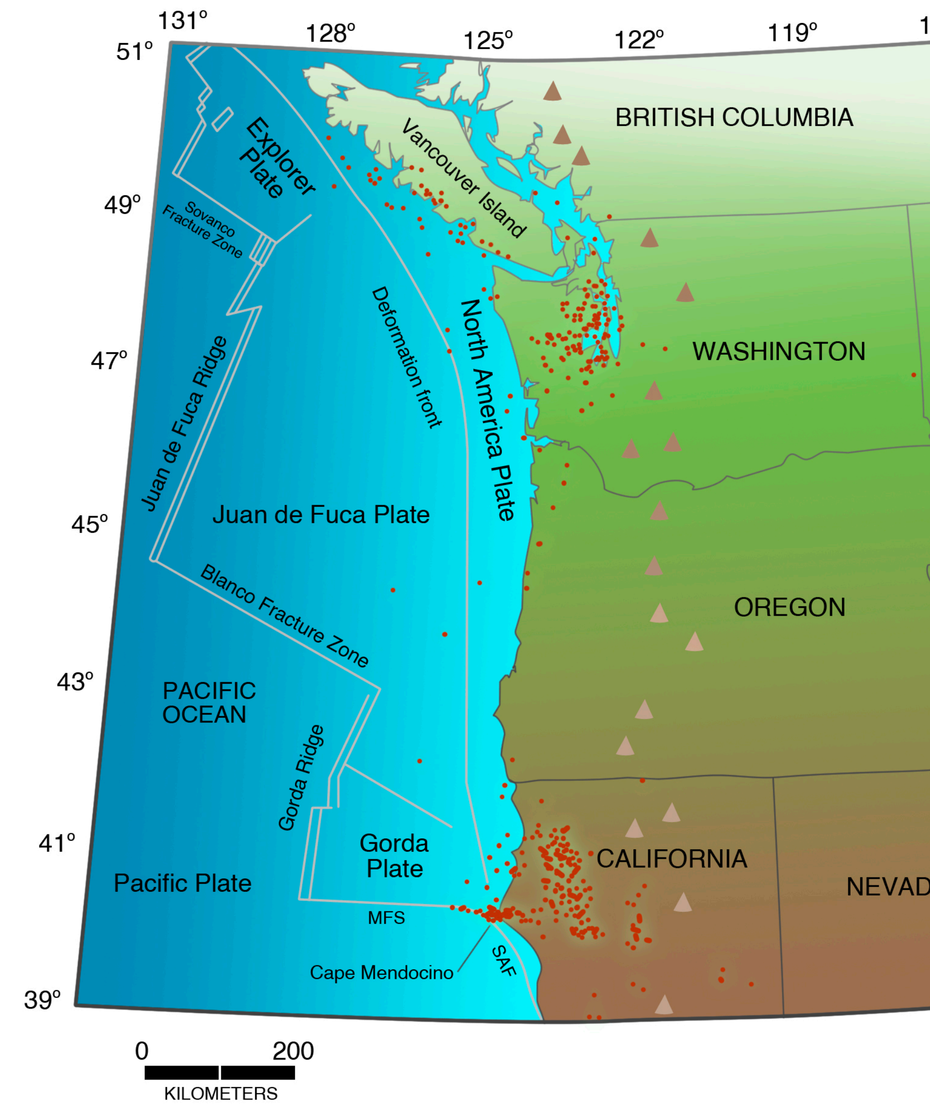
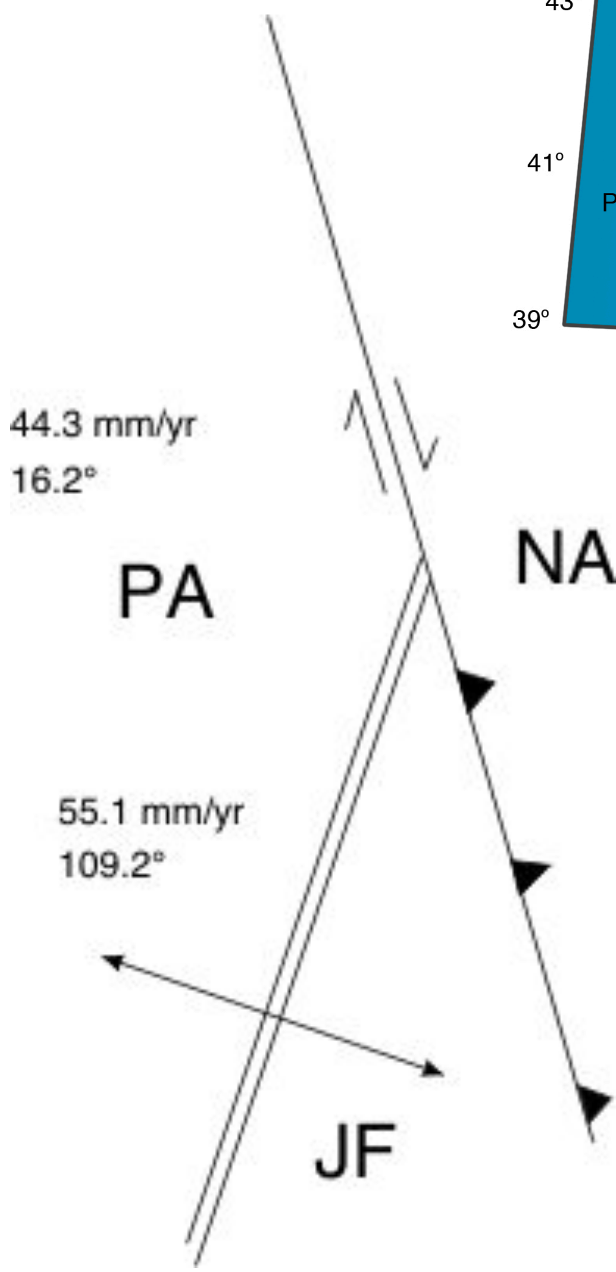
What are the rules ?

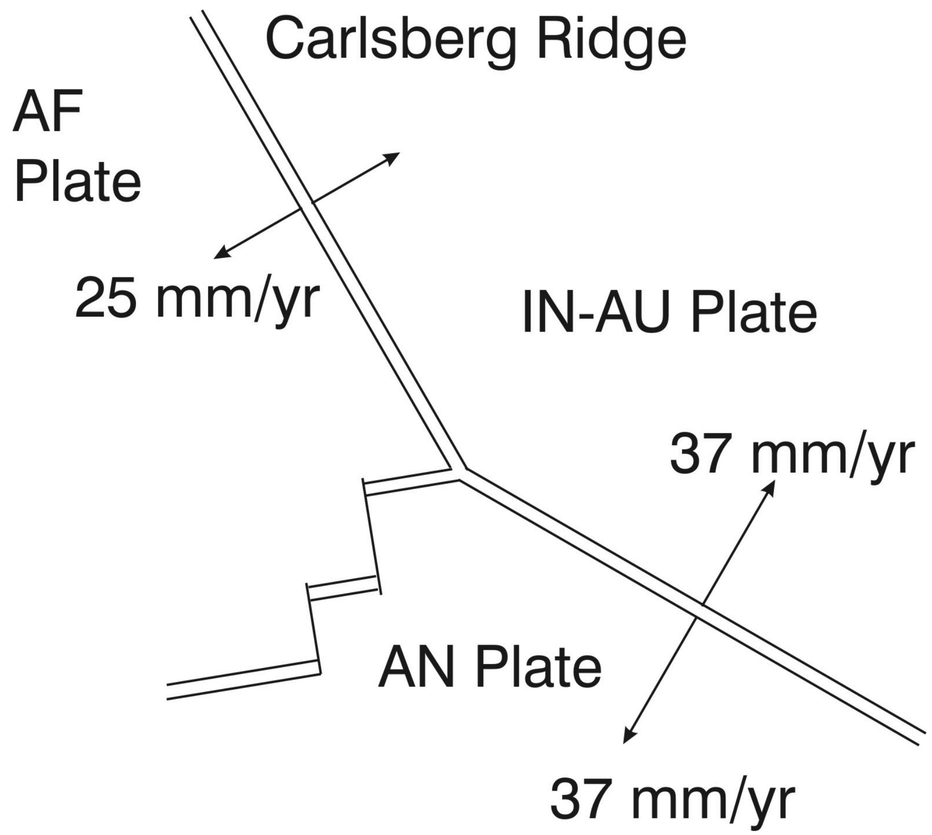
Plate boundaries: 3 types

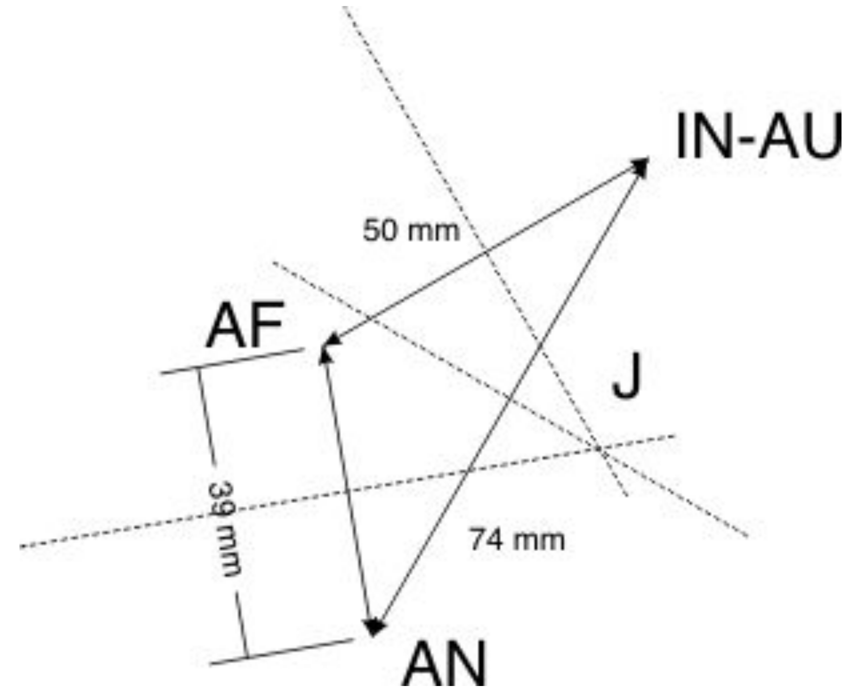
- Ridges: plates moving apart
  - Spreading is typically symmetric
  - Spreading is typically orthogonal
- Trenches: plates converging
  - Subduction is highly asymmetric
  - Subduction is not usually orthogonal
- Transform faults: motion parallel to boundary





Triple junctions



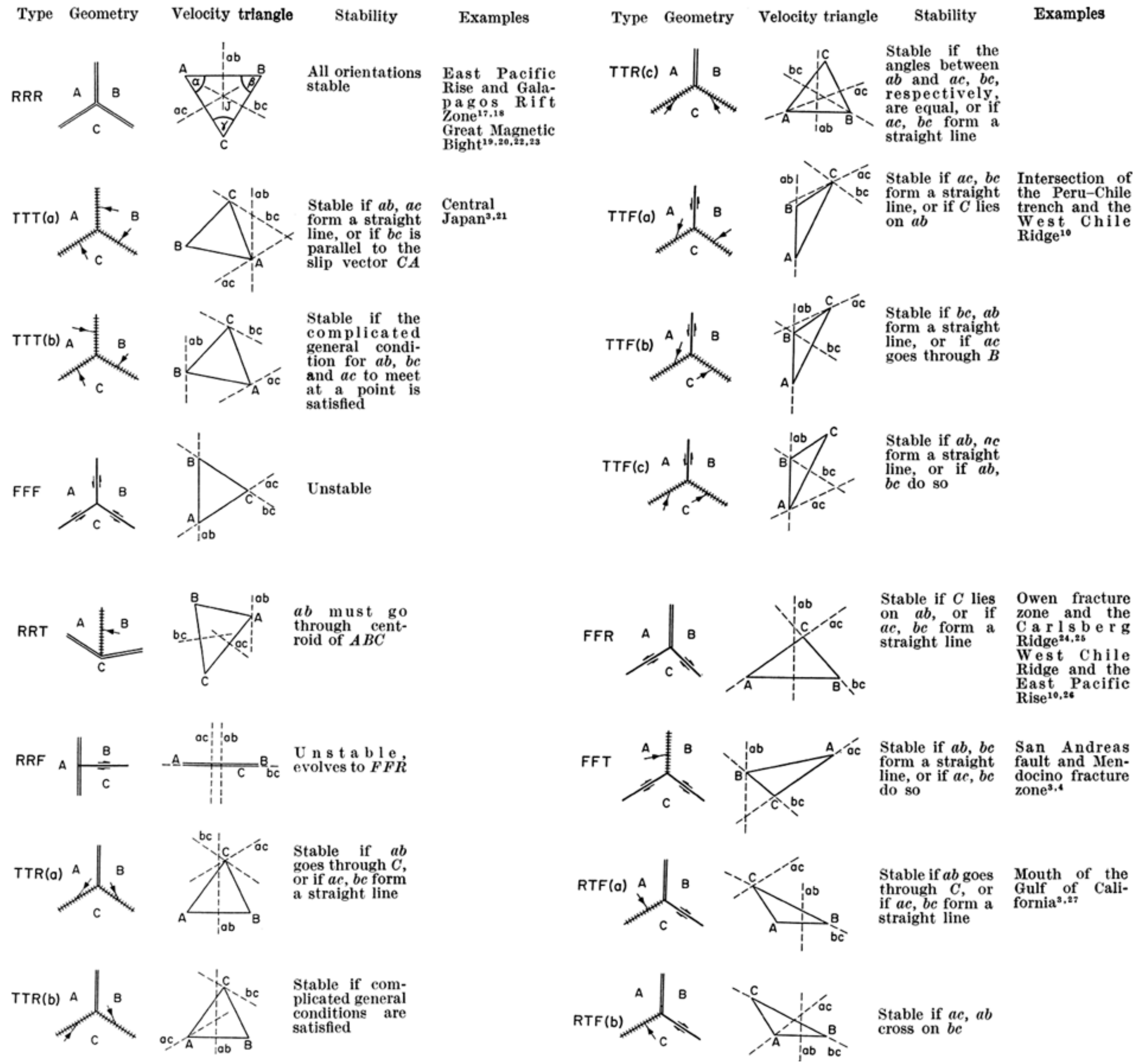


Triple junctions are places where three plates (and three boundaries) meet. E.g. at a ridge-ridge-ridge junction all the plates are separating, and all three are moving relative to the junction itself.

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

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

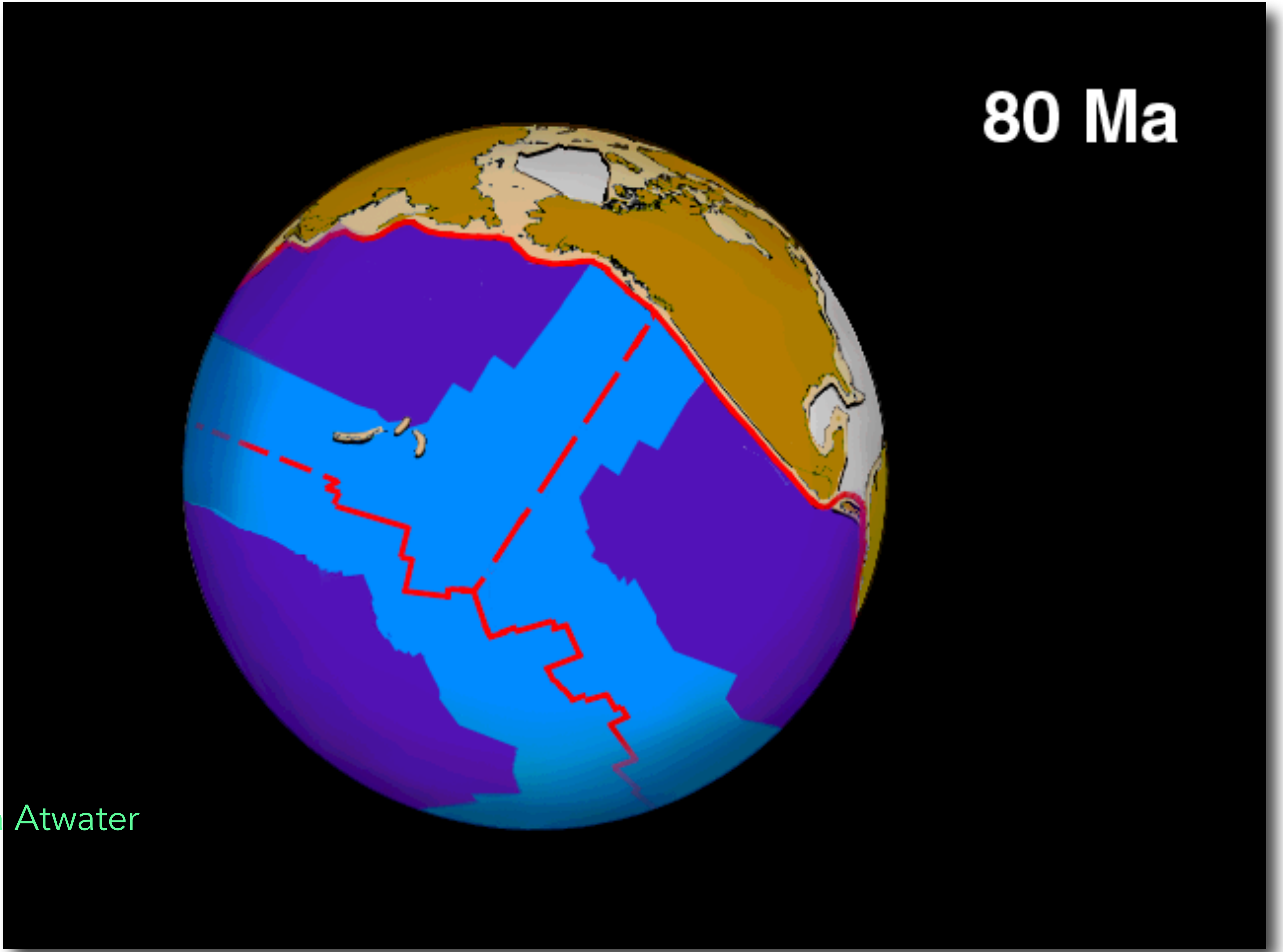
Triple junction rules can be complicated !



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	
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*	

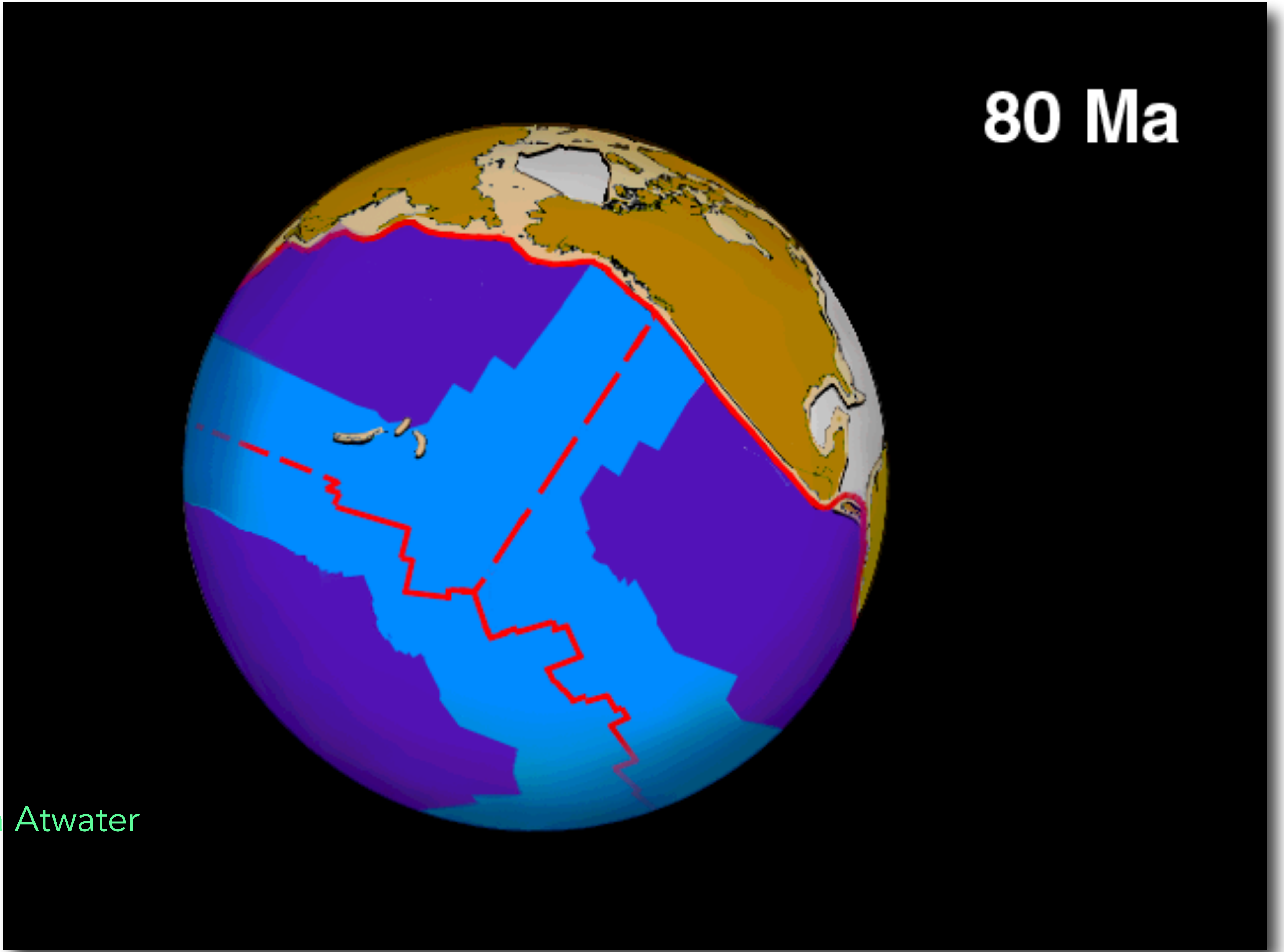
McKenzie & Parker 1967

Reconstructing past plates / boundaries



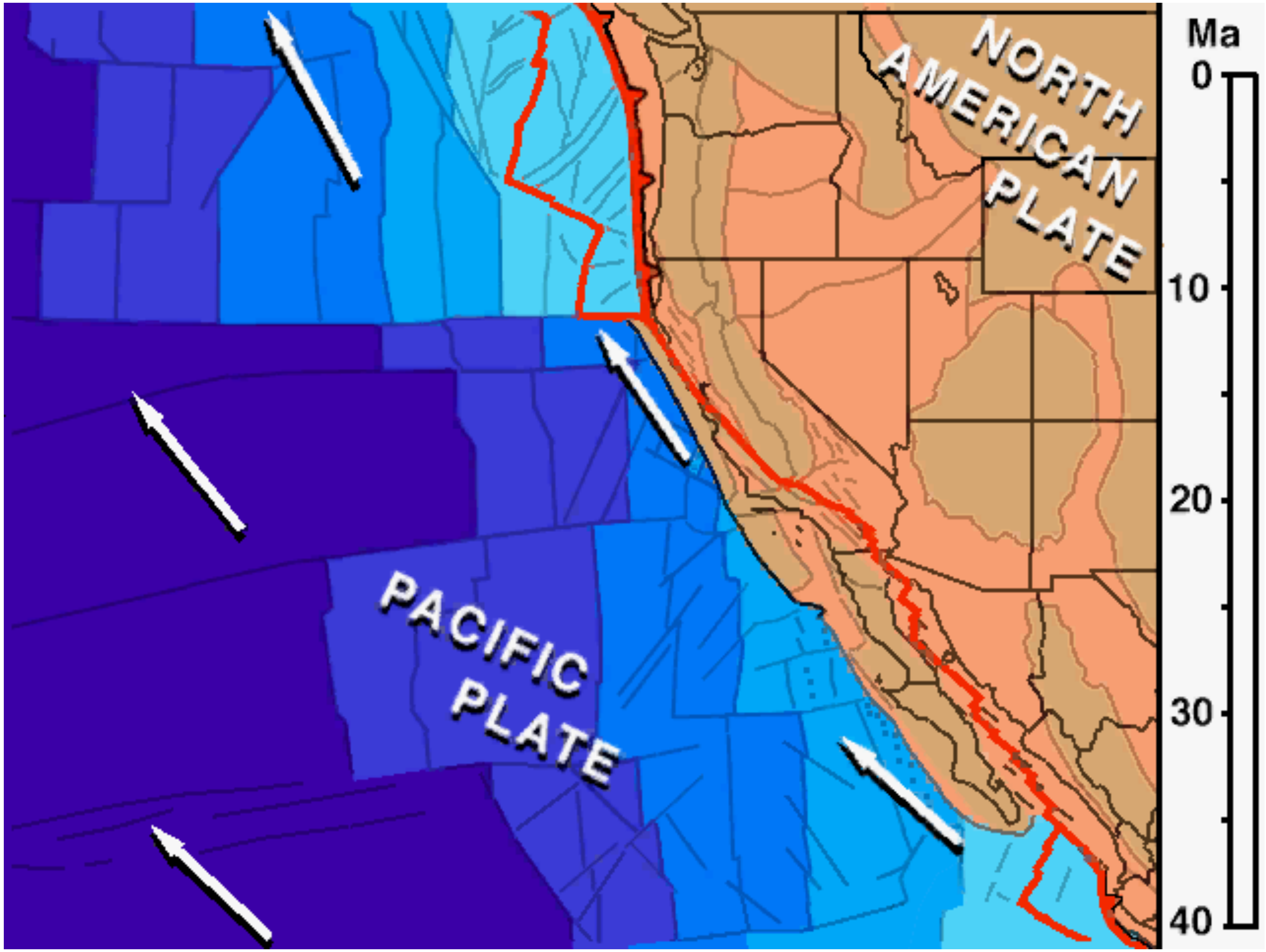
Tanya Atwater

Reconstructing past plates / boundaries



Tanya Atwater

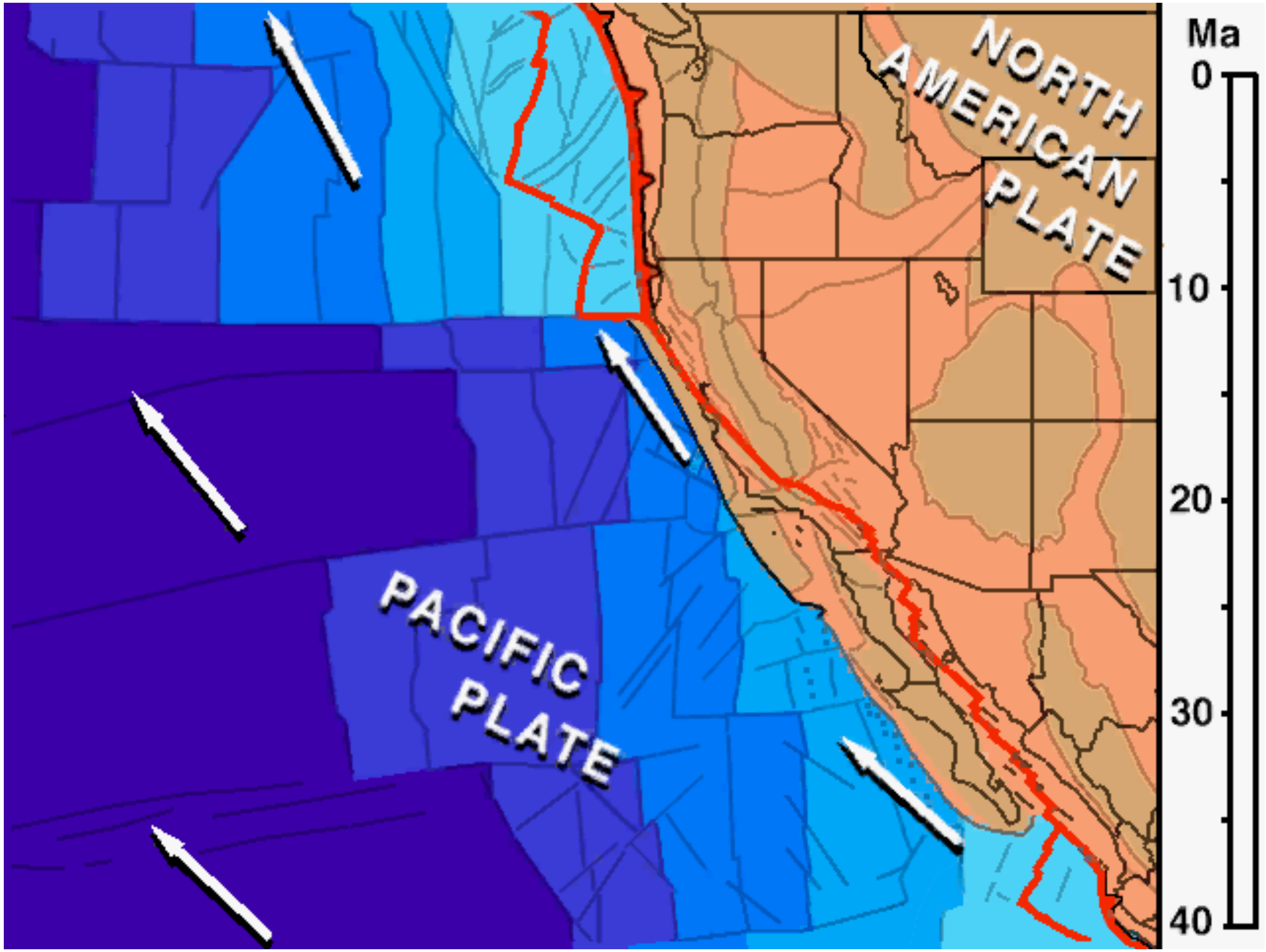
Reconstructing past reconfigurations



How do we know there was a Farallon plate ?

When does the San Andreas fault system appear ?

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

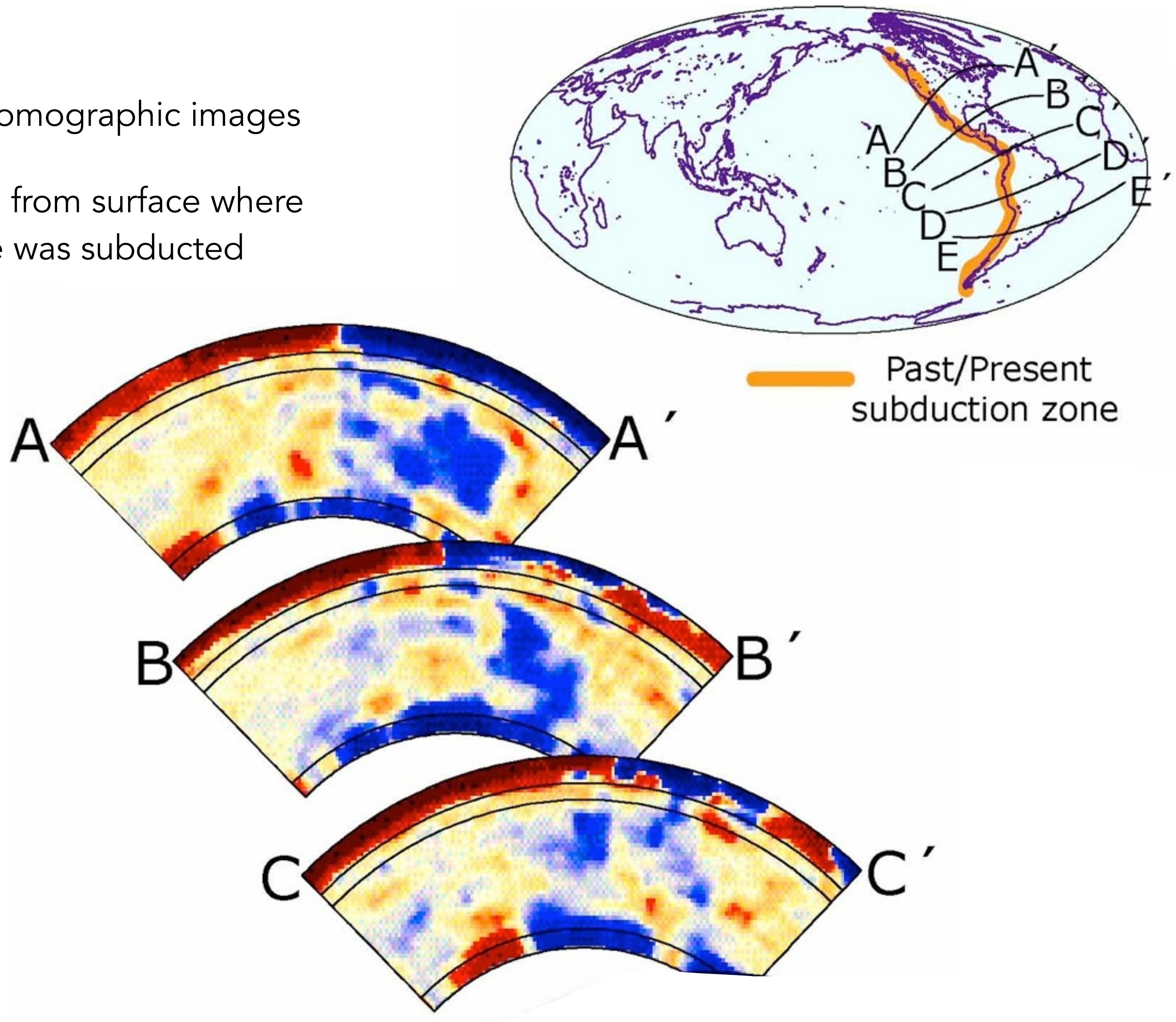
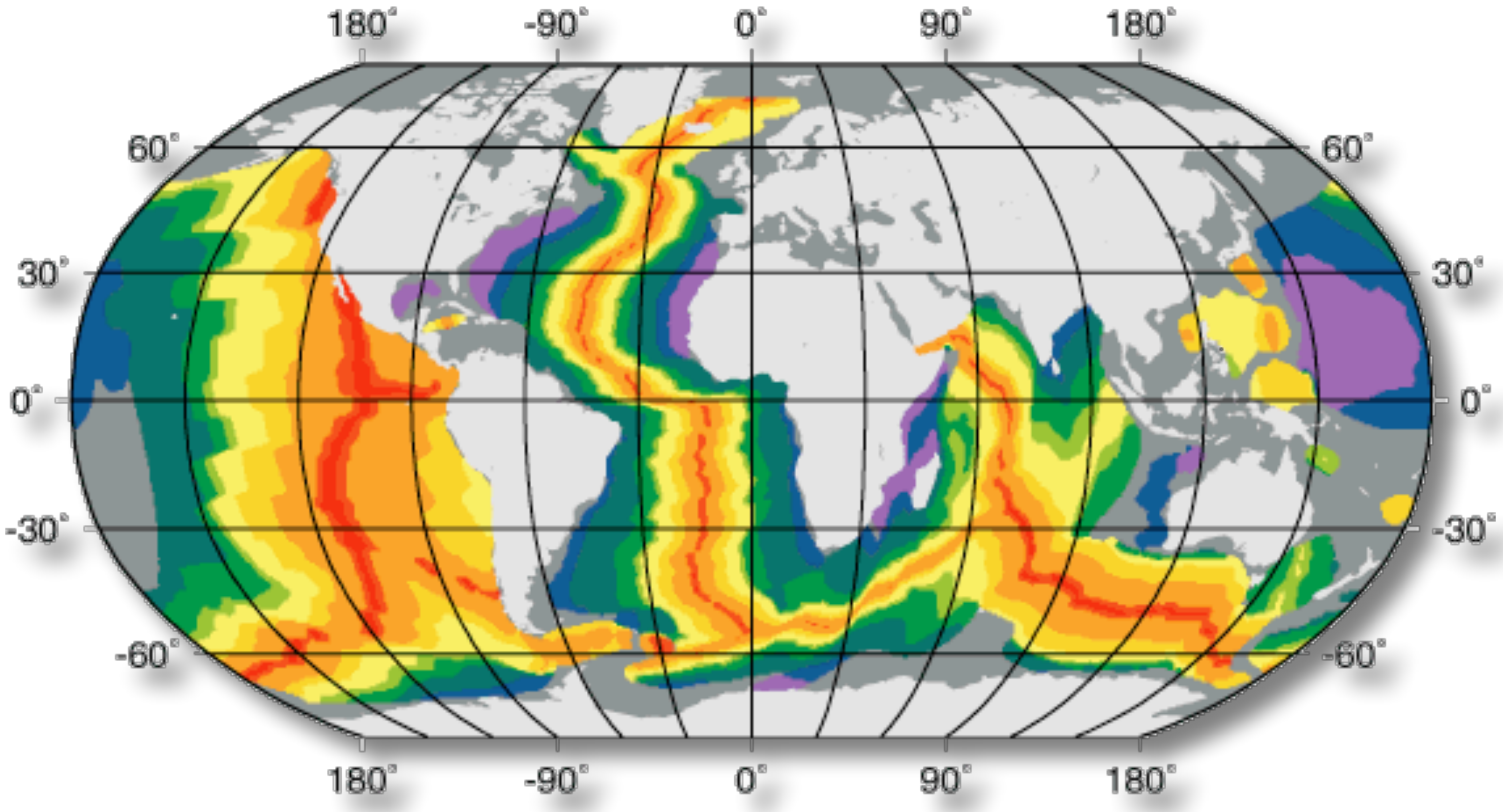
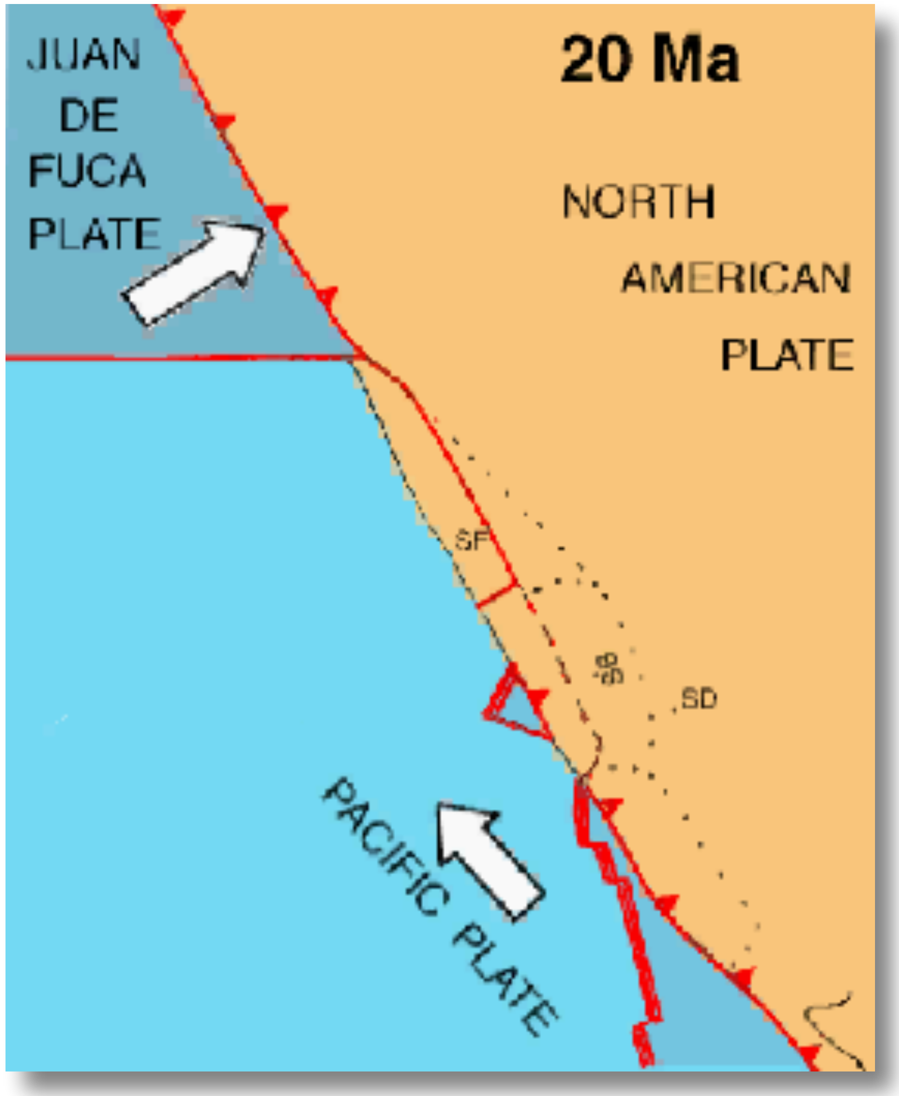


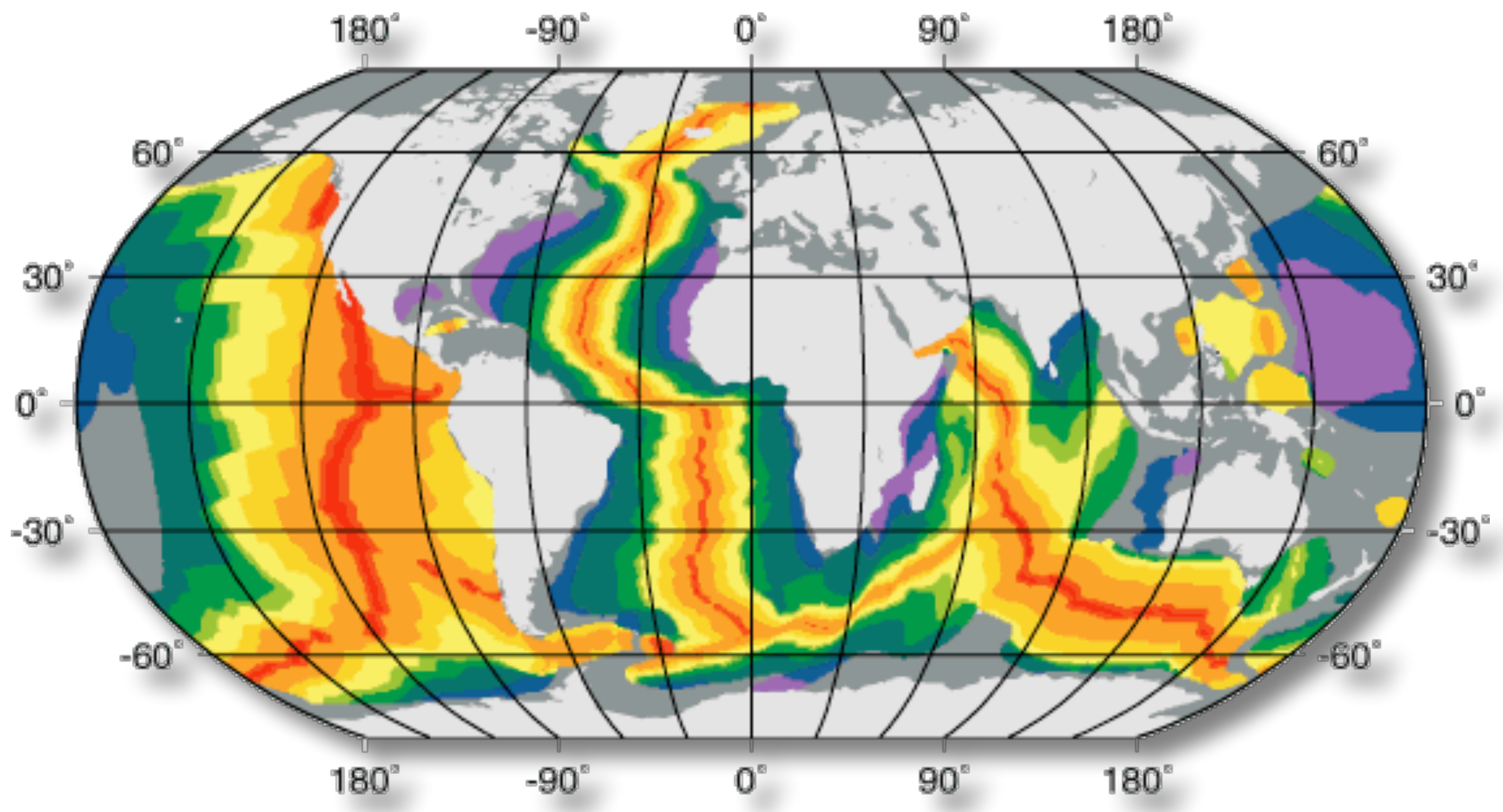
Plate boundary effects in the continent

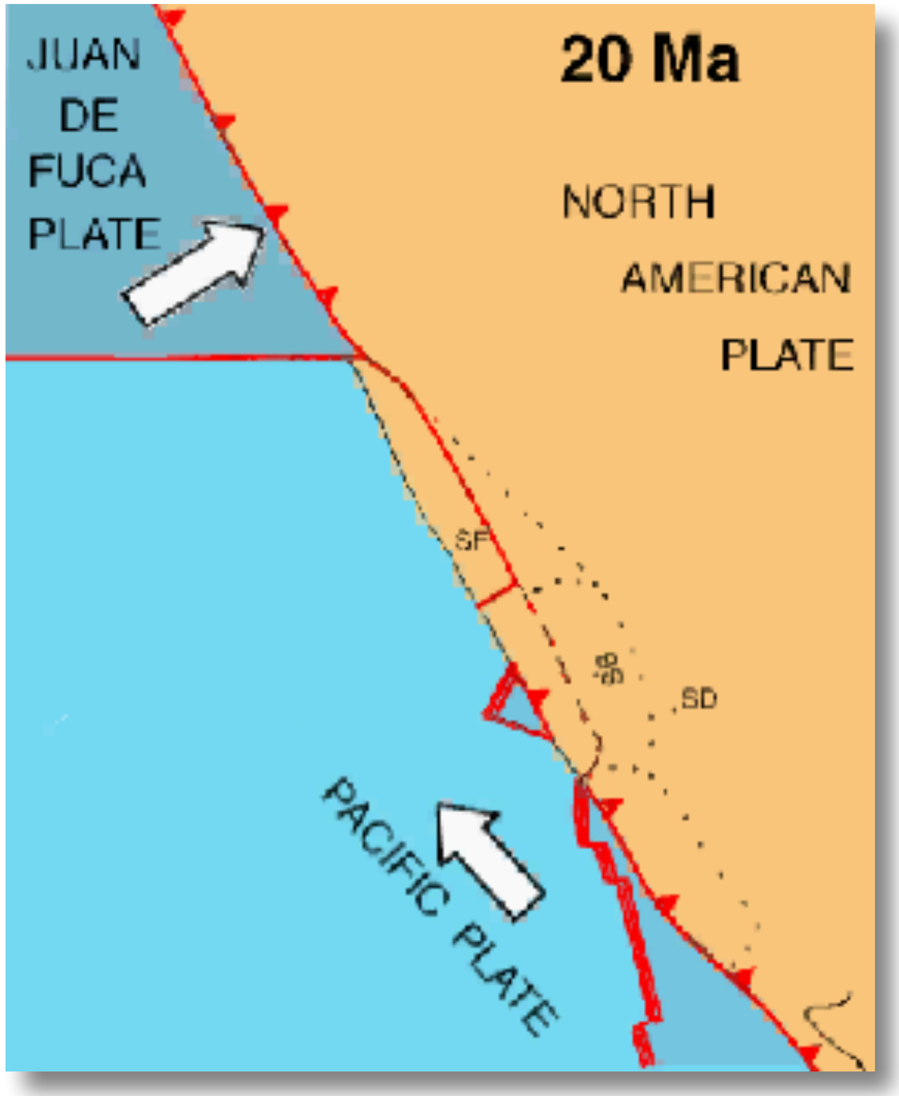




The continental crust records the changes in the plate boundary but a lot more ambiguity than in the sea floor stripes

Plate boundary effects in the continent



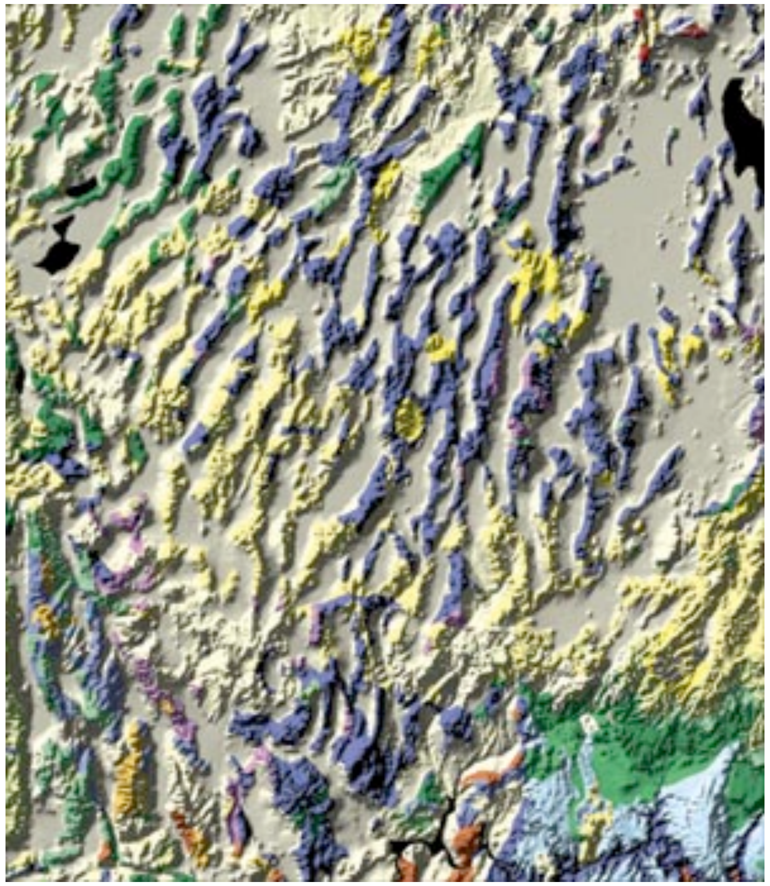


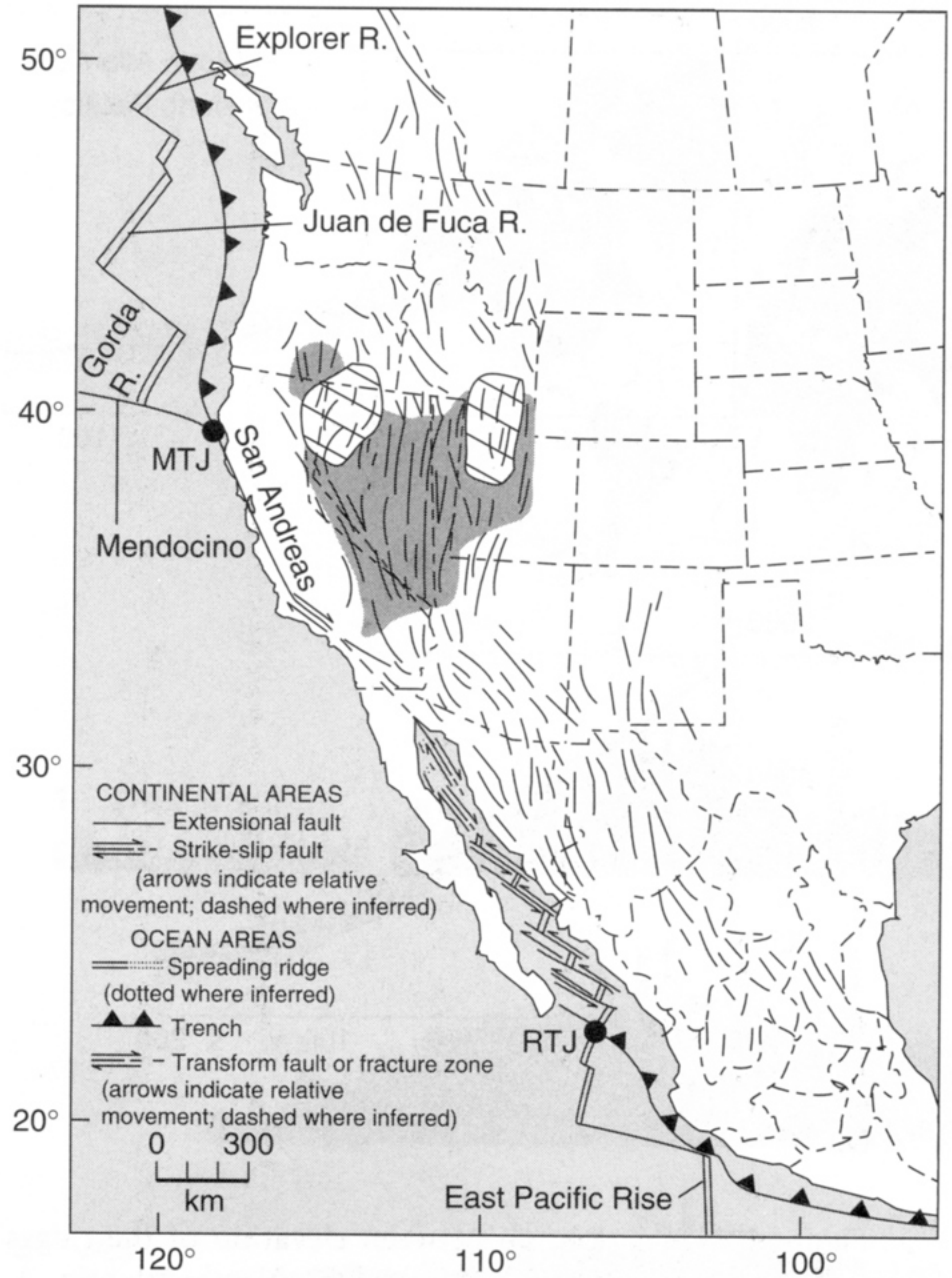
The continental crust records the changes in the plate boundary but a lot more ambiguity than in the sea floor stripes

Basin and range

Extensional tectonics

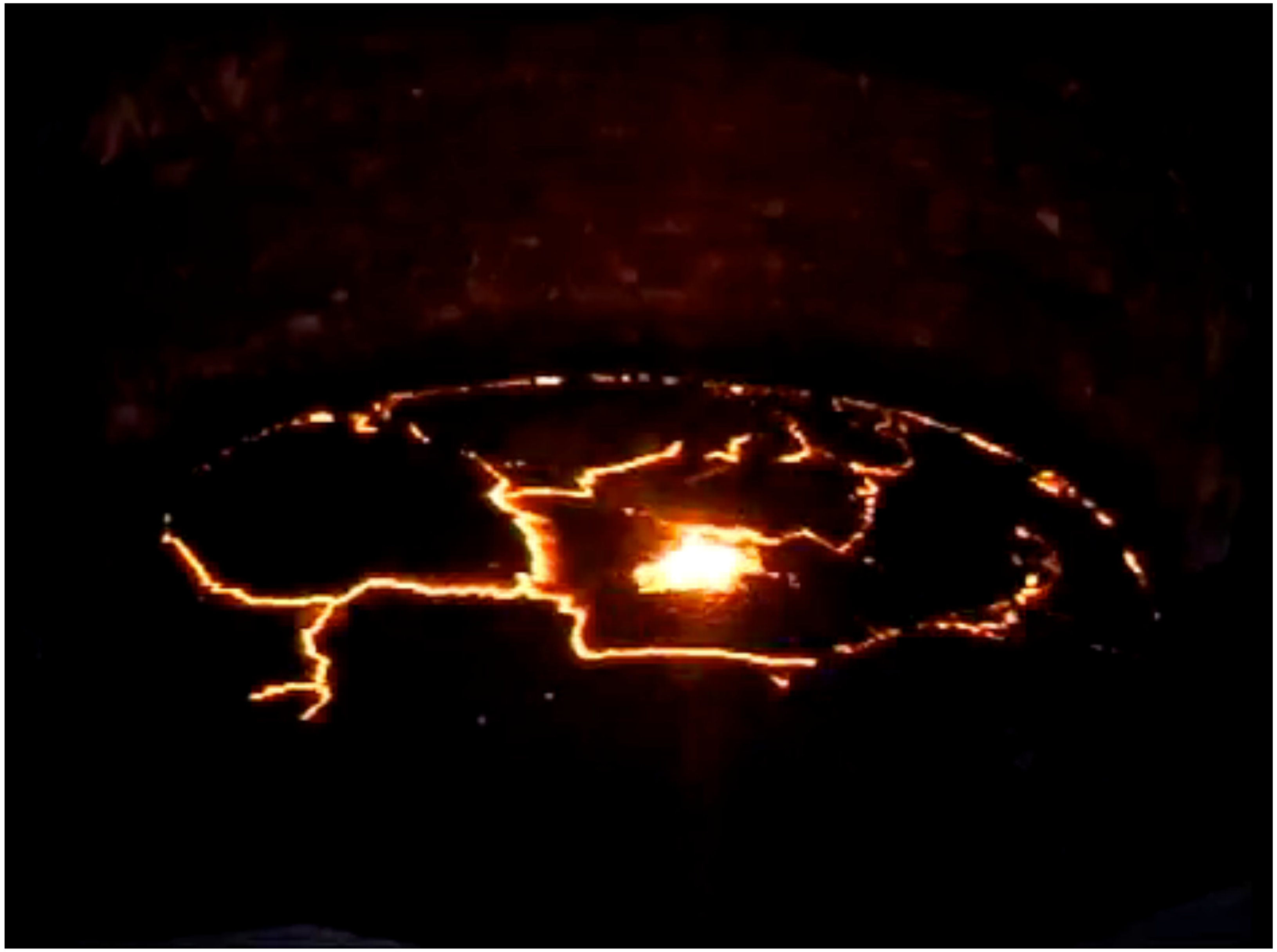
- Change of plate boundary forces
- Coupling to Pacific plate
- Slab detachment / thermal effects





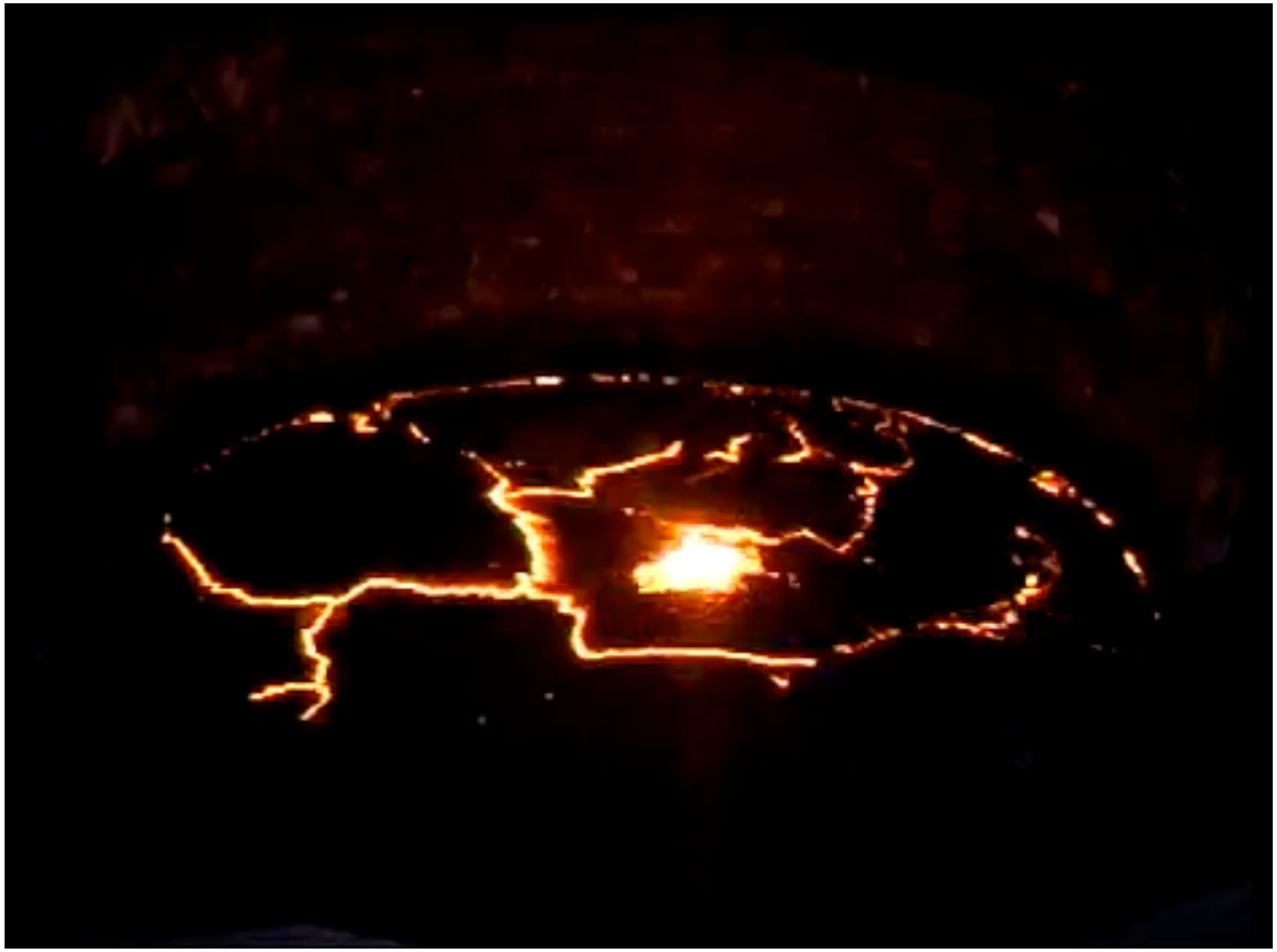
Moores & Twiss, 1995

Lava Lake Tectonics



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

Lava Lake Tectonics

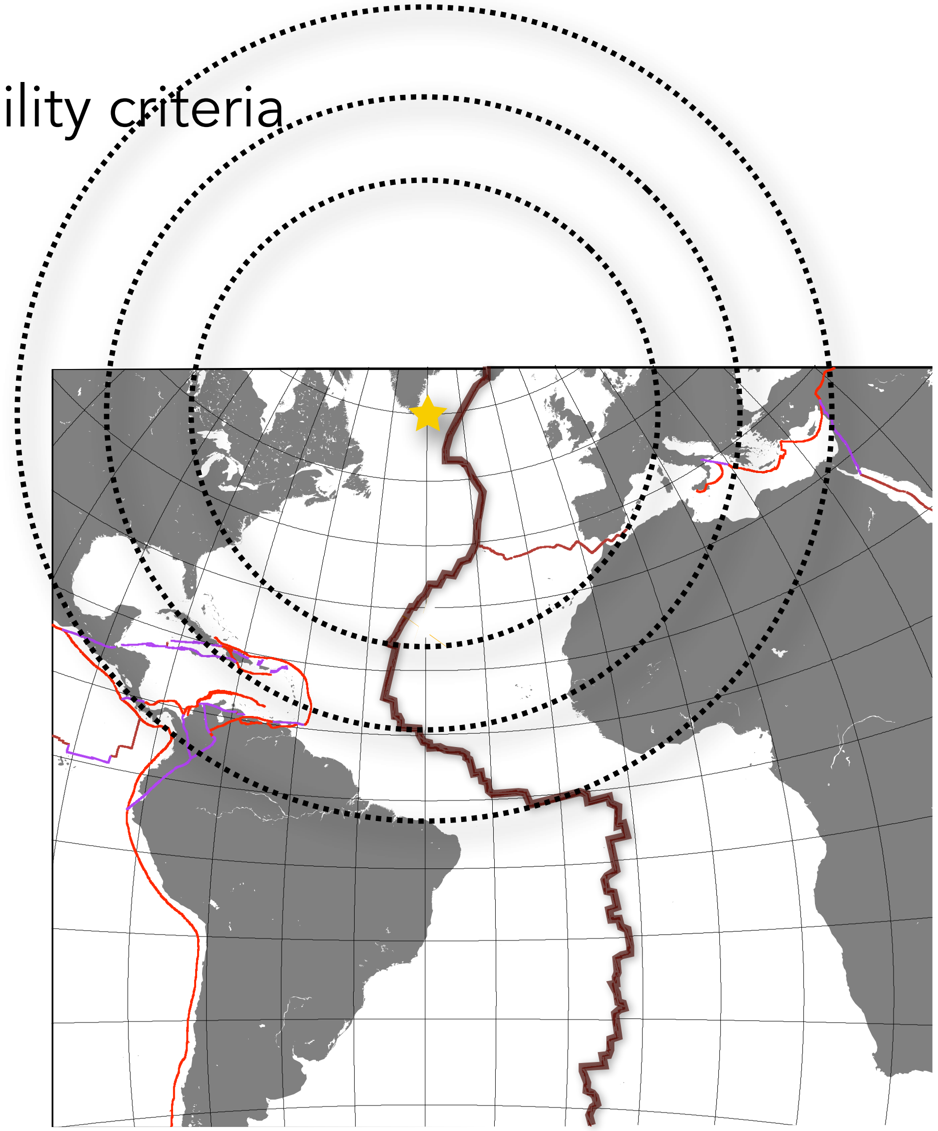


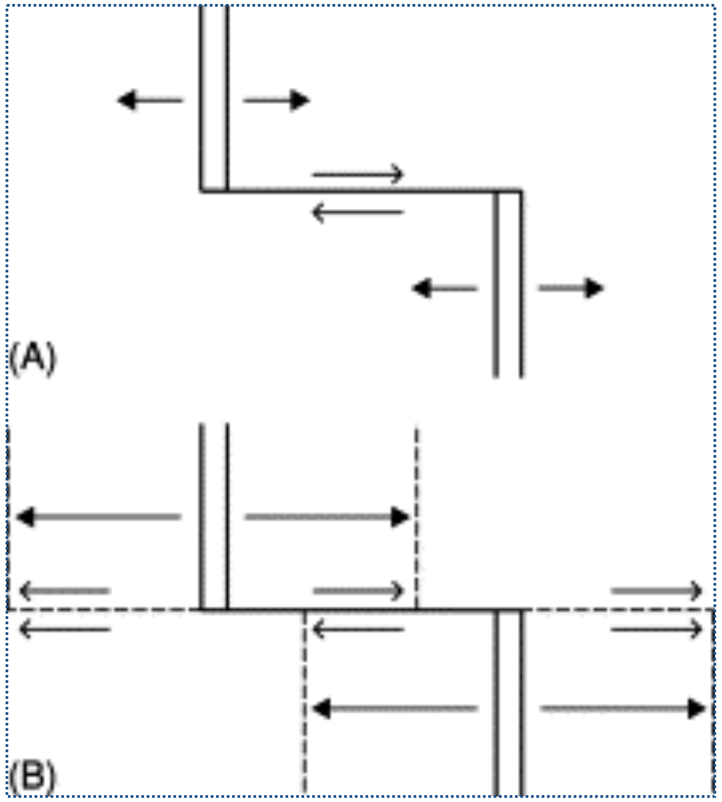
- Note how spreading centres move across the lake as spreading progresses
- Different rates for different plates, rearrangements.

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

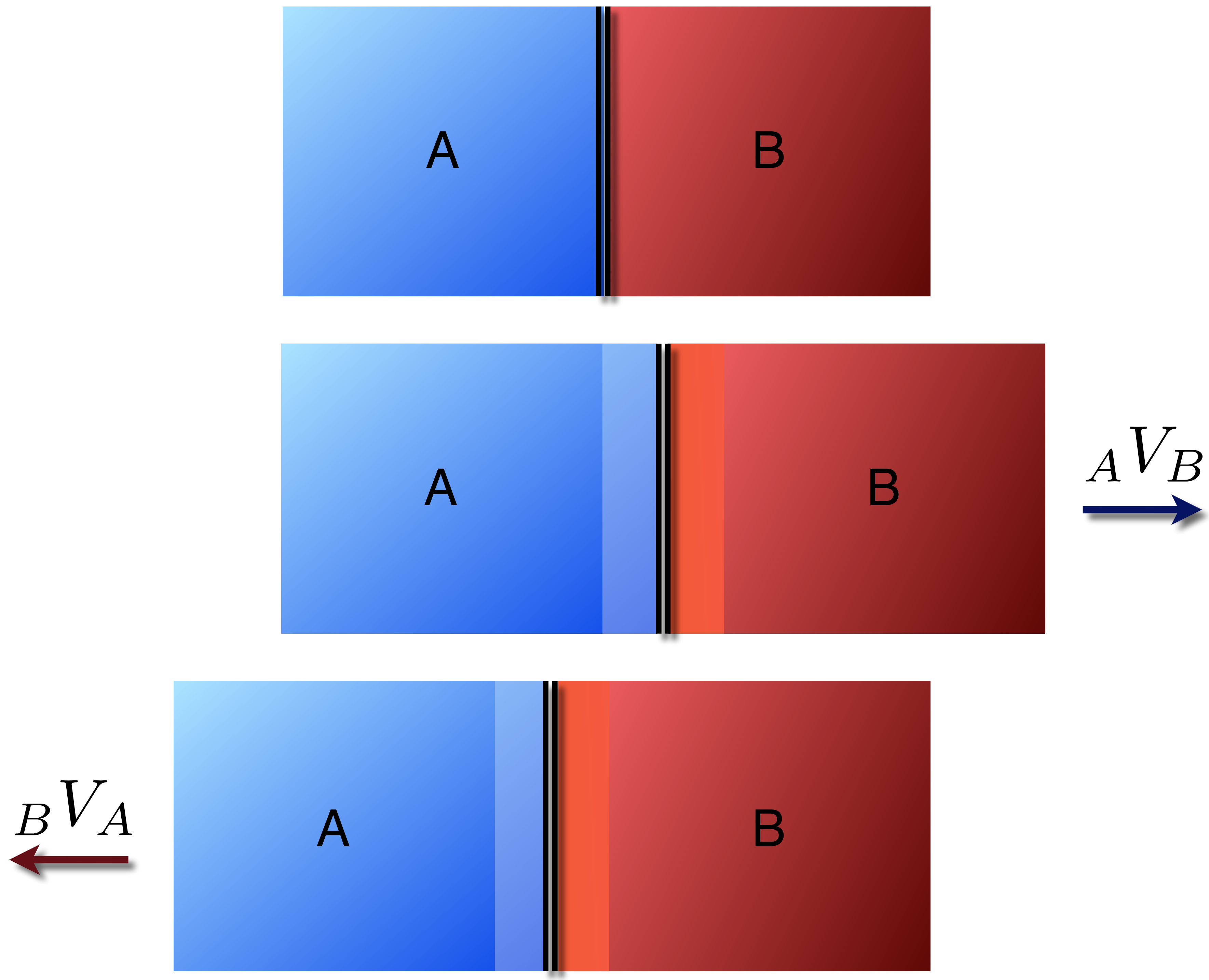




Relative velocities

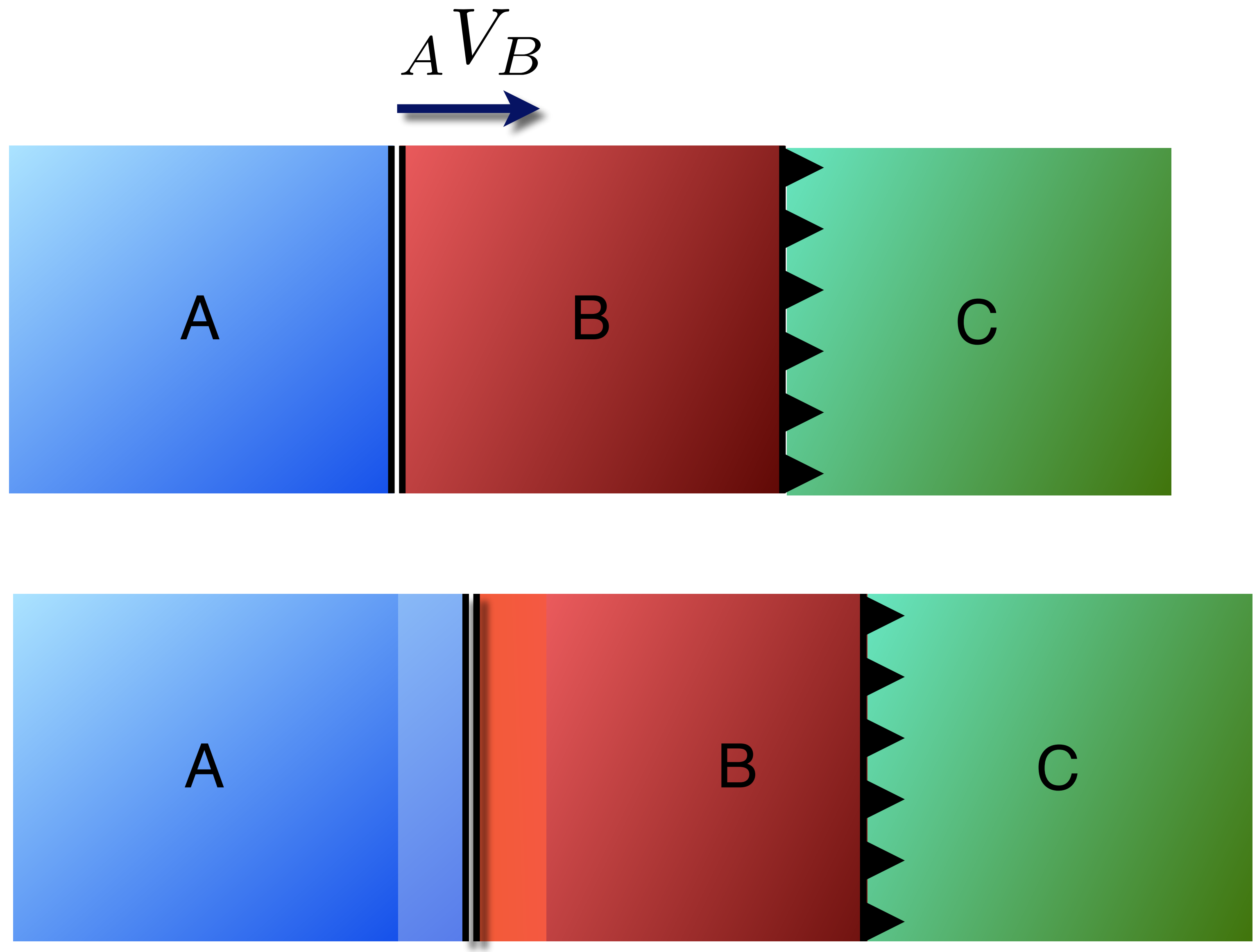
Today

Some time later...

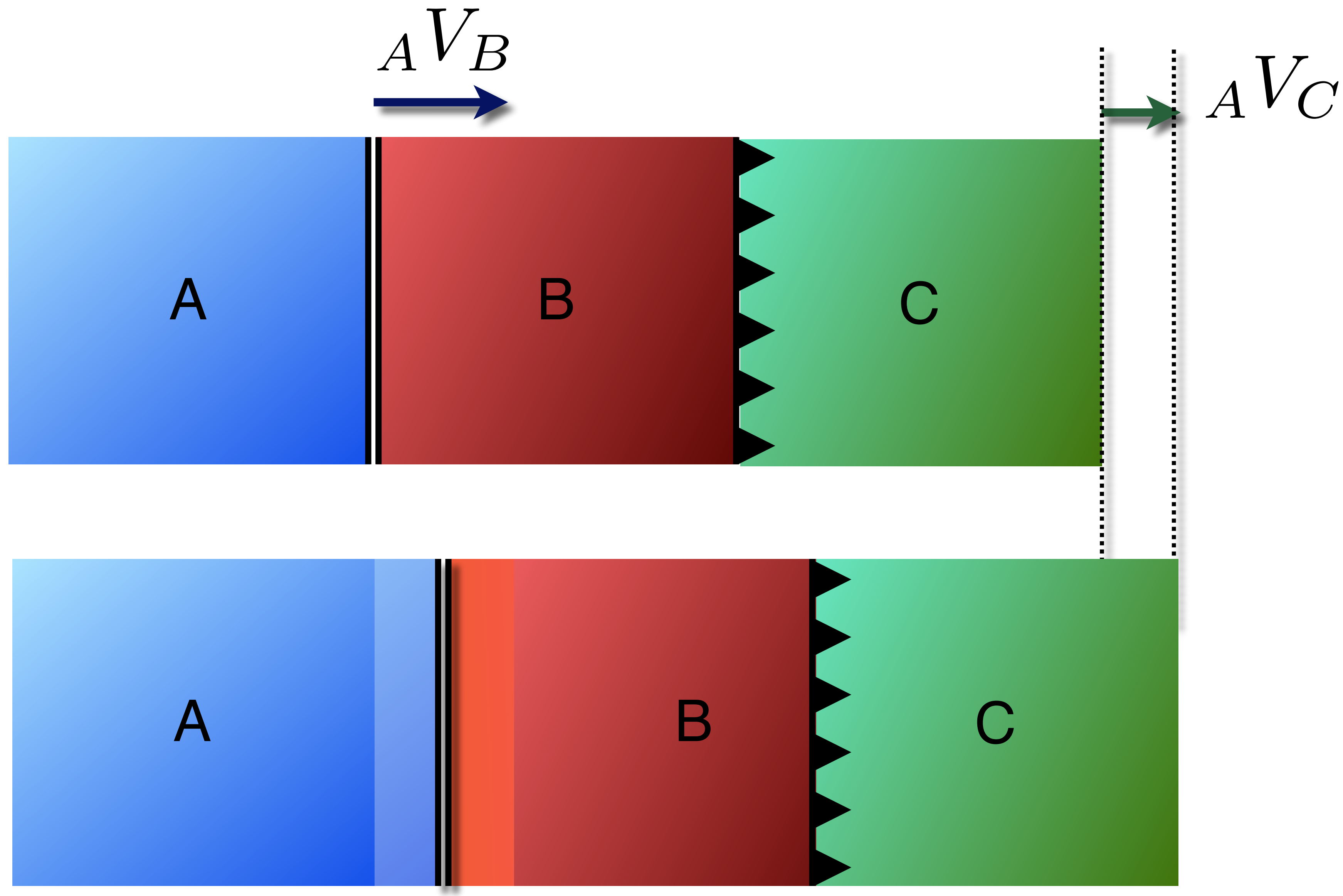


$$_{B}V_{A} = -_{A}V_{B}$$

Relative velocities



Relative velocities



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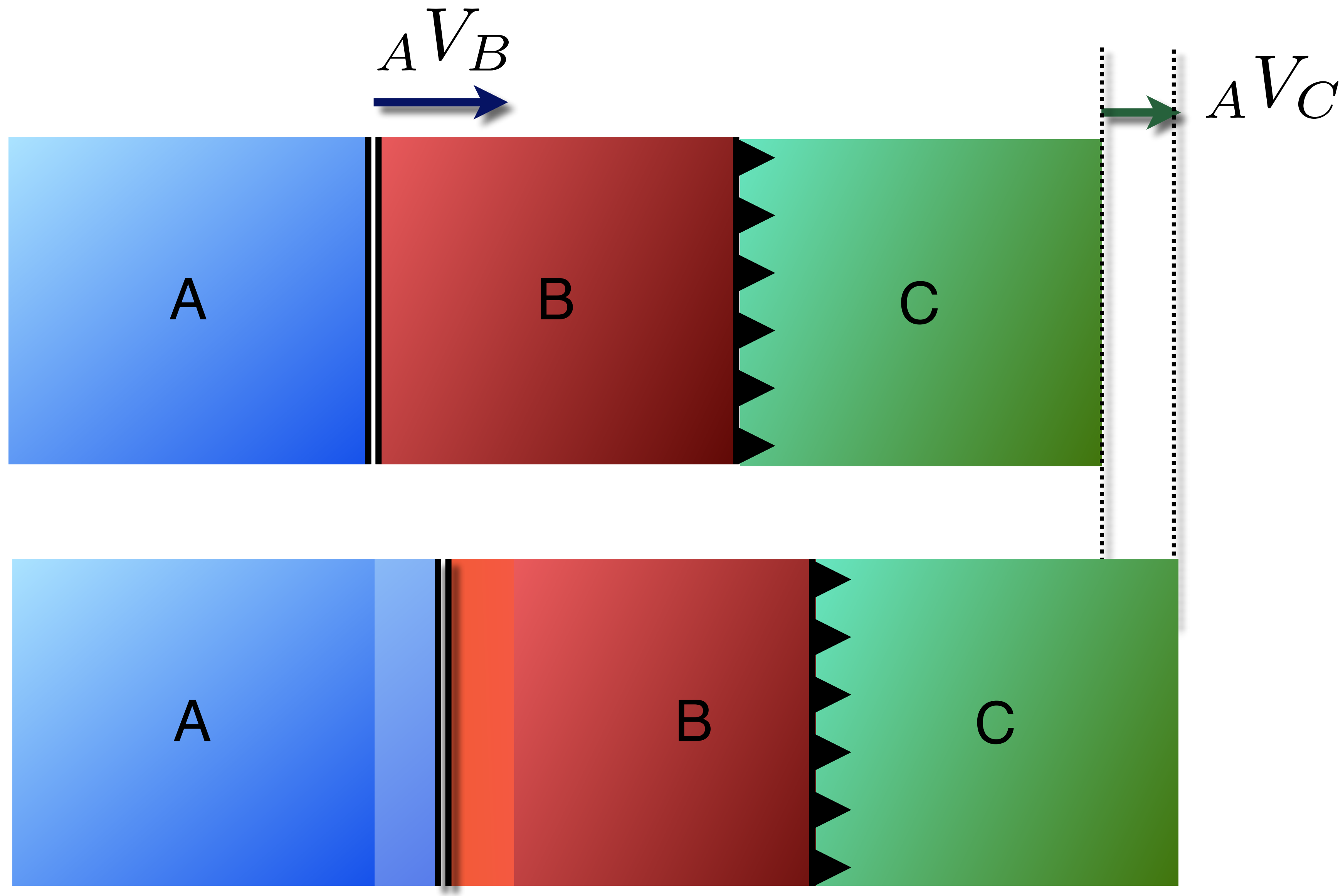
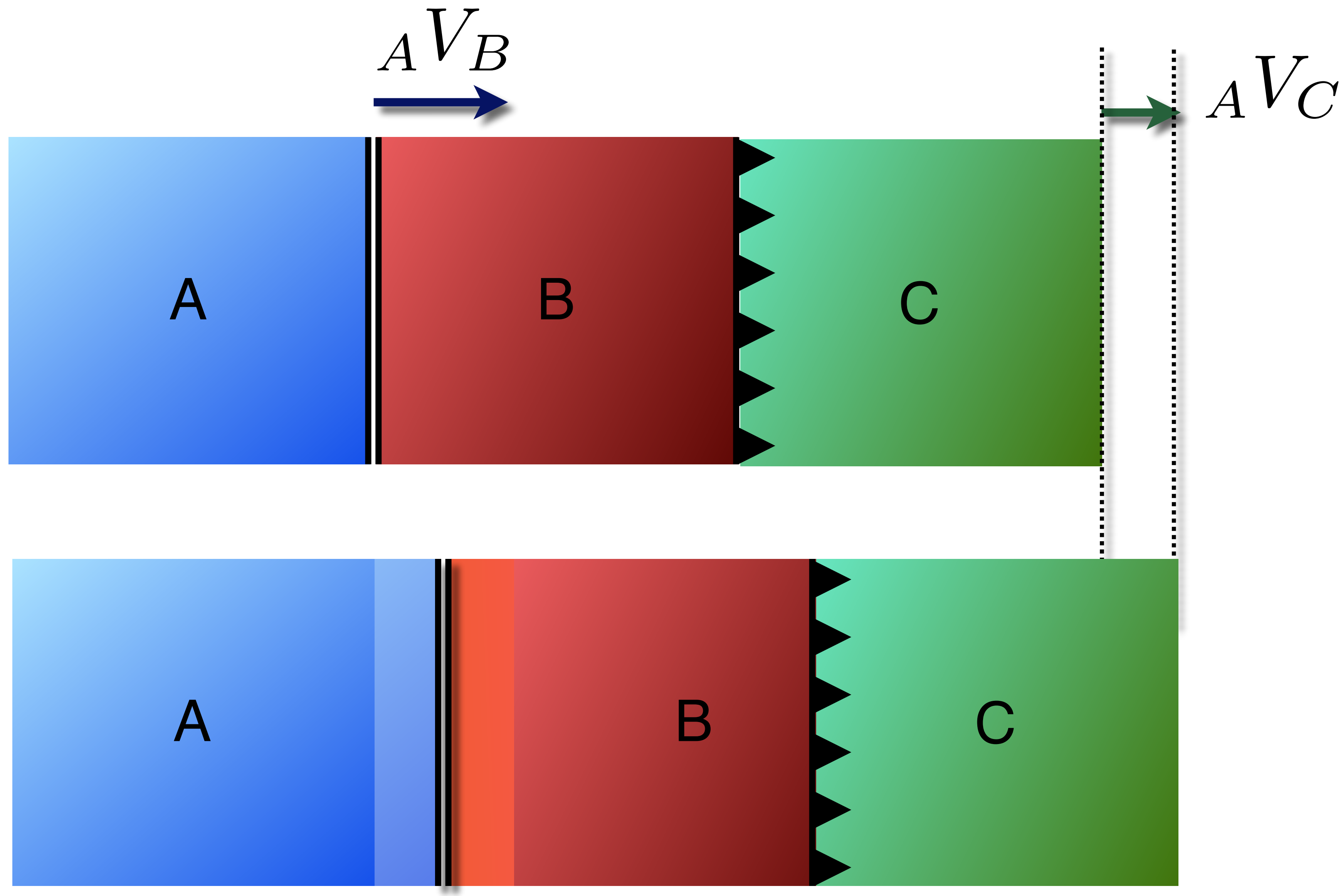


$$_AV_C = {_AV_B} + {_BV_C}$$

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

Relative velocities



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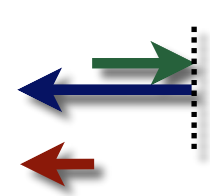
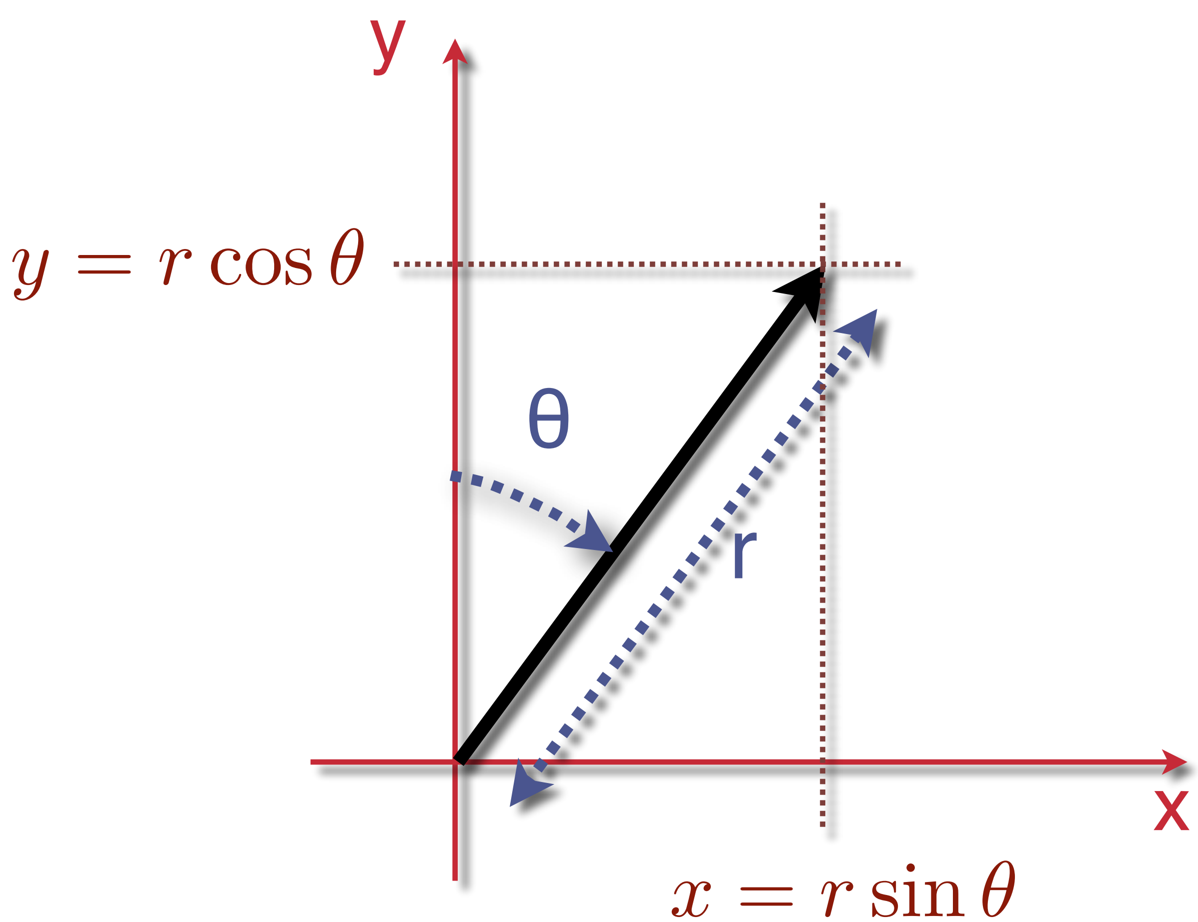


Detour — vectors

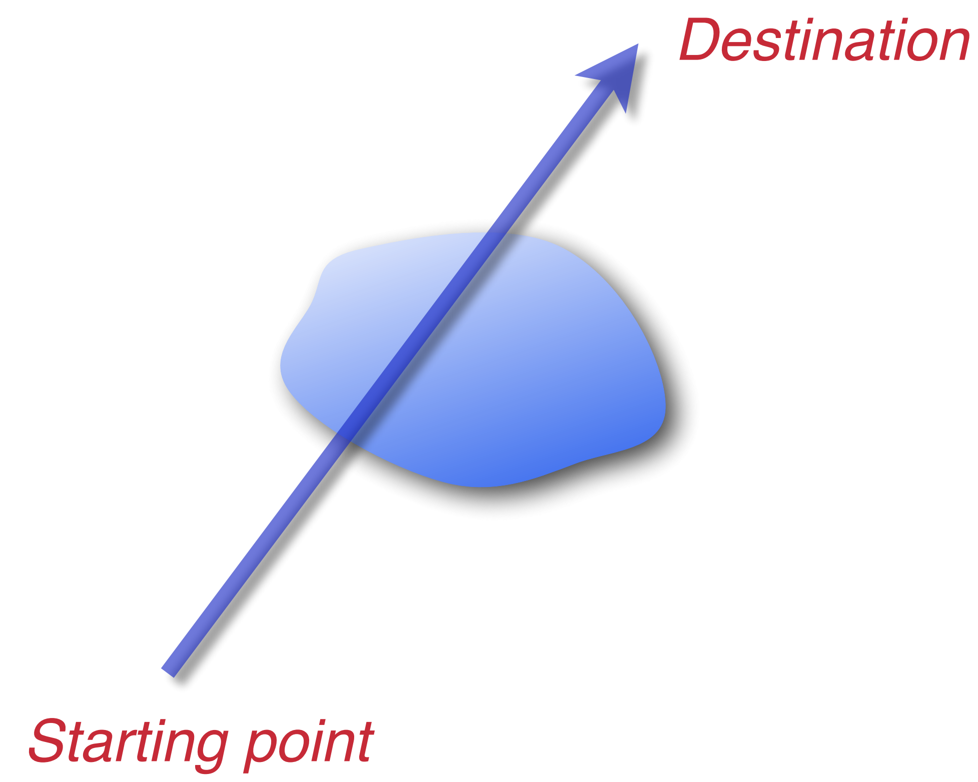
- Have magnitude and direction
- Examples:
  - Velocity (speed in given direction)
  - Acceleration
  - Displacement (offset and direction)
- Described in terms of
  - Length and Direction (r,θ)
  - Cartesian offset (x,y)



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

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 ..."*

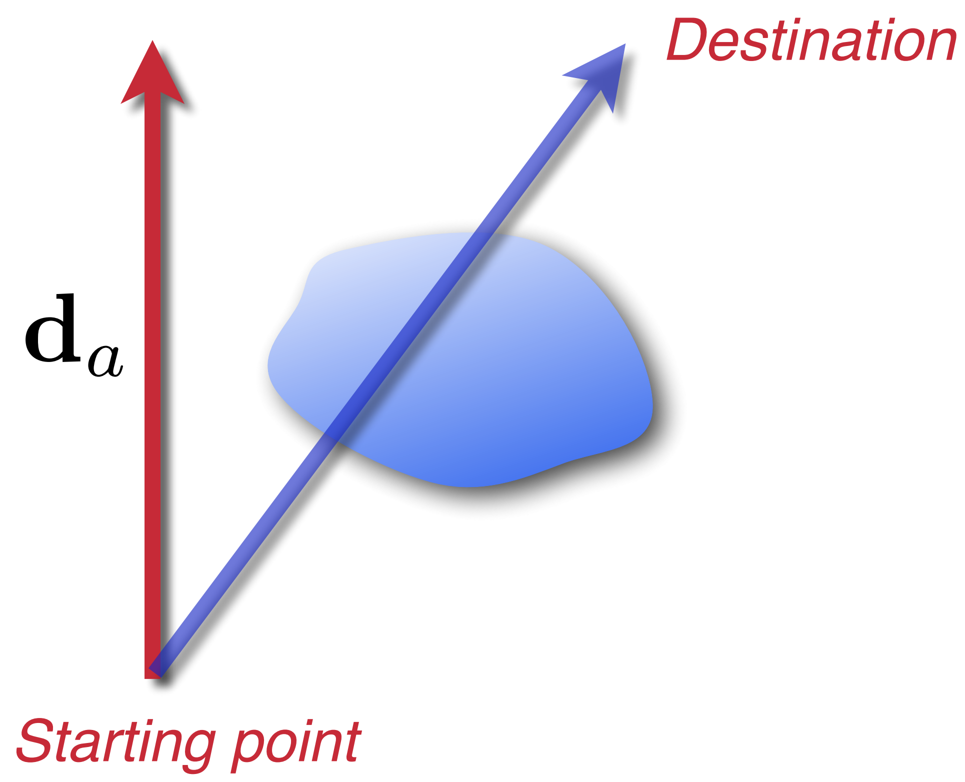
Detour — vector addition



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 ... "

Detour — vector addition



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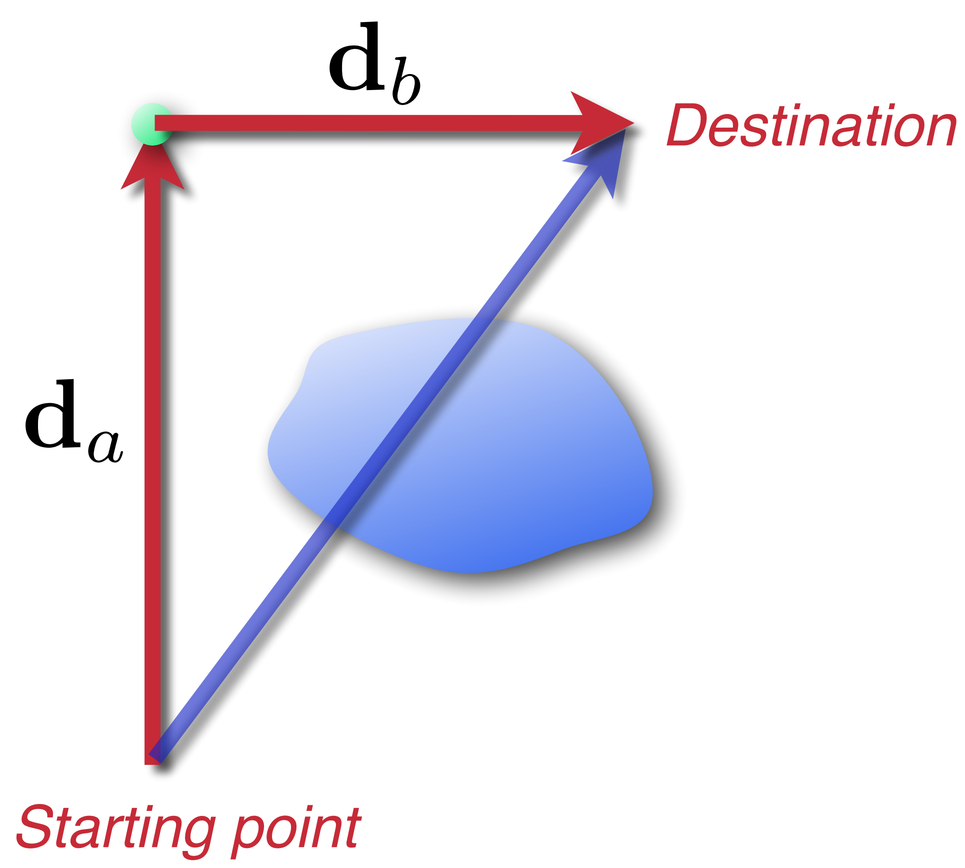

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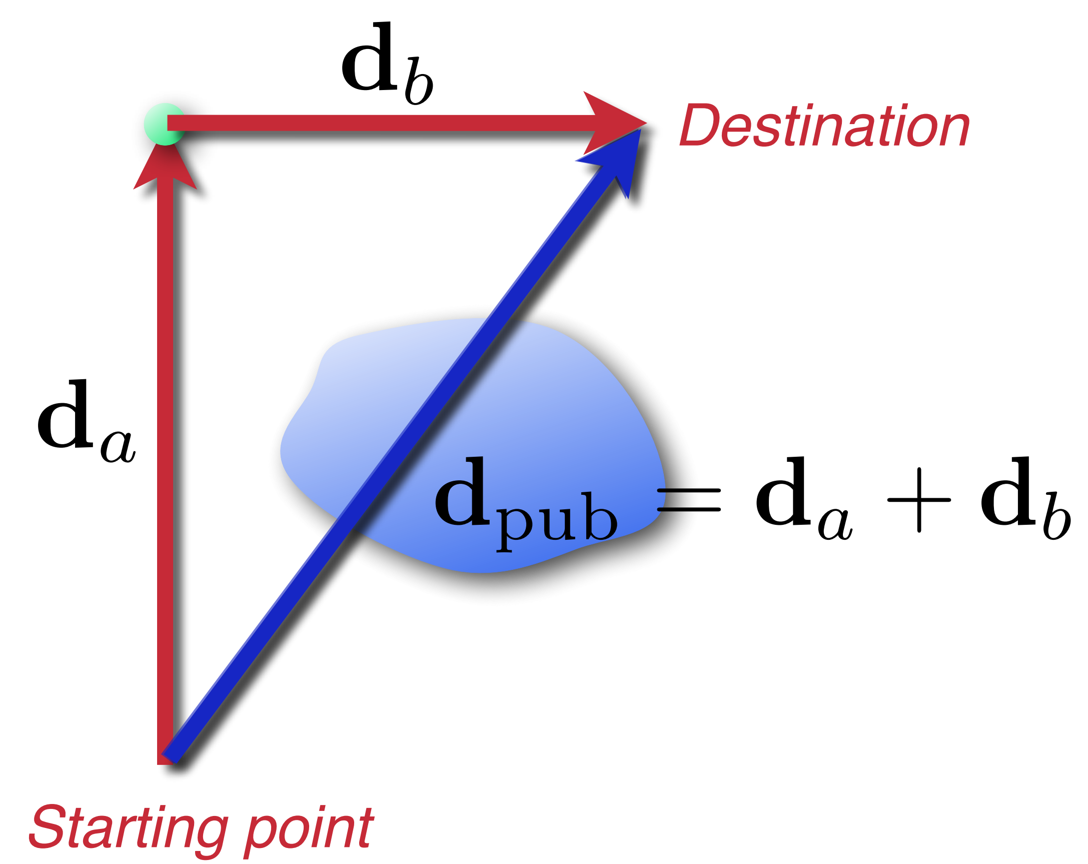

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“To get to the pub (without falling in the lake) walk 80 metres North and then 60 metres East ... ”

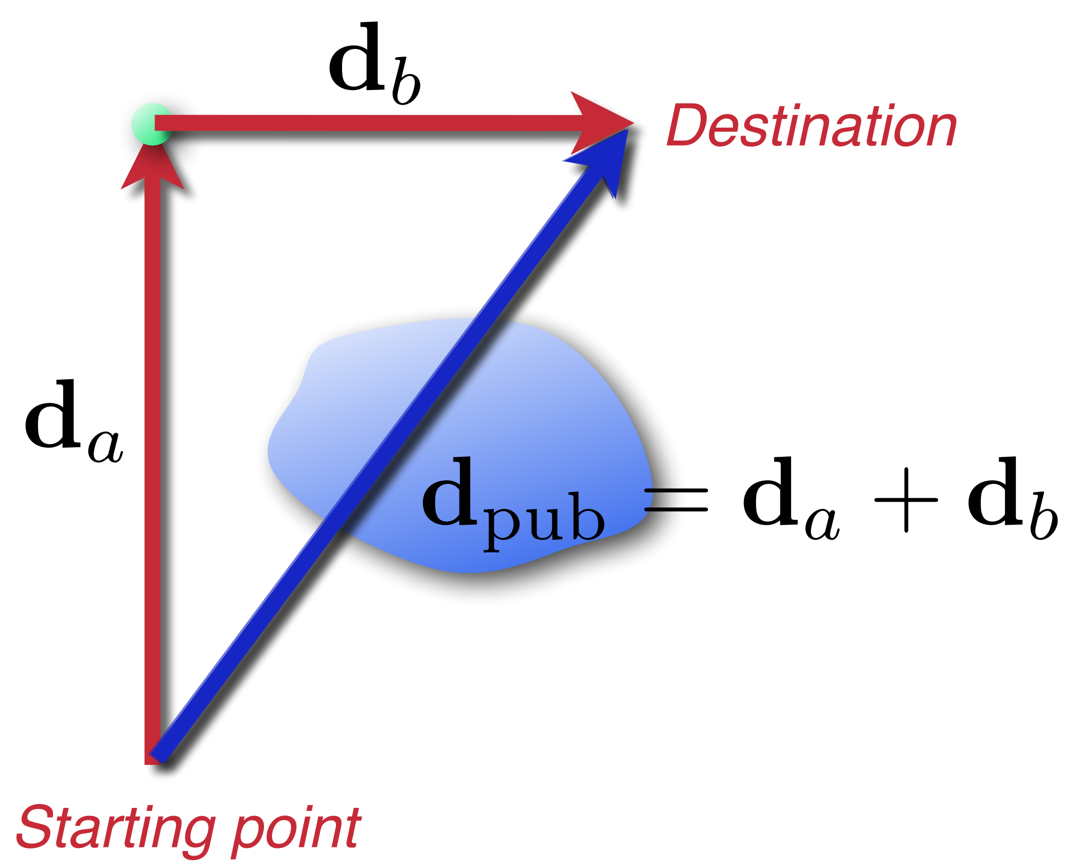
Detour — vector addition

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

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

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

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



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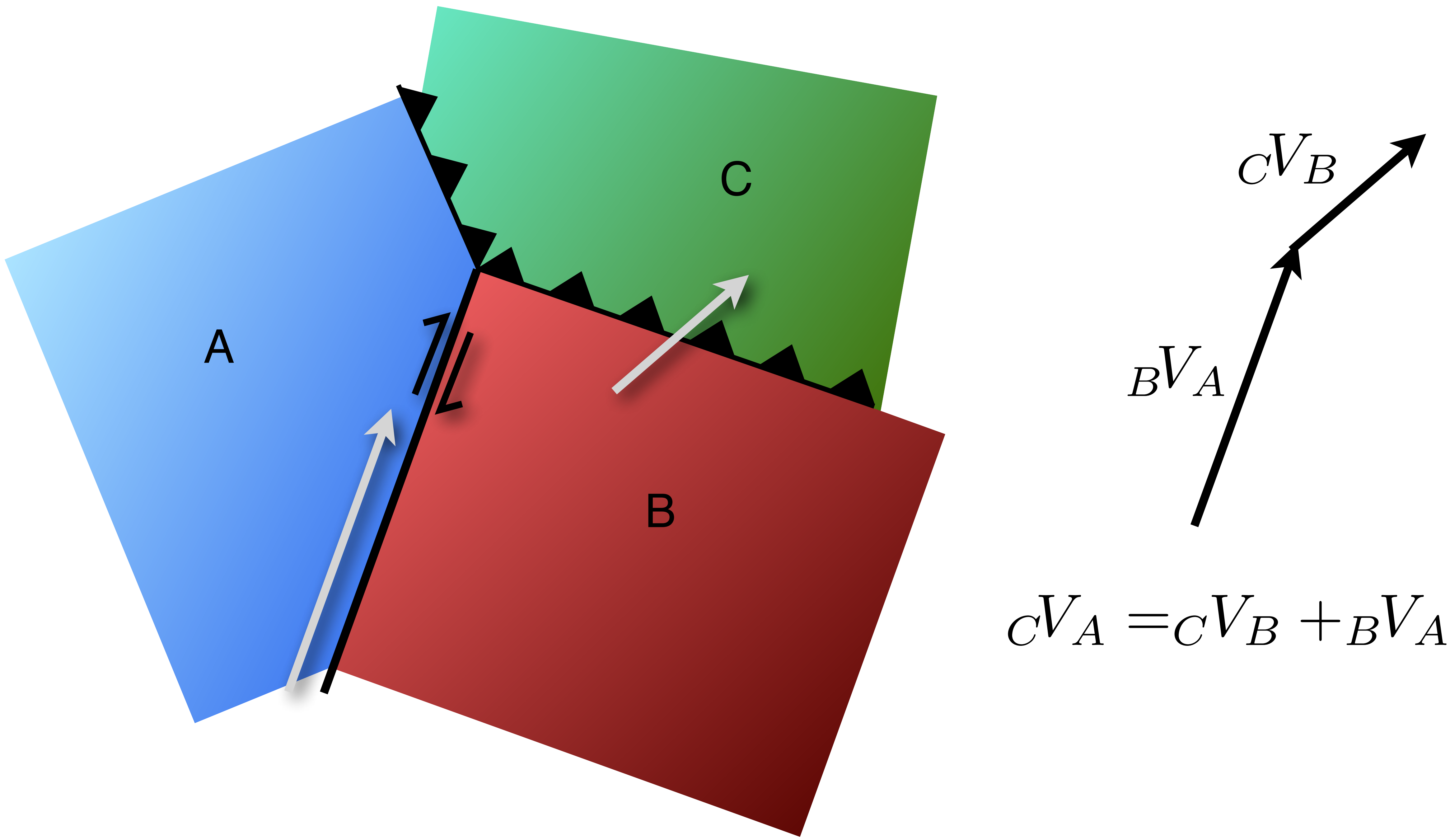
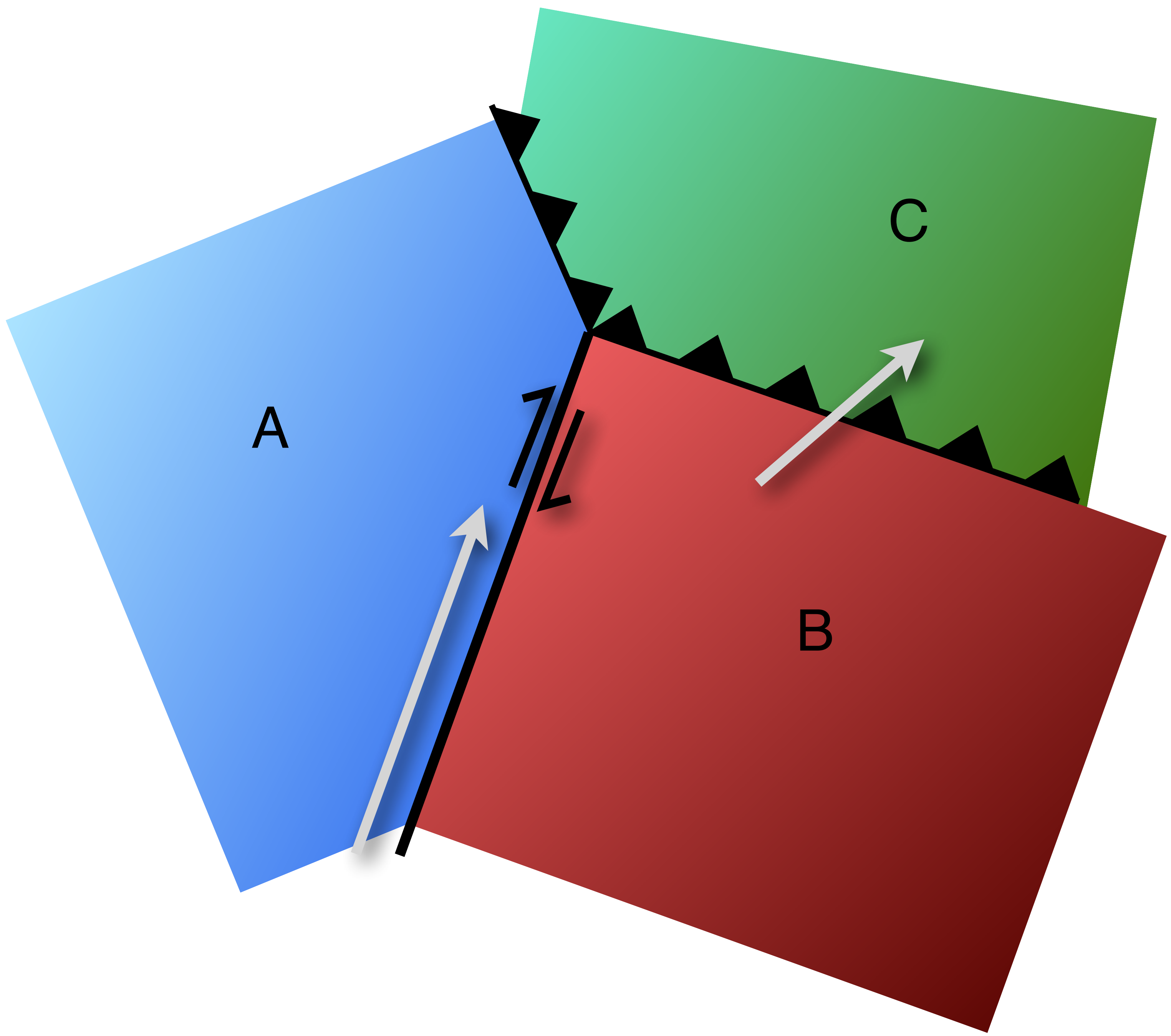
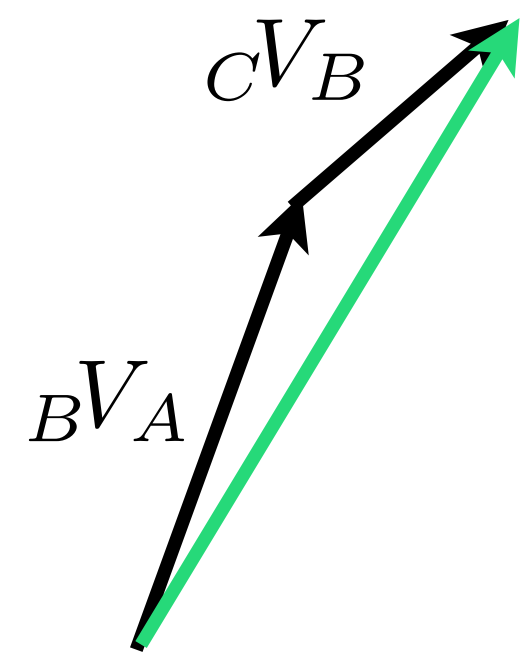
Non-orthogonal boundaries



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

Non-orthogonal boundaries





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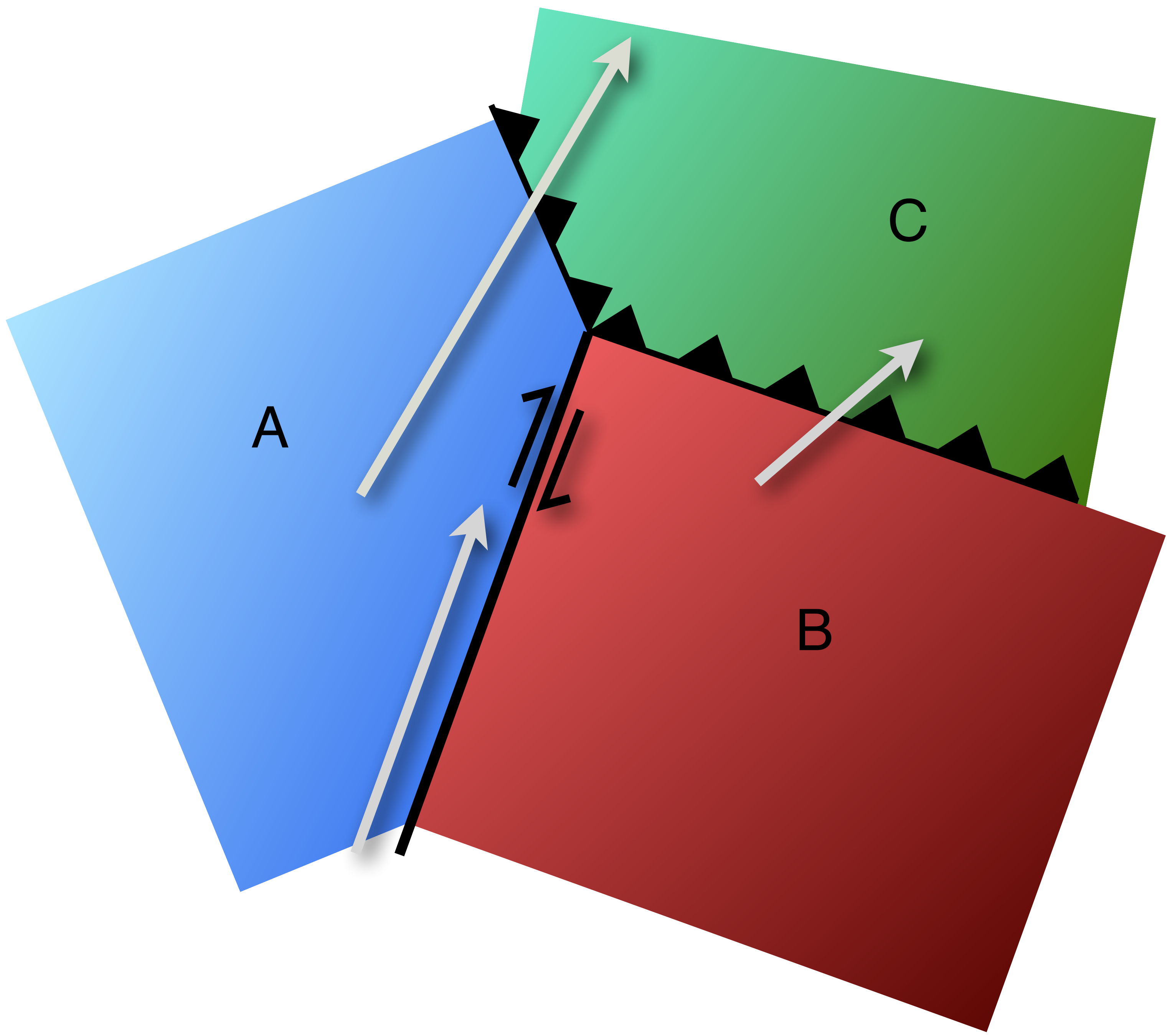

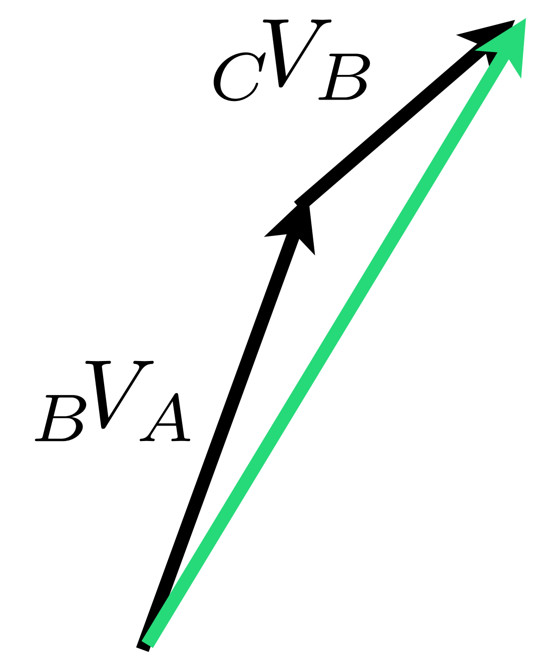

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Plate circuits

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

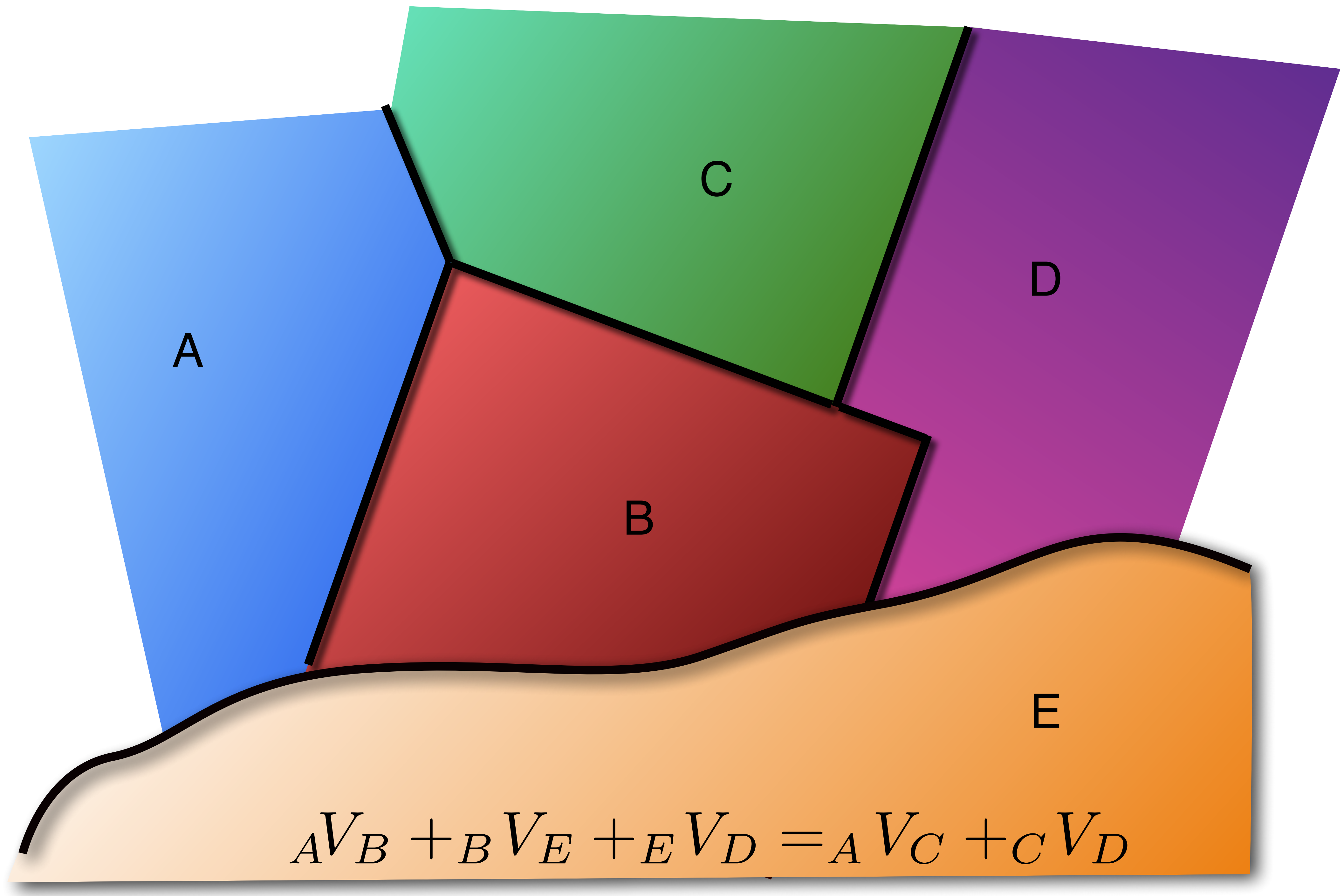
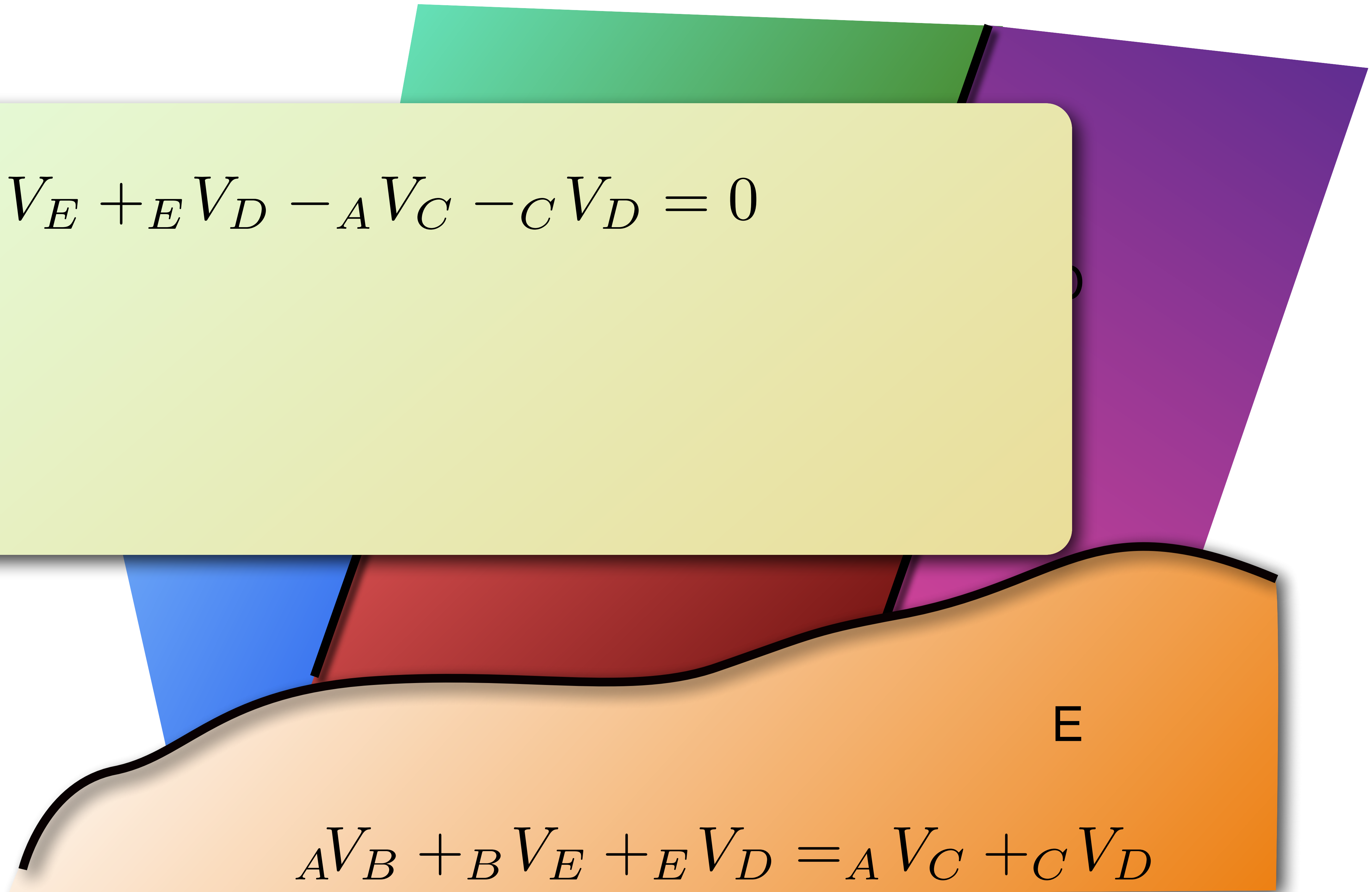


Plate circuits

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

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



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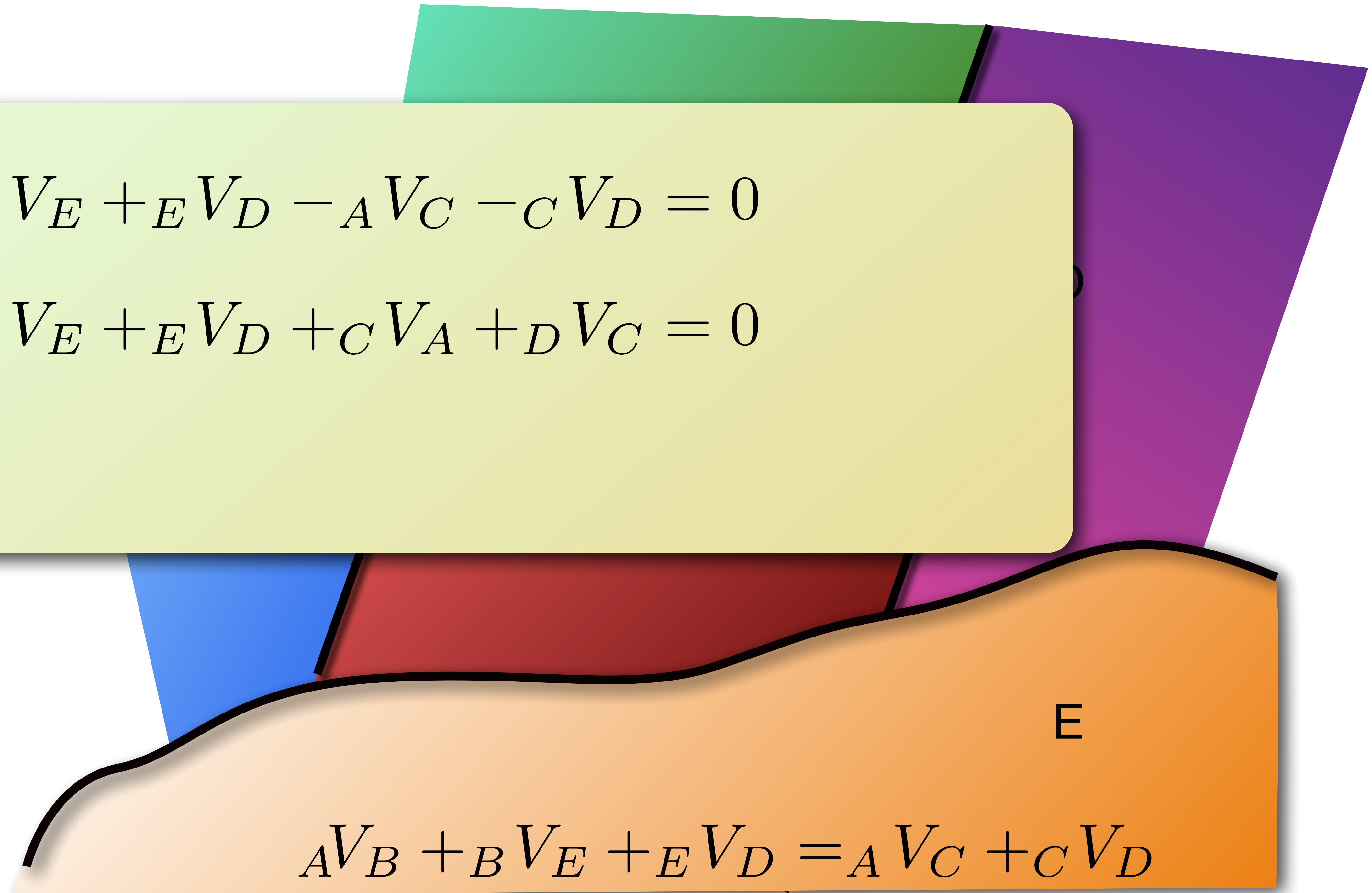

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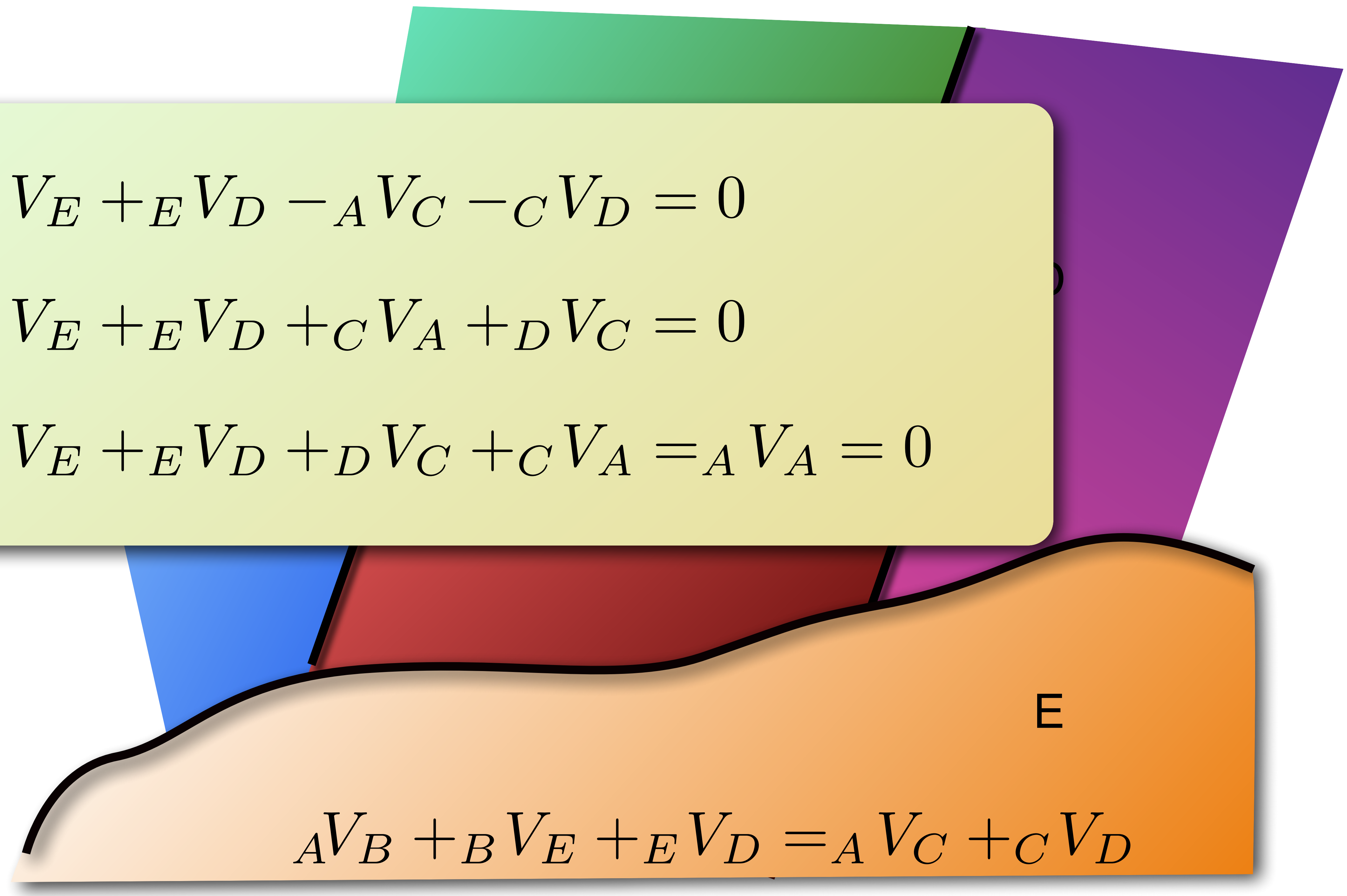
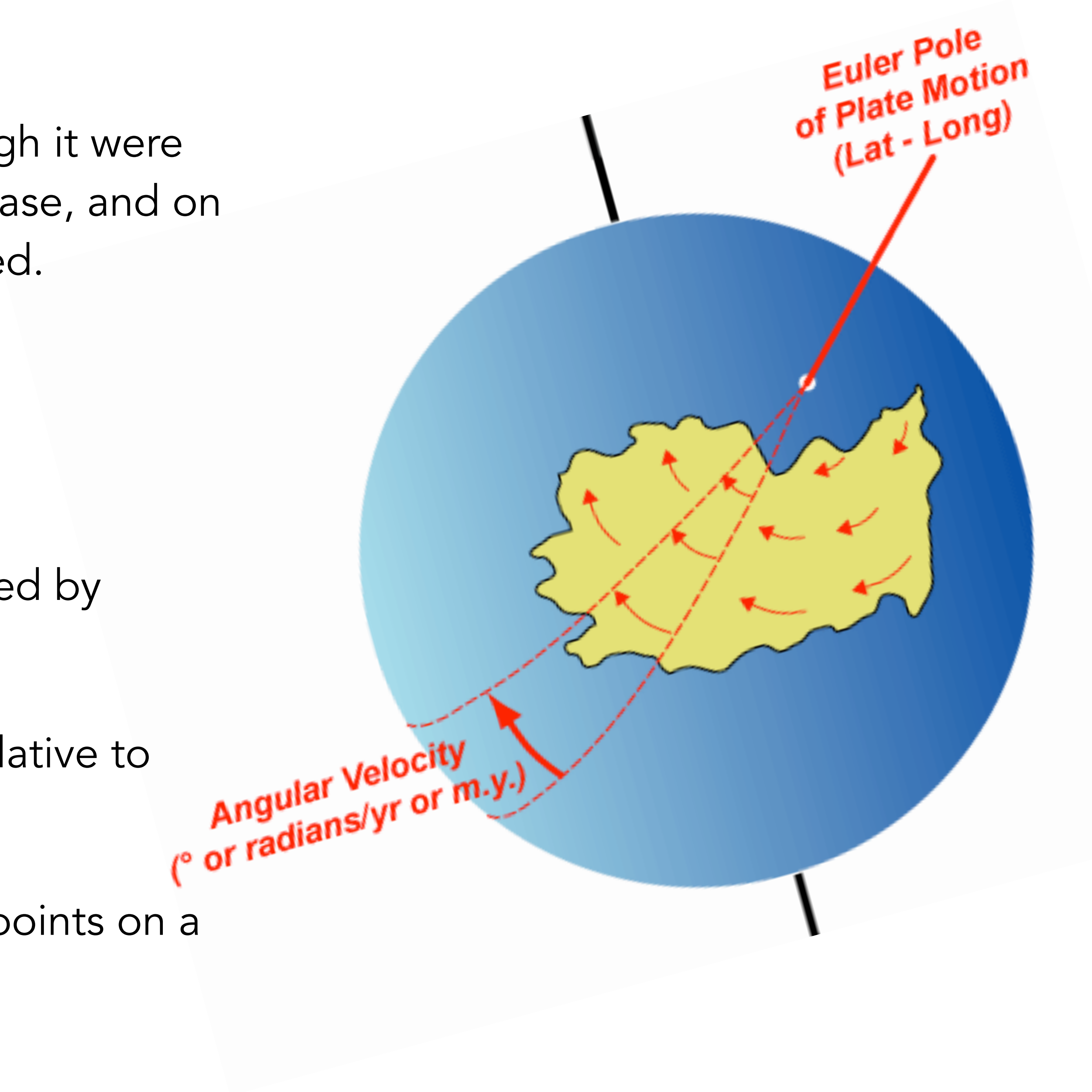


Motions on a sphere

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.

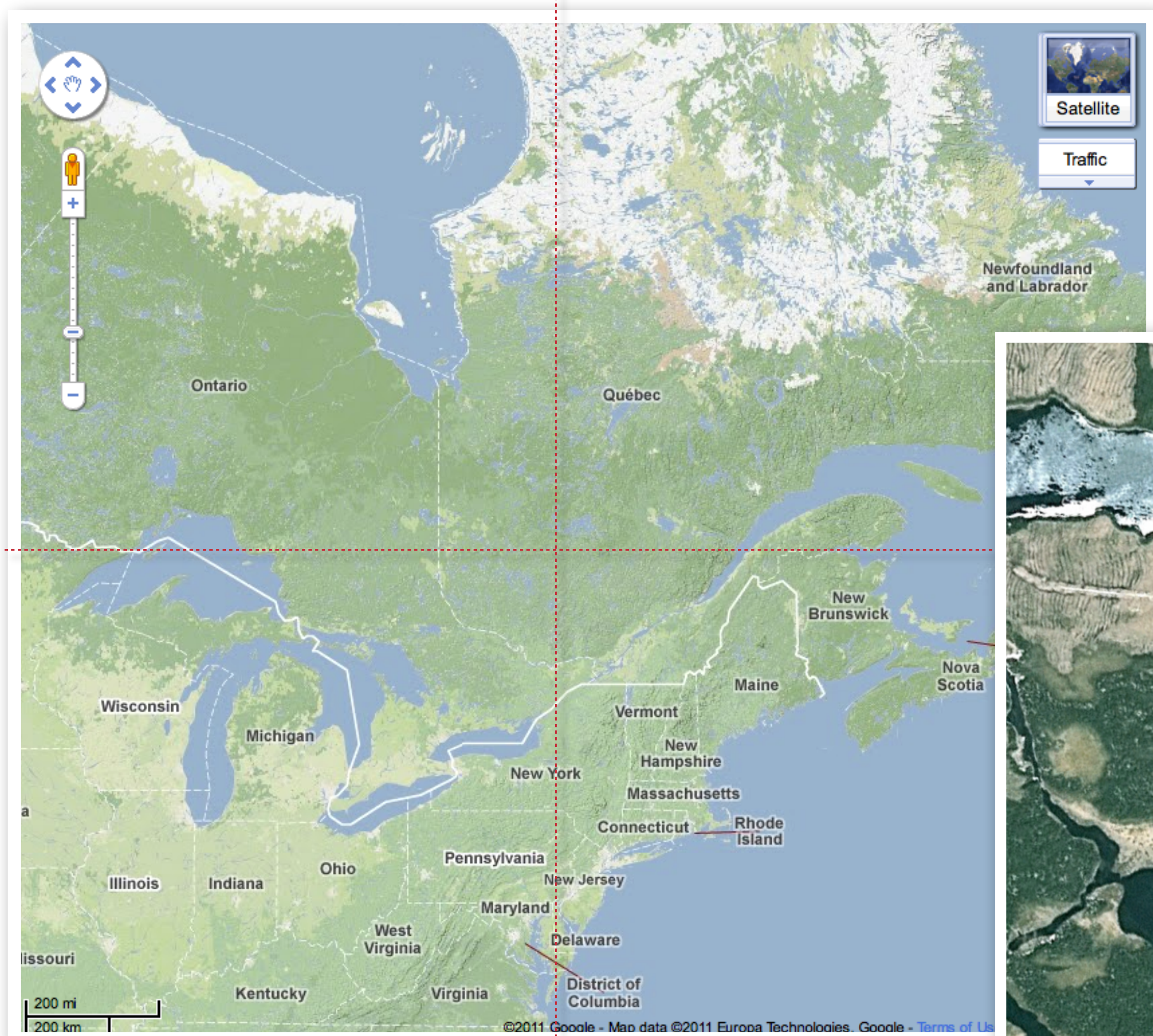


Consequences:

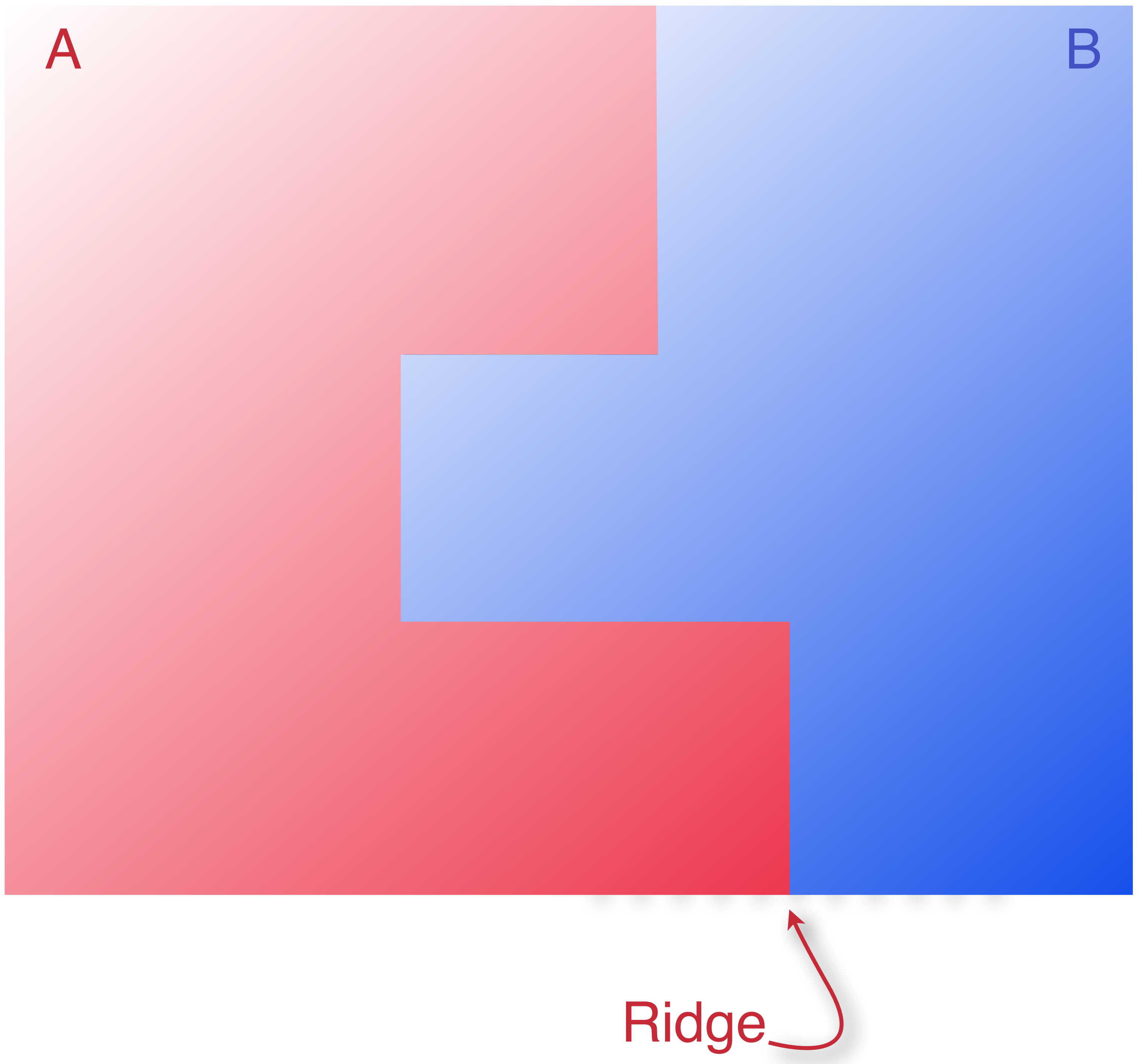
- The (relative) motion of plates is described by rotation pole and angular velocity
- Transform faults lie along small circles relative to this pole
- The velocity (magnitude & direction) of points on a plate varies systematically over the plate

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



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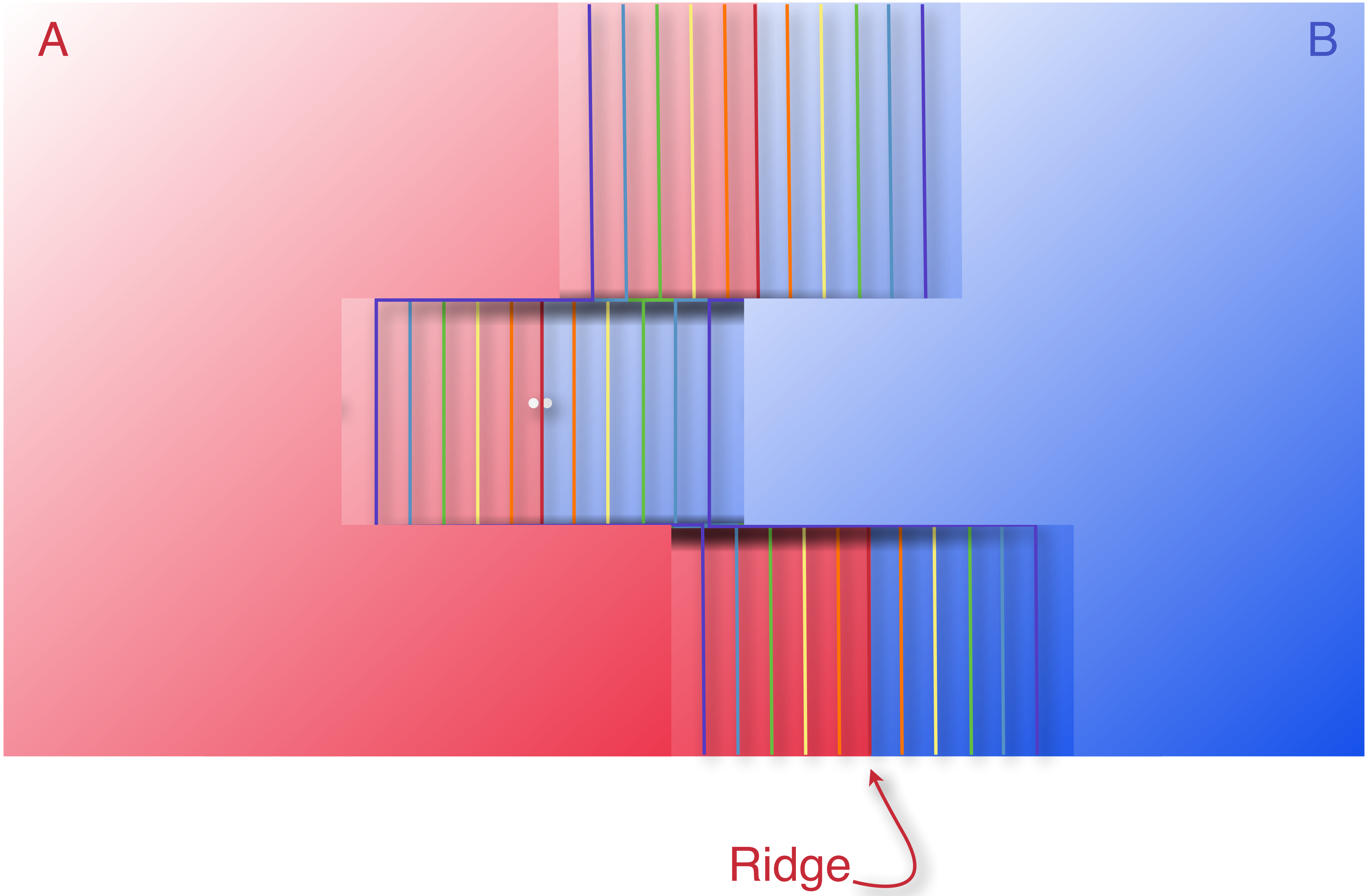

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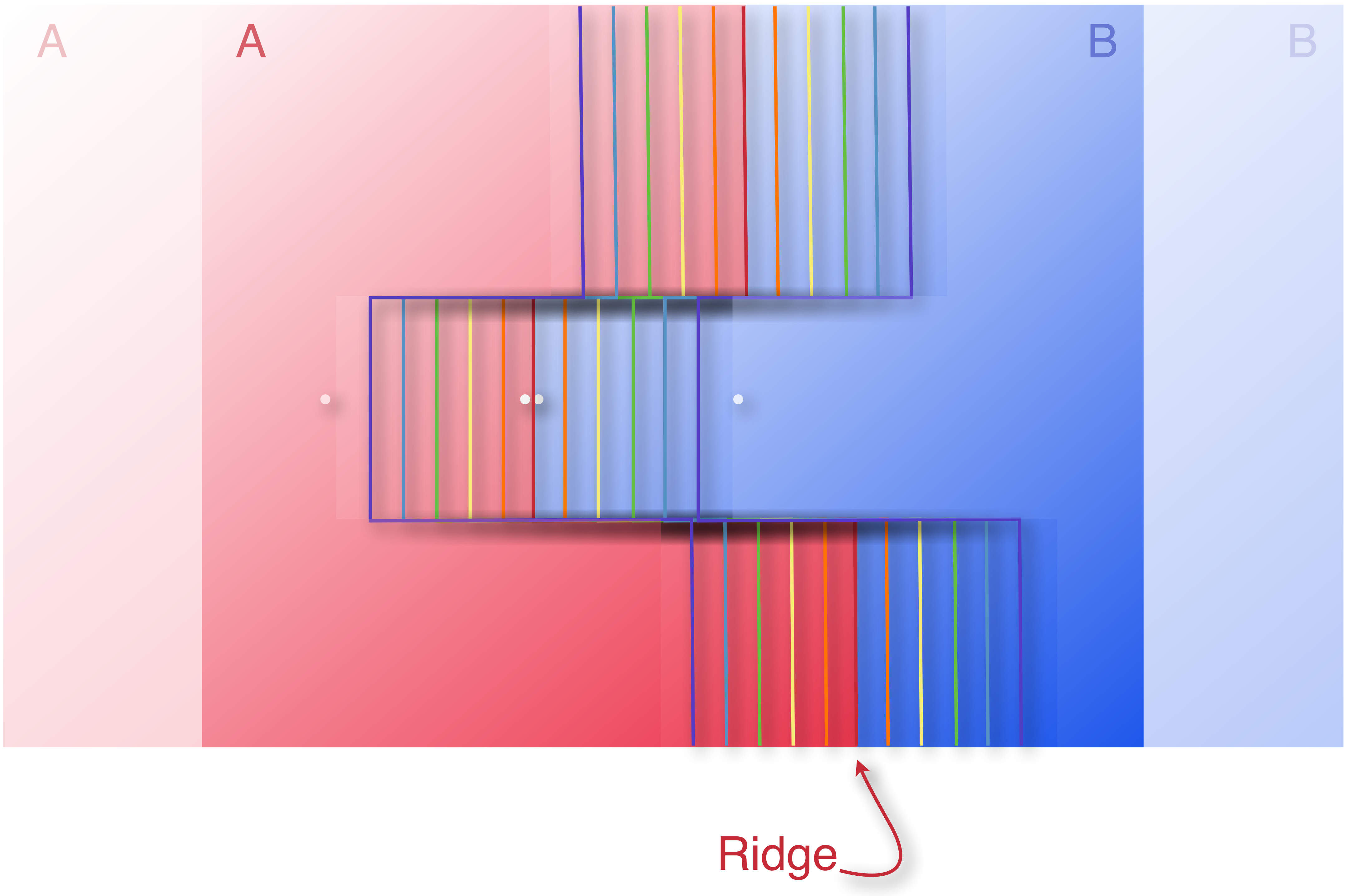
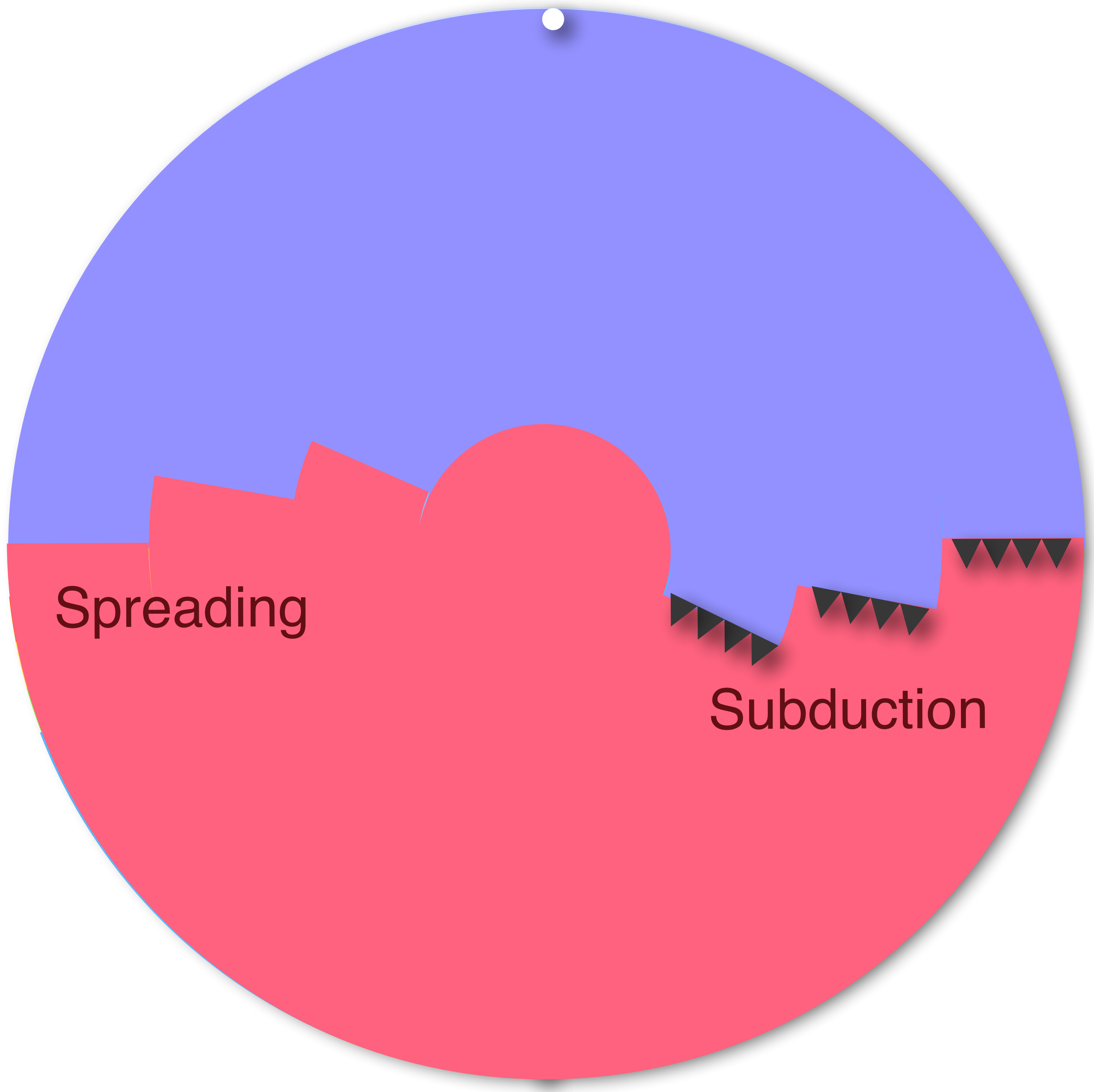


Plate motions on a sphere



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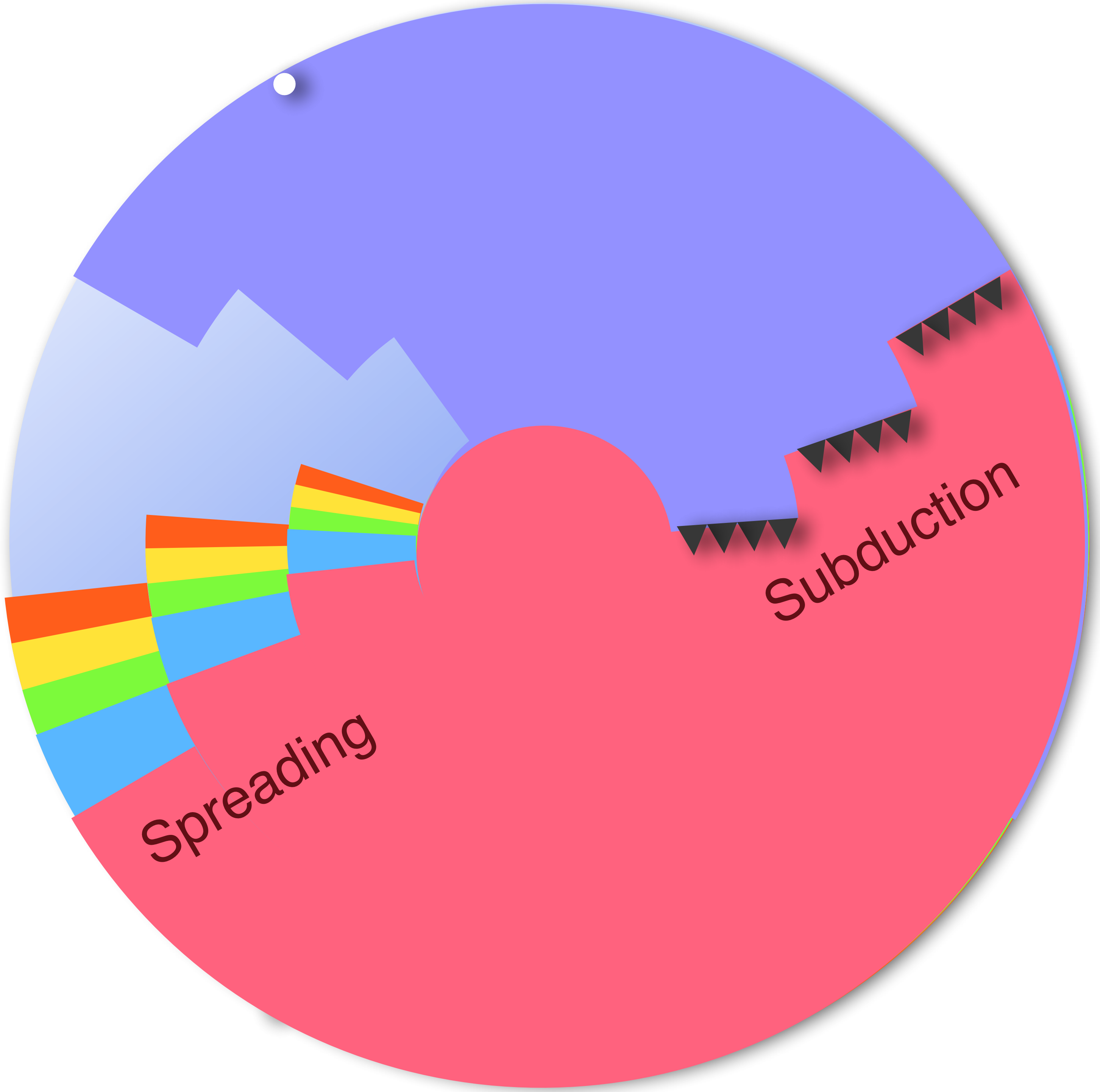
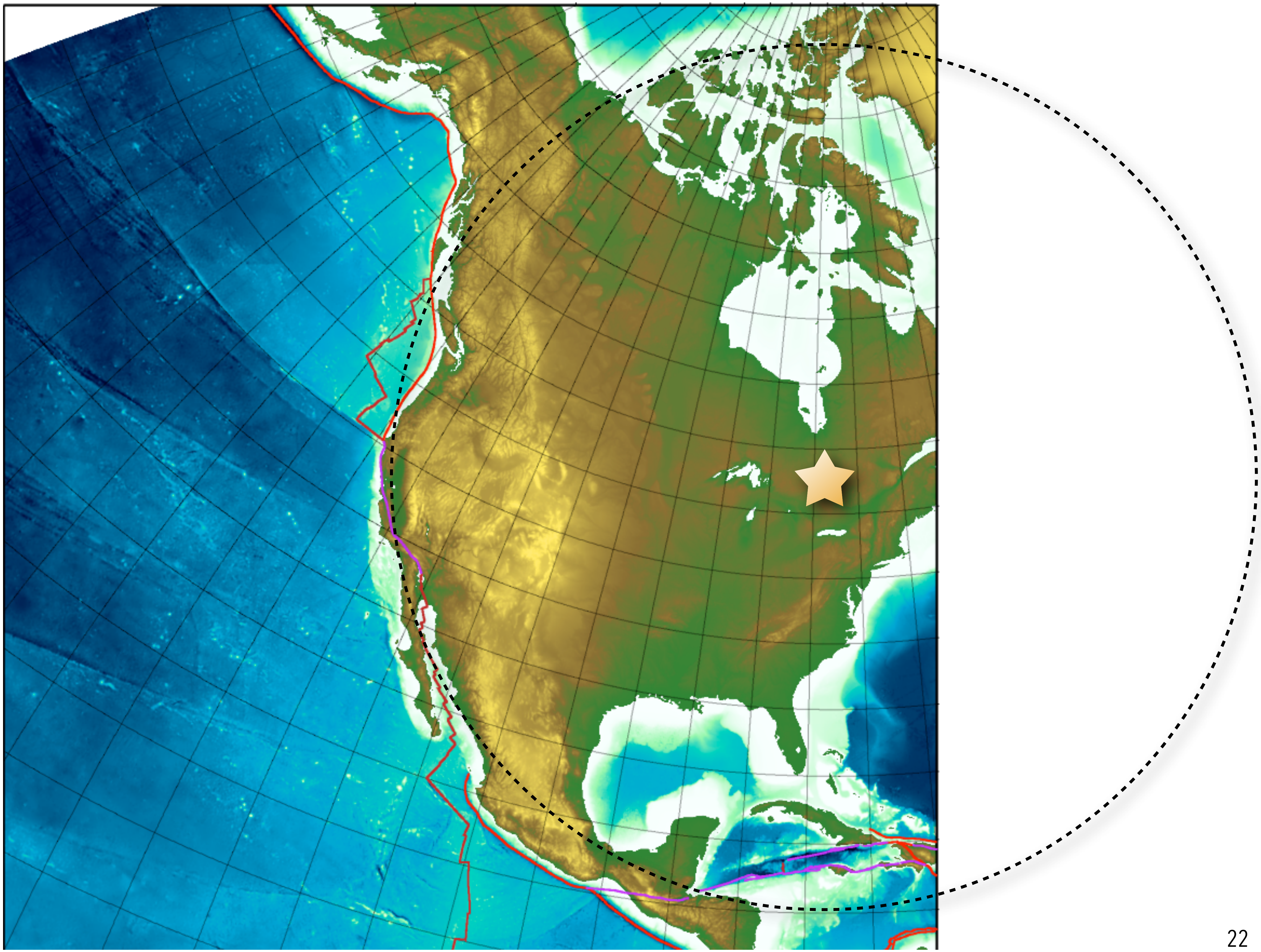
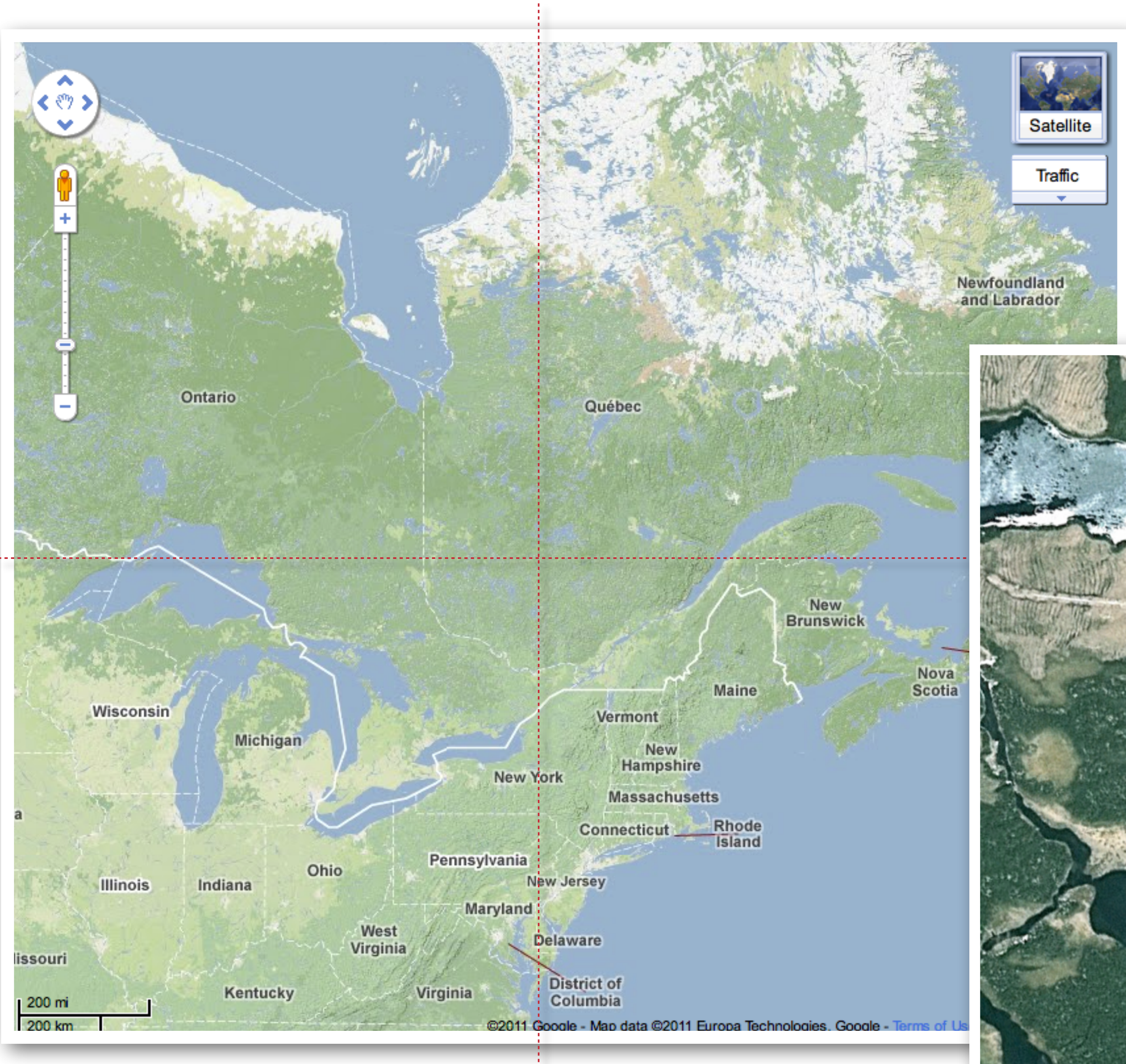


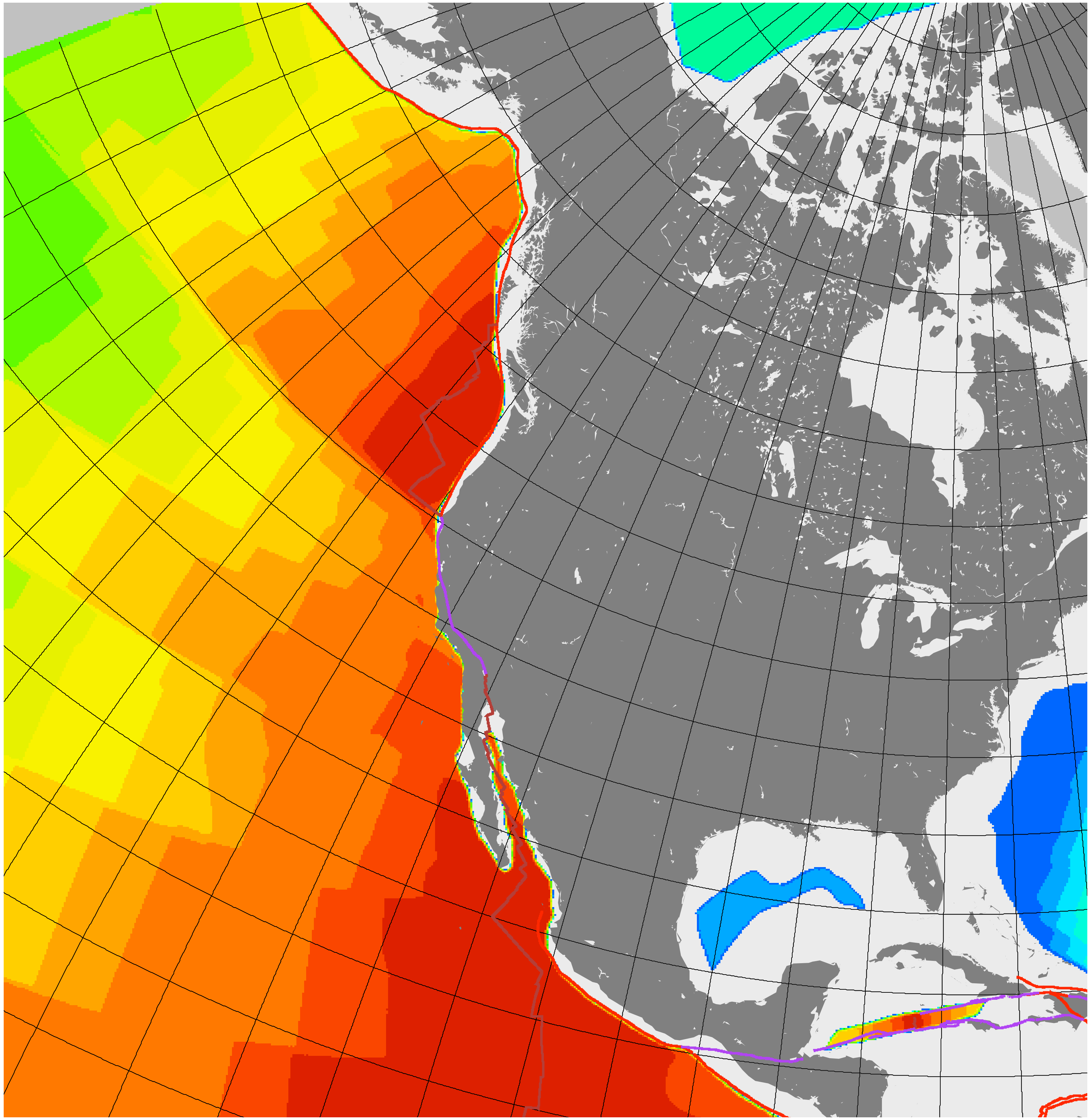
North America / Pacific elevation

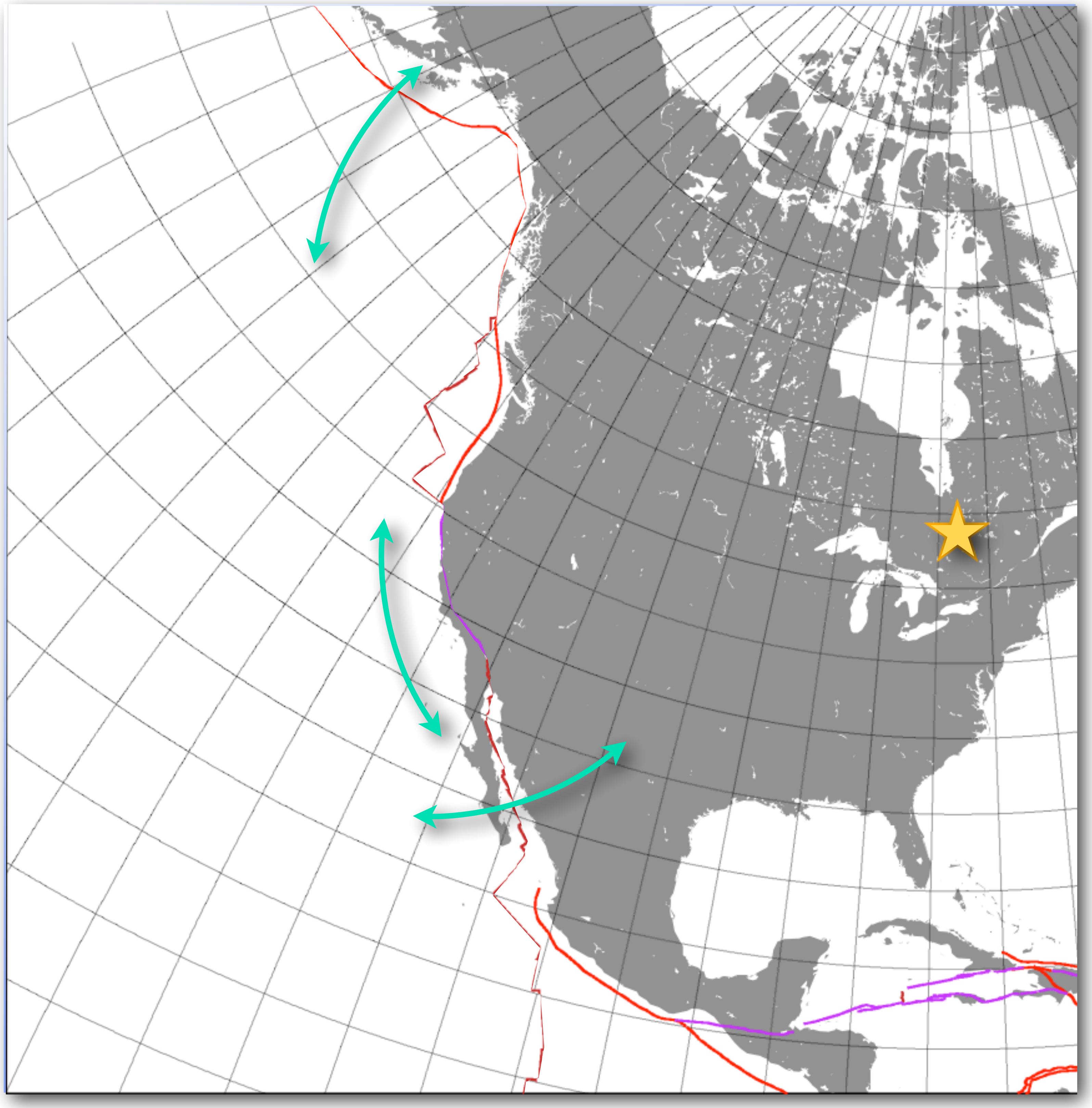


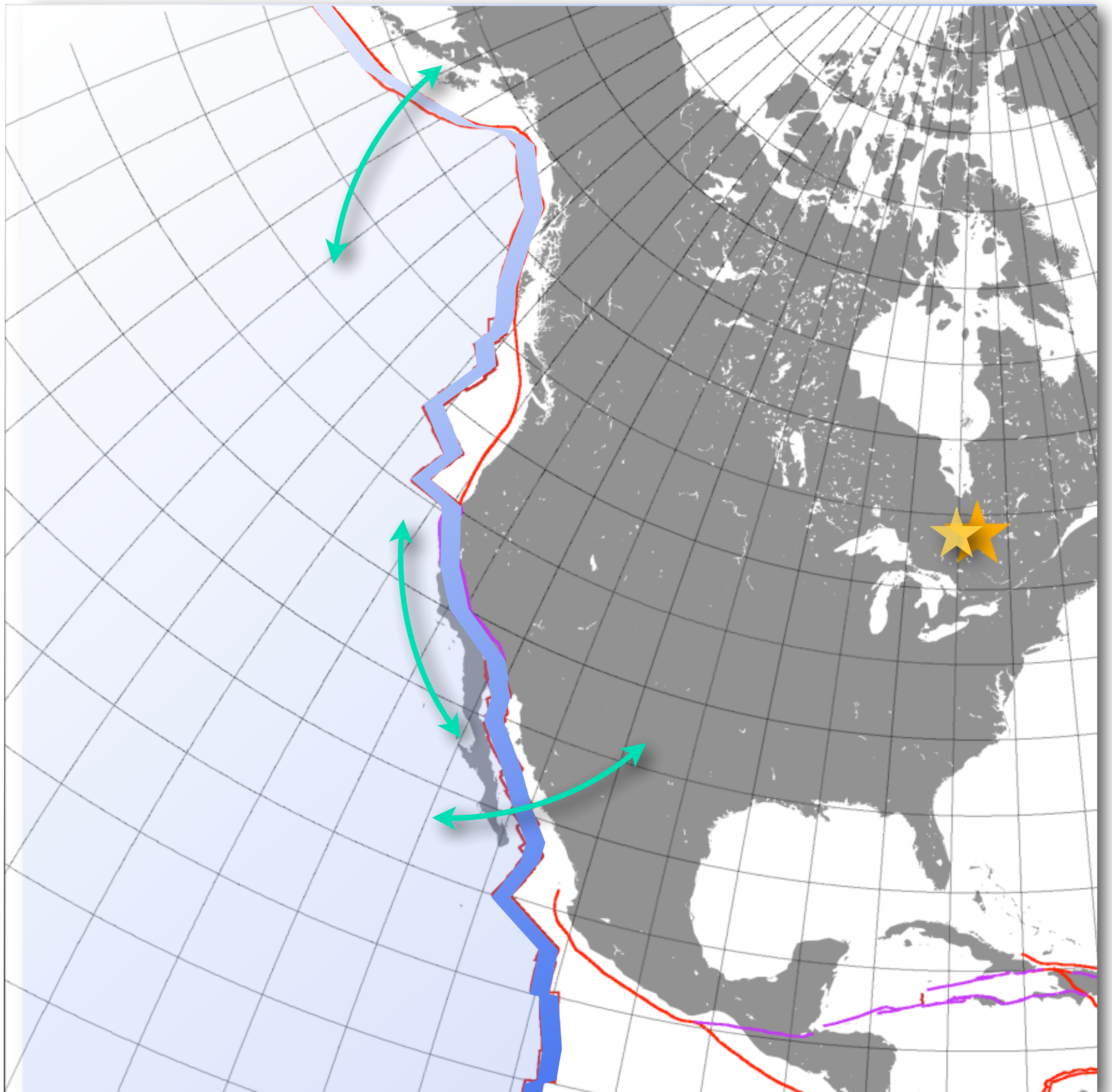
Pacific / North America Rotation Pole

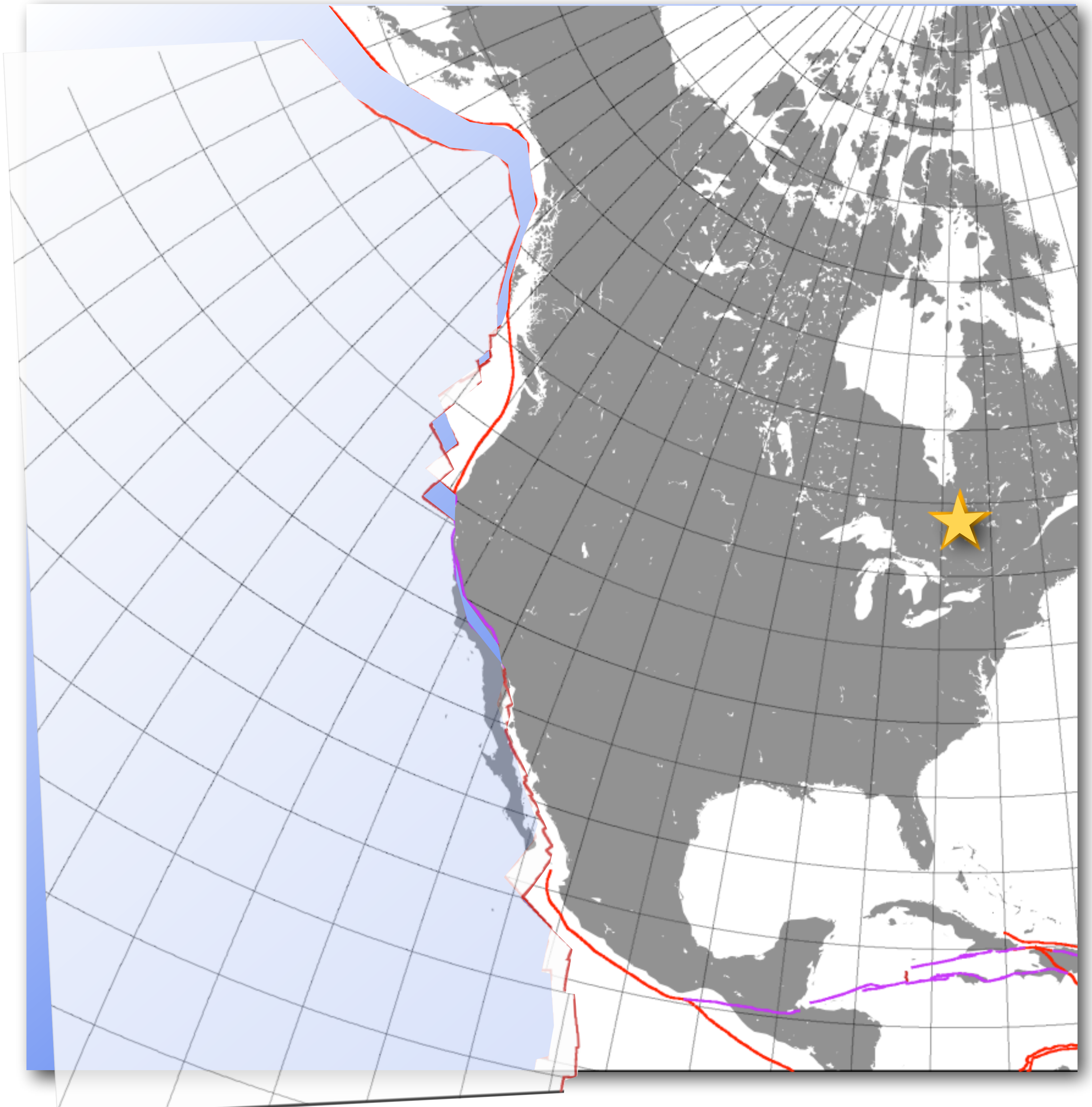


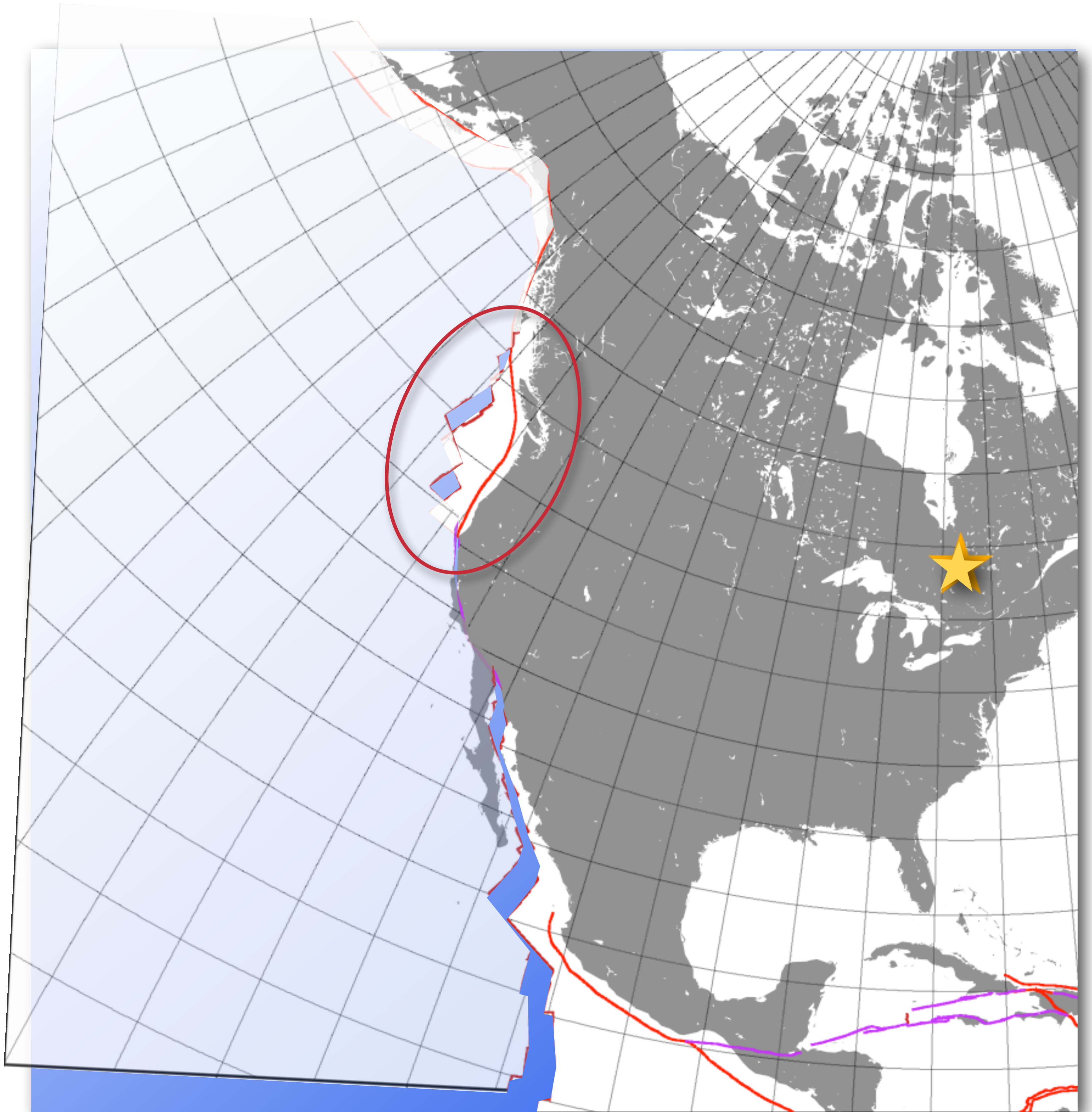
Pacific age grid



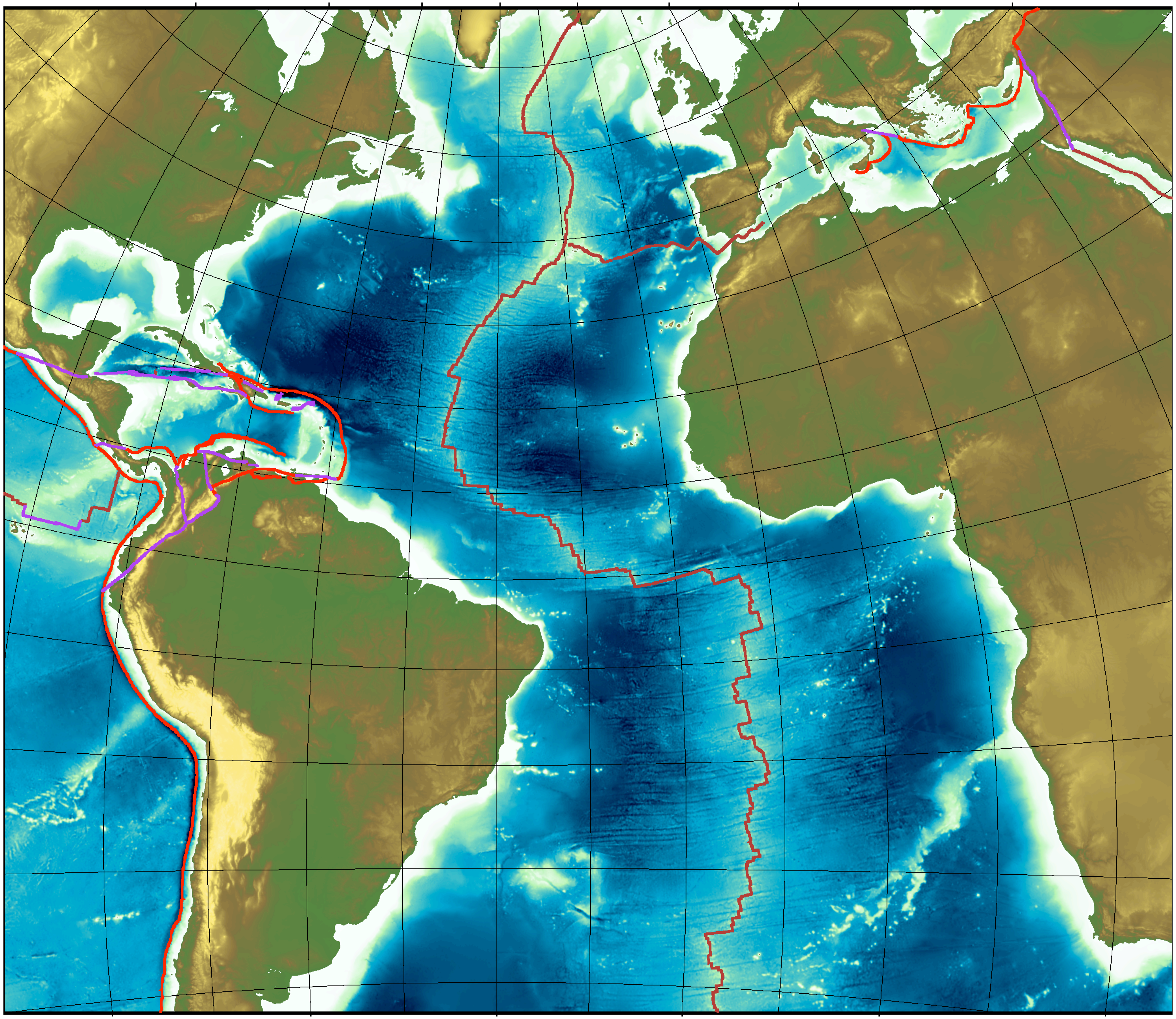




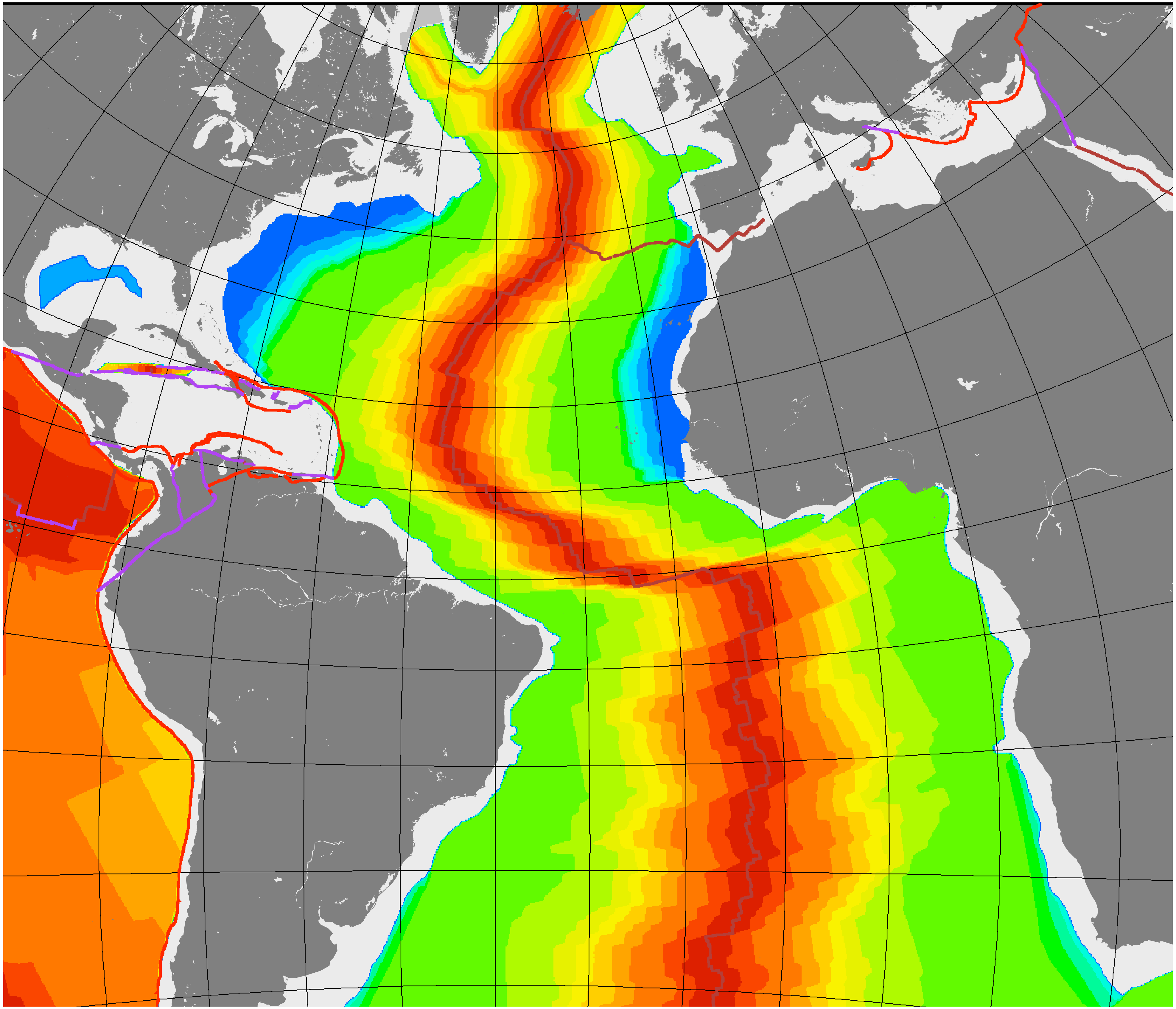


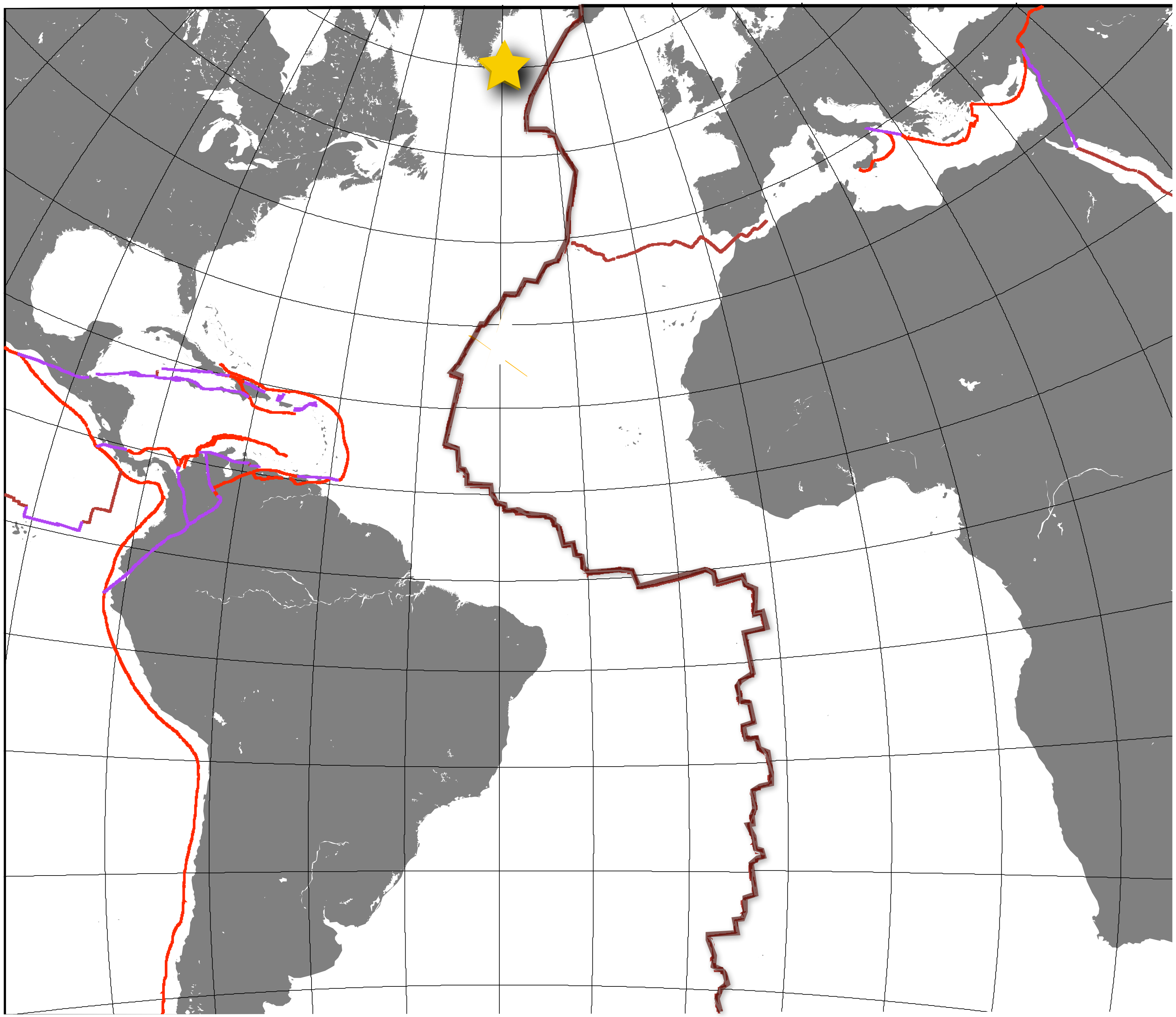


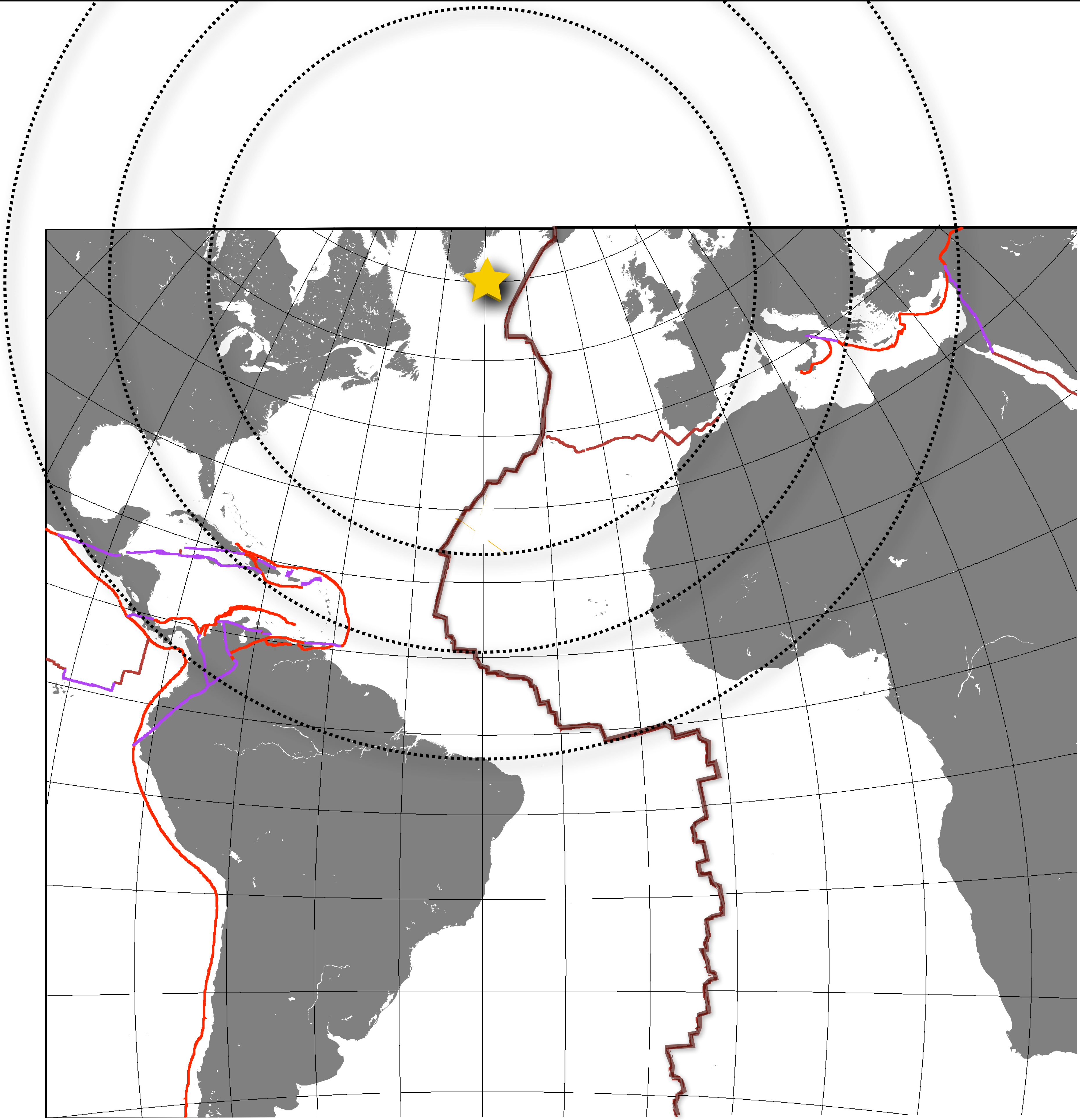
Africa / South America elevation

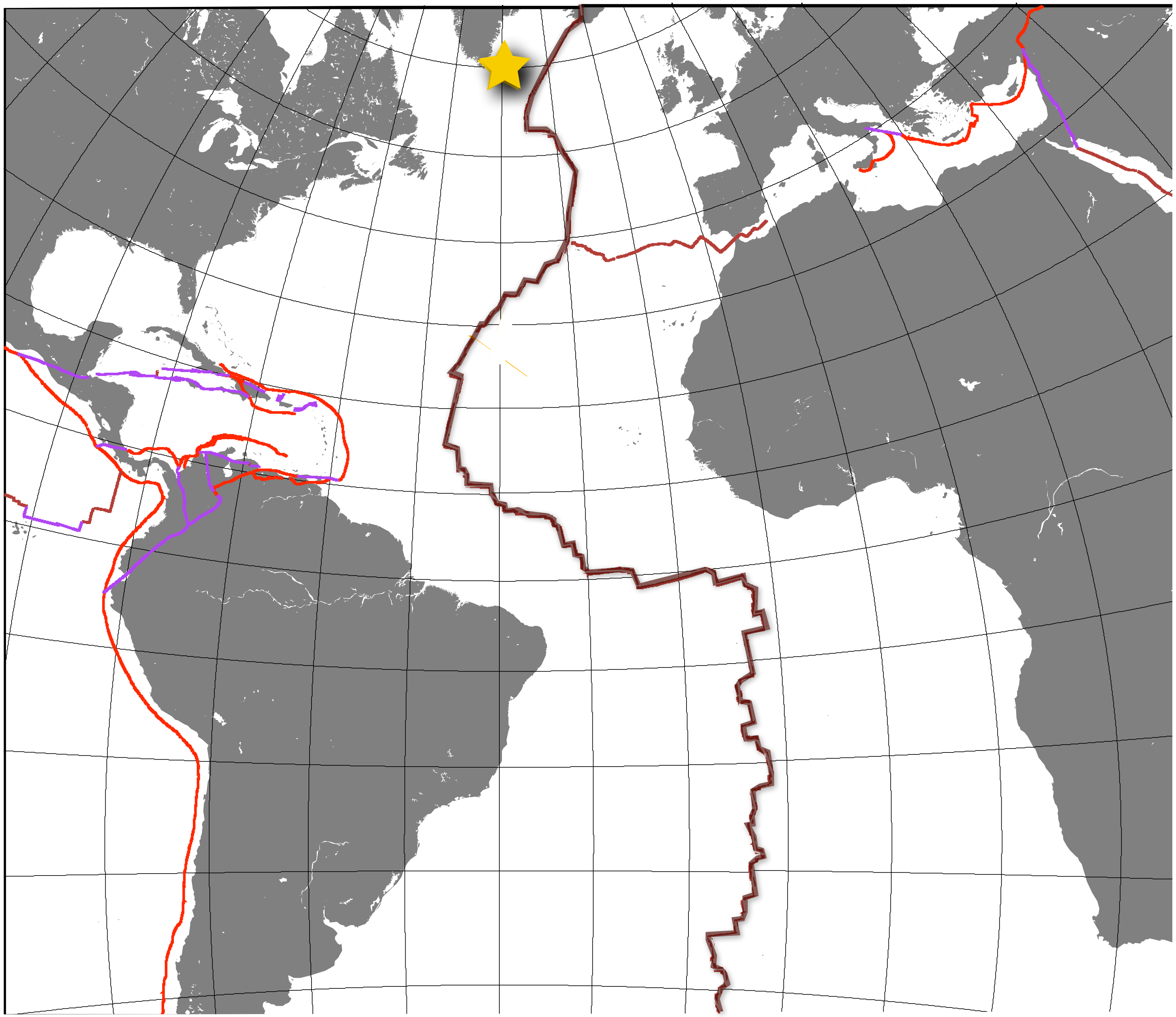


Atlantic age grid

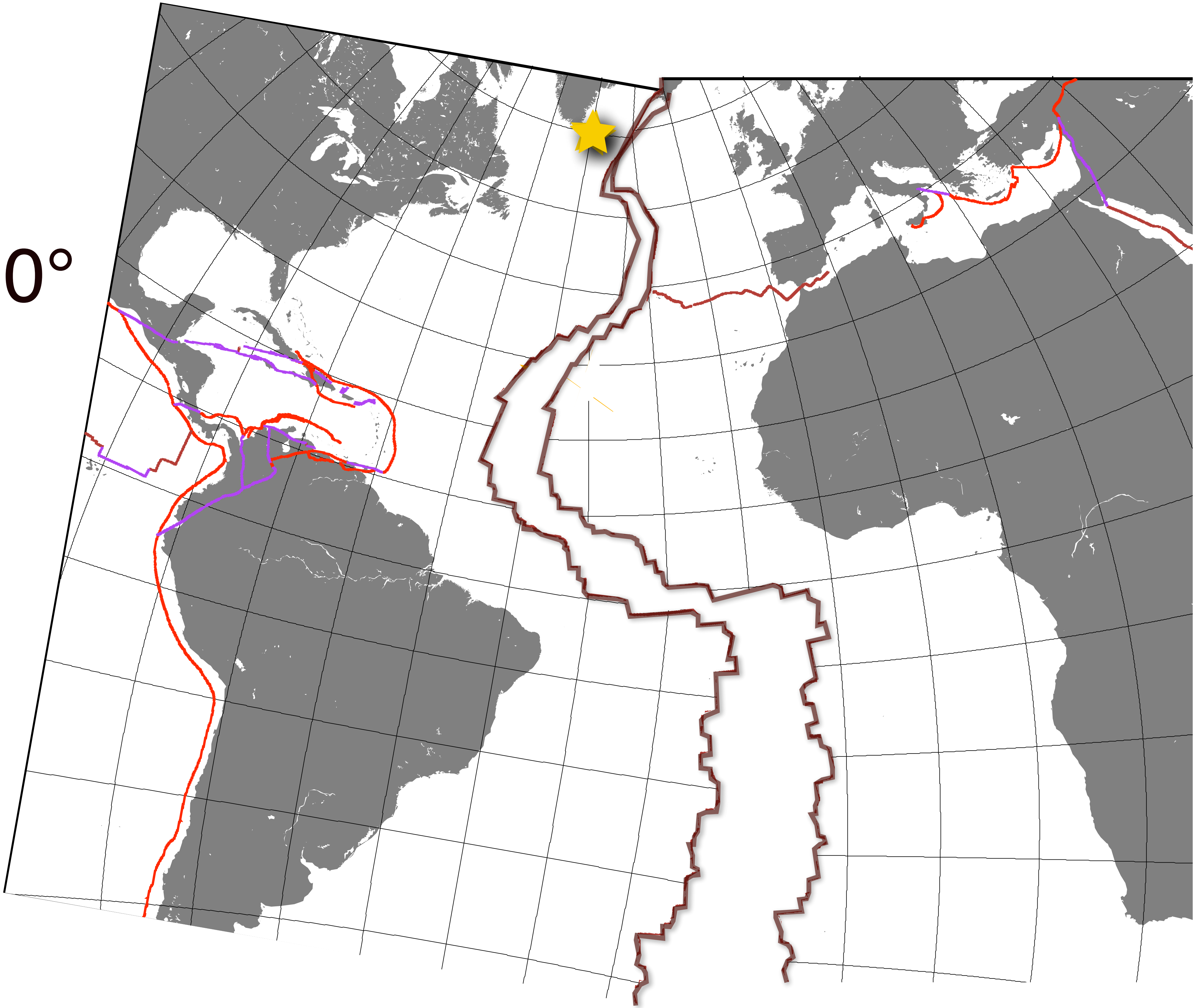




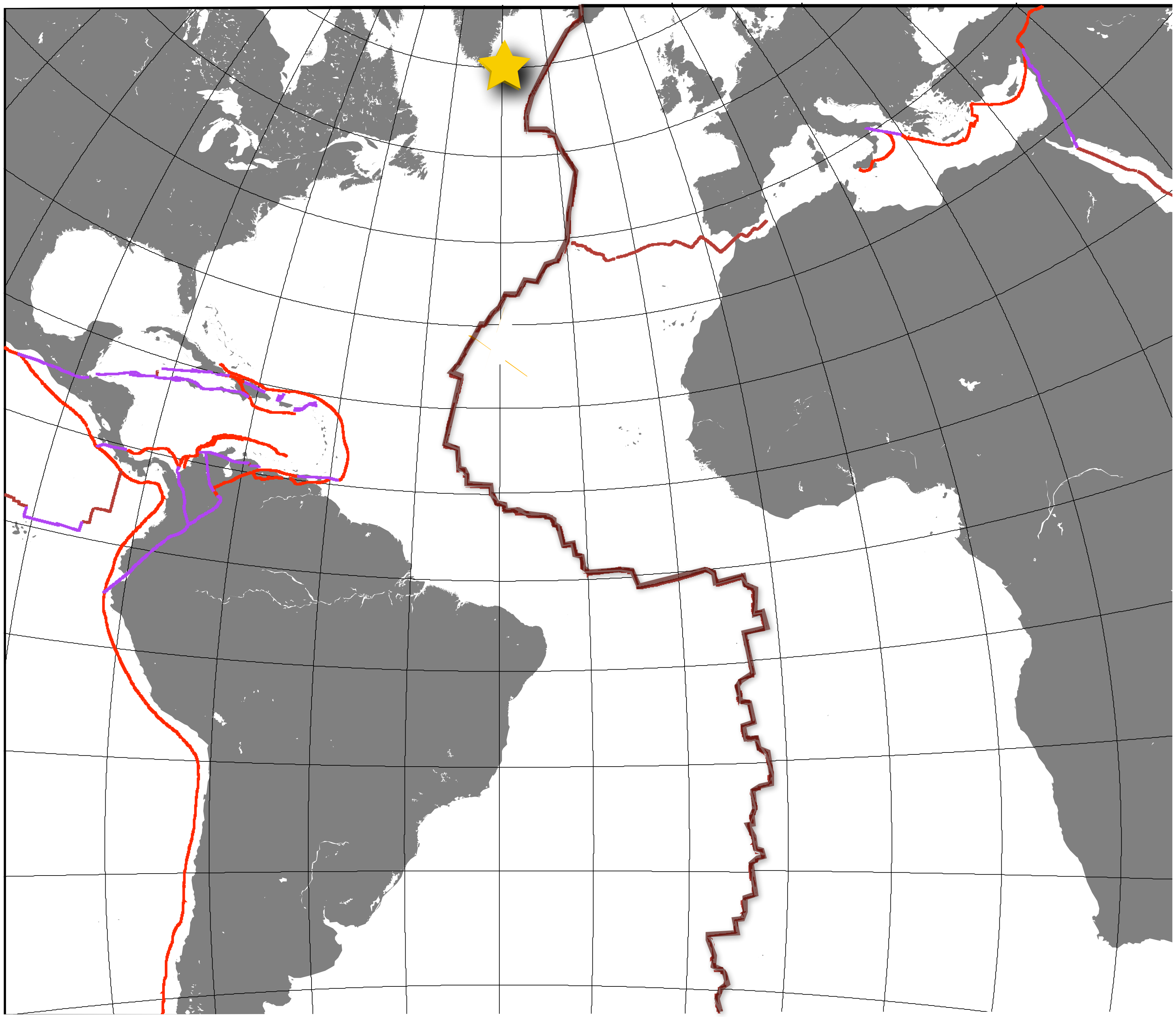




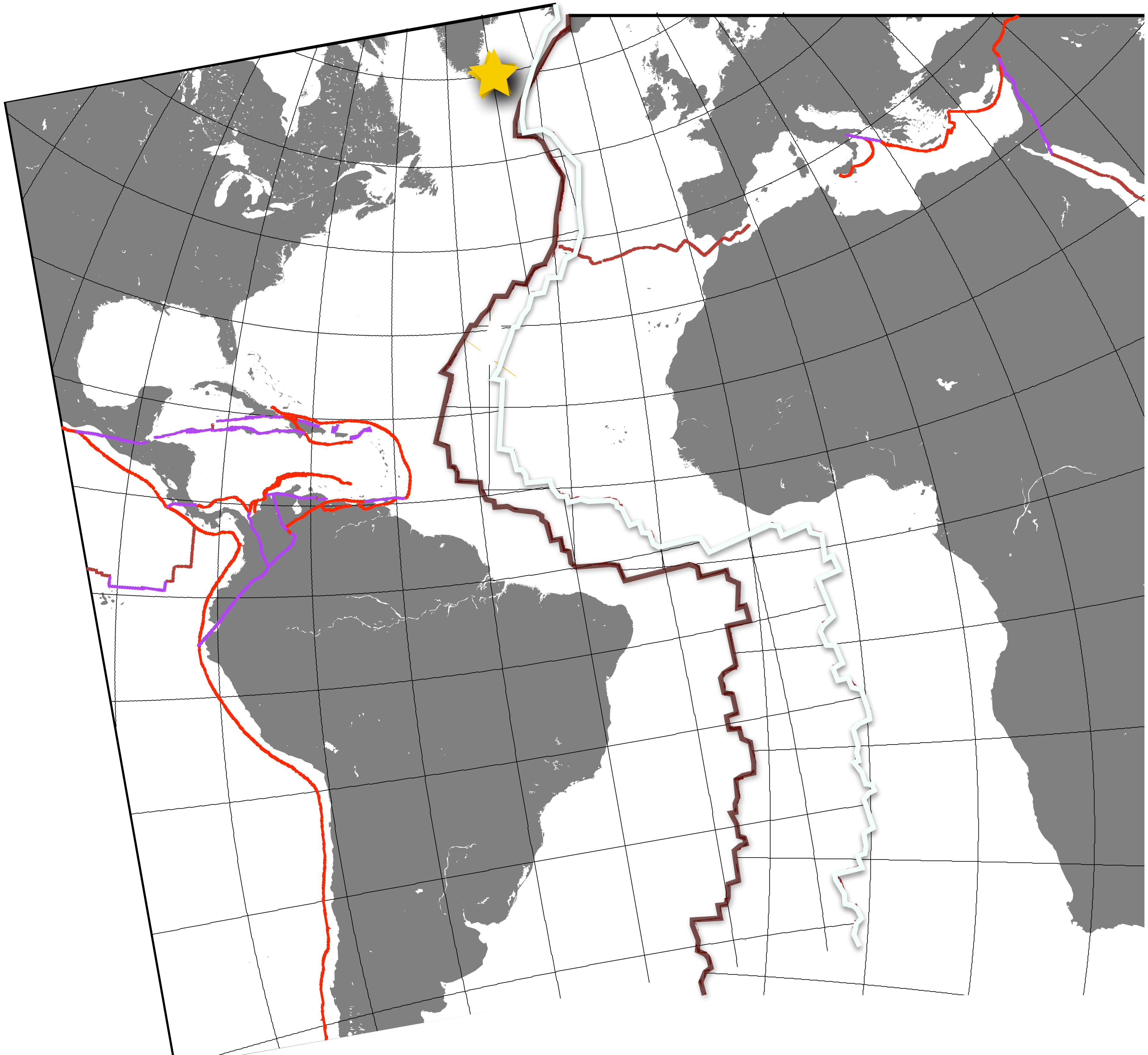
-10°



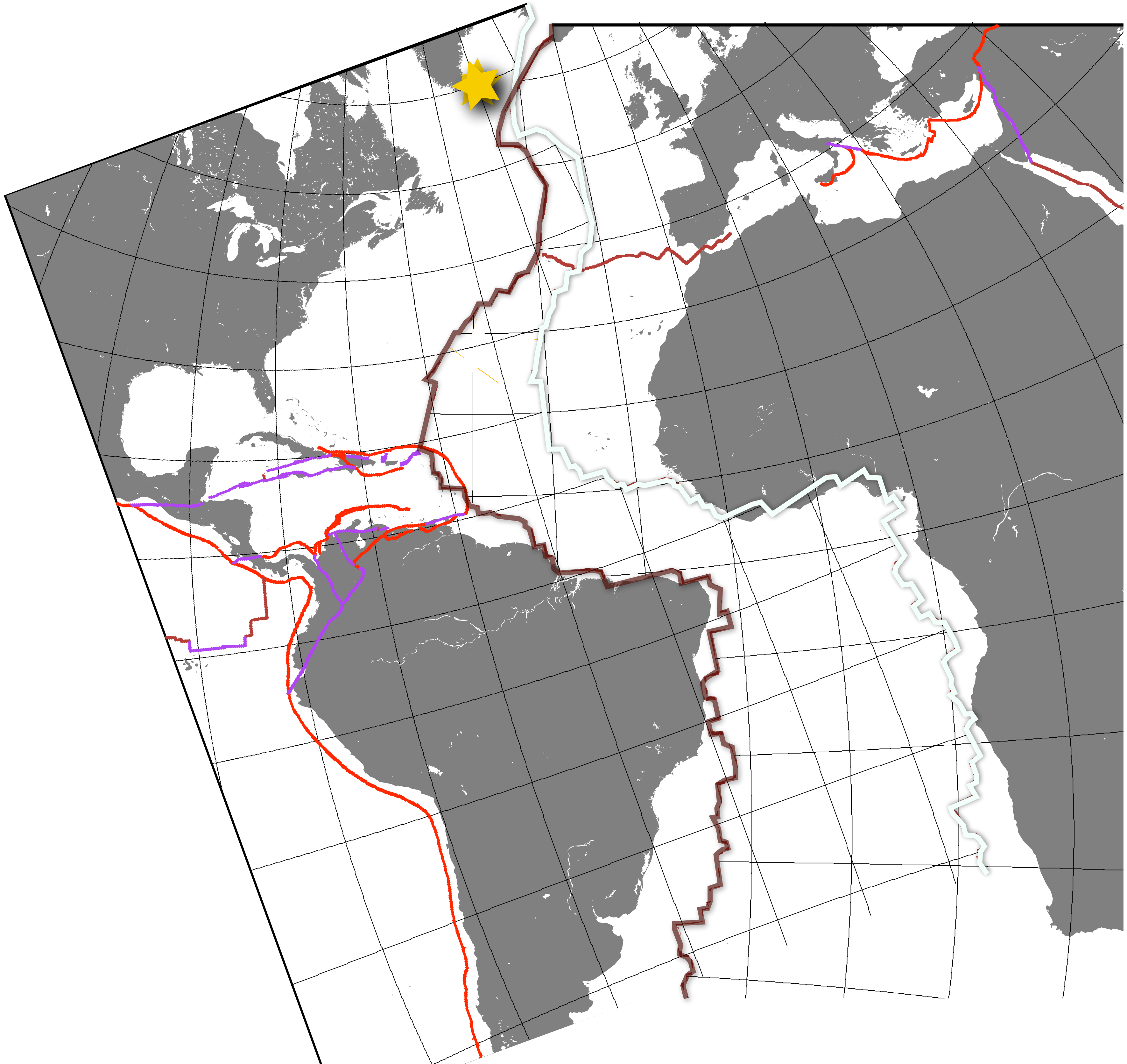
0°



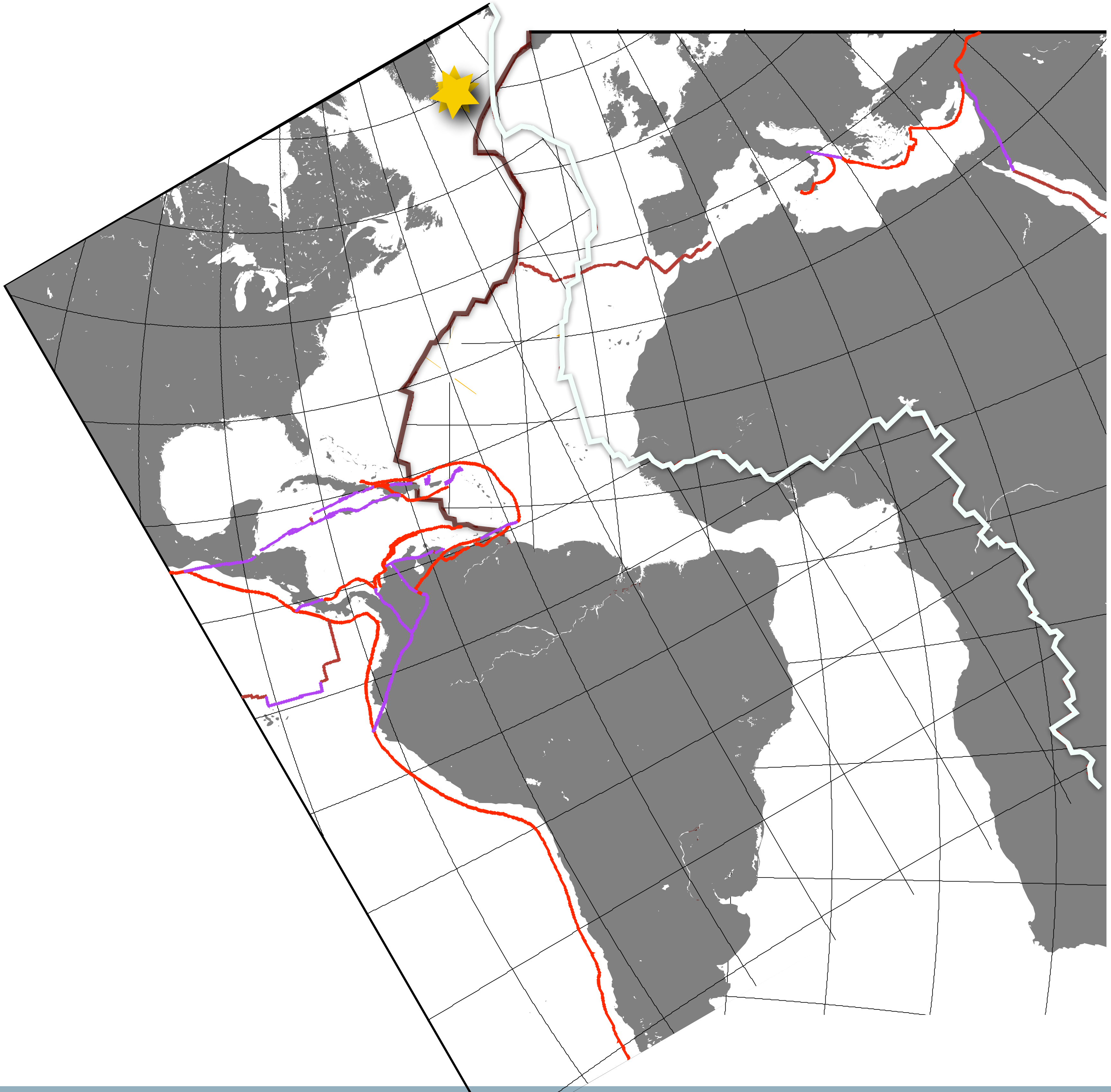
10°



20°



30°



40°