Lecture 17:

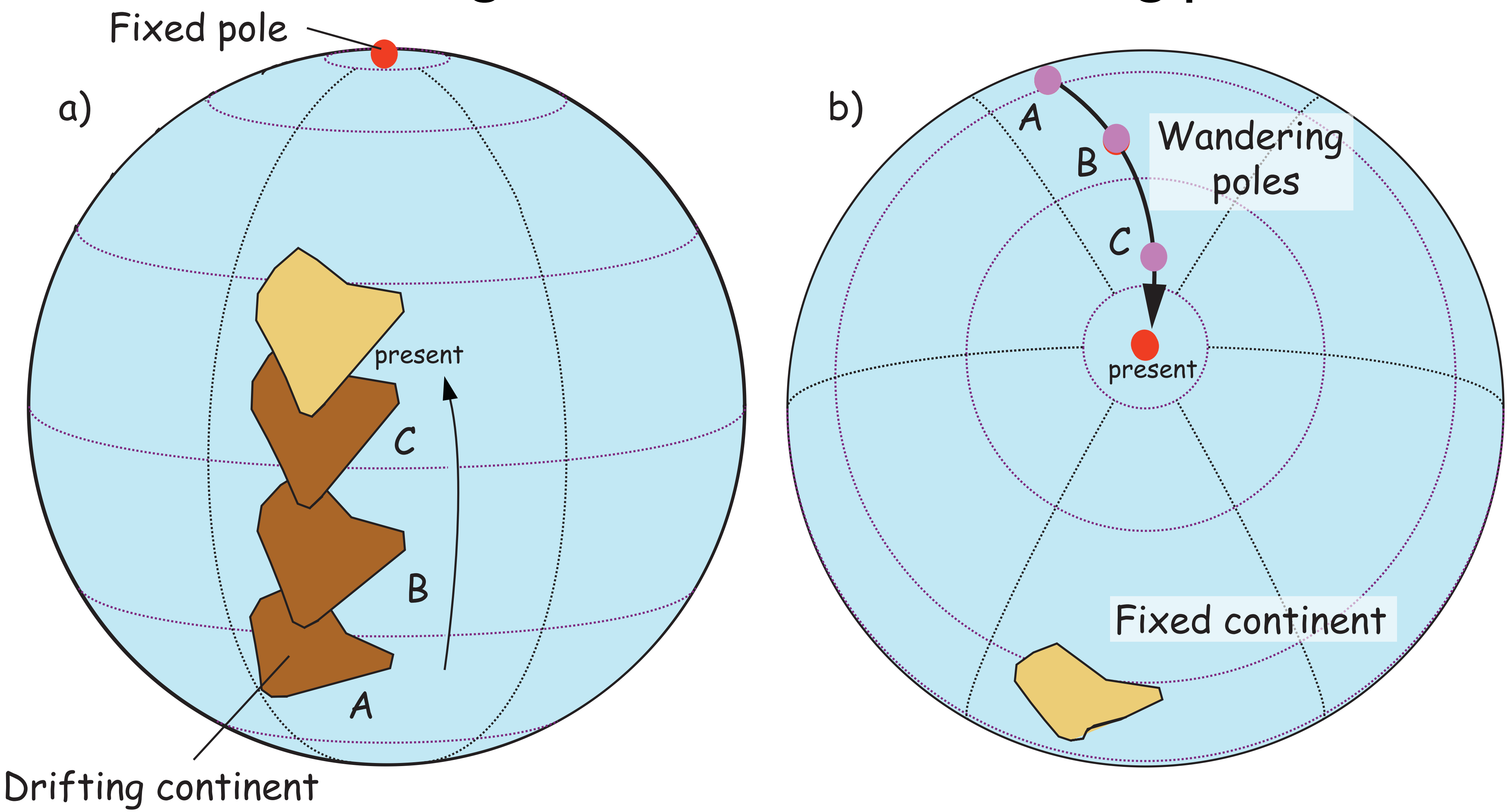
Tectonic applications

- Paleomagnetic poles
- Brief review of plate tectonics
- Apparent polar wander paths
- Paleomagnetism and plate reconstructions

Paleomagnetic poles

- Assume the magnetic field is that of a GAD on average
- If we sample over sufficient time to average out PSV, the average of all the VGPs is a PALEOMAGNETIC POLE (Exactly what is "sufficient time" is not known but must be > 10,000 years
- Hospers (1955): paleomagnetic poles could be used to test the idea of continental drift (of e.g., Wegener, 1915) or polar wandering (Milankovitch, 1933)

Wandering continents or wandering poles?



Wandering continents or wandering poles?

ROCK MAGNETISM AND POLAR WANDERING[1]

J. HOSPERS
De Bataafsche Petroleum Maatschappij (Royal Dutch/Shell Group)
The Hague, Netherlands

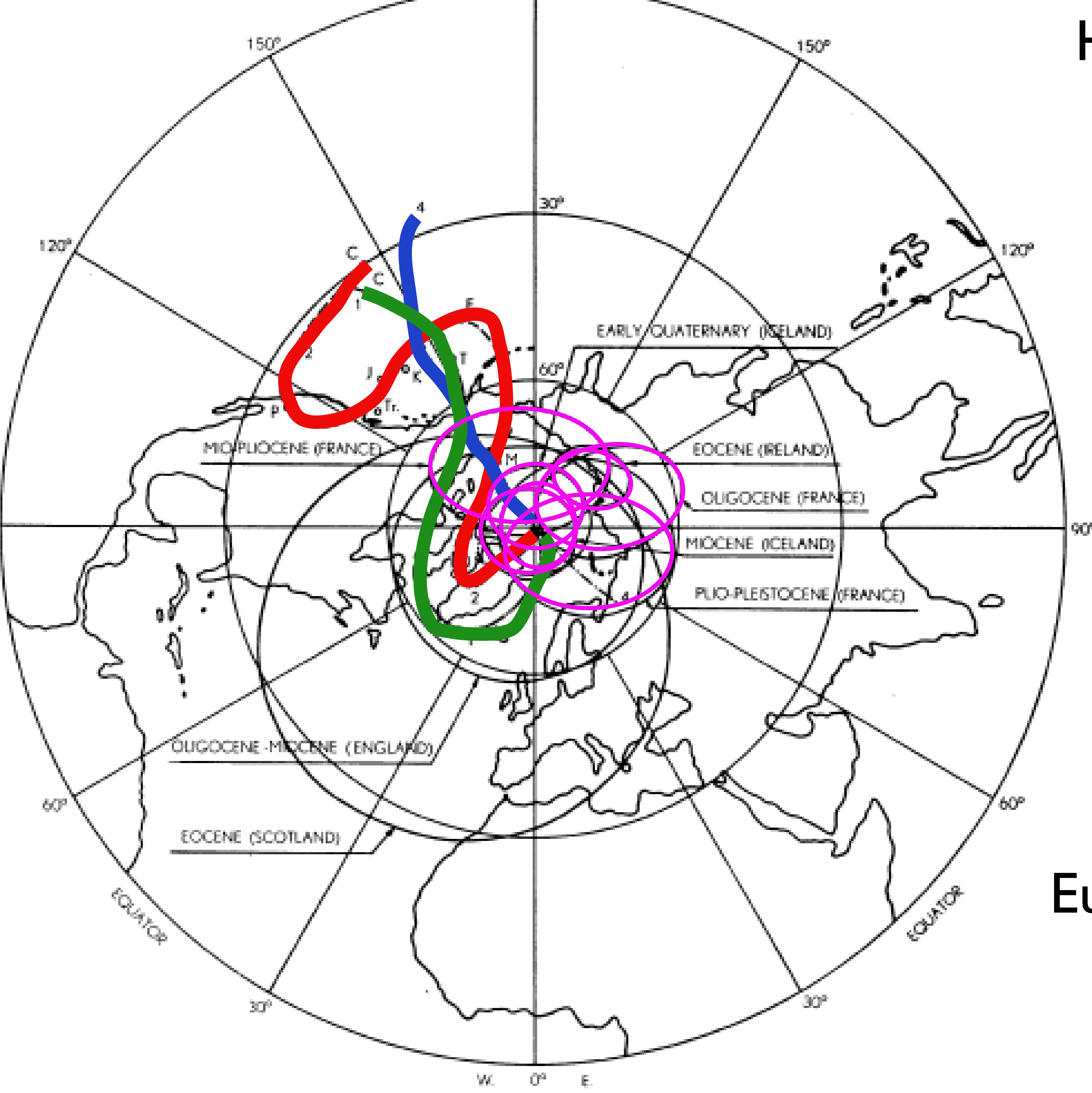
ABSTRACT

Lava flows and other igneous rocks become magnetized in the direction of the local geomagnetic field when they cool down after their formation. Similarly, sediments acquire a weak magnetic polarization on deposition. The mean direction of magnetization of series of recent lava flows and sediments has been determined; it is found that these mean directions agree closely with the theoretical dipole field. This field is the field due to a geocentric axial magnetic dipole. The conclusion is therefore drawn that the mean position of the magnetic poles (taken over a period of several thousand years) coincides with the geographic poles.

Assuming that the same is true for the geological past, the position of the geographic poles can be defined within fairly narrow limits by using the mean direction of magnetization of older rocks. Measurements on igneous rocks, of Tertiary and Quaternary age and from Europe only, are available. It is concluded that the large amount of polar wandering suggested by Kreichgauer, Köppen and Wegener, and Milankovitch cannot be reconciled with the new data. If polar wandering has taken place at all, it has not exceeded 5°–10° since Eocene times.

Hospers (1955): proposed using paleomagnetism as a test and concluded that polar wandering had not happened.

Hospers 1955

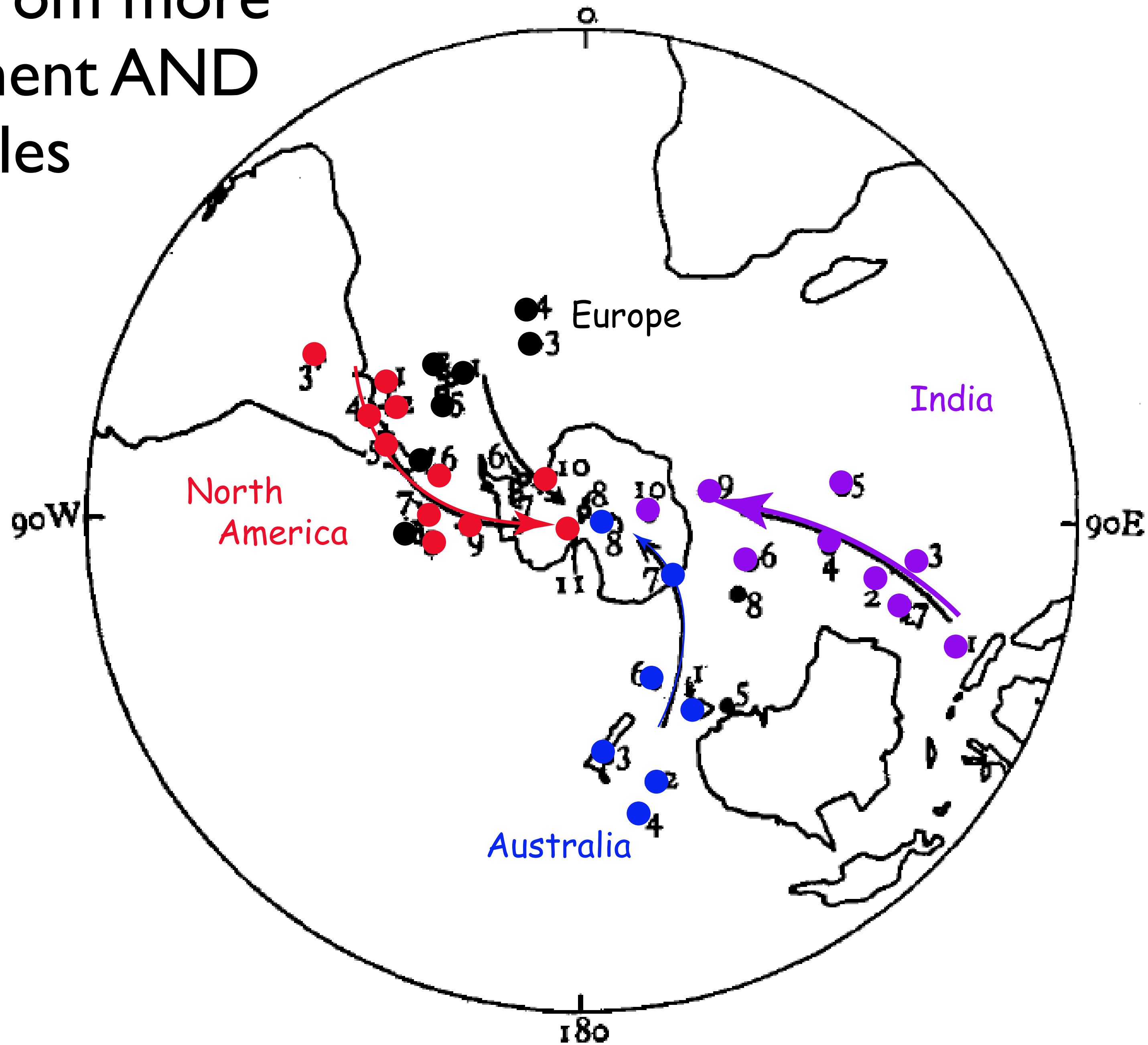


Lots of predicted polar wander paths from, e.g., Wegener and Milankovitch

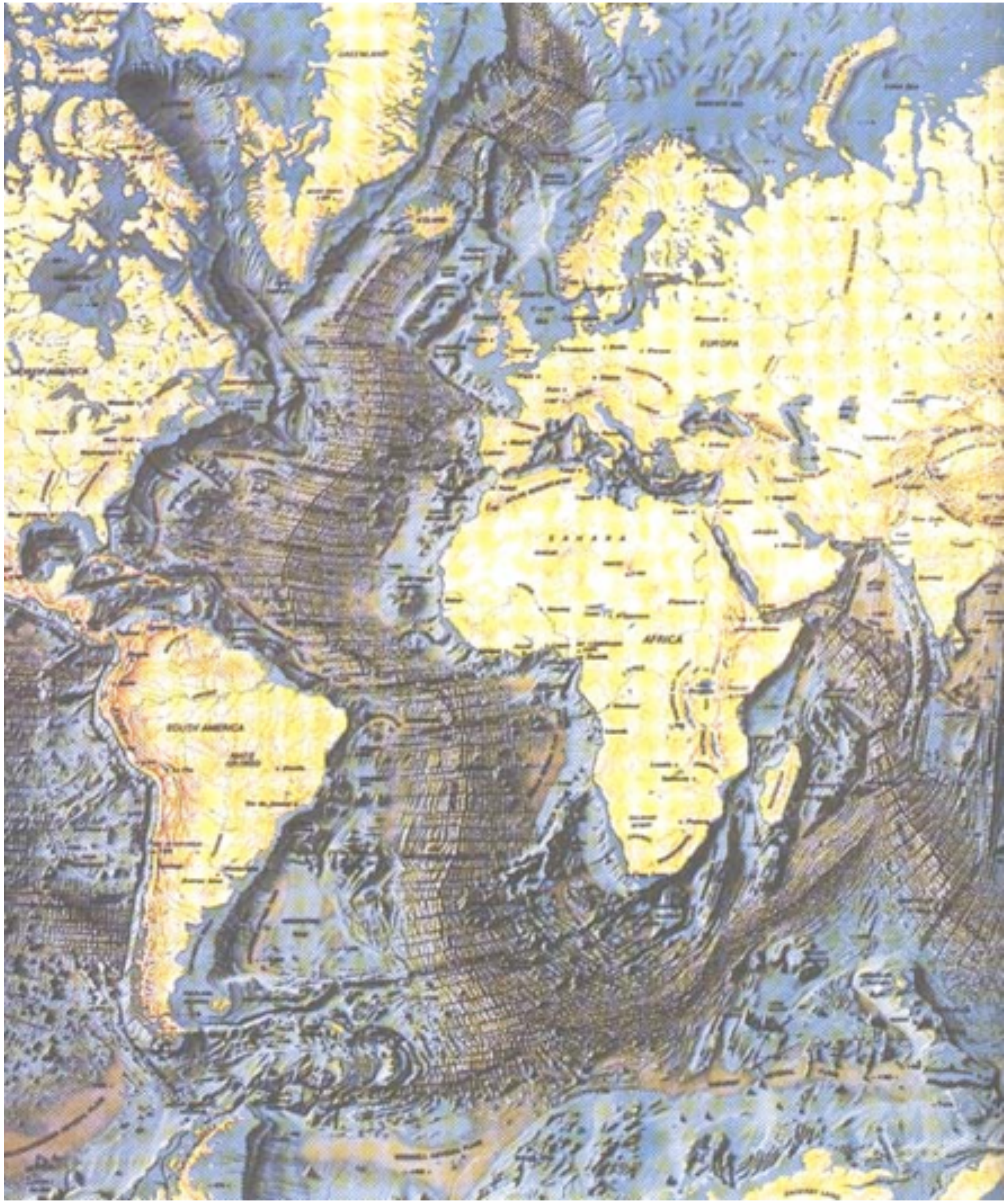
Data from Tertiary of Europe rejected all of them

But: Irving 1958

You need data from more than one continent AND older poles



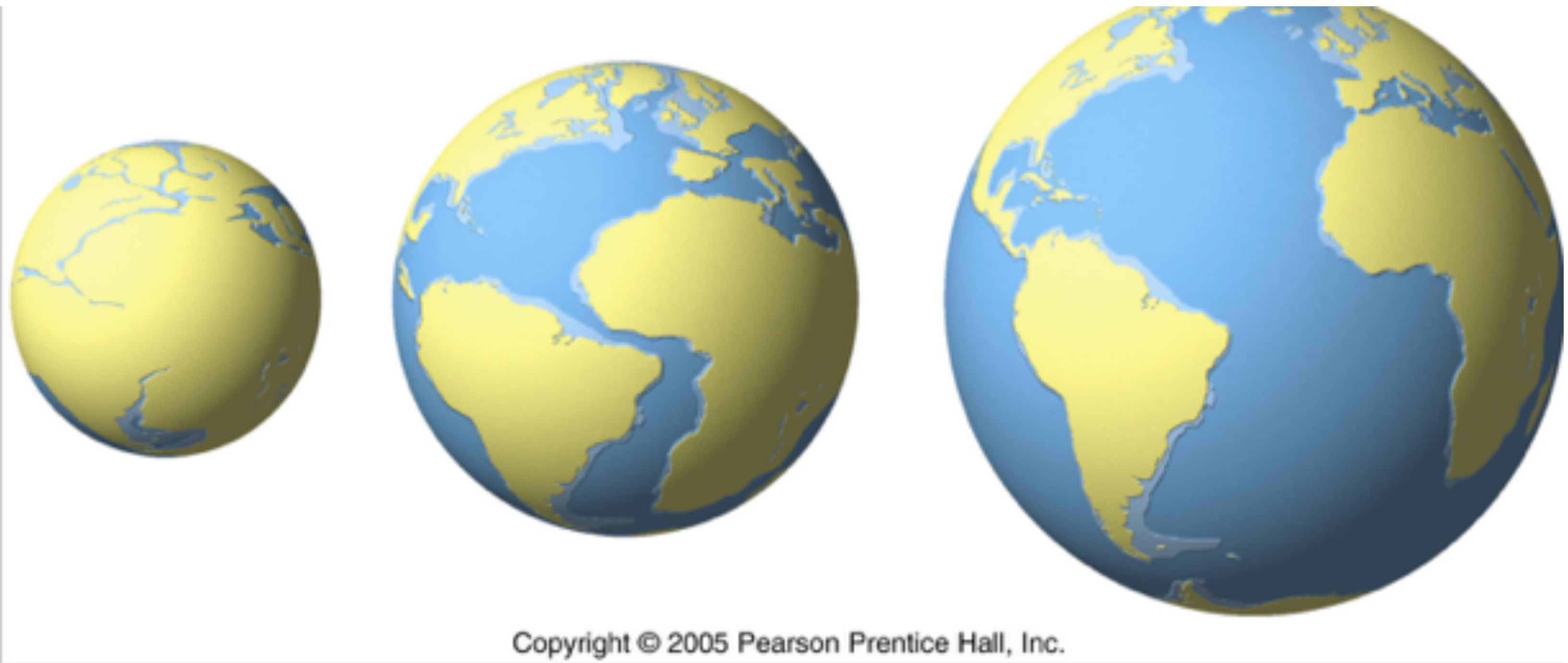
Data from 4 different continents support continental drift



meanwhile - mapping of the sea-floor

World encircling rift - Heezen and Tharp (1957)

At the time Heezen and Tharp thought the rift was from an expanding earth



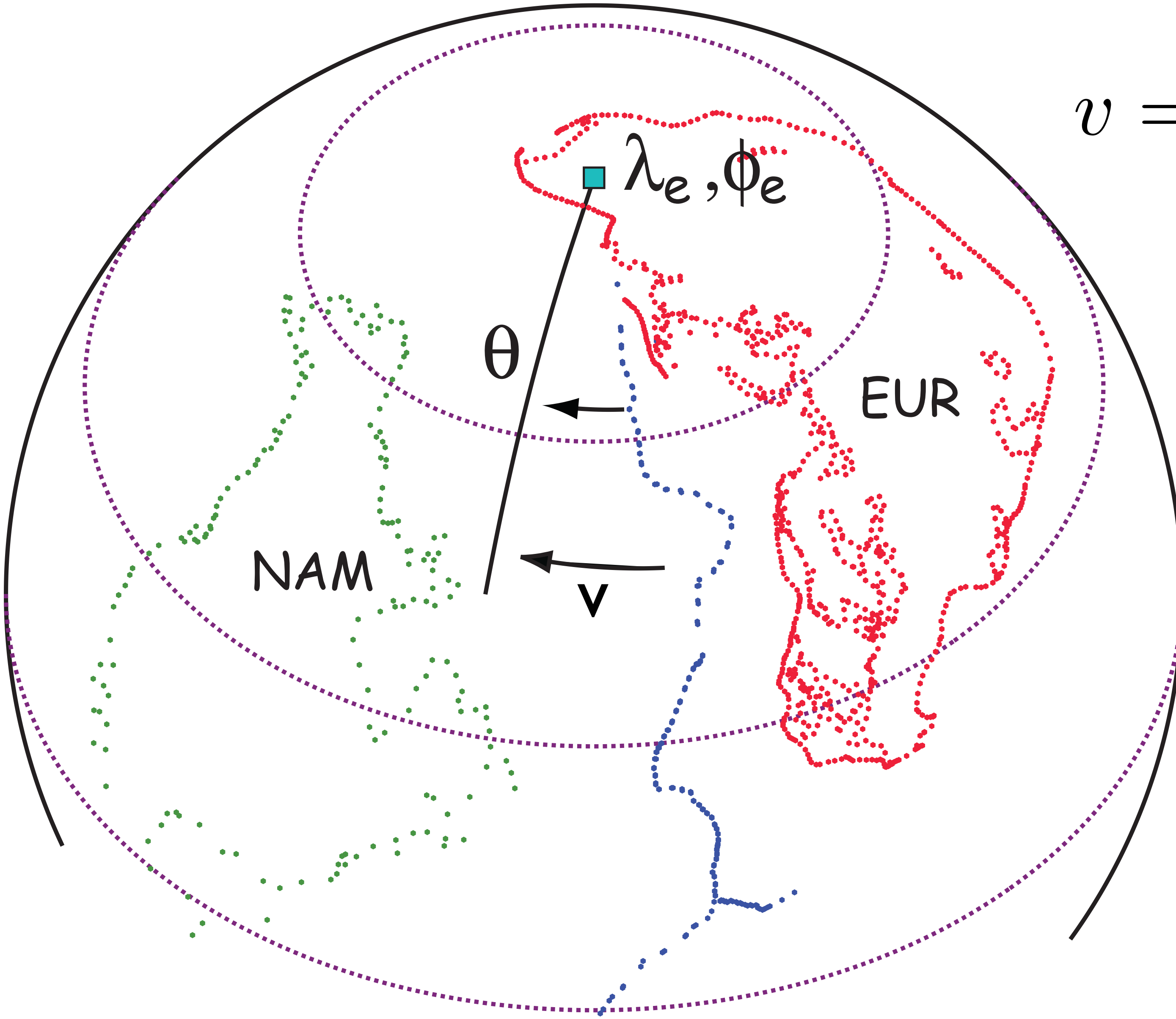
- Paleomagnetists became “drifters” in the 50’s
- No viable mechanism was proposed until the idea of sea-floor spreading (Hess, 1962)
- Sea floor spreading (versus expanding earth) gained credibility with Morely-Vine-Matthews hypothesis (Vine and Matthews, 1963) which added in polarity reversals
- Plate tectonics is “how it works”.

The major lithospheric plates

Moving plates around on a sphere

- Move continuously using an angular velocity vector: Euler pole specified by latitude, longitude and rate of rotation
- Can describe any rotation by a finite pole of rotation: latitude, longitude and total angle
- or by a sequence of "stage poles" which sum up to some total finite rotation pole

Euler poles: pairs of plates separate by rotation around a pole (λ_e, ϕ_e) at a rate of $\omega^\circ/\mathrm{Myr}$



$$v = a\omega \sin\theta$$

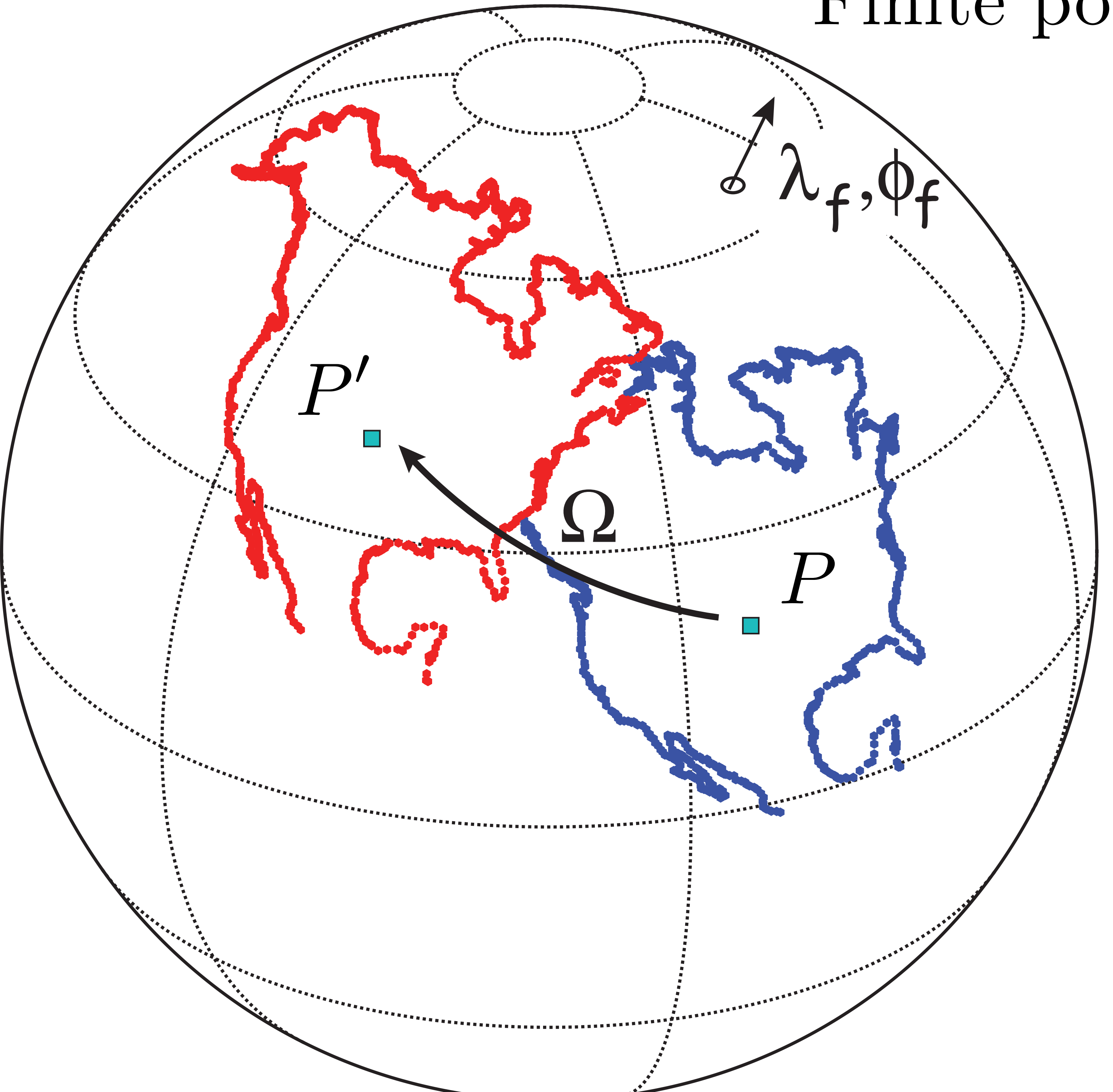
a = Earth radius

How to find Euler poles

- ridges point to them
- fracture zones make small circles around them
- magnetic anomalies give rates of spreading which via equation for velocity versus colatitude equation can give you rate of rotation

Finite pole of rotation:

$$P_f(\lambda_f, \phi_f, \Omega)$$



Given any pt on globe $P(\lambda, \phi)$

cartesian coordinates are:

$$P_1 = \cos\phi\cos\lambda$$

$$P_2 = \sin\phi\cos\lambda$$

$$P_3 = \sin\lambda$$

set up rotation matrix
Rij (see appendix) e.g.,

$$R_{11} = P_{f1}P_{f1}(1-\cos\Omega) + \cos\Omega$$

$$R_{12} = P_{f1}P_{f2}(1-\cos\Omega) - P_{f3}\sin\Omega$$

etc.

and get rotated coordinates $P_i' = R_{ij}P_j$

convert back to lat/long in usual way.... (see Chapter 2)

try program pt_rot.py

How to find finite rotation poles

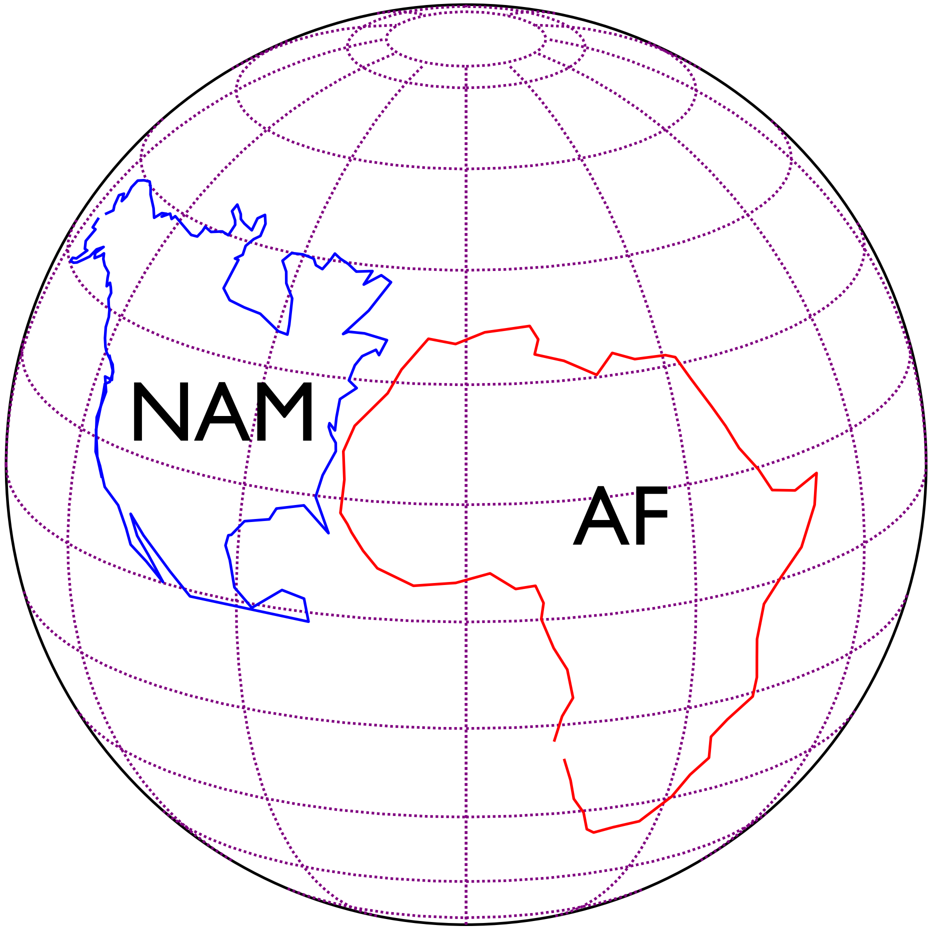
- find the rotation that "puts things back together best" by trial and error
- can use a paleomagnetic pole to rotate a plate or plate fragment back to past orientation wrt north and latitude
- or find finite rotations that cluster poles the best
- see Table A.4 for set of finite rotations that put Gondwana continents back together..

fitting things back together:

To fit North America back to Africa (from Table 16.2):

$$\lambda_f = 68, \phi_f = -14, \Omega = 75$$

("Bullard" fit)

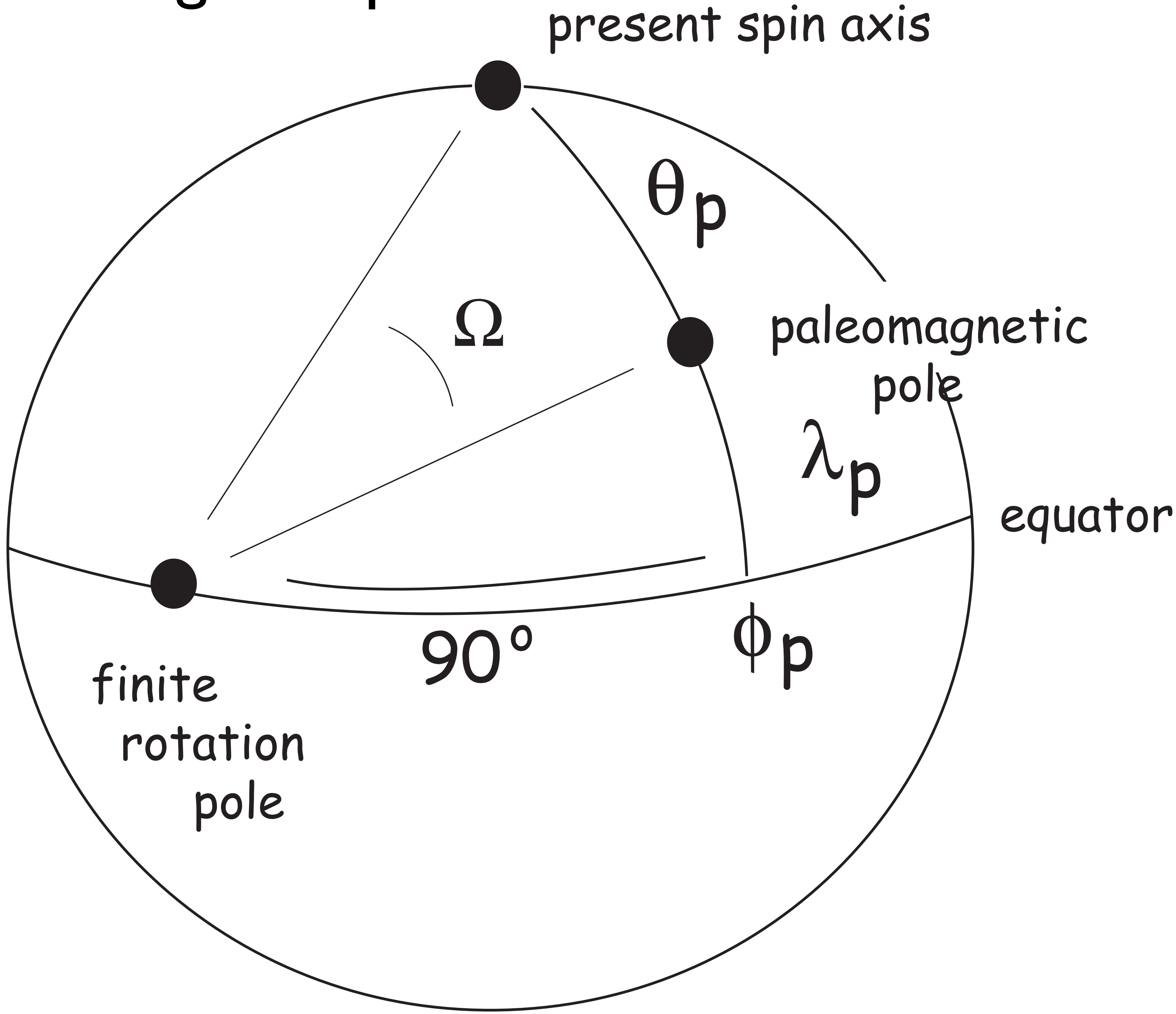


cont_rot.py -con nam -sym b- 5 -prj ortho -eye 20 0 -res c -pfr 68 -14 75

and

cont_rot.py -con af -sym r- 5 -prj ortho -eye 20 0 -res c -pfr 0 0 0

using a paleomagnetic pole

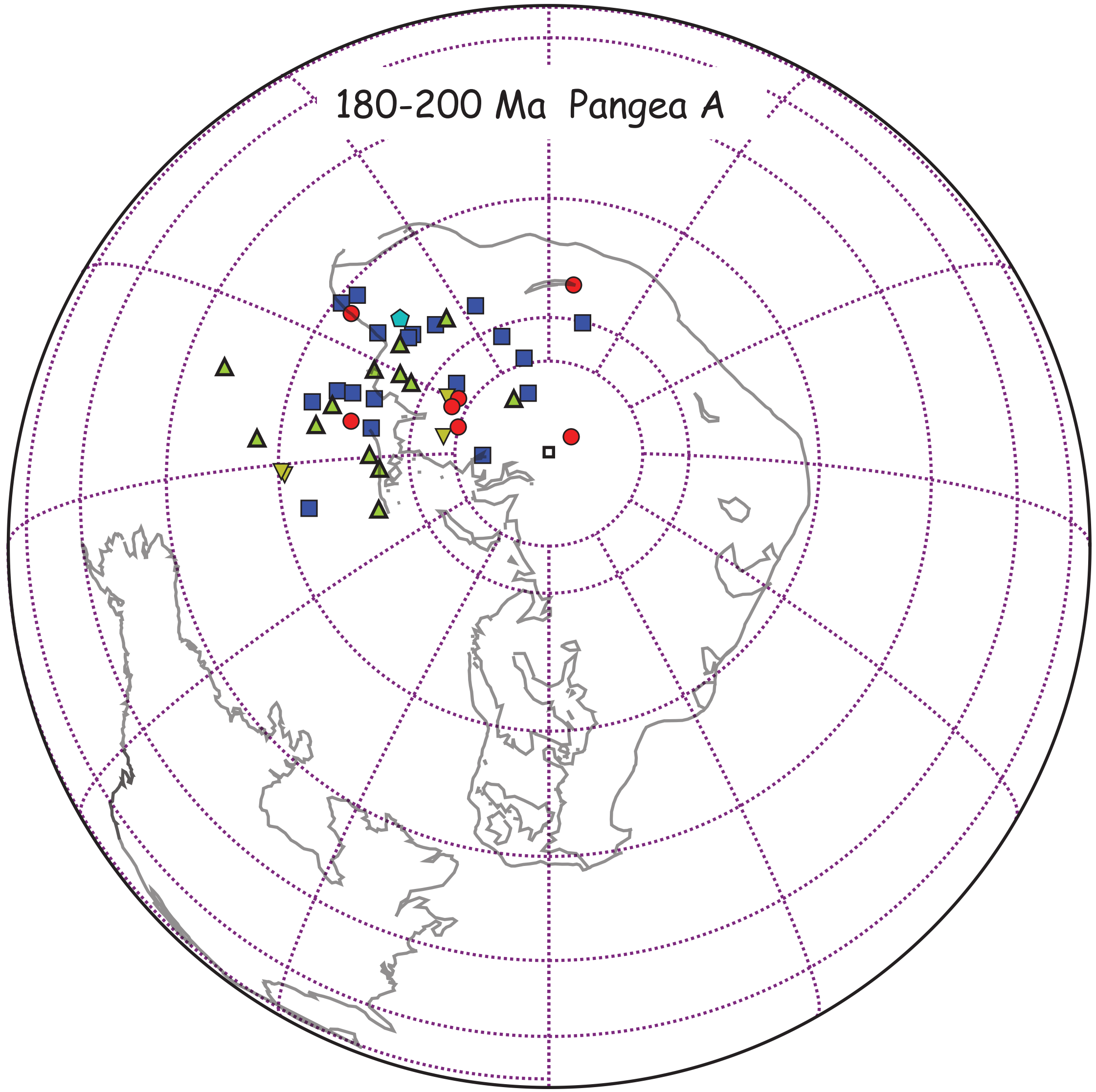


but be ware of ambiguity!

which polarity?
(a versus b)

longitude
unconstrained
(b versus c)

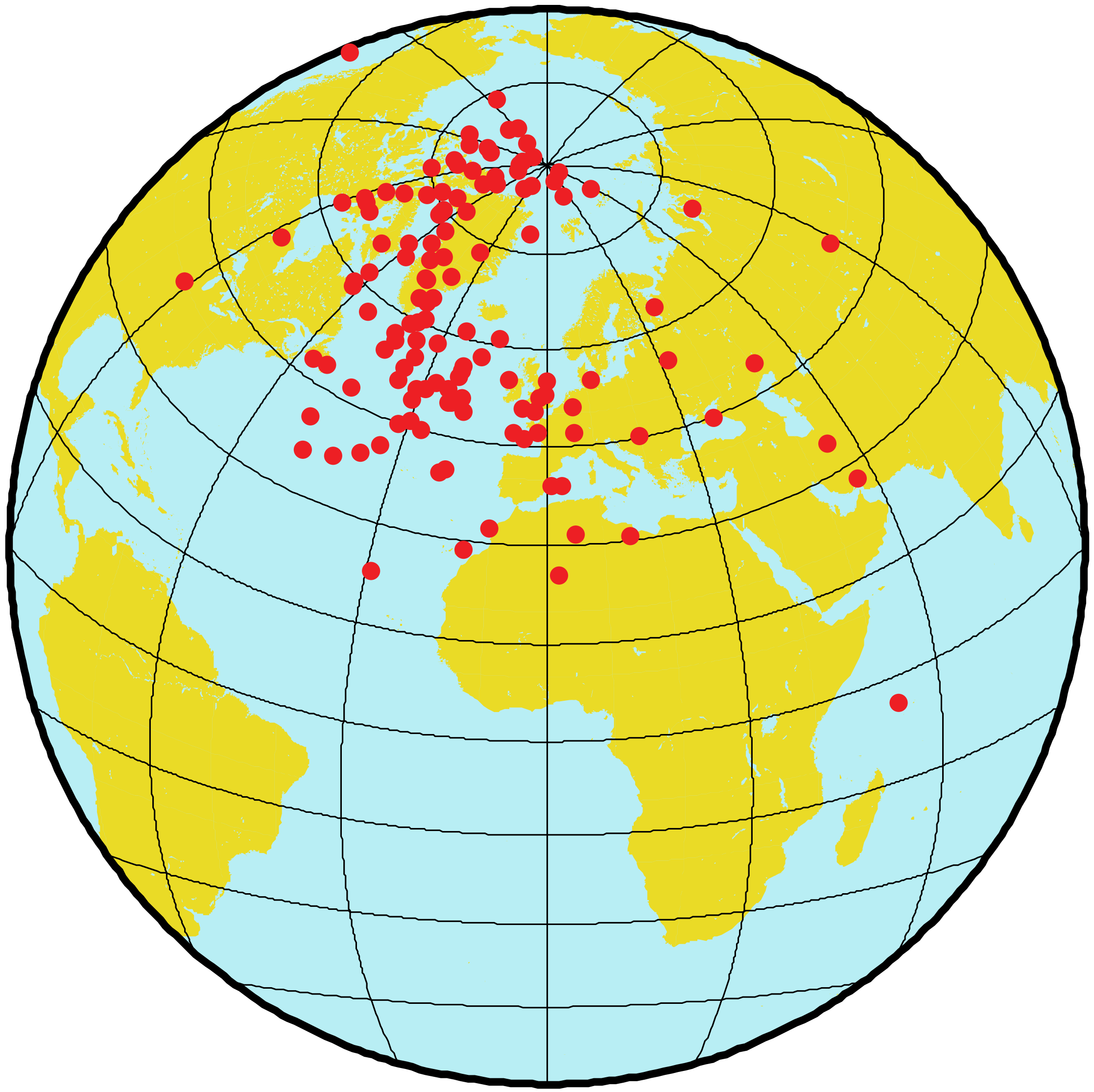
Making the paleomagnetic poles fit



Back to apparent polar wander

- There have been over 10,000 paleomagnetic poles published since 1925.
- Range in age from Archean to recent
- Range in quality from abysmal to excellent
- most are available in the pole database (GPMDB) available online: http://www.ngu.no/geodynamics/gpmdb/
- More and more available with all the supporting site level data through earthref.org/MagIC

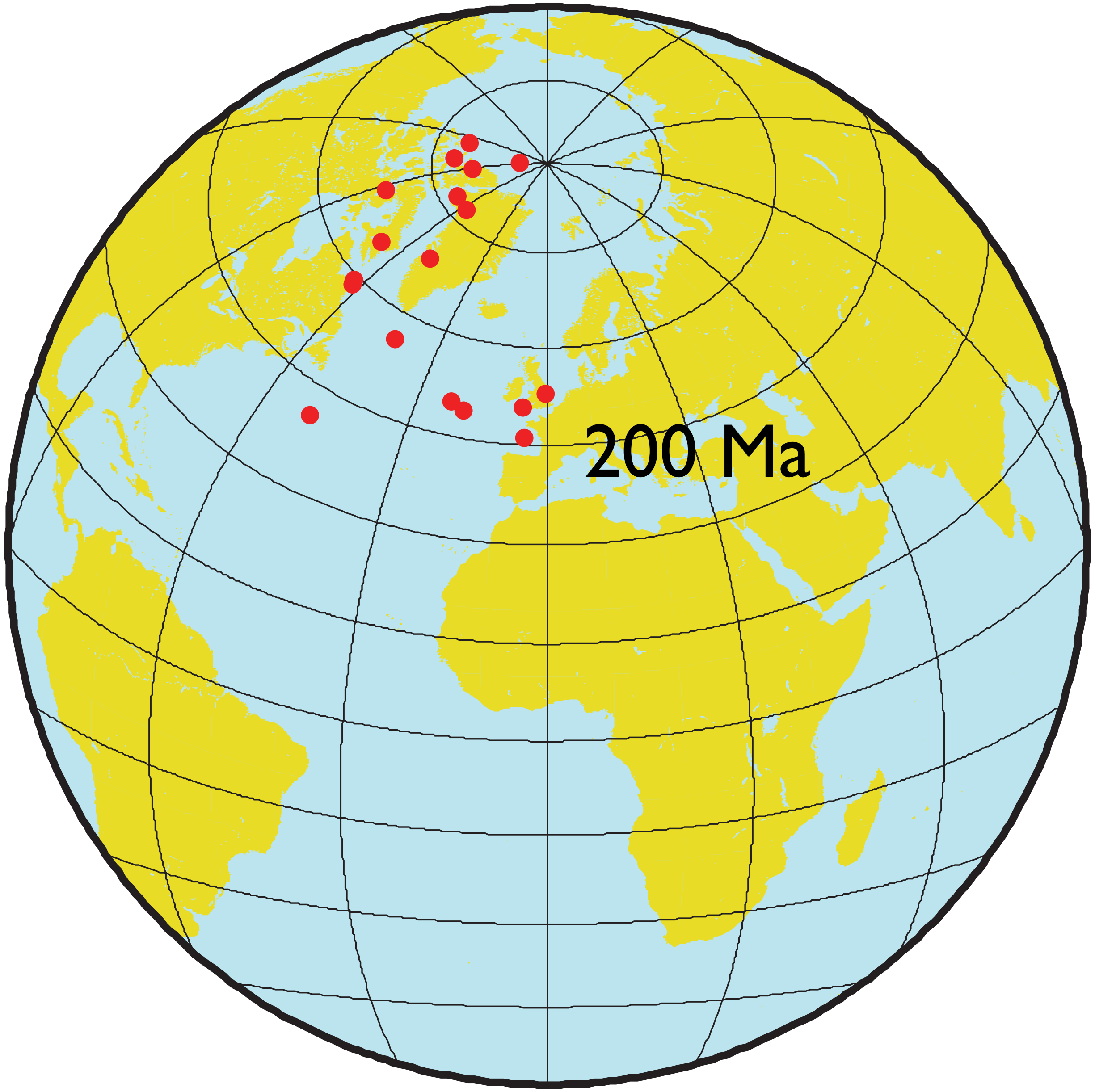
All the poles from Australia in the GPMDB



But how to select? (see book for details)

- e.g., criteria of Van der Voo (1990) or Besse and Courtillot (2002)
- Gotta know the age!
- Must be geomagnetic field and average out PSV
- Tectonic tilt (and rotation!) must be accounted for

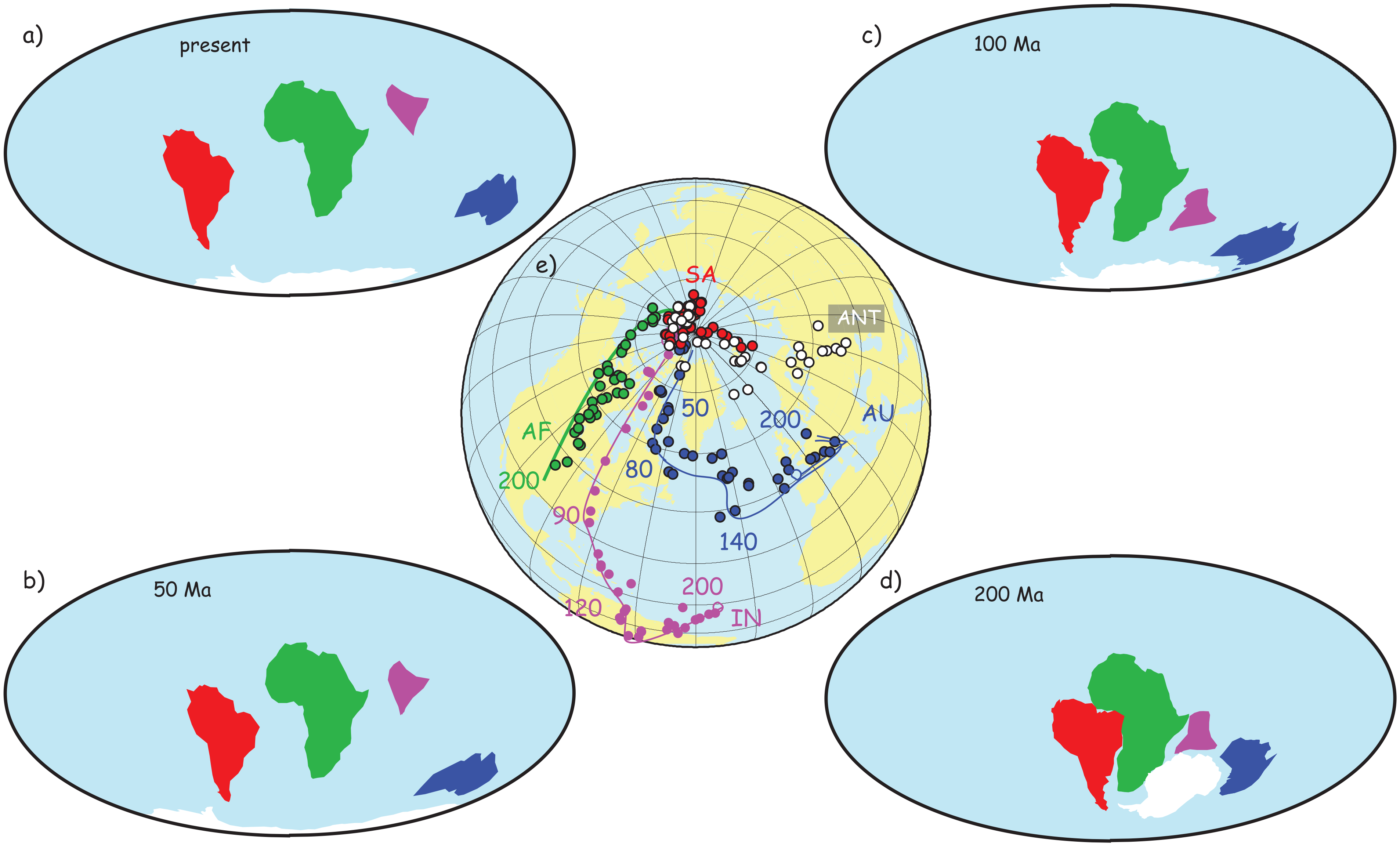
Australian pole set (<200 Ma) after selection (using BC02)



Creating “master” APWP paths

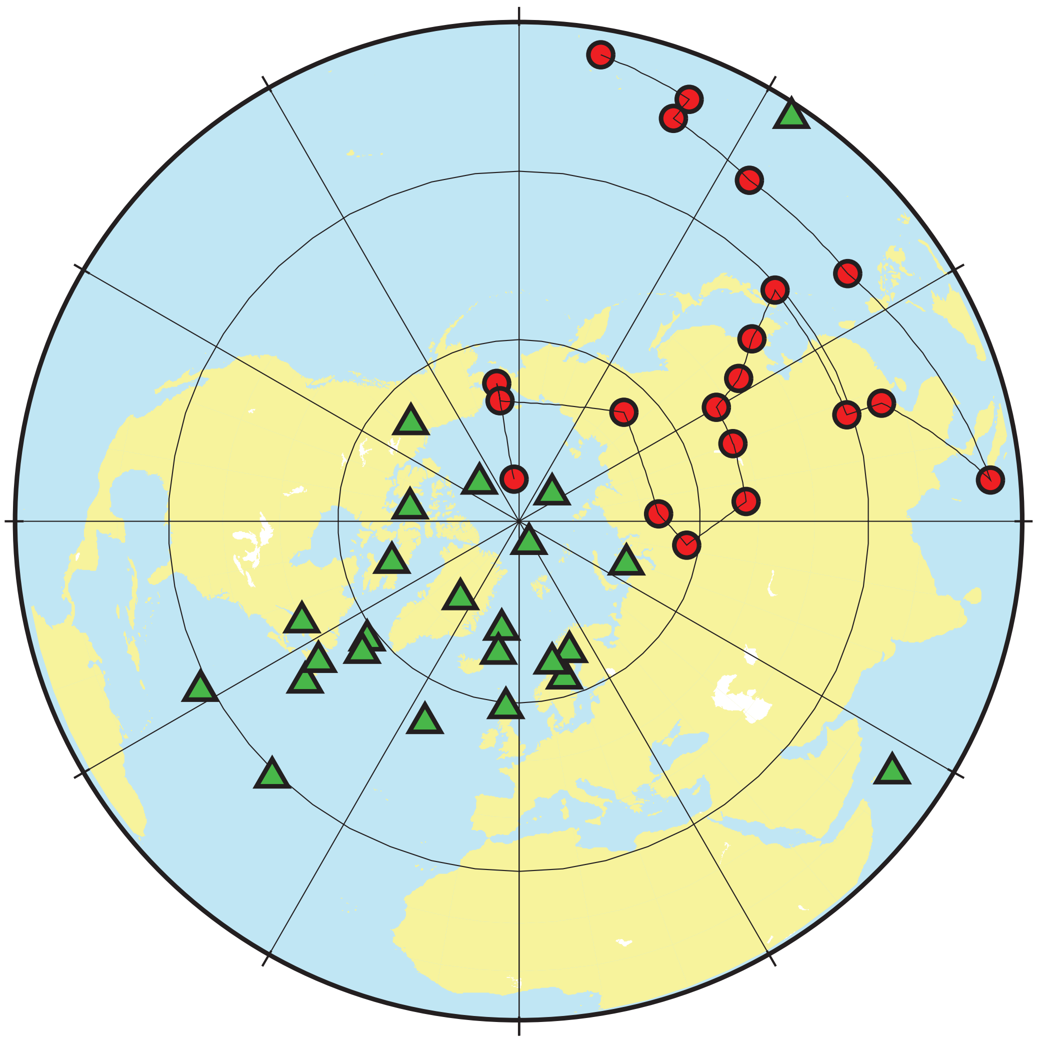
- Say we have a bunch of poles from different continents whose ages are well known.
- finite poles of rotation connecting the different continents are known (from sea floor spreading data, e.g.) - can rotate all poles to common reference frame
- average everything together to create a master APWP
- then export the poles back to each continent.

Exported master APWP for Gondwana continents



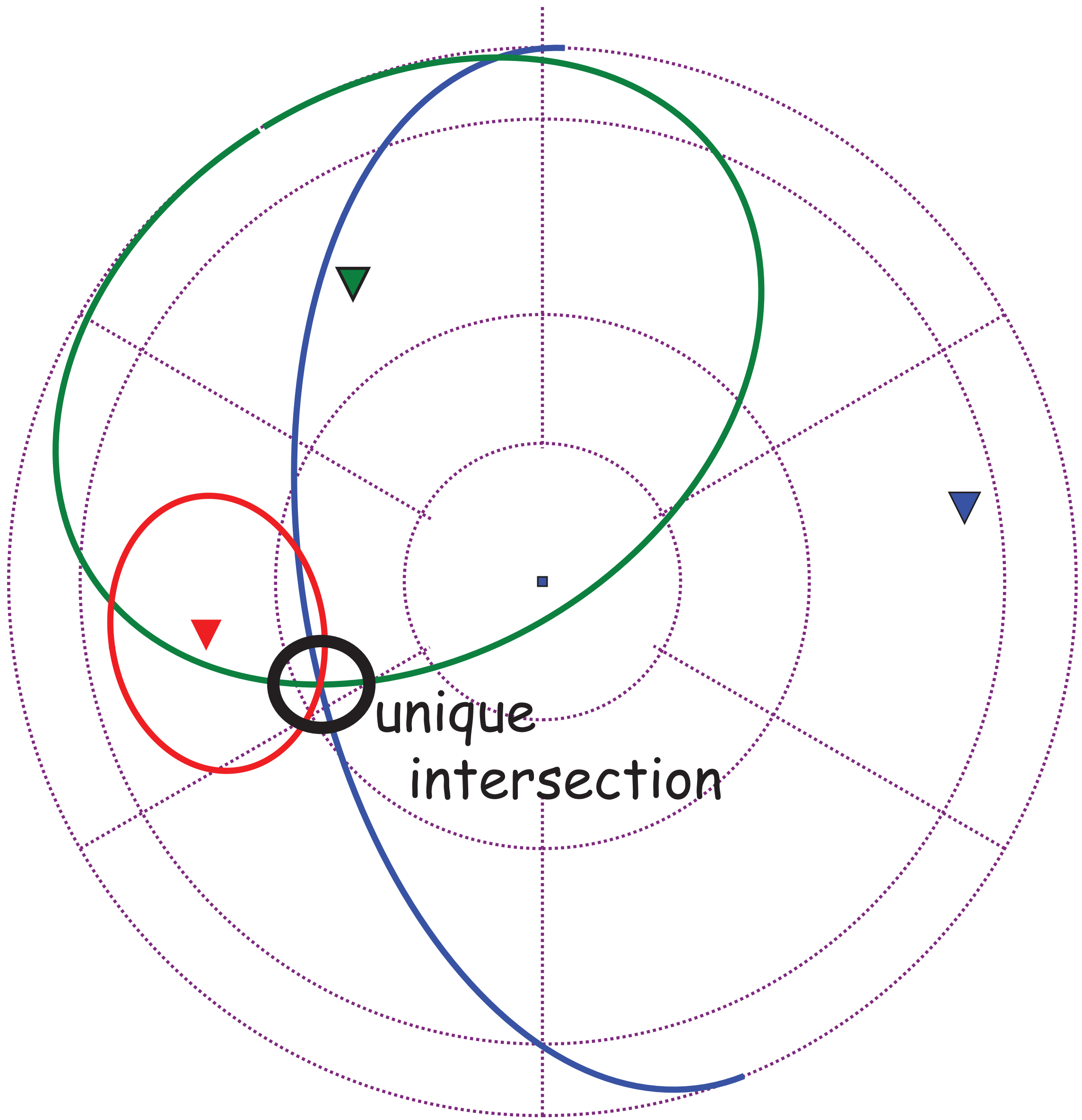
get these poles using apwp.py!

Watch out for "discordant" poles in the database!



circles: "stable" North America

triangles: "displaced terrains" from western US (e.g., Mojave desert)

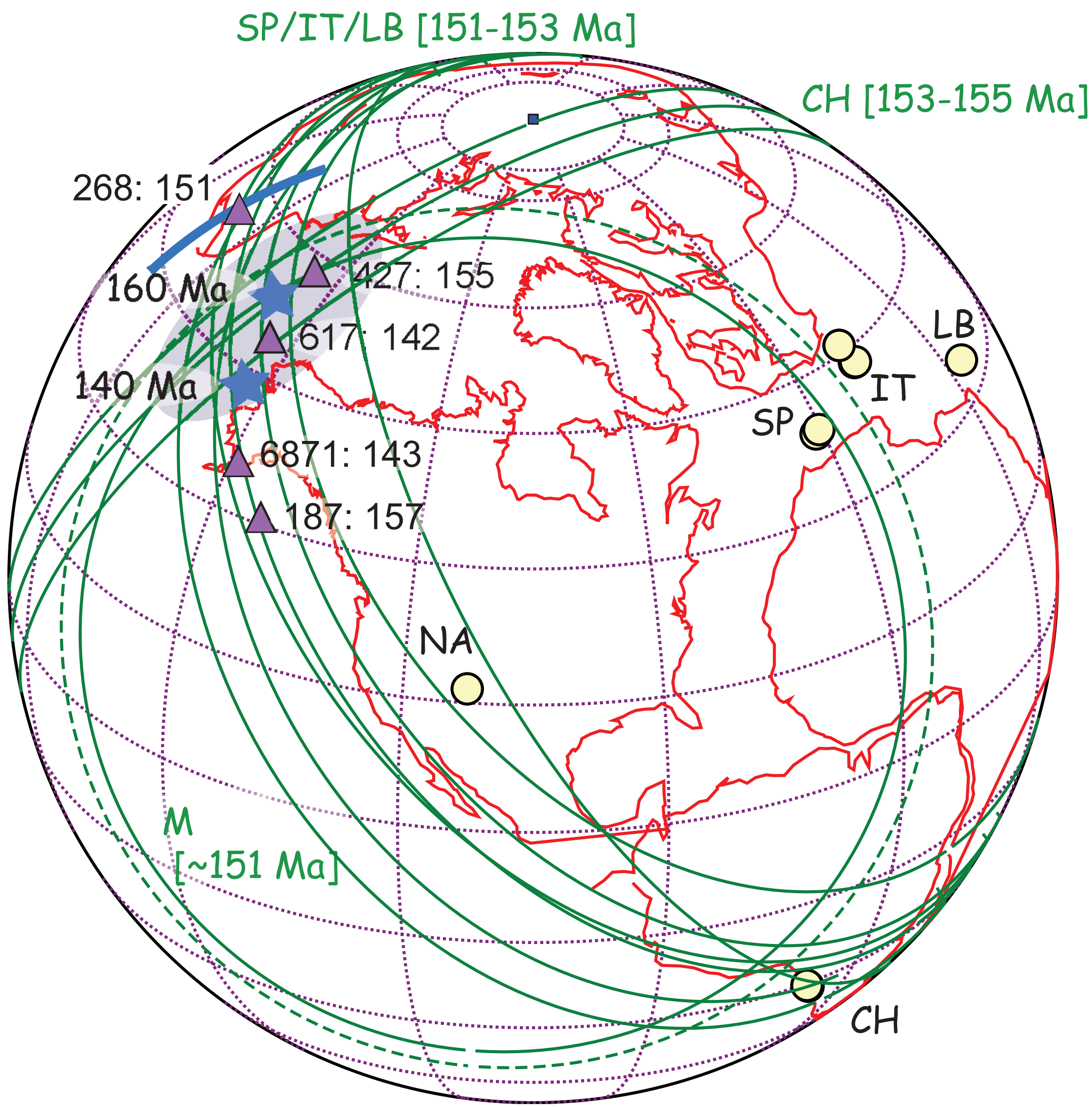


Inclination only data

still gives paleolatitude

three locations give unique pole

Example from Kimmeridgian (~150 Ma)
All rotated to Africa



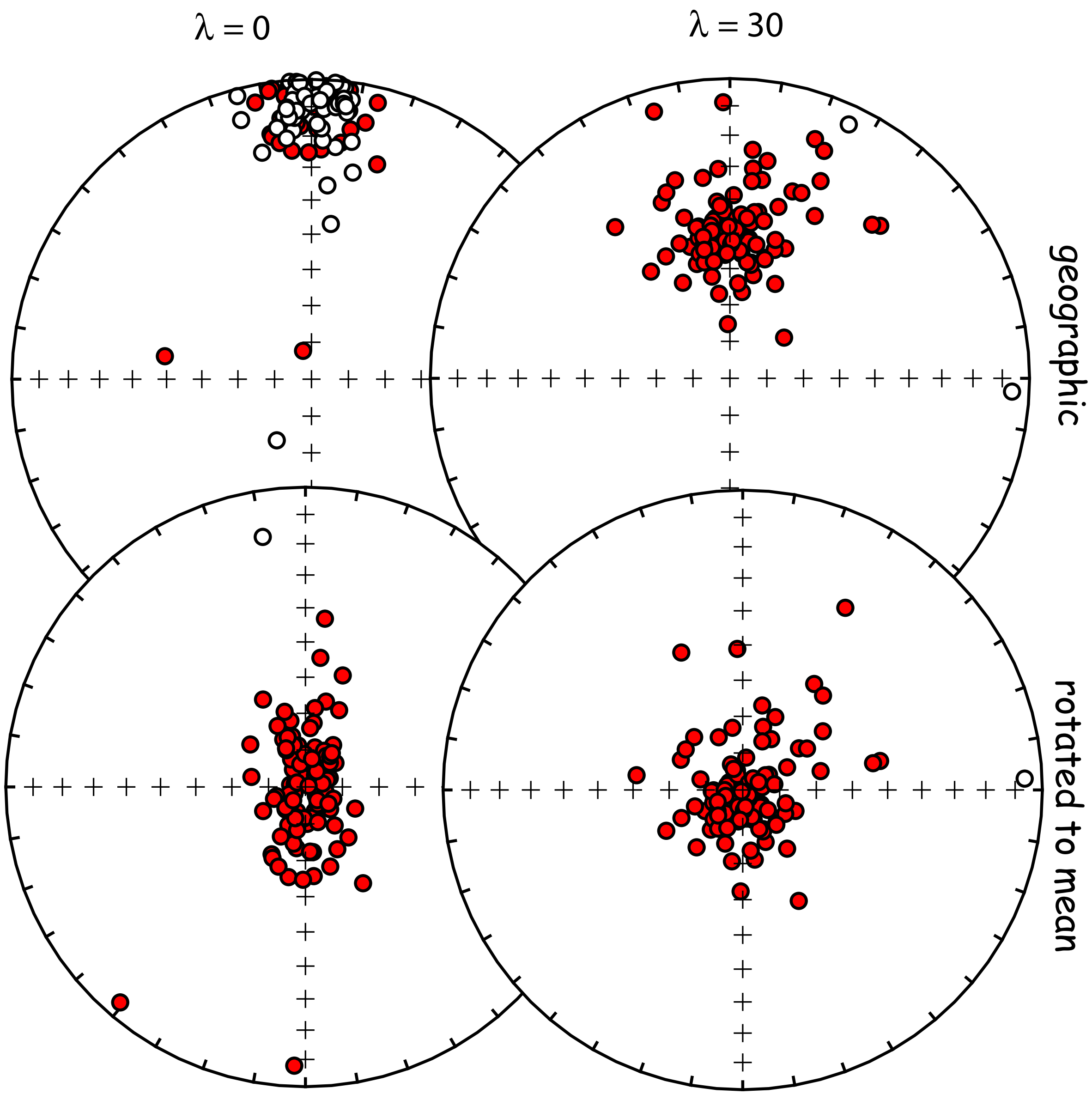
But there is a problem

- Sediments are well known for their inclination shallowing little problem
- Many poles are based on sediments
- Ergo, many poles are WRONG

But there is also a solution

- Can use the DRM tensor (lecture on tensors) to correct the poles
- OR you can use a statistical field model (say, TK03) to correct the poles
- OR you could just pull a flattening factor out of the air and use that (not my favorite way)

Predicted directions from "TK03"

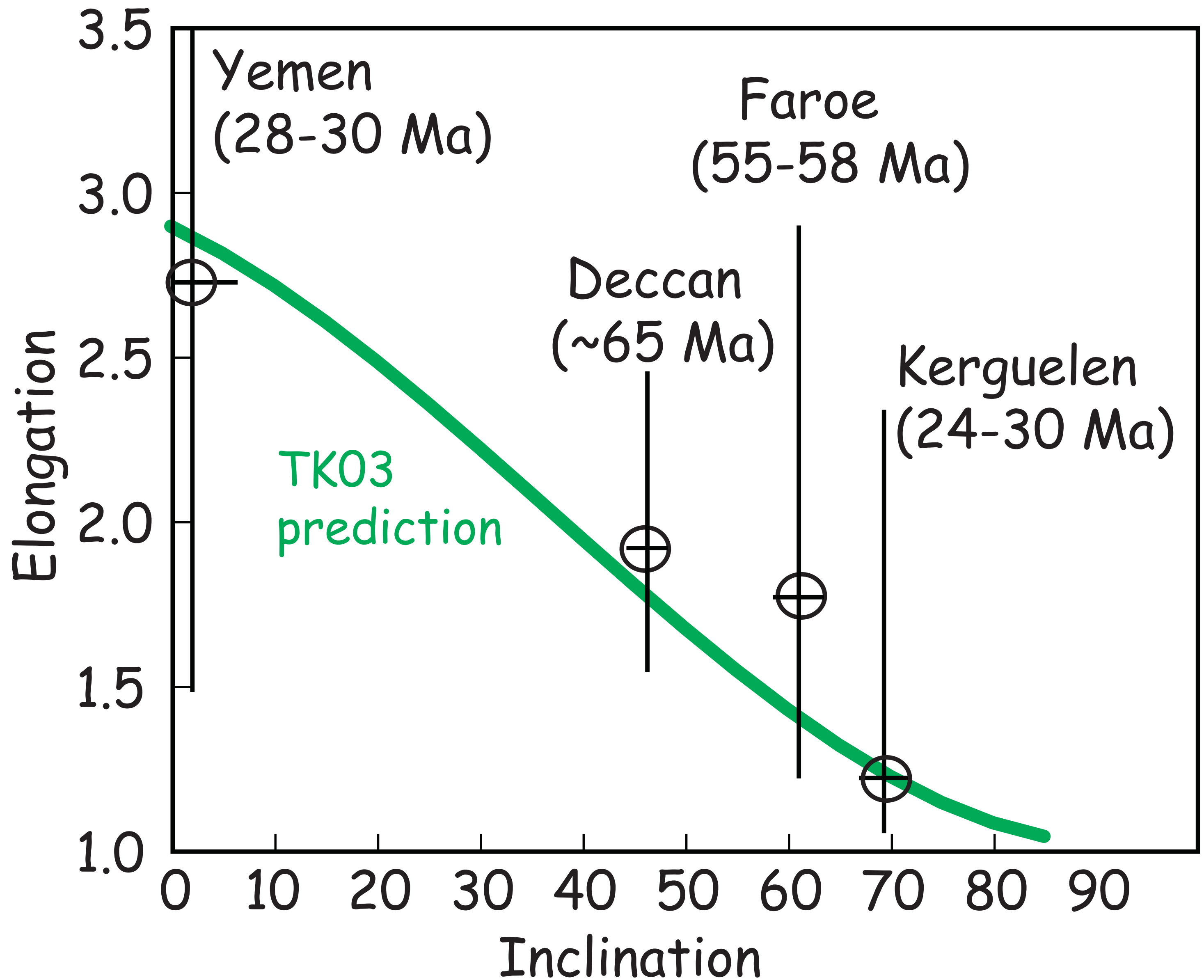


E=5.3 E=1.5

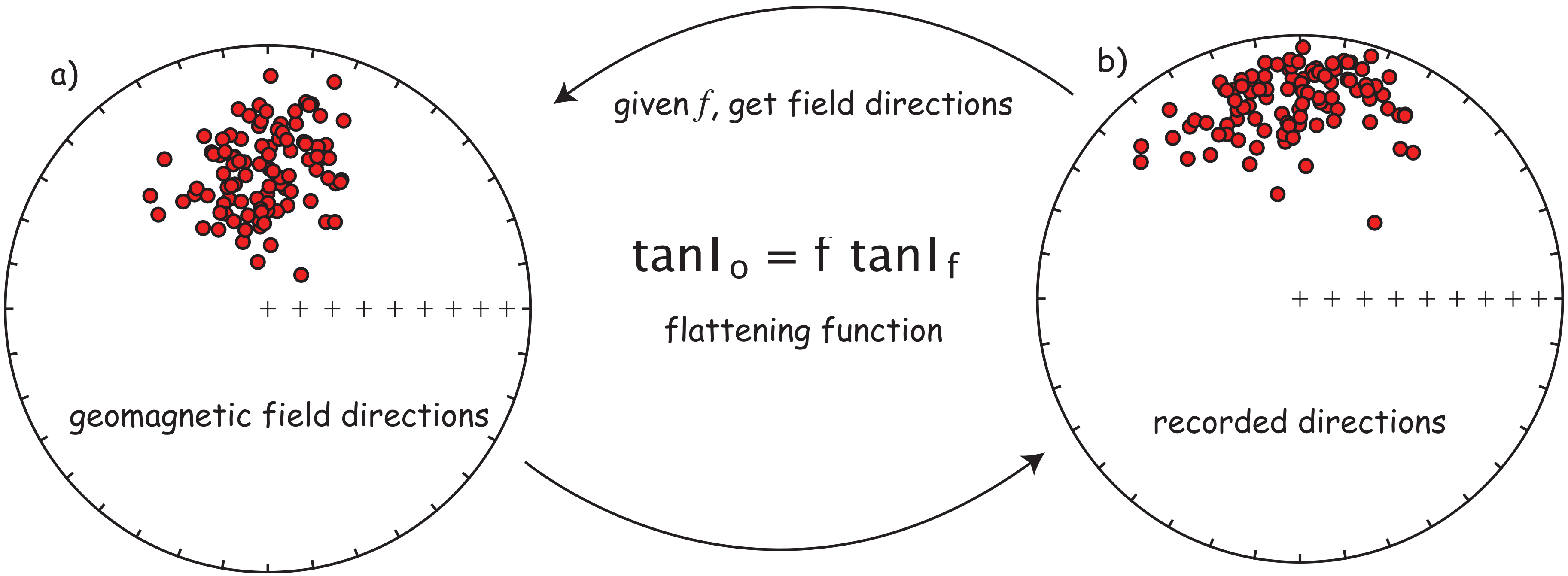
notice "elongation" versus inclination

get eigenparameters of orientation matrix (that again!) and define

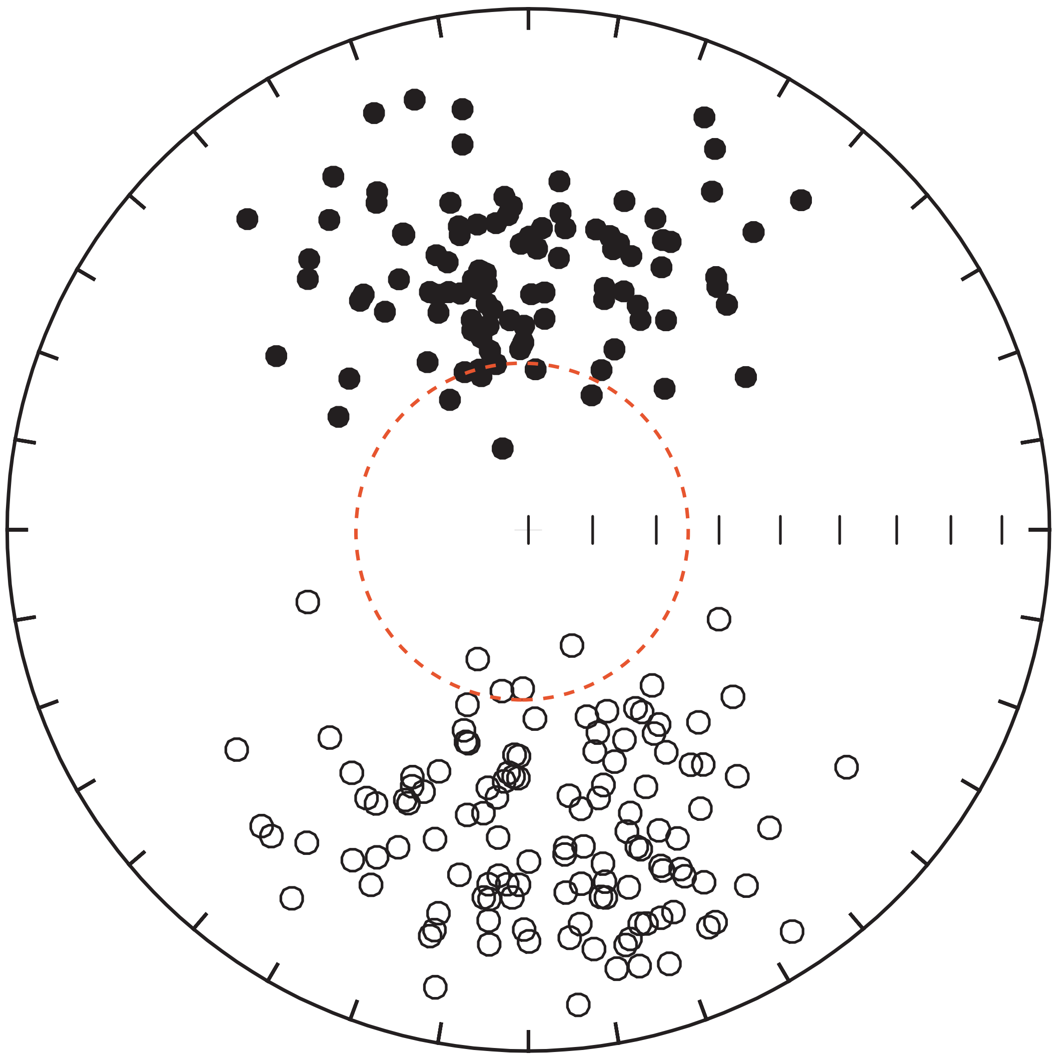
$$E = \tau_2/\tau_3$$

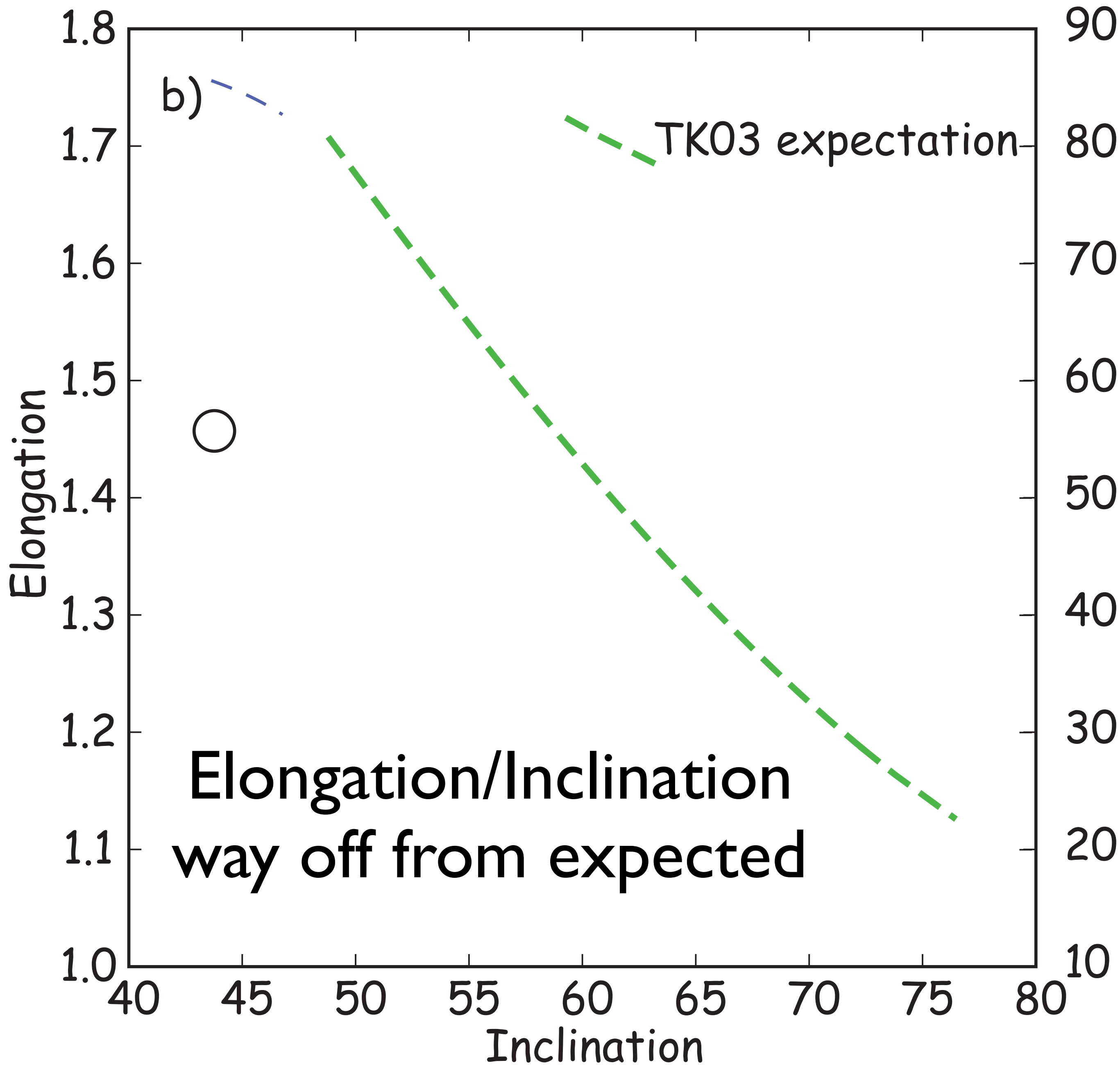

Yemen
(28-30 Ma)
Faroe
(55-58 Ma)
Deccan
(~65 Ma)
Kerguelen
(24-30 Ma)
TK03
prediction
Elongation
3.5
3.0
2.5
2.0
1.5
1.0
0
10
20
30
40
50
60
70
80
90
Inclination

geological application: "fixing" inclination error



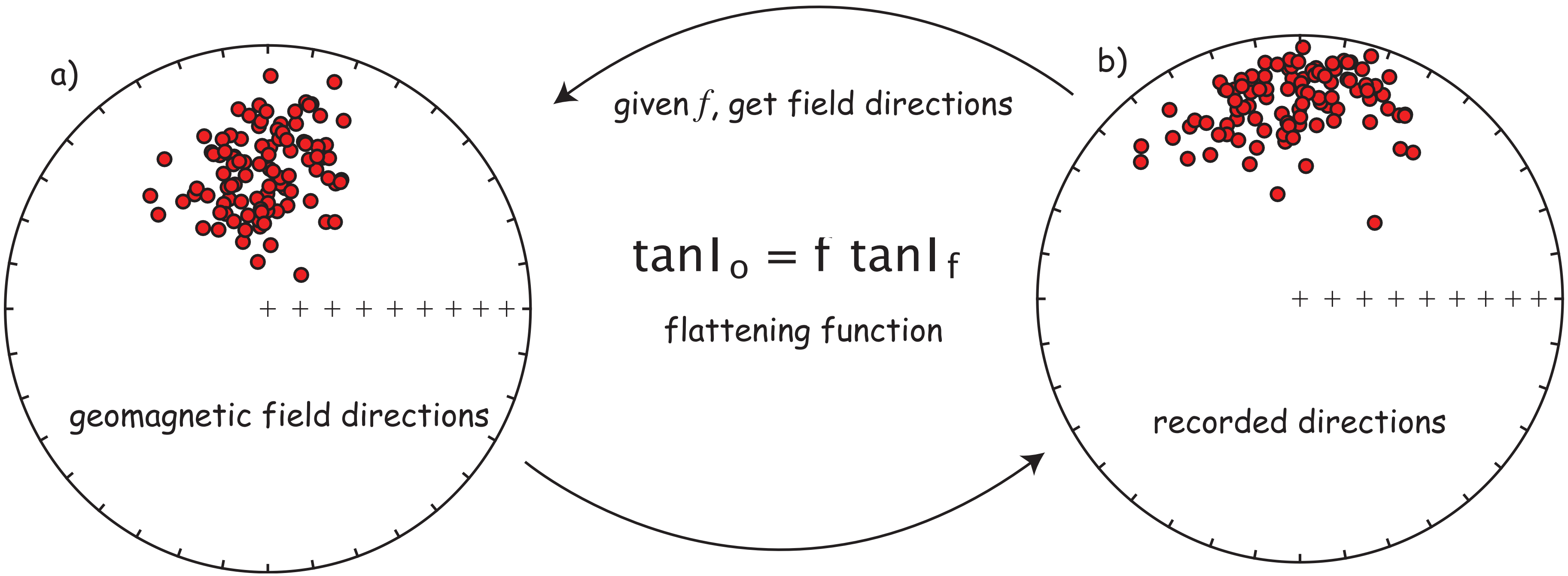
A set of "flattened" directions, which should have inc of dashed line



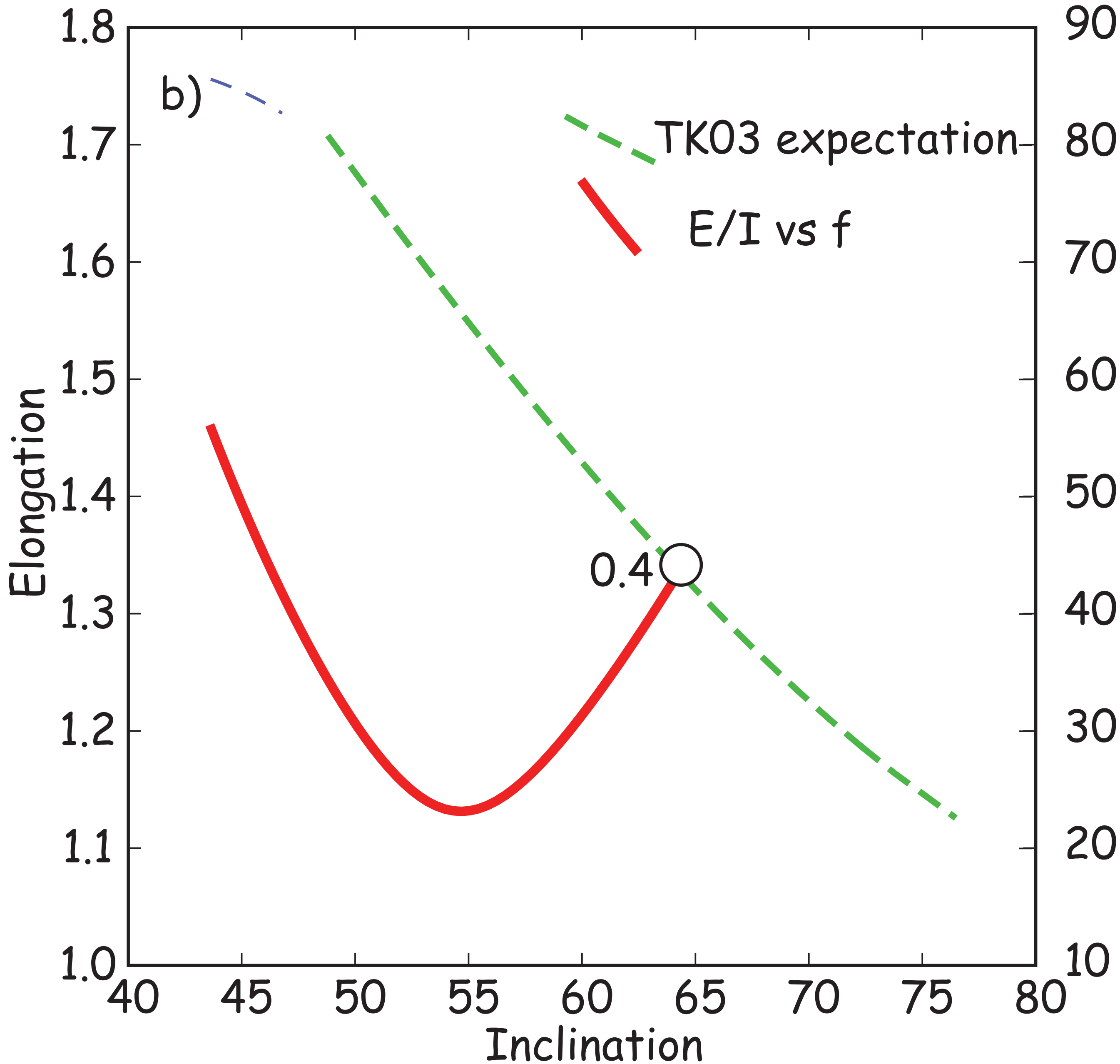


b)
TK03 expectation
Elongation/Inclination
way off from expected
Elongation
Inclination
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
40
45
50
55
60
65
70
75
80
10
20
30
40
50
60
70
80
90

unflatten data with f ranging from 1=> 0

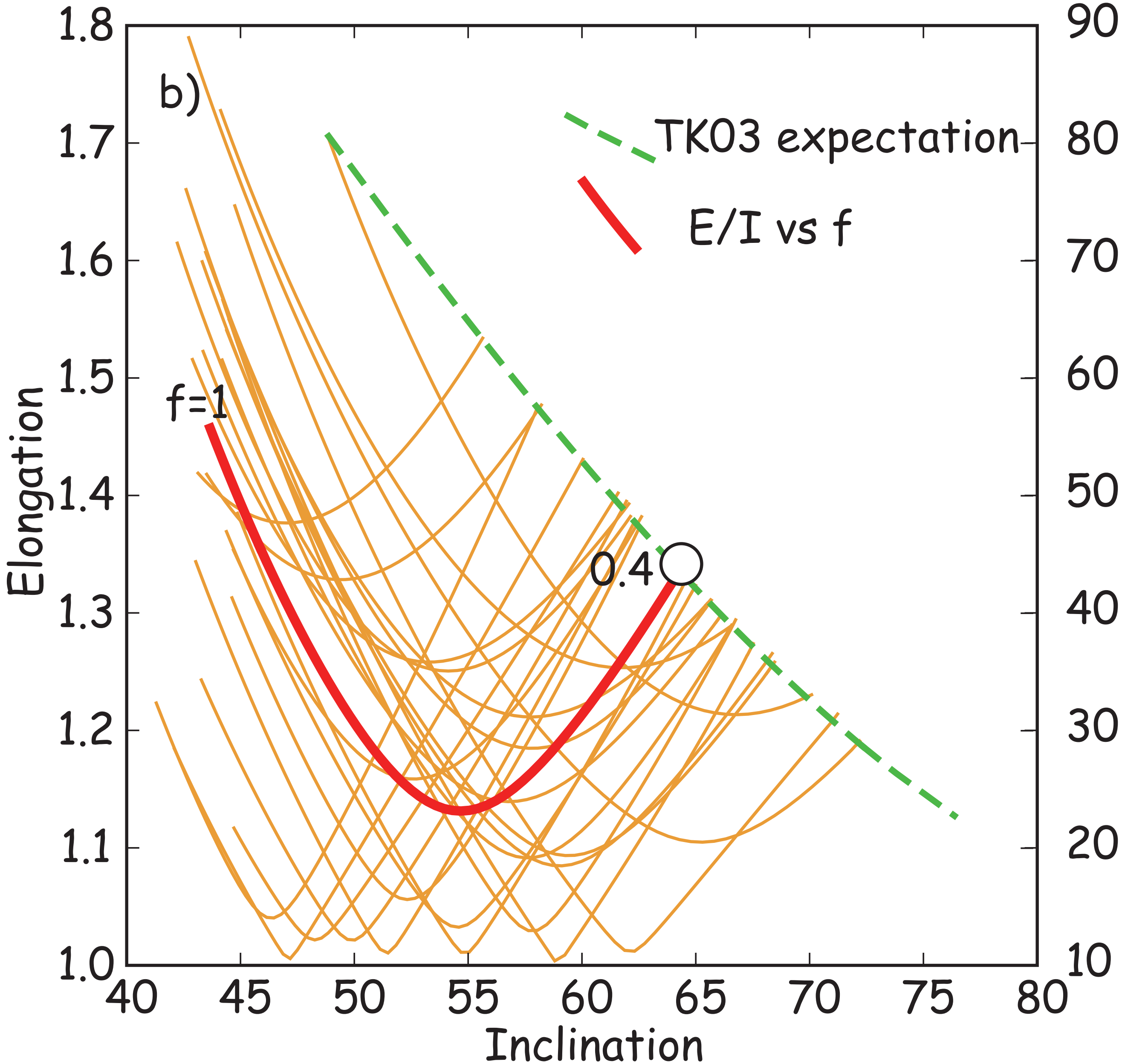


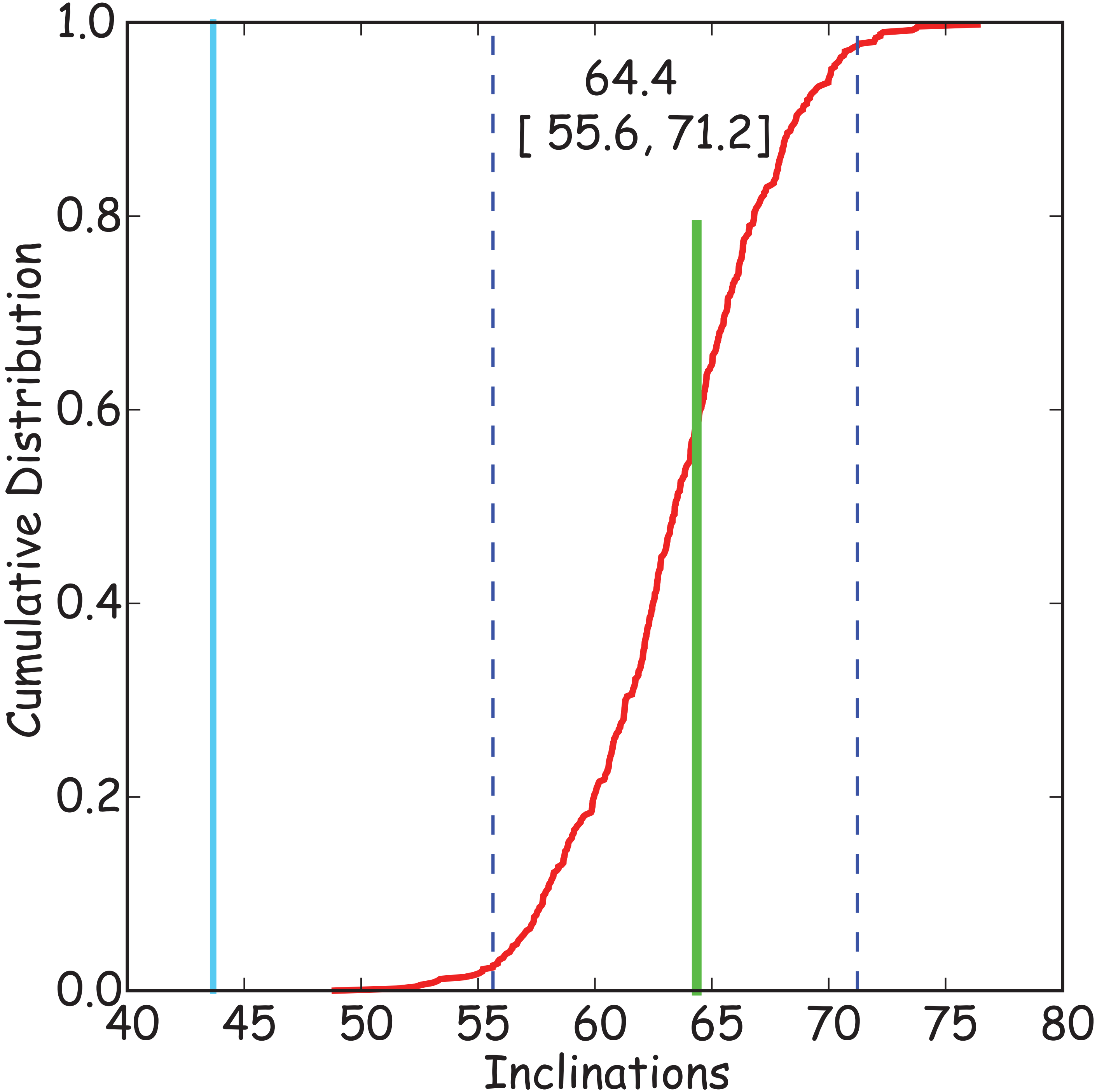
Calculate E and I at each f



find the f which matches the field model

Do a bootstrap for uncertainty





get 95% confidence bounds on "corrected" Inclination

and Bob's your uncle

Next steps

- Need to re-do the statistical field model with updated database of Cromwell
- Need to correct all the sediment poles for inclination shallowing
  - this will likely require resampling of them as most studies do not have enough data to do the E/I
  - who wants to help?