

Scheinbare Pollage

VGP = Virtual Geomagnetic Pole

- Aus der Magnetisierungsrichtung (D_0 , I_0) kann die Lage des Pols relativ zum Ort, wo die Proben entnommen wurden, berechnet werden.
- Aus der Inklination I lässt sich die **Polentfernung p** berechnen.
Der Pol liegt auf einem Kreis mit Radius p um die Probenlokalität.
- Aus der Deklination D definiert man eine Richtung entlang einem Grosskreis. **Der paläomagnetische Pol liegt dort, wo der Grosskreis den Kleinkreis schneidet.**

Scheinbare Pollage

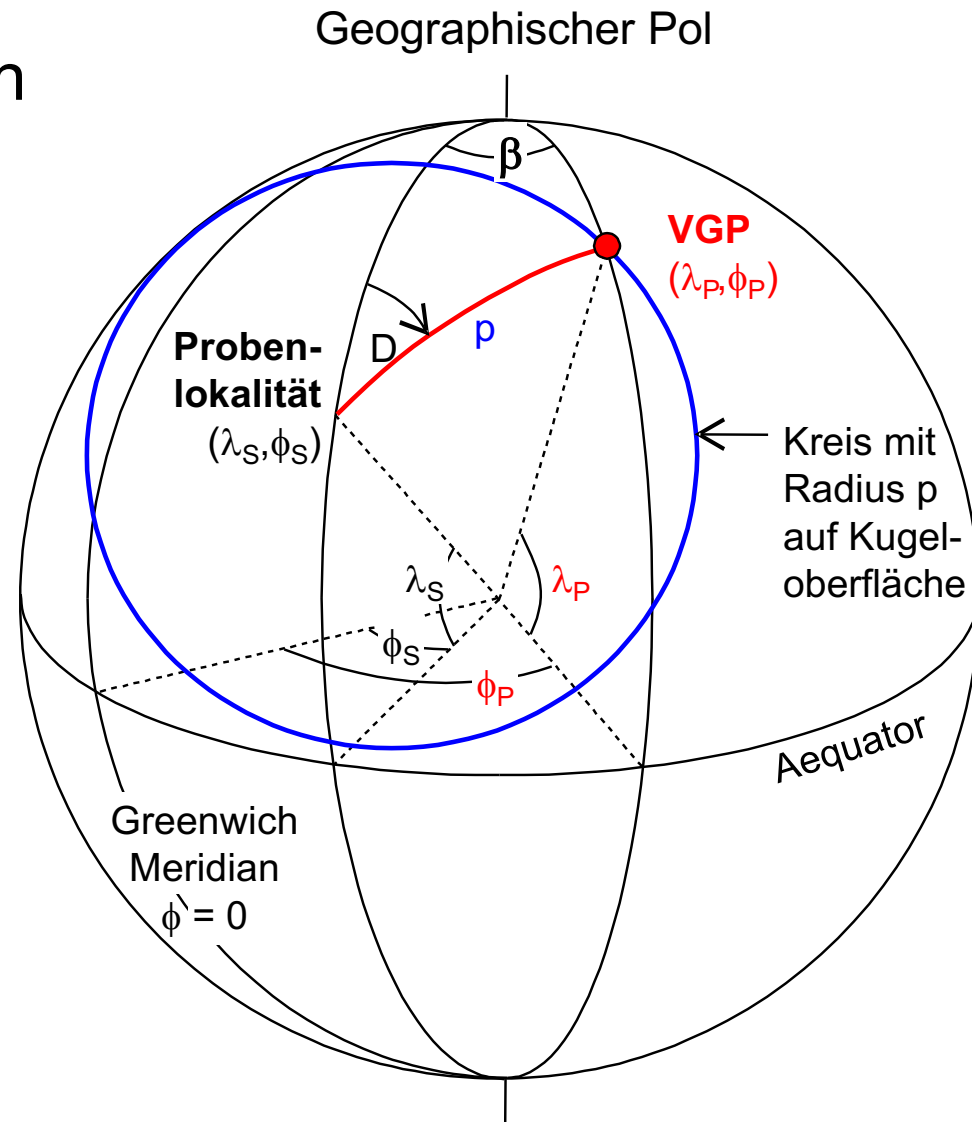
VGP = Virtual Geomagnetic Pole

Bestimmung der scheinbaren paläomagnetischen Pollage (virtual geomagnetic pole, VGP)

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

p = Polentfernung

$$\tan p = 2 / \tan I$$



Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

- Gesteine unterschiedlichen Alters auf demselben Kontinent liefern unterschiedliche VGP: verbindet man diese, entsteht eine **scheinbare Polwanderungskurve (APWP)**.
- **Jeder Kontinent hat eine eigene APWP**: Dies widerspiegelt die Bewegung des Kontinents relativ zum Pol.
- Die Kontinente werden auf der zugehörigen Platte bewegt. Relativbewegungen der Platten zueinander geben unterschiedliche APWP-Kurven.
- Dies ermöglicht die **Rekonstruktion früherer Plattenbewegungen** durch die Zusammenlegung der APWP-Kurven („Kontinentaldrift“).

Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

Beispiele:

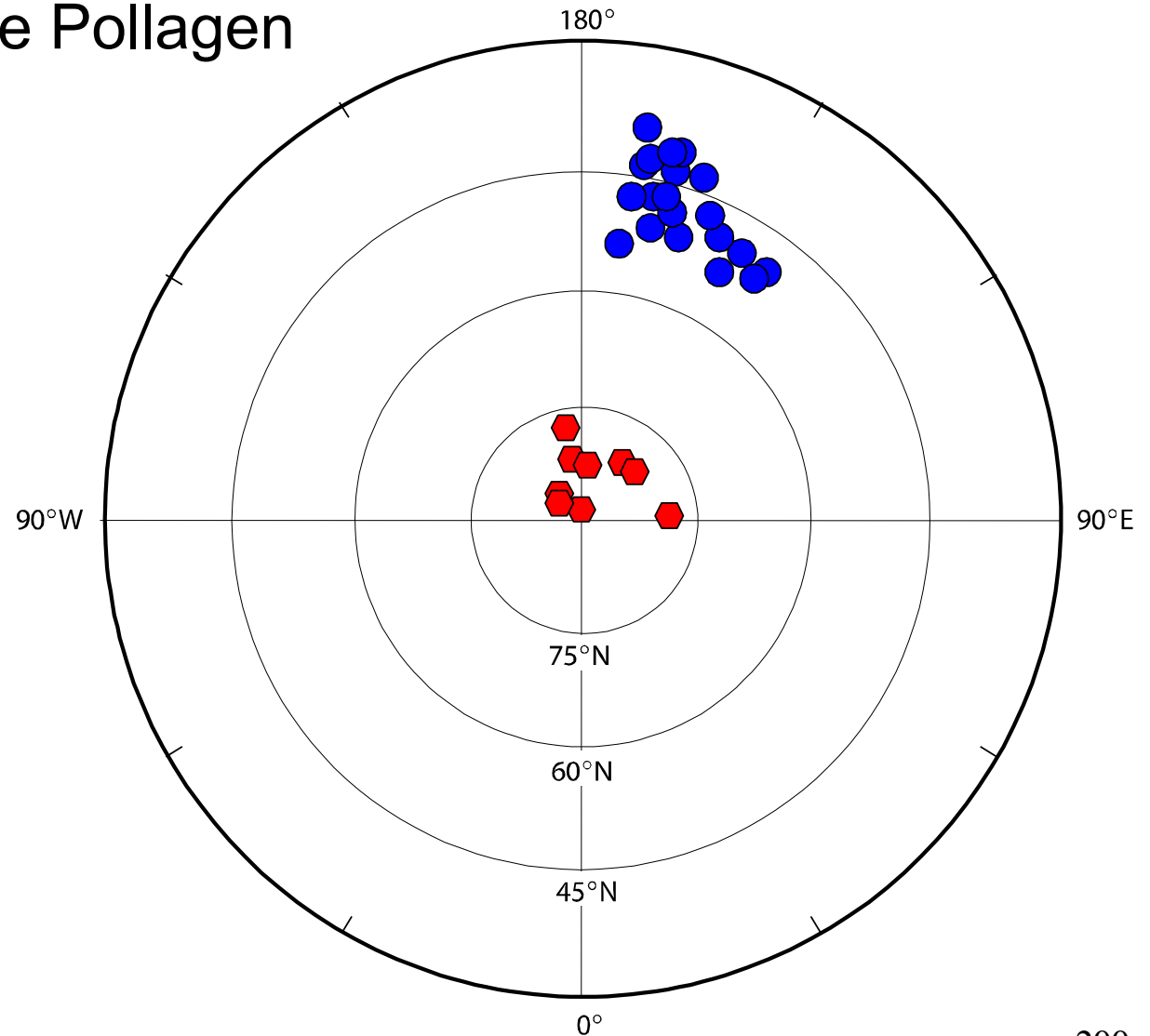
1. Junge **VGP für Europa** gruppieren sich um die Rotationsachse. Permische VGP für Europa liegen nahe des Äquators >>> entweder lag die Rotationsachse im Perm beim heutigen Äquator, oder Europa hat sich relativ zur Rotationsachse bewegt.
2. **Paläomagnetische Daten aus Europa und Nordamerika geben deutlich verschiedene APWP-Kurven**: Bewegungen der Kontinente relativ zur Rotationsachse (da es nur eine Rotationsachse gibt, können nicht zwei unterschiedliche und gleichzeitige Verschiebungen der Drehachse stattgefunden haben).
>>> Zusammenlegung der APWP-Kurven ergibt Position Europas und Nordamerikas im Perm.

Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

Beispiel 1: Europäische Pollagen

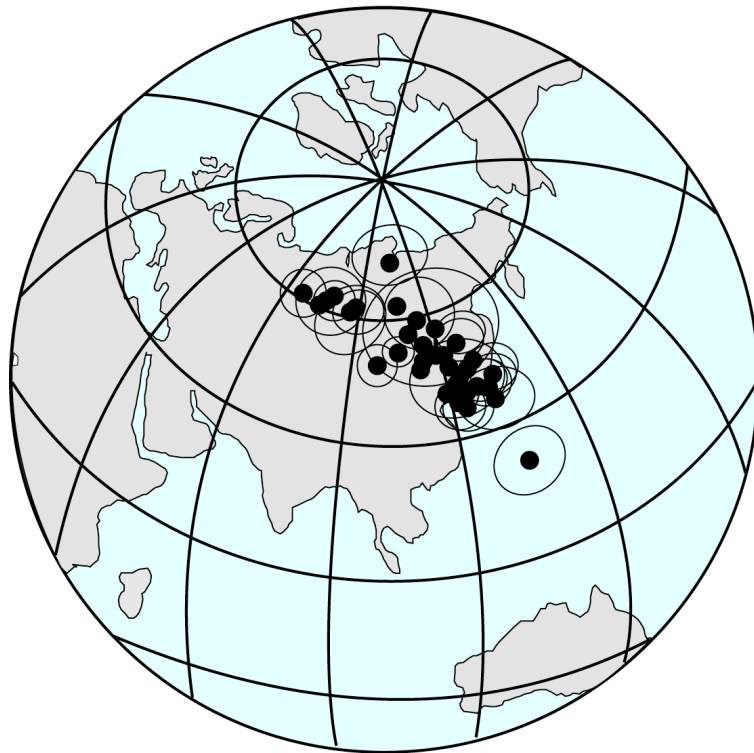
- ◆ Pliozän und Pleistozän
- Perm



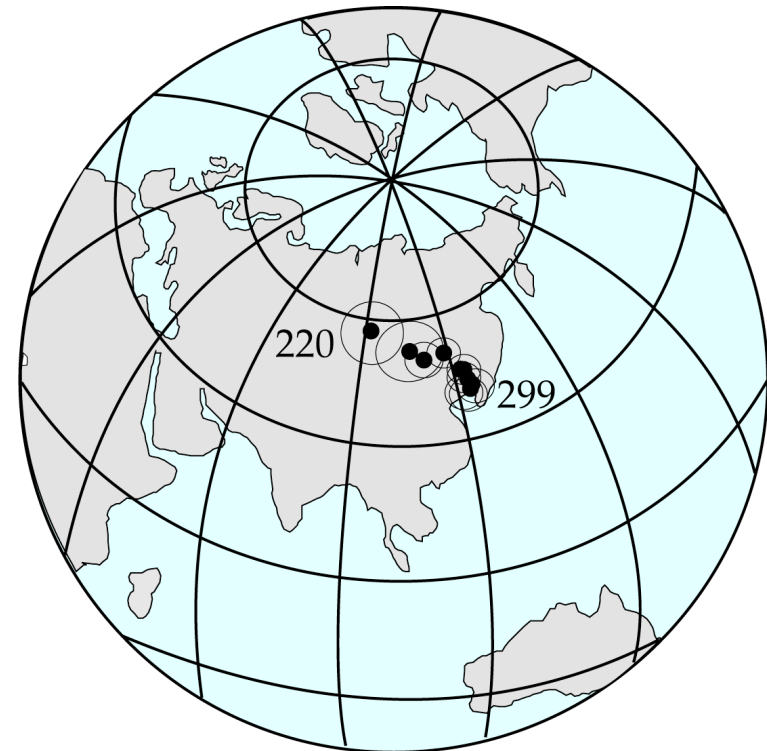
Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

Apparent Polar Wander Path



Referenzpole mit $\delta\lambda$ and $\delta\phi$

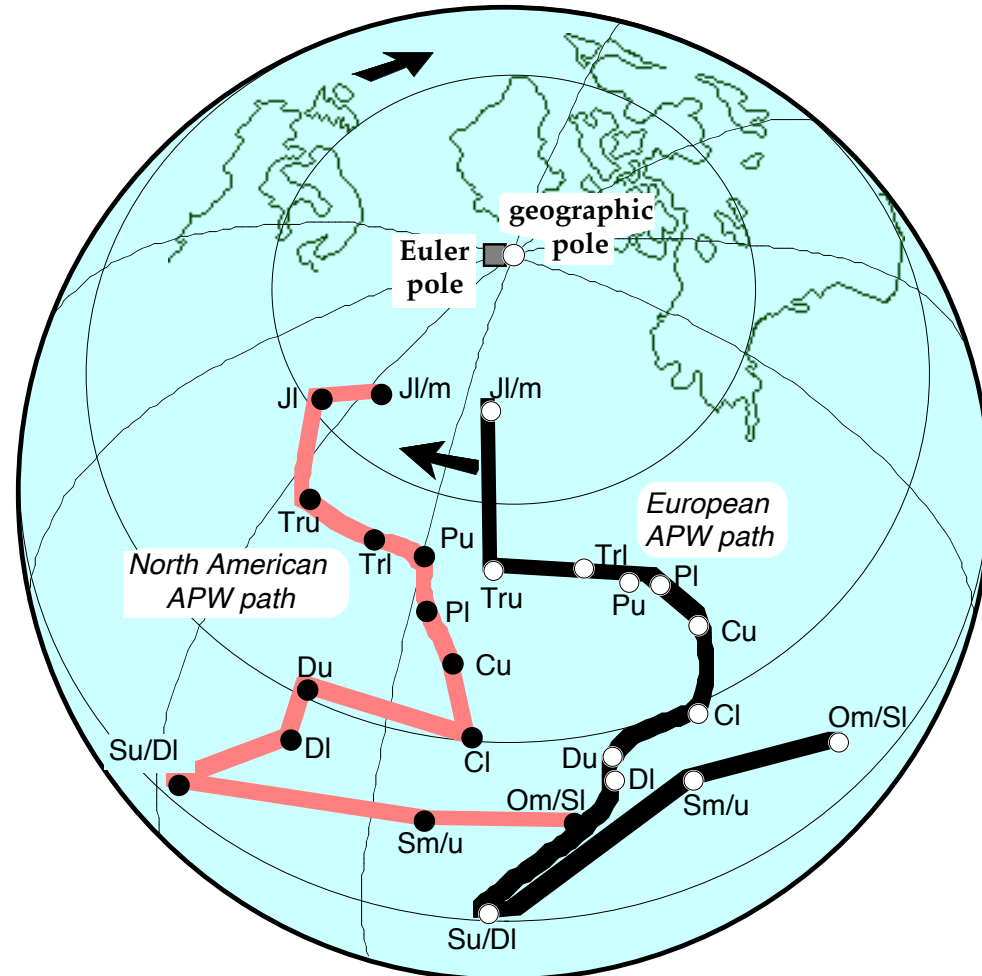


Zeitgemittelter Polwanderungsweg

Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

Beispiel 2: Scheinbare
Polwanderungskurven
Europas und
Nordamerikas

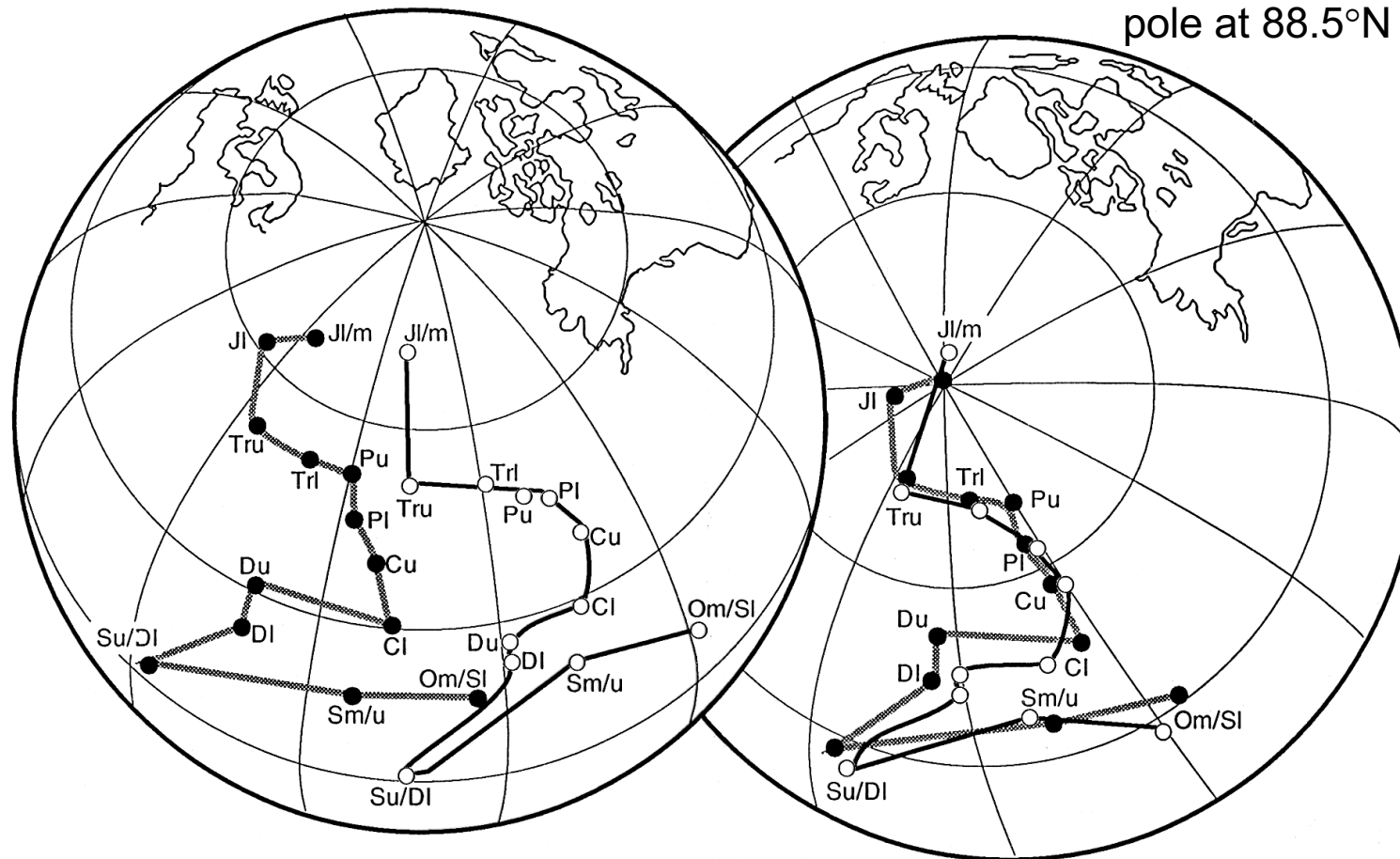


Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

Beispiel 2: Scheinbare Polwanderungskurven Europas und Nordamerikas

After rotating Europe by 38° clockwise about the Euler pole at 88.5°N 27.7°E



Scheinbare Polwanderungskurven

APWP = Apparent Polar Wander Path

Beispiel 3 & 4:

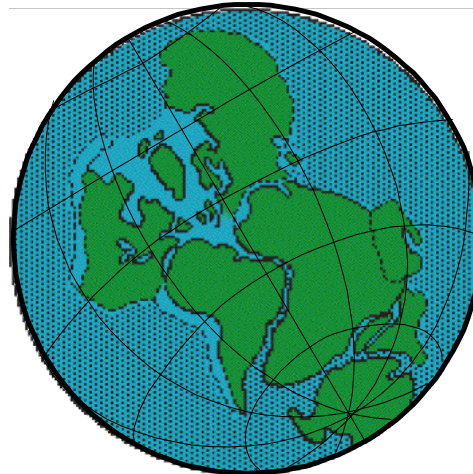
- Vor-kretassische paläomagnetische Daten aus **Afrika, Südamerika, Indien, Australien und der Antarktis** sind nur kompatibel zueinander, wenn diese Kontinente (d.h. Platten) zusammengelegt werden >>> **Superkontinent Gondwana**.
- Paläomagnetische Euler'sche Pole (PEP Modelle): die paläomagnetischen Pole liegen entlang einem APWP, der einem Kleinkreis folgt welcher auch um den Euler'schen Pol zentriert ist.

Paläomagnetismus und Plattentektonik

Mitteldevon 375 Ma



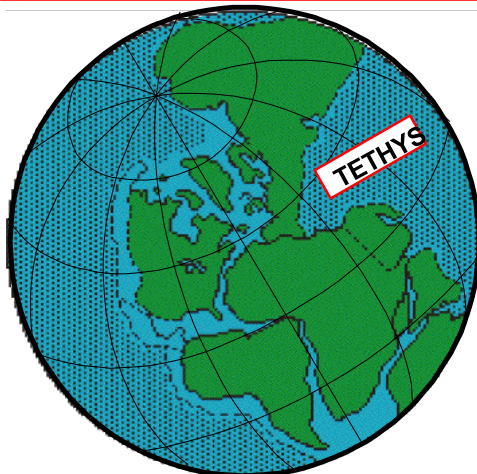
Spätkarbon 300 Ma



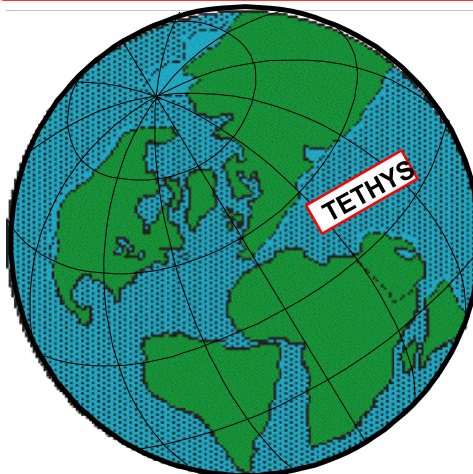
Frühperm 250 Ma



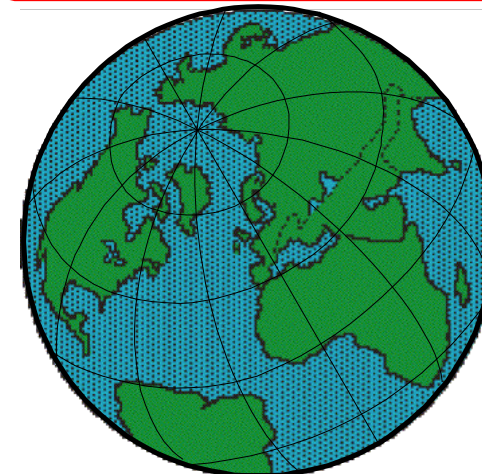
Frühjura 175 Ma



mittlere Kreide 100 Ma

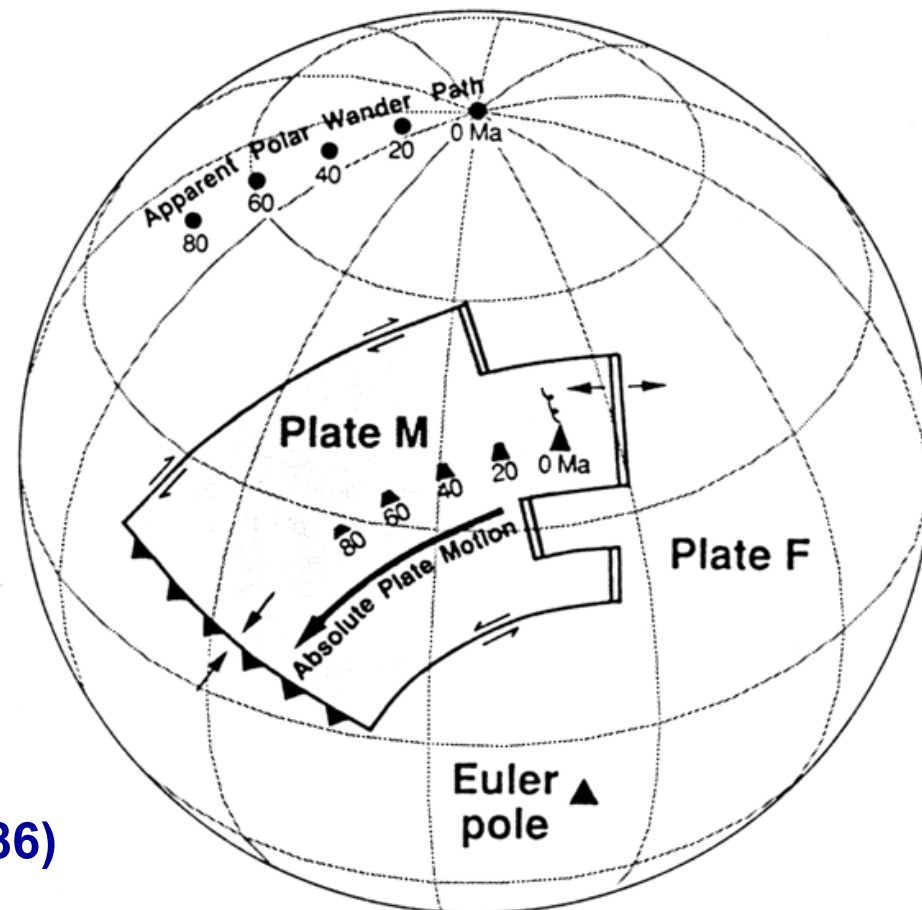


Mitteltertiär 25 Ma



Paläomagnetismus und Plattentektonik

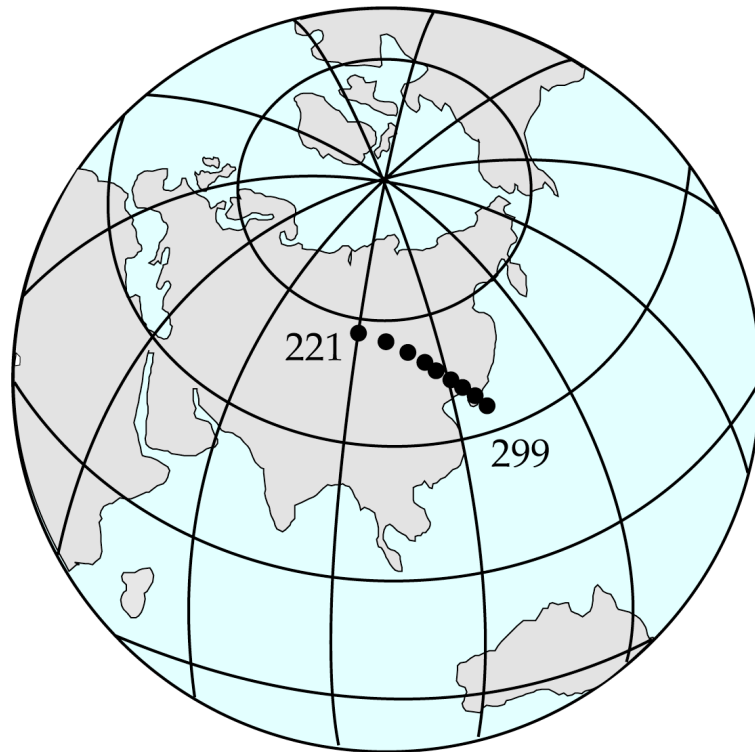
Scheinbare Polwanderungskurve: Euler'sche Rotation (PEP)



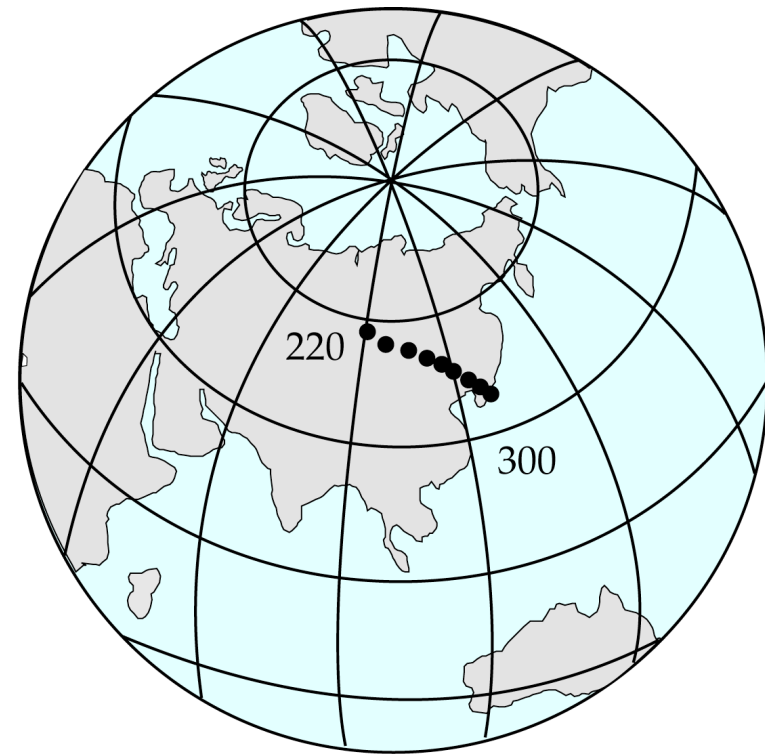
Cox & Hart (1986)

Paläomagnetismus und Plattentektonik

Scheinbare Polwanderungskurve: Euler'sche Rotation (PEP)



Euler'scher Weg nach Gordon (1984)



Kleinkreis-Weg
(Stamatakos et al., 1996)

Paläomagnetismus und Plattentektonik

Untersucht man den **Paläomagnetismus innerhalb eines Kontinentes**, so erhält man wertvolle Informationen zur **Tektonik**. Dazu benötigt man eine APWP-Kurve, um Referenzrichtungen (bzw. Referenzpole) zu berechnen.

- **Deklinationsabweichung** vom Referenzwert >>> tektonische Rotation.
- **Inklinationsabweichung** vom Referenzwert >>> Breitenänderung infolge tektonischer Verschiebung.

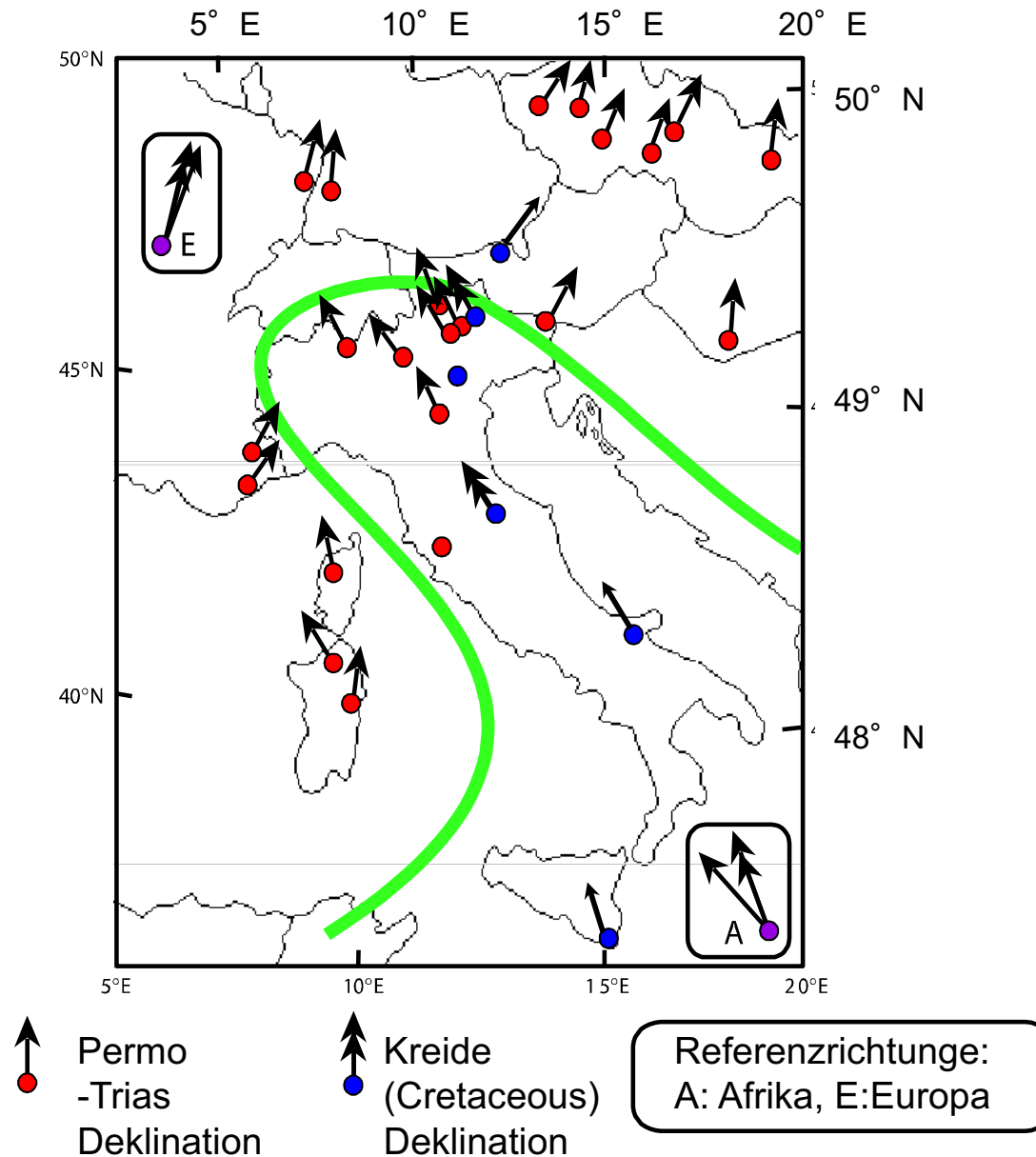
Paläomagnetismus und Plattentektonik

Beispiel:

Europa und der Mittelmeerraum:

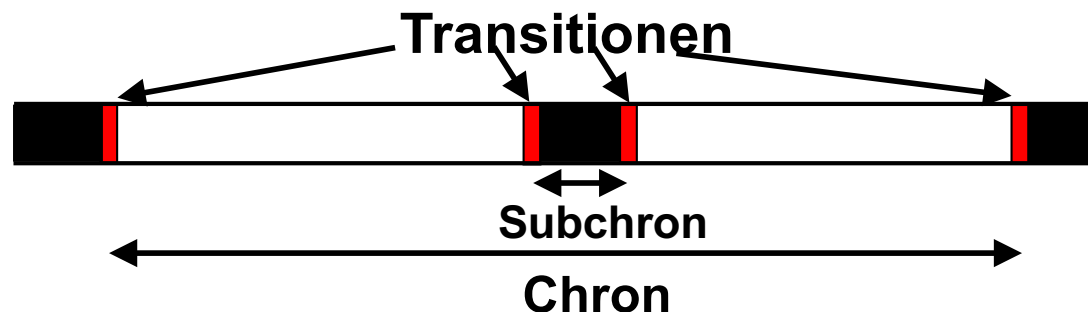
- In Zentraleuropa **nördlich der Alpen** sowie in Frankreich westlich der Alpen findet man **konsistente Deklinationen nach \pm Nordosten**, unabhängig vom Alter (die entsprechenden Inklinationen sind unterschiedlich wegen des APWPs).
- **Südlich der Alpen**, in Italien und Sardinien-Korsika, beobachtet man **Deklinationen nach Nordwesten**.
- Interpretation: **Rotation der italienischen Halbinsel im Gegenuhrzeigersinn relativ zu Europa**. Die italienischen paläomagnetischen Daten haben eine afrikanische Herkunft. Die italienische Halbinsel ist ein Sporn der afrikanischen Platte (Adria).

Paläomagnetismus und Plattentektonik



Geomagnetische Polarität

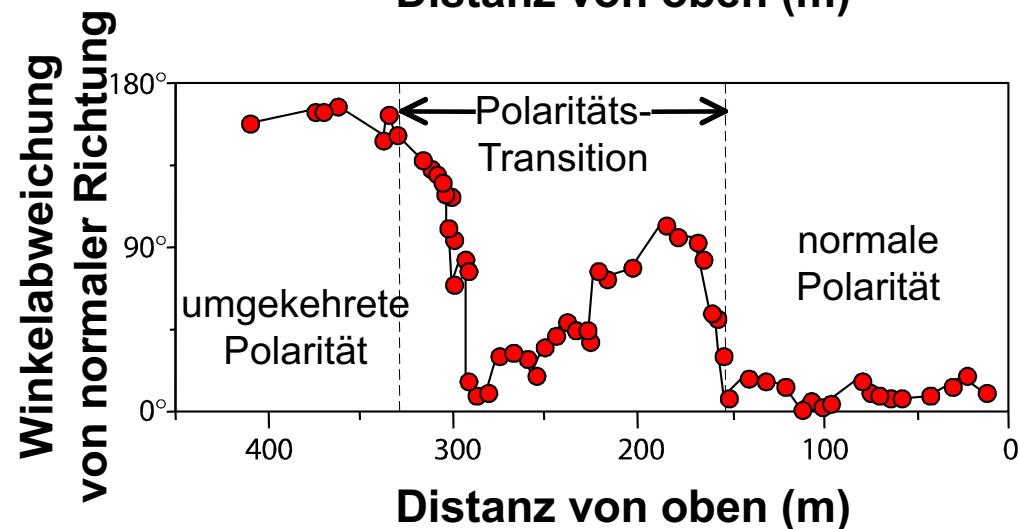
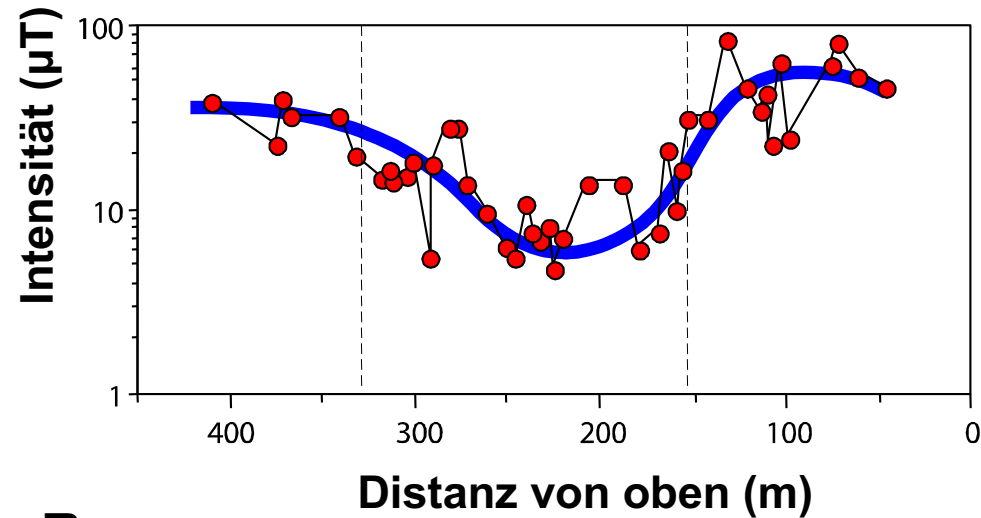
- Beobachtungen an radiometrisch datierten Laven sowie an Tiefseesedimenten zeigen, dass eine **Umkehrung der Polarität ungefähr 3'500 – 5'000 Jahre dauert (Transition)**.
- Die Polarität bleibt dann für längere Zeit konstant.
- Polaritätsintervalle:
 - Chrons** ($\approx 100'000 - 10'000'000$ Jahre)werden unterbrochen durch:
 - Subchrons** ($\approx 10'000 - 100'000$ Jahre)
- Gelegentlich wandert der magnetische Pol in intermediären Breiten ($50^\circ \text{ S} \leq \lambda \leq 50^\circ \text{ N}$). Solch ein Ereignis wird **Exkursion** genannt (Dauer 5'000 – 10'000 Jahre).



Geomagnetische Polarität

Steens Mountain (Oregon), Miozän Polumkehrung

Logarithmic
Scale !



Judith Edelman

Album: Clear Glass Jar (2009)

It's the buzz when I'm full
Of your sweet magnetic pull
It's the tug that I crave
It's how opposites behave
Is electricity all there is to you and me?
In the field, in the field
Where the static is revealed
If the north isn't true
Will I lose my way to you?
Is electricity all there is to you and me?

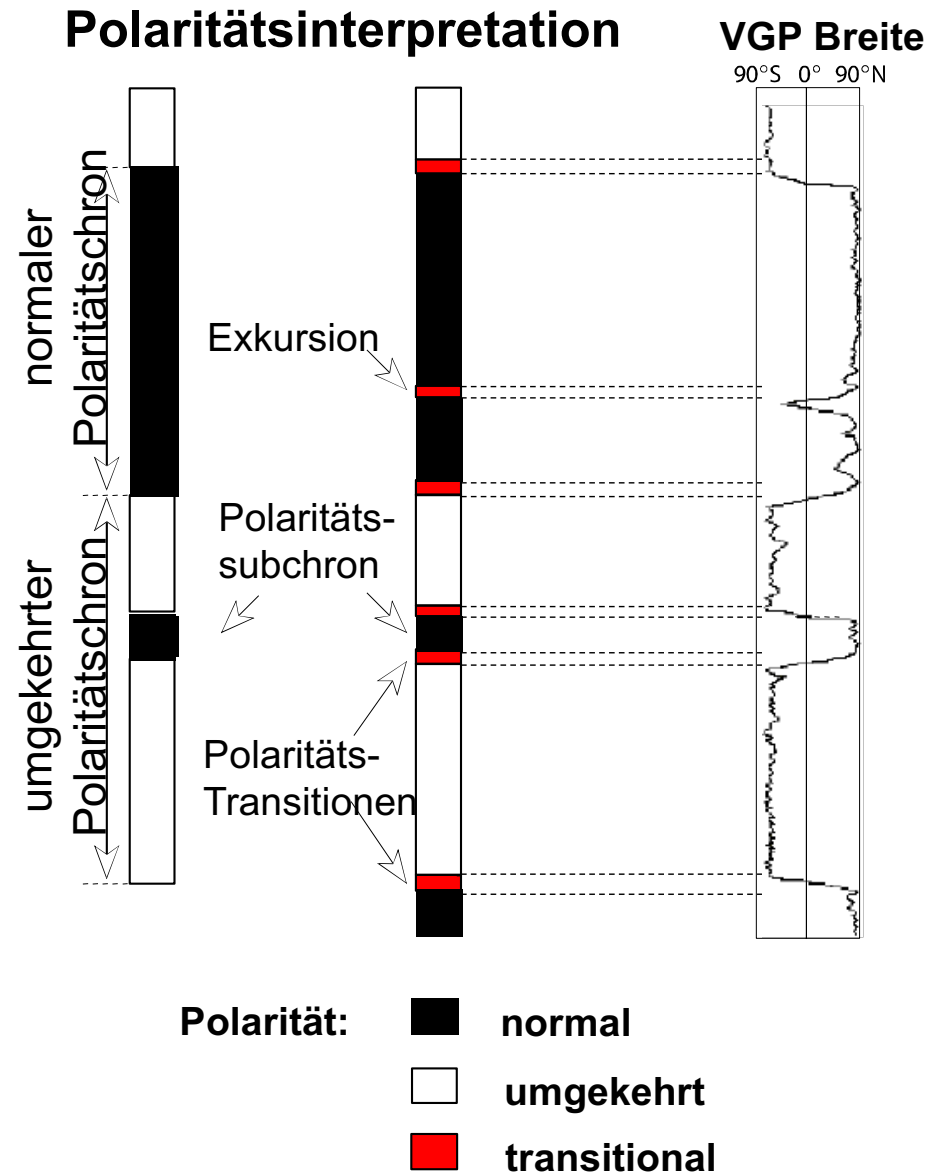
Chorus:

What's gonna happen when the magnetism fades?
Will we burn up one bright day?
Will the aurora borealis give us one last show?
You can't leave love to science when you go.
In the deep molten heart
Where these strange attractions start
If we are passionate
Will this rock remember it?
Is electricity all there is to you and me?

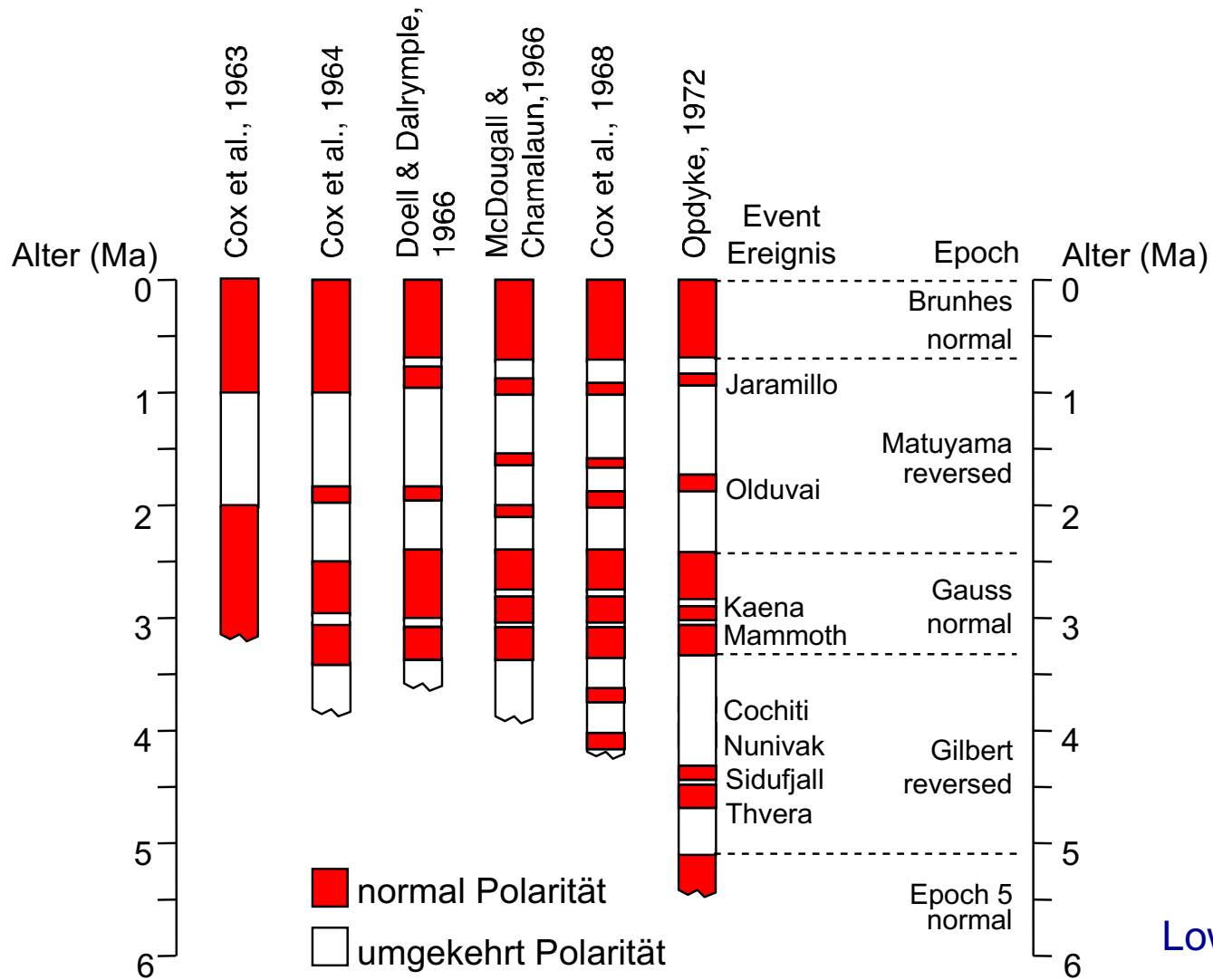
Magnetische Zeitskala

- Polaritätsuntersuchungen in radiometrisch datierten Gesteinen liefern die **Polaritätsgeschichte** zu jedem Zeitpunkt **der letzten 5 Mio Jahre**.
- **Bestätigung der gleichen Polaritätsabfolge in Tiefseesedimenten** (unterschiedlicher Magnetisierungsmechanismus, pDRM statt TRM) schliesst aus, dass es sich um ein mineralogisches Phänomen handelt.

Magnetische Zeitskala



Magnetische Zeitskala

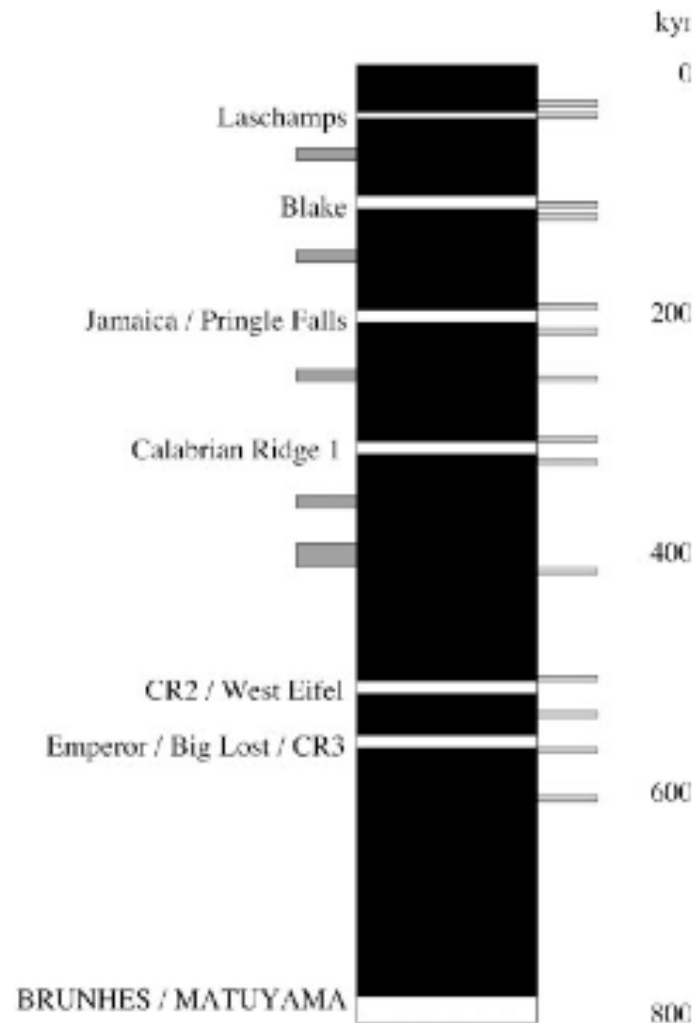


Lowrie, 1997

Gradual refinement of time scale

More excursions in the Brunhes

Global events
(Langereis et al, 1997)



Events seen in 4
Atlantic marine cores
(Lund et al, 1998)

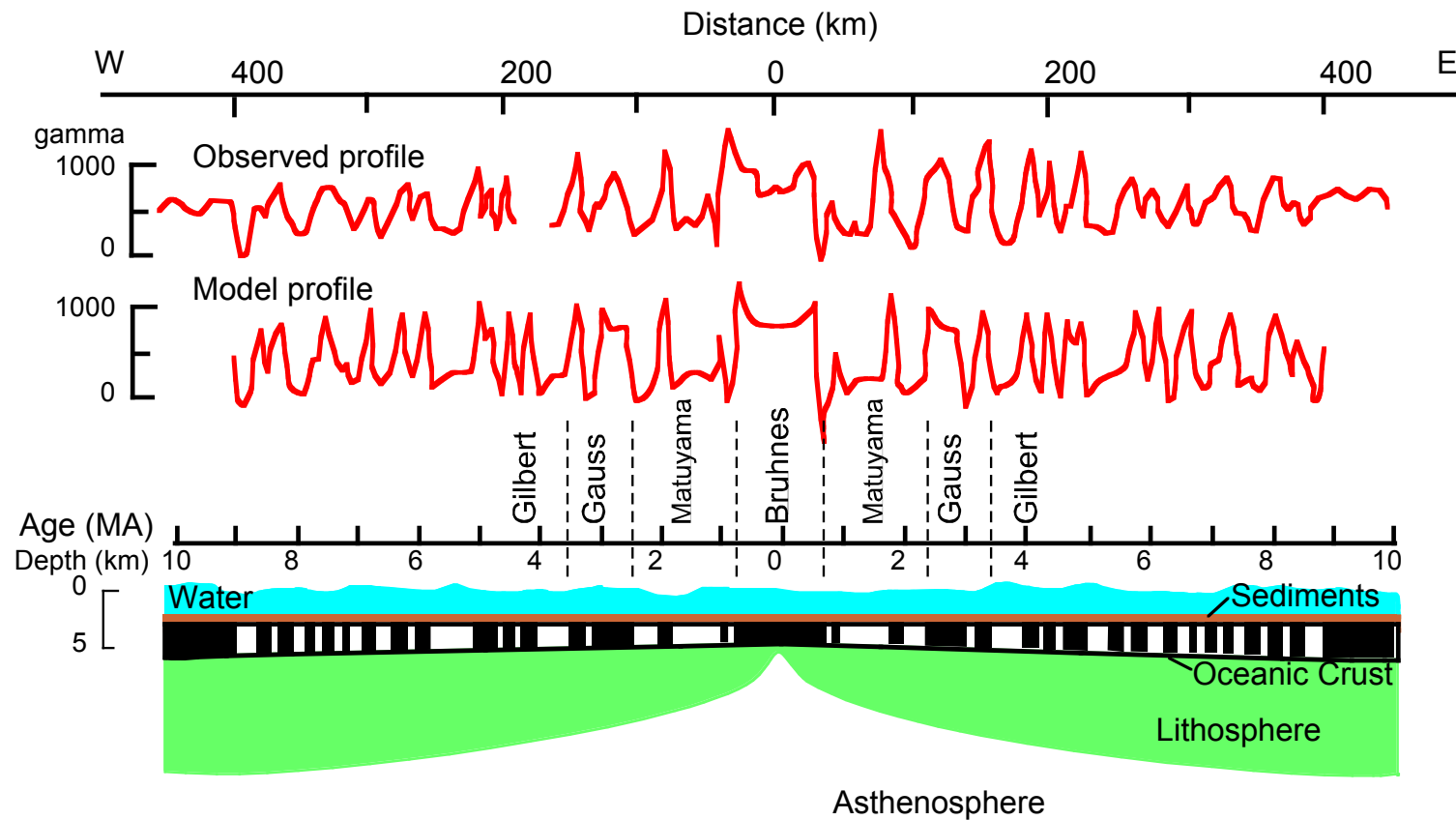
Magnetische Zeitskala

Seafloor-spreading:

- Durch das SFS wird am konstruktiven Rand einer Platte die Polarität des Feldes in der Magnetisierung der ozeanischen Kruste registriert.
- **Magnetisierungskontraste** zwischen Krustenblöcken liefern **starke magnetische Anomalien**, die beidseits des ozeanischen Rückens symmetrisch zueinander sind.
- **Hypothese von Vine & Matthews** (1963): ozeanische Anomalien >>> Polaritätsabfolge des Erdmagnetfelds.
- Liefert die **Polaritätsabfolge der letzten 180 Mio Jahre** aus ozeanischen magnetischen Anomalien.

Magnetische Zeitskala

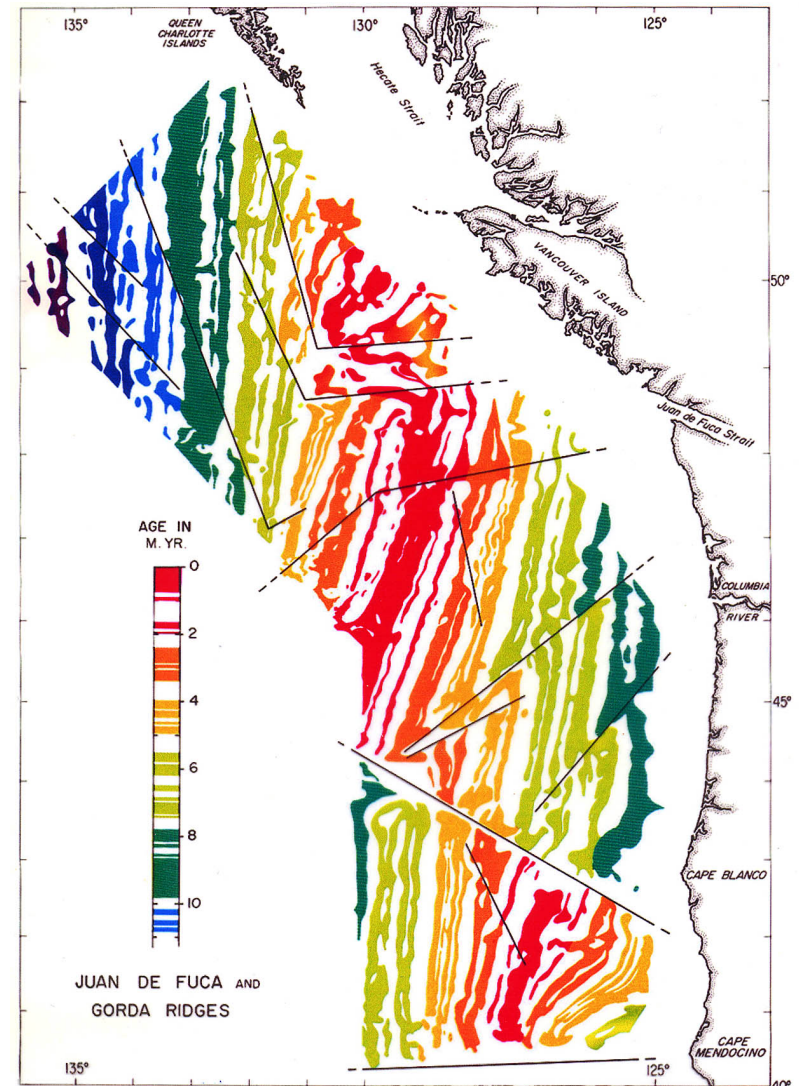
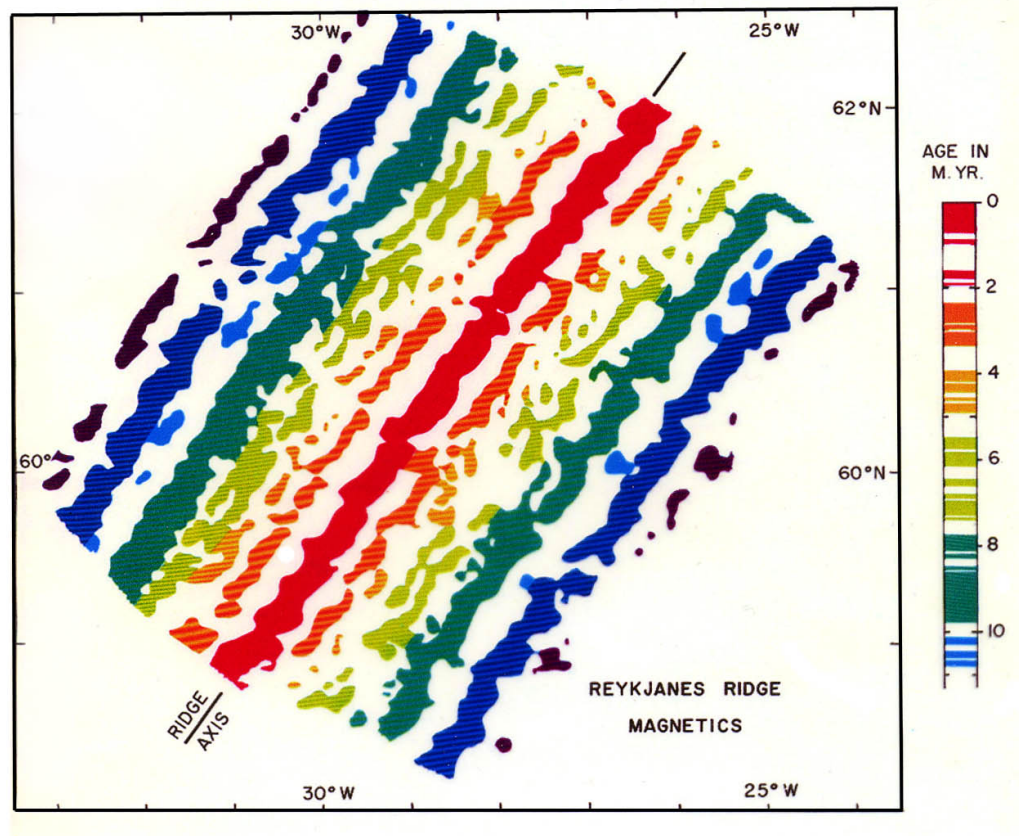
- Sea floor spreading und die magnetische Zeitskala



nach
Lowrie, 1997

Magnetische Zeitskala

Seafloor-spreading



Magnetische Zeitskala

Magnetostratigraphie:

- Sedimente die im Meer abgelagert wurden und heute auf Kontinenten liegen, werden alle 50 – 100 cm nach stratigraphischer Höhe beprobt und paläomagnetisch untersucht.
- Beispiel: Gubbio, Scaglia Rossa Kalkstein >>> Position der K-T-Grenze in 29R (65 Ma). Santon – Campan bei 33R-34-Grenze (83 Ma).
- Identifizierung und Datierung von oberkretassischen Anomalien in 3 Ozeanen.
- Herstellung einer magnetischen Zeitskala für die letzten 150 Mio Jahre (seit dem mittleren Jura).
- **Datierung des Ozeanbodens.**
- **Genaue Bewegungen der Platten können rekonstruiert werden, Konsequenzen auf Kontinente abgeschätzt.**

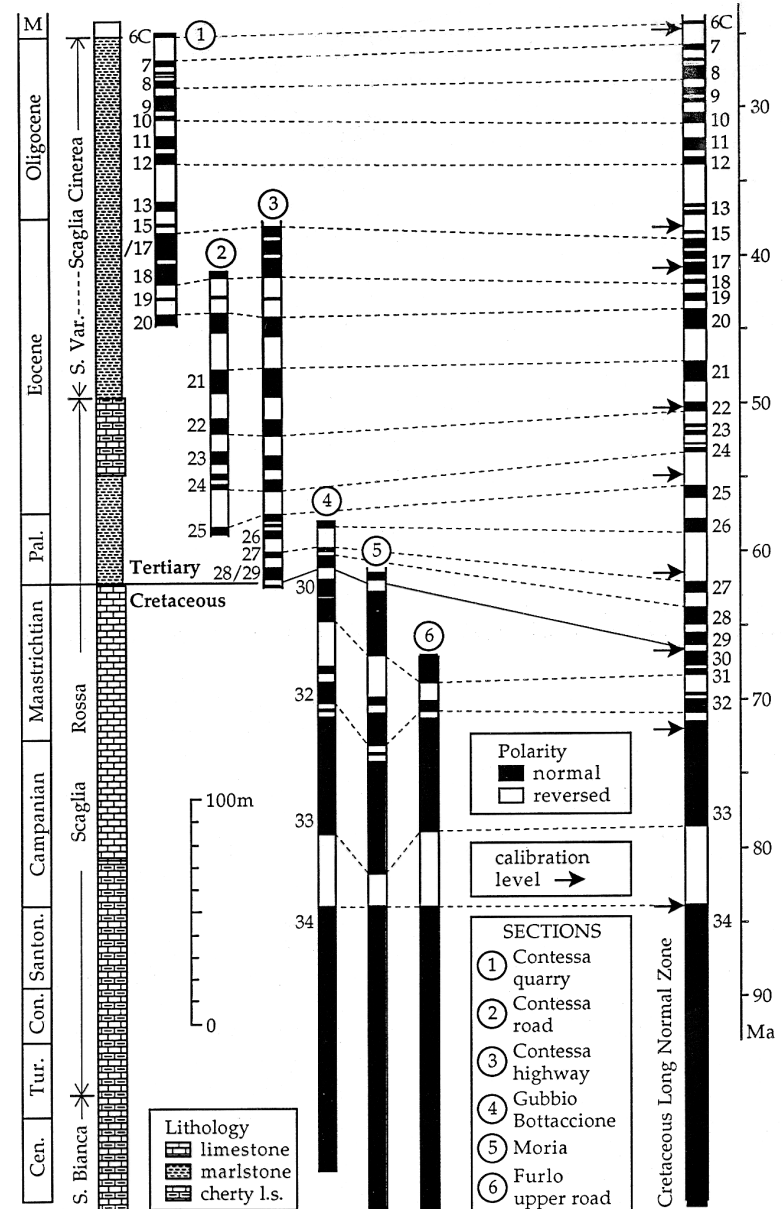


- Alvarez (2009) writes `` *In a classic case of scientific serendipity (=glücklicher Zufall), Lowrie and Alvarez stumbled onto the polarity record of the Scaglia, while focusing upon tectonic palaeomagnetism....*
- *It thus became clear that two high- resolution magnetic tape recorders are operating in the Earth, one in the ocean crust and the other in pelagic limestones. The oceanic recorder is running as much as 6000 times faster than the limestone recorder but the same characteristic fingerprint pattern of long and short normal and reversed polarity zones has been captured by both recorders – in several hundred kilometres of ocean crust and in 150 m of pelagic limestones*

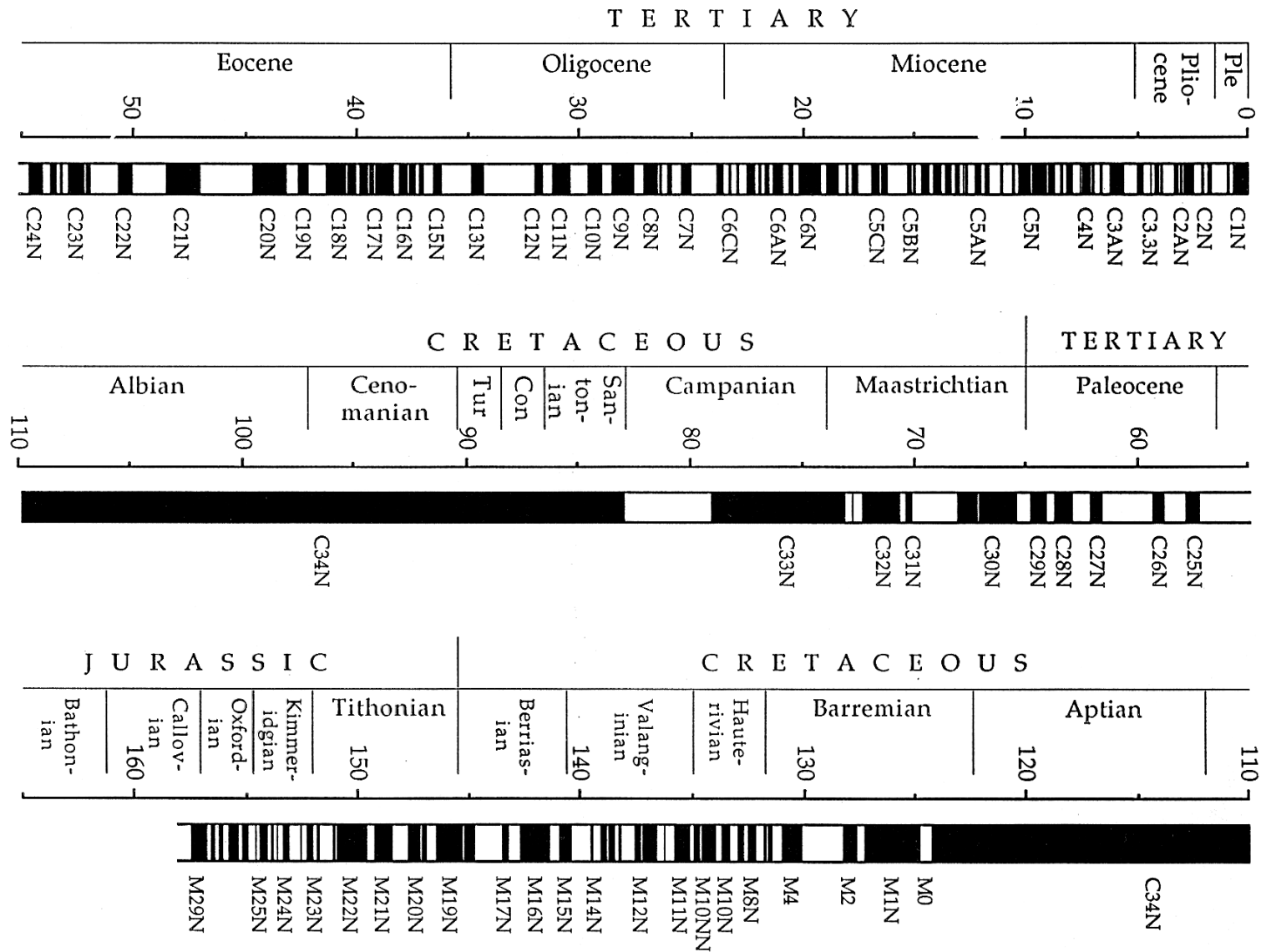
Magnetische Zeitskala

Sedimente die im Meer abgelagert wurden und heute auf Kontinenten liegen, werden alle 50 – 100 cm nach stratigraphischer Höhe beprobt und paläomagnetisch untersucht.

Lowrie & Alvarez (1981) -correlate Gubbio limestone sequences in Italy with marine magnetic anomalies and refine timing



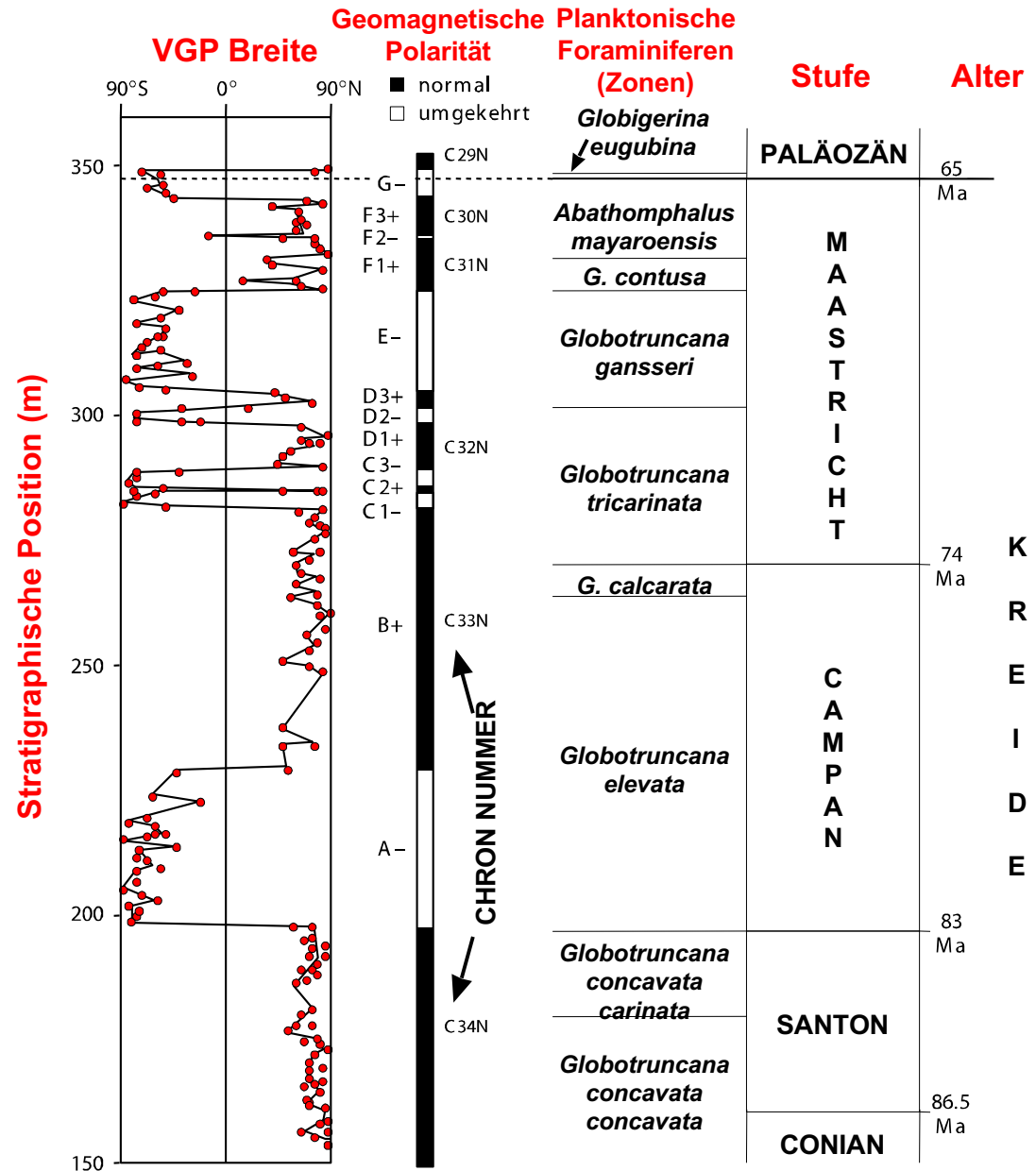
Magnetische Zeitskala



Magnetische Zeitskala

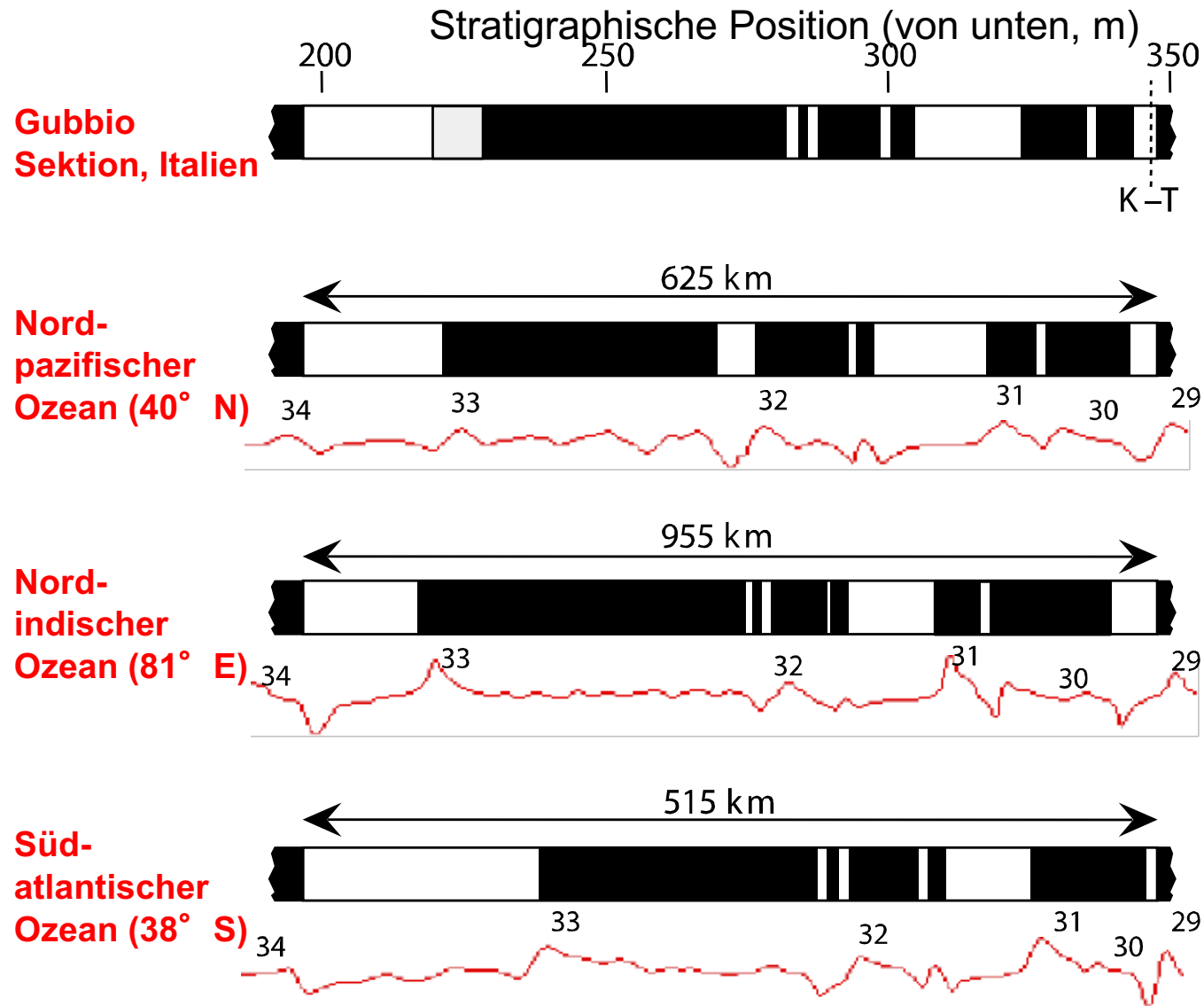
Gubbio, Scaglia Rossa Kalkstein
 >>> Position der K-T-Grenze in 29R (65 Ma). Santan – Campan bei 33R-34-Grenze (83 Ma).

Gubbio limestone 200m thick.
 Many palaeontological studies define stage boundaries >>> often supply absolute ages for ocean magnetic anomalies. Much intercalibration possible.



Magnetische Zeitskala

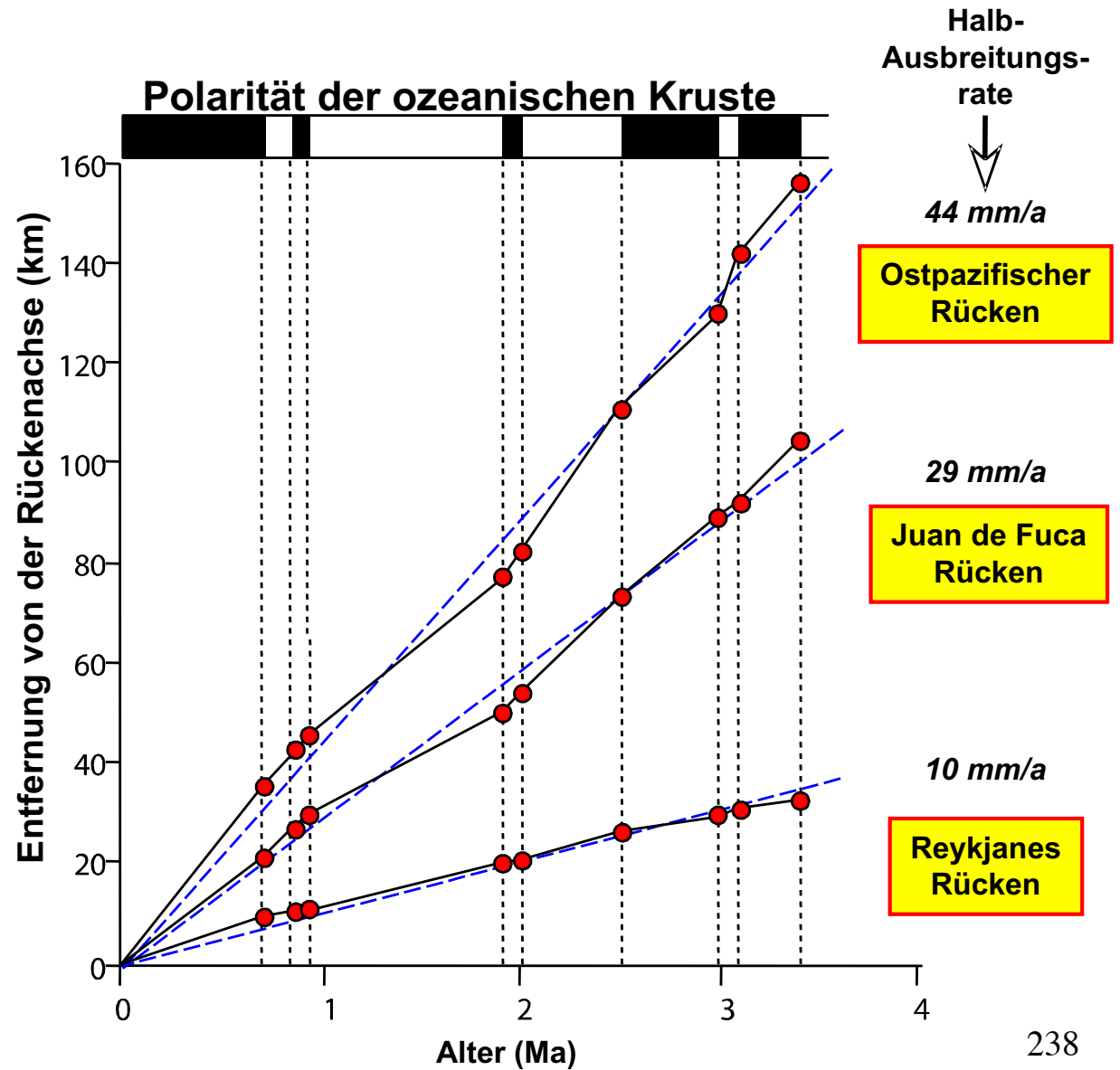
Identifizierung und Datierung von oberkretassischen Anomalien in 3 Ozeanen.



Magnetische Zeitskala

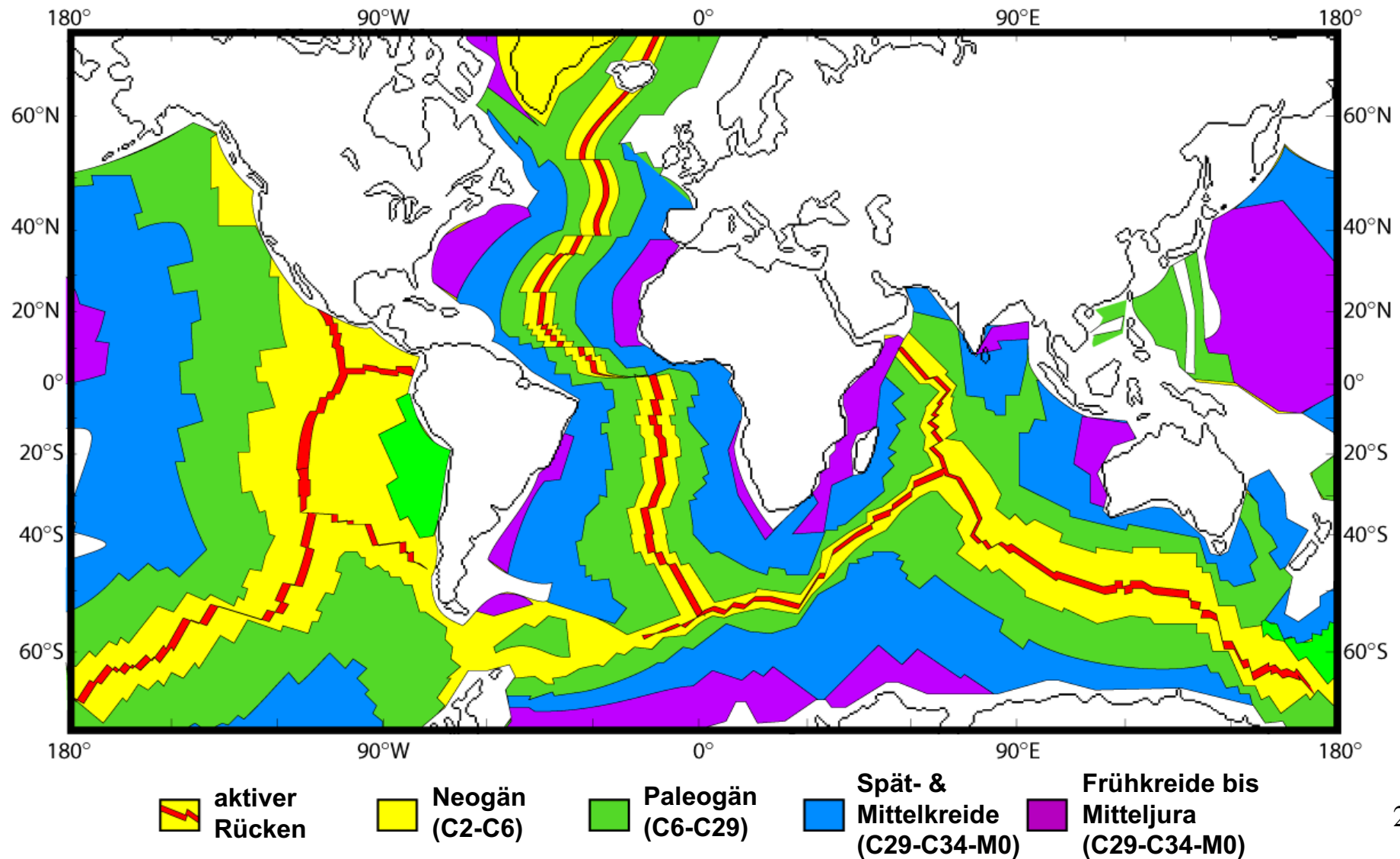
Seafloor-spreading

Datierung des Ozeanbodens.



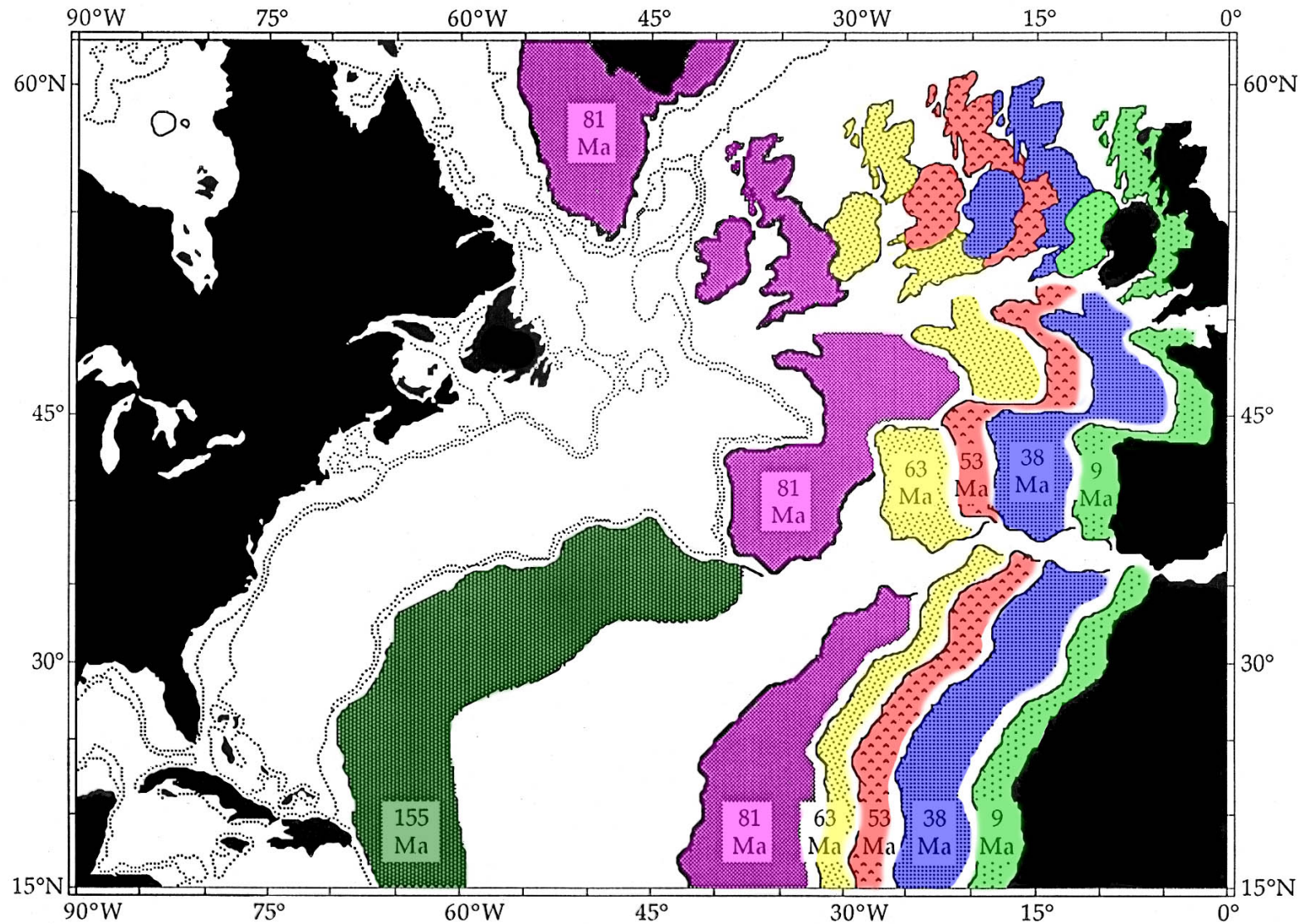
Plattentektonik

Genauere Bewegungen der Platten können rekonstruiert werden

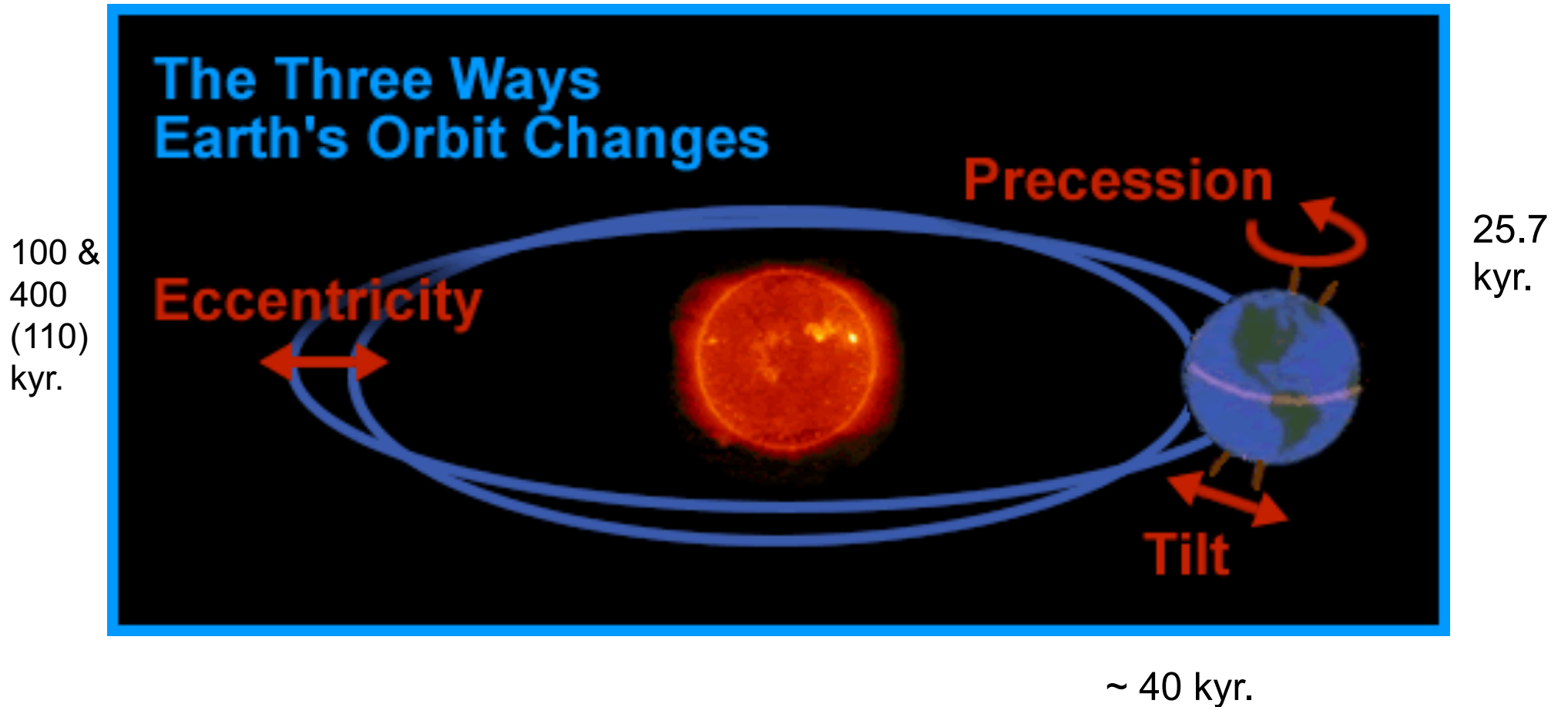


Plattentektonik

Konsequenzen auf Kontinente abgeschätzt.

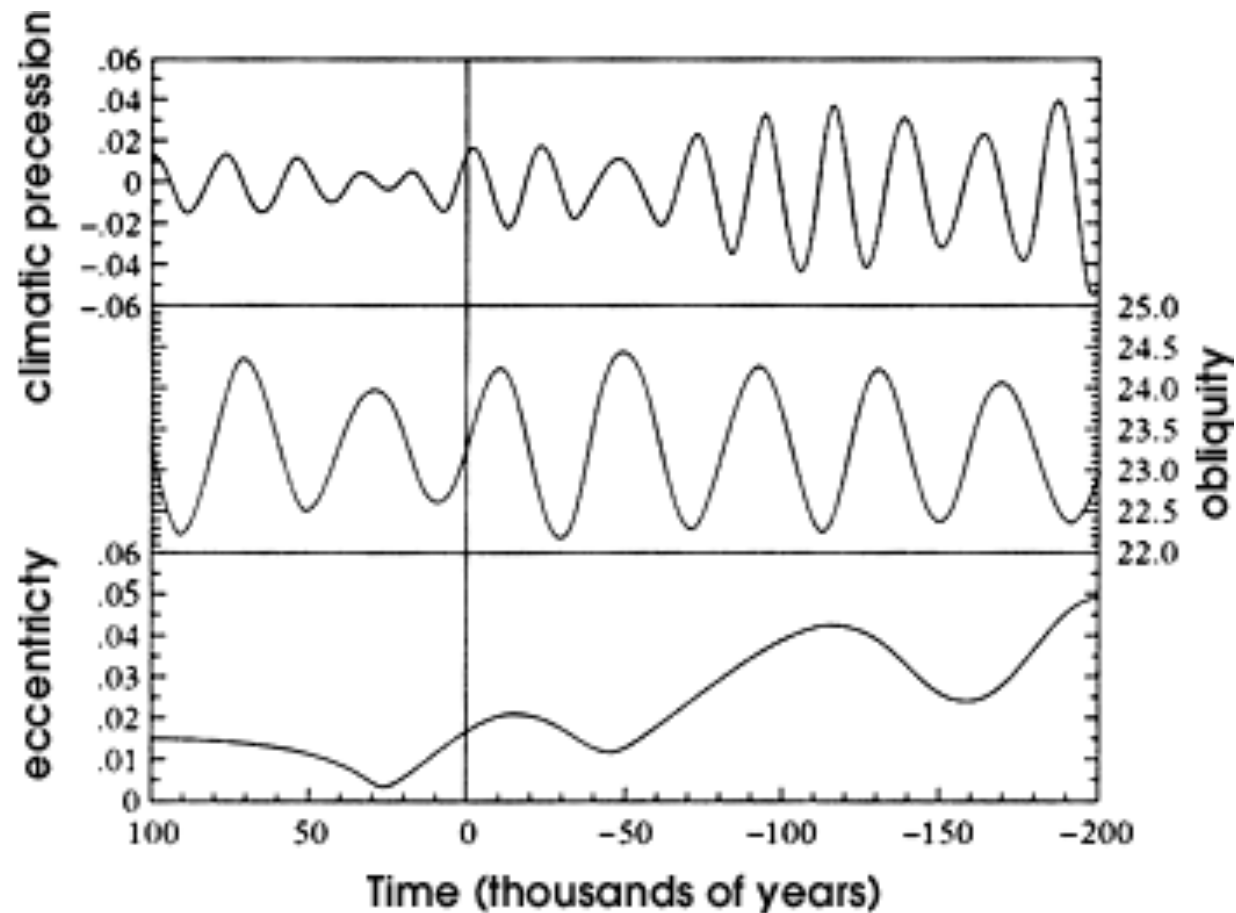


Milankovitch-Zykeln



Präzession + Exzentrizität = ~21 kyr.

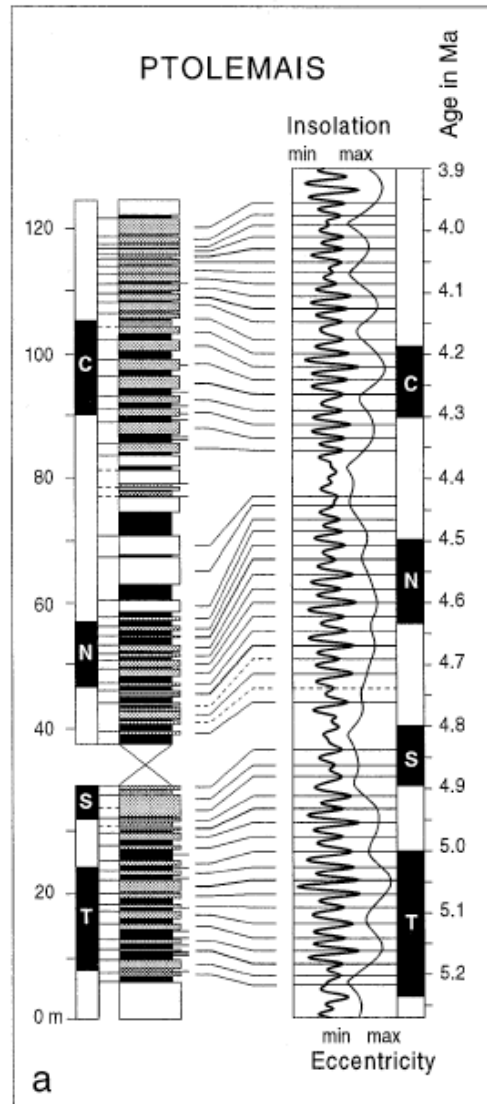
Milankovitch-Zykeln



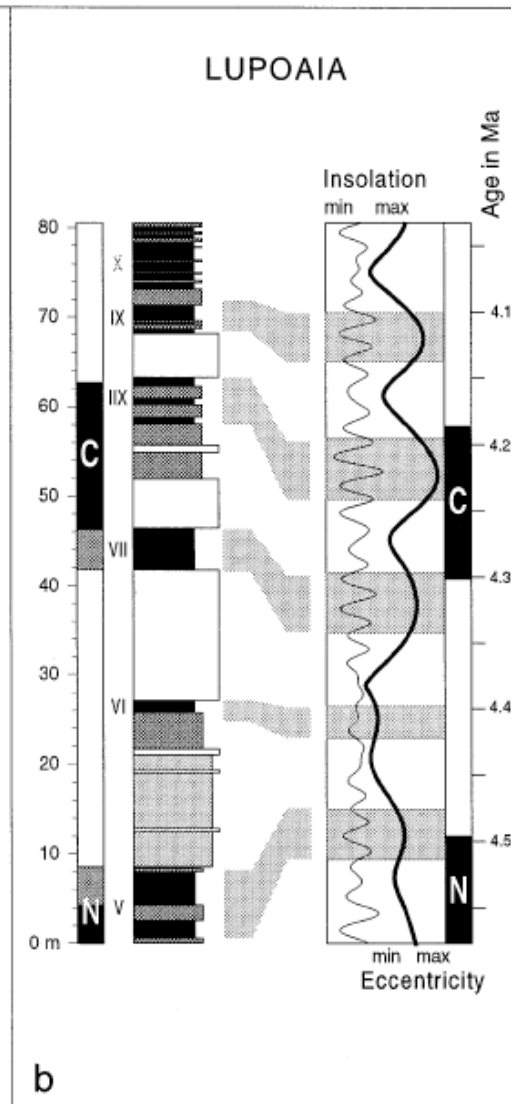
Berger 1977, *Celestial Mech.*, 15, 53-74.

Magnetische Zeitskala

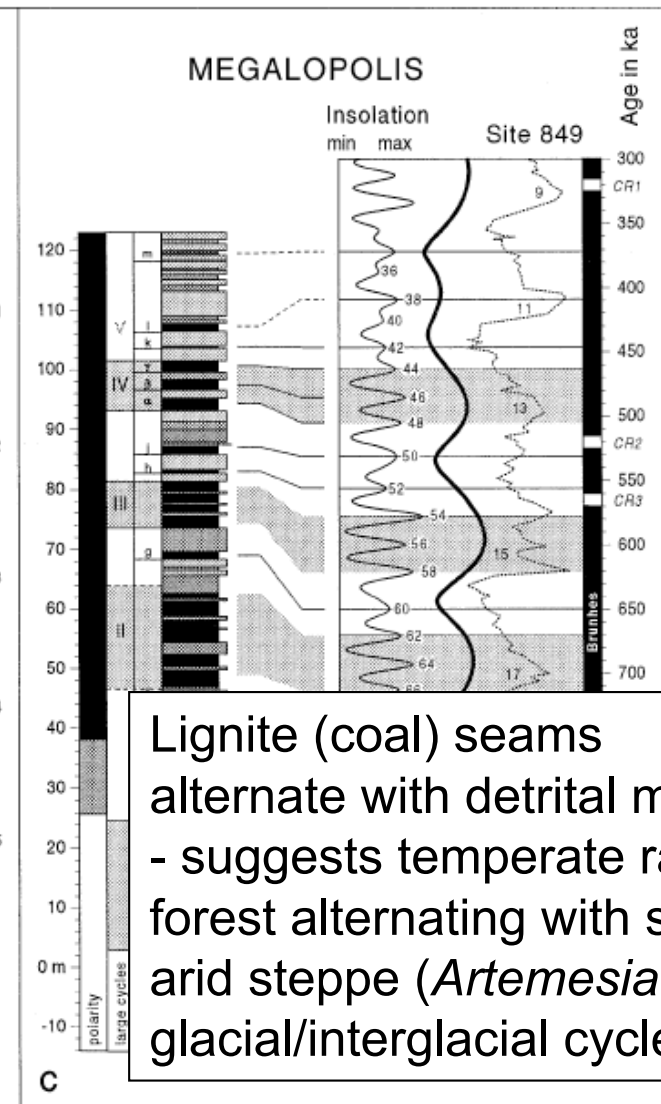
Northern Greece



Southern Romania



Southwest Greece

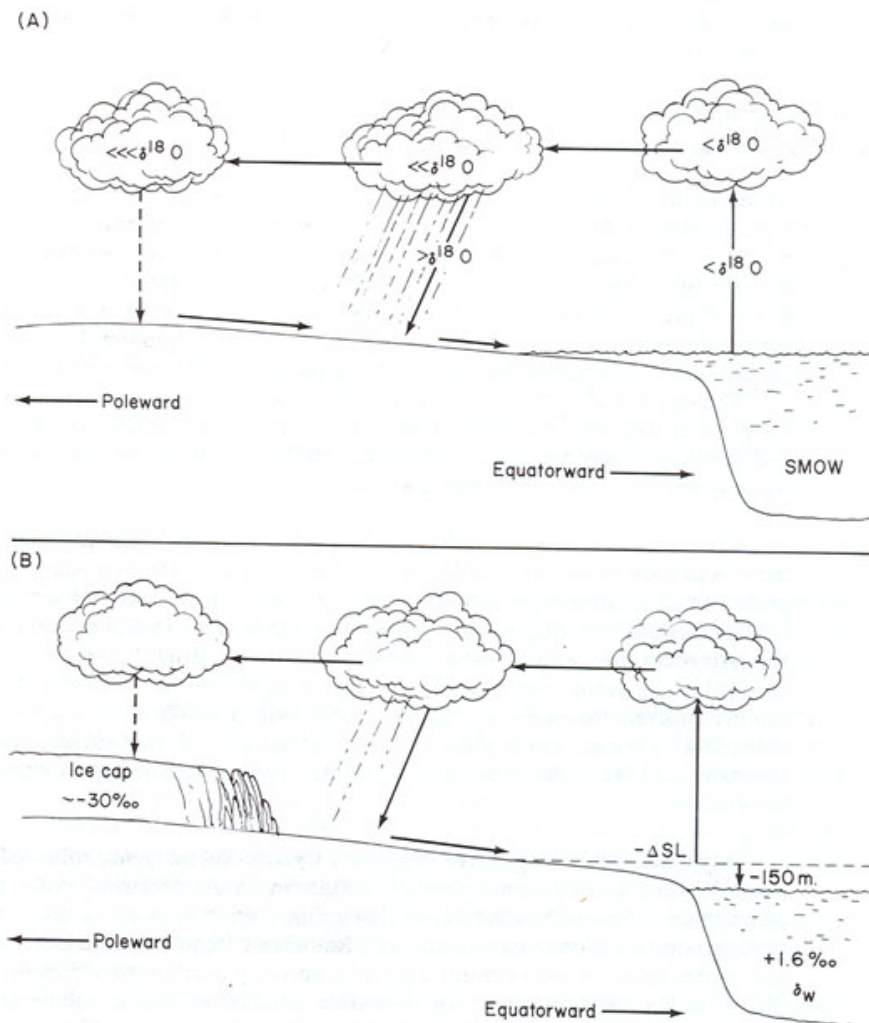


Lignite (coal) seams alternate with detrital muds - suggests temperate rain forest alternating with semi-arid steppe (*Artemesia*)>>> glacial/interglacial cycles

Stable isotopes of oxygen: a proxy for temperature but now considered an almost direct measurement

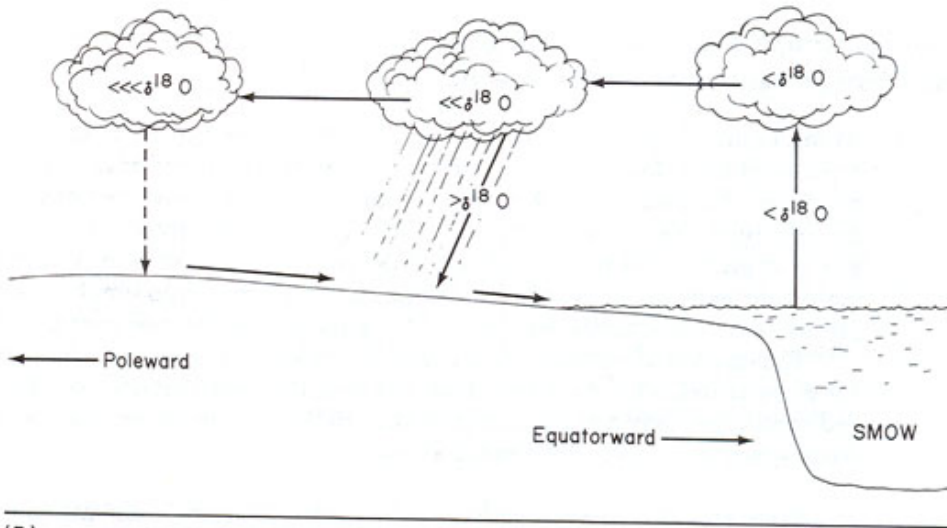
- Stable isotopes: do not decay over time. Ex, O_{16} and O_{18} .
- O_{18} is produced from O_{16} through the bombardment of O_{16} by ultraviolet radiation in the uppermost atmosphere.
- Anything that incorporates oxygen into its chemical structure will do so with some ratio of $O_{18}:O_{16}$. We can measure the ratios of these isotopes in the lab

O_{18}/O_{16} fractionation

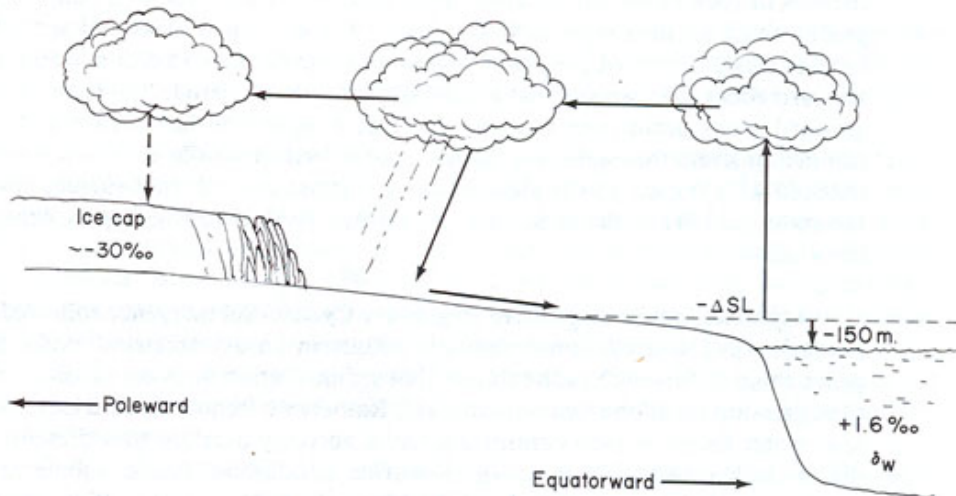


H_2O is evaporated from sea water. The oxygen in the H_2O is enriched in the lighter O_{16} . This H_2O condenses in clouds, falling on land as precipitation. Thus, H_2O that is part of the terrestrial water cycle is enriched in the light O_{16} isotope and sea water is enriched in the heavier O_{18} isotope

(A)



(B)



Glacial ice is therefore made up primarily of water with the light O_{16} isotope. This leaves the oceans enriched in the heavier O_{18} , or “more positive.”

During glacial periods, more O_{16} is trapped in glacial ice and the oceans become even more enriched in O_{18} . During interglacial periods, O_{16} melts out of ice and the oceans become less O_{18} rich, or “more negative” in O_{18}



- Birds
- Sea Turtles, Newts
- Rainbow trout
- Spiny Lobster
- Zambian mole rats



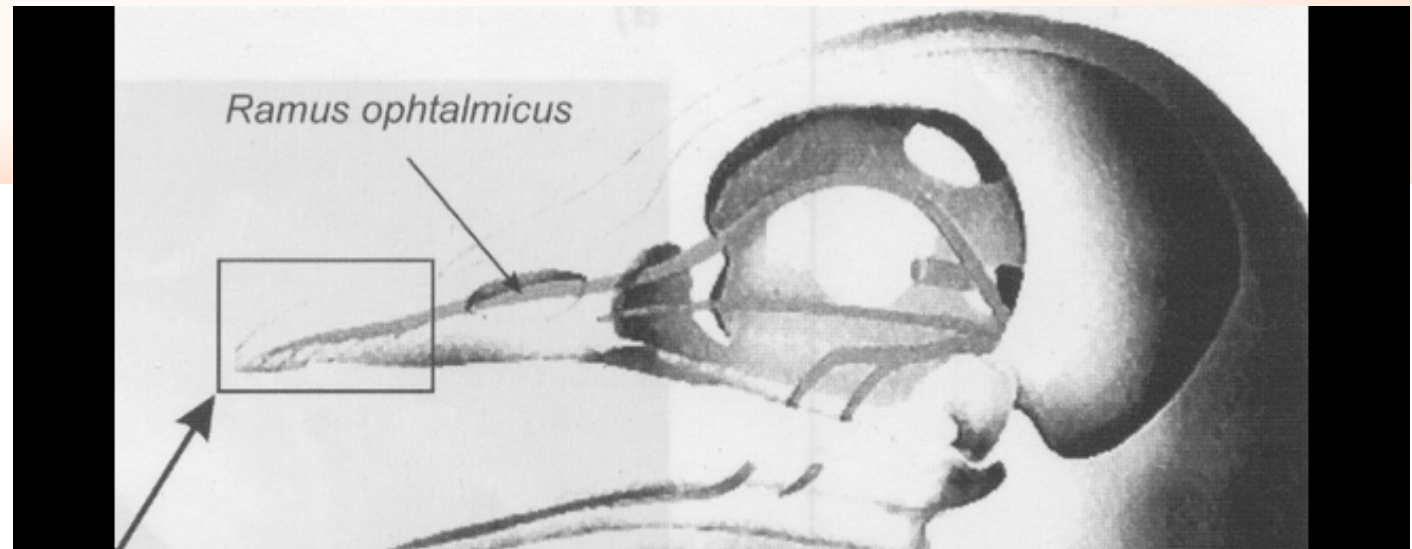
Migratory birds shown to use a magnetic compass

European Robin, *Erithacus rubecula* (Muscicapidae)
Pied flycatcher, *Ficedula hypoleuca* (Muscicapidae)
Wheatear, *Oenanthe oenanthe* (Muscicapidae)
Common whitethroat, *Sylvia communis* (Sylviidae)
Garden warbler, *Sylvia borin* (Sylviidae)
Subalpine warbler, *Sylvia cantillans* (Sylviidae)
Blackcap, *Sylvia atricapilla* (Sylviidae)
Goldcrested kinglet, *Regulus regulus* (Sylviidae)
Dunnock, *Prunella modularis* (Prunellidae)
Silvereye, *Zosterops lateralis* (Zosteropidae)
Yellow faced honeyeater, *Lichenostomus chrysops* (Meliphagidae)
Red-eyed vireo, *Vireo olivaceus* (Vireonidae)
Scarlet grossbeak, *Carpodactus erythrinus* (Fringillidae)
Chaffinch, *Fringilla coelebs* (Fringillidae)
Indigo bunting, *Passerina cyanea* (Emberizidae)
Savanna sparrow, *Passerculus sandwichensis* (Emberizidae)
Snow bunting, *Plectrophenax nivalis* (Emberizidae)
Bobolink, *Dolichonyx oryzivorus* (Icteridae)

W. Wiltschko & R. Wiltschko (1996) *J. Exp. Bio.*, **199**, 29.

Superparamagnetic magnetite in upper beak

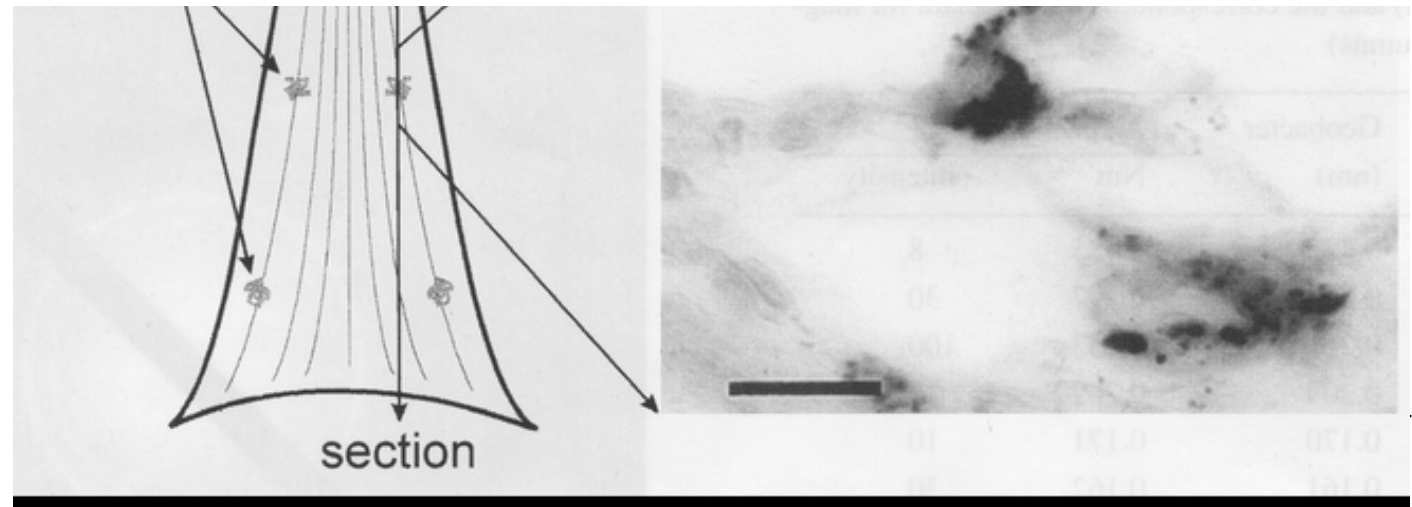
Hanzlik et al 2000

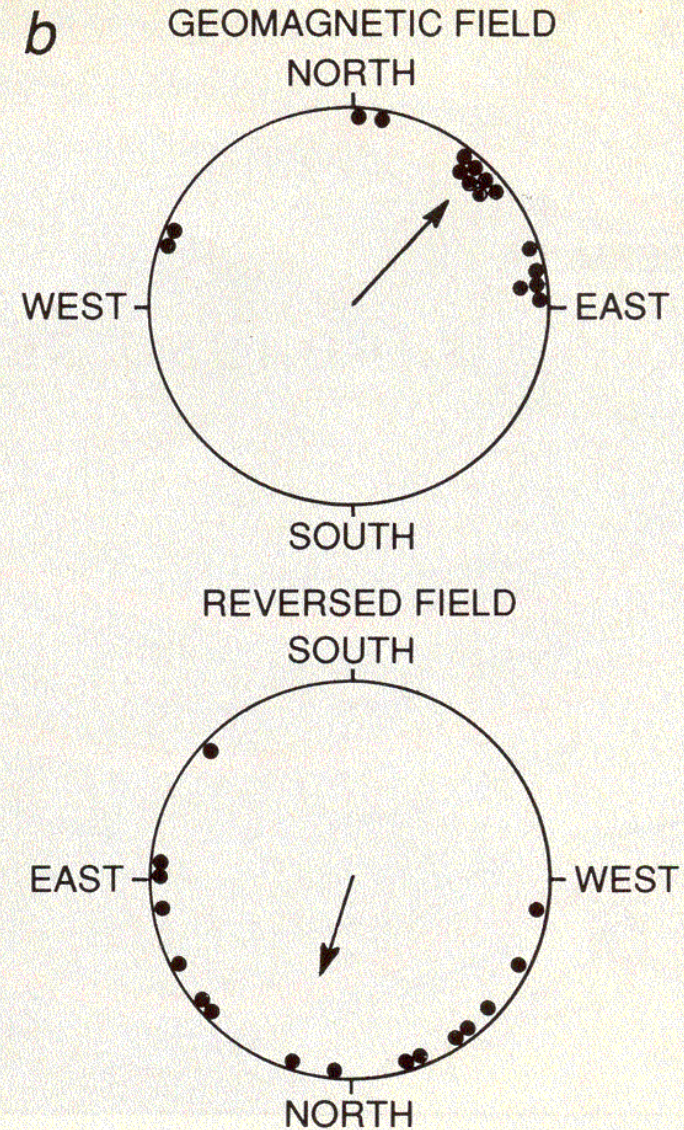
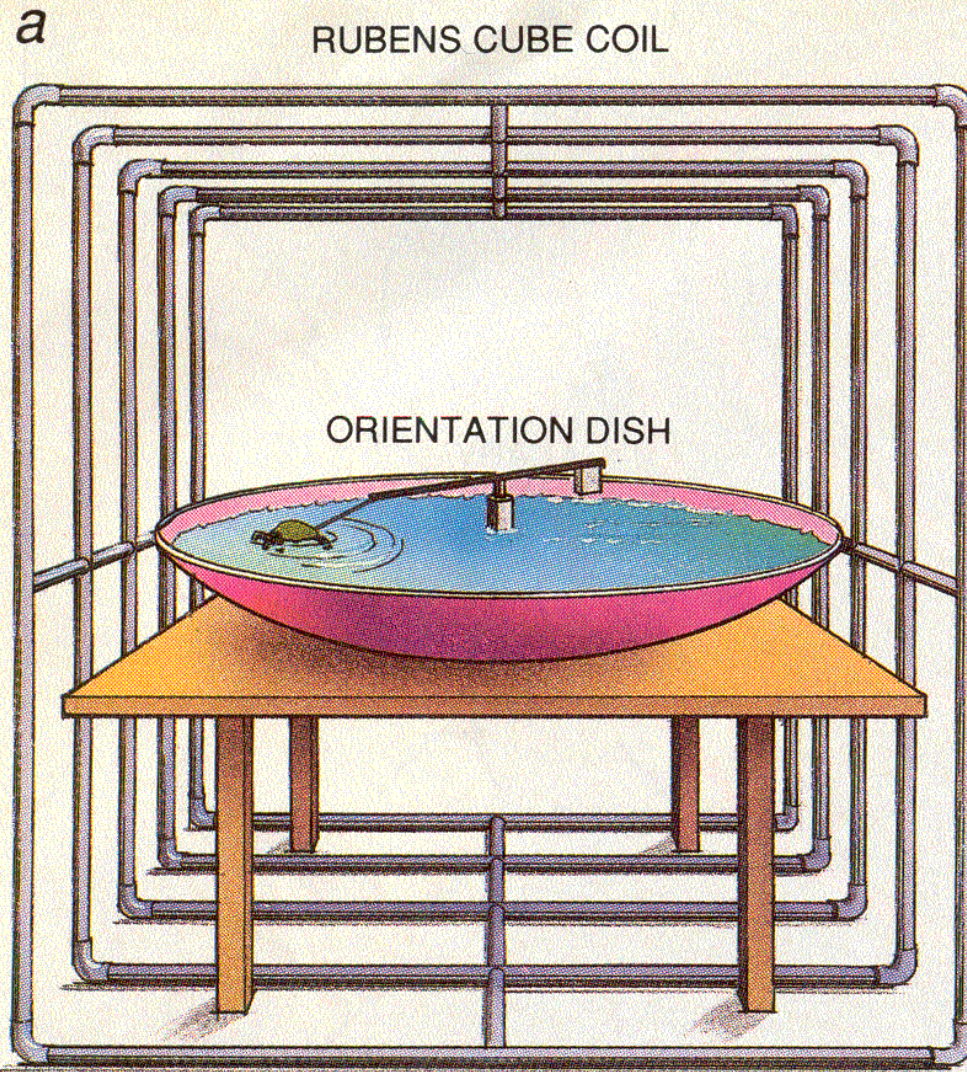


Clusters of iron-rich cells in the upper beak of pigeons are macrophages not magnetosensitive neurons

Christoph Daniel Treiber¹, Marion Claudia Salzer¹, Johannes Riegler², Nathaniel Edelman¹, Cristina Sugar¹, Martin Breuss¹, Paul Pichler¹, Herve Cadiou³, Martin Saunders⁴, Mark Lythgoe², Jeremy Shaw⁴ & David Anthony Keays¹

Nature, 2012



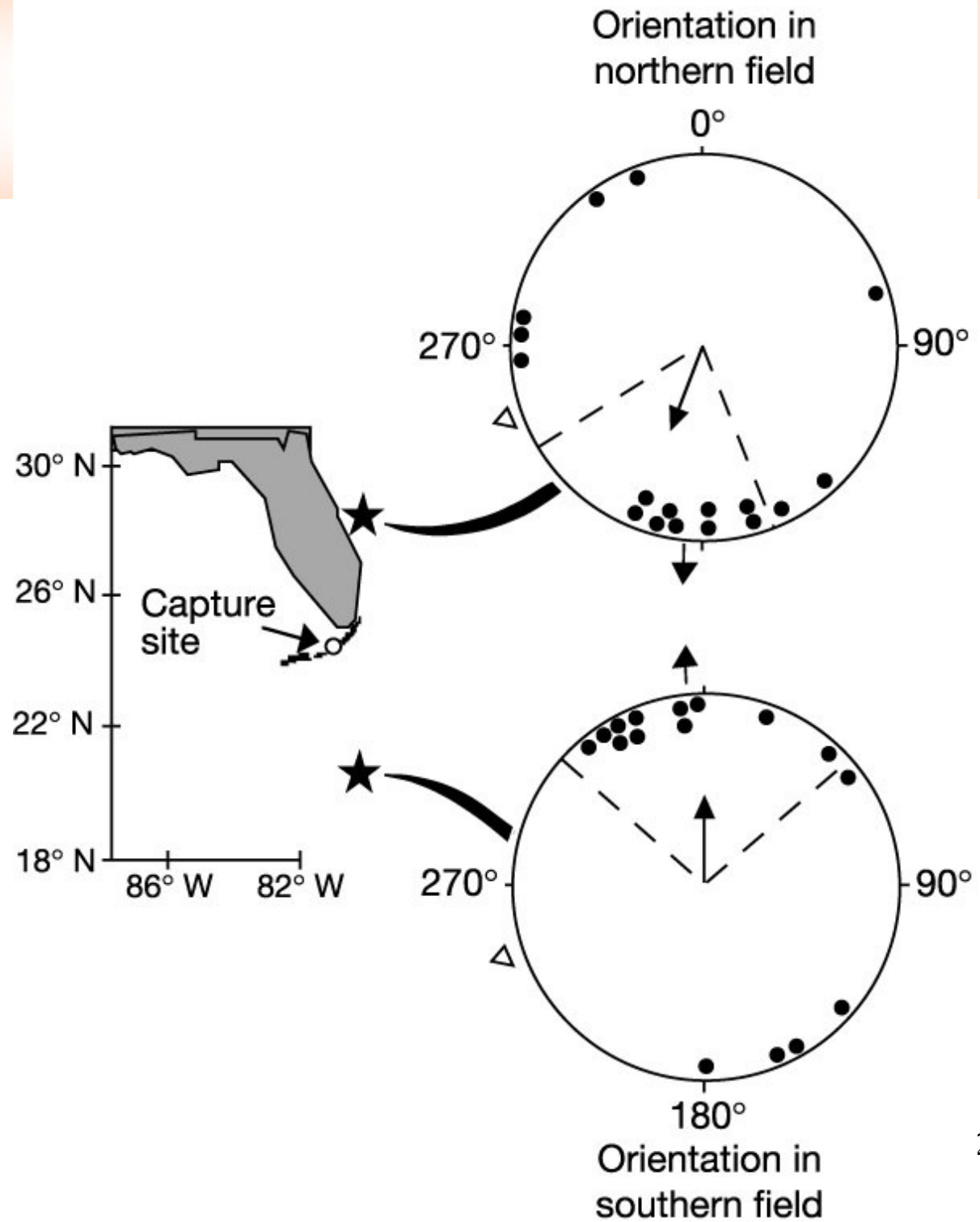


MAGNETIC-ORIENTATION APPARATUS demonstrates that Florida loggerhead hatchlings can detect the earth's magnetic field (*a*). Each turtle is tethered to the lever arm, which electronically tracks the turtle's swimming direction. The Rubens cube coil is used to reverse the direction of the magnetic field. Findings (*b*) show that most individuals (*dots*) swim in directions between magnetic north and east under both conditions. The arrow represents the average direction of the group.

Spiny Lobster

Boles & Lohmann (2003)

First invertebrate



Animal Navigation - References

Walker et al *Nature* **390** 371-376 (1997) Show magnetoreceptors are in nose of rainbow trout

Lohmann et al *Science* **294** 364-366 (2001)
Loggerhead turtles use magnetic field for navigation

Boles & Lohmann *Nature* **421** 60-63 (2003) Spiny lobsters

MagR protein as magnetoreceptor in fruit flies – controversy discussed in *Nature* **527** 283-284 (2015)

The mystery of the magnetic cows

Researchers disagree over replication of study showing that cows line up with Earth's magnetic field.

Daniel Cressey

11 November 2011

In 2008, the world's media was captivated by a study apparently showing that cows like to align themselves with magnetic fields. But attempts to replicate this finding have left two groups of researchers at loggerheads, highlighting the problems faced by scientists working to replicate unusual findings based on new methods of data analysis

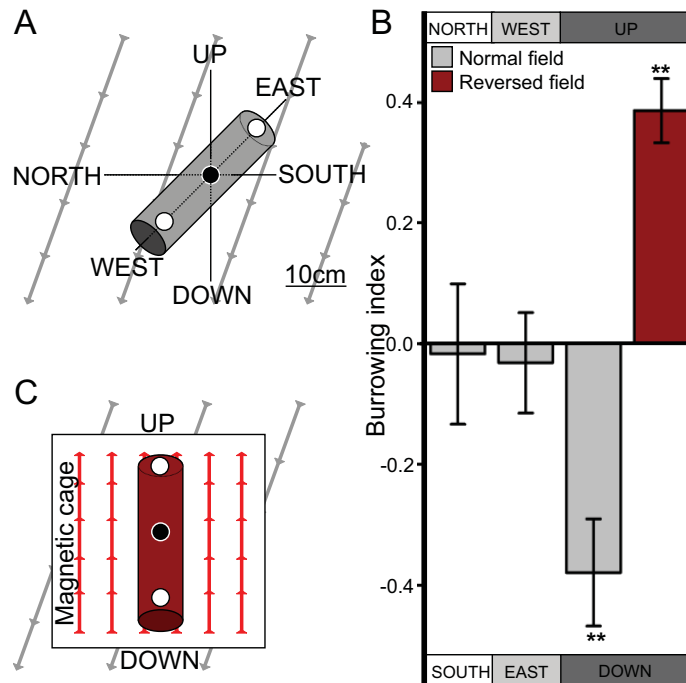
Long-sought 'biocompass' discovery claimed

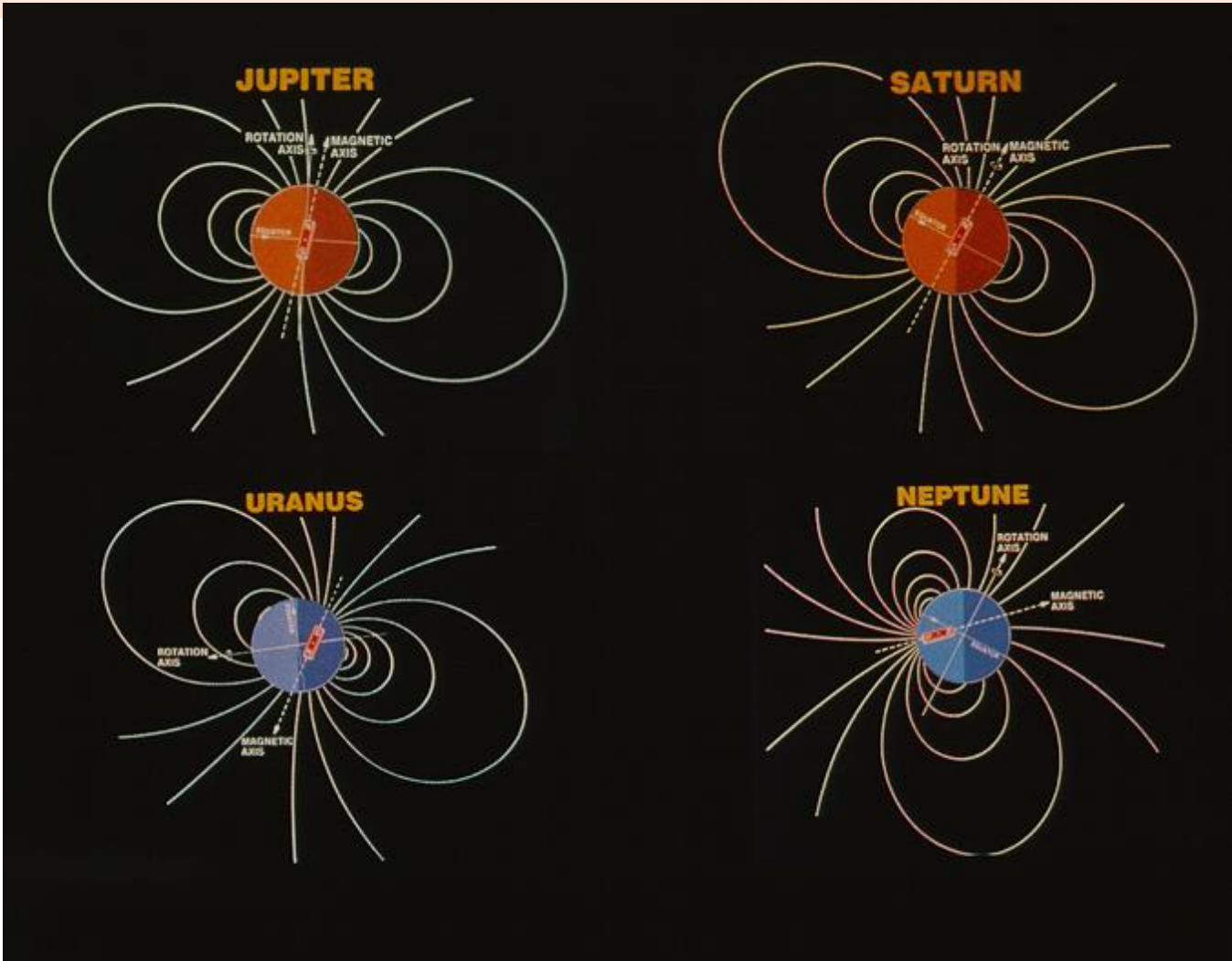
Protein complex offers explanation for how animals sense Earth's magnetic pull.

“It's an extraordinary paper,” says Peter Hore, a biochemist at the University of Oxford, UK. But Xie's team has not shown that the complex actually behaves as a biocompass inside living cells, nor explained exactly how it senses magnetism. “It's either a very important paper or totally wrong. I strongly suspect the latter,”

“If MagR is the real magneto-receptor, I'll eat my hat.”

der Fadenwurm *C. elegans*



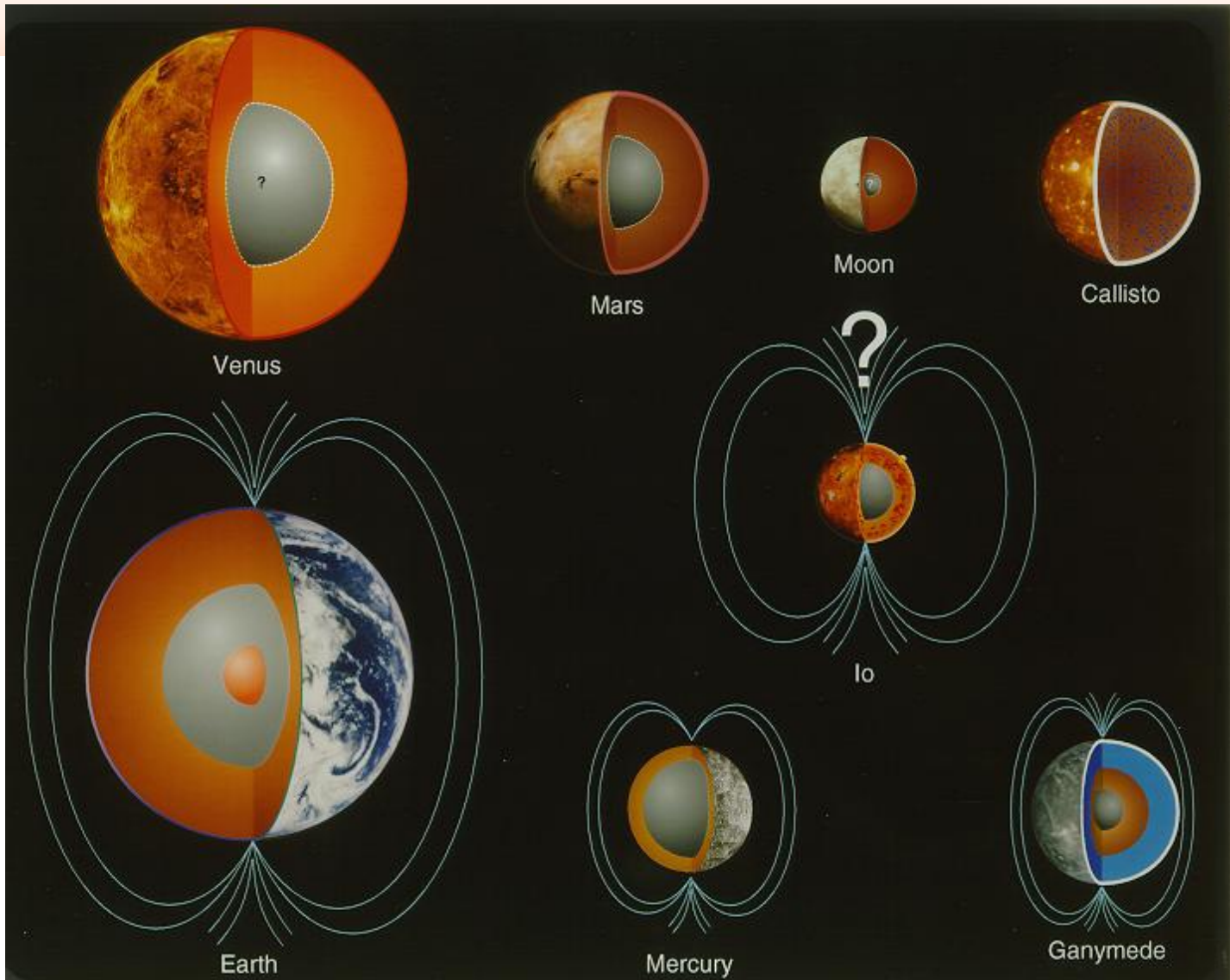




Planetary magnetic fields

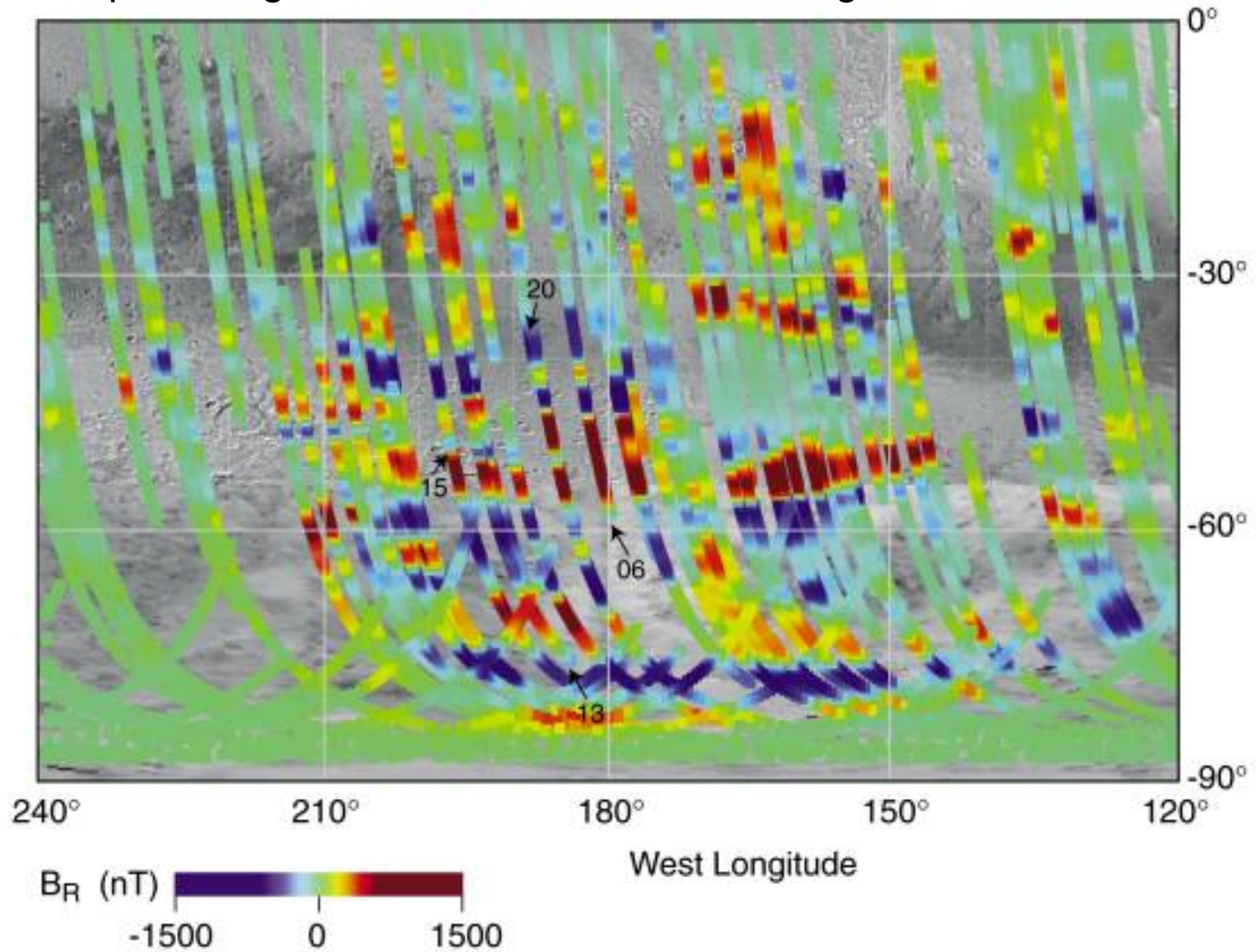
Planet	Earth	Jupiter	Saturn	Uranus	Neptune
Radius, km	6,378	71,400>	60,300	25,600	24,800
Spin period, hrs	24	9.9	10,7	17.2	16
Magnetic Moment/MEarth	1	20,000	600	50	25
Mean equatorial field, Gauss	0.31	4.28	0.22	0.23	0.14
Dipole tilt and sense	+11.3°	-9.6°	0°	-59°	-47°

Table in Lowrie (first Edition) is somewhat out of date.



Mars

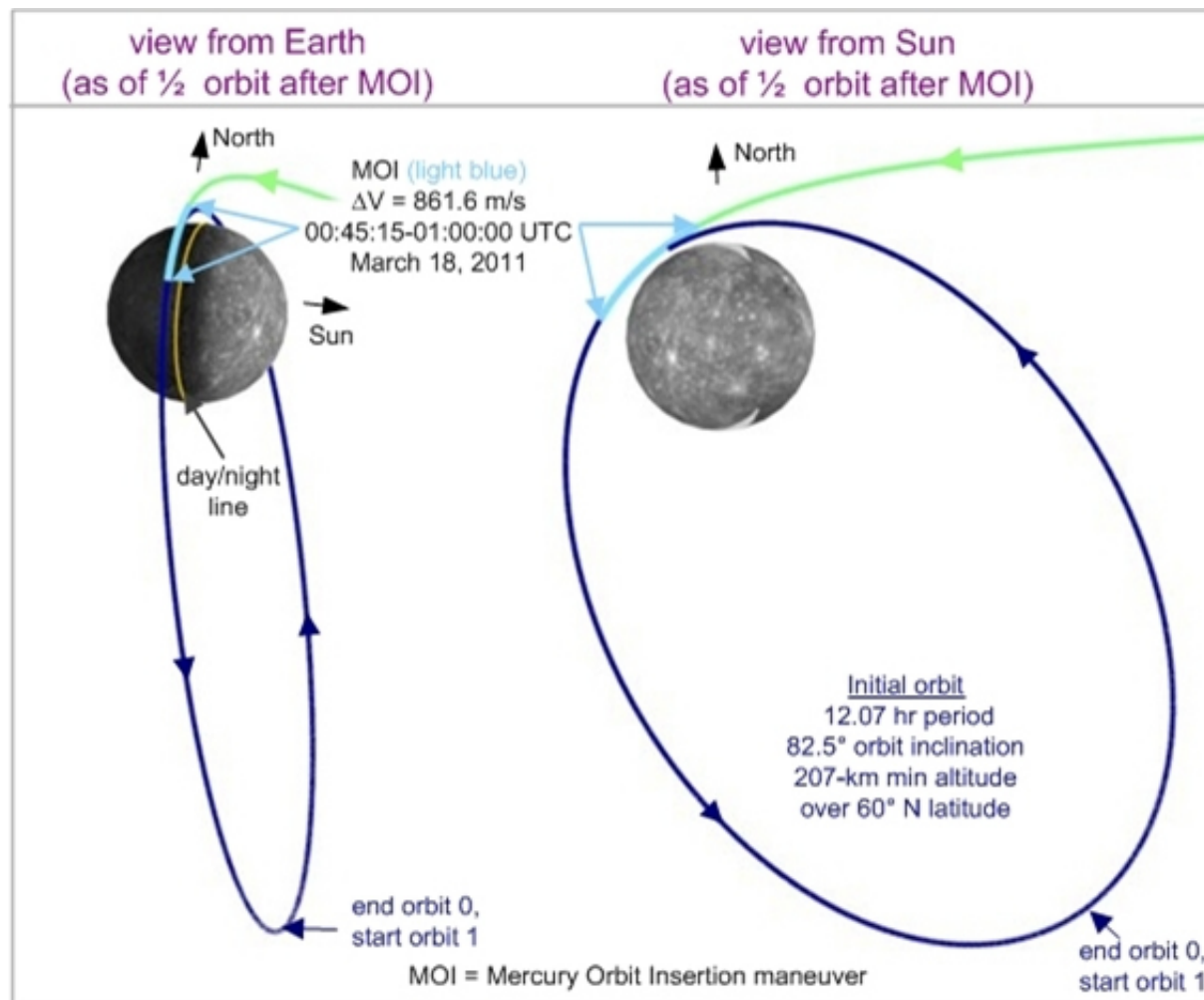
Implies magnetisations 10-100 times stronger than on Earth



Mercury Messenger – the first ever spacecraft to orbit Mercury

Carries a vector magnetometer to better characterise the B field

On March 17th 2011 Messenger successfully entered orbit
The orbit was very elliptical – lowest altitude is ~ 200km
Ended April 30 2015



Mariner 10 flyby in 1974 showed the magnetic field to be weak, (about 350nT at the equator, on the surface)

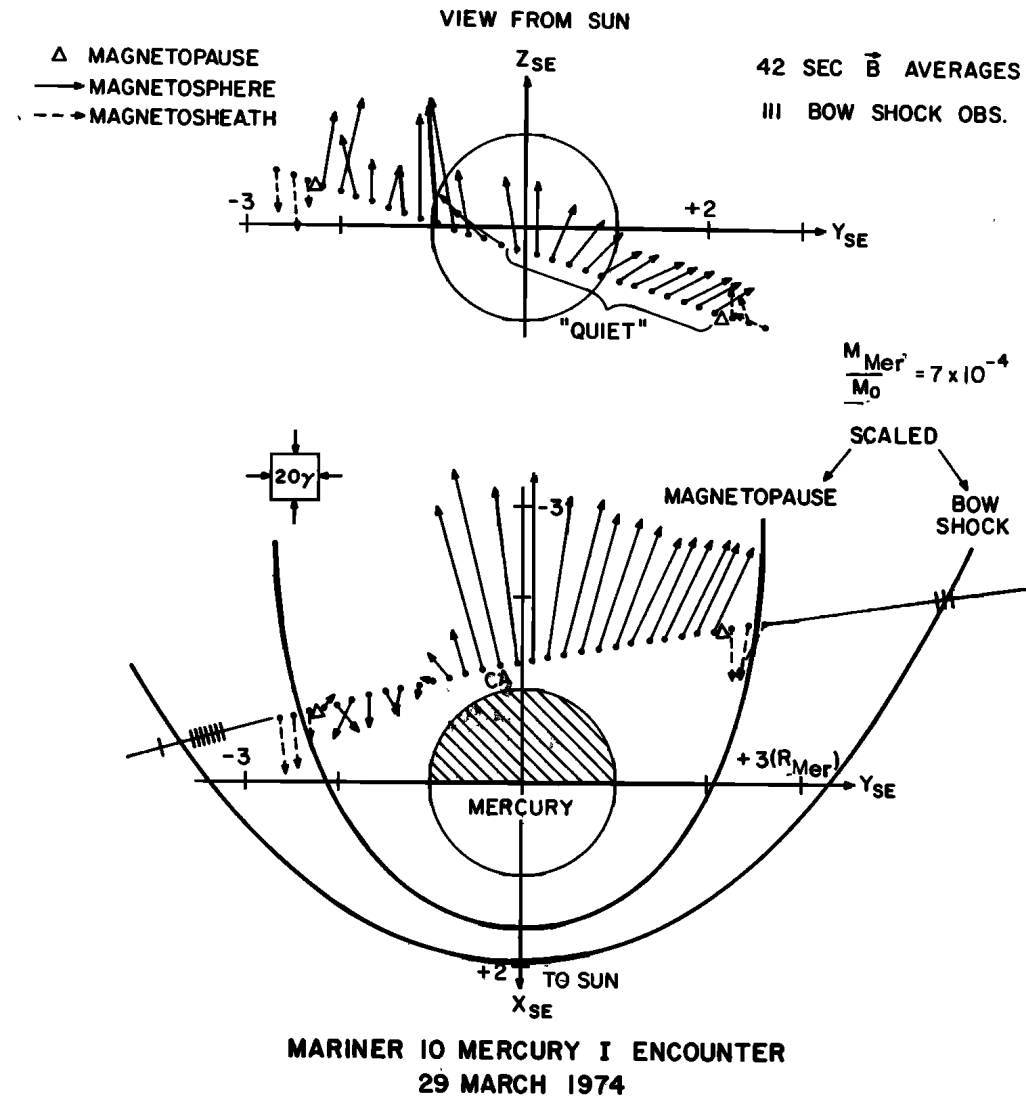
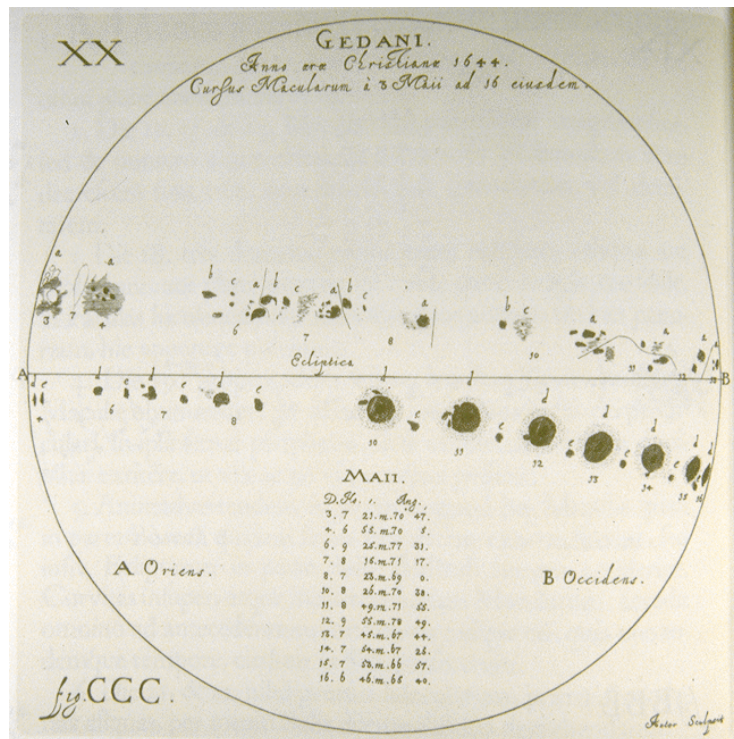
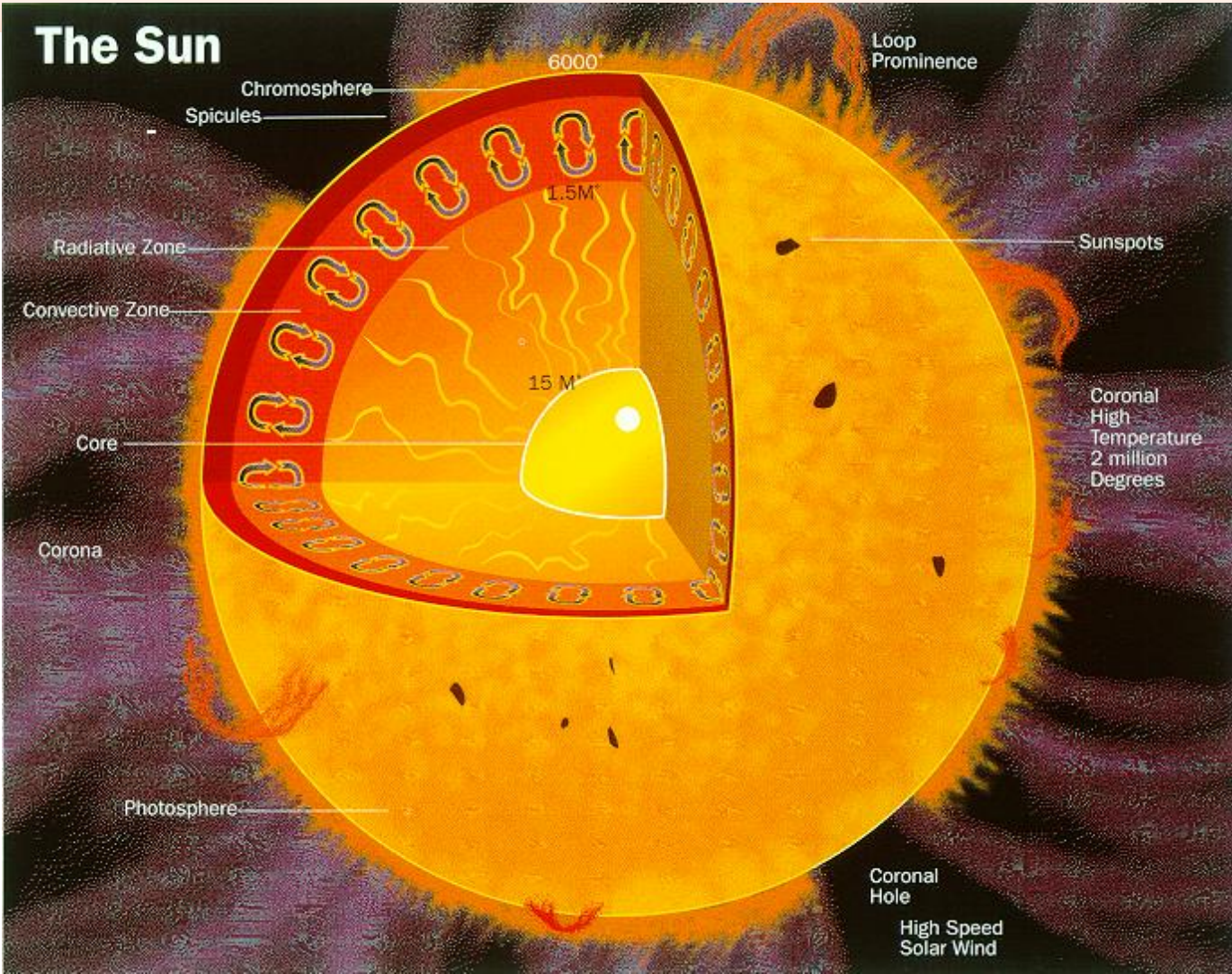


Fig. 2. Observed 42-s average magnetic field vectors superimposed on trajectory of Mariner 10 in X-Z (top) and X-Y (bottom) planes during transit of Hermean magnetosphere. The actual magnetopause crossings are identified, along with the detached bow shock observations. The boundaries represent a best graphical fit obtained by scaling the case of the solar wind interaction with the earth for $M = 7 \times 10^{-4}$ of the earth's magnetic moment; $R_{Mer} = 2439$ km.

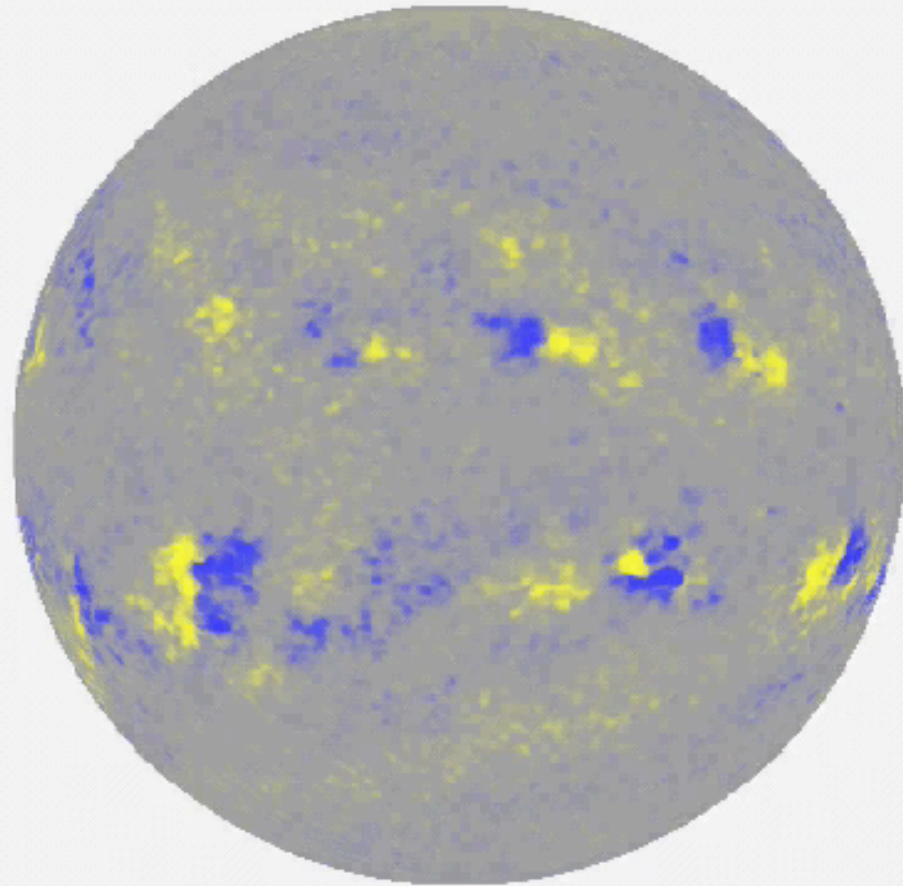
Solar and planetary magnetic fields

- Sunspots detected from 28 BC onwards (seen with naked eye!)
- Associated with intense magnetic fields
- Systematic observations made by Galileo





Our Sun



Planetary missions

Recent: Mars Global Surveyor 1997-2006

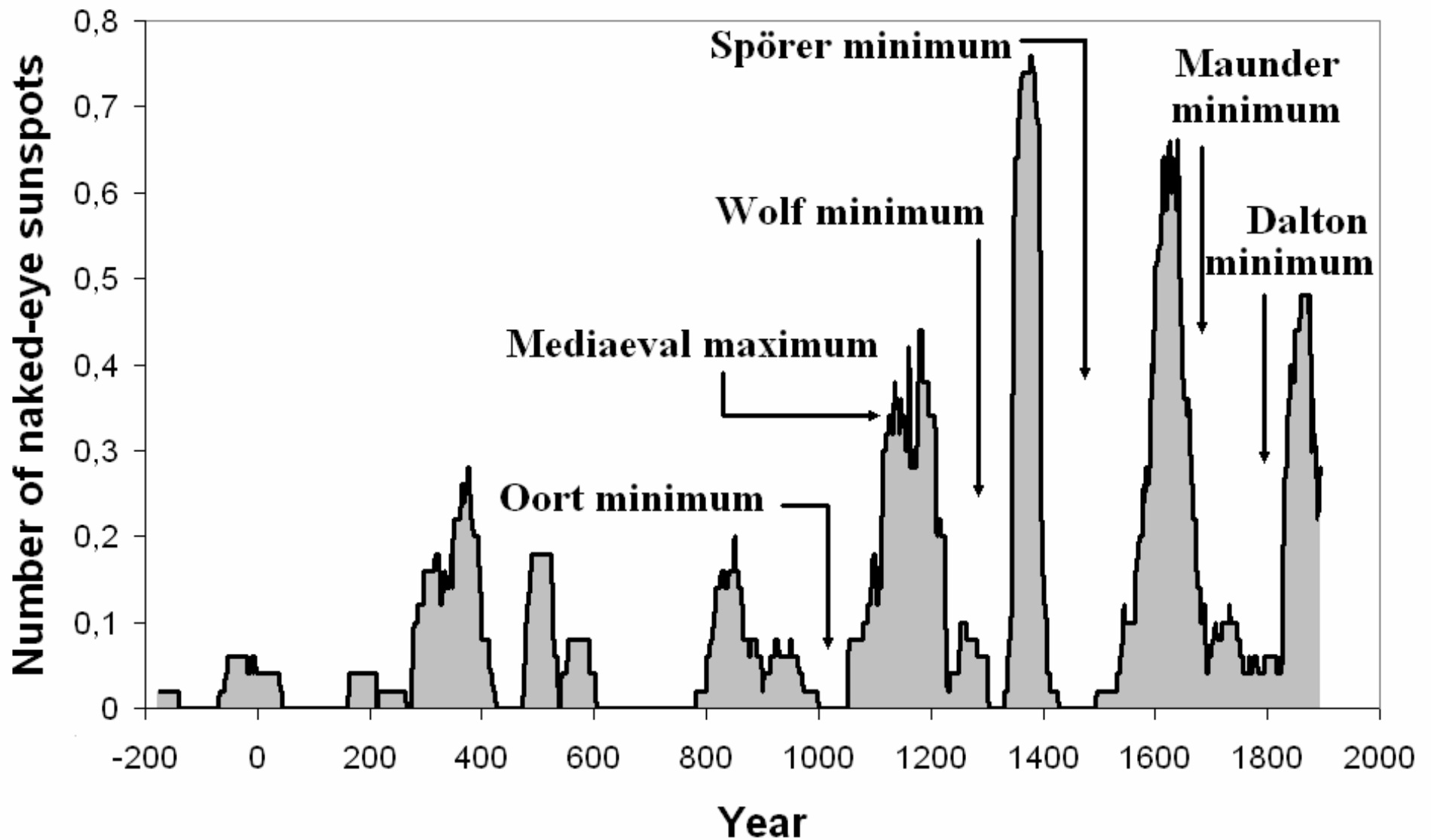
In orbit: Mercury Messenger, departed 2004, arrived in orbit March 2011, ended 2015

Juno mission to Saturn, launched 2011, arrived 2016, completed 18 orbits

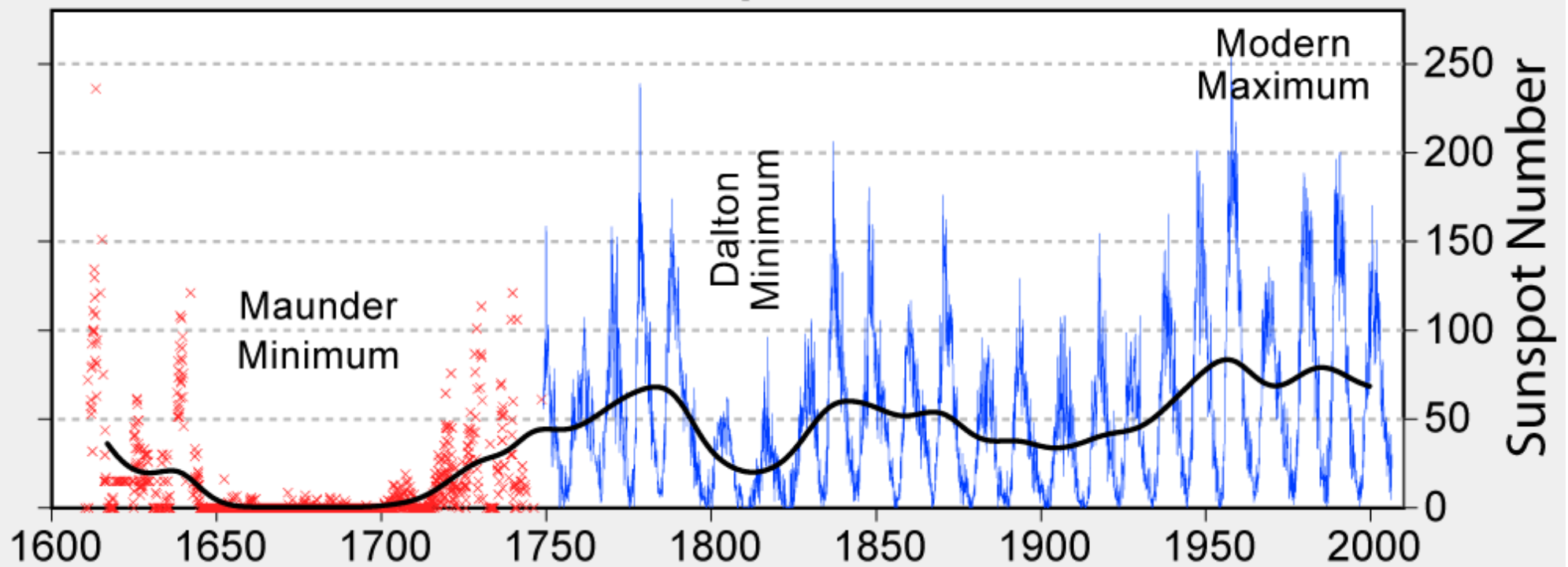
Planned: Bepi-Colombo, to Mercury left 2018, arrives 2025

ETH Sternwarte 1859-1864, built by Wolf

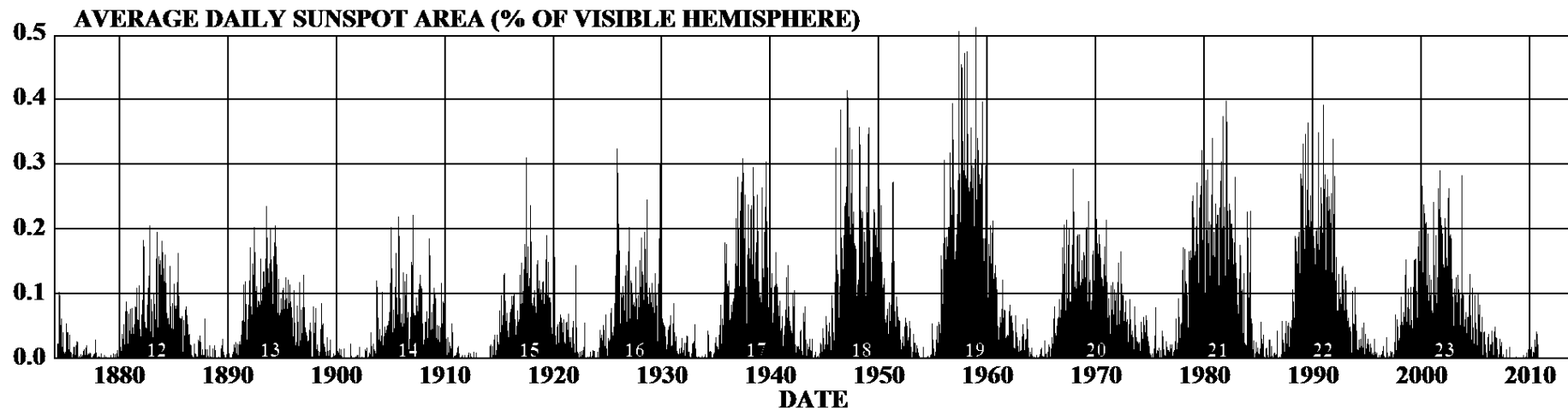
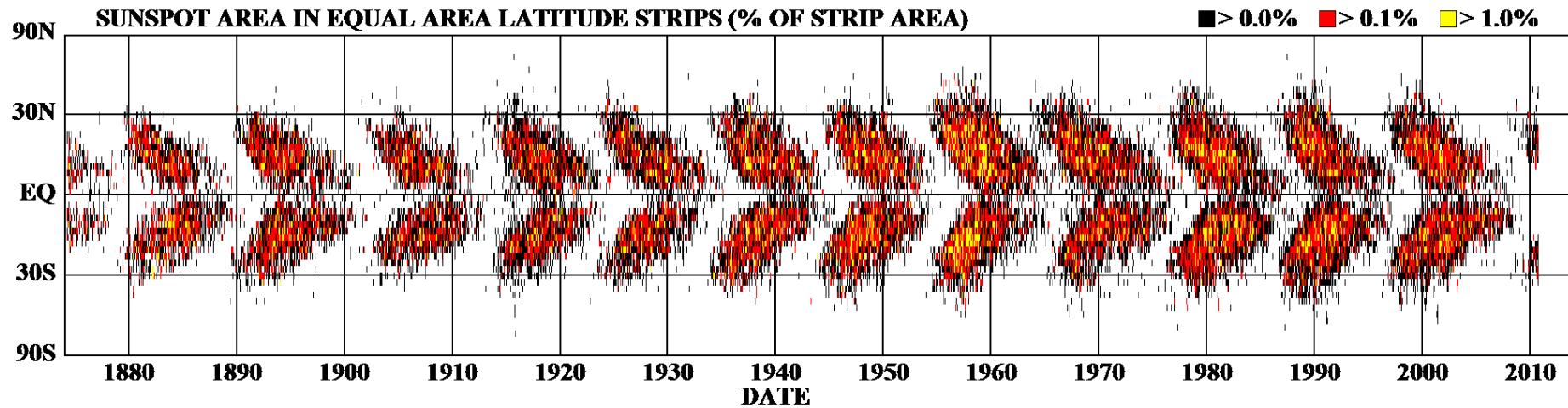




400 Years of Sunspot Observations



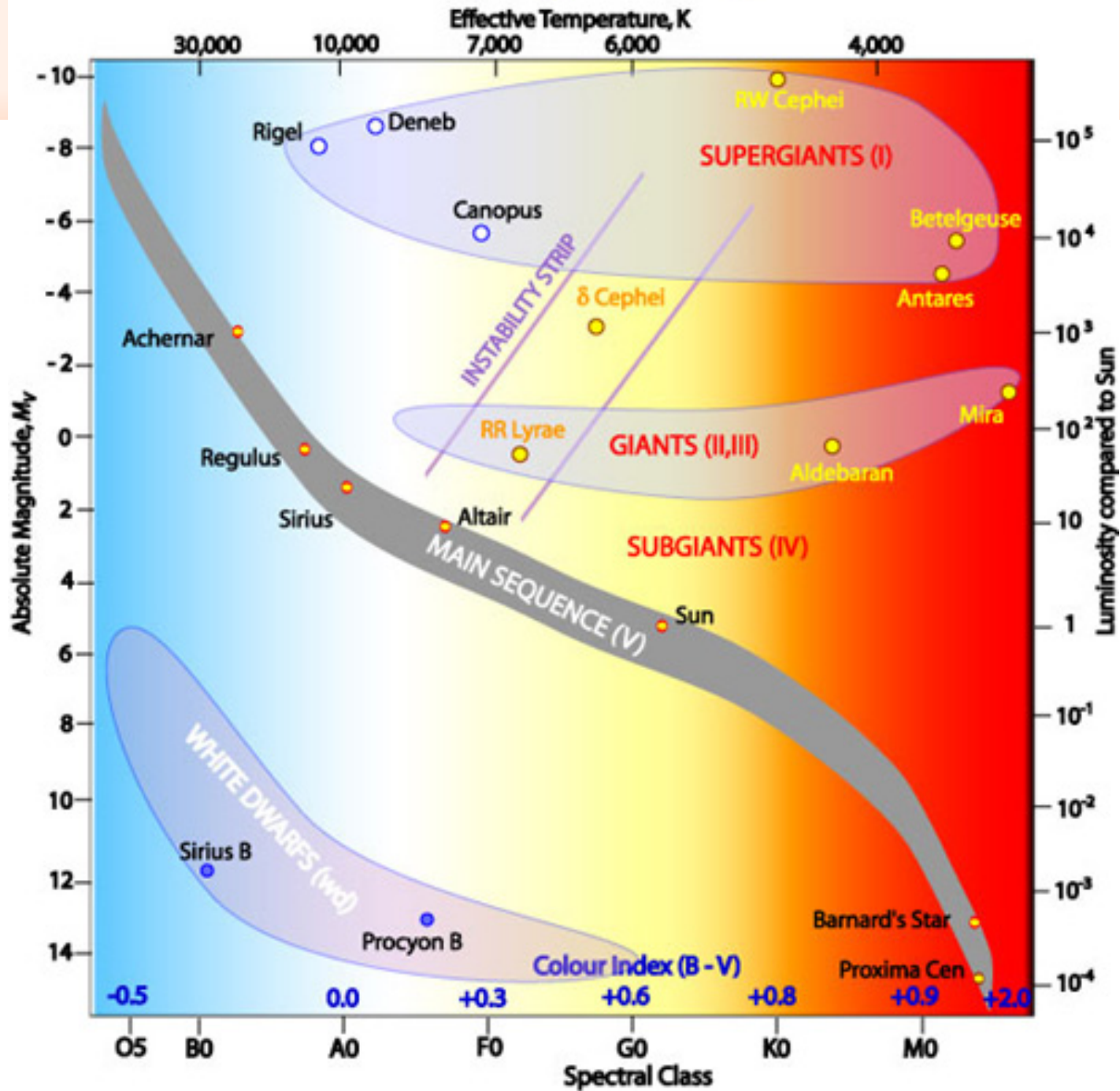
DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



Magnetic fields of stars

Stars other than our Sun also are found to have magnetic fields

Hertzsprung-Russell Diagram



Detection of magnetic fields on stars

Tools to detect fields: Zeeman splitting

See http://www.ast.obs-mip.fr/article.php3?id_article=457

the many faces of dynamo

explore M_{\star} vs P_{rot} diagram

detect Zeeman signatures & map large-scale field

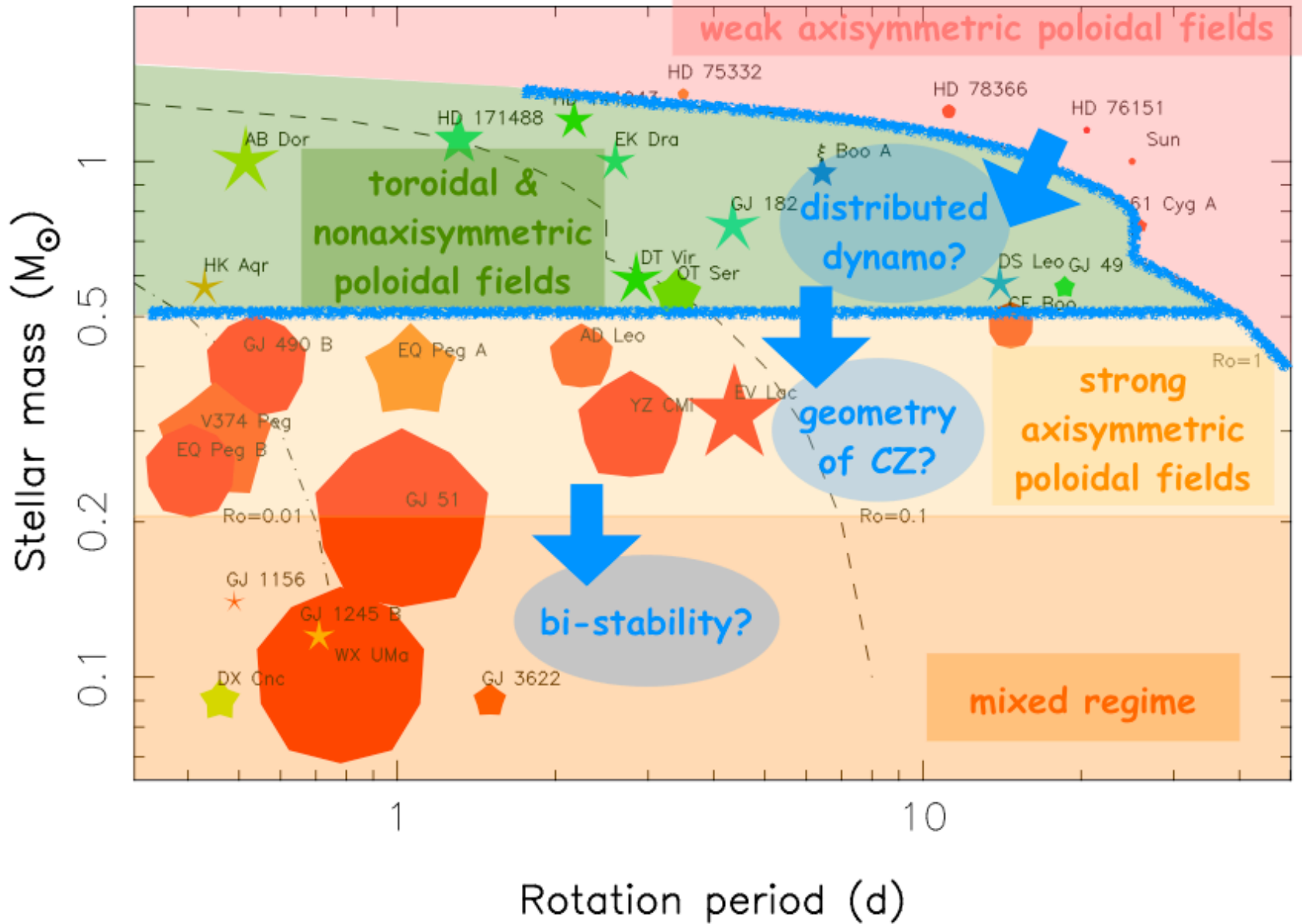
M_{\star} : from 0.1 to 1.5 M_{\odot} - P_{rot} : from 0.4 to 30 d

- > (i) magnetic energy, (ii) fractional energy of poloidal component & (iii) degree of axisymmetry of poloidal component

magnetic energy of large-scale field = symbol size

fractional energy of poloidal component = symbol color
poloidal - mixed - toroidal

axisymmetry of poloidal component = symbol shape
(● axisymmetric - ★ non-axisymmetric)



Even magnetic cycles have been found

Tau Boo – first star (other than Sun) to have a magnetic cycle:
fields flip sign every 1.1 years.

Also is known to have an orbiting exoplanet Tau Boo b
(5.9 Jupiter masses) see

<http://www.openexoplanetcatalogue.com/system.html?id=tau%20Boo%20A%20b>

Exoplanets

