Plate reconstruction and palaeomagnetism

GEO-DEEP9300

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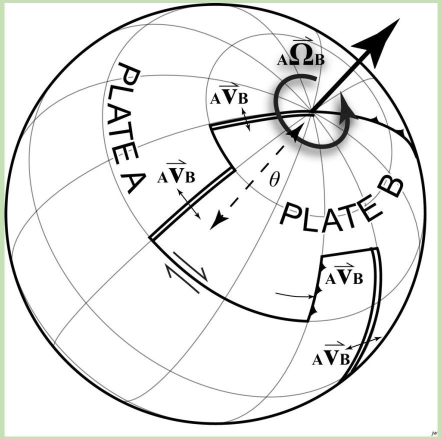
Plate reconstruction

- The lithosphere is broken into pieces (plates) that move over the asthenosphere
- They move along plate boundaries
  - Convergent (subduction)
  - Divergent (seafloor spreading)
  - Transform (strike-slip)



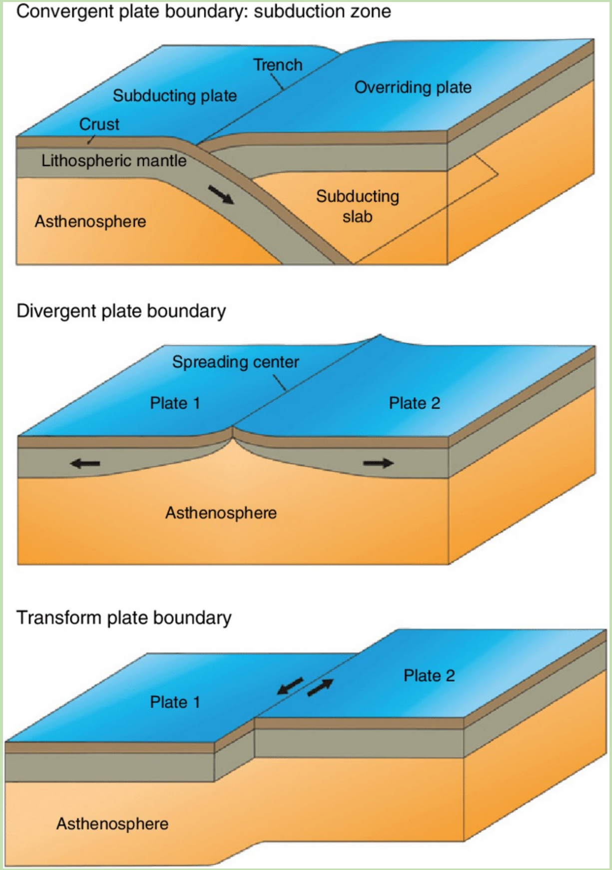


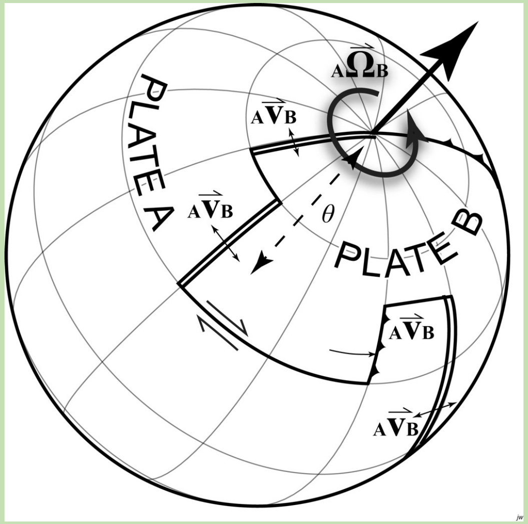
Figure by Duarte and Schellart (2016)

Plate reconstruction

- The Earth is a sphere and the plates move over its spherical surface are rigid
- How can we define their movement about the sphere?
- Poles of rotation – Euler poles

  - The displacement of a rigid body across a sphere can be represented by rotation around an axis that passes through the centre of the sphere

  - Intersection of pole rotation axis and surface



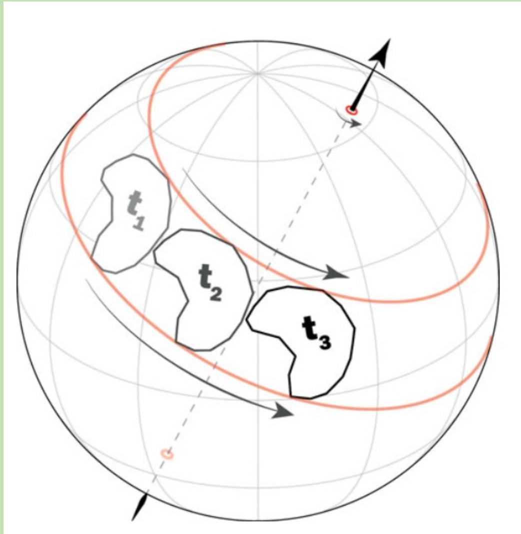
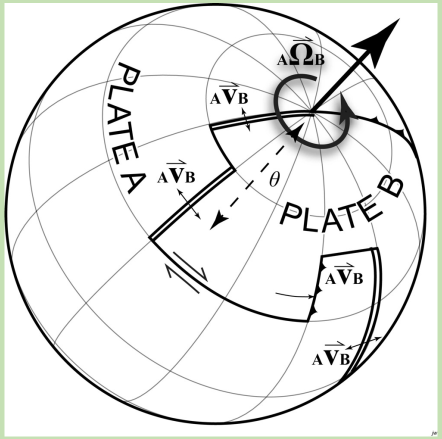


Figure by Domeier and Torsvik (2017)

Plate reconstruction

- Plate boundaries and Euler poles
- Divergent (seafloor spreading)
  - Follows great circles that intersect the Euler pole
  - Spreading velocity decrease
- Transform (strike-slip)
- Convergent (subduction)



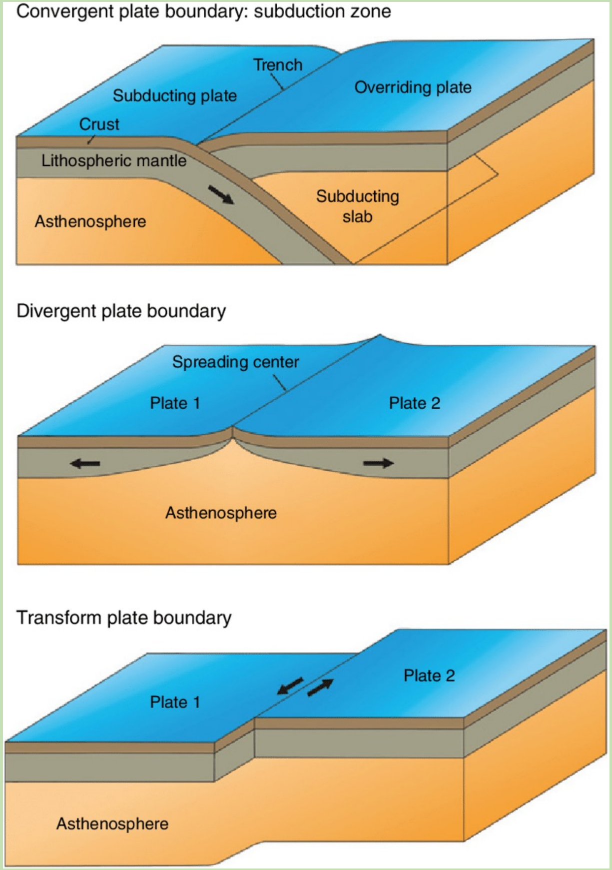


Figure by Duarte and Schellart (2016)

Plate reconstruction

- We can reconstruct the position of the tectonic plates at different times in the past
- When we do this we must follow a plate motion reference frame

- Relative reference frame
  - Motion in relation to something else that is moving
  - For example other moving plate
- Absolute reference frame
  - Motion in relation to a fixed point
  - For example the Earth’s lower mantle or geodynamo

Plate motion reference frames

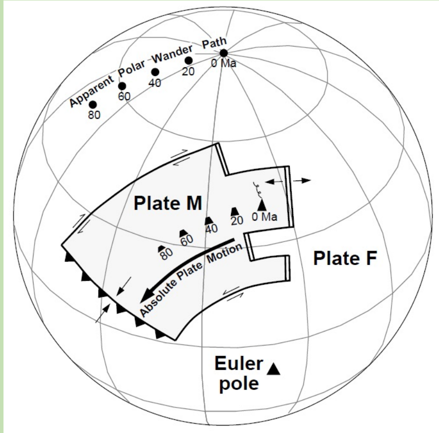
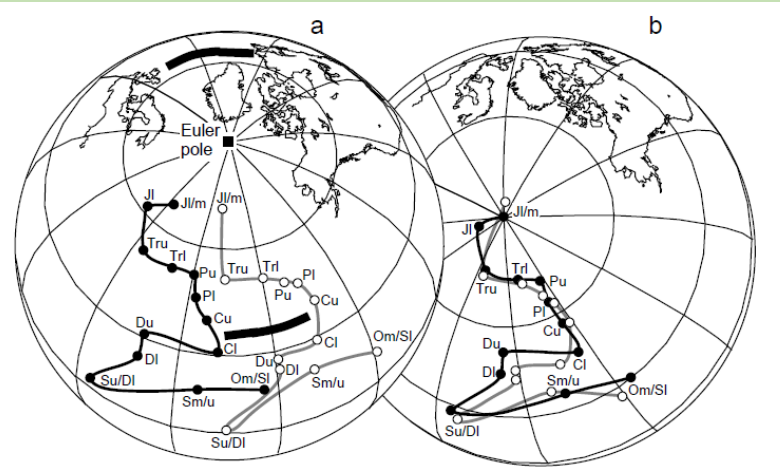
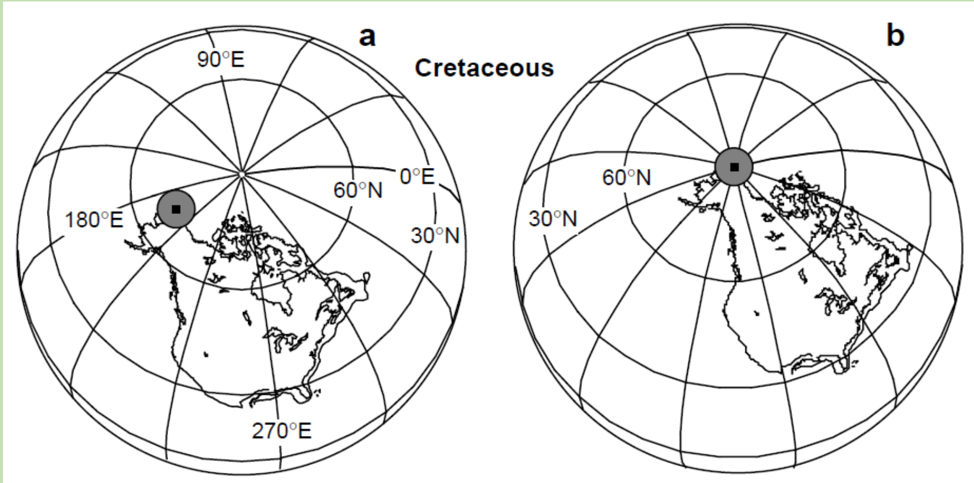


Figure by Butler (1992)

- Marine magnetic anomalies (relative – back to about 180 Ma)
- Transform faults (relative – back to about 180 Ma)
  - Relative plate motion reference frames, fracture zones
- Hotspot tracks (linked to mantle plumes; absolute)
  - Tracking hotspot paths as lithosphere moves over a mantle plume
- Subducted slabs (absolute – slab sinking rate may differ)
  - Identifying old subductions slabs in the mantle to find places of palaeosubduction
- Deep mantle plumes (absolute – edge of LLSVPs – back to about 300 Ma)
  - hotspots, LIPs, kimberlites
- Palaeomagnetism (absolute when linked to geodynamo)

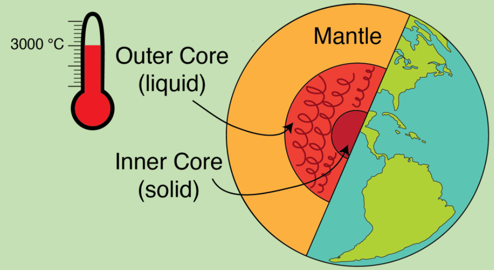
Palaeomagnetism as a tool for plate reconstruction



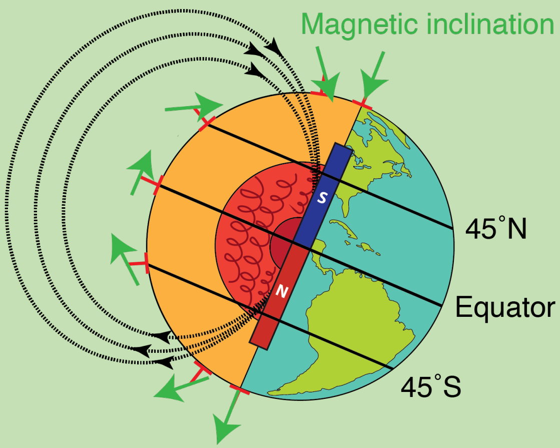


Figures by Butler (1992)

Earth's magnetic field (EMF)



- Generated by convection currents in the molten metal of the outer core
  - This is called the geodynamo
  - Bar magnet?



Figures by A. van der Boon

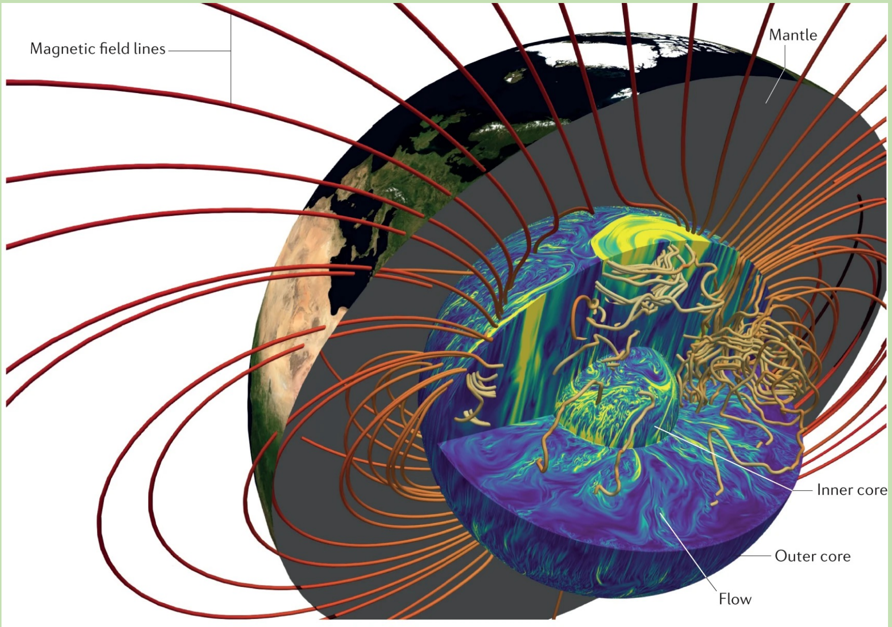
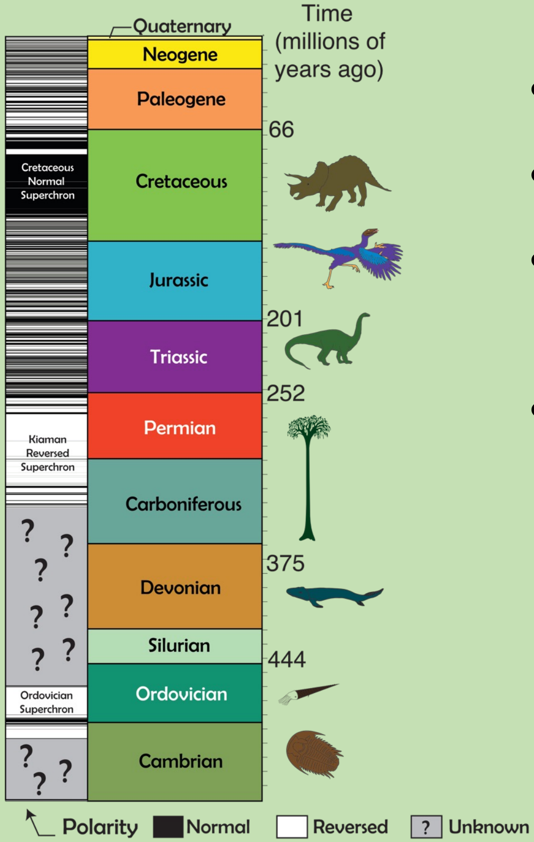


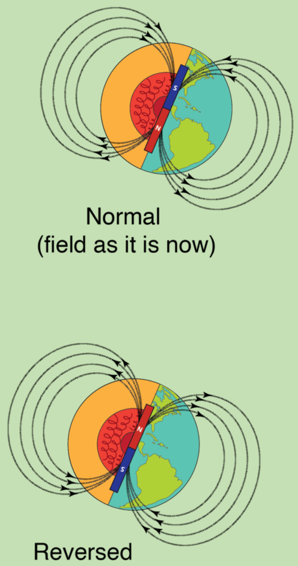
Figure modified from Landeau et al. (2022)

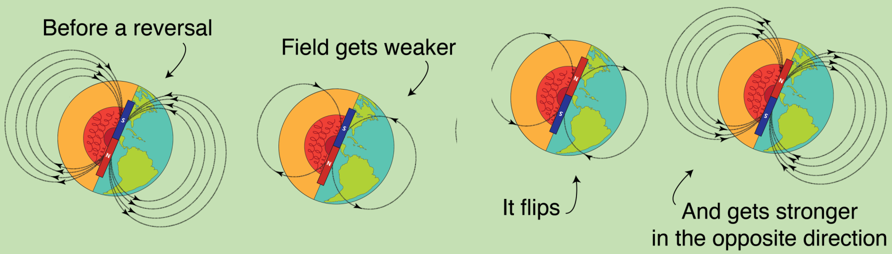
Earth's magnetic field (EMF)



Figures by A. van der Boon

- Normal polarity vs. reversed polarity
- Today: EMF flows from S to N
- Reversals – irregular intervals
  - Only a few thousand years to flip
- Magnetostratigraphy
  - Record of polarity reversals





Earth’s magnetic field (EMF)

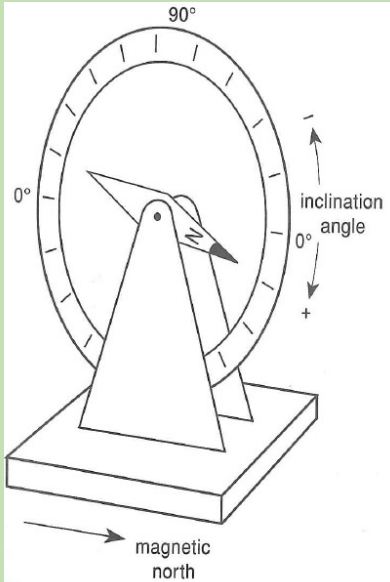
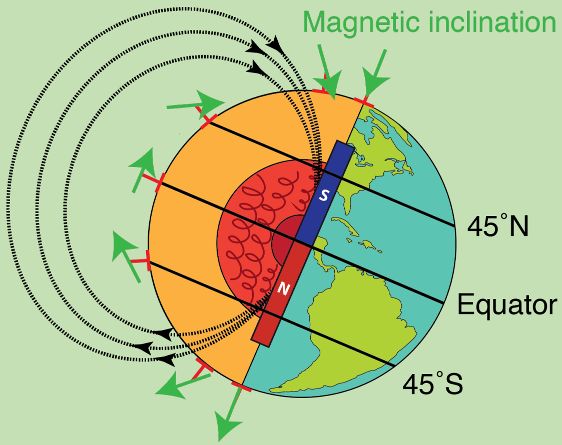


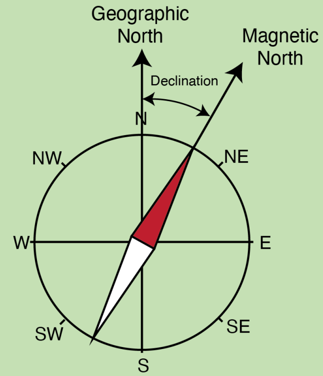
Figure from Mussett and Khan (2000)

- EMF flows in paths from one pole to another
- Magnetic dip and inclination
  - The inclination of the Earth’s magnetic field changes with latitude
  - But not with longitude!
  - The EMF is symmetric about its axis

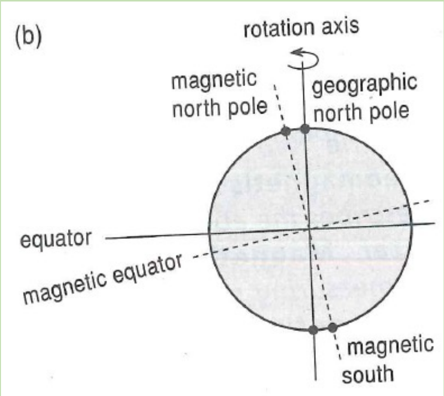


Figures by A. van der Boon

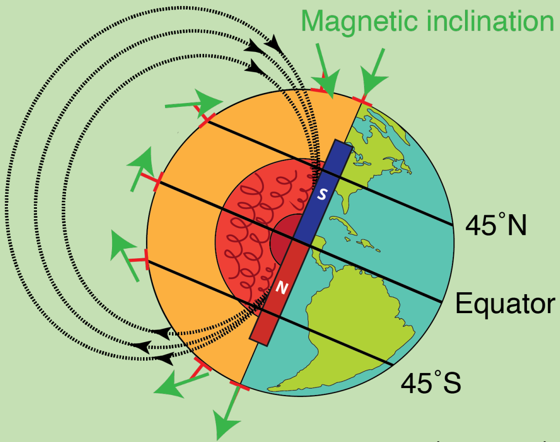
Earth's magnetic field (EMF)



- The axis of EMF vs. rotation axis – aligned?
  - No!
  - Magnetic declination
  - Secular variation
    - The magnetic axis will move around the rotation axis in and irregular loop
  - BUT!
    - If we average out the direction of the magnetic axis….



Figures from Mussett and Khan (2000)



Figures by A. van der Boon

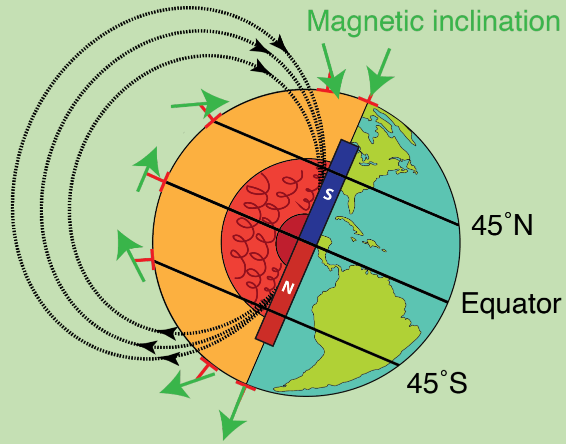
Earth’s magnetic field (EMF)

- Averaged over a couple thousand years, the EMF is like a geocentric, axial dipole:

The GAD hypothesis!

$$tanI = 2tan\lambda$$

“In GAD we trust”



Earth's magnetic field (EMF)

- We assume magnetic north aligns with geographic north through time:

The GAD hypothesis!

$$\tan I = 2\tan\lambda$$

- True north vs. magnetic north
- Inclination and palaeolatitude

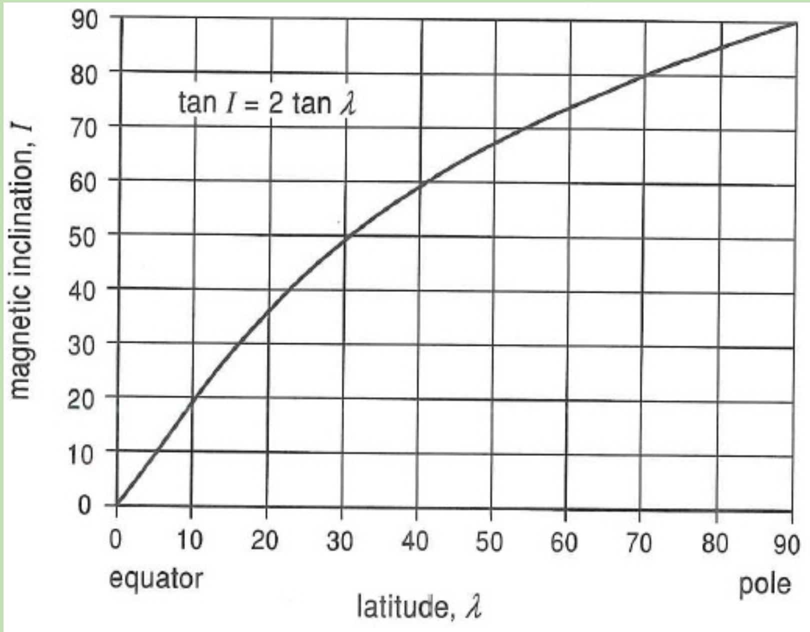
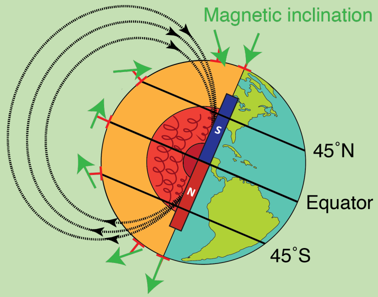


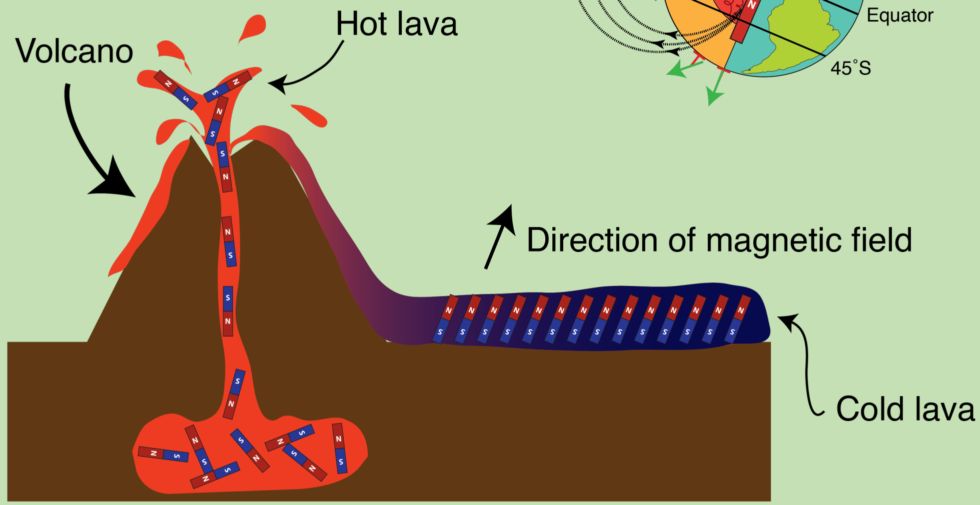
Figure from Mussett and Khan (2000)

Palaeomagnetism

- The direction and strength of the EMF is recorded in rocks as they form
  - Magnetic carriers record the field strength and direction
  - Magnetic grains align themselves to the current field
  - Remanent magnetisation

- The changes in the magnetic field through time can be revealed and reconstructed using palaeomagnetism.
- Palaeomagnetism to reconstruct plate motions





Figures by A. van der Boon

Plate reconstruction - palaeopoles

- Rocks magnetised at the same time, but at different latitudes will reveal different magnetic directions
- But they share the same north pole!

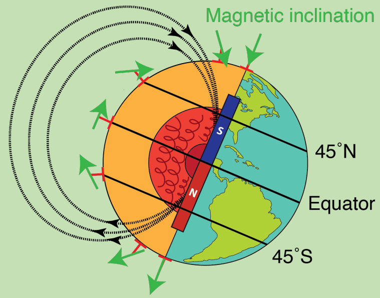


Figure by A. van der Boon

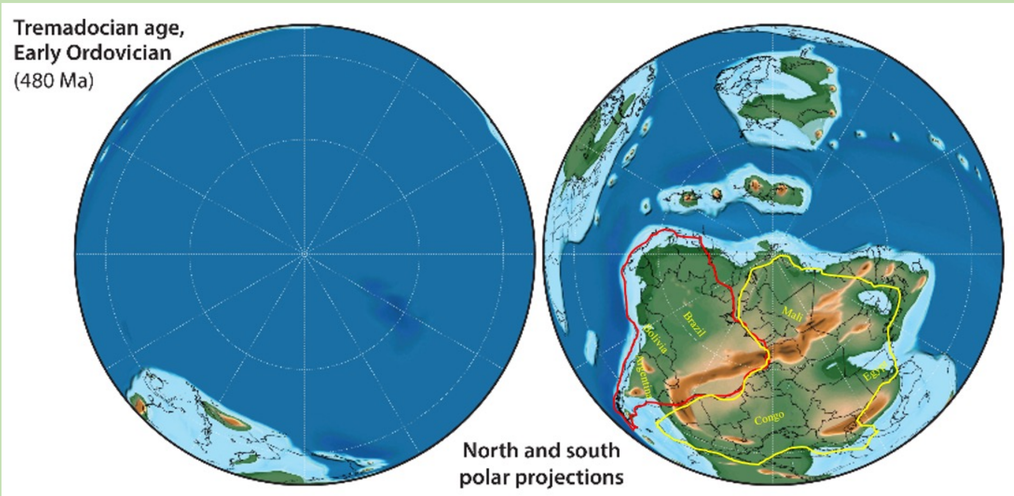


Figure from Scotese (2021)

Plate reconstruction - palaeopoles

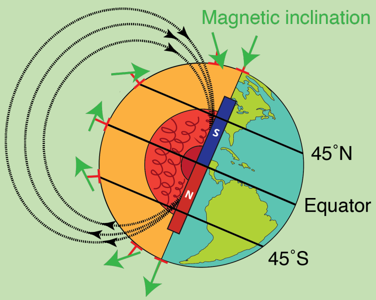


Figure by A. van der Boon

- But they share the same north pole!
- The palaeoposition of a landmass given by the position of its north pole rather than the position of the landmass itself
- Palaeopole:

  Represents where the N pole was located in the past at a specific time

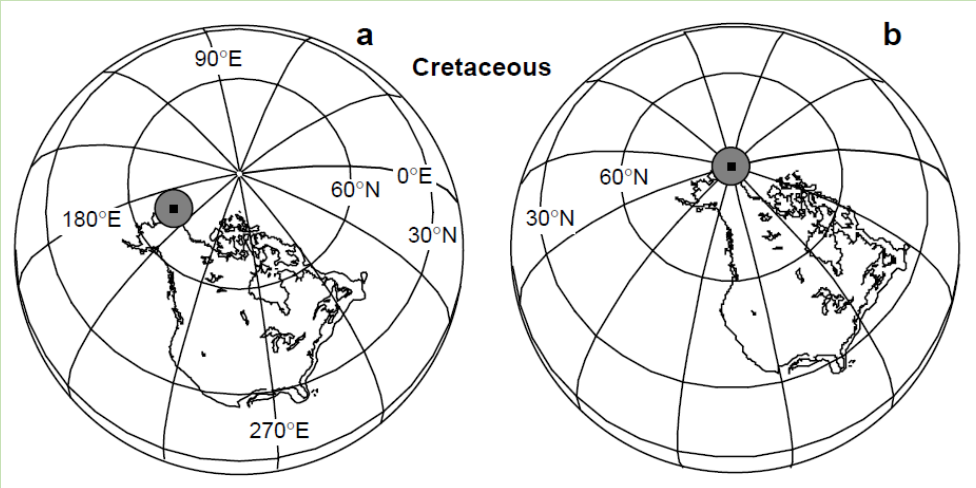


Figure from Butler (1992)

Plate reconstruction - palaeopoles

- We assume the plate is fixed in its present position and that it is the N pole that has moved – not the plate
- But: GAD !!
  - The north pole of course does not move
  - We are reconstructing the position of the plate - not by showing where the plate was located at the time, but by showing where the N pole was located IN RELATION to the plate at the time
  - Apparent pole, it appears as though the north pole was in this spot at this time

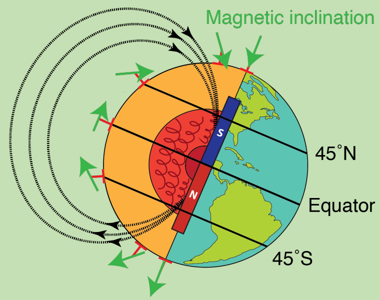


Figure by A. van der Boon

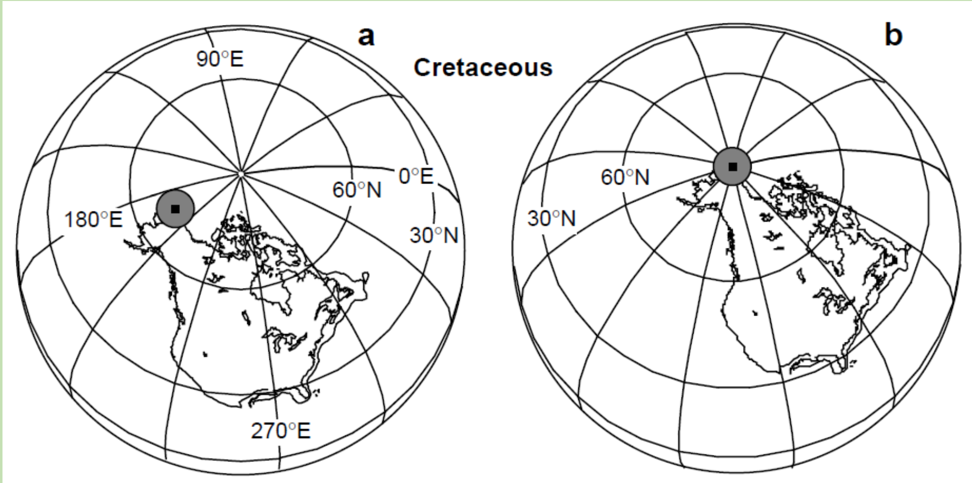
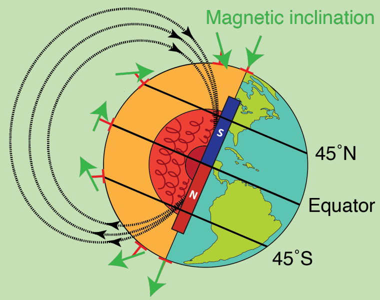


Figure from Butler (1992)

Plate reconstruction - palaeopoles

- We can then move the apparent pole so that it aligns with the North pole
- Move pole+plate using an Euler pole to reconstruct plate placement
- Now we know how the plate has moved N-S and how it has rotated …
- But not how it has moved E-W
- Limitation of palaeomagnetism



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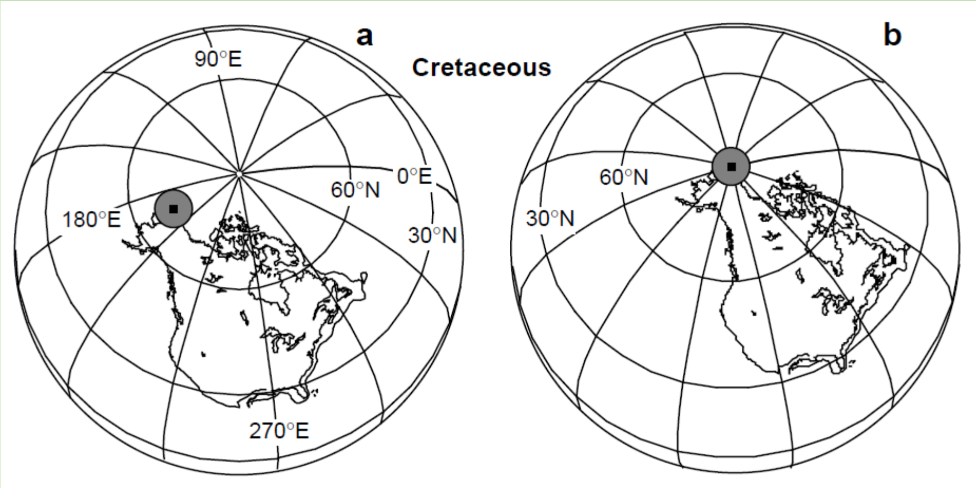

Figure from Butler (1992)

Plate reconstruction - APWPs

- To find how a plate position has change in longitude
  - A succession of rocks from the same place with remanent magnetisation
  - Many palaeopoles for the same plate
- See how to pole appears to move
  - Apparent polar wander path (APWP)
  - Use Euler pole to describe APWPs

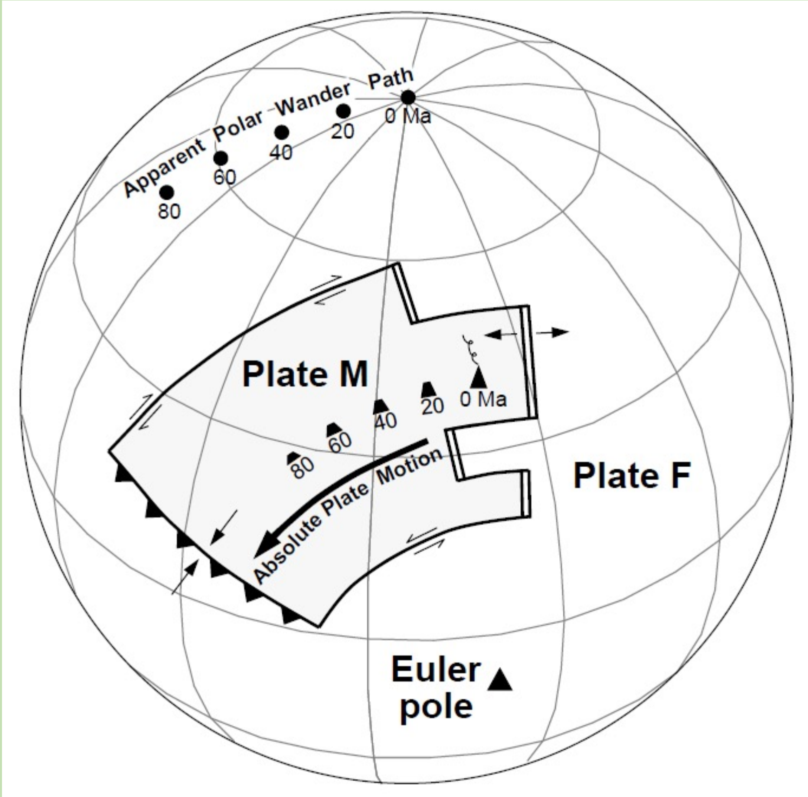

Plate reconstruction - APWPs

- APWPs of different plates at same time – relative movement
- Europe vs N.America from Ordovician-Triassic
- APWPs not the same, but similar shape
- And if we close the Atlantic?
- These paths today?

- APWPs – ensamble and breakup of landmasses
  - Paths converge, overlap, then diverge again

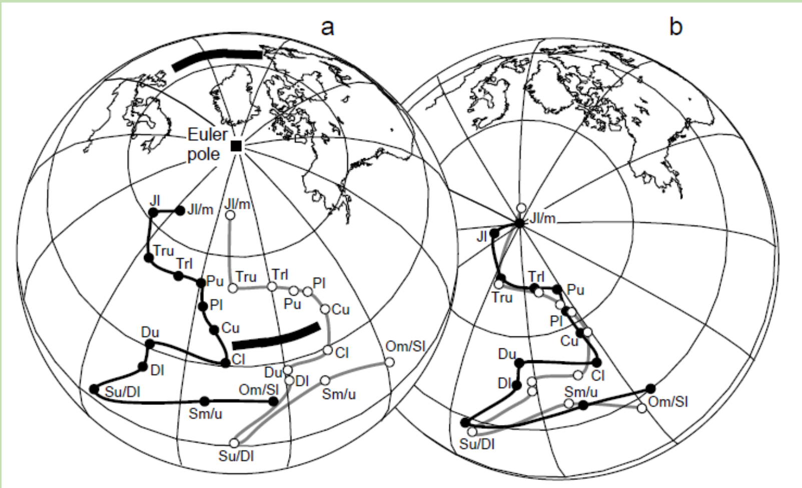

Figure from Butler (1992)

Plate motion reference frames - united

- Marine magnetic anomalies (relative)
- Transform faults (relative)
- Hotspot tracks (absolute)
- Subducted slabs (absolute)
- Palaeomagnetism (absolute)

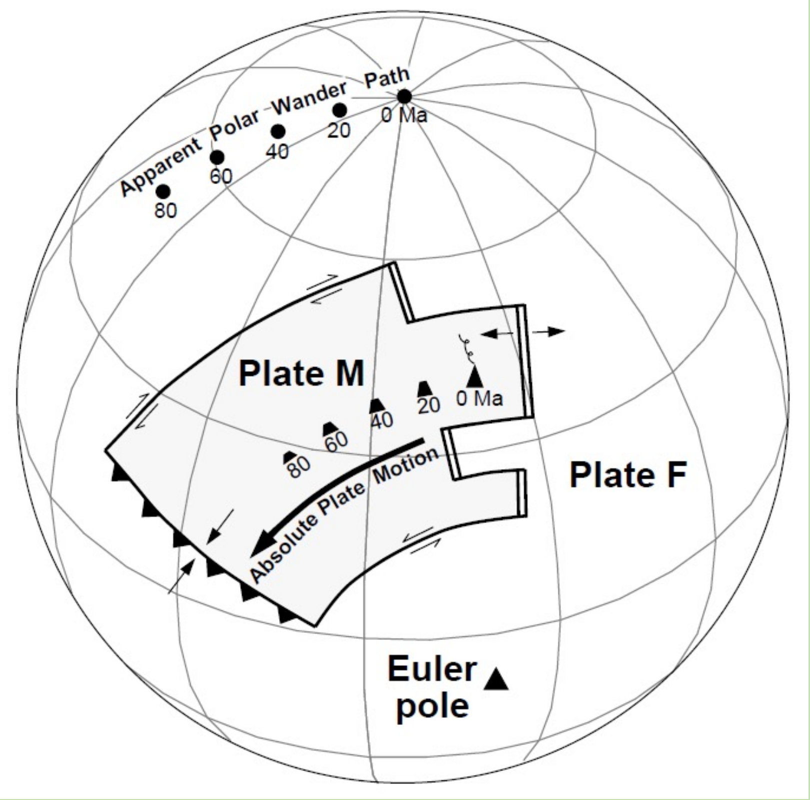

Figure by Butler (1992)

Thank you!

☺

- We analyse a lava and find the magnetic declination and inclination preserved by the magnetic carriers in the rock
- Declination 20 degrees
- Inclination 50 degrees
- $tan I = 2 tan\lambda$
- λ=30 degrees
- Pole is located at 90-30=60 degrees away