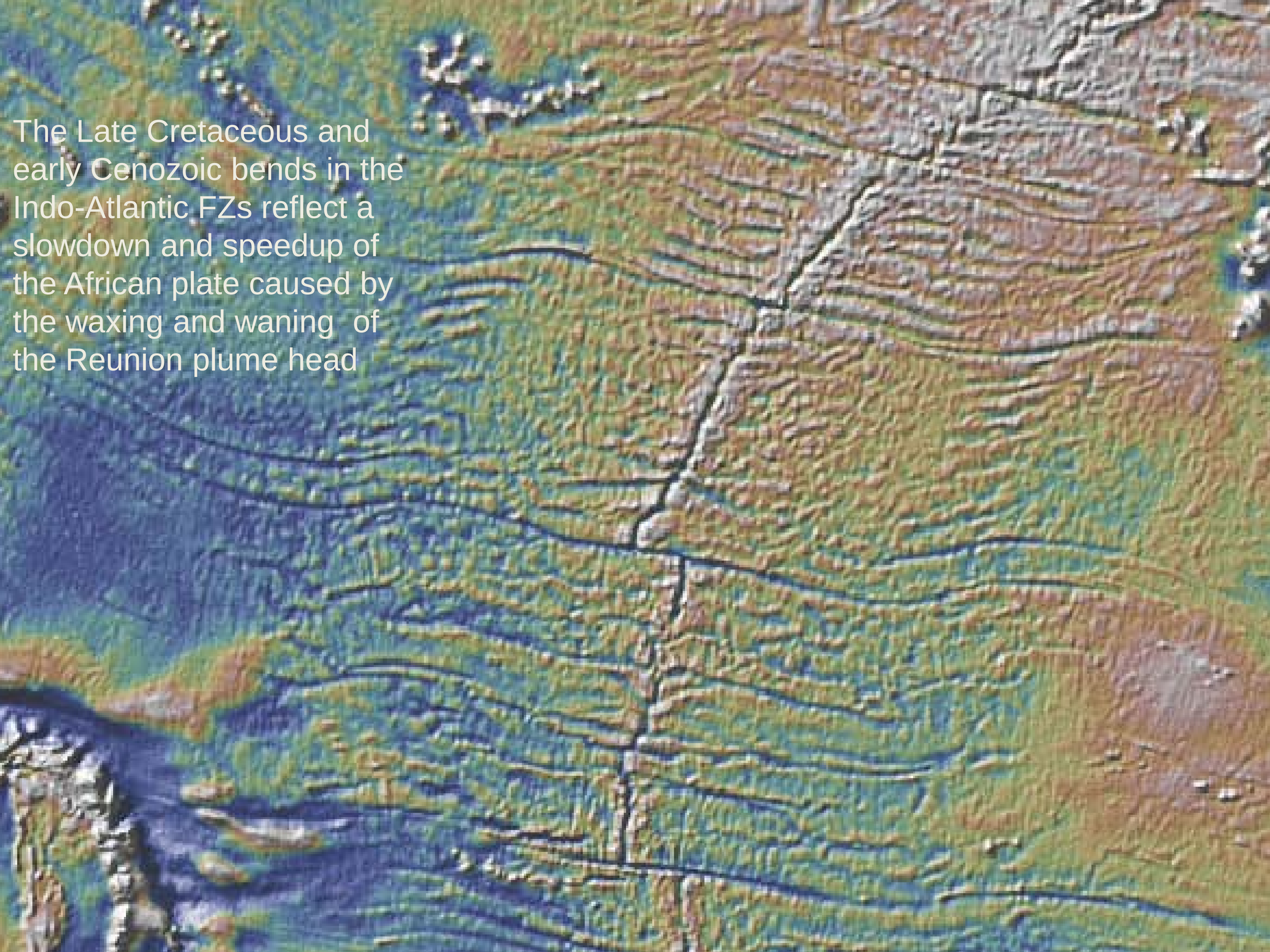
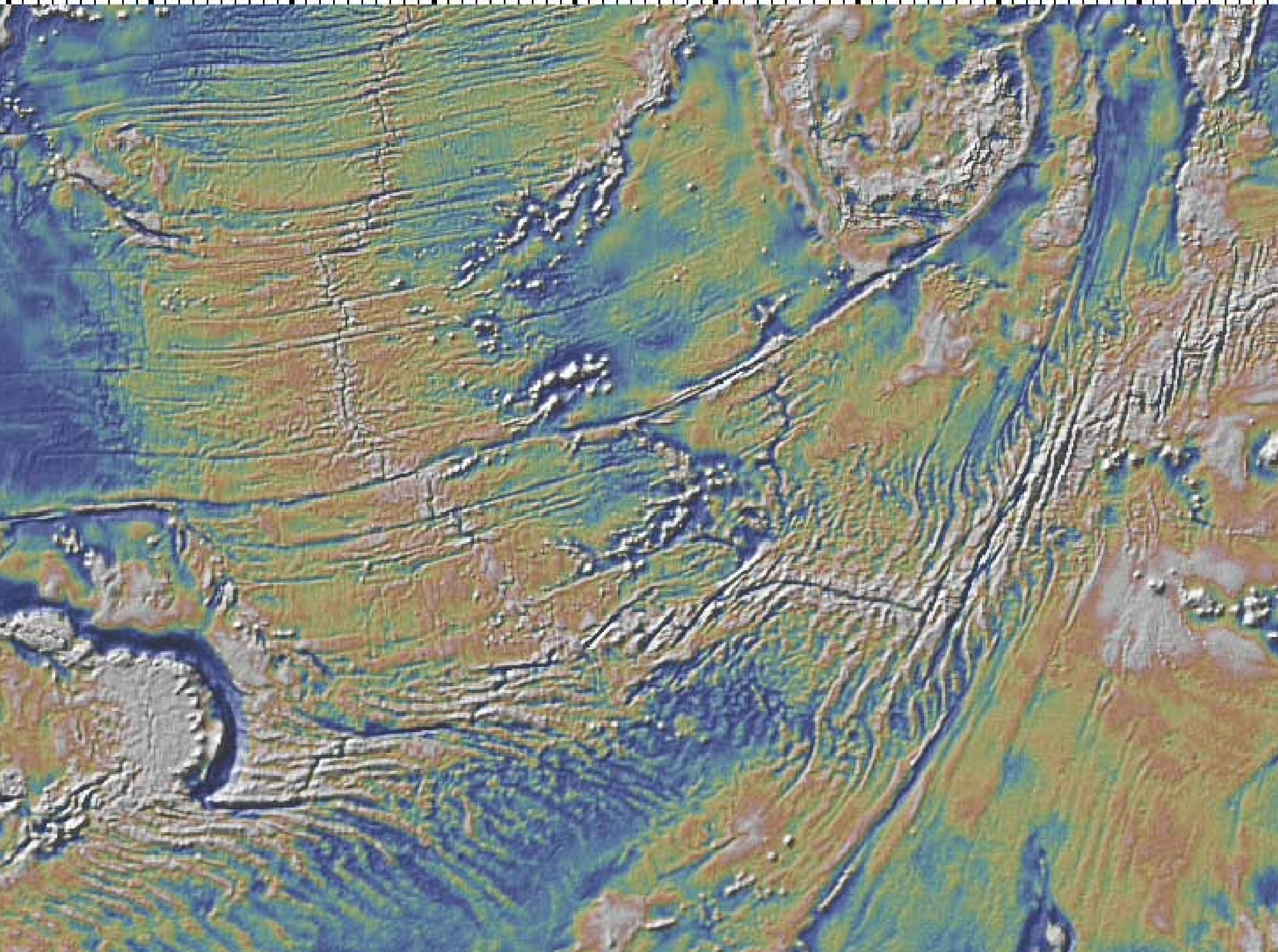
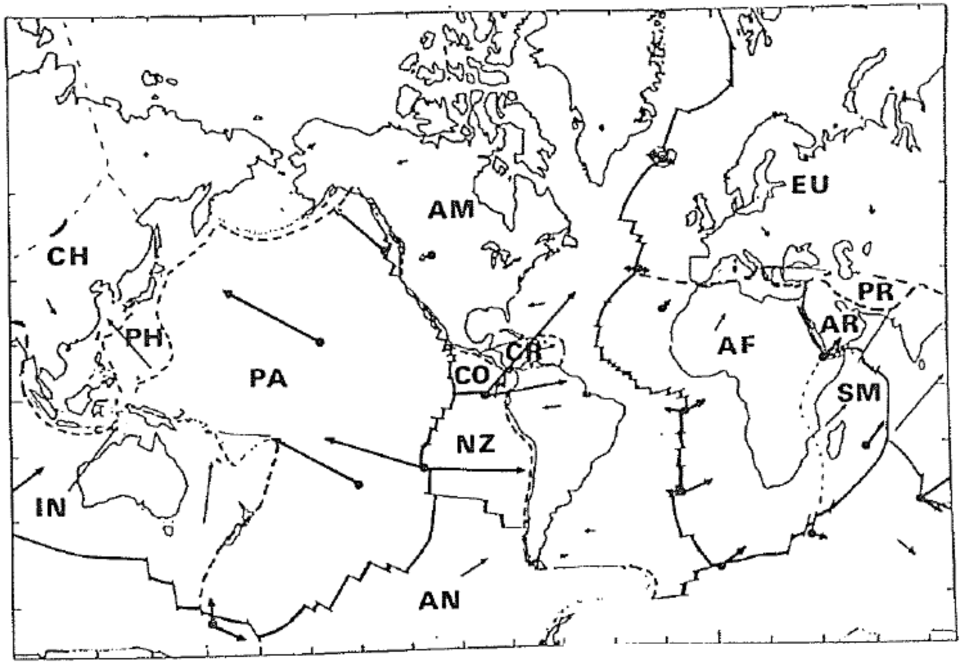
Effect of the Reunion plume head on Indo-Atlantic tectonics in the Late Cretaceous and early Cenozoic

Steve Cande and Dave Stegman


The Late Cretaceous and
early Cenozoic bends in the
Indo-Atlantic FZs reflect a
slowdown and speedup of
the African plate caused by
the waxing and waning of
the Reunion plume head

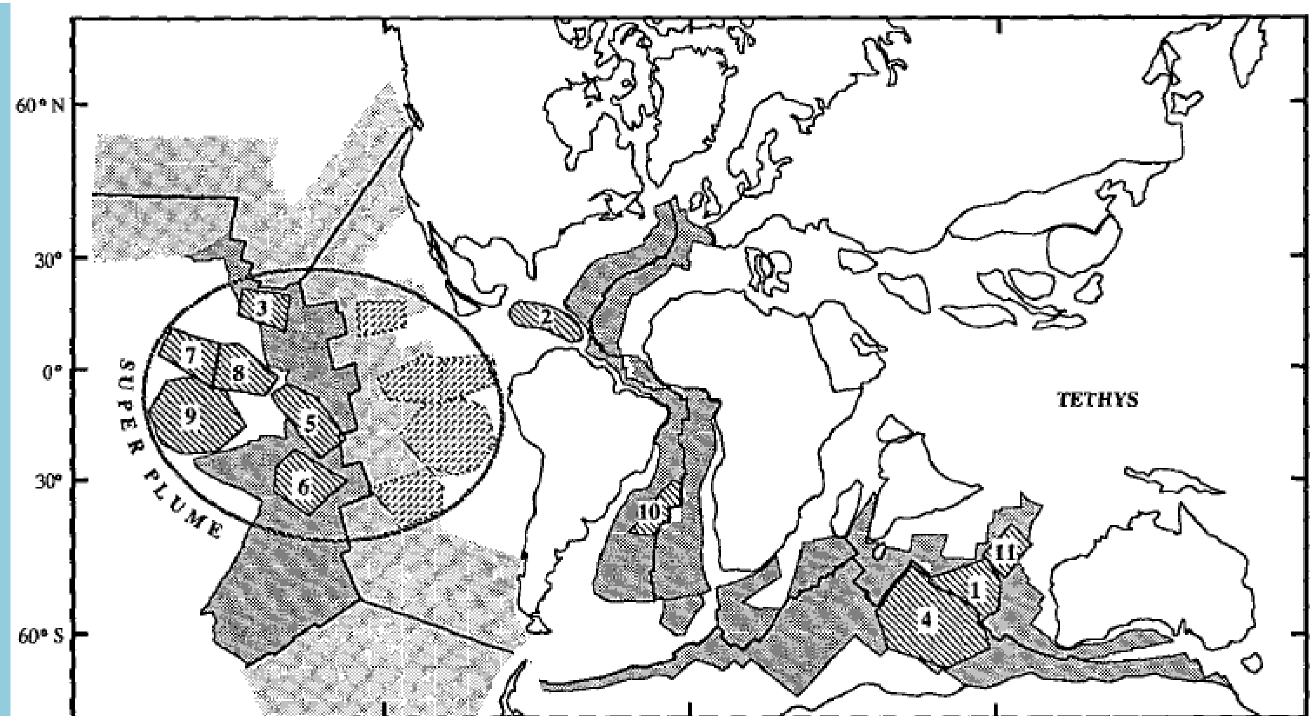




What role do plumes play in driving plates?

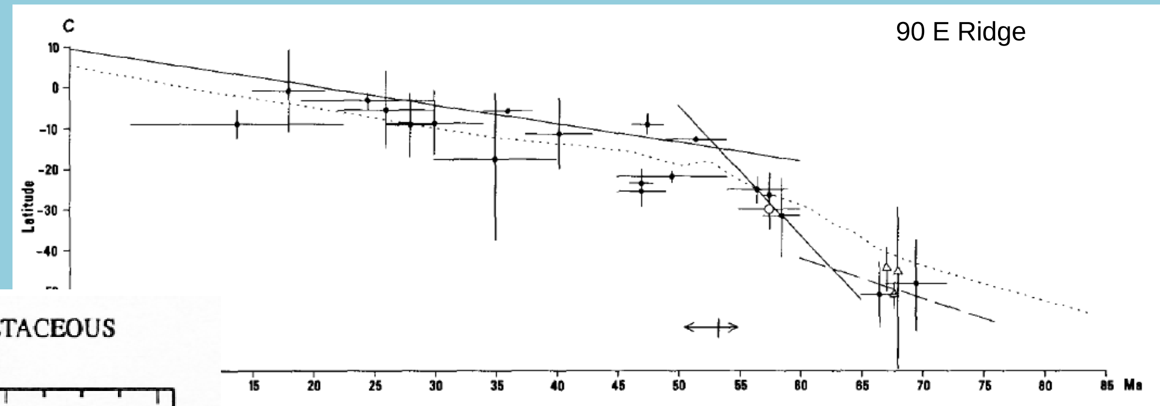
Some speculation but no obvious plume driving force; it's mostly slab pull and ridge push.

Morgan (1972)

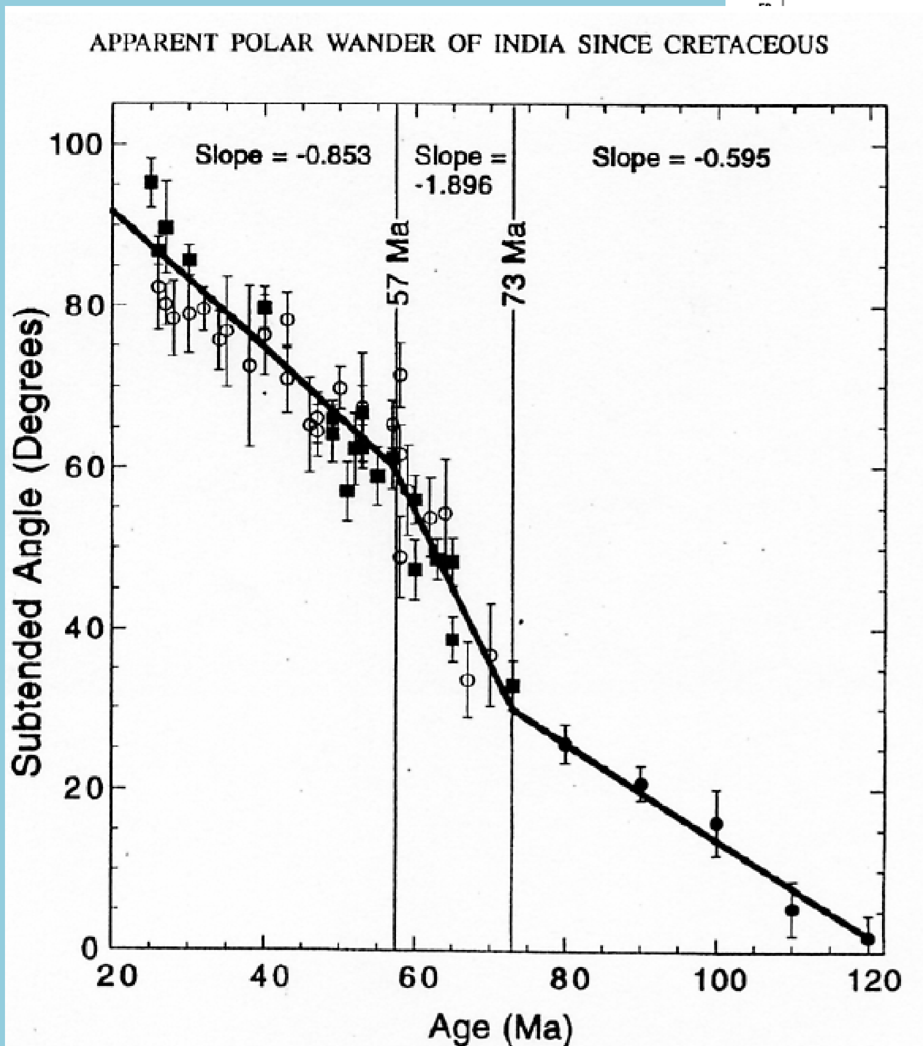


Larson's Superplume (1991)

If there ever was a candidate for a plate being driven by plume forces, it is India in the Late Cretaceous and early Cenozoic



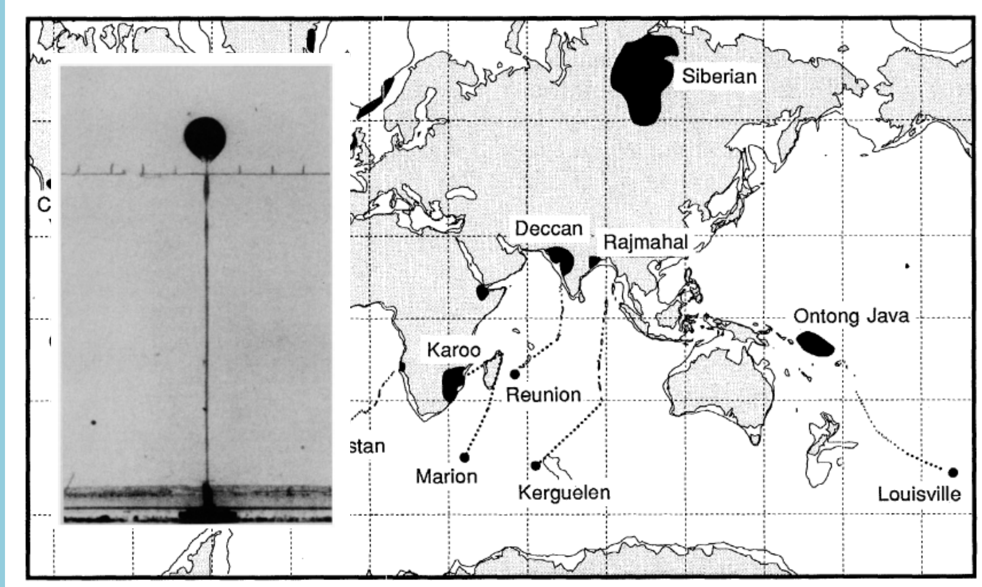
Klootwejk et al. (1991)



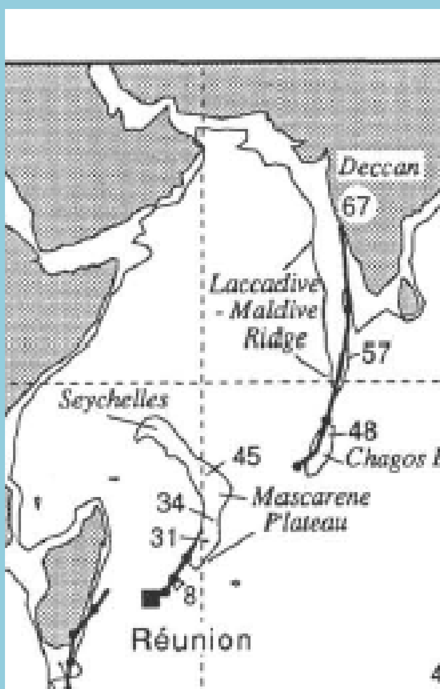
Paleomagnetic studies constrain the fast motion of India to a relatively short interval of ~15 Ma

Acton (1999)

The connection being the Reunion plume head

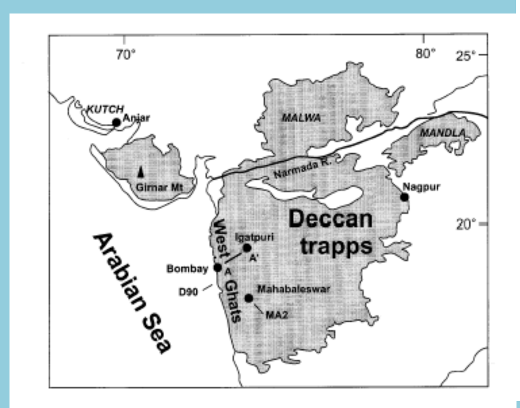


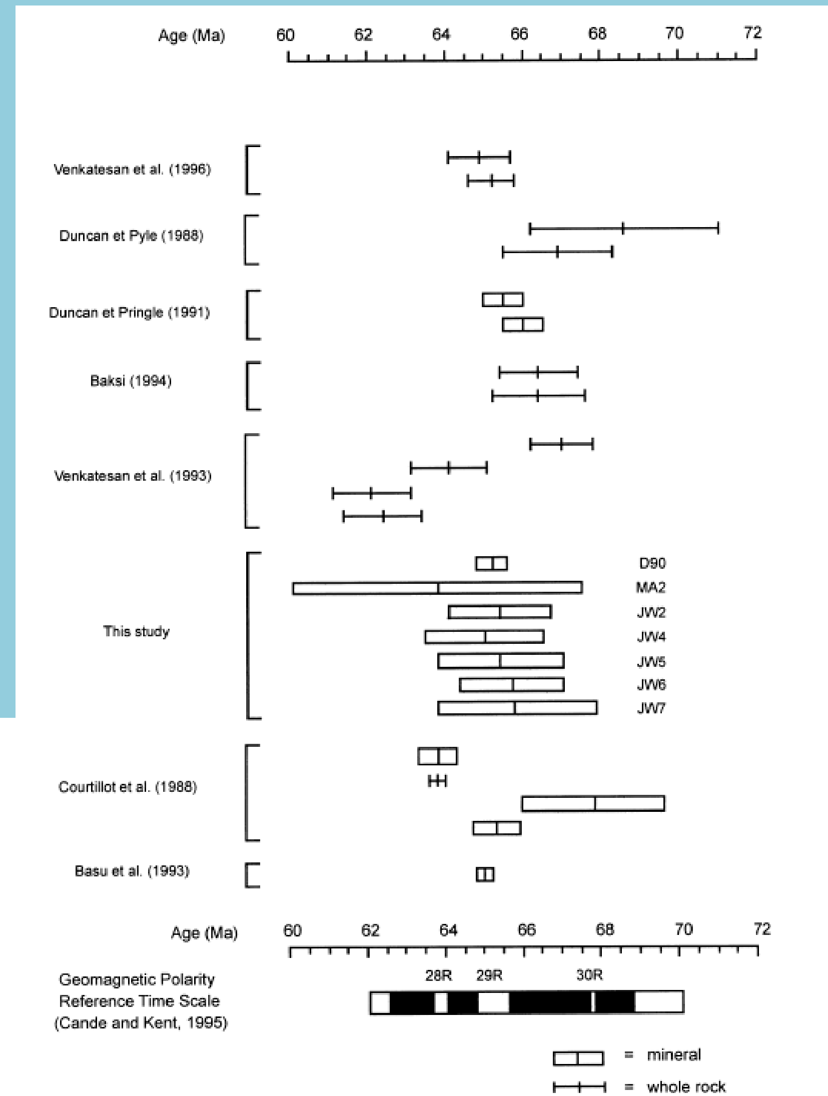
Richards et al. (1989)



Duncan (1991)

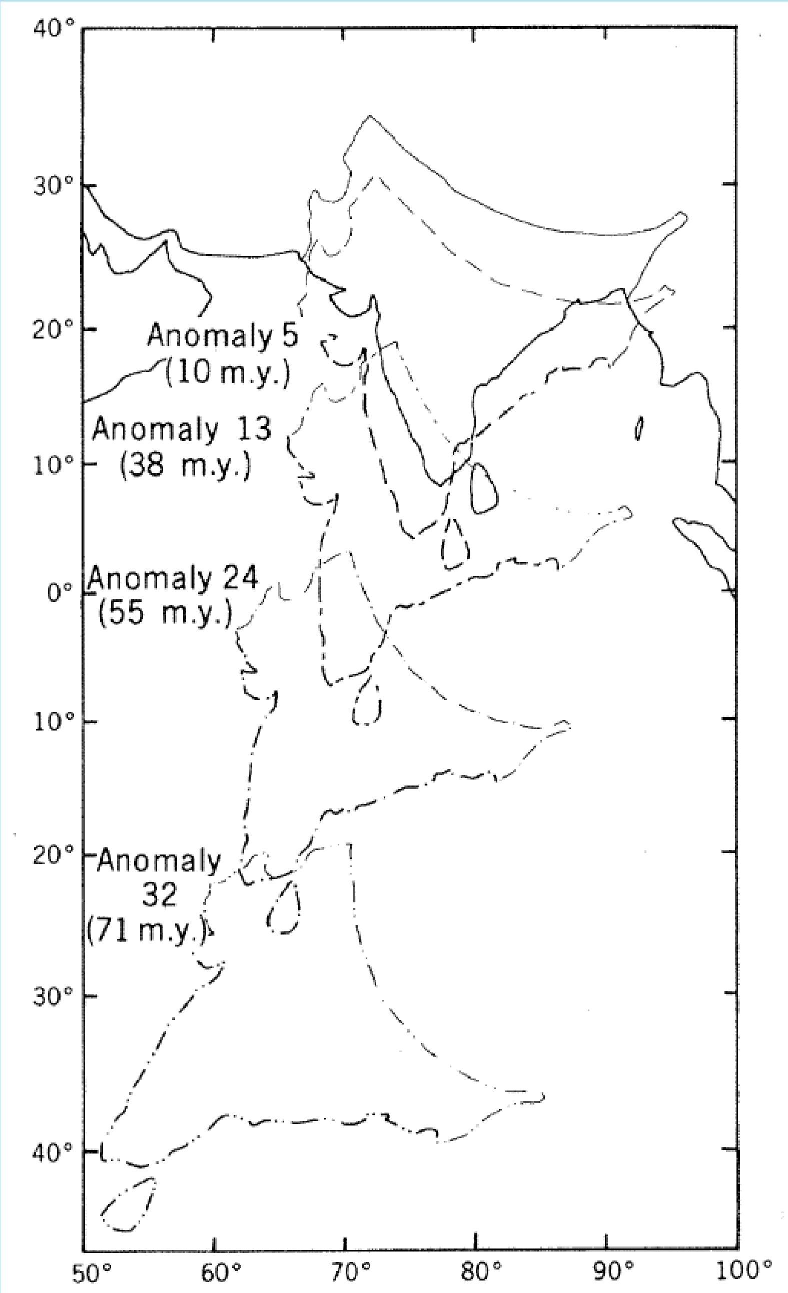
Ar-Ar ages of Deccan Traps cluster around 65.5 Ma straddling the K/T boundary



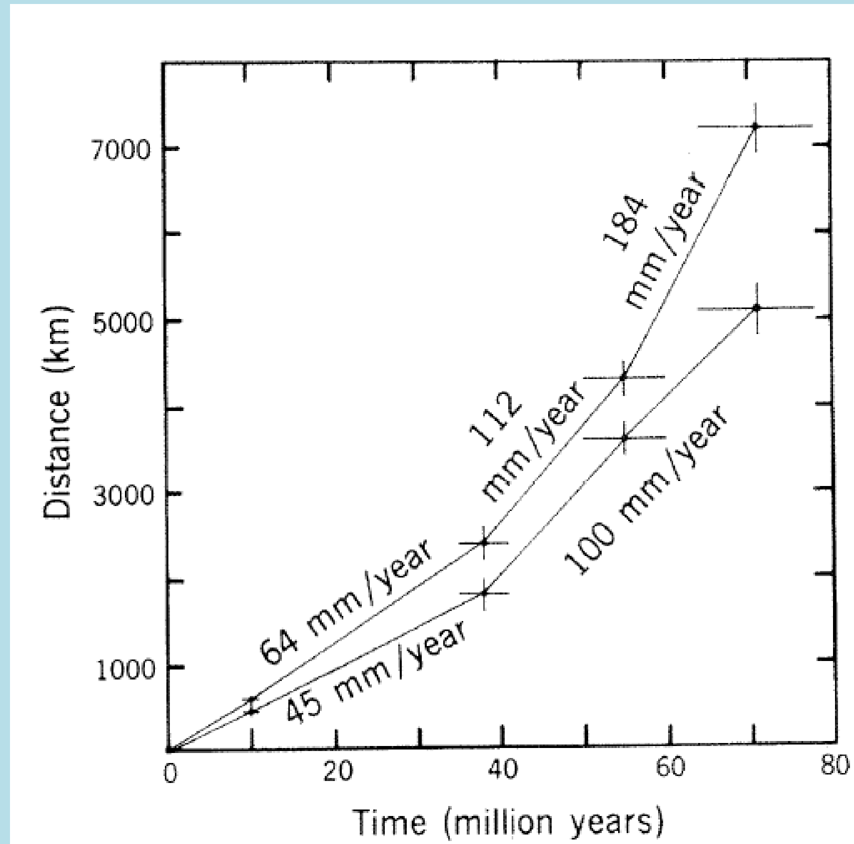


Hofmann et al. (2000)

Indian Ocean Tectonics 101



Slowdown of India between 55 and 40 Ma has long been associated with the collision of India with Eurasia

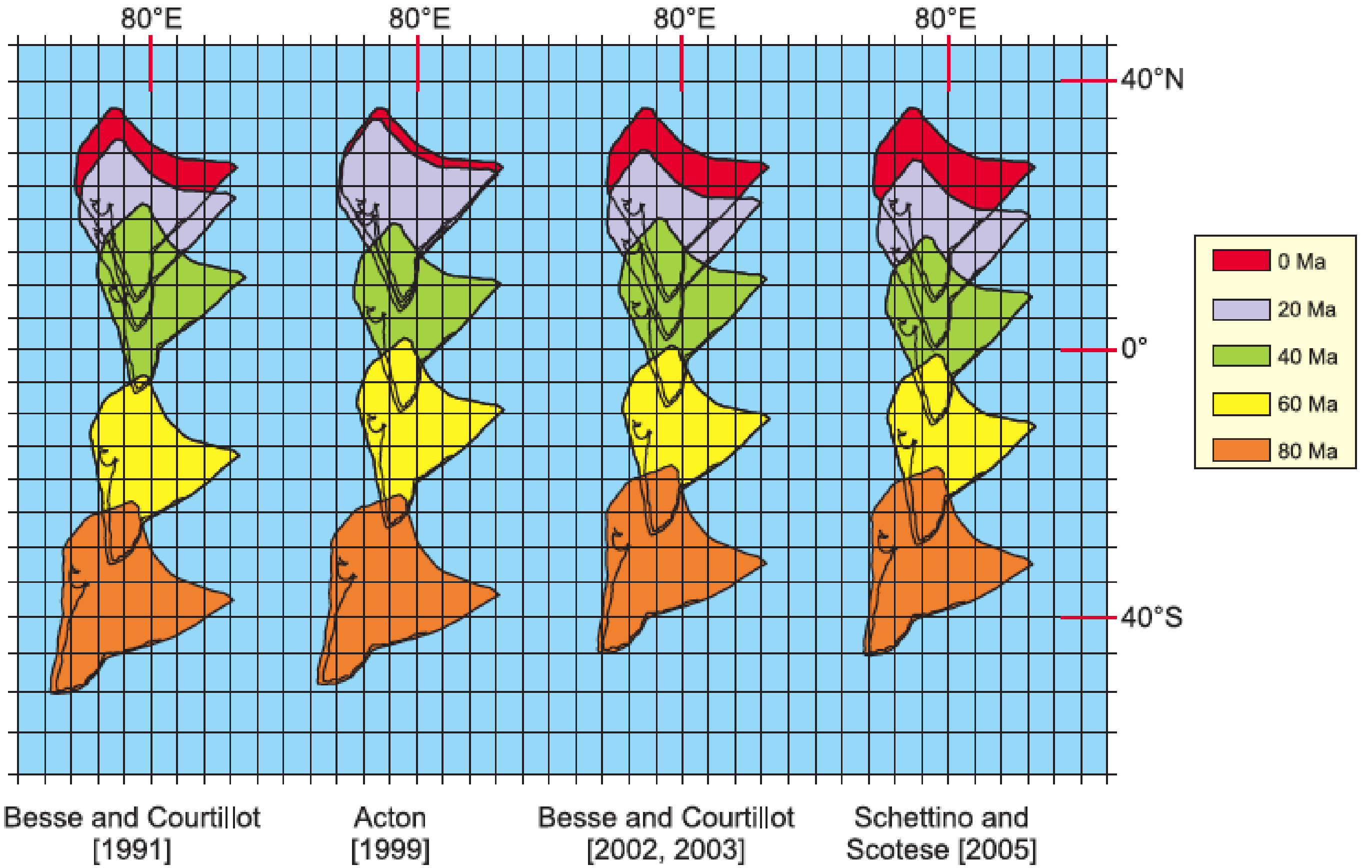


Molnar and Tapponnier (1975)

When and where did India and Asia collide?

Jonathan C. Aitchison,[1] Jason R. Ali,[1] and Aileen M. Davis[1]

(2007)



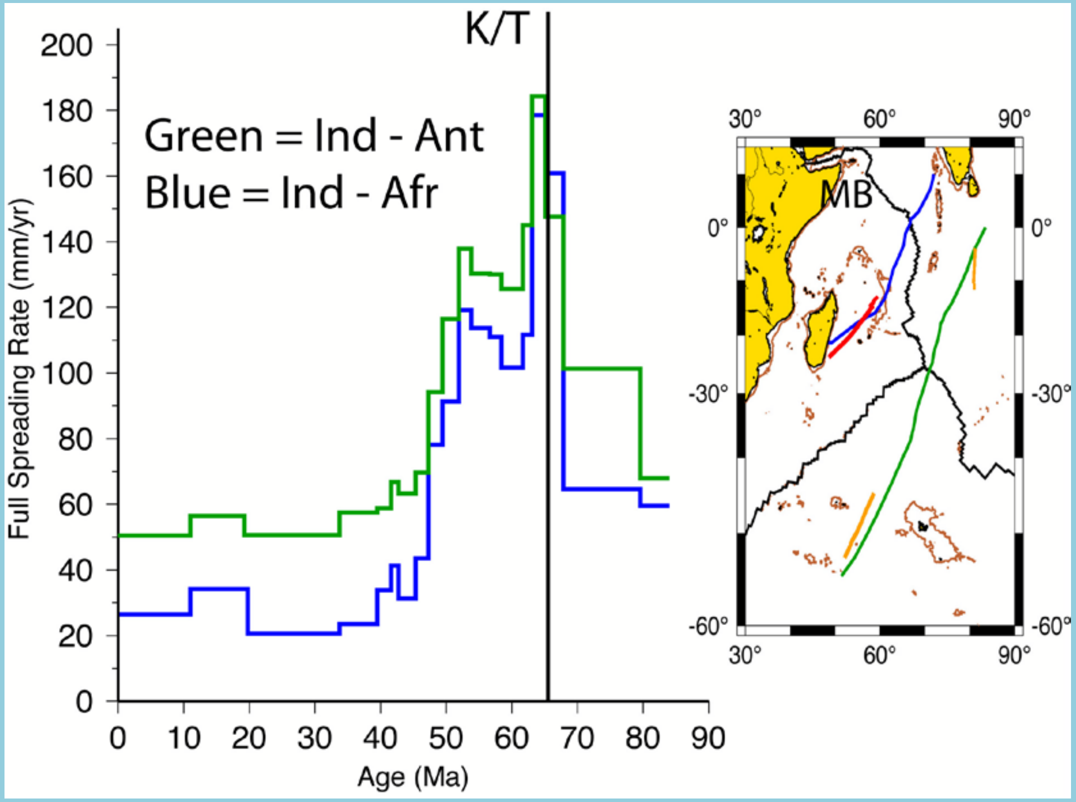
Still controversial. Some say 55 Ma, others say as young as 35 Ma

55 Ma "event" might correspond to collision with an island arc

Size of "Greater India"

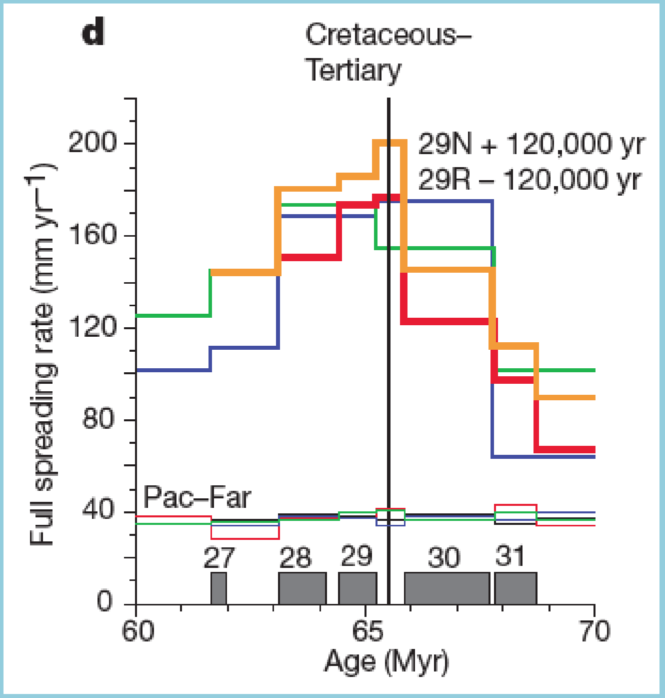
Revised history of rapid spreading:

The speed up started around 68 Ma, peaked around the K/T boundary (65.5 Ma), and fell off twice, first around 62 Ma, and again between 52 and 45 Ma.

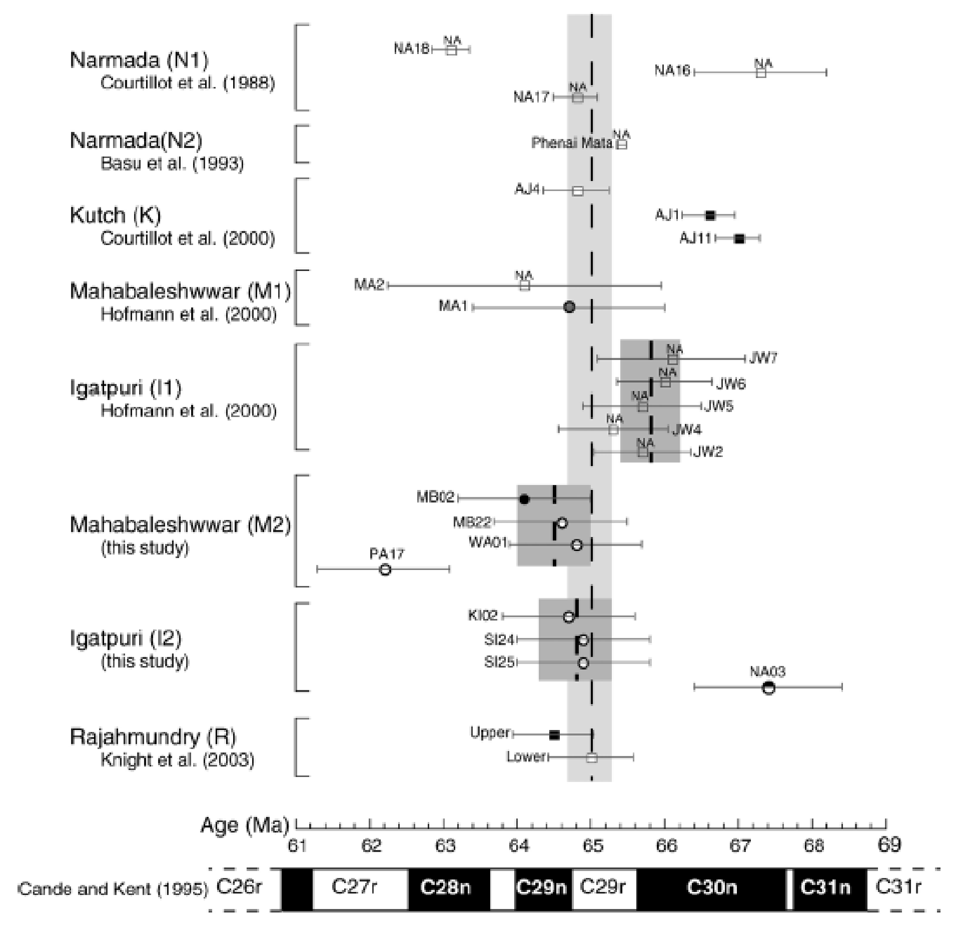


Cande and Stegman (2011)

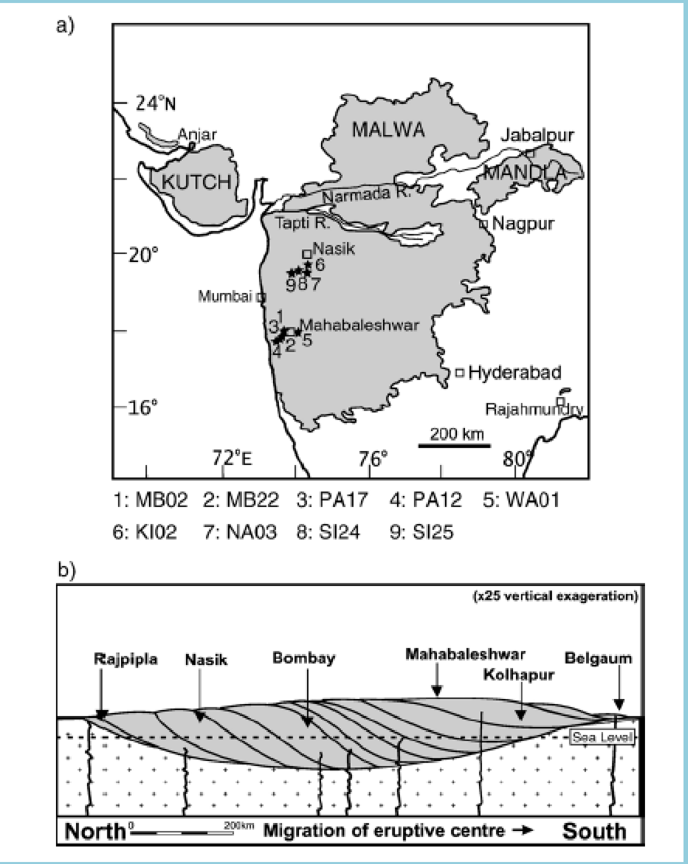
If zoom in on the period from 70 to 60 Ma, see that fastest motion was at Chron 29R



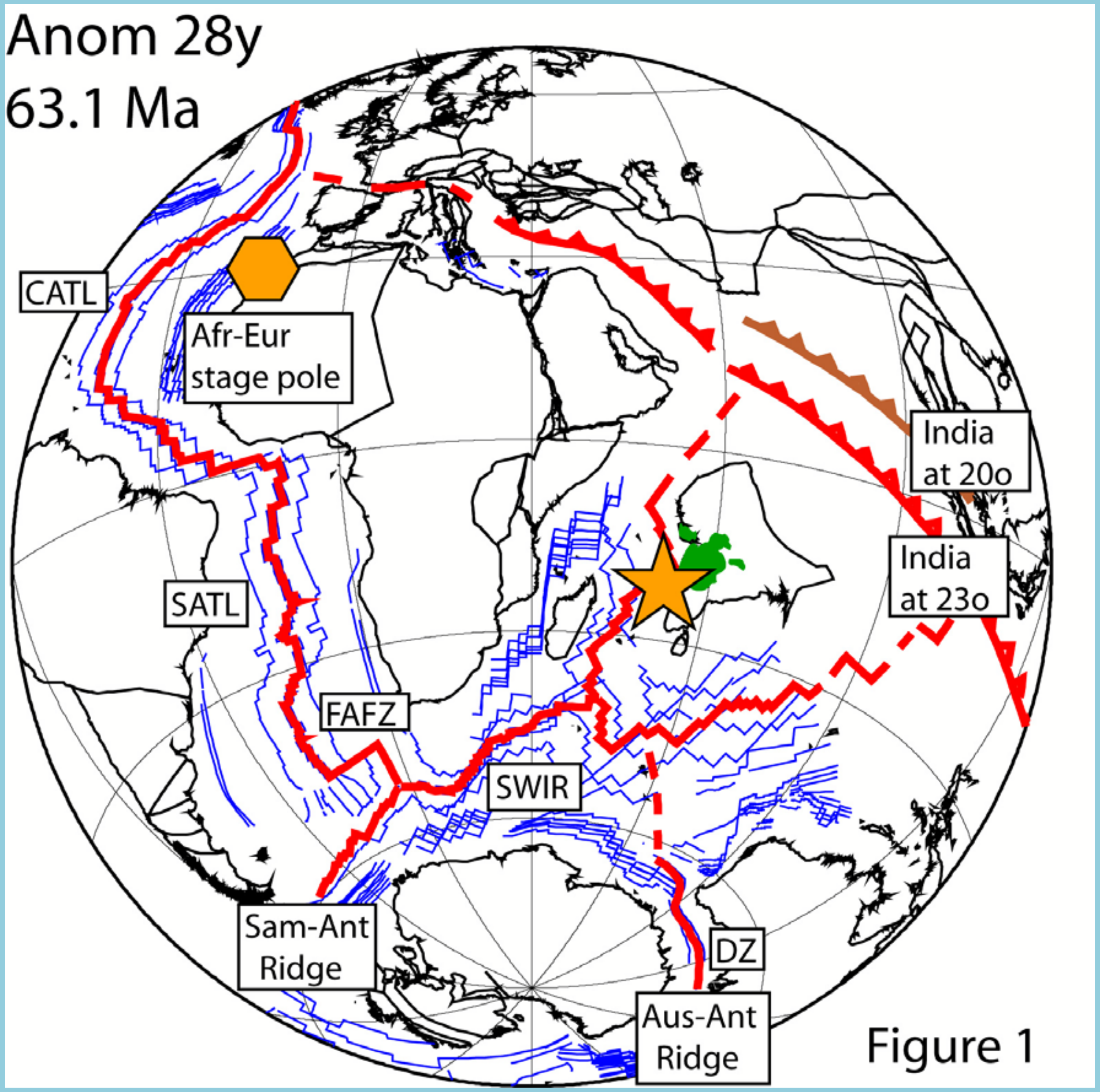
The time of fastest spreading was roughly synchronous with the maximum outpouring of Deccan flood basalts – Chron 29



75% of the eruptive volume during Chron 29R. Eruptions started around Chron 30/31.



(Chenet et al., 2007)

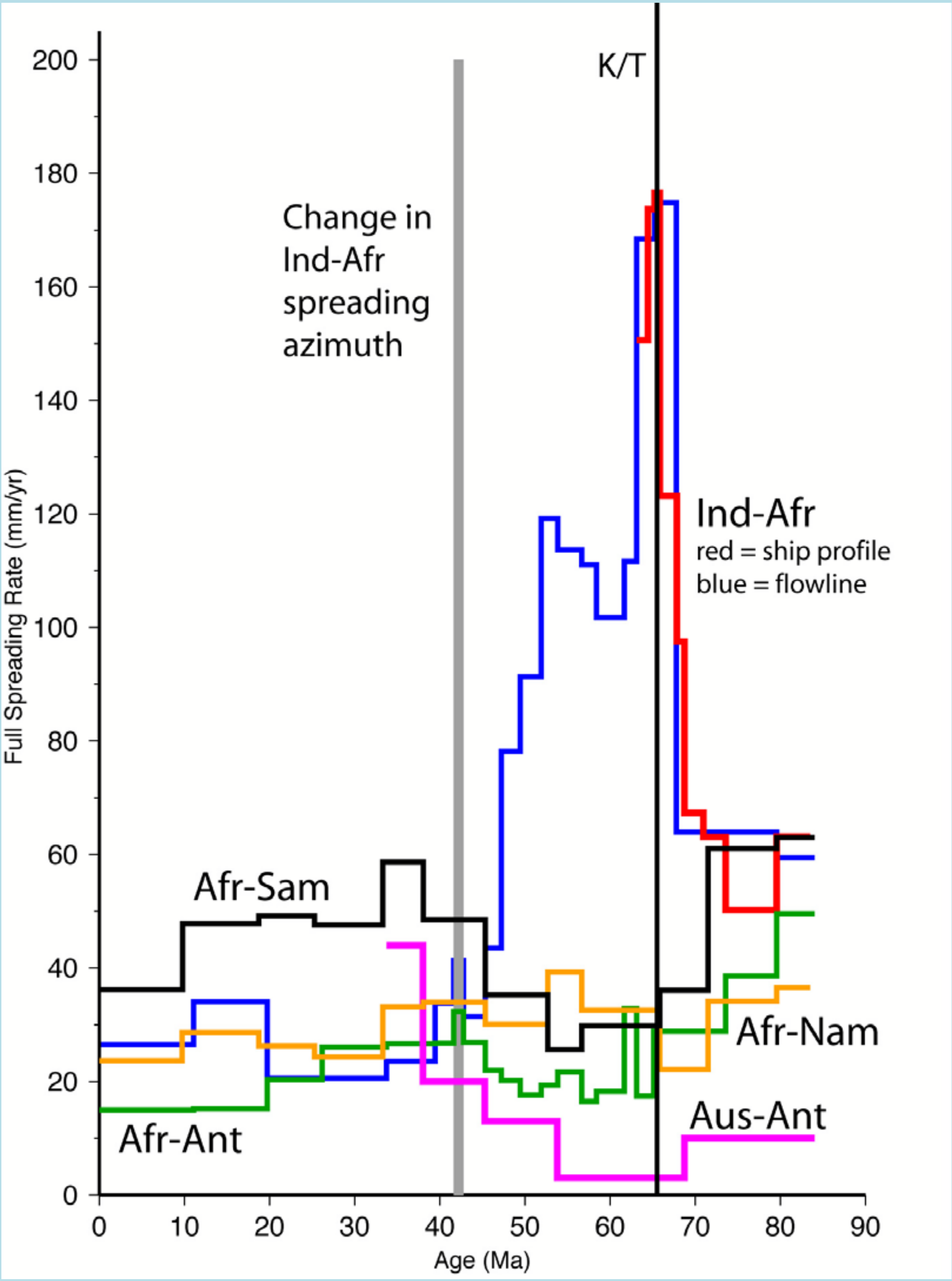


More clues …

The speed-up of India was accompanied by a slowdown in Afr-Nam, Afr-Sam and Afr-Ant and by dramatic changes in spreading direction.

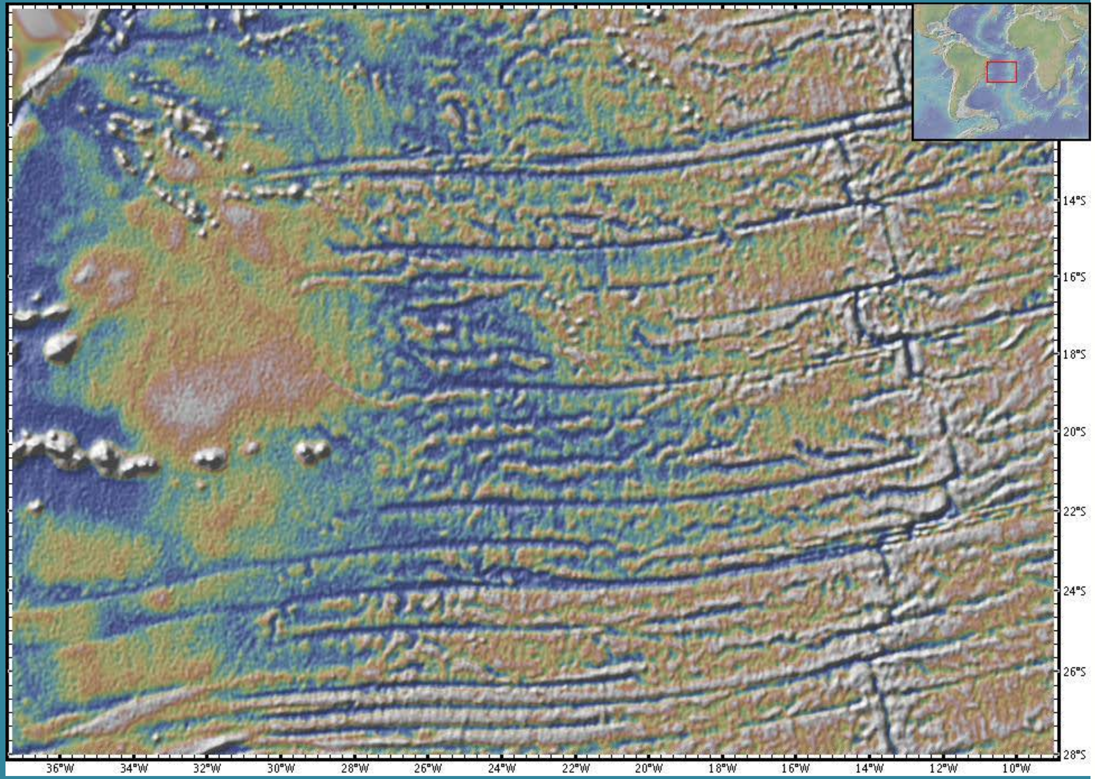
(Cande and Stegman, 2011)

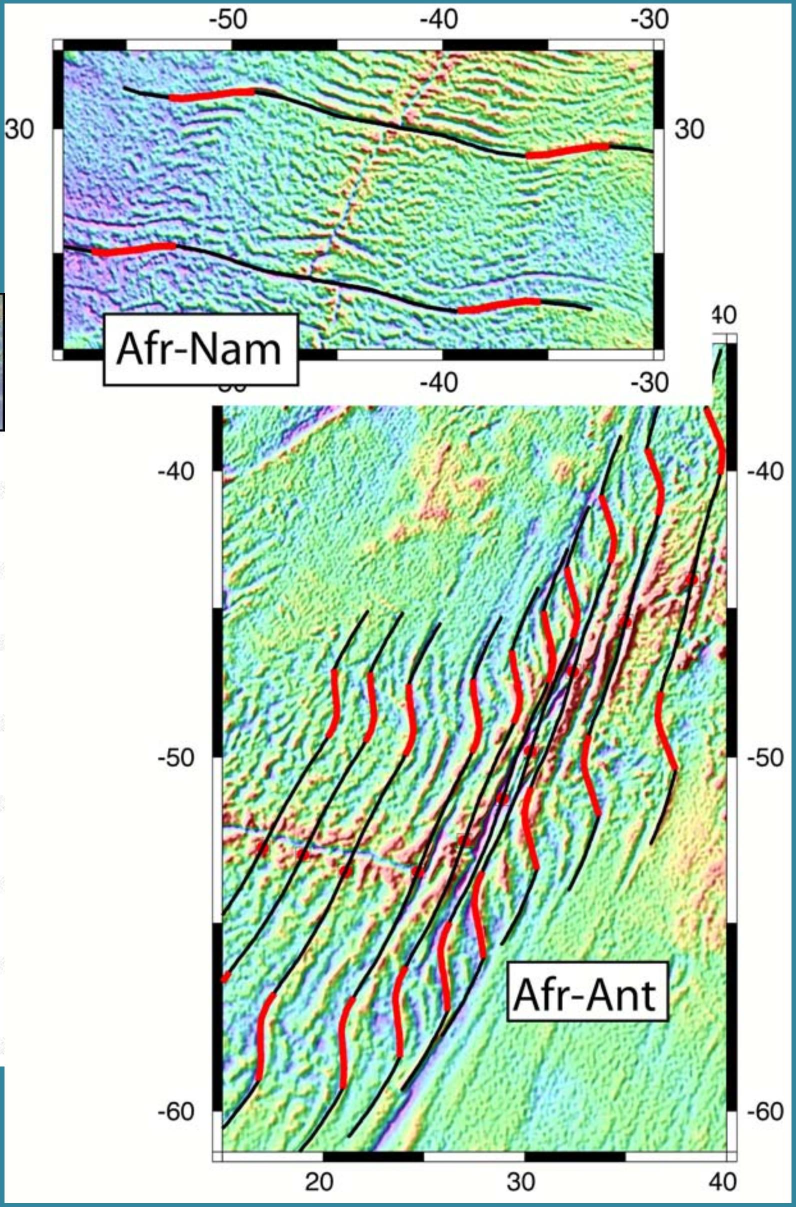
The speed-ups and slowdowns were in sync and transitory.



Cande and Stegman (2011)

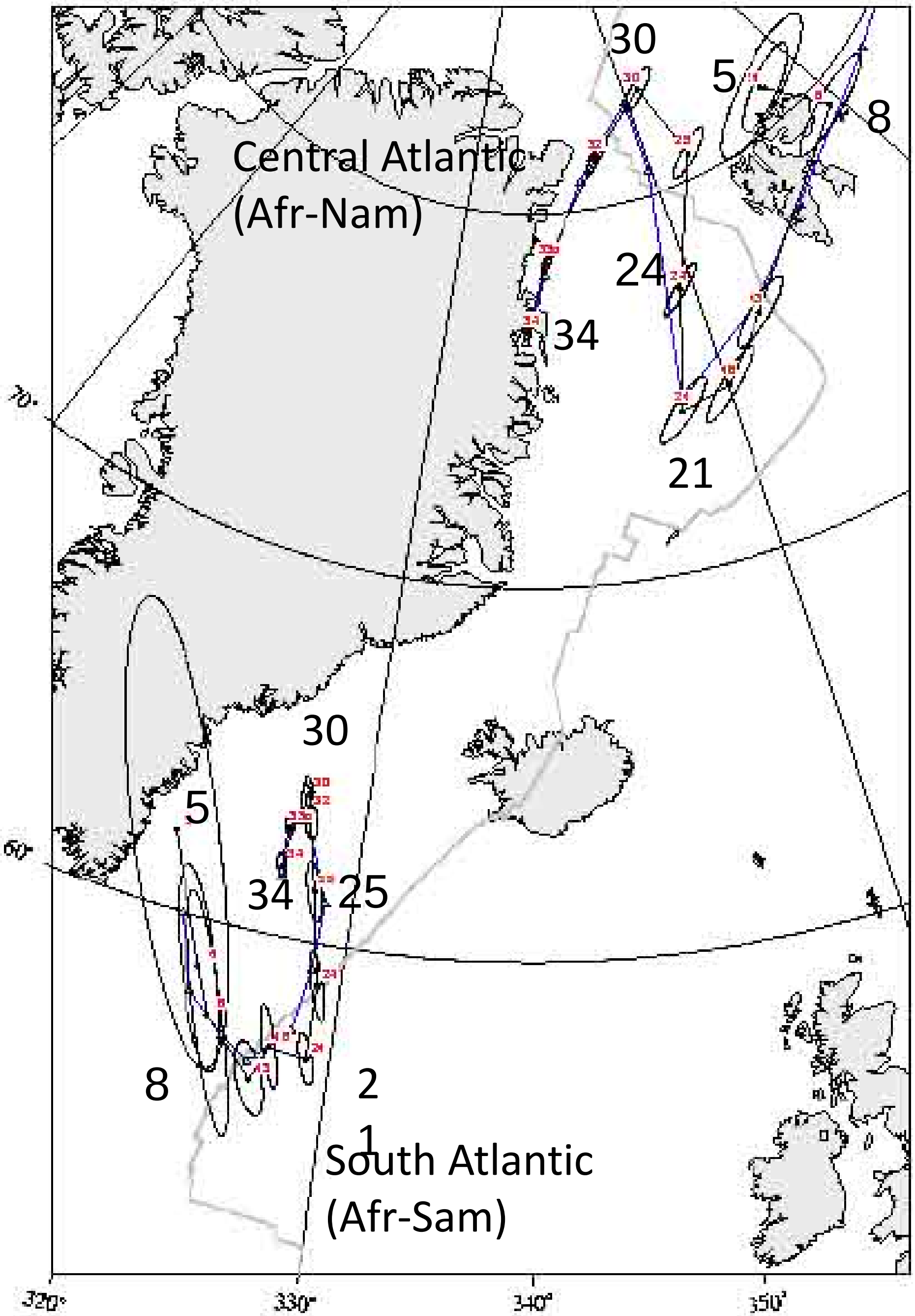
The slowdown/speed-up corresponds to dramatic changes in spreading direction, particularly in the Central Atlantic and SWIR





And a dramatic increase in the the topographic relief in the South Atlantic

Cande and Stegman (2011)



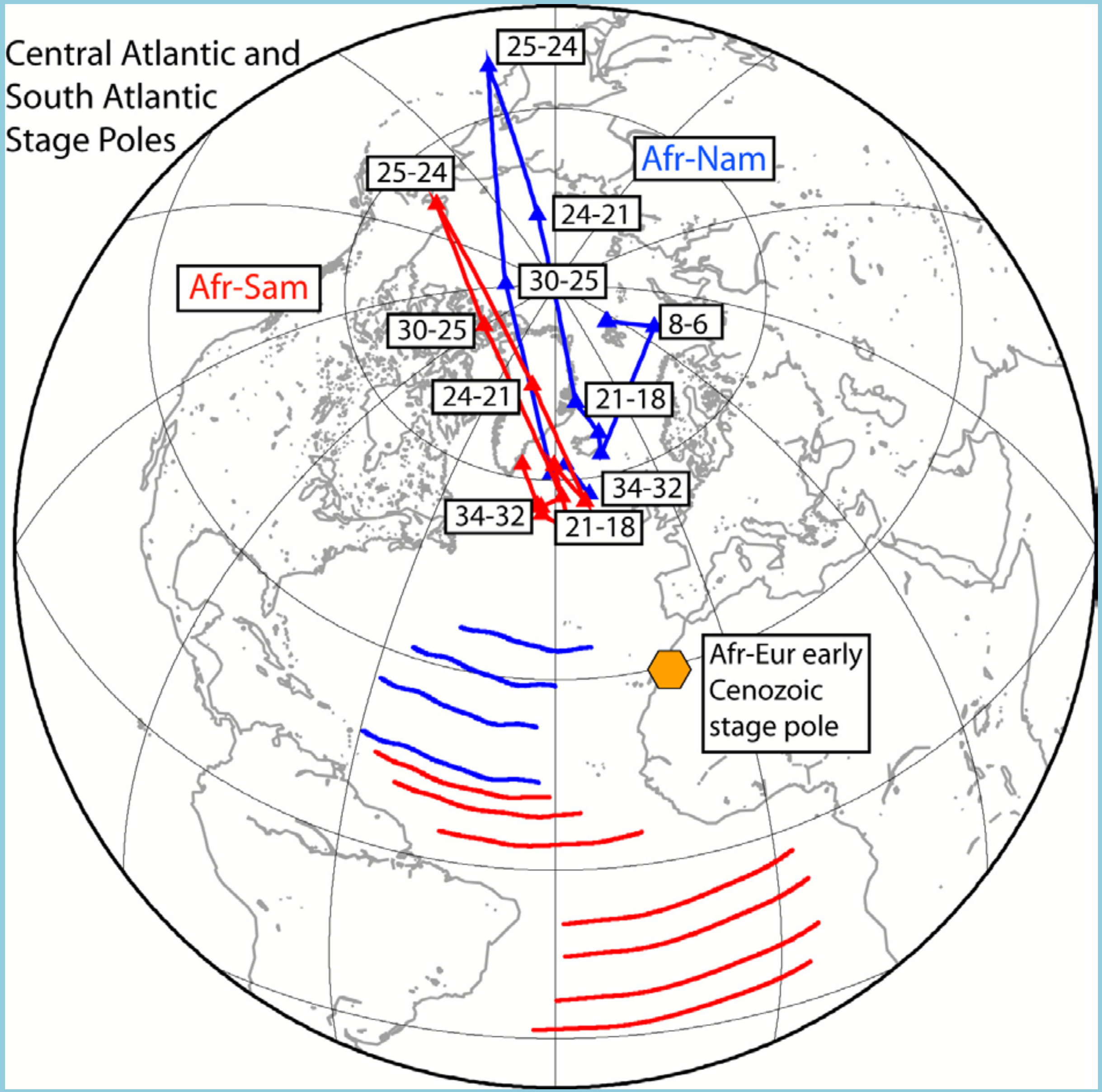
To understand the plate motions, look at the Euler finite rotations for Afr-Nam and Afr-Sam.

Both sets of finite rotations migrate northwards between Chrons 34 and 30 and then migrate southwards between Chrons 30 and 21.

Müller et al. (1999)

More revealing, look at the stage poles:

Central Atlantic and South Atlantic stage poles exhibit transitory “swings” starting around Chron 32 and ending around Chron 18.

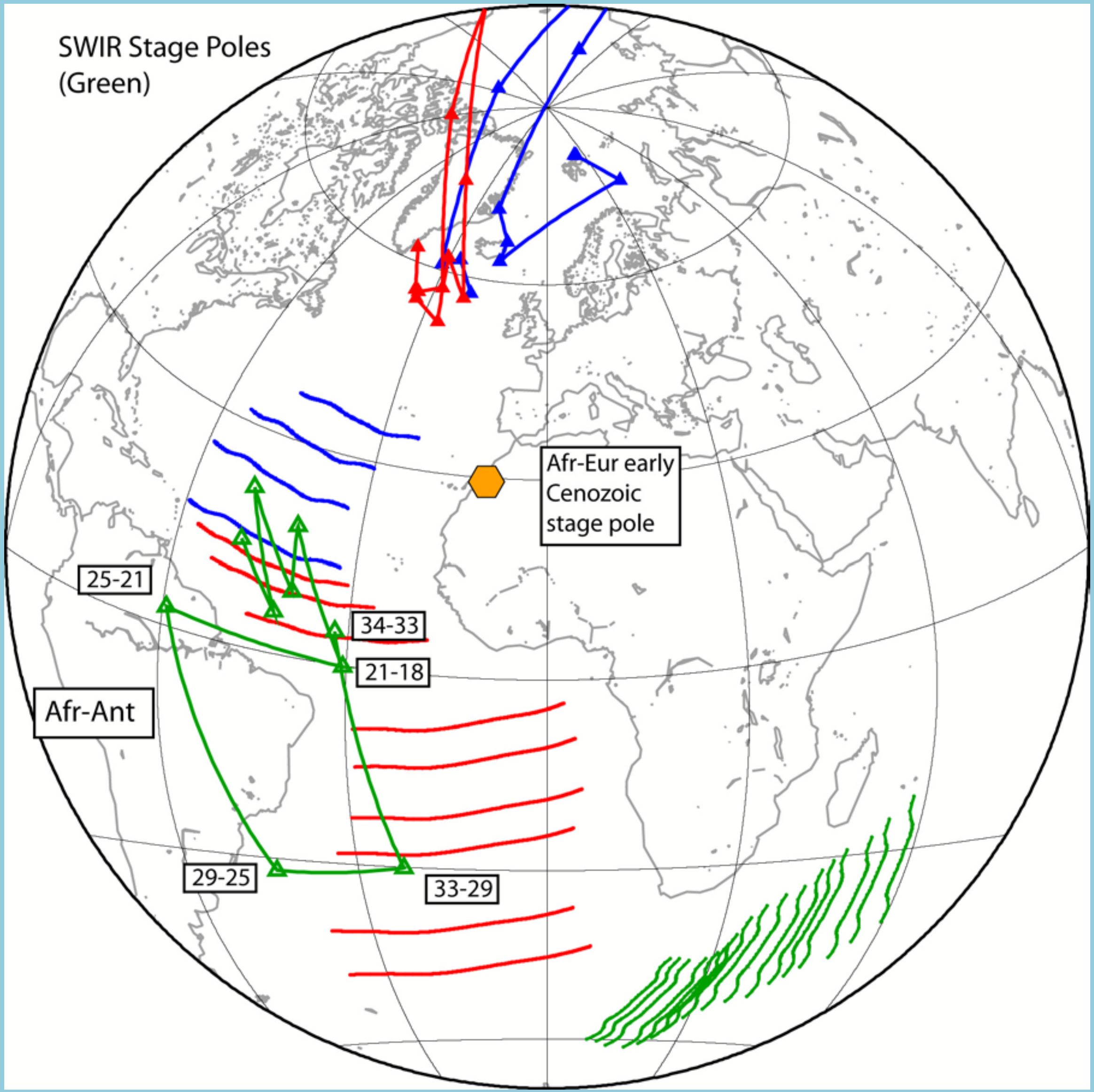


Stage poles from Müller et al. (1999)

The “swing” is also present on the Southwest Indian Ridge.

An arc passing through these poles intersects the other two arcs near the Afr-Eur stagepole

Treat stage poles as velocity vectors.



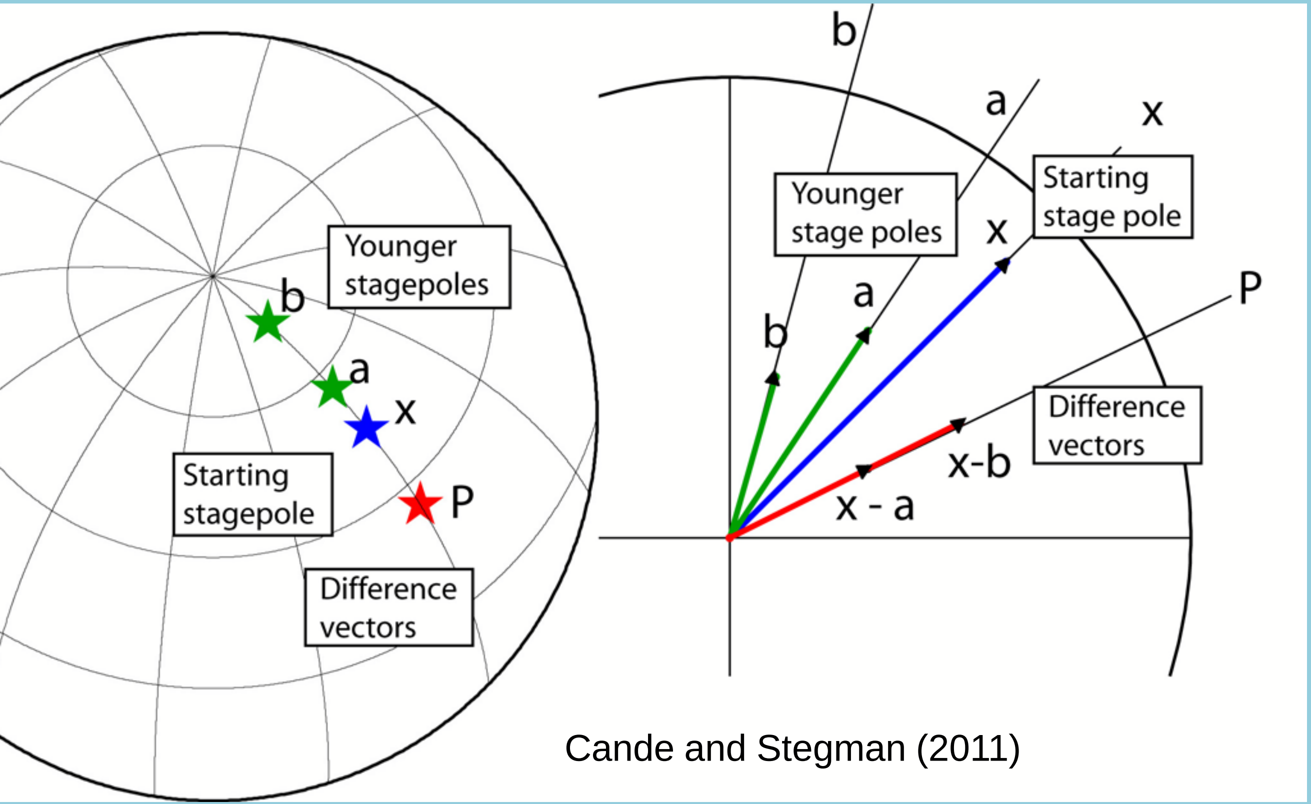
SWIR stage poles from Cande et al. (2010) and Nankivell (1997)

Stage pole swing:

Treat the stage poles as velocity vectors.

Find that as the locations of the vectors migrate, the rate changes in a systematic fashion

The difference between an intermediate vector and the starting vector always lies in the same place (P)

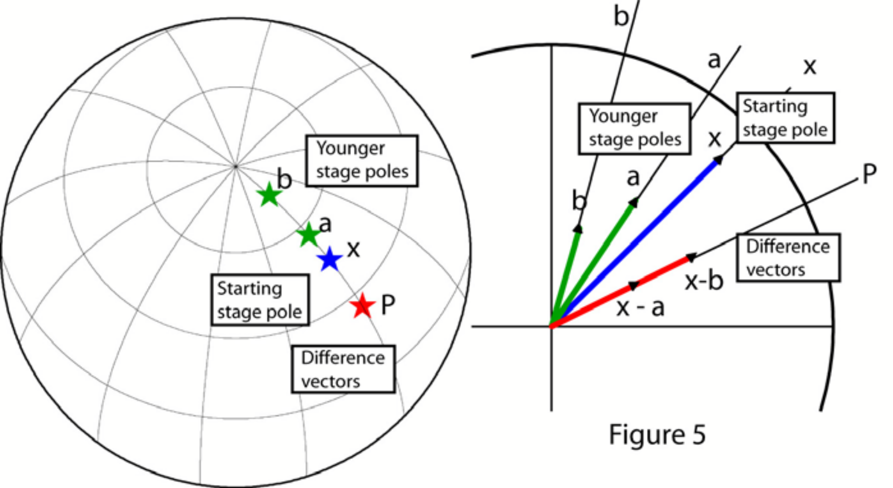


Cande and Stegman (2011)

Because this swing is seen on all three ridges, it is primarily the motion of Africa which is changing

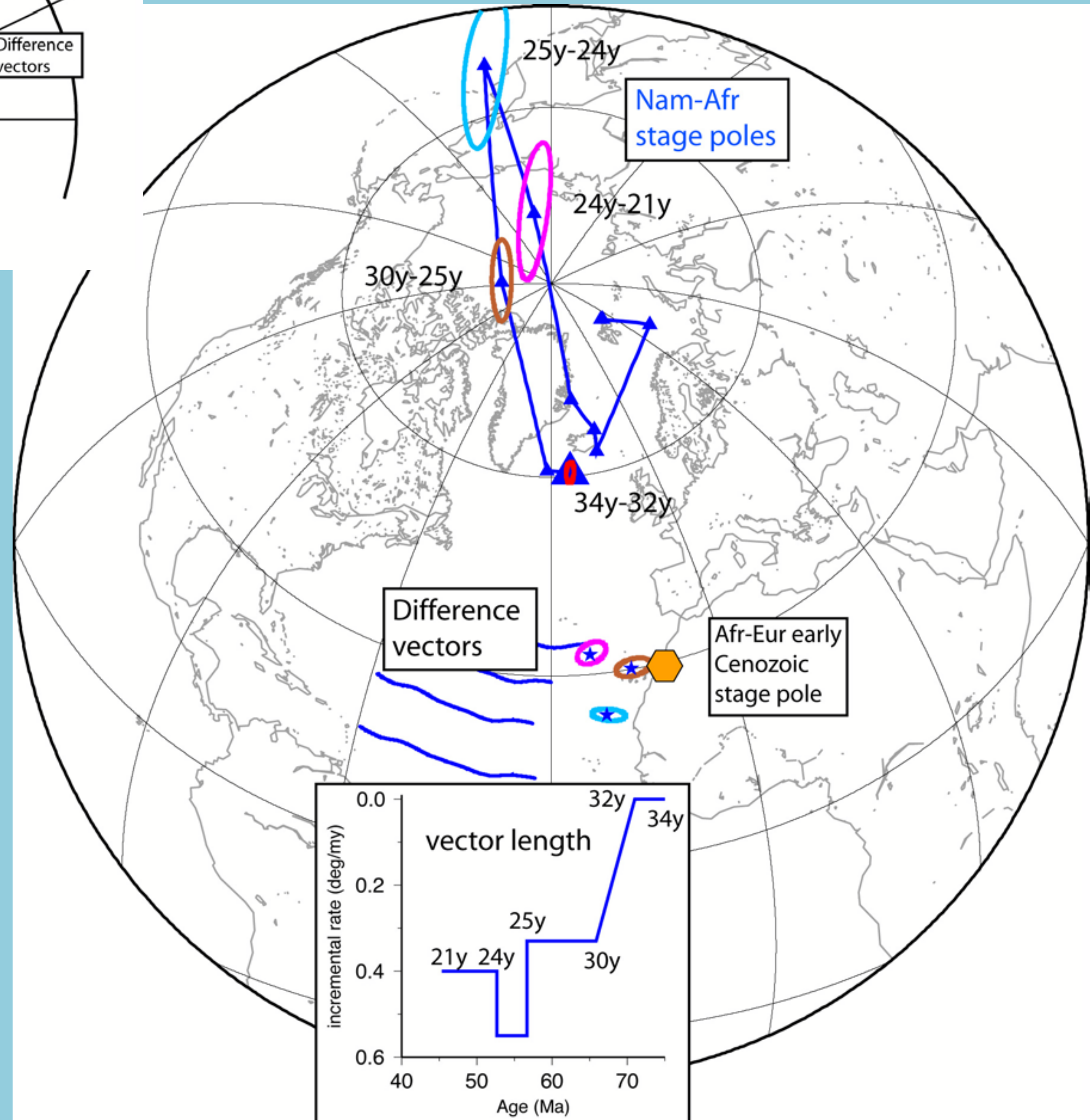
Swing records slowing/speed-up of Afr w.r.t. mantle

Example: Nam-Afr:
Difference vectors using 34y-32y as the "starting" vector

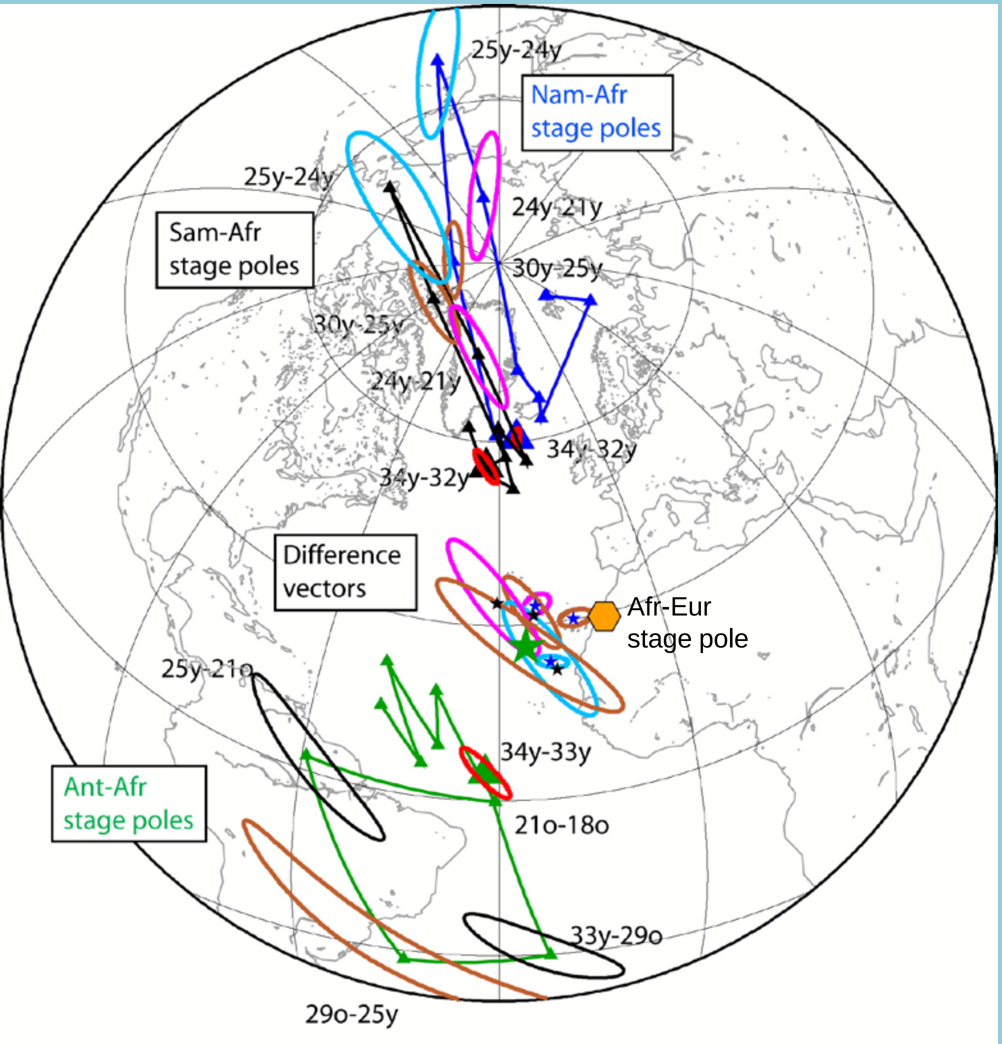


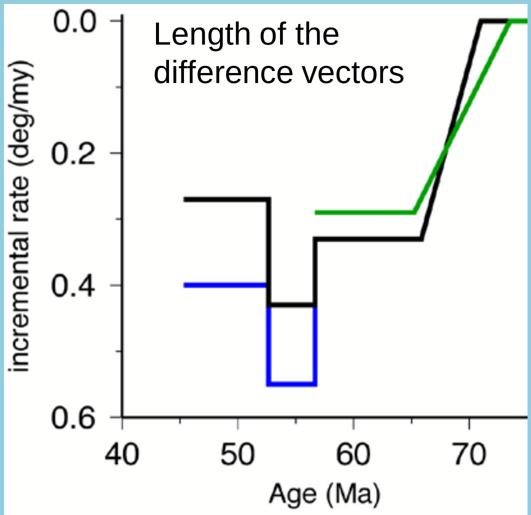
Difference vectors all fall near the Afr-Eur early Cenozoic stage pole. Vector lengths first lengthen then shorten.

Note: vector lengths are plotted upside down



All three ridges on the same plot





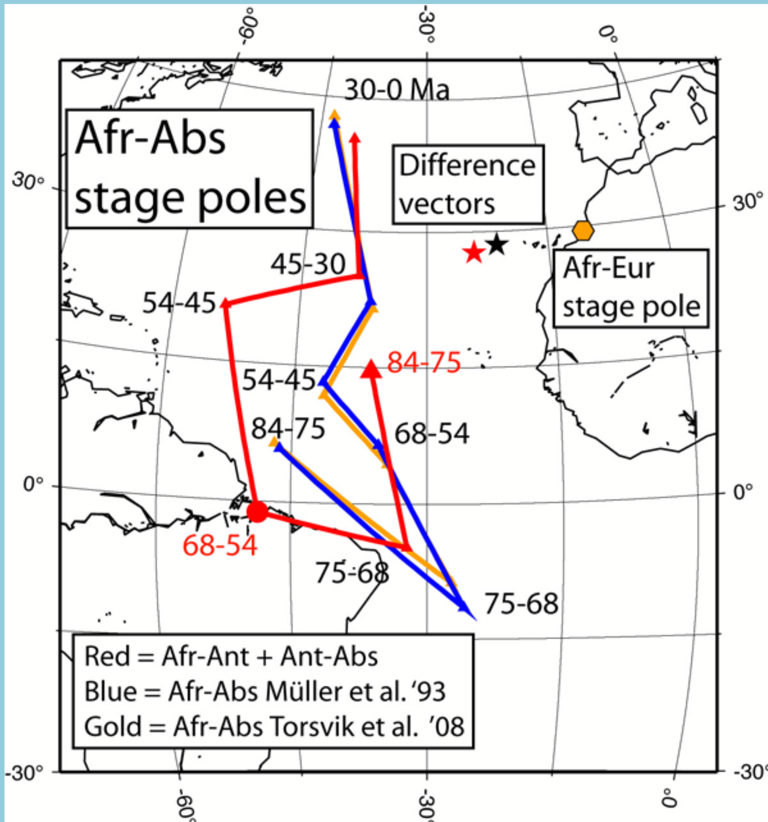
Cande and Stegman (2011)

Interpretation:

1) Africa's motion relative to the mantle slowed down/sped-up about the Afr-Eur stage pole

2) The rate of Afr-Eur convergence dropped precipitously between 70 and 65 Ma, perhaps stopped, and then sped-up at 50 Ma.

Africa-Absolute motion



Cande and Stegman (2011)

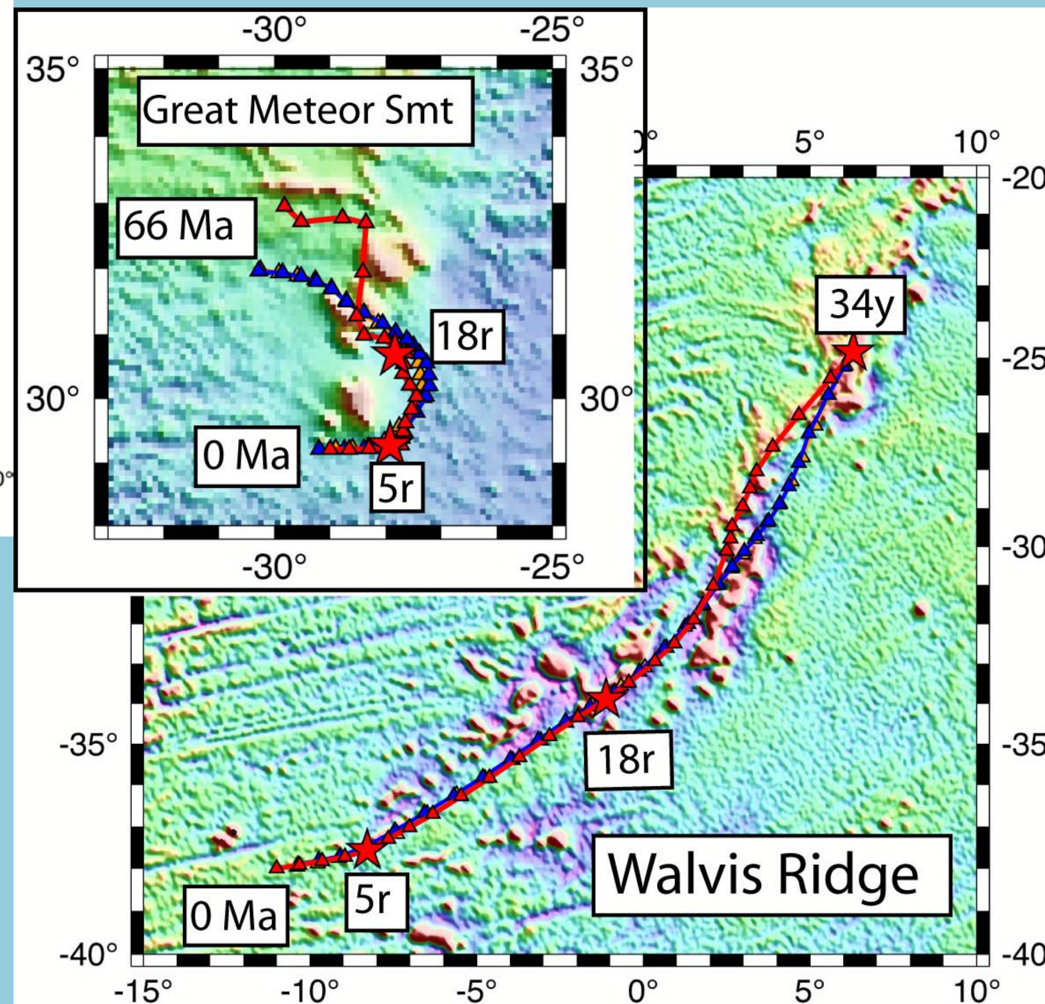
Test: Afr-Abs stage poles should show the same swing

Published Afr-Abs rotations do not show the swing; it is a difficult motion to capture.

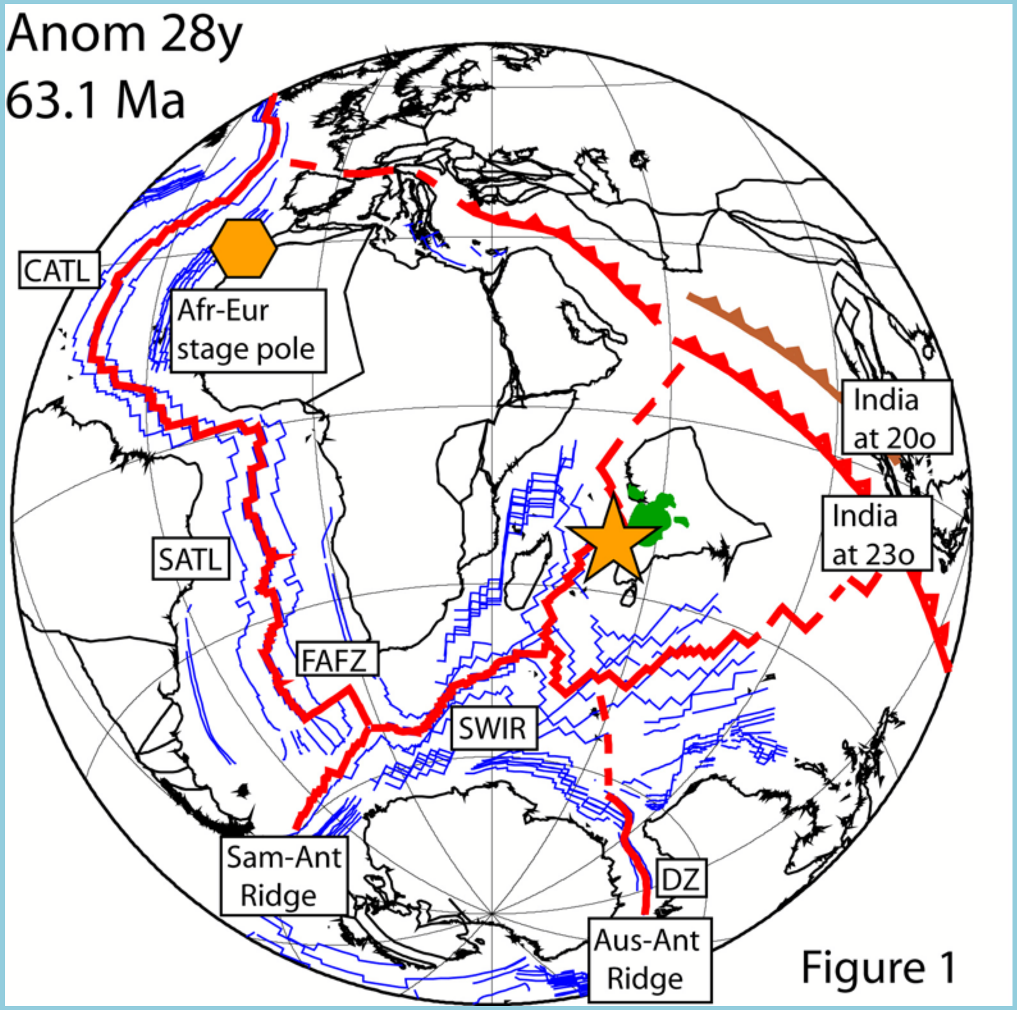
Ant-Abs motion is simpler.

We calculated a set of Afr-Abs rotations by adding Afr-Ant relative motion to three of Müller's 1993 Ant-Abs rotations.

The resulting Afr-Abs rotations have "the swing" (not unexpected) and fit African hotspots better (a pleasant surprise)



Interpretation:



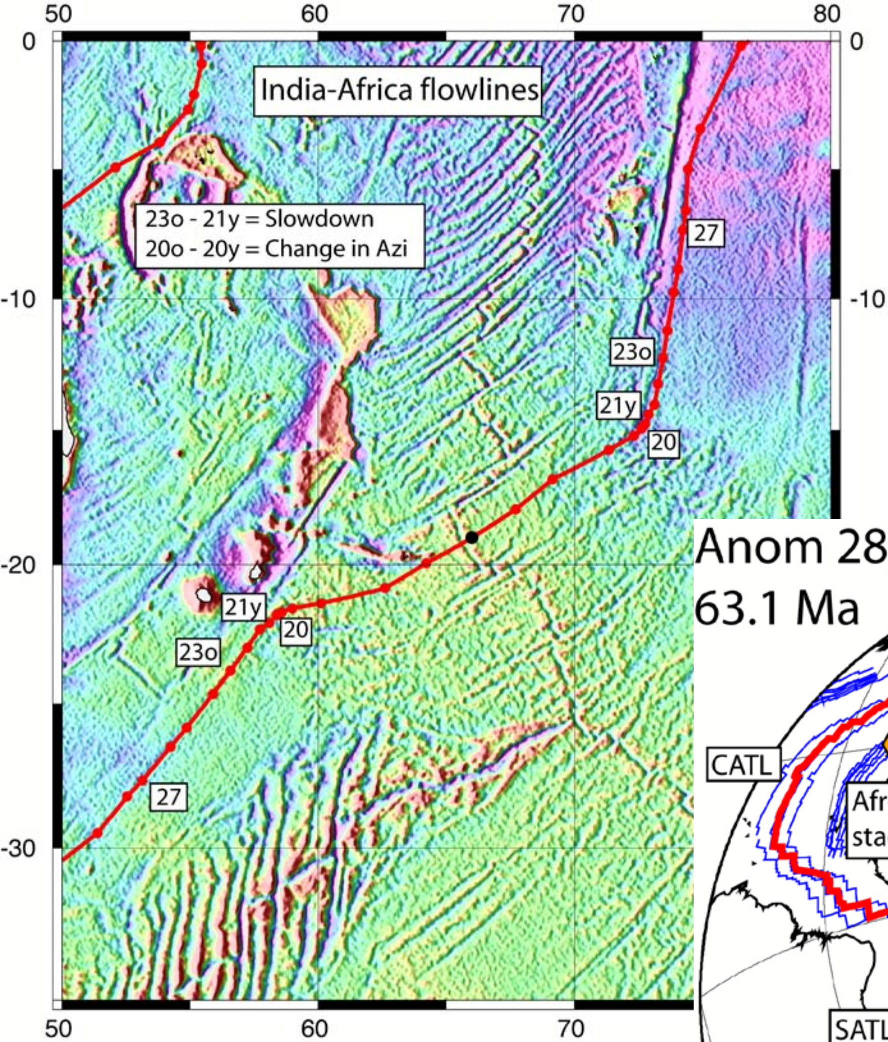
Cande and Stegman (2011)

There was a large driving/enabling force associated with the Reunion plume head

The changes in motion at 67 Ma were due to the onset of the plume head; the changes at 52 Ma were due to the waning of the plume head

Events which share the transitory character of India and Africa were also affected by this force

Africa’s pivot point is 90° away from the Reunion plume.



Tectonic Implications:

The collision of India with Eurasia may not have occurred until Chron 20 (the 'hard" collision), which would reduce the size of "Greater India".

Alternatively, an earlier collision might have been masked by plume driven motions.

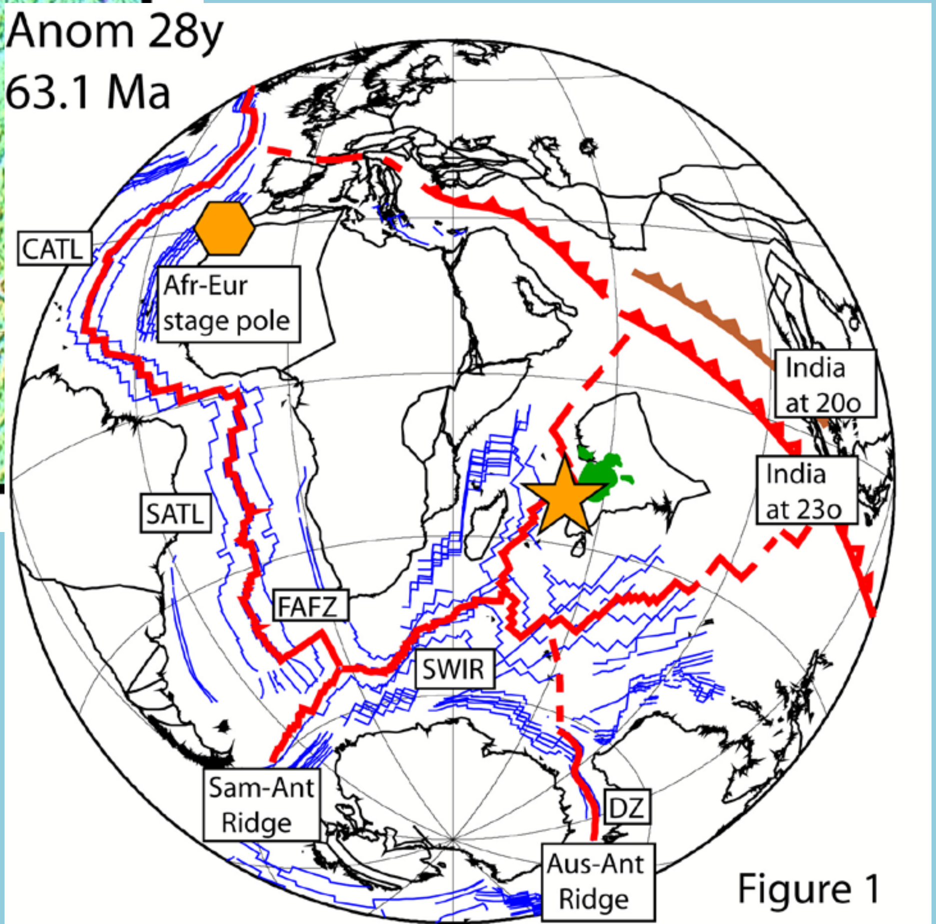
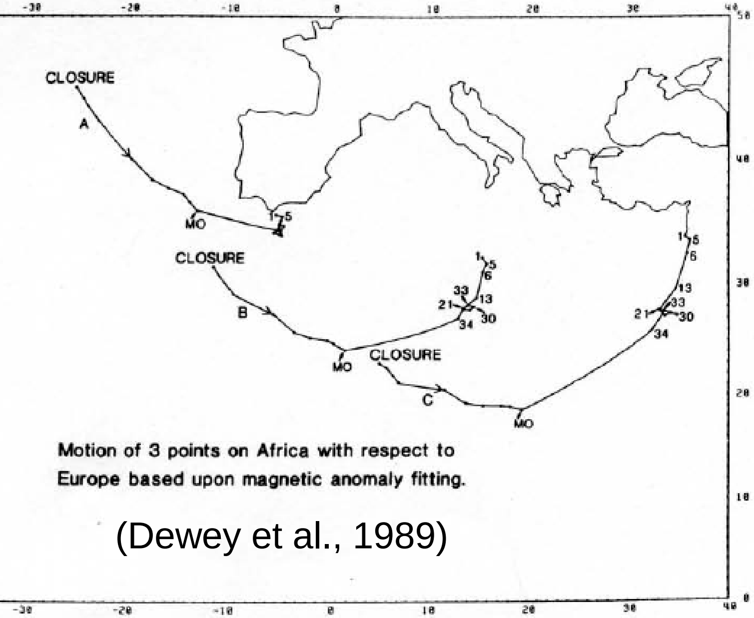


Figure 1

23o – 21y slowdown has no change in azimuth



(Dewey et al., 1989)

A slowdown in Africa-Eurasia motion is predicted from the Afr-NoAm-Eur plate circuit and is consistent with the geology of the Alps

Trümpy's “Paleocene Restoration,” a period of tectonic quiescence.

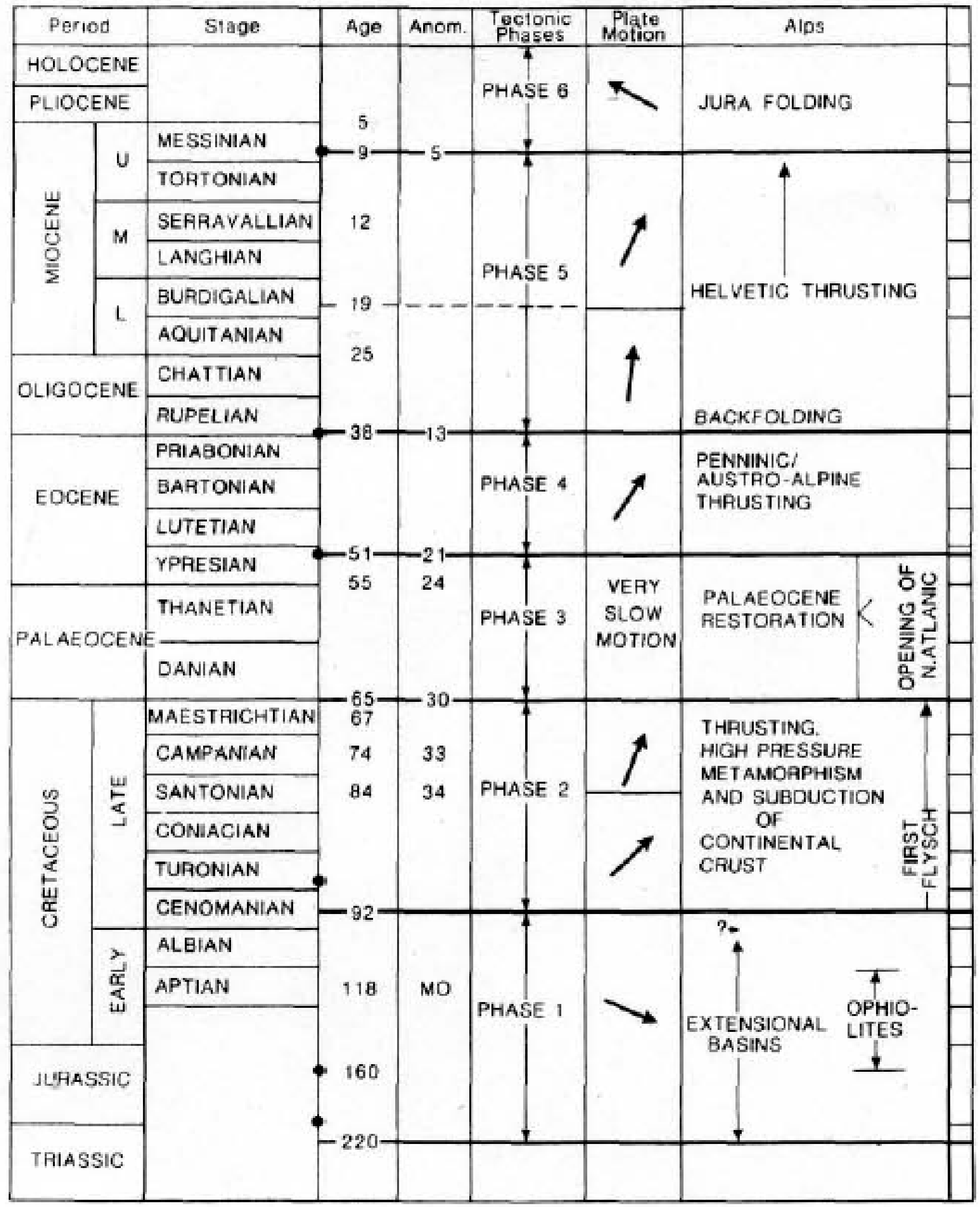
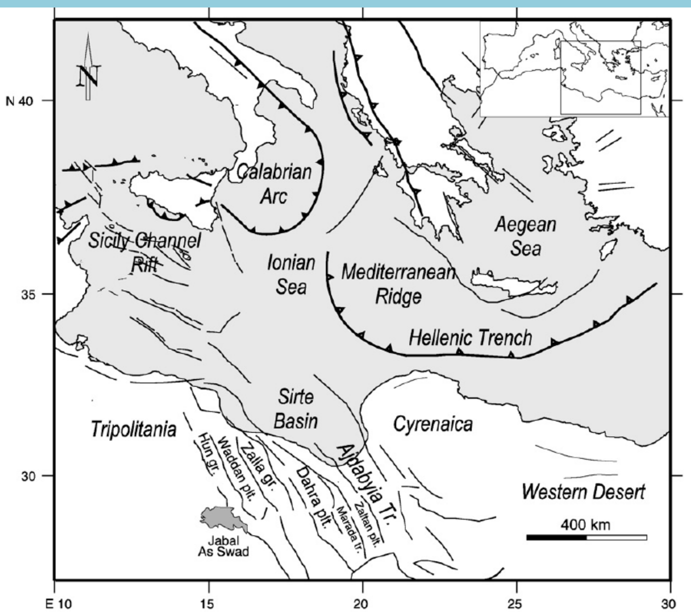


FIG. 2. Correlation chart showing the general direction of Africa's motion with respect to Europe and correlations with various tectonic events in the Alps, Mediterranean Sea, and the Atlantic Ocean.

Capitanio et al. (2009) EPSL

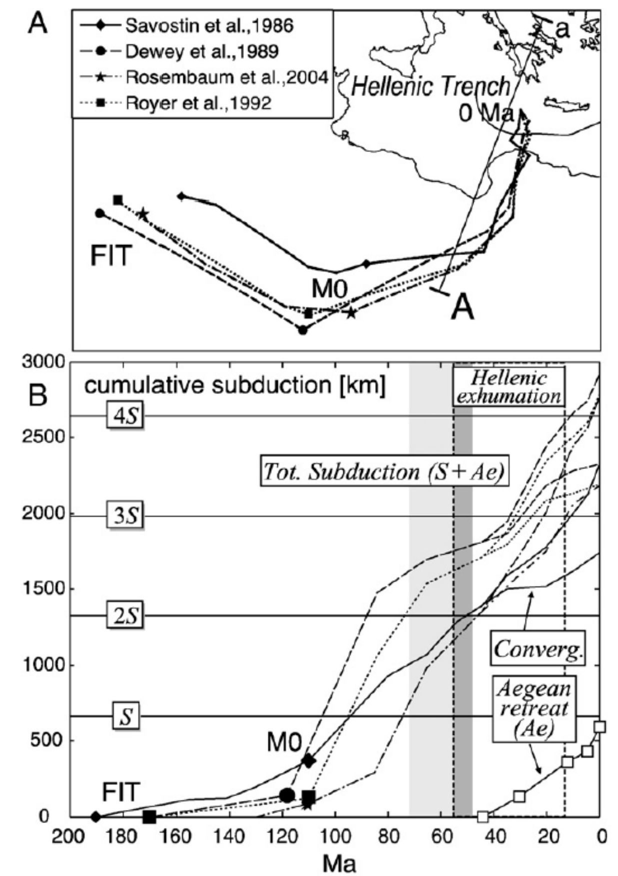
ABSTRACT

North Africa's Sirte basin opening is an enigmatic feature in the complex Meso-Cenozoic rearrangement of Mediterranean tectonics. New borehole data inversion constrains its deformation history showing a stretching event starting ~70 Ma and terminating in a further abrupt increase at ~50 Ma, rapidly fading afterwards. The timing of this event hardly reconciles with the Mesozoic major plates reorganization

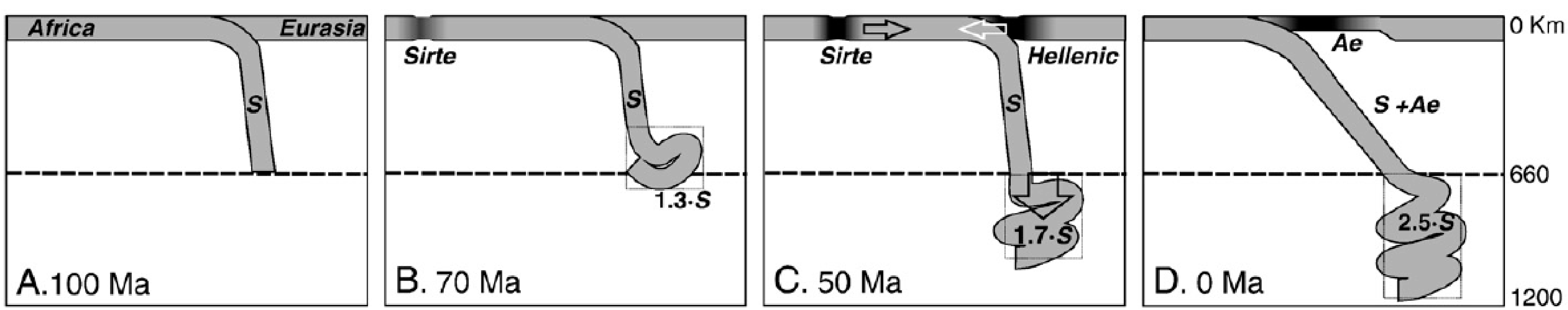


Slab avalanche?
Or restoration of pre-plume force balance?

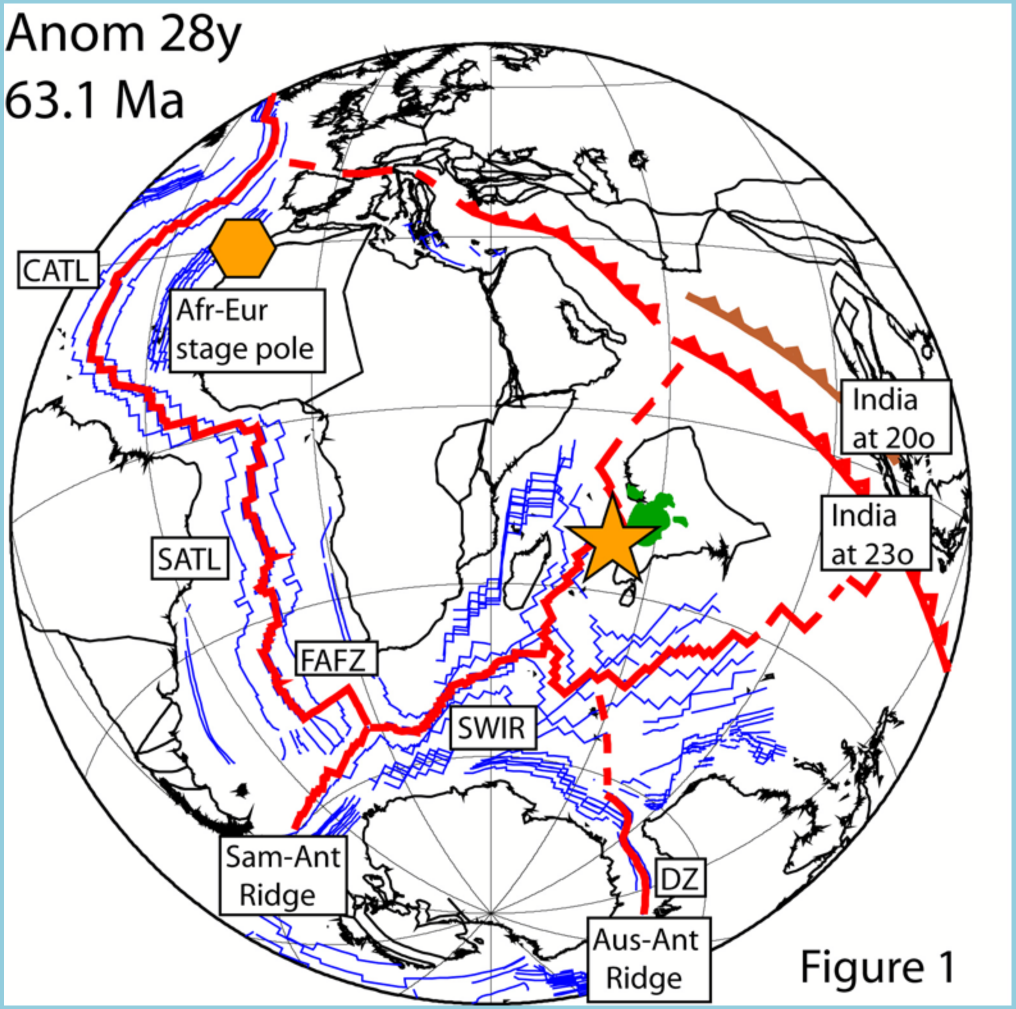
The *Sirte Basin* has proven *oil reserves* estimated at 43.1 billion barrels

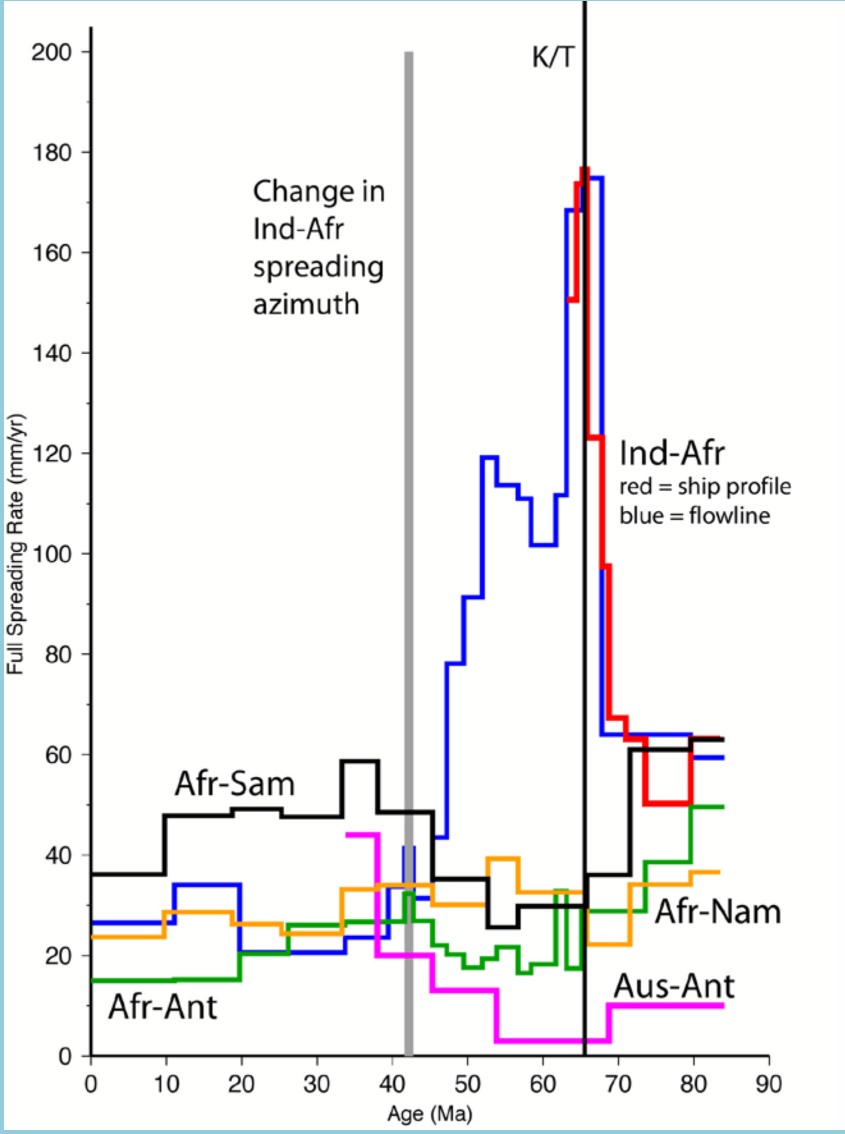


F.A. Capitanio et al. / Earth and Planetary Science Letters 285 (2009) 210–216 215



Other Indo-Atlantic ocean transitory tectonic changes between 67 and 52 Ma: Ex. Aus-Ant

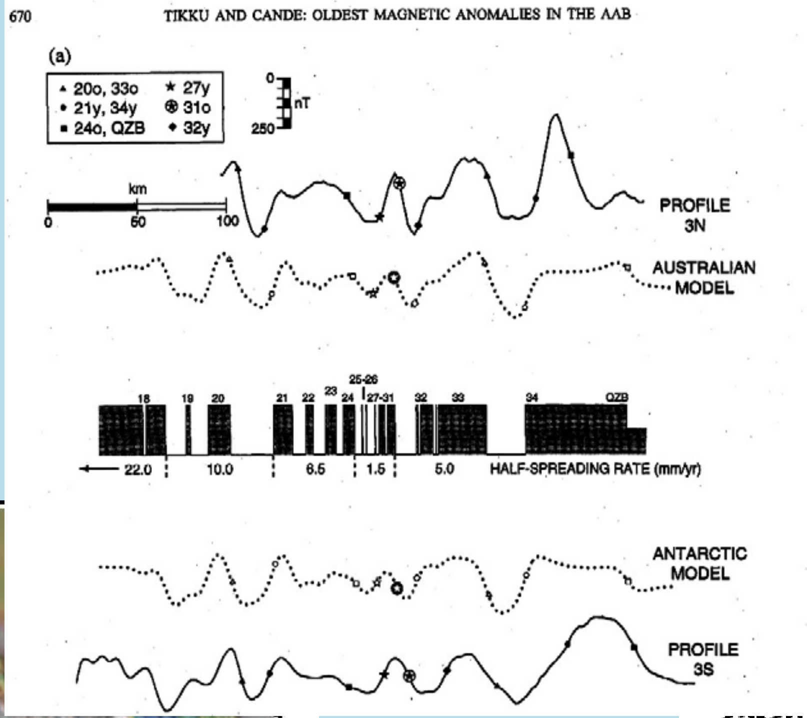


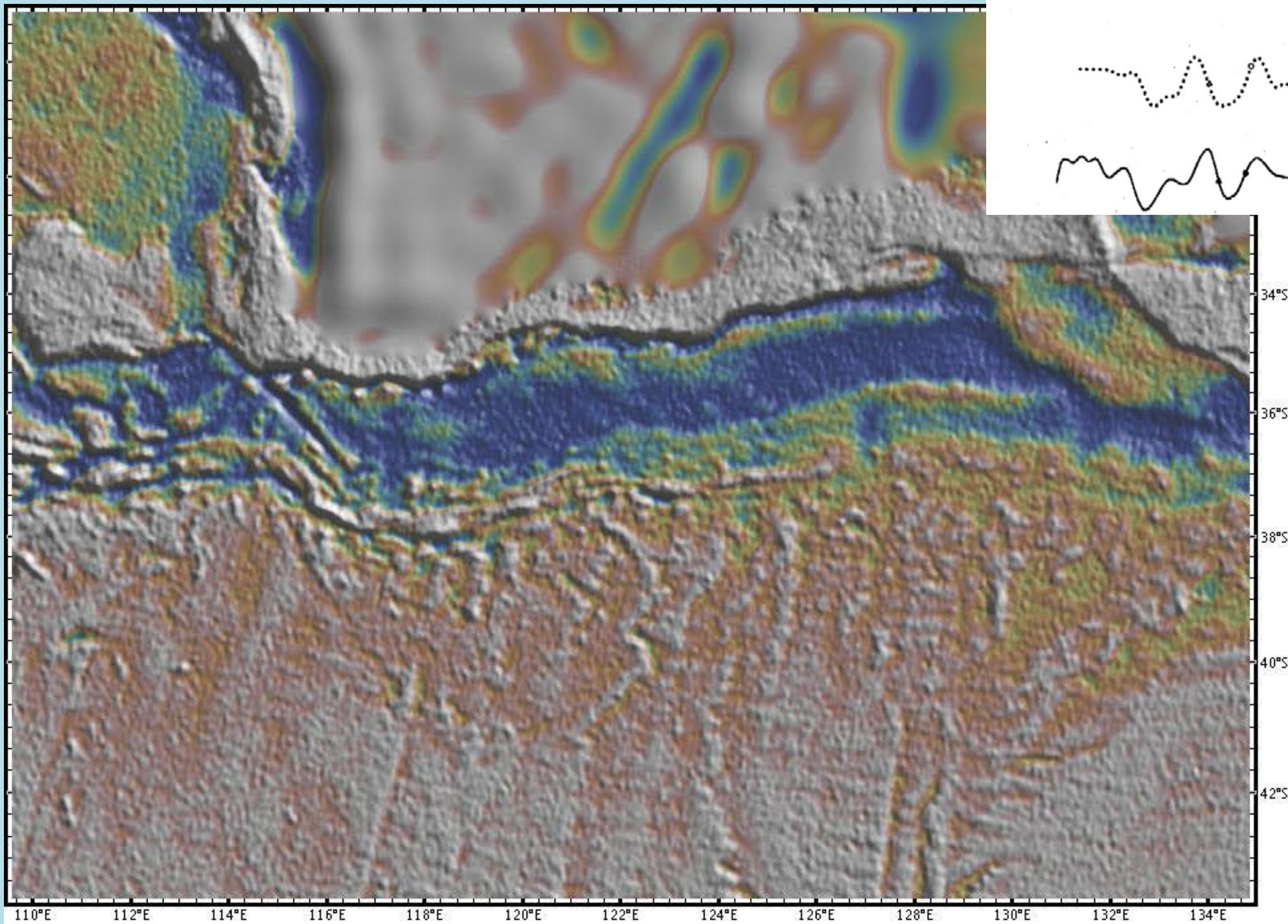


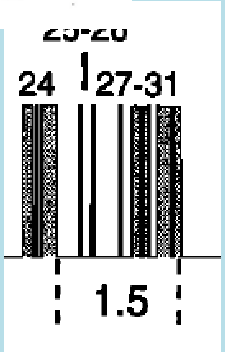
Spreading in the Australia – Antarctica Basin essentially stopped between 70 and 55 Ma; total rate of only 3 mm/yr!

During this time generated conjugate strips of extremely rough topography: the Diamantina Zones

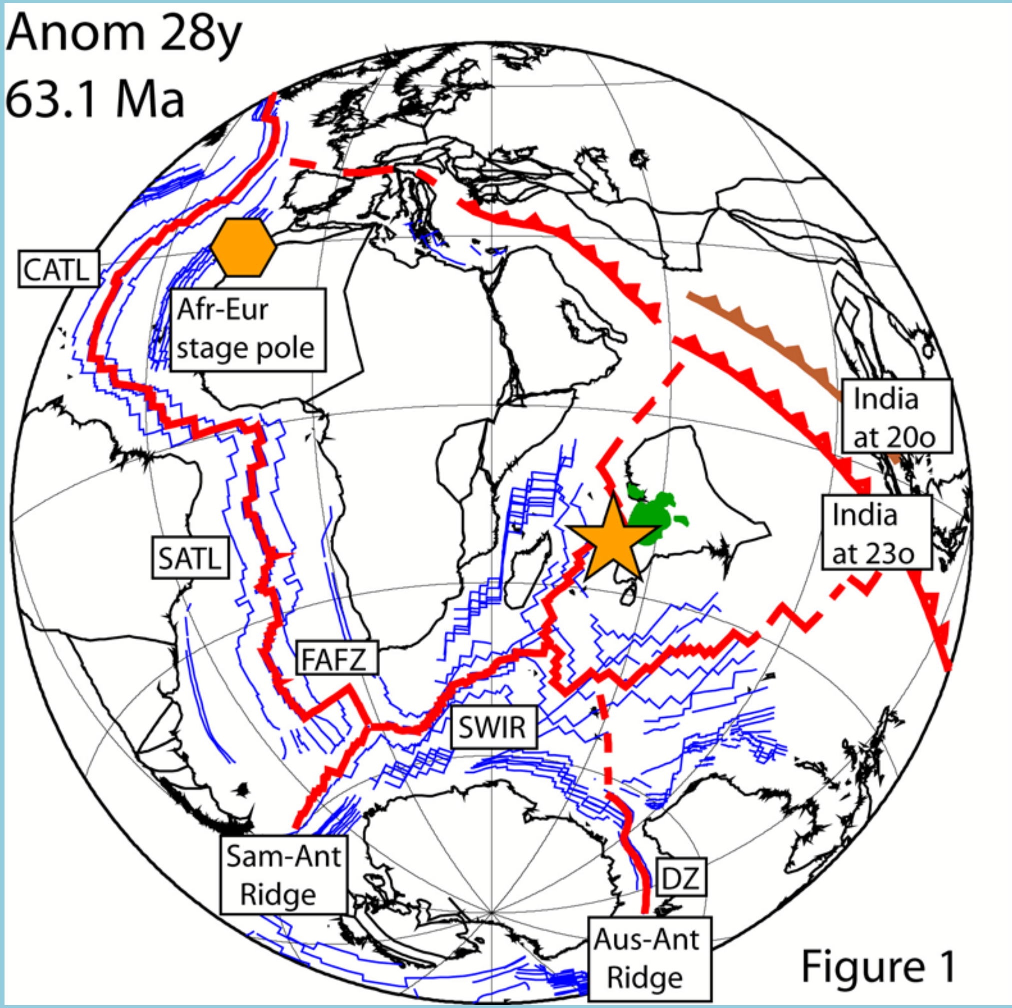
99)



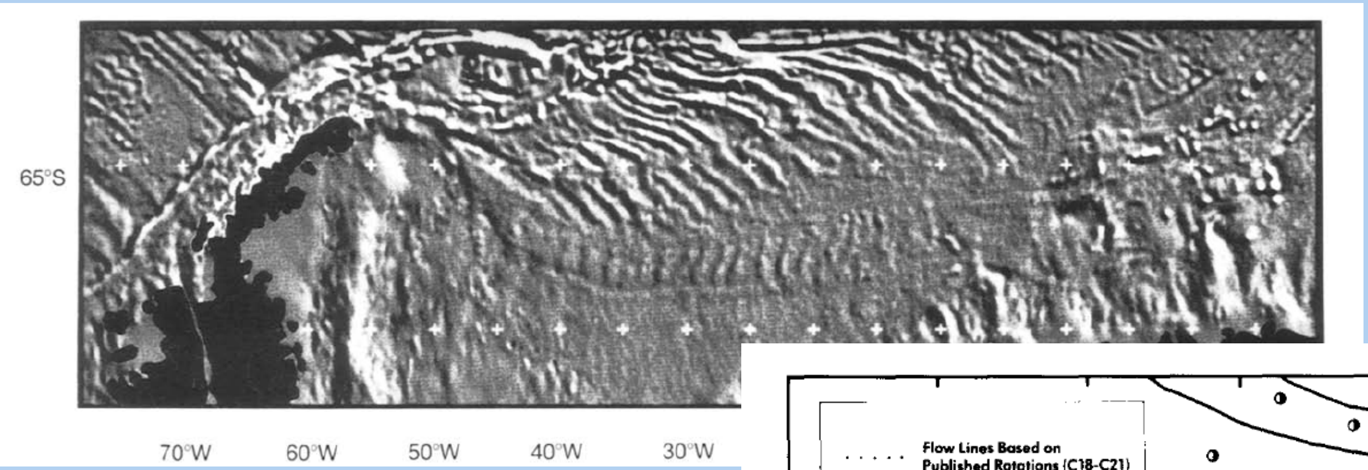




Diamantina Zone

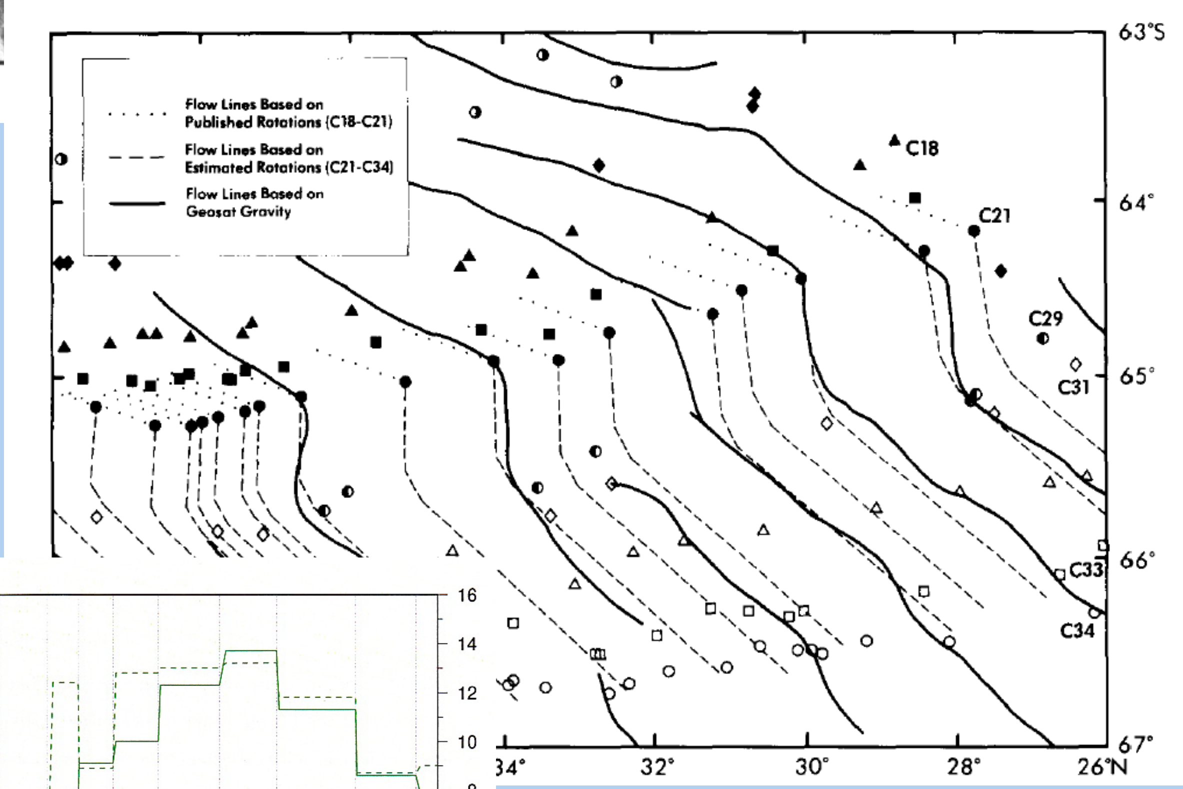


South America – Antarctic ridge has a similar transitory change in spreading rate and azimuth …

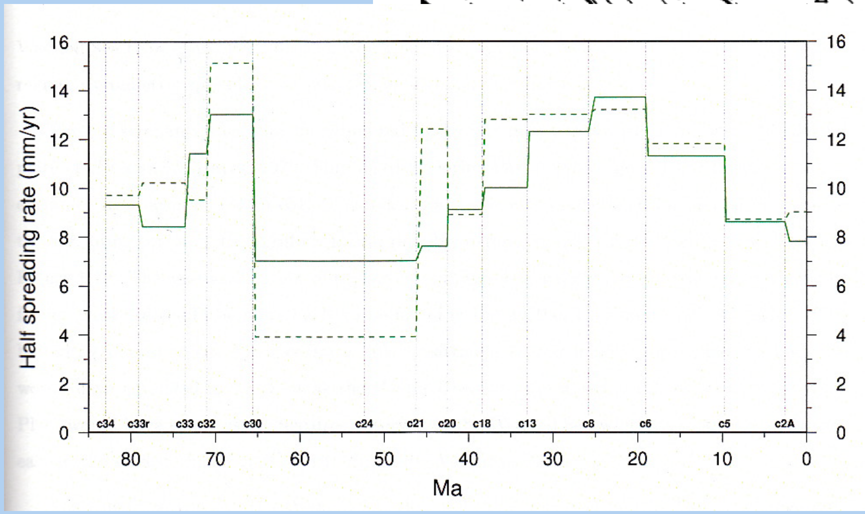


(Livermore and Woollett, 1993)

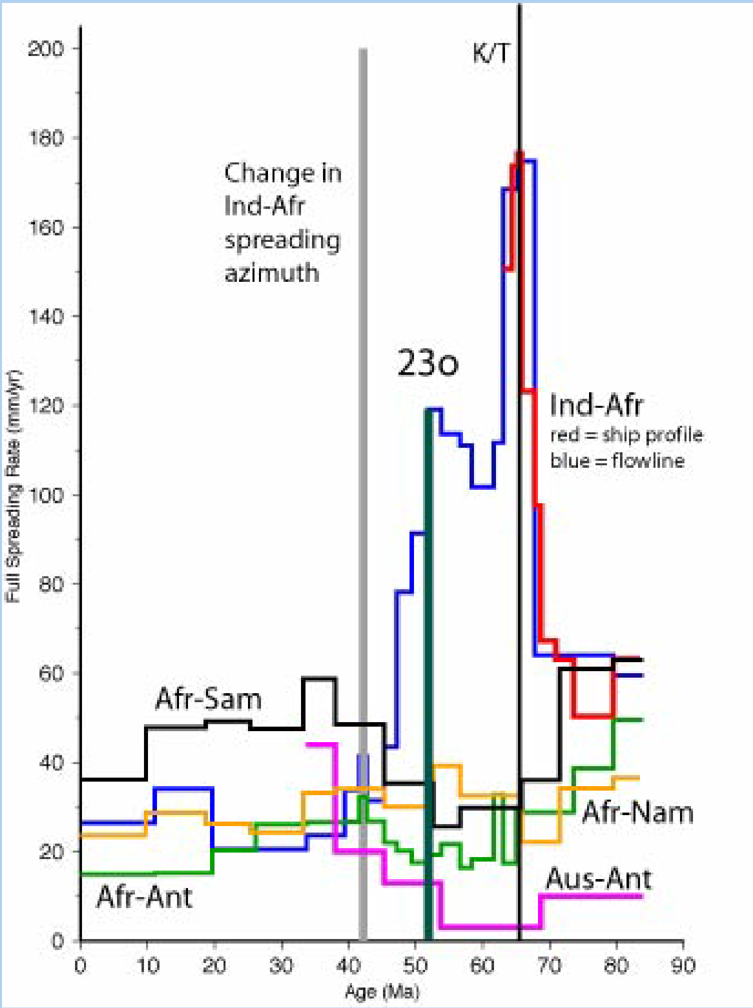
The South America-Antarctic ridge flowlines



Sam-Ant half spreading rates



(Nankivell, 1997)

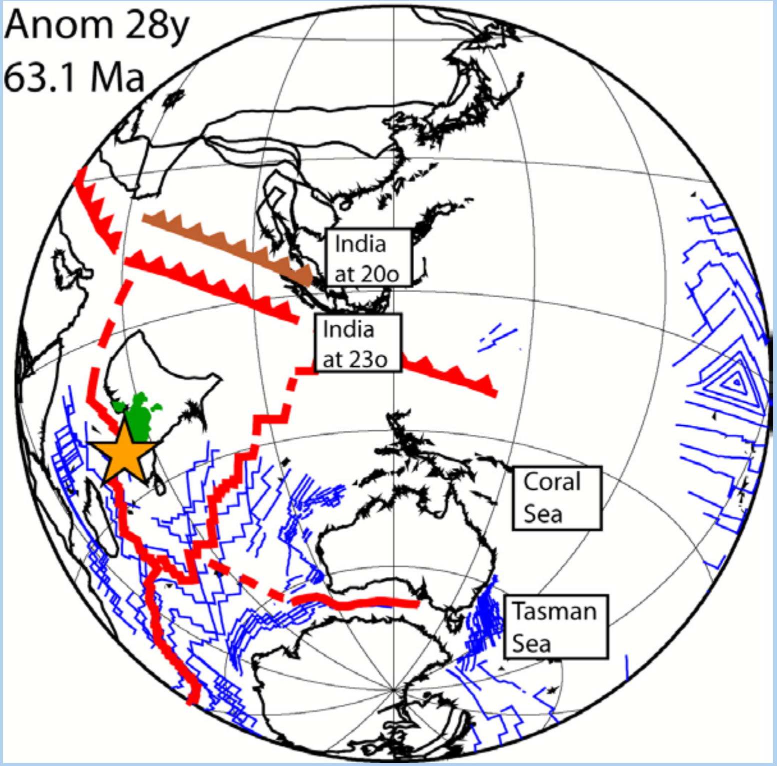


There are a number of Pacific events around Chron 23o (52 Ma). Is there a link?

•Spreading in both the Tasman Sea and Coral Sea stopped during Chron 23R

• Westward subduction started at the Izu-Bonin and Tonga trenches at 52 Ma

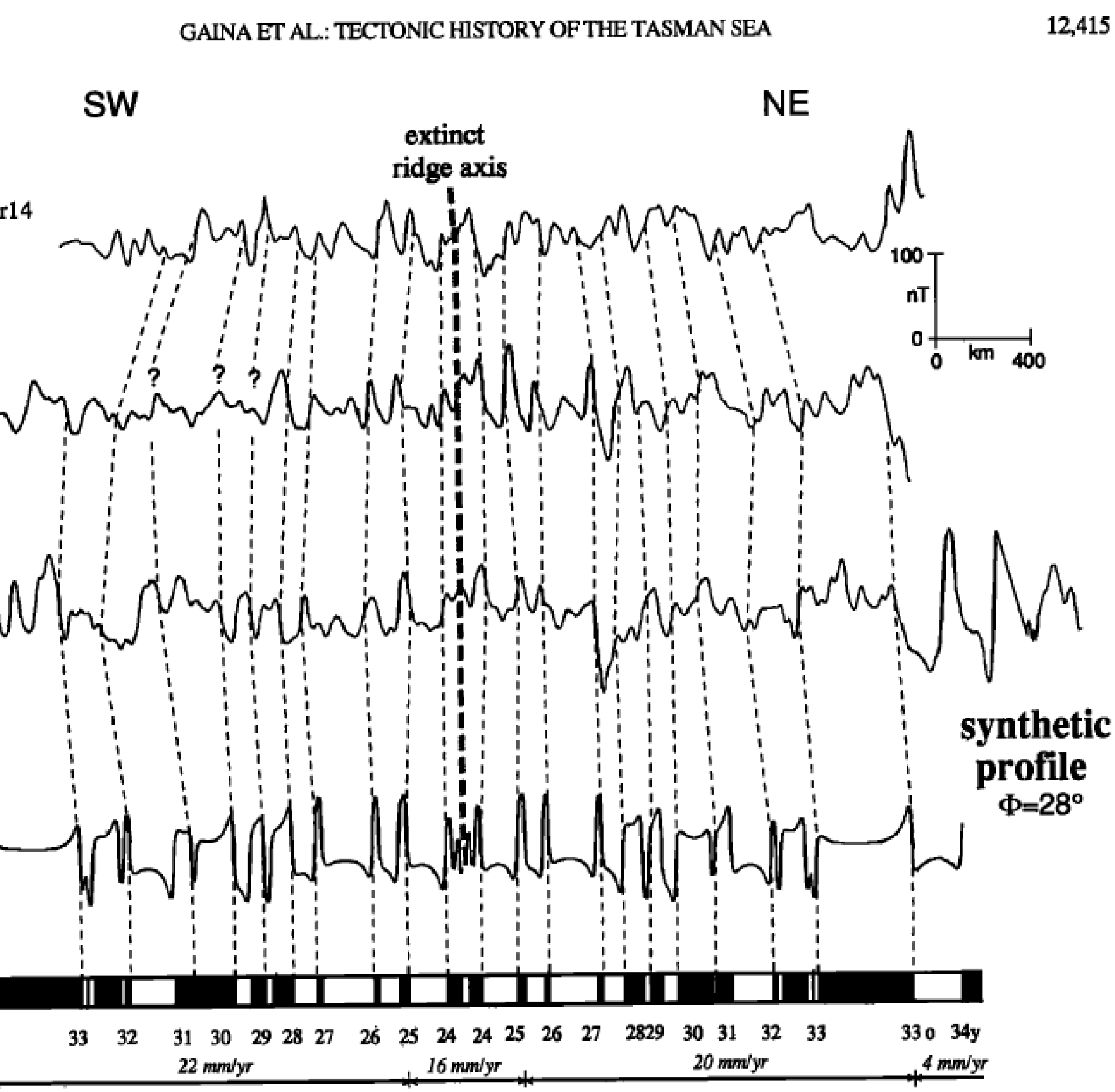
•Pacific-Kula and Pacific-Farallon "reorganized" at 23o

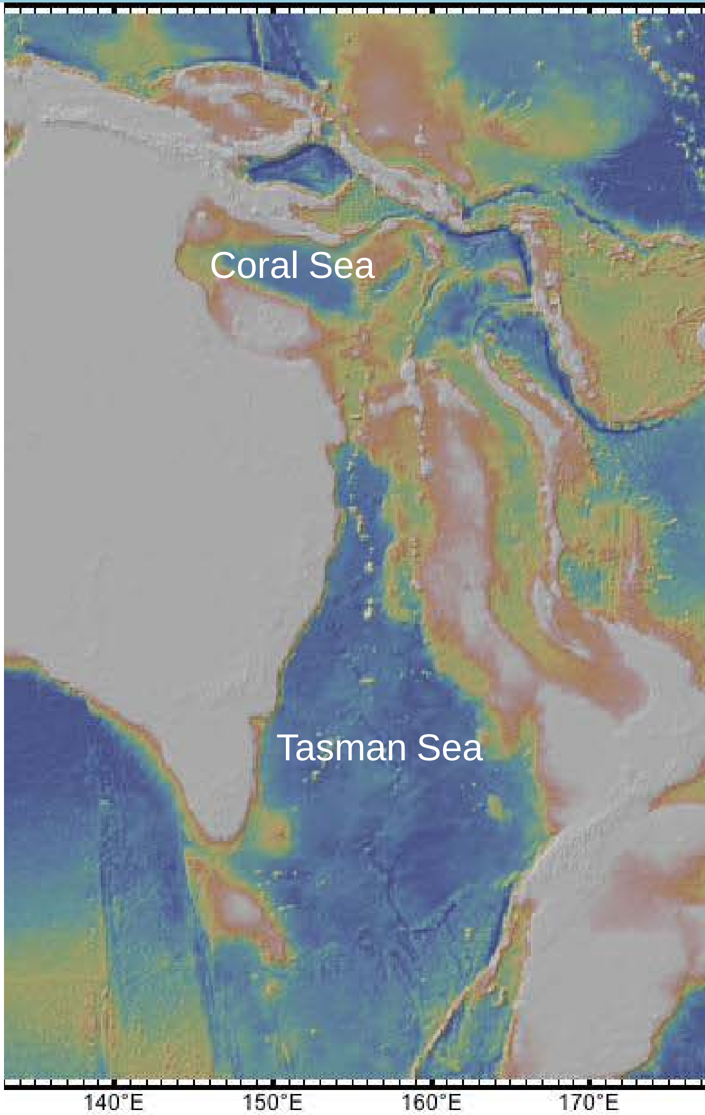


Gaina et al. (1999)

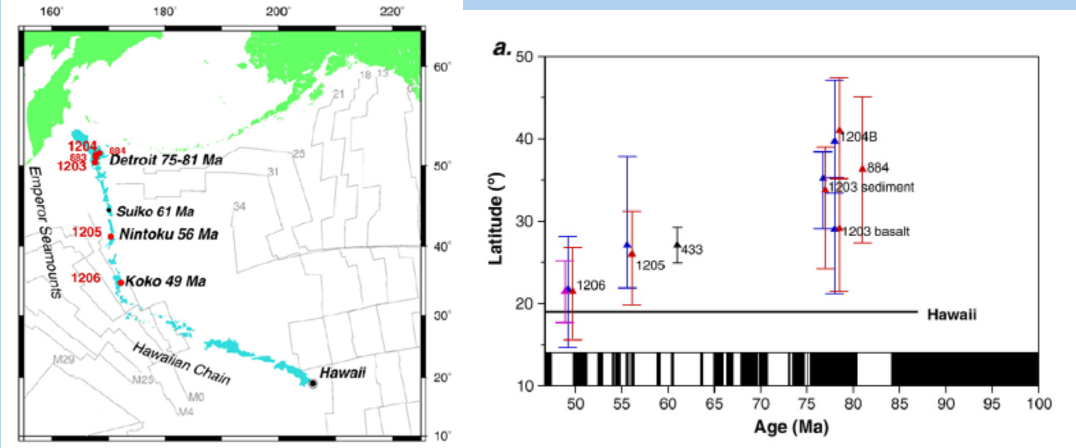
Both the Coral Sea and Tasman Sea stopped spreading at Chron 23R (52 Ma)

Arguably, large southward shift in Pac-Aus Euler pole





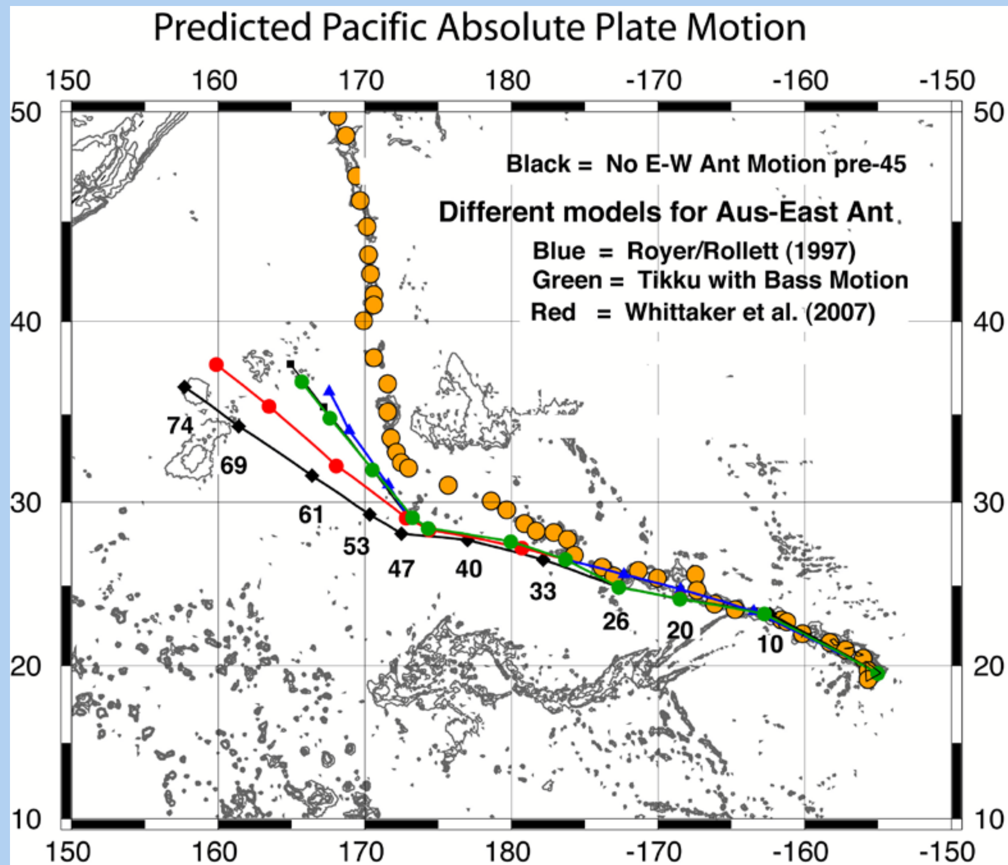
The Bend in the Hawaiian Emperor chain is now attributed in large part to a period of southward drift of the Hawaiian hotspot which ended around 50 Ma.



(Tarduno, 2007)

But 50 Ma also corresponds to changes in the absolute motion of the Pacific plate as predicted from the plate circuit

And the waning of the Reunion plume seems to be very effective at changing plate motions …



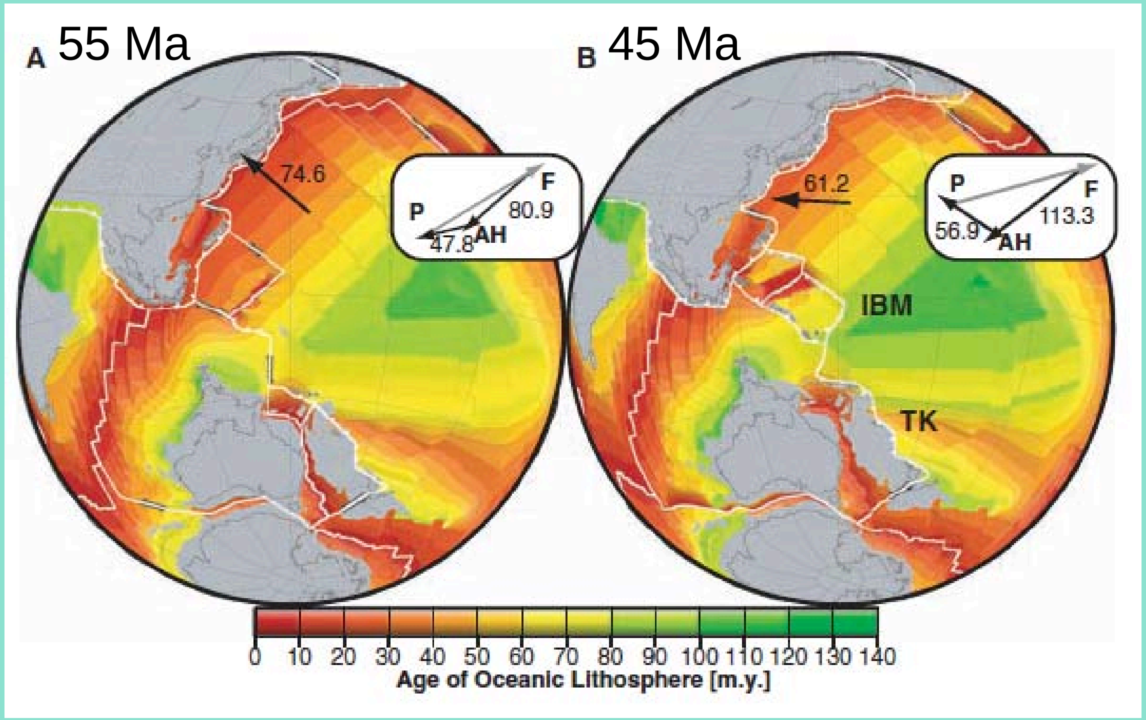
Effects of the Reunion plume head:

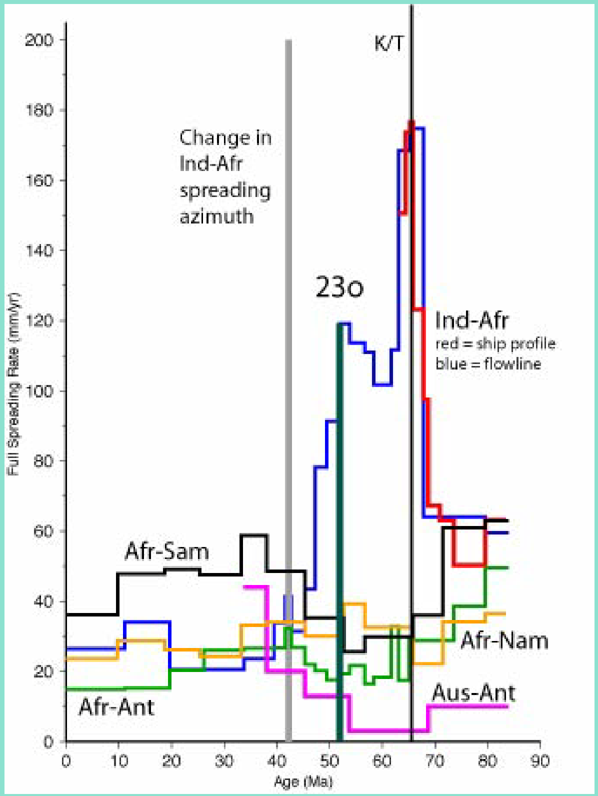
•Enabled India to move at 200 mm/yr
•Slowed/stopped Afr-Eur convergence
•Caused bends in the Atlantic and SWIR FZs
•Caused other transitory changes in plate motion

Many Southwest Pacific tectonic events occurred at the start of the waning of the plume (52 Ma) and might be related.

Jason Morgan (Holden and Vogt, 1977)

What caused changes at 23o?





Whittaker et al. (2007) attribute change to subduction of Pacific-Izanagi spreading ridge

But, would this cause a sudden event?

Could the waning of the Reunion plume contribute to this?

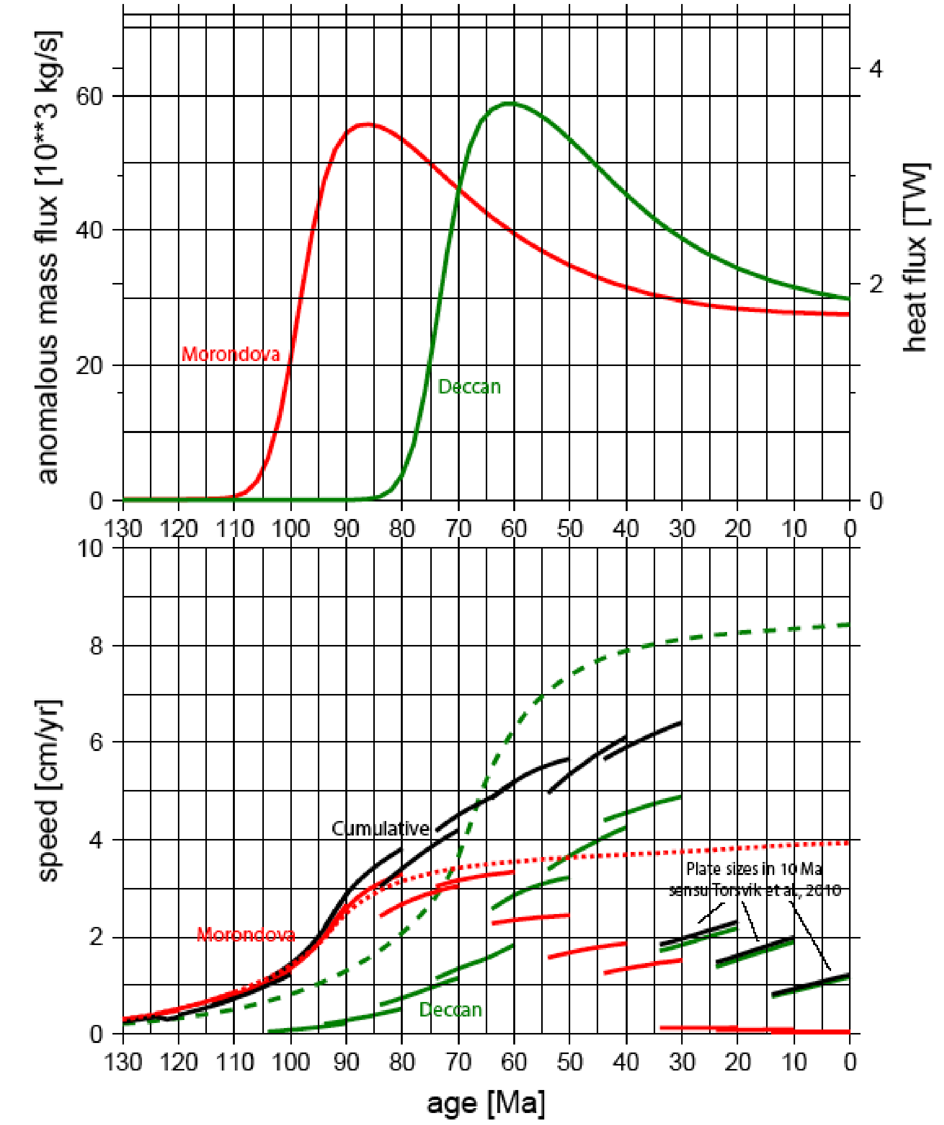
Acceleration and deceleration of India-Asia convergence since the Cretaceous: roles of mantle plumes and continental collision

DOUWE J.J. VAN HINSBERGEN[1,2], BERNHARD STEINBERGER[3,1,2], PAVEL V. DOUBROVINE[1,2] AND RENÉ GASSMÖLLER[4] (2011, JGR)

Our observations challenge the modelers …

Recently, geodynamacists have modeled the effect of the Reunion plume head on India's motion

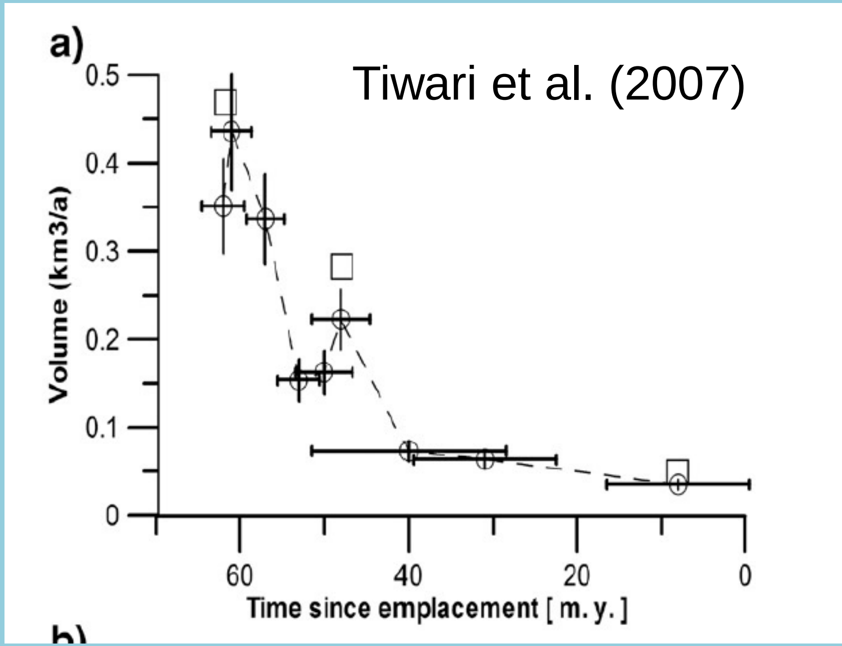
Predicted speed-up is too small and too protracted; slowdown is too slow.

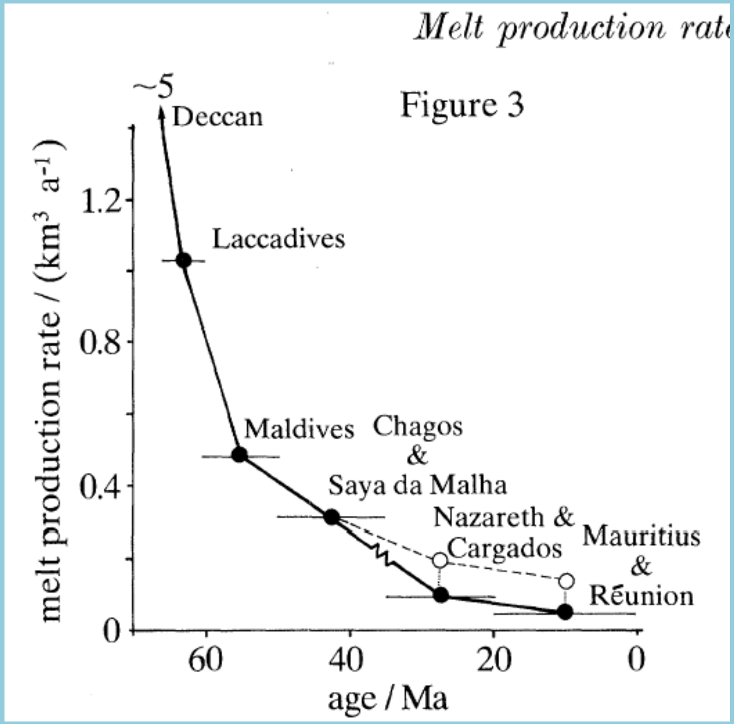


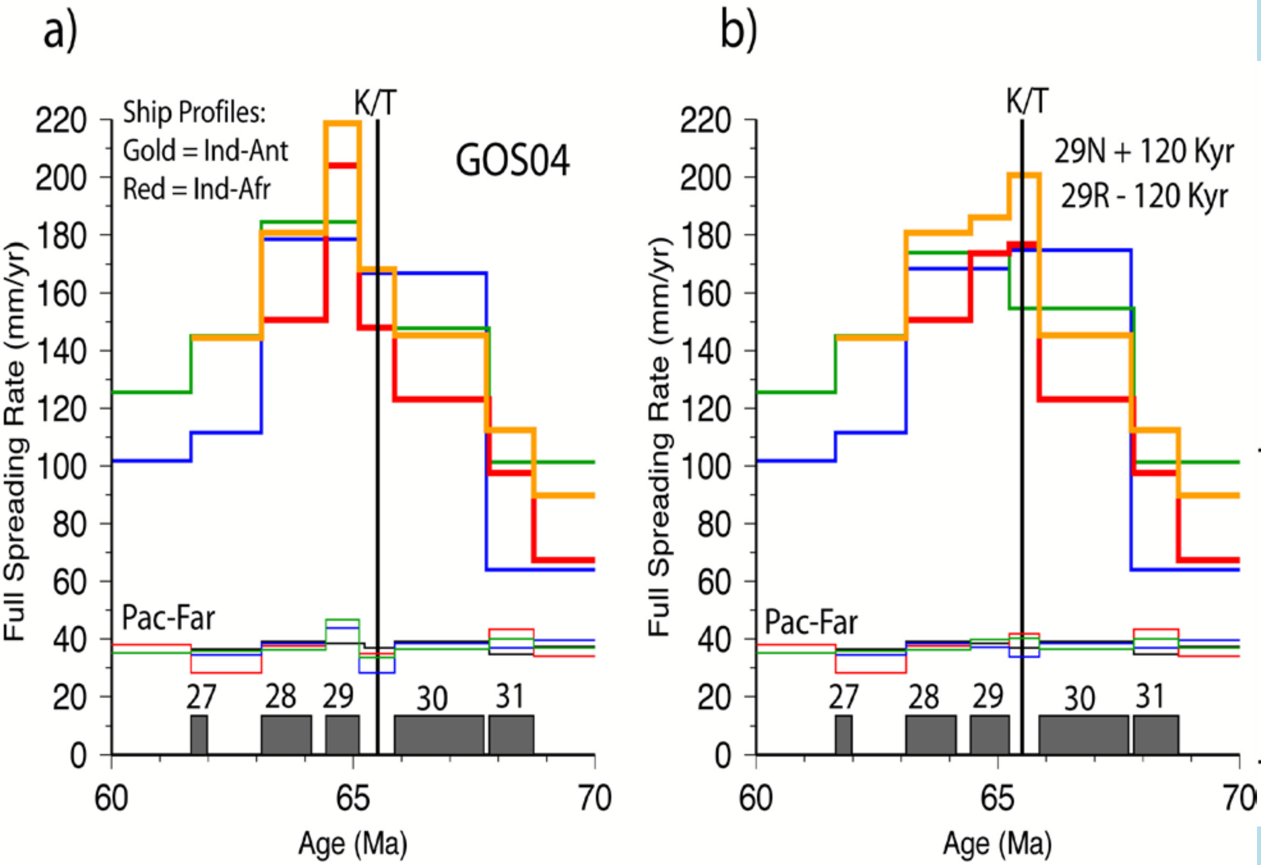
Consistent with the eruptive history of the Reunion plume:

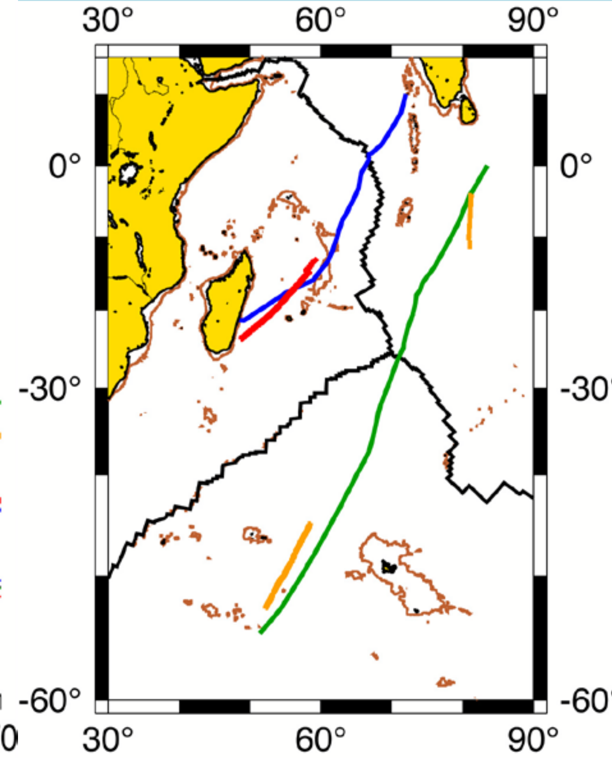
Left: Estimates of melt production versus time of the Reunion plume based on elastic thickness studies.

Below: Reunion melt production from White (1993)









Cande and Stegman (2011)

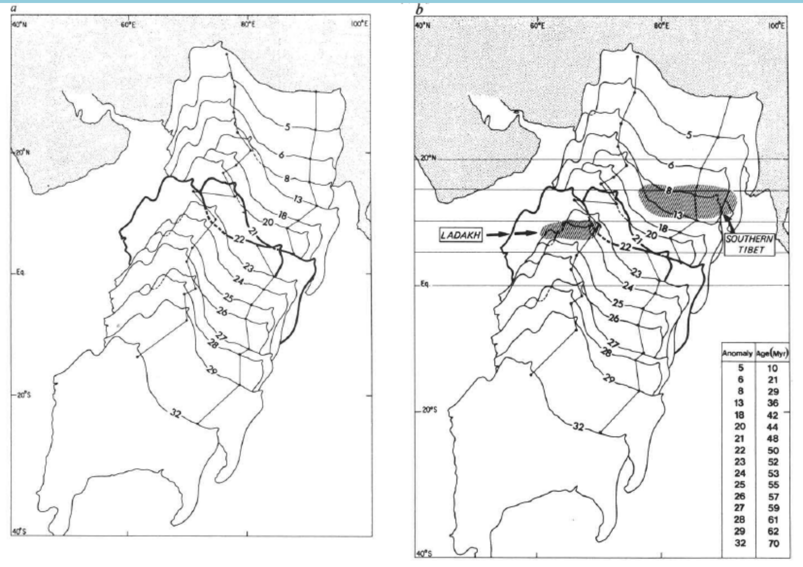
Ship profiles show a maximum spreading rate of 220 mm/yr within Chron 29N.

Pacific-Farallon profiles show that timescale needs tune-up within Chron 29.

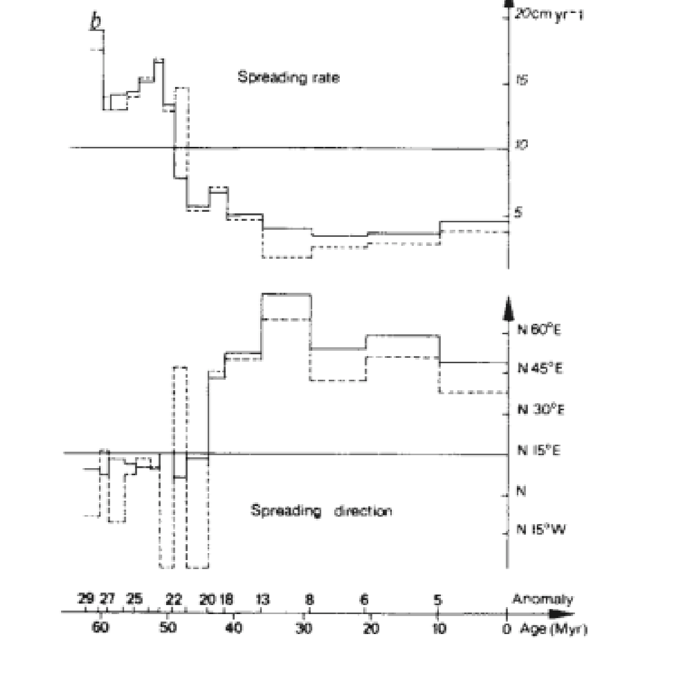
After tune-up, maximum rate is a little slower (200 mm/yr) and a little earlier (within Chron 29R)

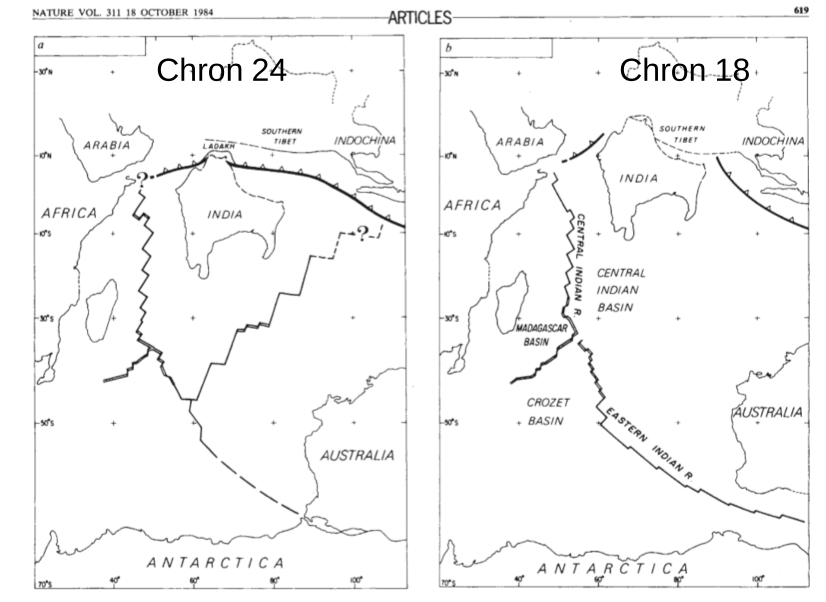
Suggests plume force …

Two major tectonic events in the early Cenozoic Indian Ocean:



India-Africa motion



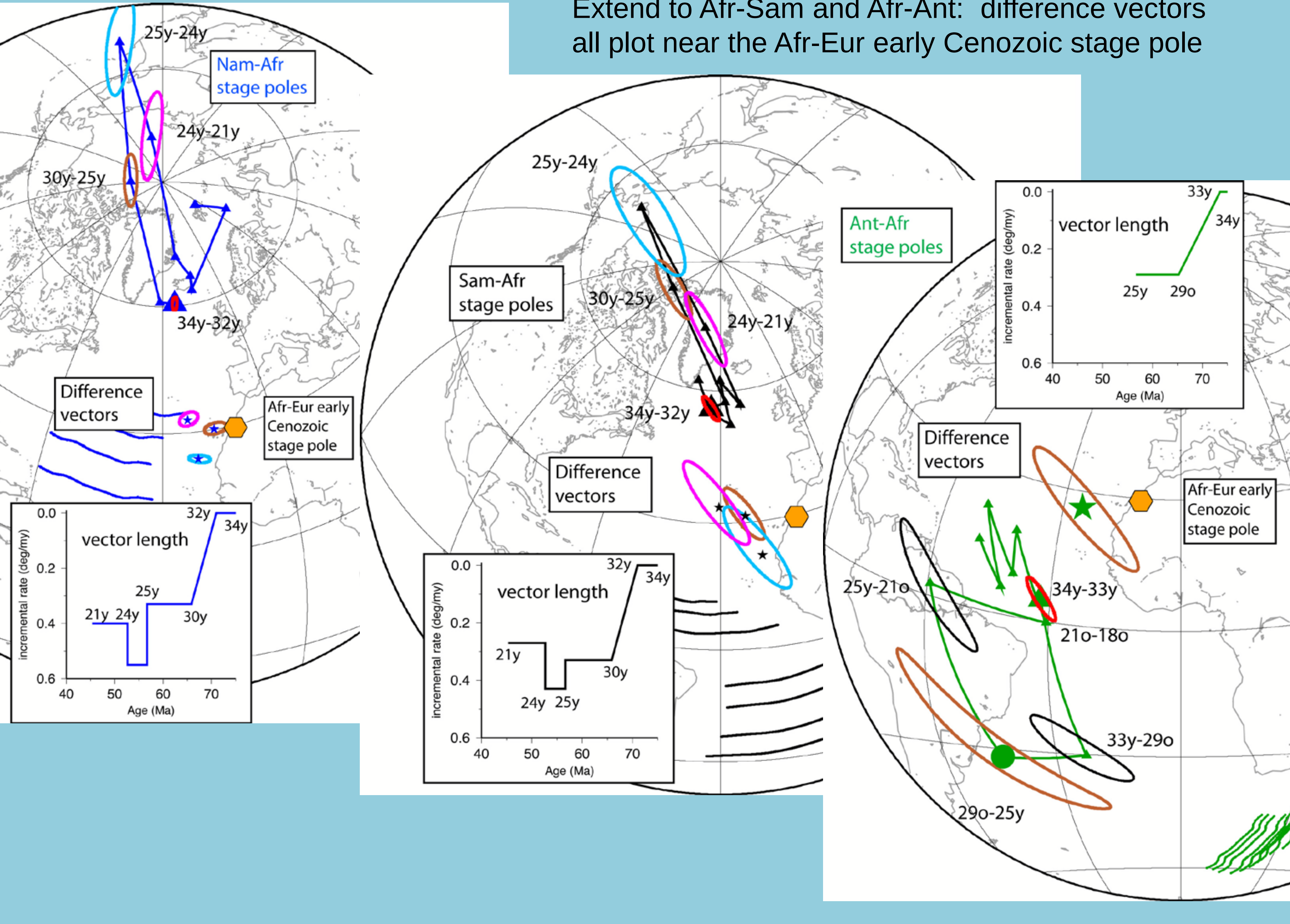


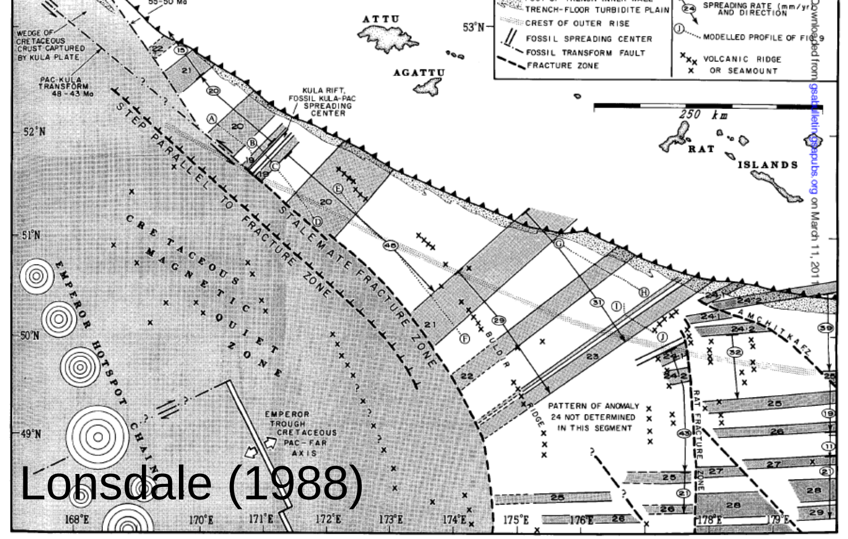
First, a period of slowing centered on Chron 22 (50 Ma)
Then, a sharp change in Azimuth at Chron 20 (43 Ma)

Interpreted as an initial “soft” collision of India with Eurasia, followed by a “hard” collision

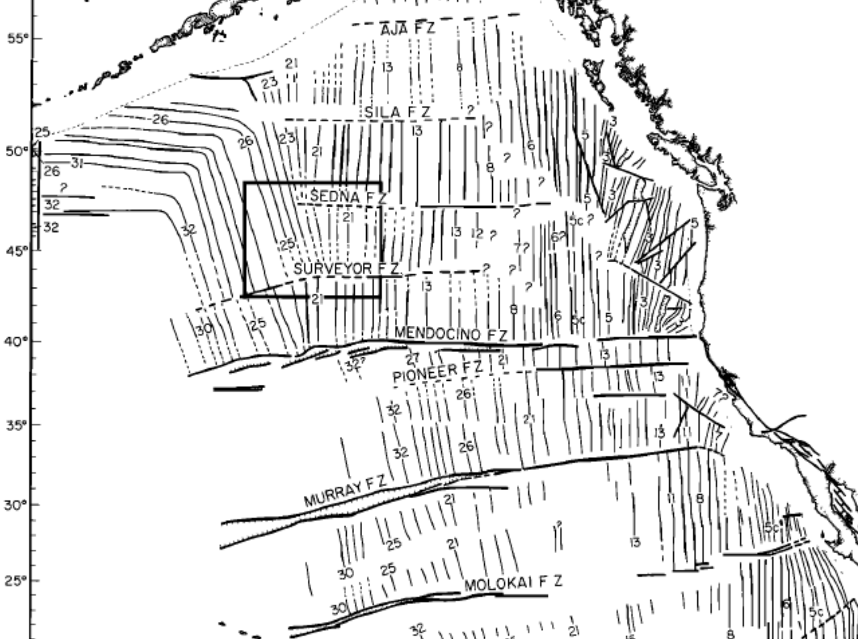
(Patriat and Achache, 1984)

Extend to Afr-Sam and Afr-Ant: difference vectors all plot near the Afr-Eur early Cenozoic stage pole



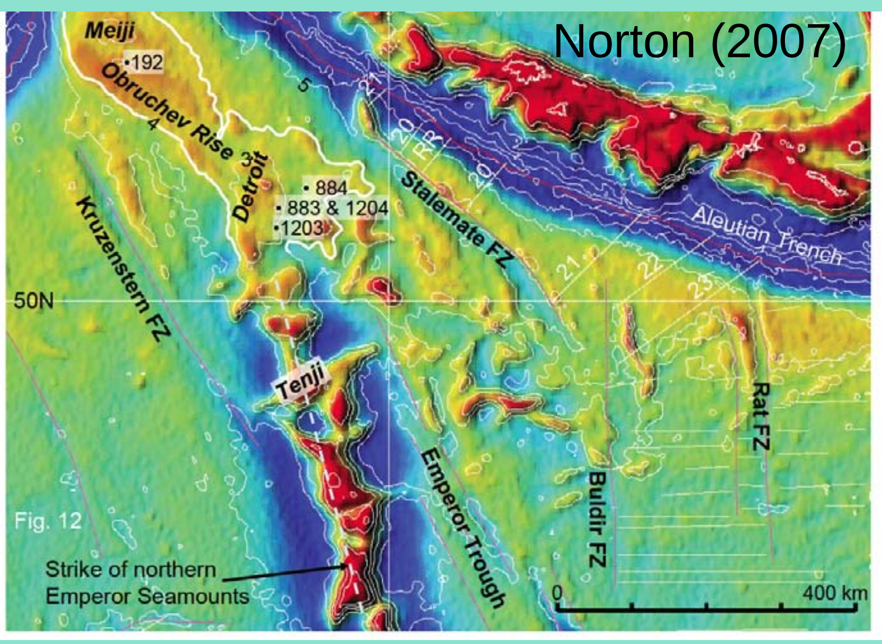


Lonsdale (1988)



Hey, Menard, Atwater (1988) JGR

And Chron 23R (52 Ma) is the time of major changes in azimuth of Pacific-Farallon and Pacific-Kula (Izanagi) spreading.



Norton (2007)