Lecture 15:

The ancient geomagnetic field

- Why study the ancient field
- Paleosecular variation:
  - the Holocene
  - past 5 Myr
- Excursions and reversals

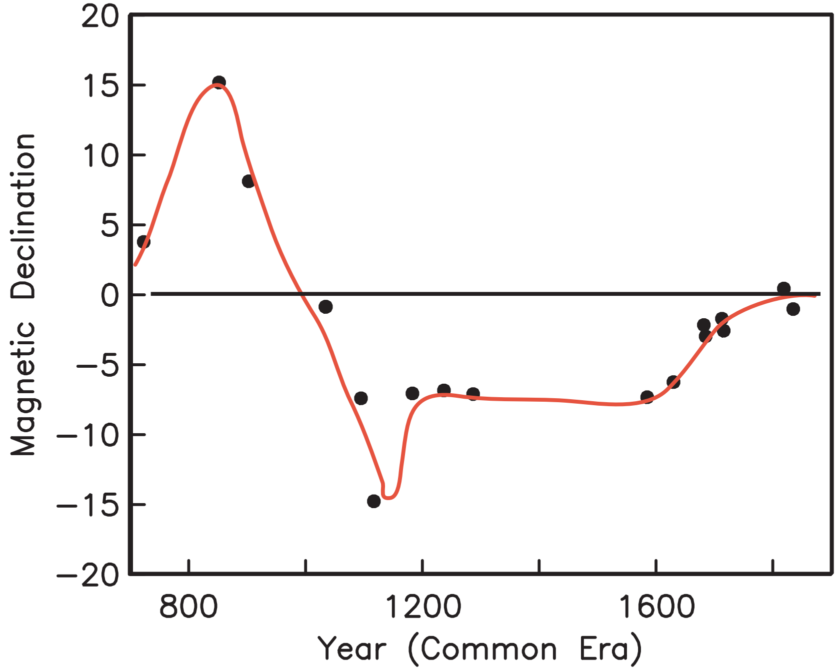
Why study the ancient geomagnetic field

- The geomagnetic field is an umbrella shield us from cosmic ray bombardment - effects radionuclide production
- Some animals detect the magnetic field
- relationship of geomagnetic field and conditions at the core/mantle and the inner/outer core boundaries
- tectonic and geological applications require a knowledge of secular variation: e.g., when (or if) it is averaged out to a GAD?
- Are we heading for a reversal now? past is key to present....

Oldest measurements of magnetic field

In first century China, used "south-pointing spoon" for Feng Shui

Measured declination and discovered secular variation in 8th century



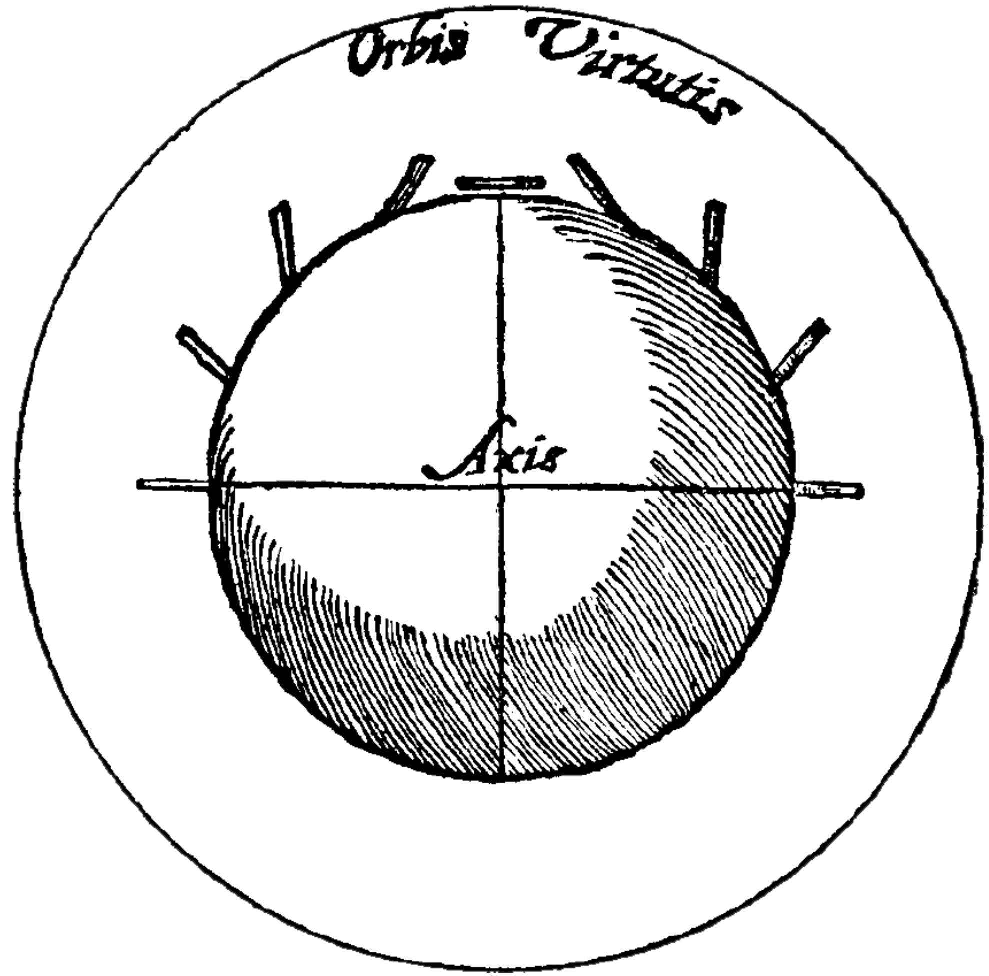
In Europe:

Petrus Perigrinus described compasses in 1269 (along with a recipe for mead).
made measurements on lodestone

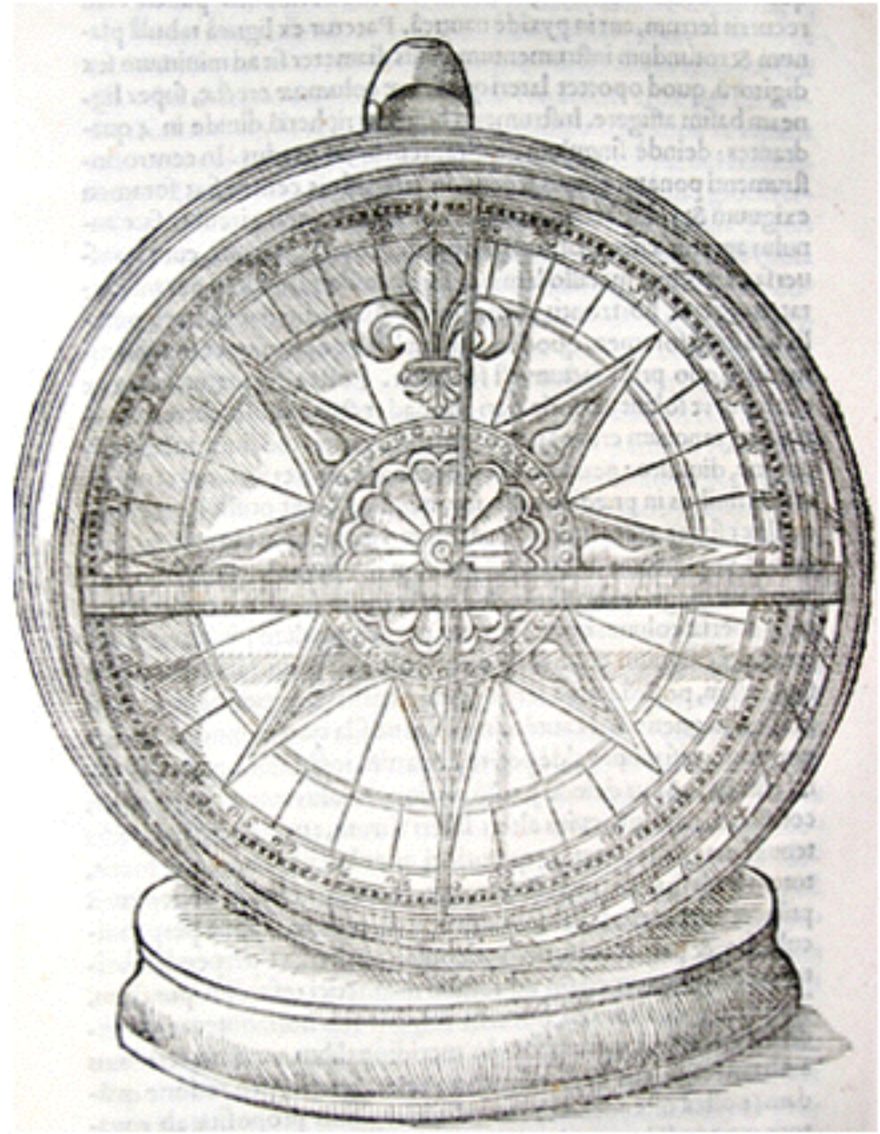
Thought compasses pointed to the pole star

FIG. I.—AZIMUTH COMPASS

William Gilbert published "de Magnete" in 1600 describing magnetic studies of the Earth and magnetic materials.   He compiled a lot of measurements of the field. Said: "The Earth itself is a great magnet!"



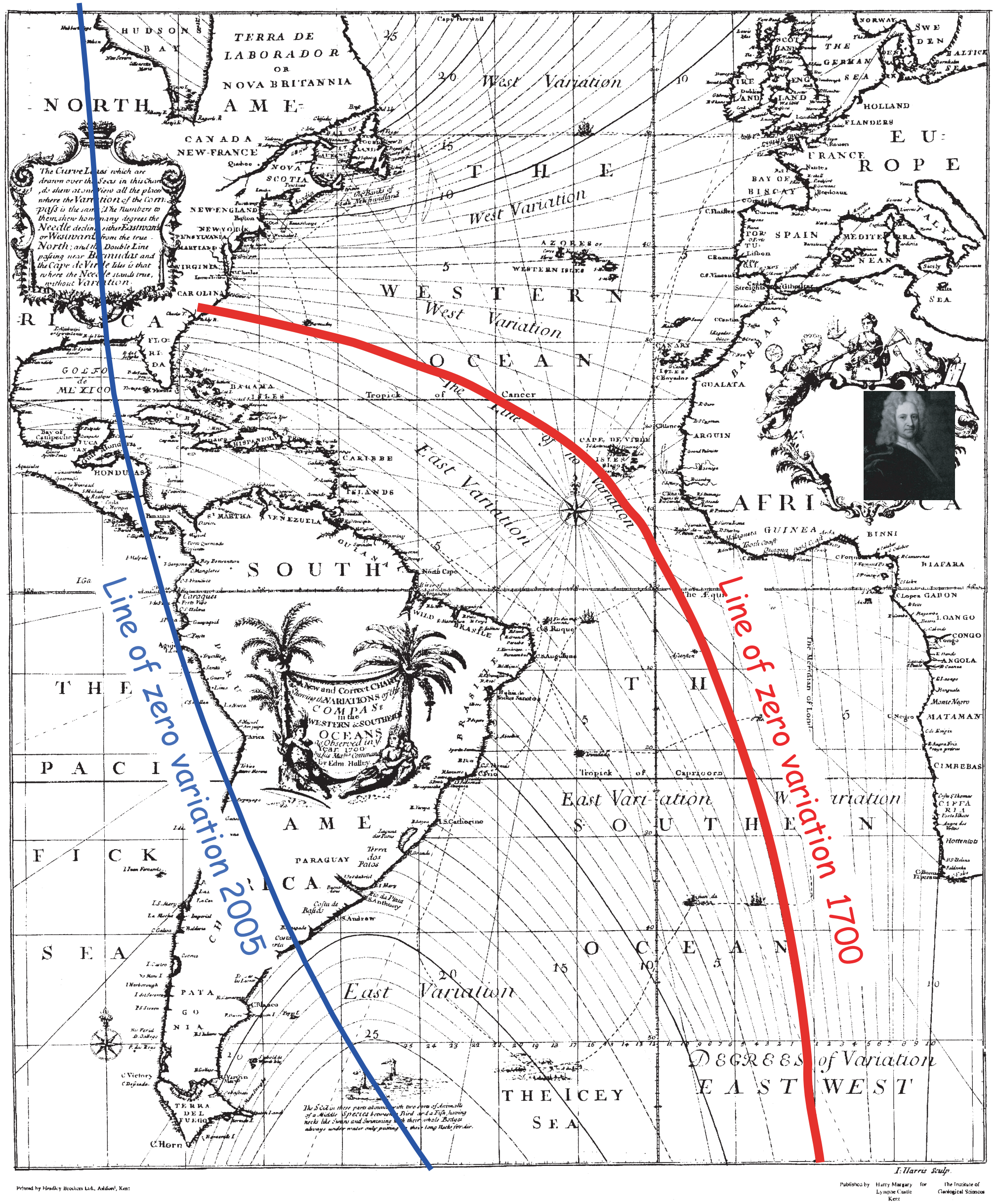
Henry Gellibrand (1634) studied magnetic declination records in London over 50 years - noted change in declination from 11 to 4. (Re)discovered secular variation



Gilbert: Instrument for Measuring Magnetic Declination.

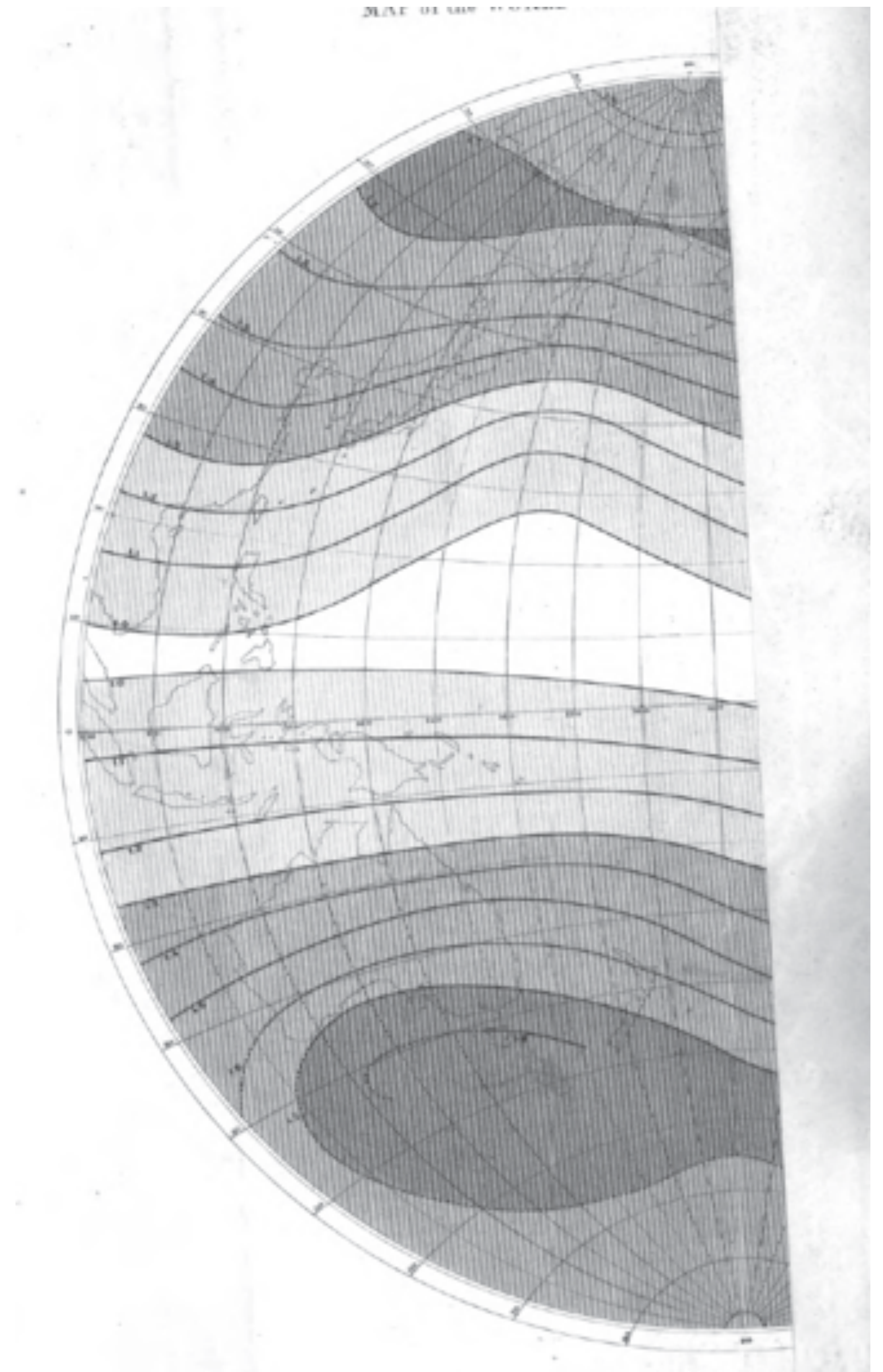
Edmund Halley went to sea on the Pink Paramore (1698-1701) and produced the first geomagnetic chart

Shortly thereafter, noticed major features appeared to move west - “westward drift”



Sabine (1883) reported that De Rossel measured intensity of the magnetic field on the D'Entrecasteaux (1791-1794) demonstrating that it increased away from the equator

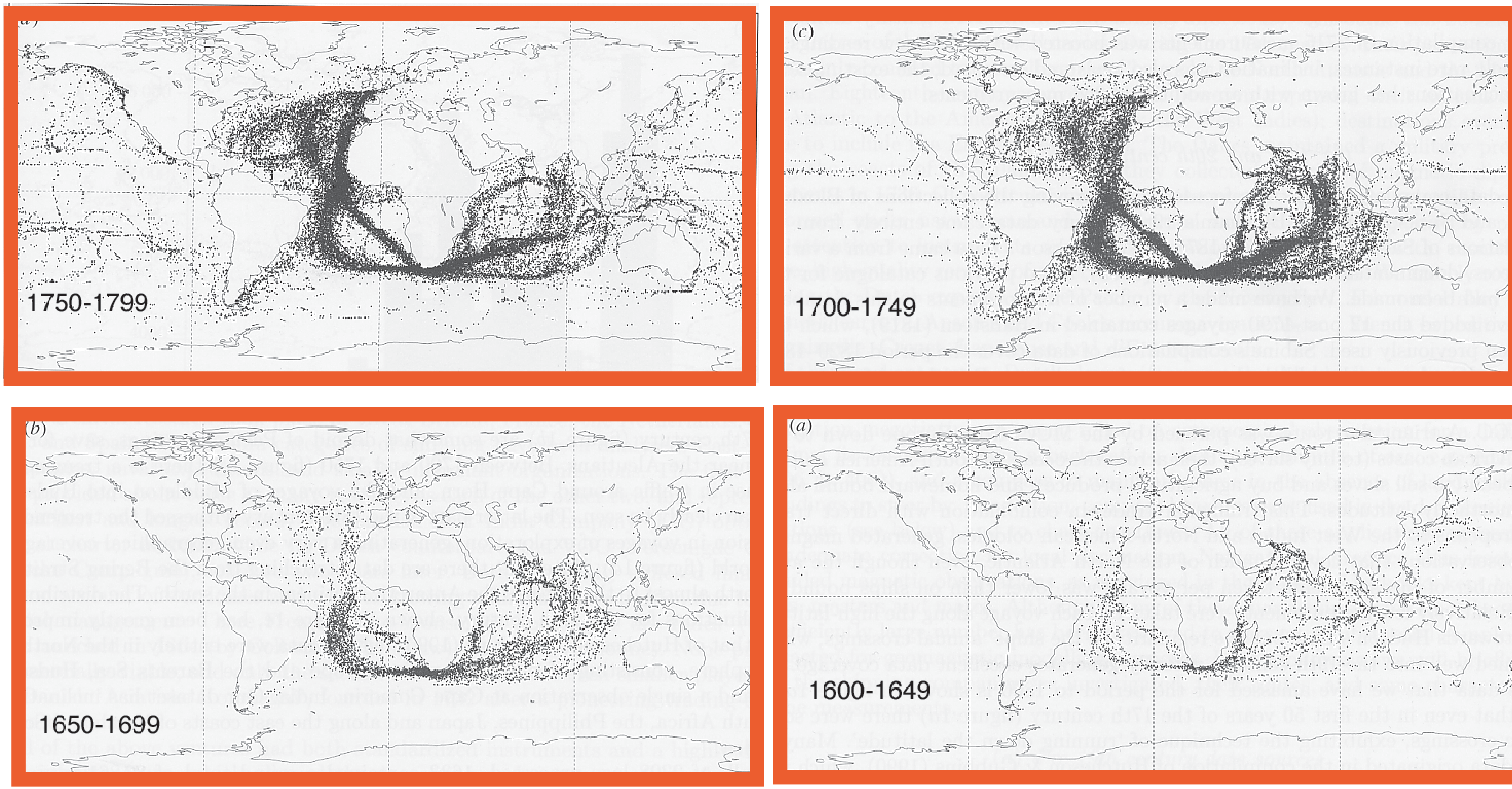
There may have been earlier measurements - but they were lost at sea



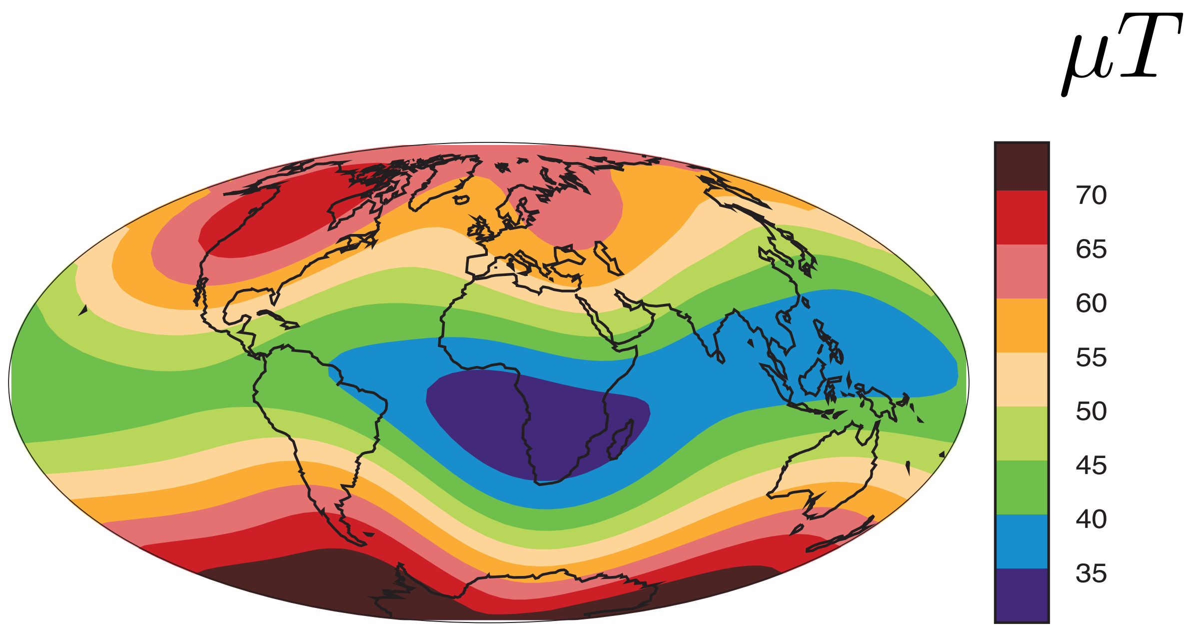
Carl Friedrich Gauss invented spherical harmonics. made first geomagnetic field model in 1835 and demonstrated that 99% of the field is of internal origin

Initiated systematic geomagnetic field observations at observatories

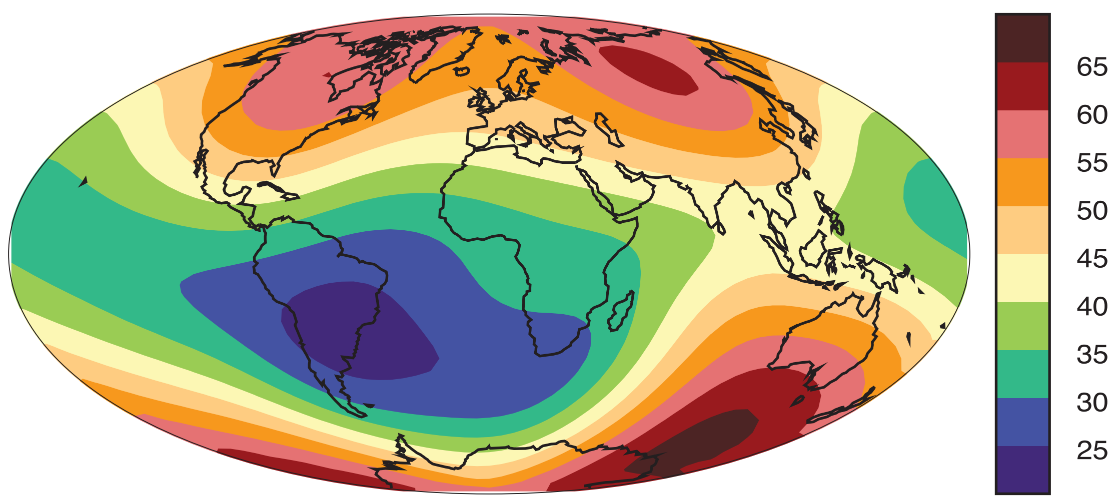
A. Jackson et al. (2000) compiled data from ship's logs dating from 1600. Extended IGRF-like field models back to 1600. Called the GUFM model



1600 (GUFM1)

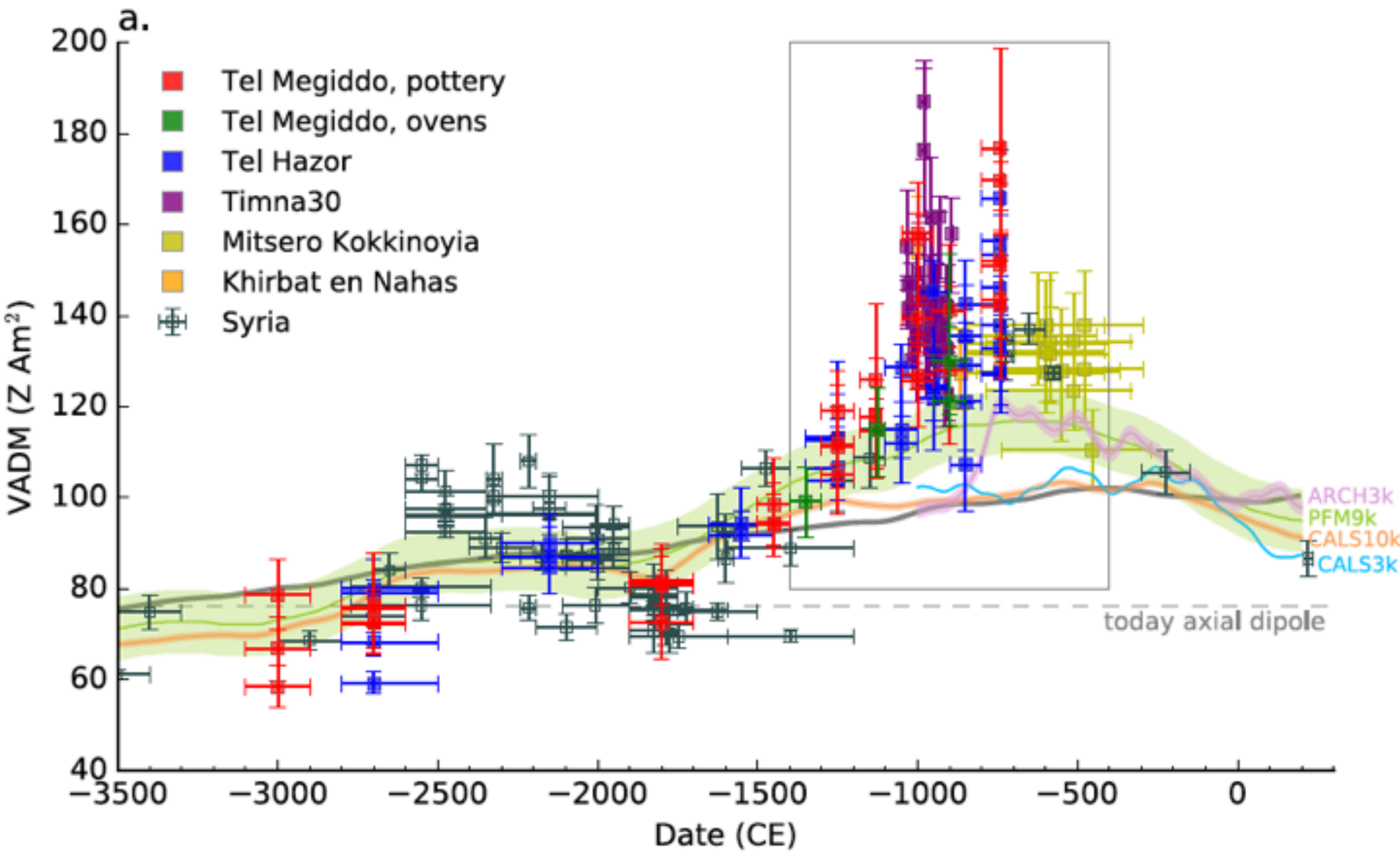


2000 (IGRF)



- Prior to about 1600, measurements are few and far between
- To study the field in times before that, we rely on “accidental” records
    - archeological materials (field of archeomagnetism)
    - geological materials (paleomagnetism)
- Field models now combine sedimentary, archaeomagnetic and paleomagnetic data (e.g., Korte and Constable series of models called CALSxK)

Compare "Levantine curve" of Shaar et al., 2015) with popular models



some comments

- If you compare even the most recent field model with high resolution data - the two do not agree very well
- New data sets being published every month and new models every few years
- so... the Korte et al. approach is the way to go; we just need more and better data with better age constraints

Statistical models of PSV and the time averaged field

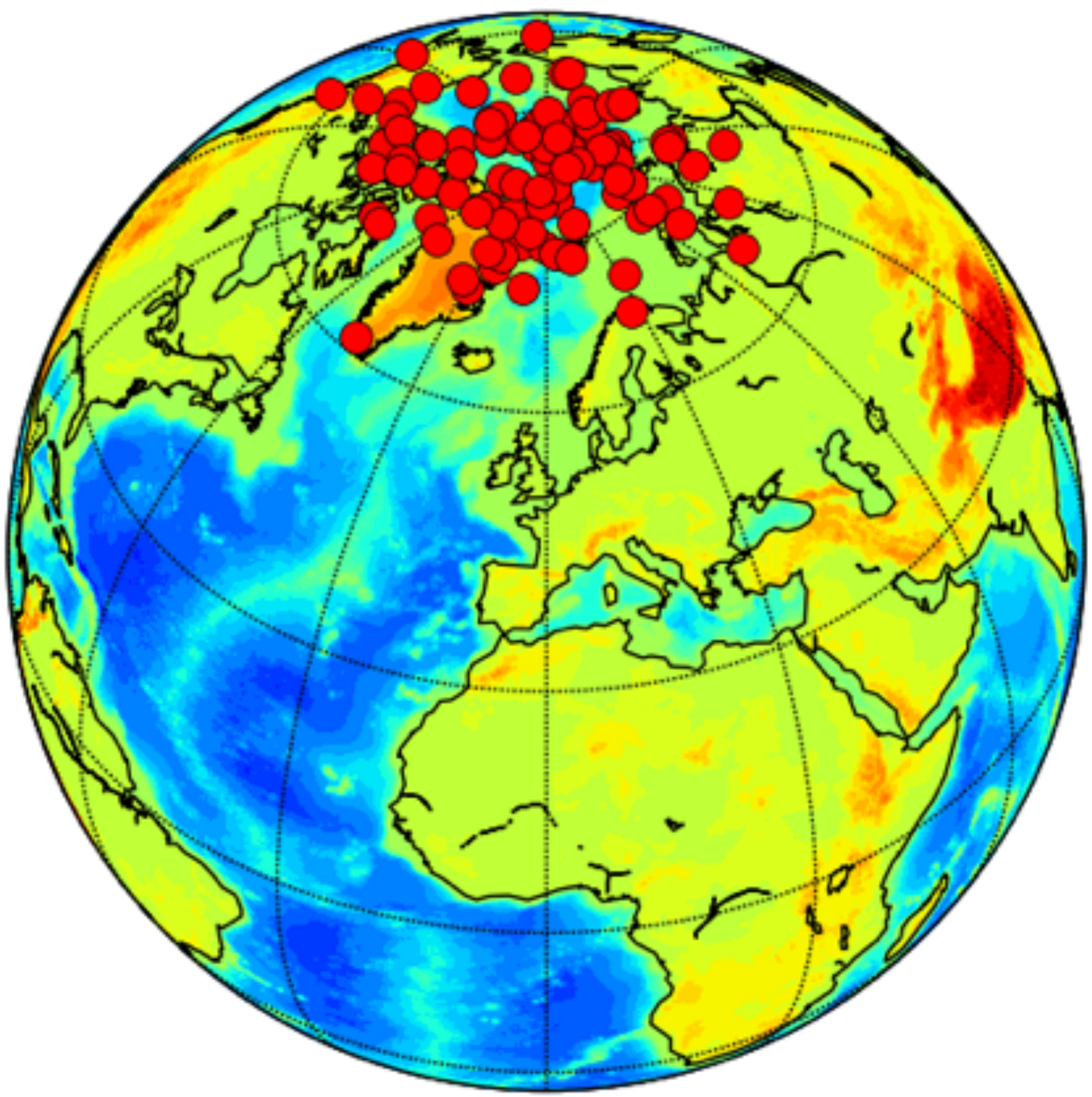
- Brief history of PSV models
- Current status
- Applications in paleomagnetism

Models of PSV: a brief history

- Model “B”: Dipole wobble (Creer et al., 1959)
- Model “A”: non-dipole field (NDF) wobble (Irving and Ward (1963)
- Models “C”, “D”, “E” and “M”: combinations of “A” and “B” type models (summarized by McElhinny & Merrill (1975)
- Model “G”: effect of symmetric and antisymmetric spherical harmonic terms (McFadden et al. (1988)
- “Giant Gaussian Process”: wiggling spherical harmonics (starting with Constable & Parker, 1988)

```
fisher.py -k 35 > dipole_wobble.vgps

plot_map_pts.py -prj ortho -sym ro 10 -eye 45 0 -f dipole_wobble.vgps -rec c -R -B -etp
```



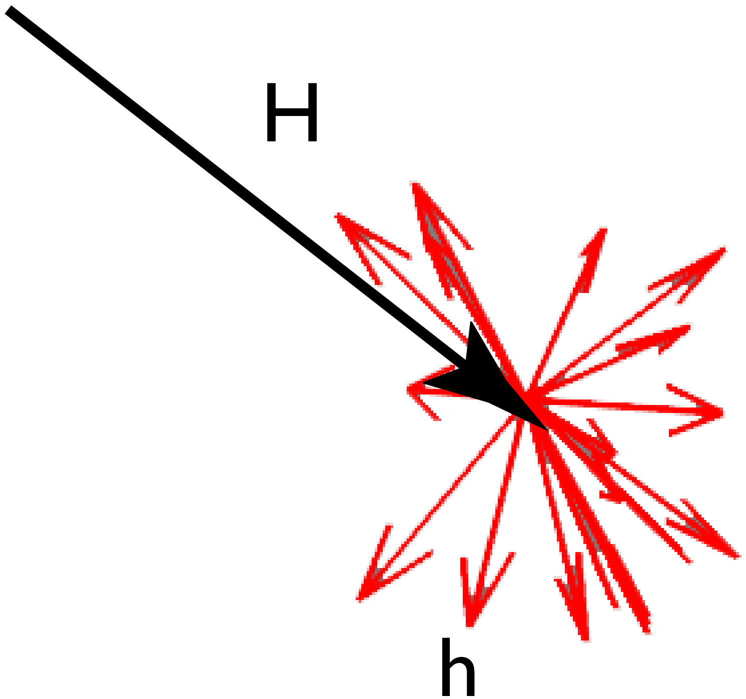
Model “B”:
Dipole wobble
Fisher distributed
set of VGPs with k of 35

Creer (1959, 1962)

Summary for Model "B"

- Model B predicts scatter in directions assuming all PSV comes from a wobbly dipole with k~35
- Directional dispersion decreases with latitude
- would predict that you would see the same pole everywhere at the same time (no westward drift! and no weird lobes)
- no latitudinal dependence of VGP scatter
- directions are not Fisher distributed except at high latitude

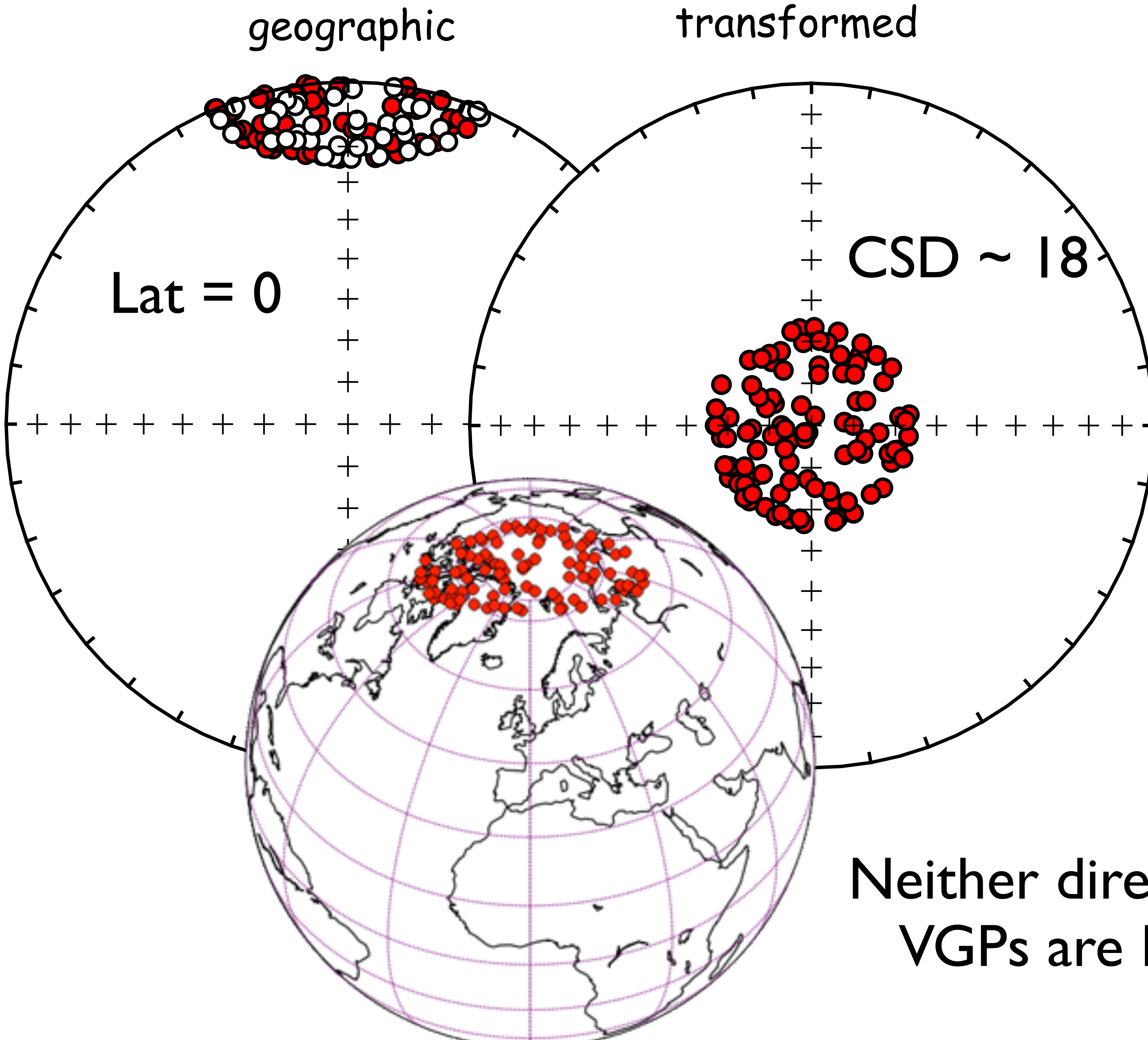
Now for model "A"



Field vector H is perturbed by uniformly distributed h's

h/He ~ 0.4

where He is equatorial field strength

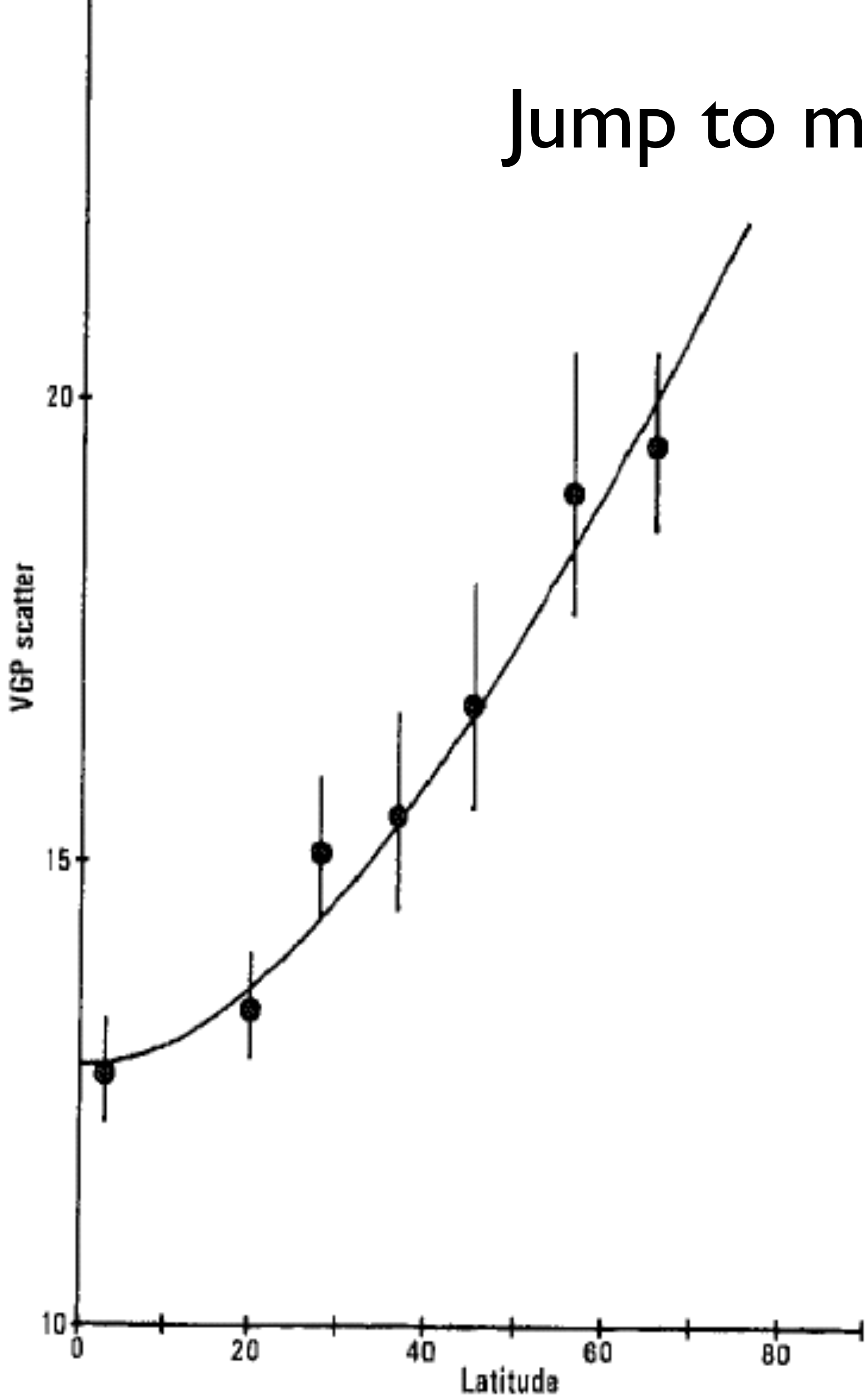


Neither directions, nor VGPs are Fisherian

Summary for Model “A”

- Model A predicts scatter in directions assuming all PSV comes from a perturbed dipole direction with ND component ~0.4 of GAD
- Directional dispersion decreases with latitude
- predicts latitudinal dependence of VGP scatter
- neither directions nor VGPs are Fisherian, but directions ARE circularly symmetric

Jump to model "G"

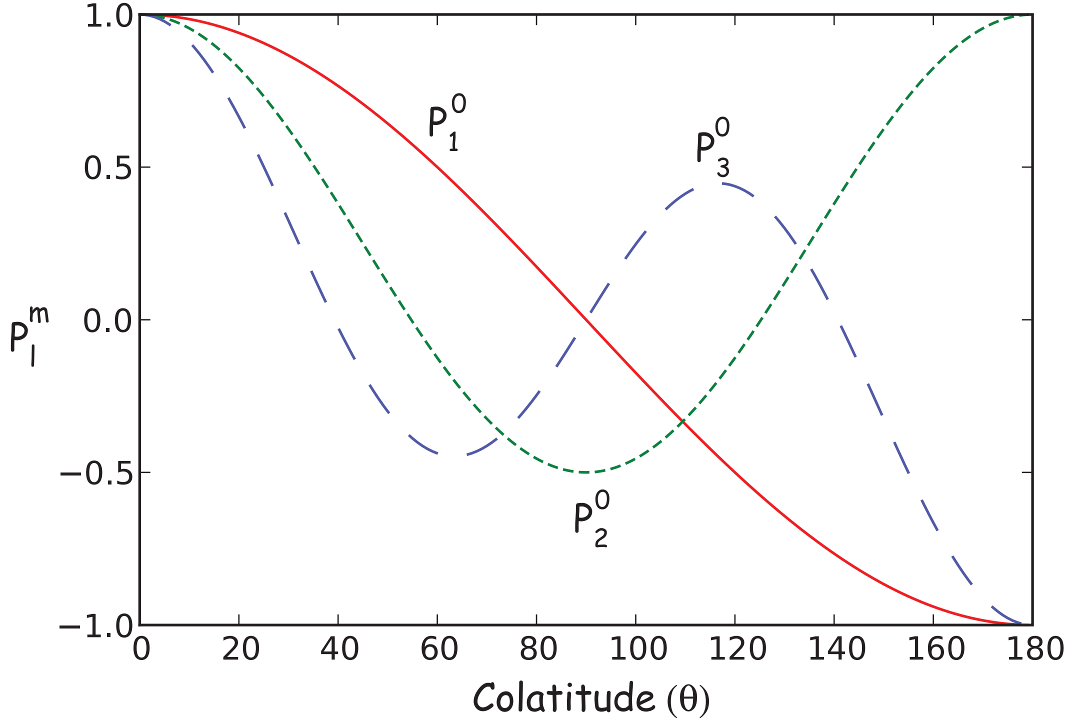


McFadden et al. (1988) re-analyzed lava flow data for last 5 Myr

Used "S" statistic (Eq 11.10 in book)

$$S^2 = \frac{1}{N-1} \sum \Delta_i^2$$

Flashback to Chapter 2: remember the gauss coefficients: g_l^m, h_l^m



l-m odd: antisymmetric about the equator a.k.a "dipole family"

l-m even: symmetric about the equator a.k. "quadrupole family"

- Split scatter in VGPs into that coming from dipole terms (Sd) and that coming from quadrupole terms (Sq)
- M&M ’88 noted that “quadrupole” family terms do not have a strong latitudinal dependence in scatter in associated VGPs while “dipole” family does, so

$$S^2 = (a\lambda)^2 + b^2$$

- a is dipole and b is quadrupole terms - fit to data with a = 0.21 and B=13.5

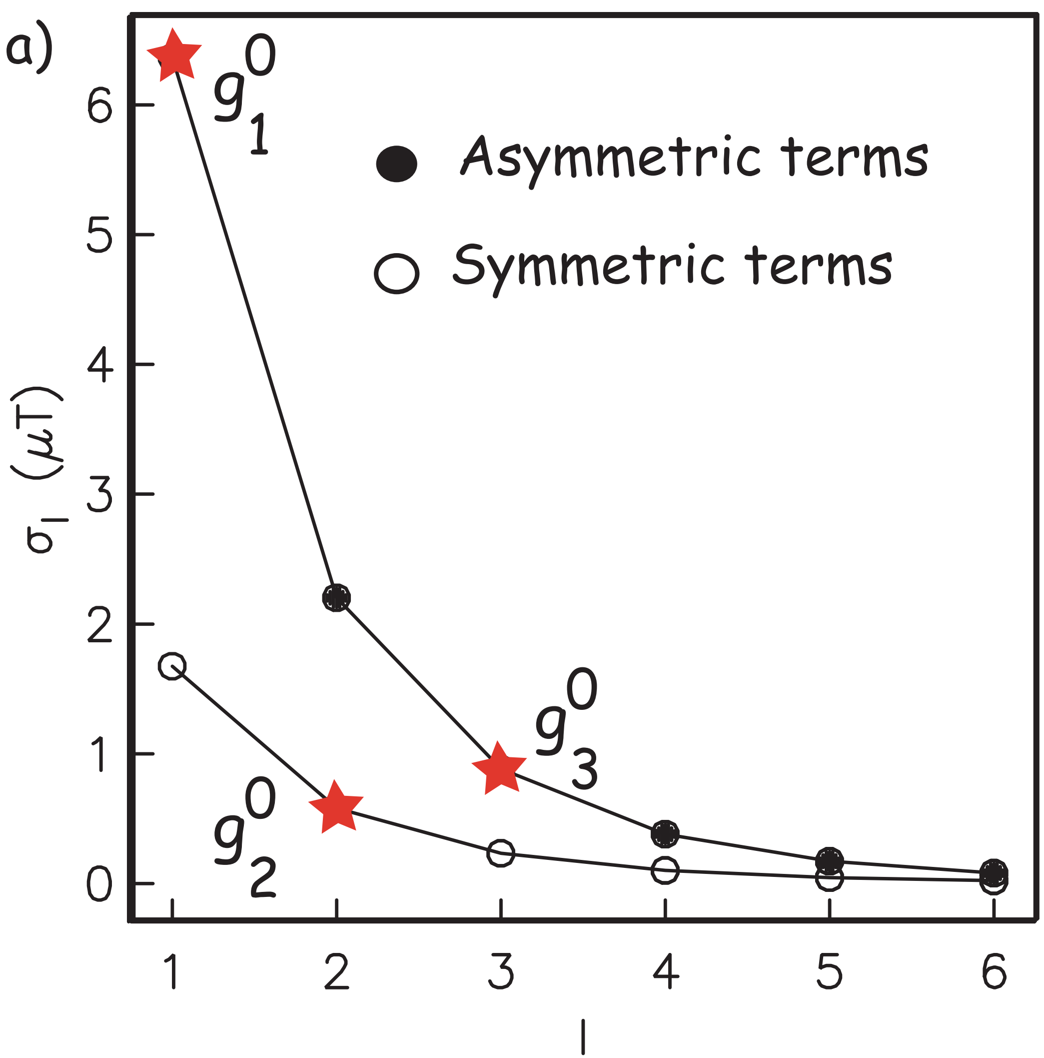
Giant gaussian process type models

- Pioneered by Constable and Parker (1988)
- Generate field models, so can predict directional variations AND intensity variations
- Assumes that all gauss coefficients are normally distributed with standard deviation that varies as an inverse function of degree
- all but axial dipole and quadrupole terms have zero mean

Summary of CP88

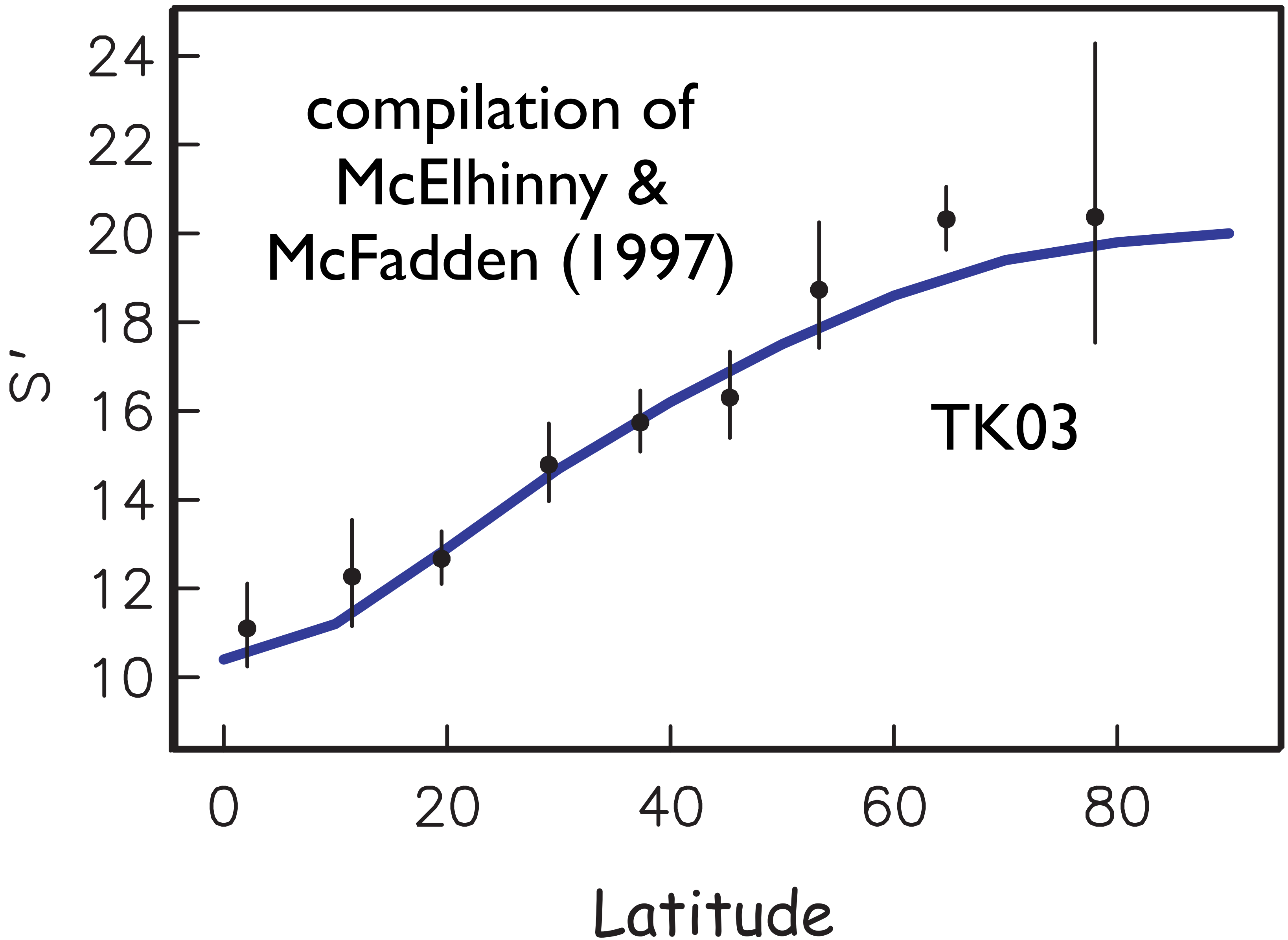
- Does not predict any variation of VGP scatter with latitude
- This was “fixed” in subsequent models by assigning scatter to different terms to fit the data
- Models increasingly ad hoc

Tauxe and Kent (2004) version (TK03)



return to simple variation of sigma versus latitude with one modification: asymmetric terms more scattered by a constant factor β

Scatter of predicted VGP dispersion versus lava flow data



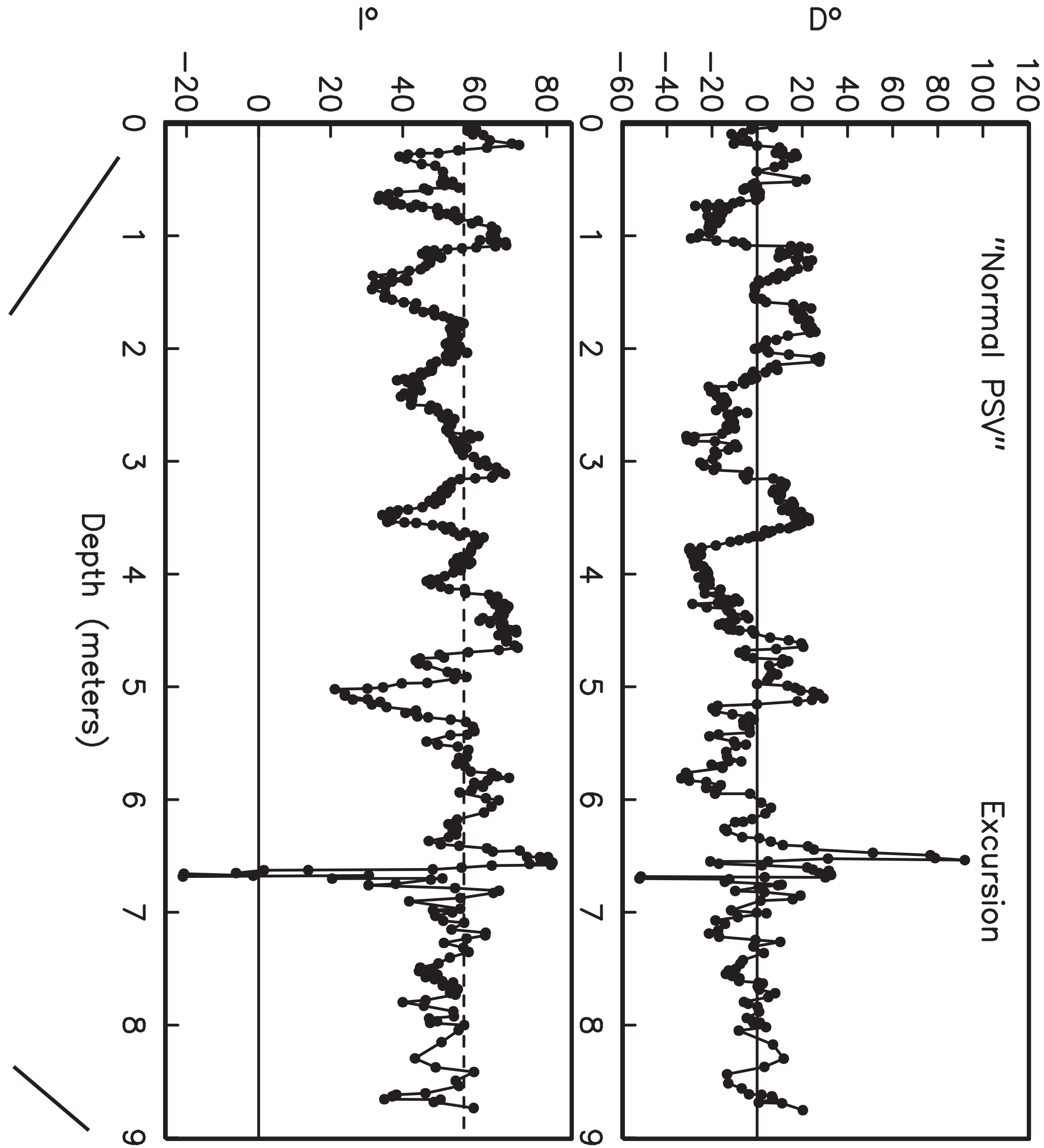
Summary of TK03

- Predicts directions and VGP scatter versus latitude
- Ignores longitudinal variation
- Agrees very well with E/I data throughout Earth history (so far)
- BUT: Underpredicts most recent high southern latitude VGP scatter! (Lawrence et al. 2009) => Cromwell is re-doing it!
- Applications in geology will be discussed in Lecture 16 (stay tuned)

Excursions

A classic example - the Mono Lake excursion

Wilson Creek Beds, Mono Lake

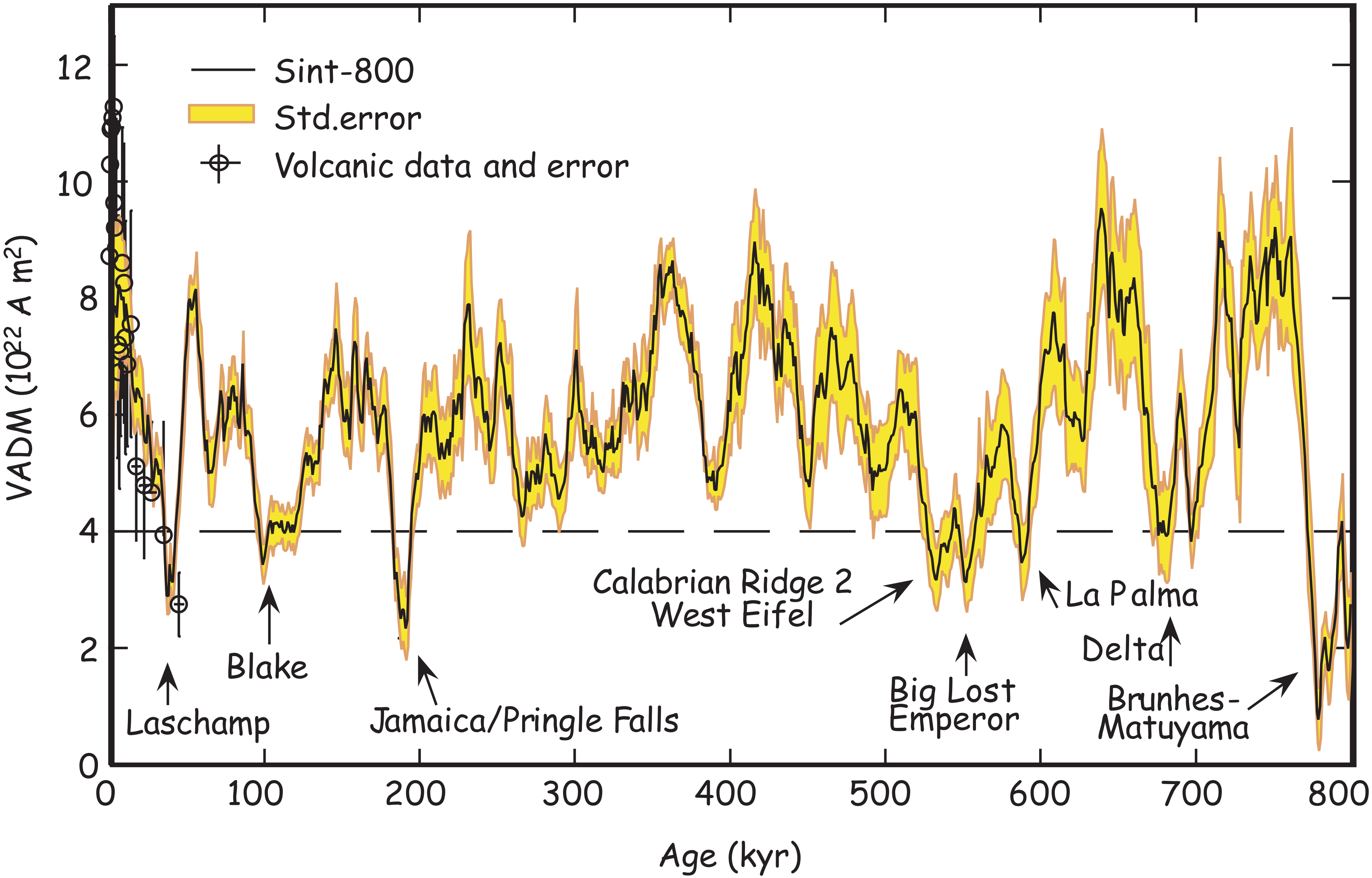


debate over exact age - could be ~30ka or even ~43ka

what are "excursions"?

- Definition varies:
  - original definition was a deviation in directions so - some use directional variation > 45° VGP latitude
  - some recognize lows in field strength
- Are they global or only locally observed?

Laschamp is a globally recognized “DIP” at about 40ka

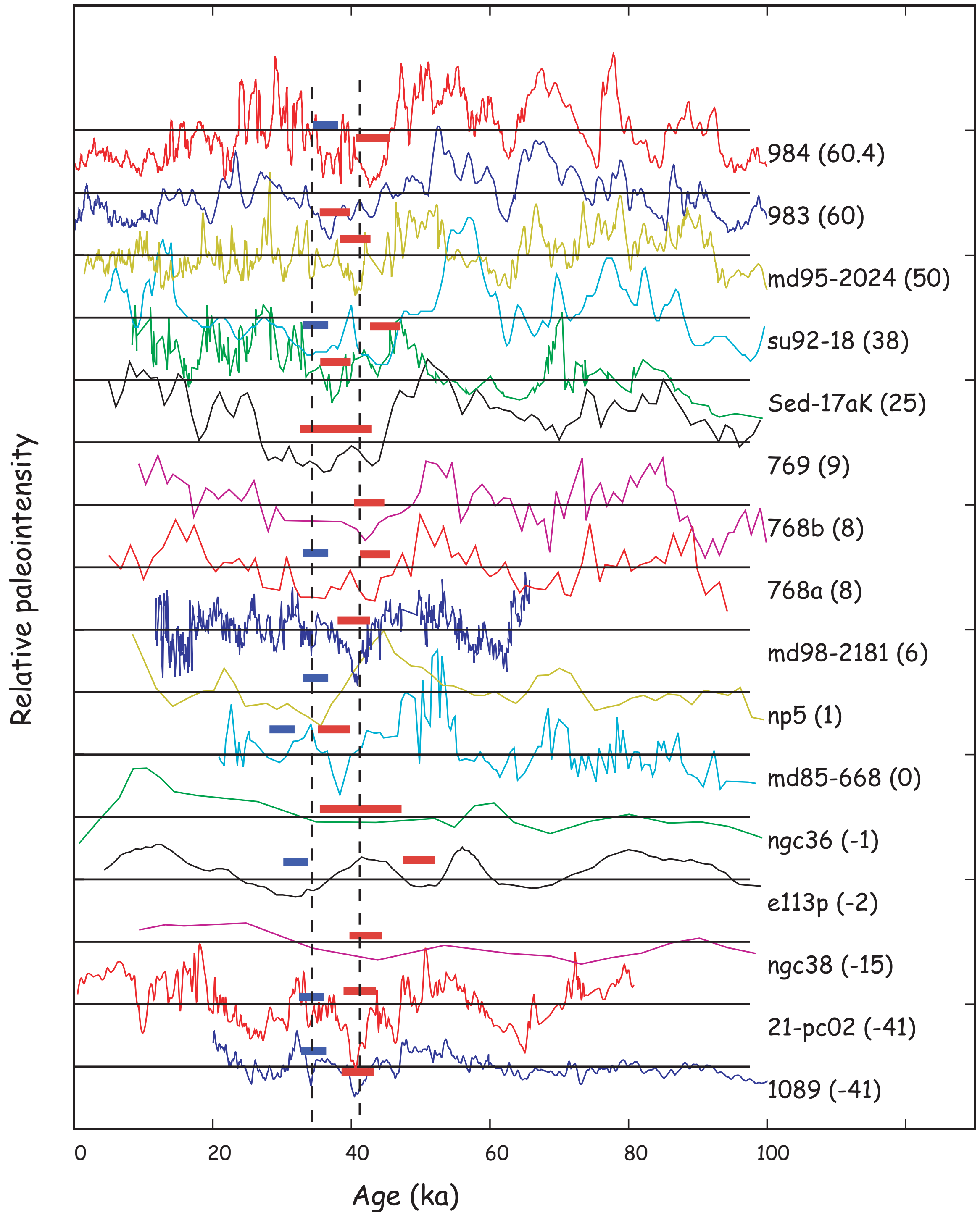


are the Mono Lake and Laschamp different excursions?

- Huge argument over age and precedence
- Are there two excursions (~30 ka and ~40 ka)?
- Chapter 14 looks at lots of different data sets
- The smart money is on the bet that the Mono Lake excursion = Laschamp
- but there might be another one....

Do you see two excursions?

Sometimes yes, sometimes no

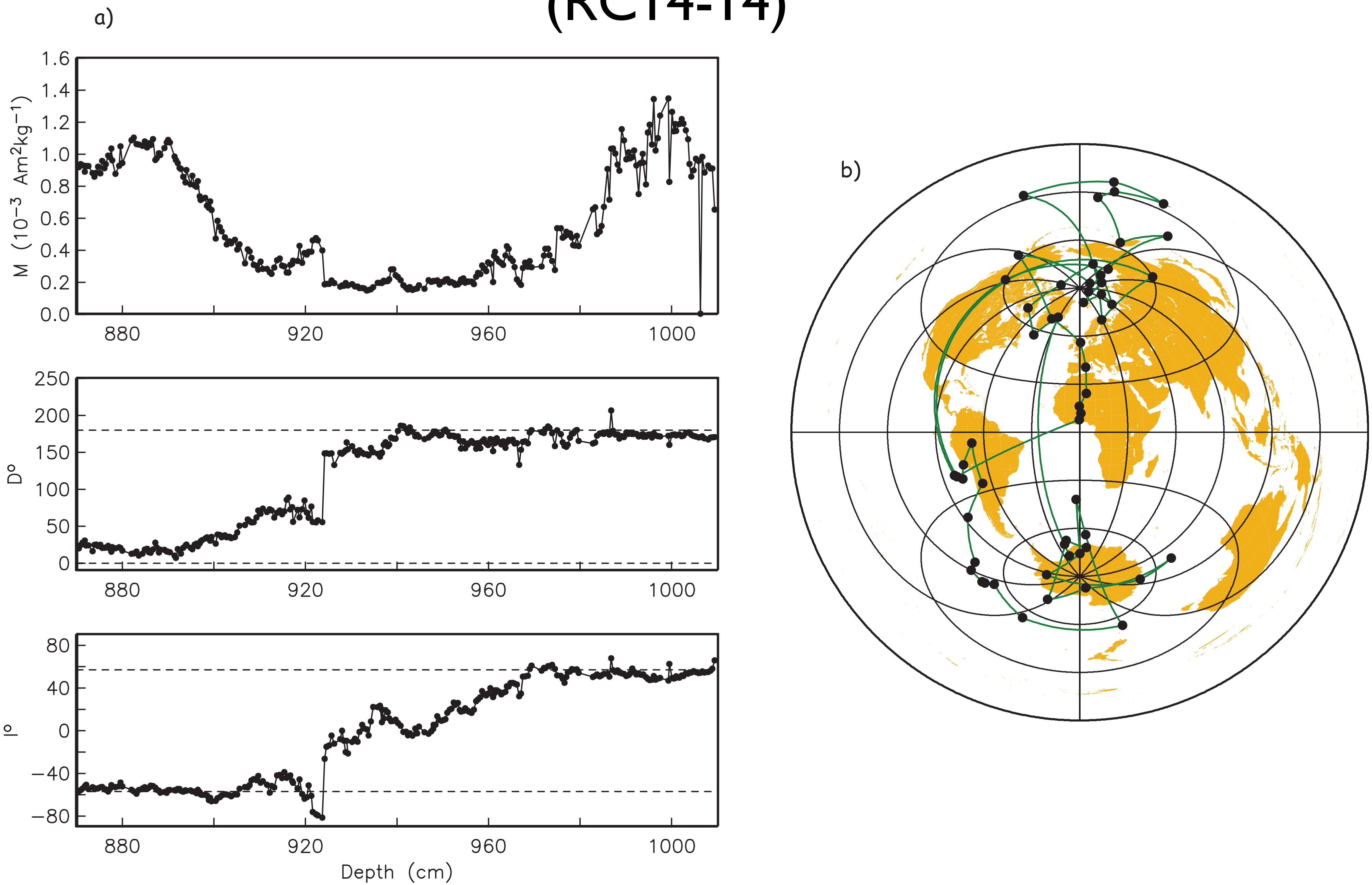


Reversals

Are they real?

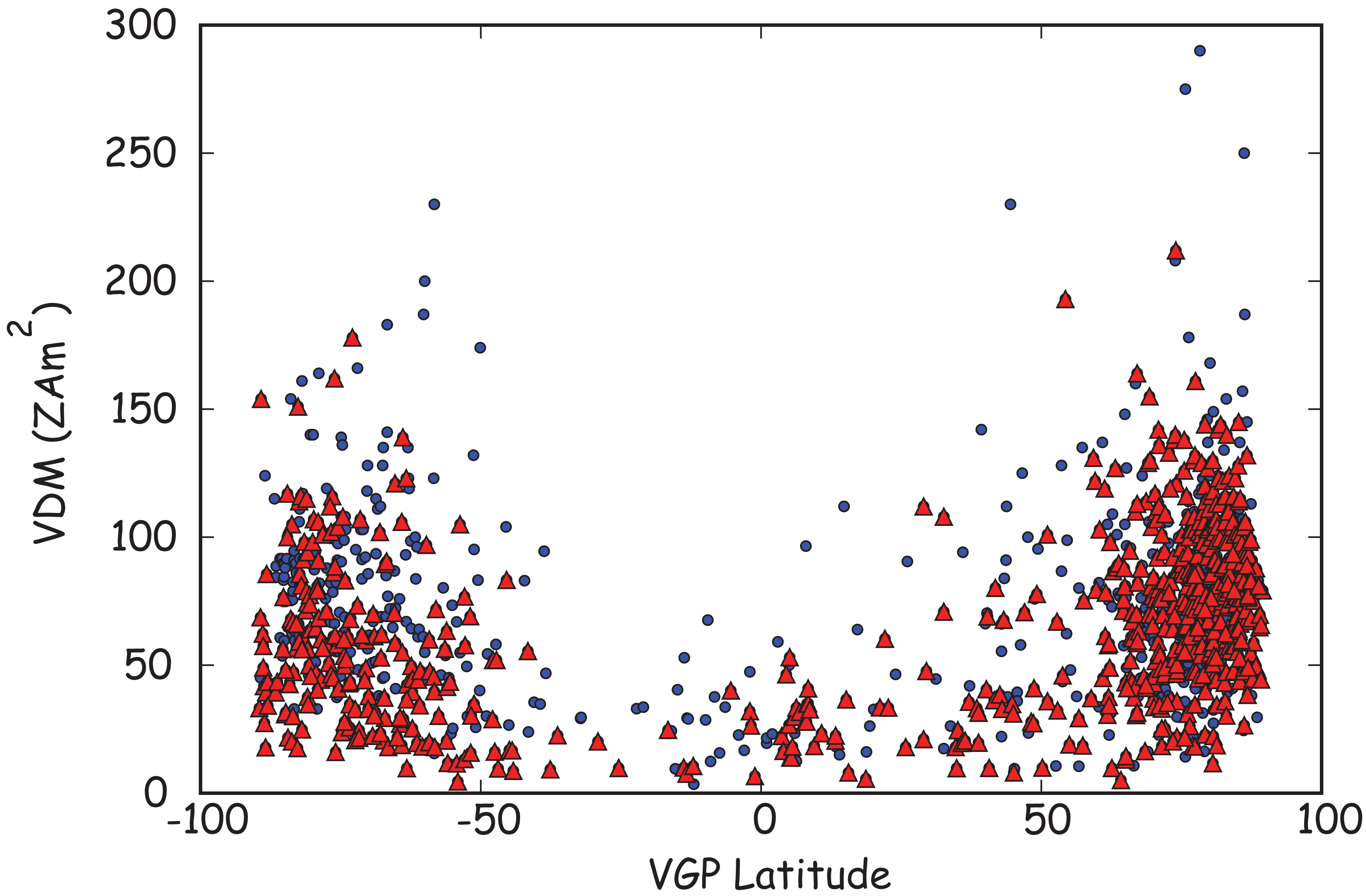
- David (1904) and Brunhes (1906) noticed reversely magnetized rocks
- Mercanton (1926) argued for field reversal because there were reversely magnetized rocks all over the world
- Matuyama (1929) documented a stratigraphically consistent succession in Japan
- Invention of K-Ar dating techniques settled the matter (Cox et al. 1963; McDougall & Tarling, 1963)

Classic example from deep-sea sediment core (RC14-14)



What happens during reversal?

- Huge arguments
  - duration (100s to 1000s of years)
  - rates of change?
  - field structure (dipolar, multipolar, preferred VGP paths?)
  - cause (growth of “flux patches”...)
- Substantial agreement over
  - when (the geomagnetic polarity time scale)
  - field strength is always low


300
250
200
150
100
50
0
-100
-50
0
50
100
VDM (ZAm^2)
VGP Latitude