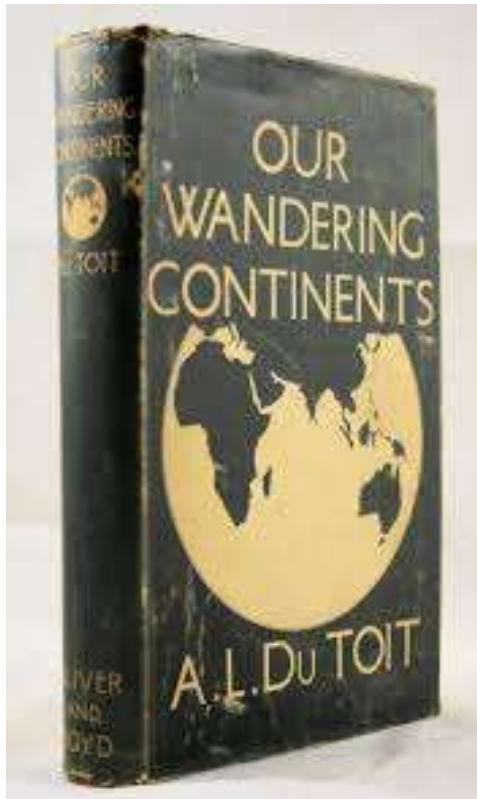


A. L. du Toit Lecture Series

Lecture 35 : 2018



1878-1948

The Geology of South Africa (1927)
reprinted 1939 and 1954

Our Wandering Continents (1937)



GSSA 2018 A L du Toit Lecturer

The 2018 Alex du Toit Lecturer is Professor Lewis D Ashwal of the University of the Witwatersrand

Prof Ashwal will present

“Wandering continents of the Indian Ocean”,

documenting his discovery of ancient continental crust underlying parts of the Indian Ocean.

This work has been reported by the popular press, including international coverage by the BBC

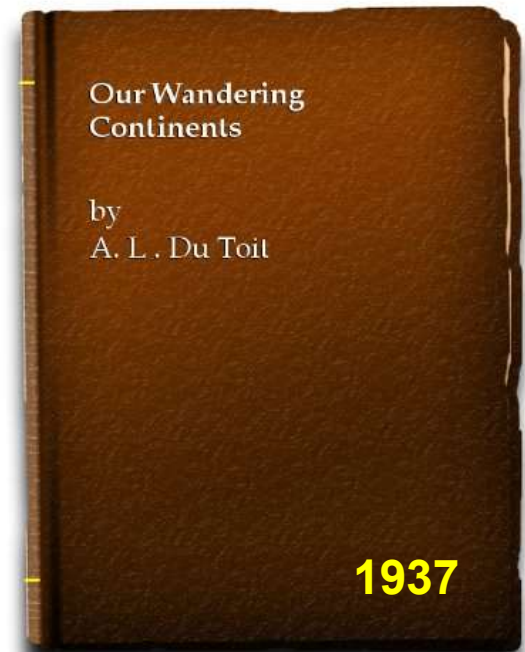


Wandering continents of the Indian Ocean

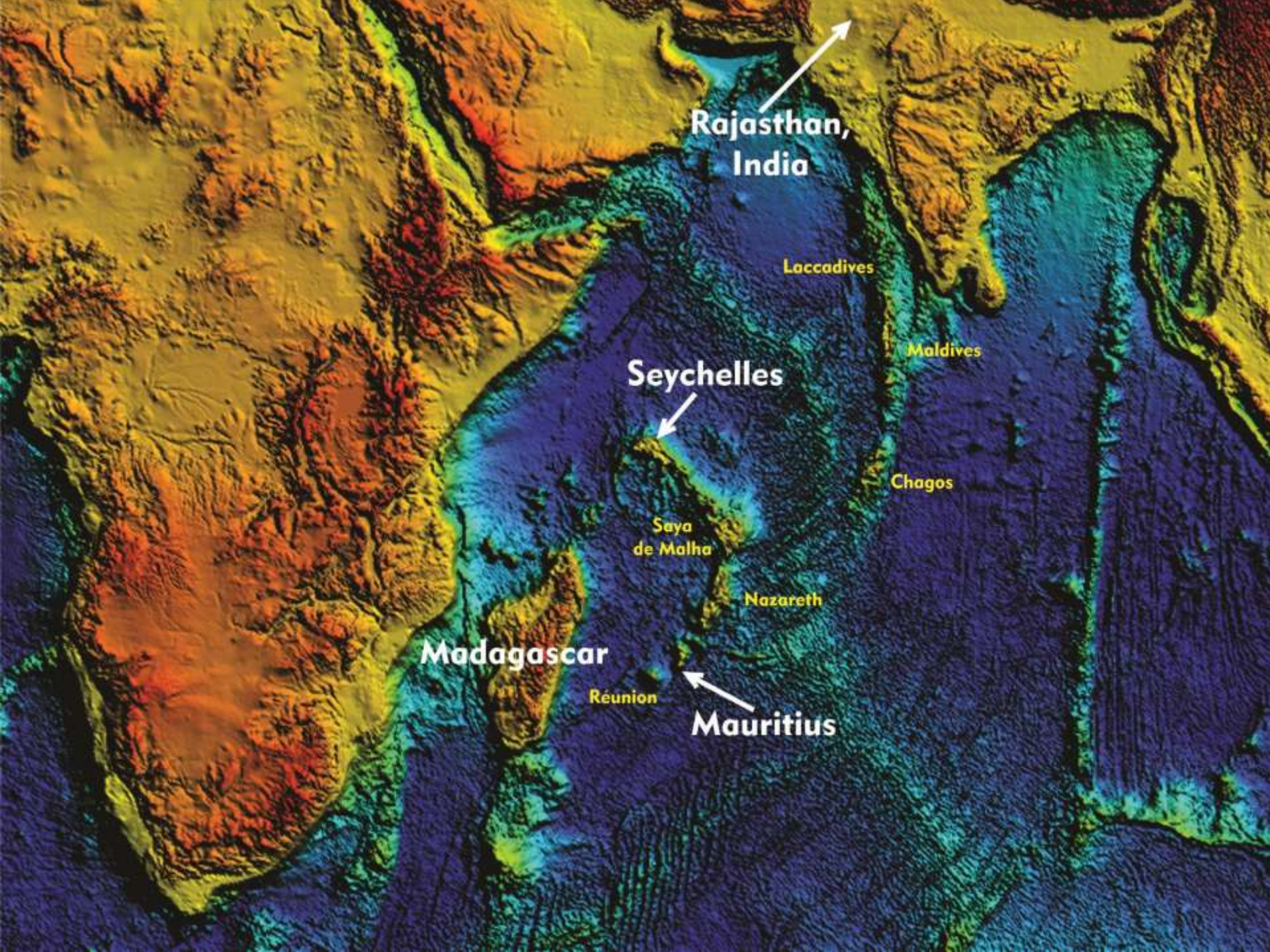


Photo courtesy Sharad Master

Lew Ashwal
Wits University



...inducement... to develop...
“Comparative Geology,”...
the study of continental fragments
(Du Toit 1937, p. 133)



Rajasthan,
India

Laccadives

Seychelles

Maldives

Chagos

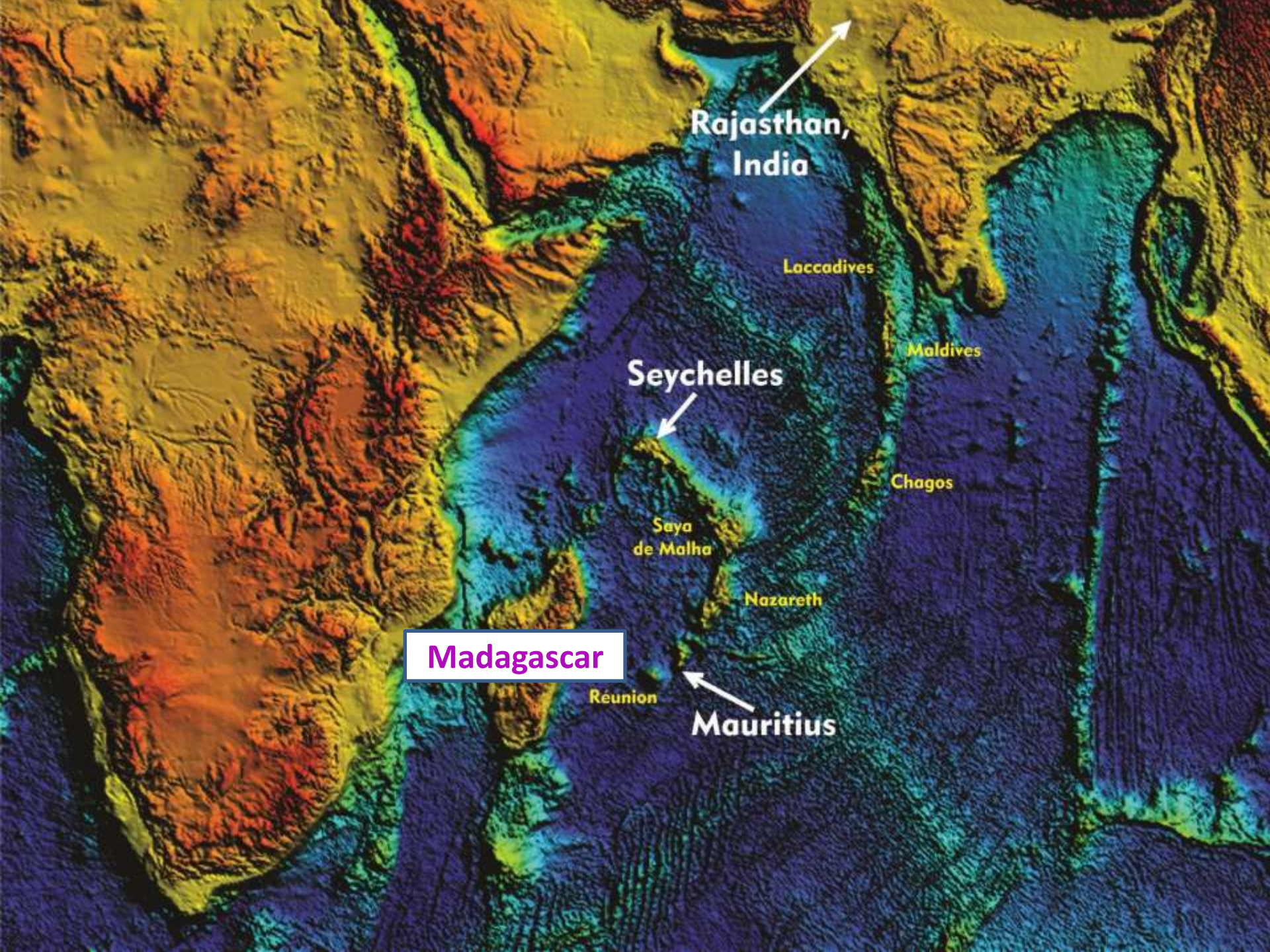
Saya
de Malha

Nazareth

Madagascar

Réunion

Mauritius



Rajasthan,
India

Laccadives

Maldives

Seychelles

Chagos

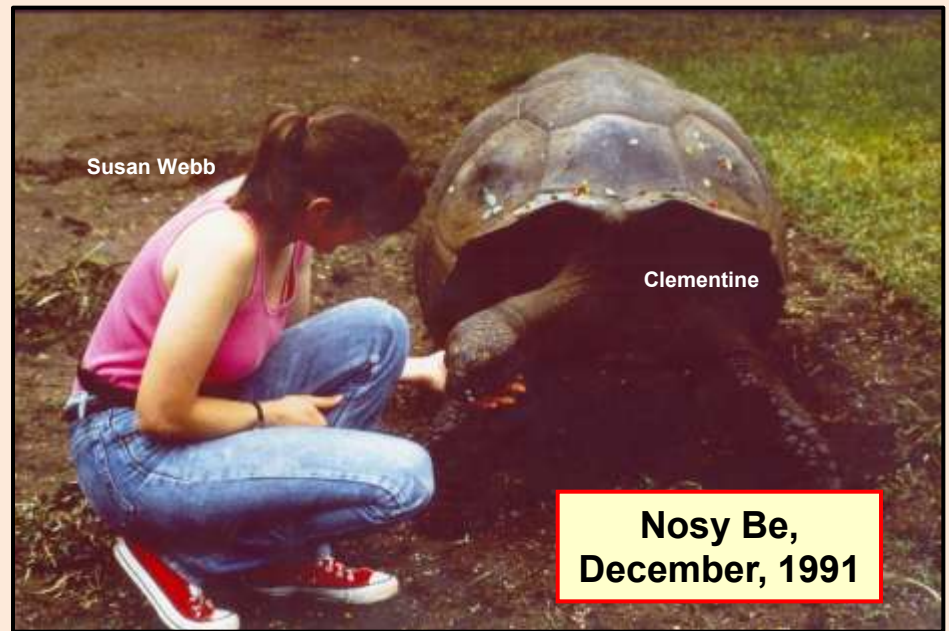
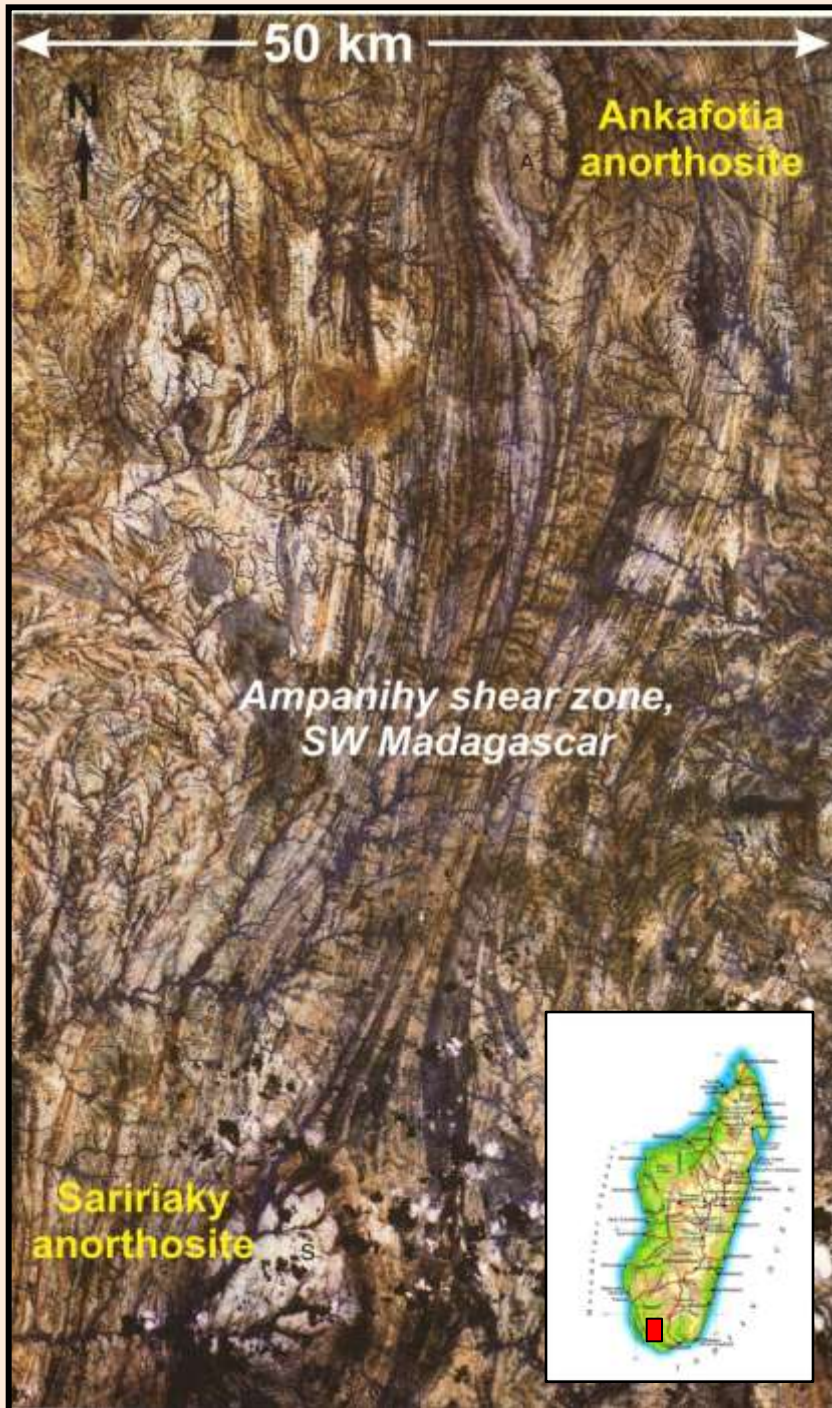
Saya
de Malha

Nazareth

Madagascar

Réunion

Mauritius



Madagascar



MADAGASCAR CARTE GÉOLOGIQUE

Henri Besairie
(1964)



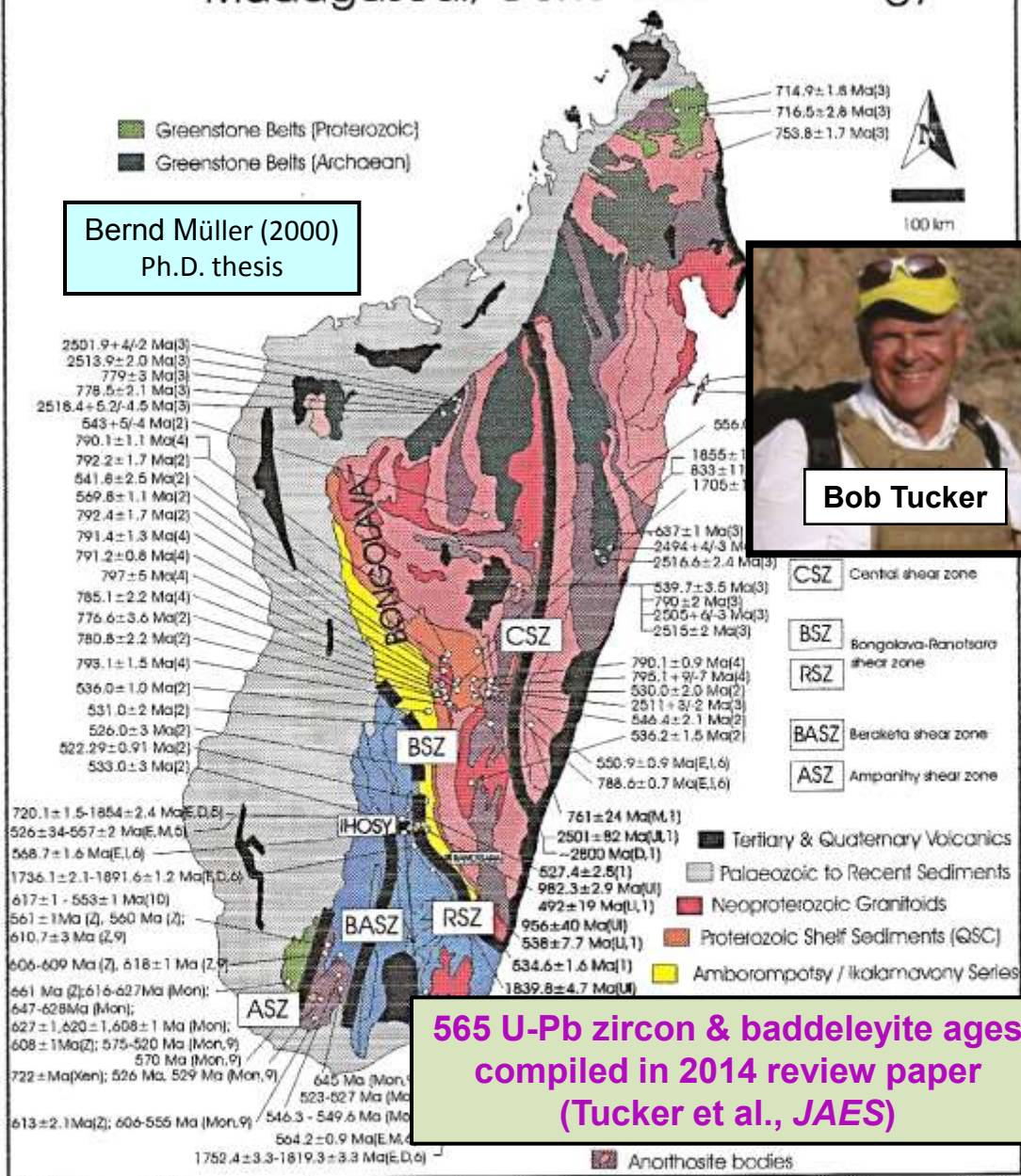
Henri-Michel Besairie



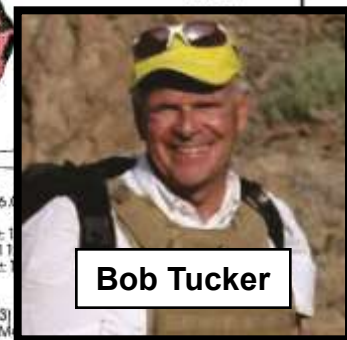
Madagascar, Generalized Geology

Greenstone Belts (Proterozoic)
Greenstone Belts (Archaean)

Bernd Müller (2000)
Ph.D. thesis

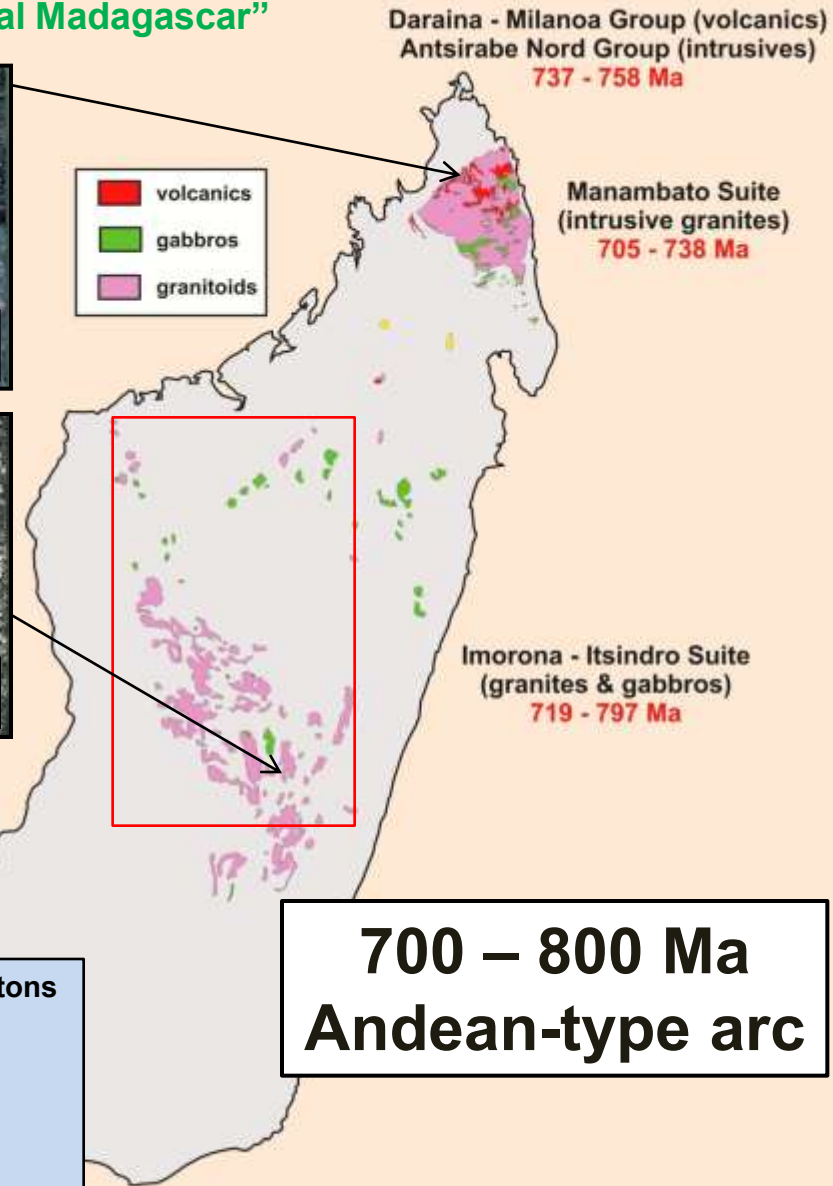
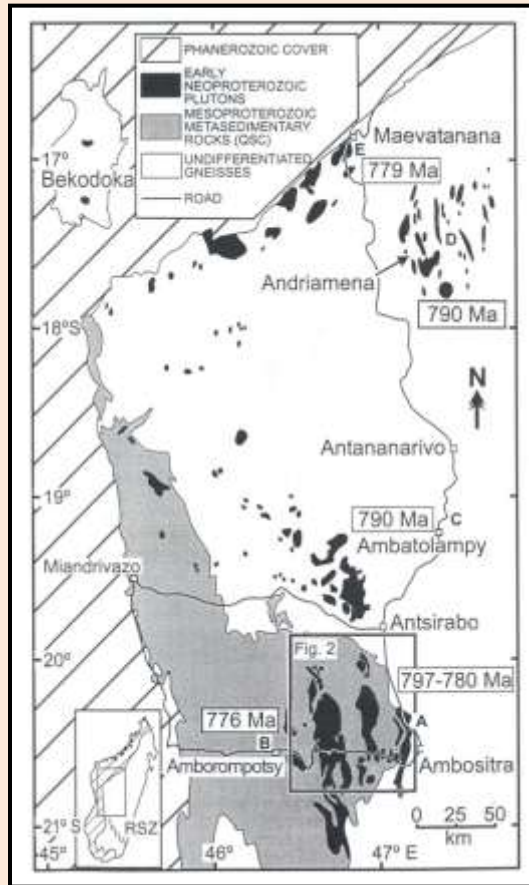


Bob Tucker



565 U-Pb zircon & baddeleyite ages
compiled in 2014 review paper
(Tucker et al., JAES)

“Neoproterozoic continental arc magmatism in west-central Madagascar”



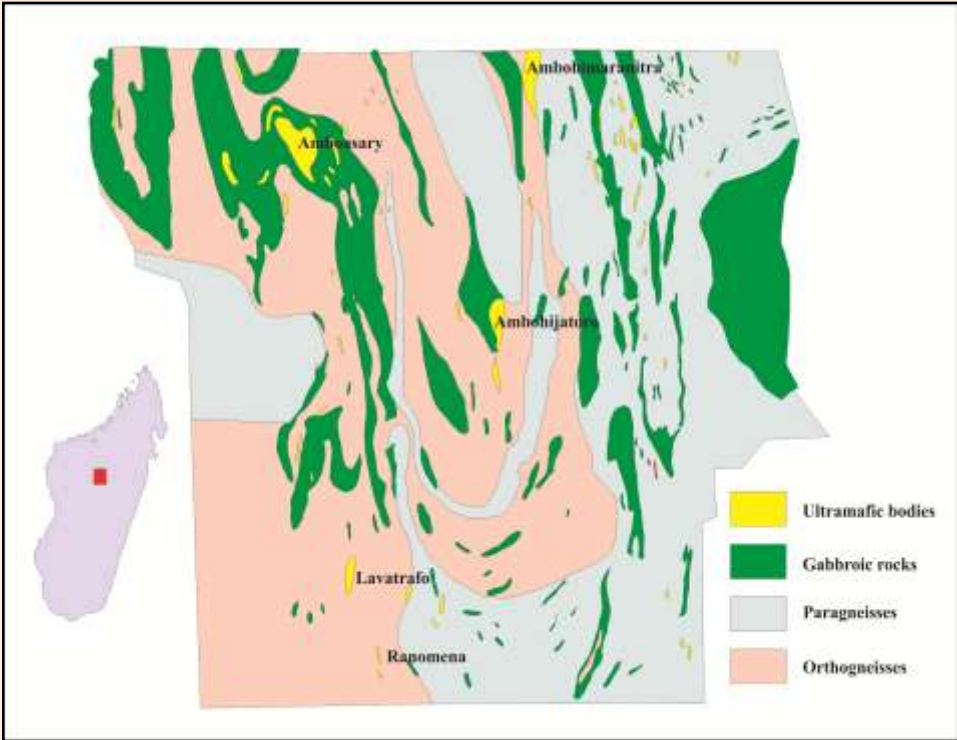
Andean-type arc supported by:

- 450 km belt of coeval gabbro & granitoid plutons
- nested plutons with high aspect ratios (10:1)
- complex mingling of gabbro & granitoids
- alkaline gabbros ($\text{Na}_2\text{O} + \text{K}_2\text{O}$ up to 8 wt.%)
- primary hornblende & biotite in gabbros
- Cu mineralization in both

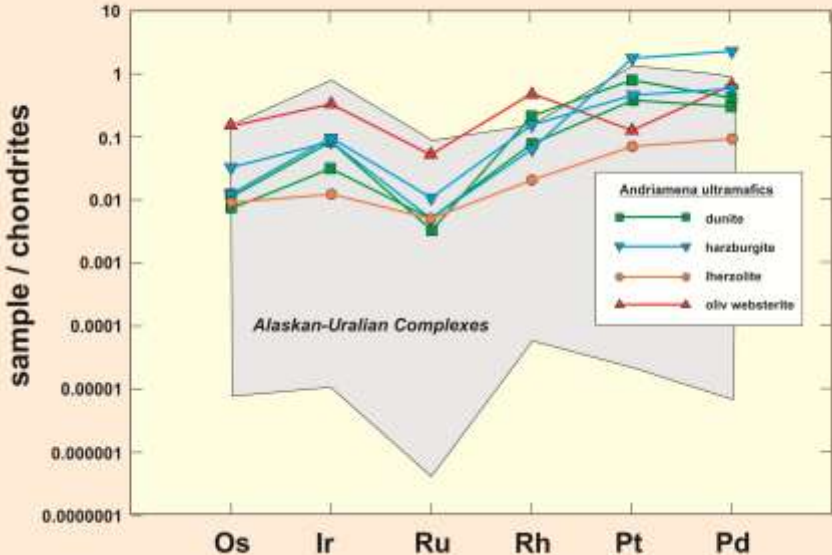
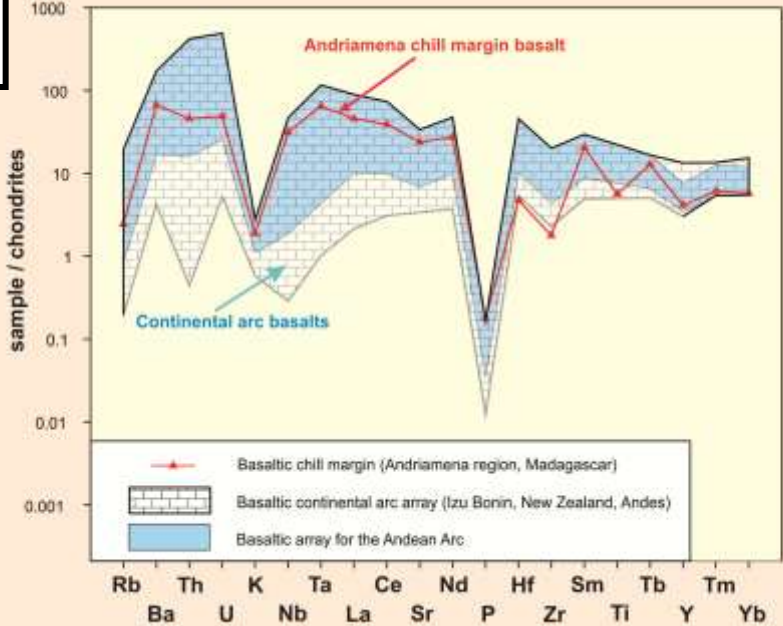
**700 – 800 Ma
Andean-type arc**

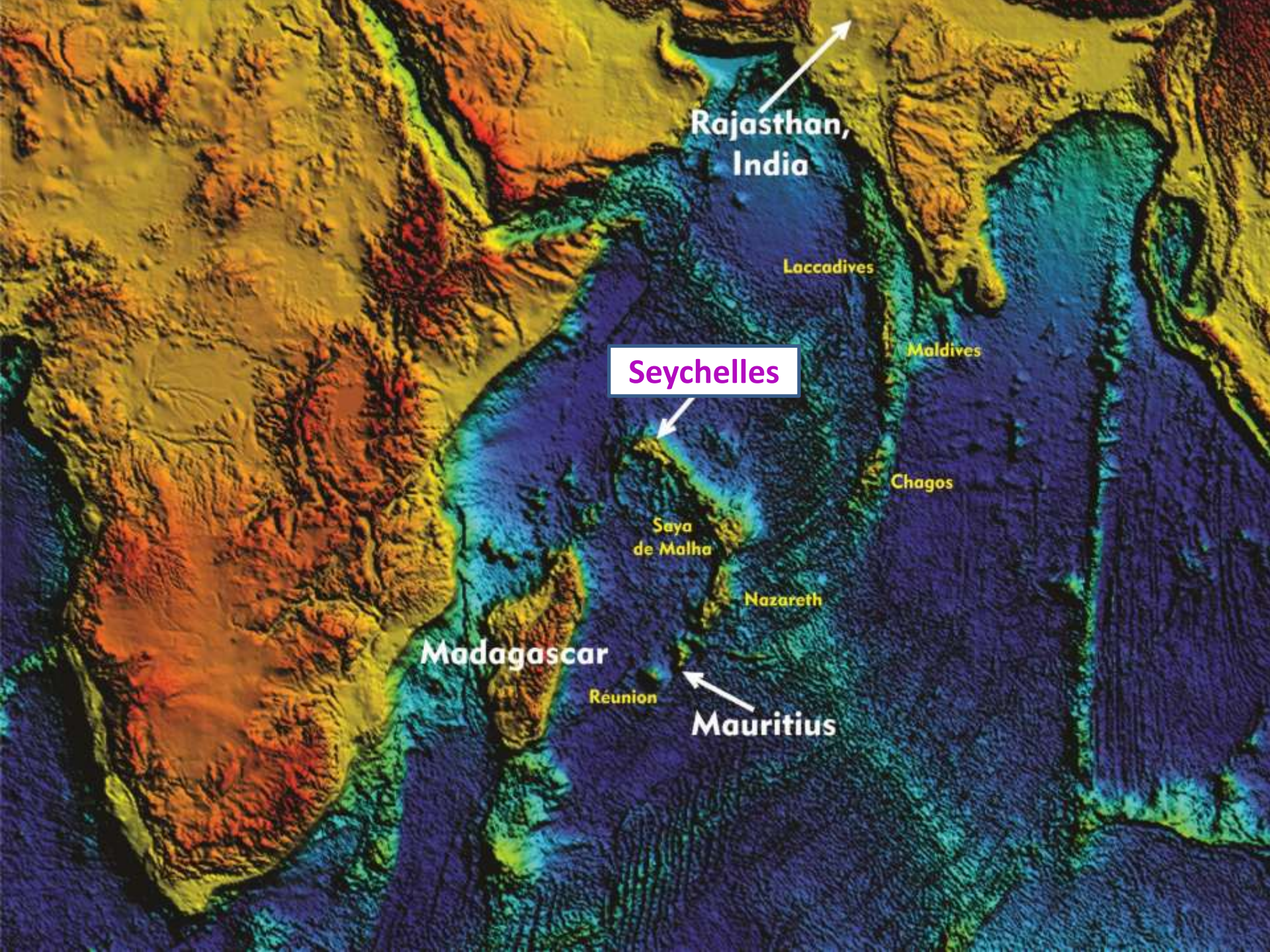
**Neoproterozoic ultramafic-mafic complexes,
central Madagascar (787 ± 16 Ma)**

Trace elements & PGE similar to Alaskan – Uralian complexes (roots of continental arcs)



G.M. Bybee (2008 *Hons. Project*)

Bybee et al. (2010 *EPSL*)



Rajasthan,
India

Laccadives

Maldives

Seychelles

Chagos

Saya
de Malha

Nazareth

Madagascar

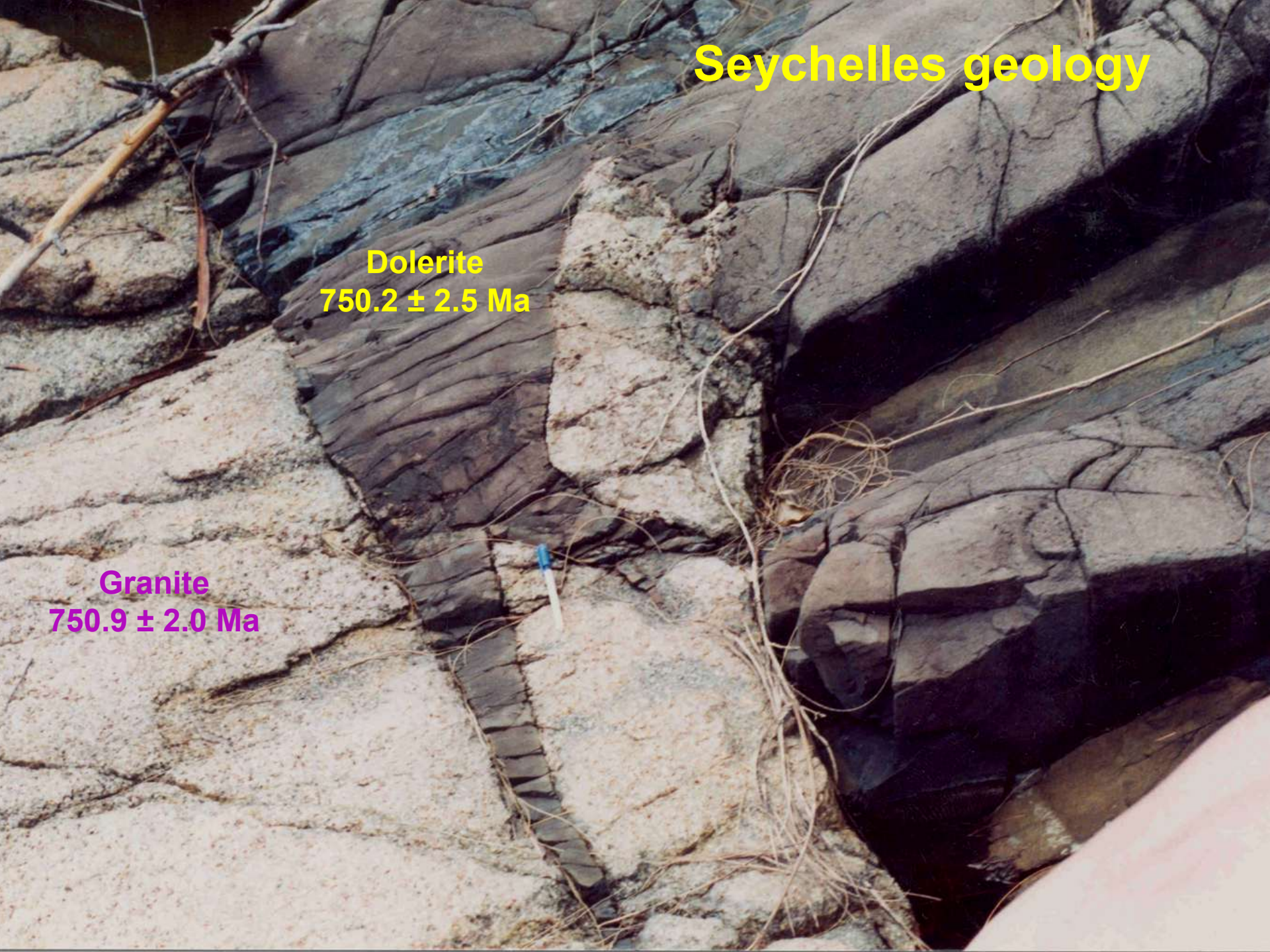
Réunion

Mauritius

Silhouette from North Island, Seychelles



Seychelles geology

A photograph of a geological outcrop in the Seychelles. The image shows a complex arrangement of rock layers. Dark, layered Dolerite is visible in the upper and right portions, while lighter-colored Granite is in the lower-left. A small blue and white object, possibly a pen or pencil, is placed on the granite for scale. The rocks are weathered and have some roots growing on them.

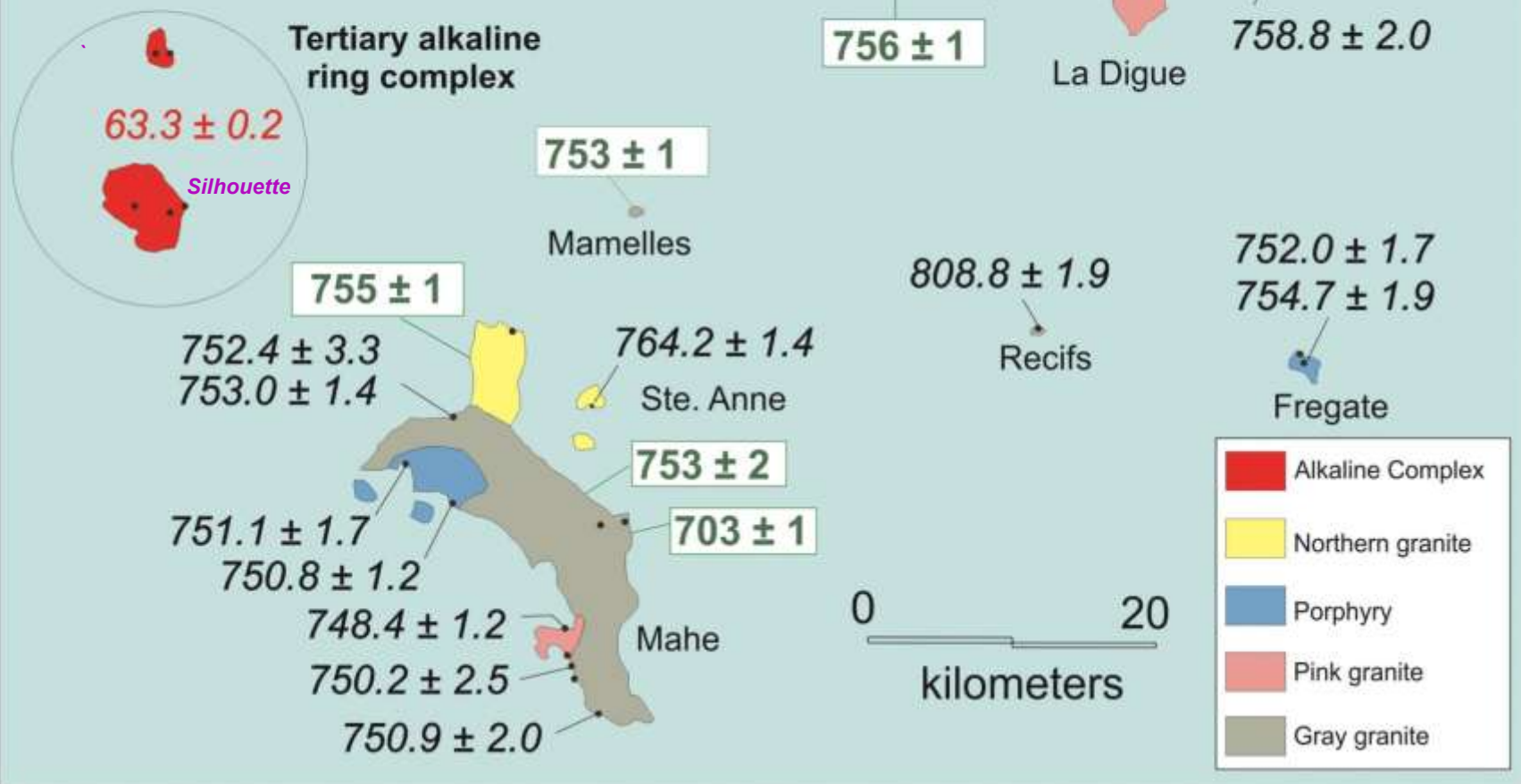
Dolerite
 750.2 ± 2.5 Ma

Granite
 750.9 ± 2.0 Ma

SEYCHELLES

U-Pb zircon ages in Ma

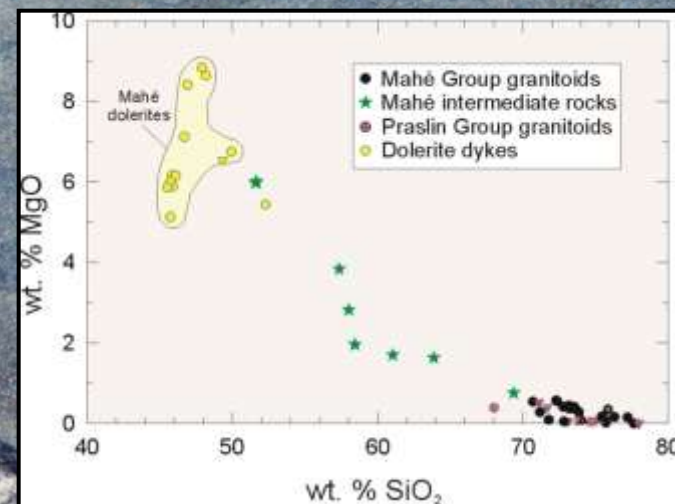
Tucker et al. (2001)
Stephens et al., 1997



**Age range: 703 ± 1 – 809 ± 2 (n = 21),
 but most cluster at 753 ± 4 (n = 19)**

Petrogenesis of Neoproterozoic Granitoids and Related Rocks from the Seychelles: the Case for an Andean-type Arc Origin

L. D. ASHWAL^{1*}, D. DEMAIFFE² AND T. H. TORSVIK³

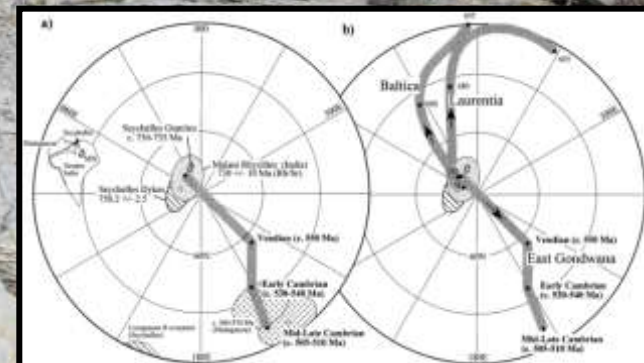


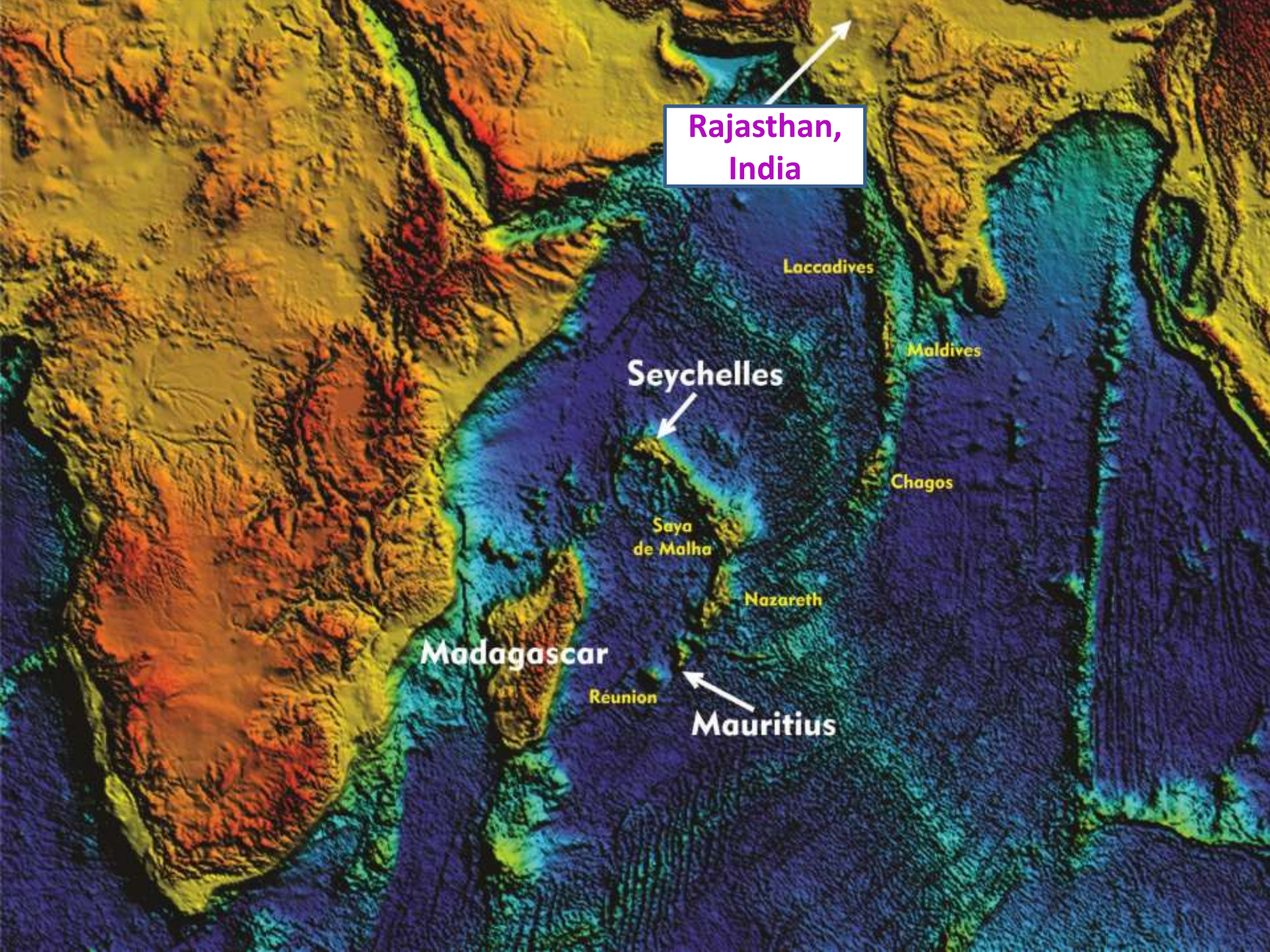
SEYCHELLES: Arguments for Andean arc setting:

- age span of ~100 m.y.
- biot- & hbl-d-bearing, metaluminous, I-type granitoids
- coeval dolerites
- intermediate rocks
- isotope arrays between depleted mantle & ancient crust
- palaeomag reconstructions place SEY at margin of Rodinia

Trond

Morgan
Ganerød





Rajasthan,
India

Laccadives

Maldives

Seychelles

Chagos

Saya
de Malha

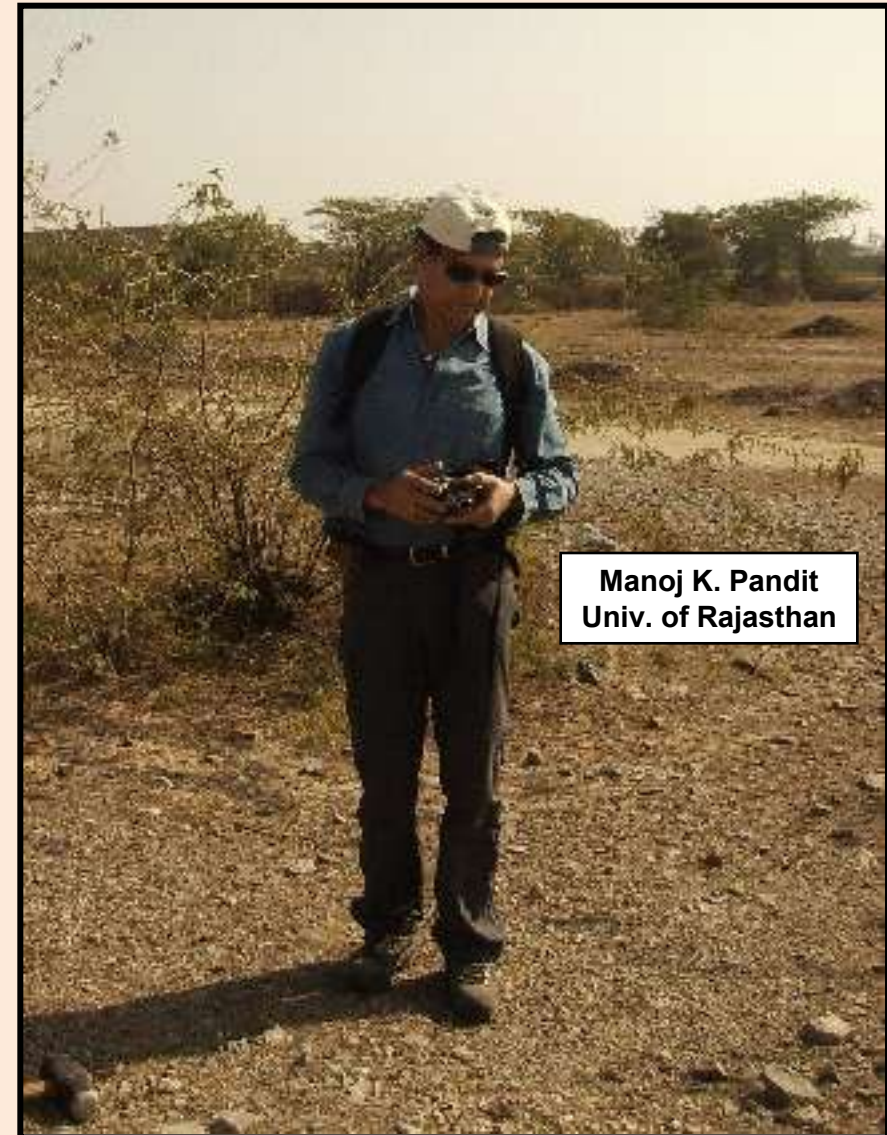
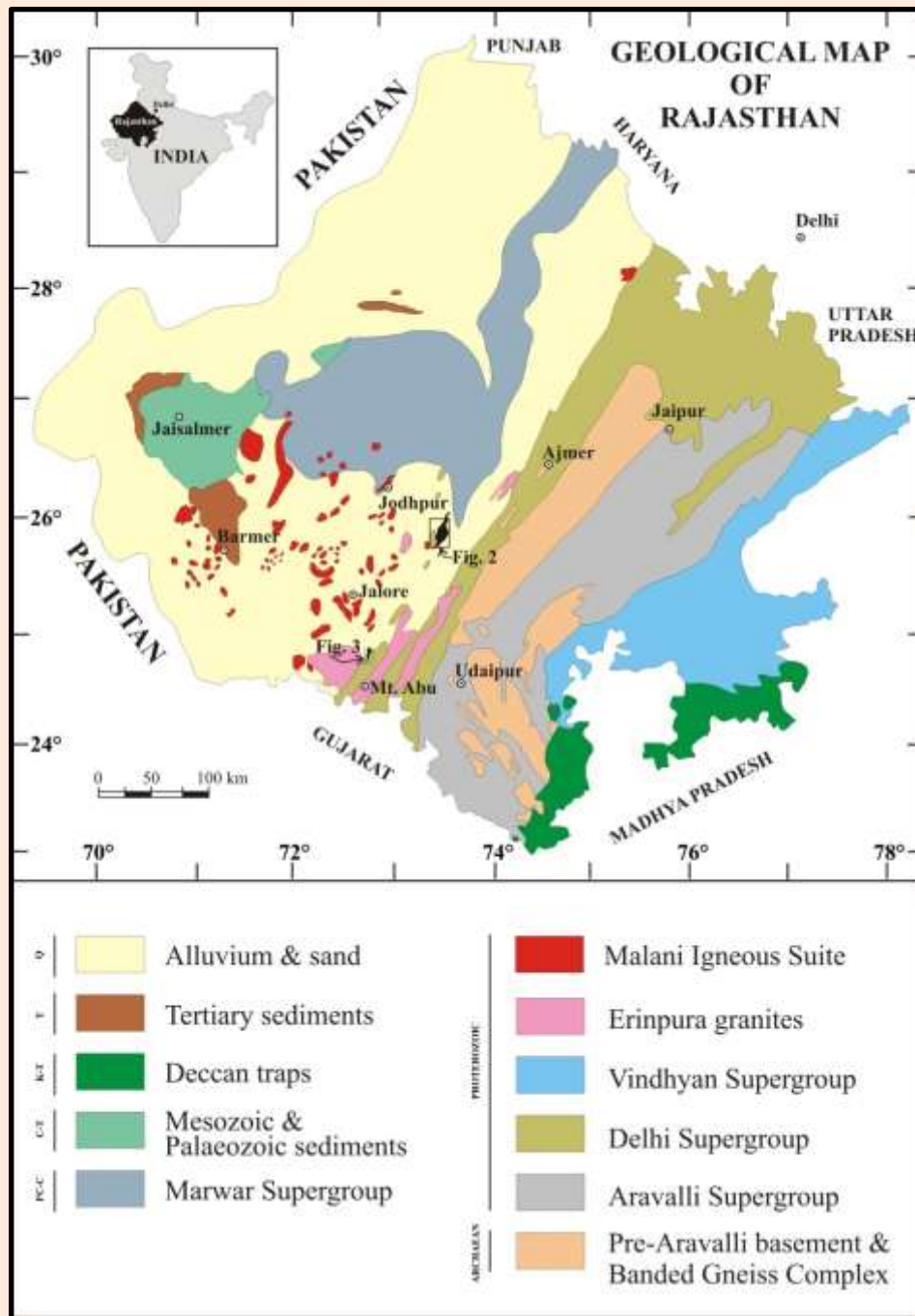
Nazareth

Madagascar

Réunion

Mauritius

Malani Igneous Suite



Manoj K. Pandit
Univ. of Rajasthan

Dolerite dyke cutting granitoids, Mt. Abu, Rajasthan

dolerite: 759 ± 12 Ma

granitoids:
 $764 \pm 3 - 768 \pm 3$ Ma

3. 3. 2002

Jodhpur

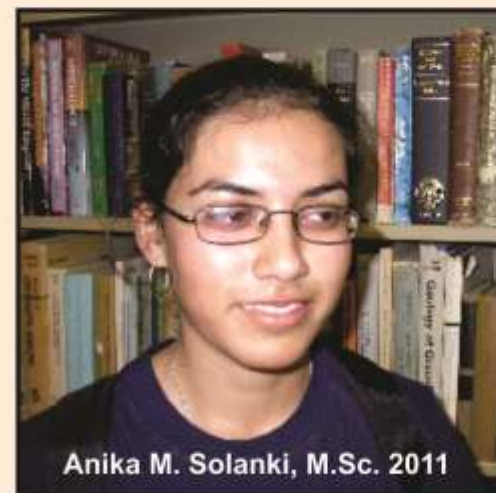
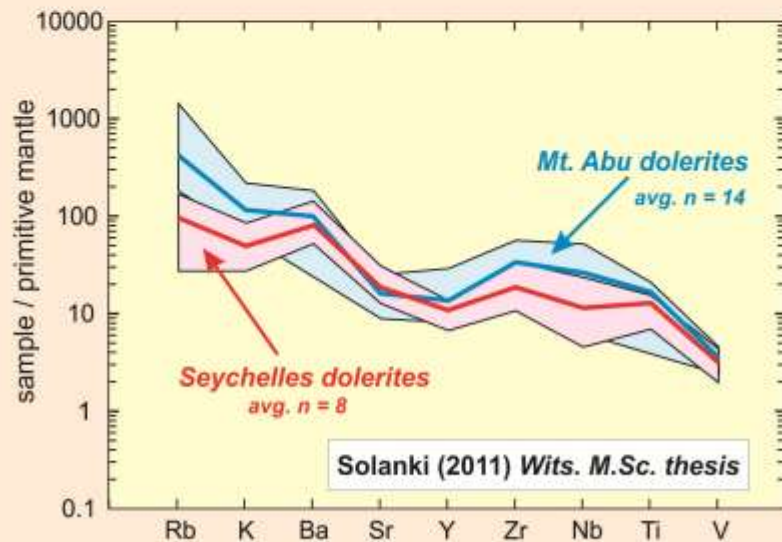
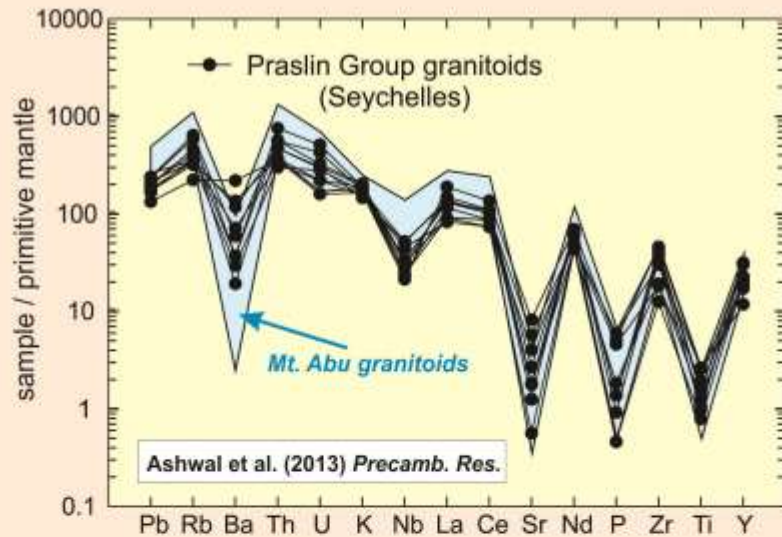


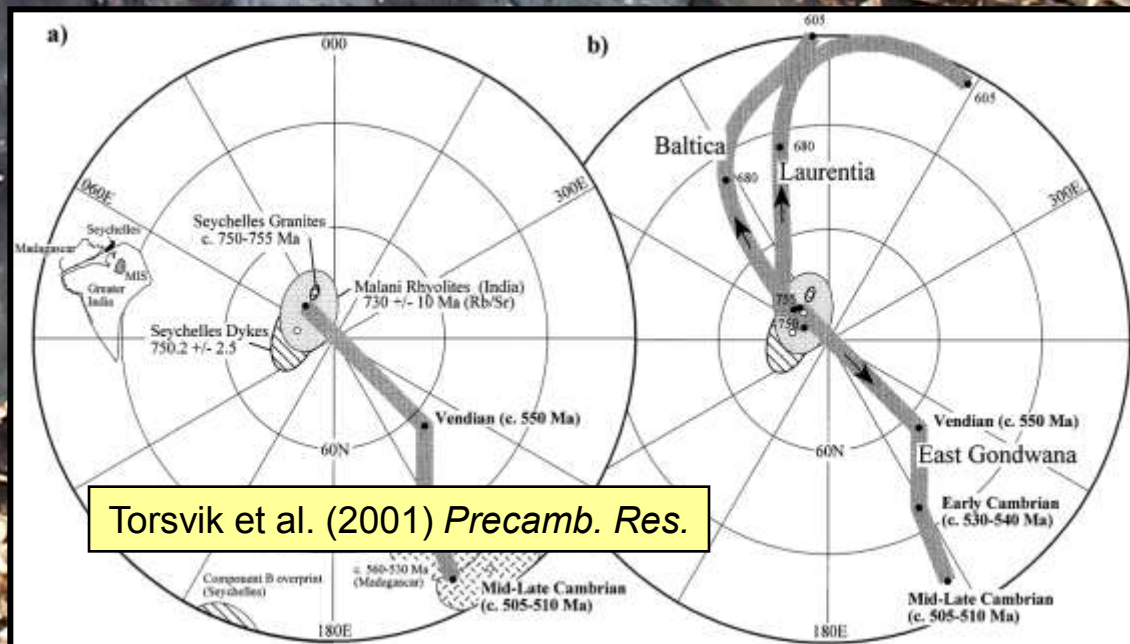
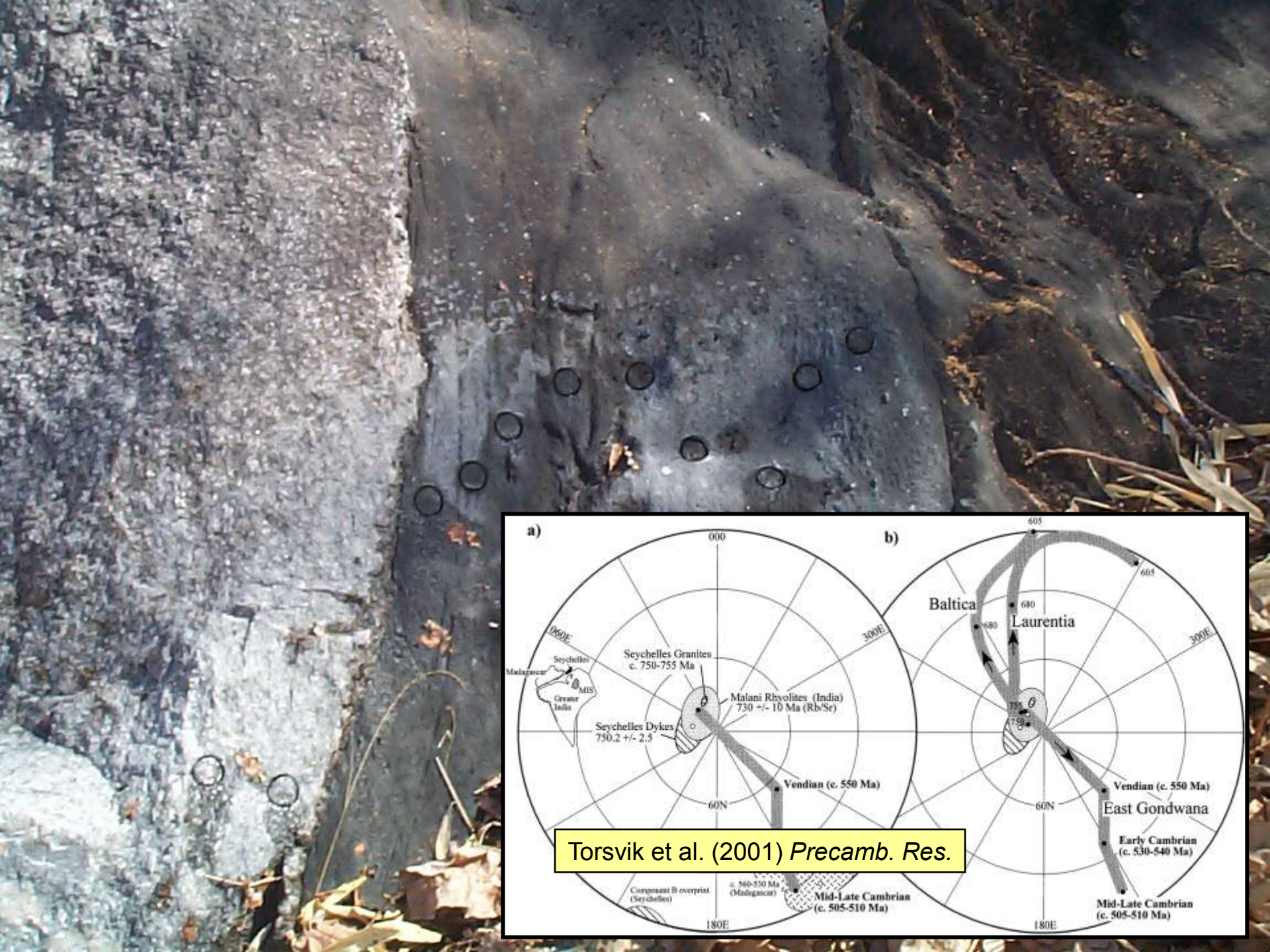
Mehrangarh fortress (1460)

**Basal Marwar Supergroup
(Jodhpur Group)
Early Cambrian (524-542 Ma)**

**Malani rhyolites (Mt. Abu equivalents)
751-771 Ma**

Malani – Seychelles comparison

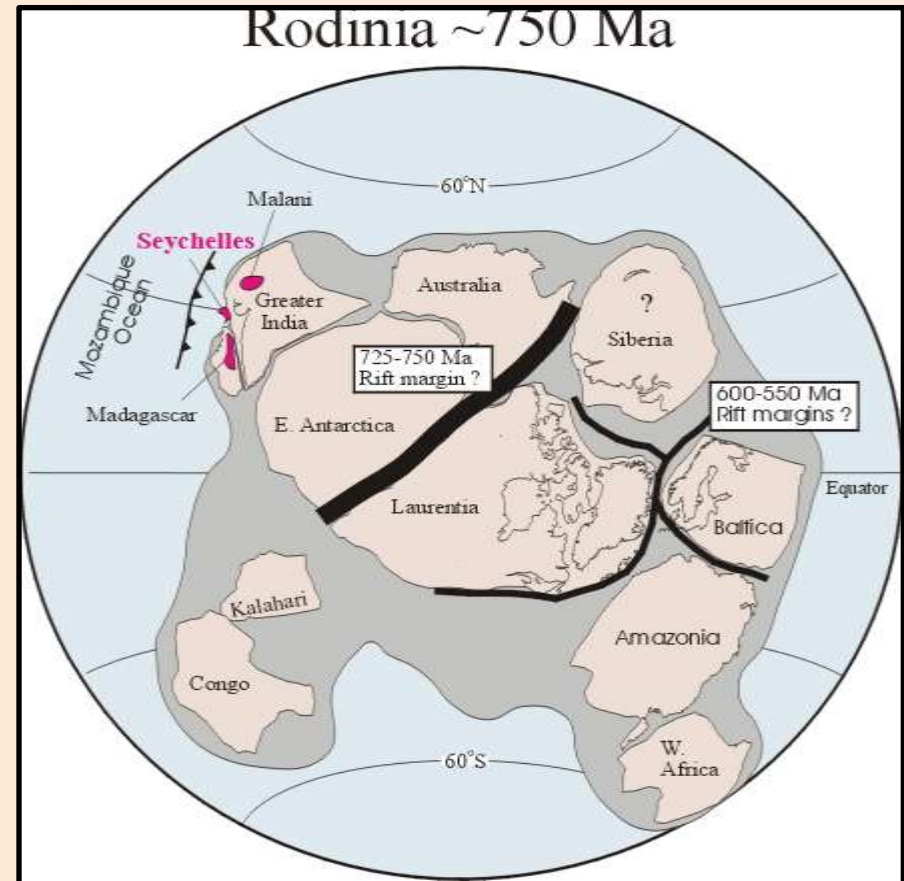
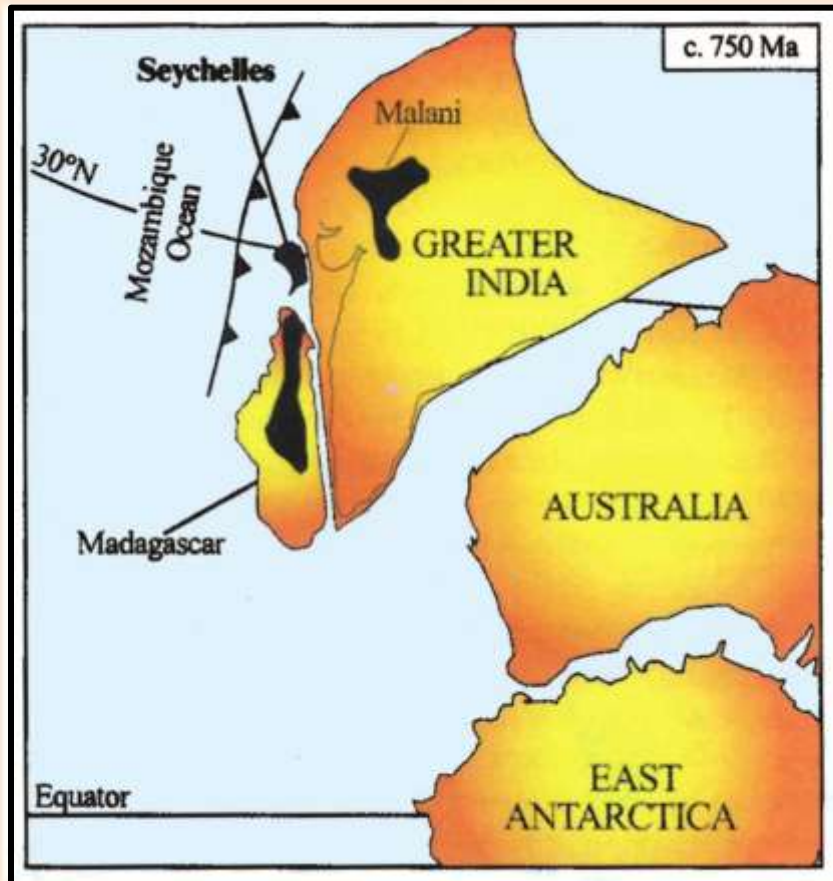




Madagascar – Seychelles – Malani link based on:

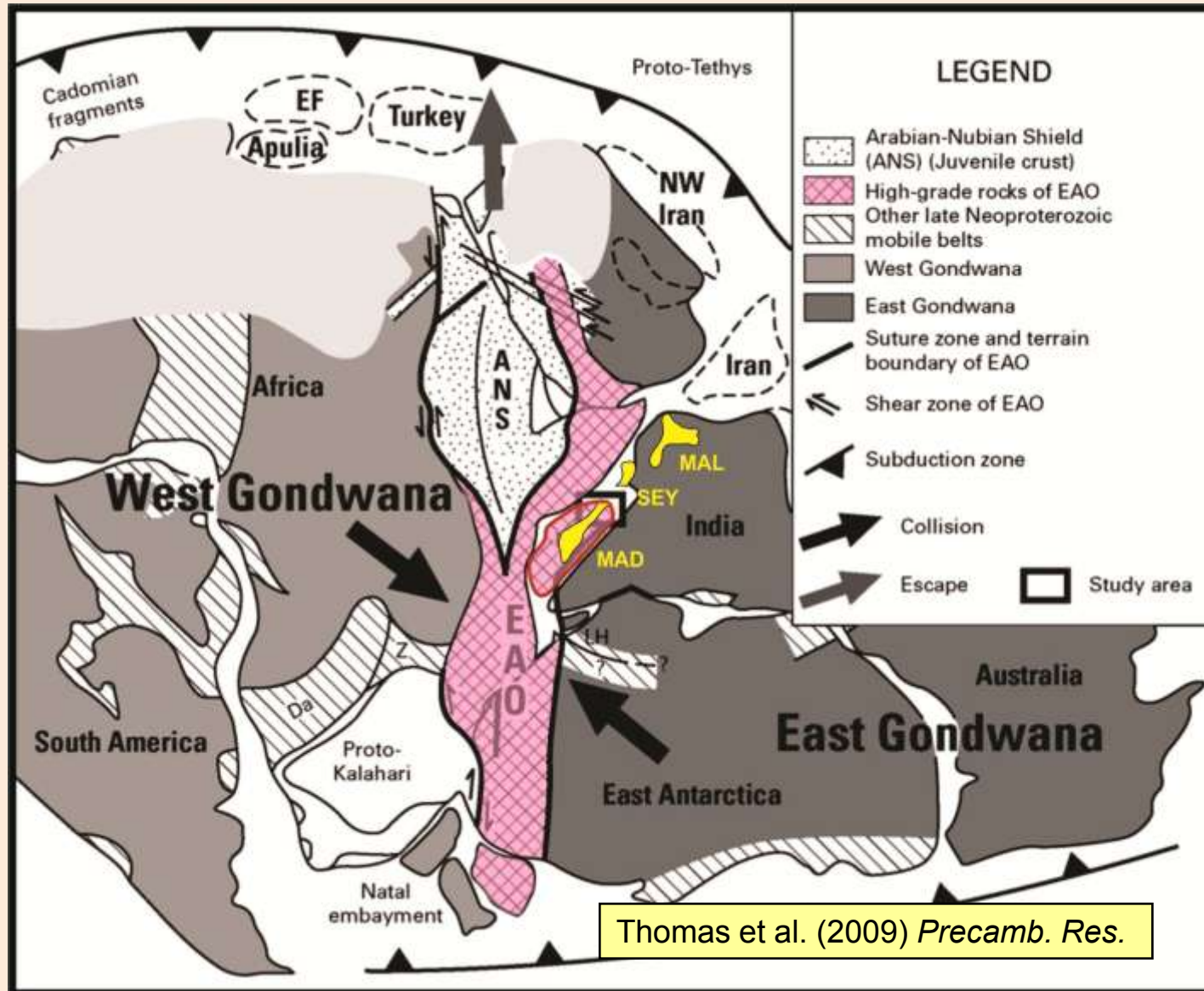
- geology
- geochronology
- petrology & geochemistry
- palaeomag

Andean arc interpretation
supported by marginal
paleoposition in Rodinia



Torsvik et al. (2001) *Precamb. Res.*

Assembly of Gondwana by Pan-African collisions ~500-550 Ma



P.F. Hoffman (1991)

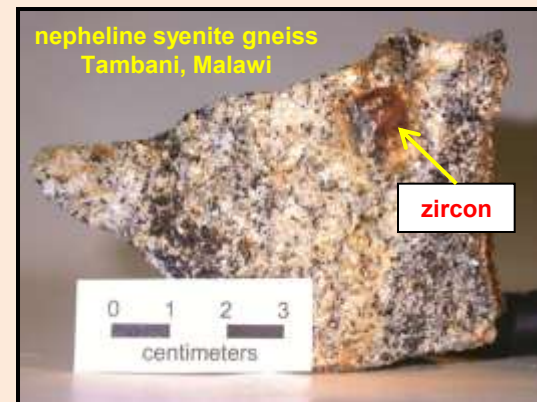
East & West
Gondwana
joined at
East African Orogen

MAL & SEY,
but not MAD
escape high-grade
metamorphism &
deformation

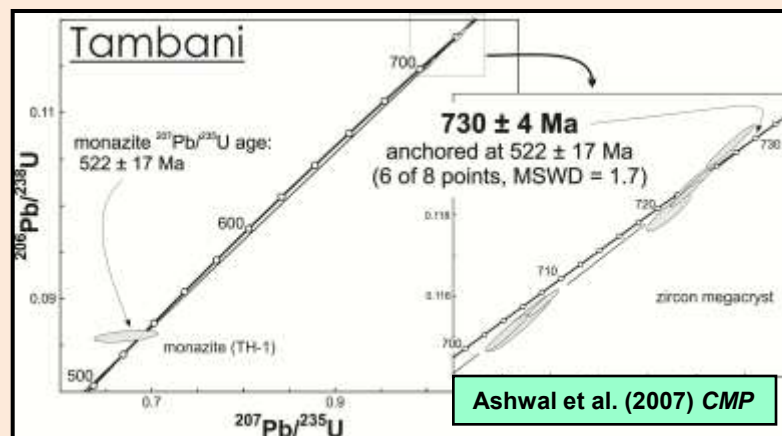
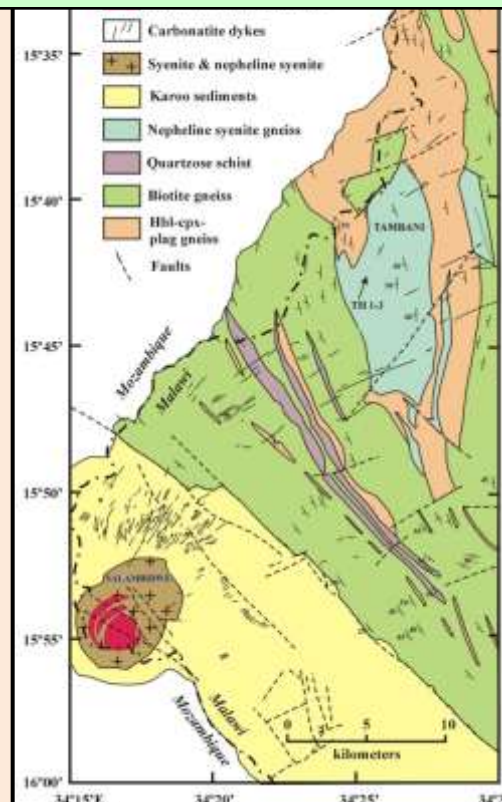
Alkaline Rocks & Carbonatites (ARCs & DARCs)



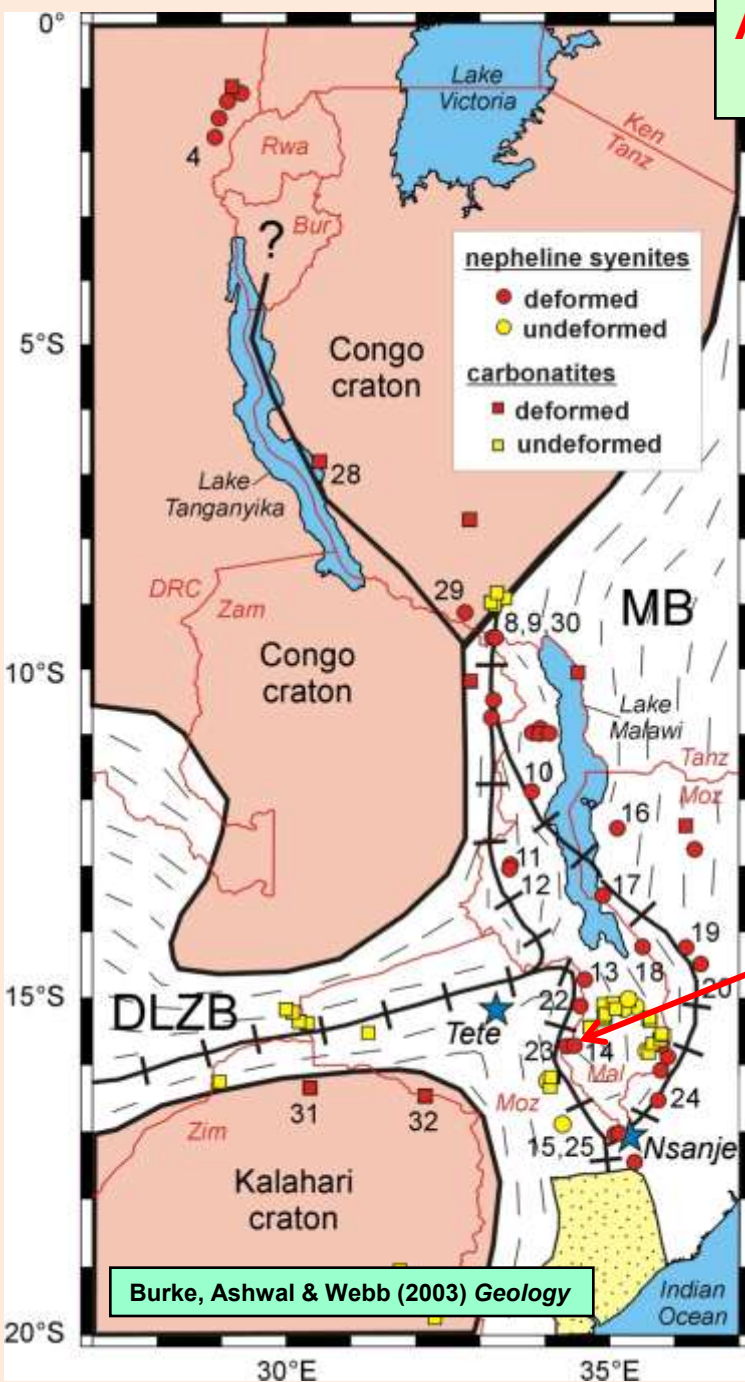
Kevin Burke



zircon

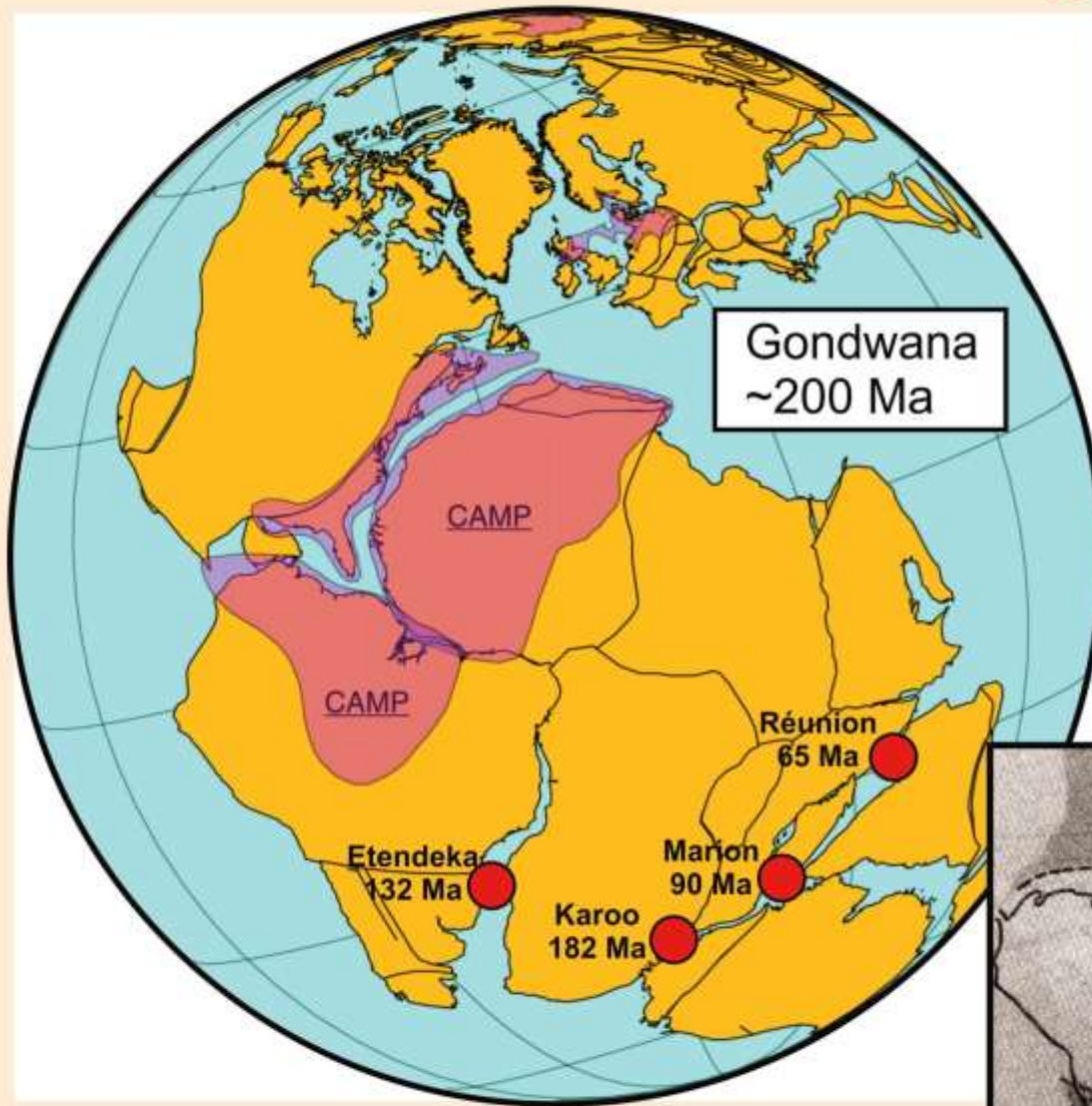


Ashwal et al. (2007) CMP



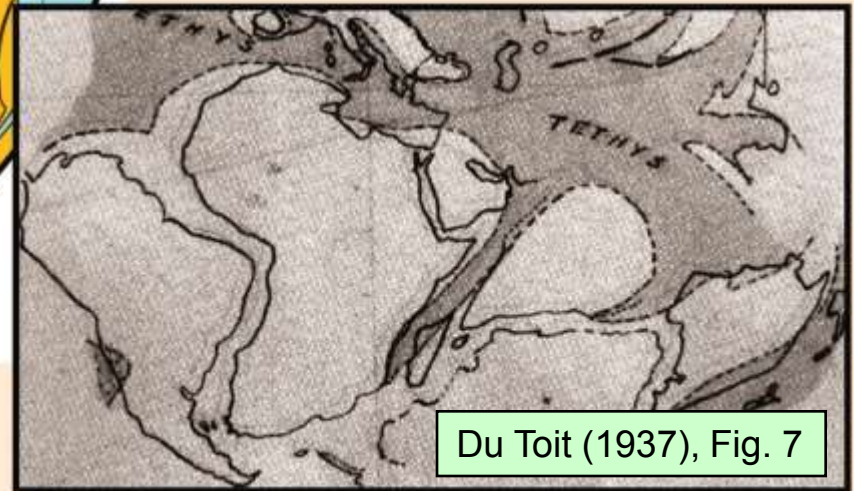
Burke, Ashwal & Webb (2003) Geology

Gondwana break-up: role of plumes



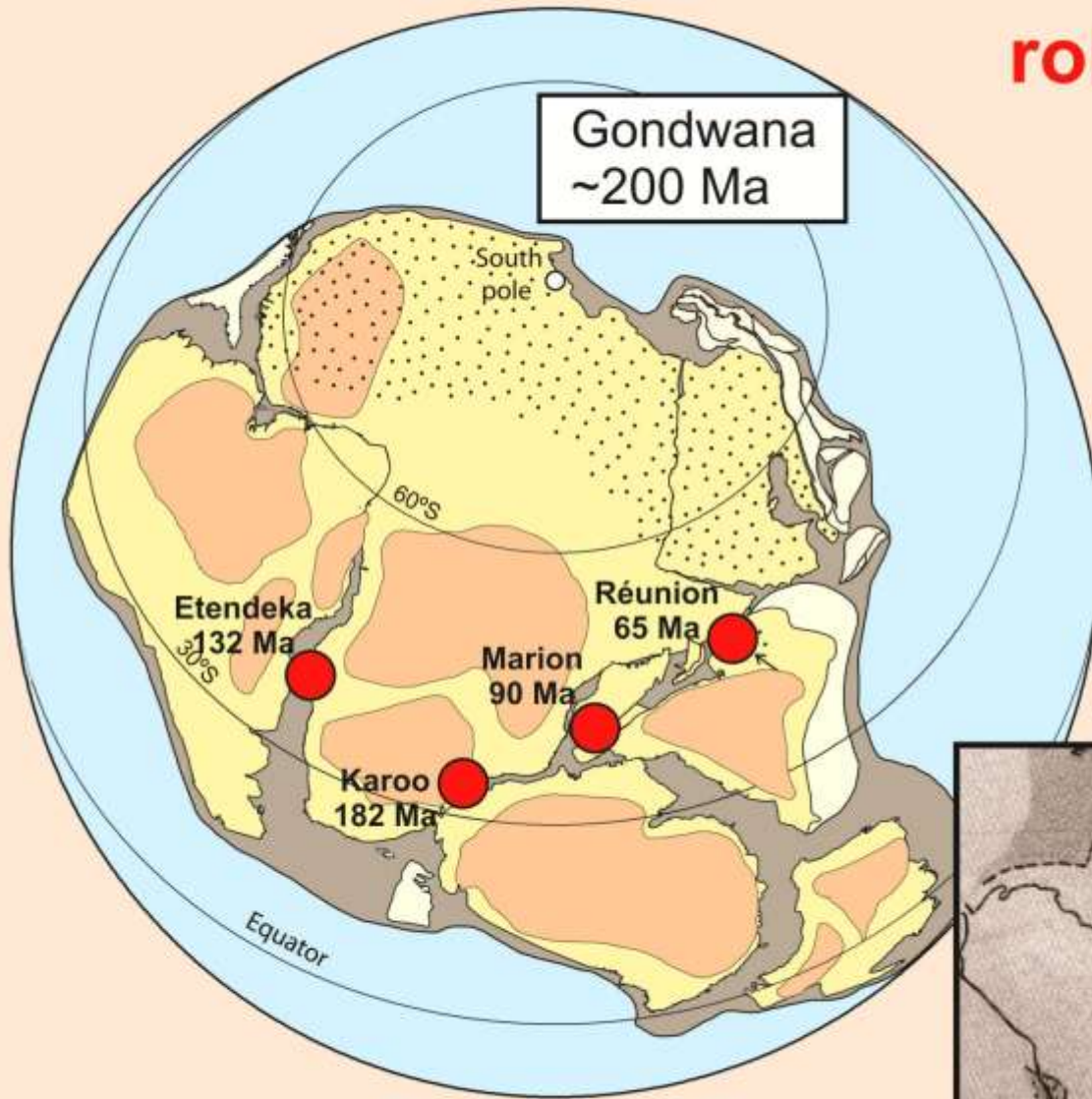
Age (Ma)	LIP	Plume
65	Deccan	Réunion
90	Madagascar	Marion
132	Etendeka/ Paraná	Tristan
182	Karoo	Bouvet

Buiter & Torsvik (2014) *Gondwana Res.*

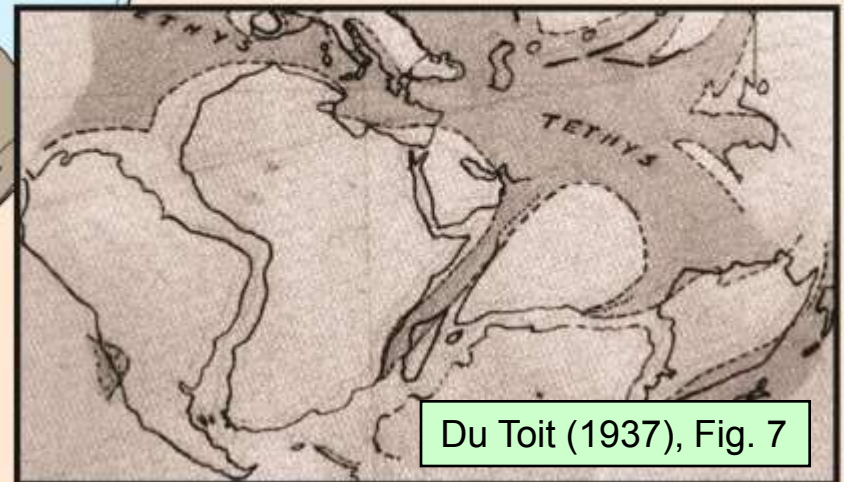


Du Toit (1937), Fig. 7

Gondwana break-up: role of plumes



Age (Ma)	LIP	Plume
65	Deccan	Réunion
90	Madagascar	Marion
132	Etendeka/ Paraná	Tristan
182	Karoo	Bouvet



Du Toit (1937), Fig. 7

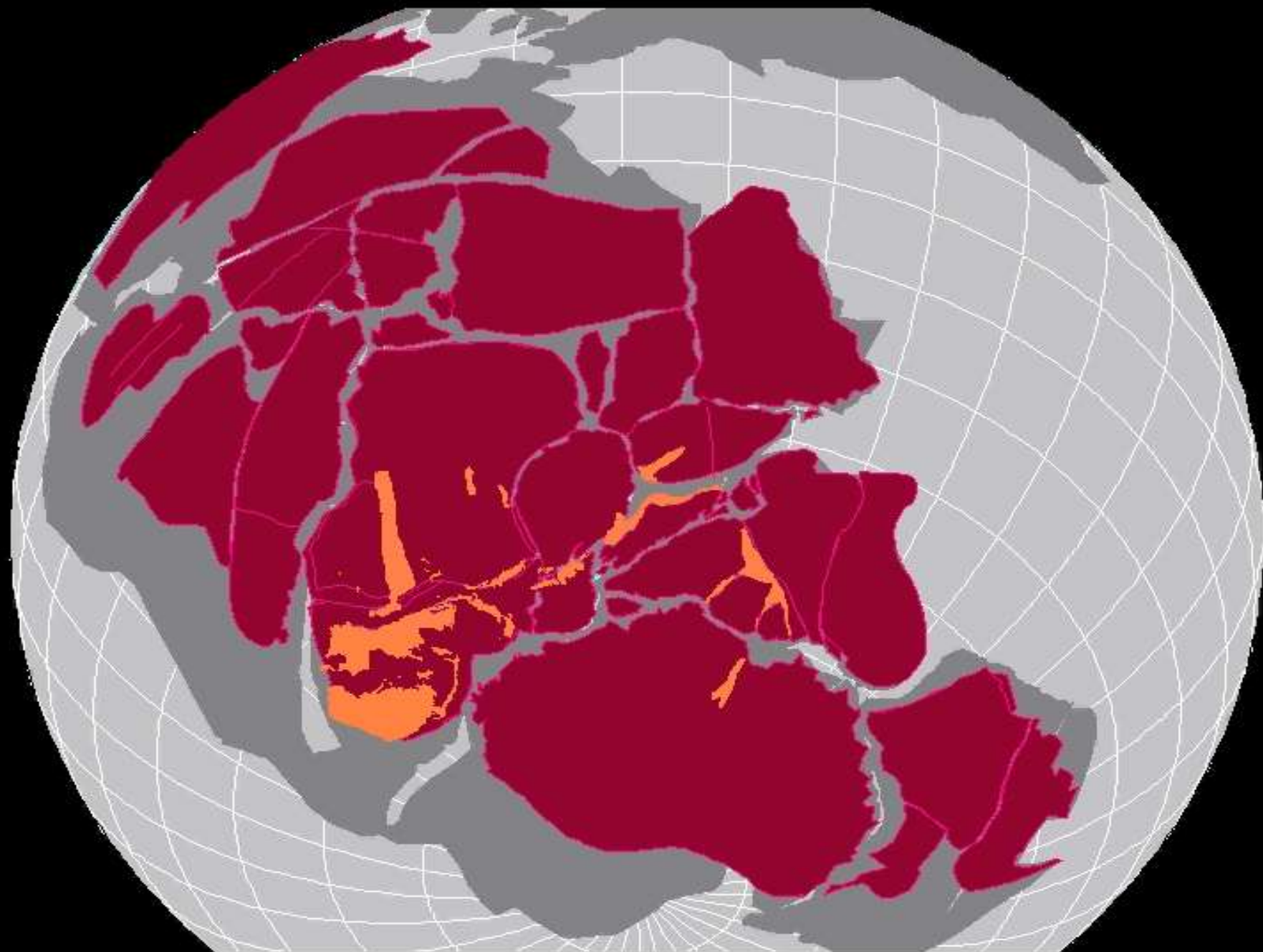
Gondwana break-up animation

Colin Reeves (2004)

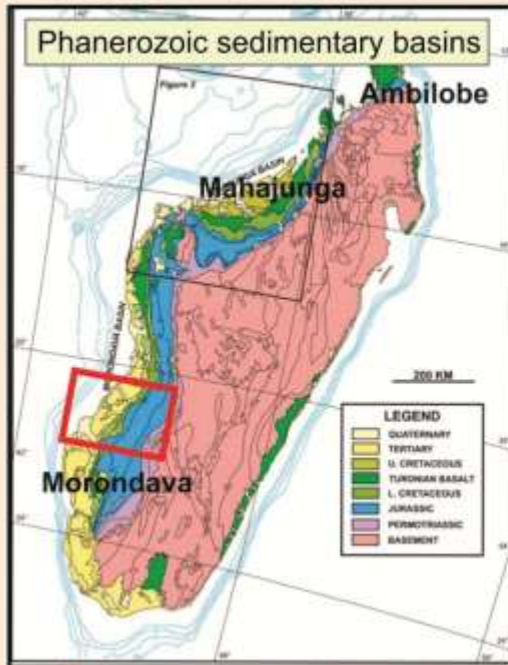


Note:

- Plume impingement- Bouvet (Karoo) -182 Ma
Tristan (Etendeka) – 132 Ma
Marion (Madagascar) – 90 Ma
Réunion (Deccan) – 65 Ma
- [India + Mad + Antarctica] separates from Africa ~150 Ma,
drifts southward (Karoo plume ?)
- Madagascar separates from India ~90 Ma,
India drifts northward (Marion plume ?)

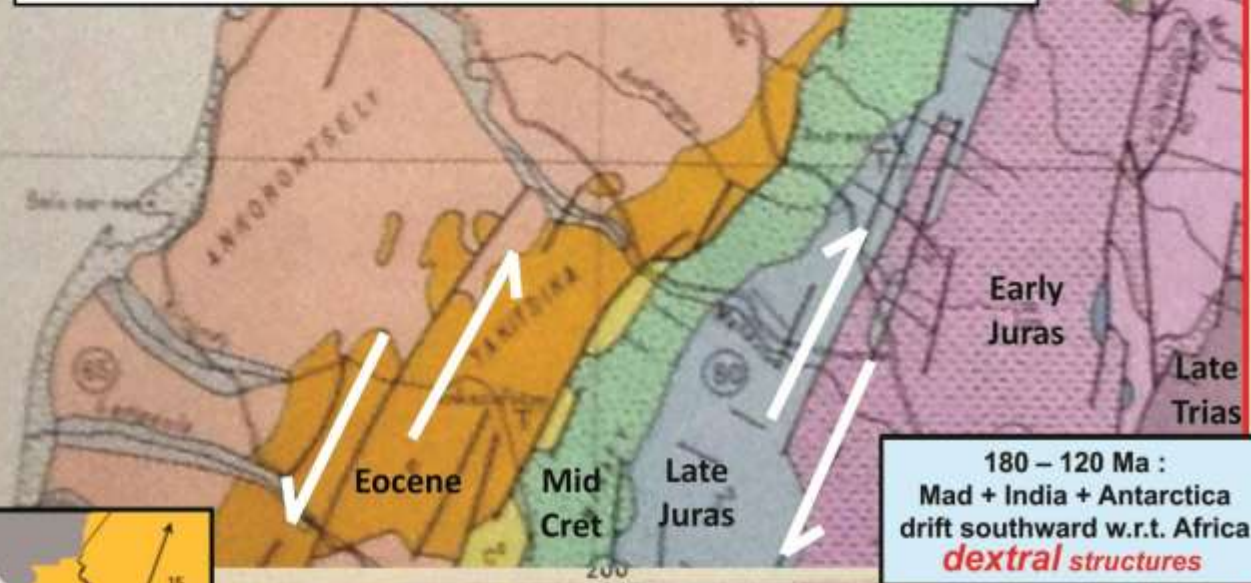


Phanerozoic sedimentary basins

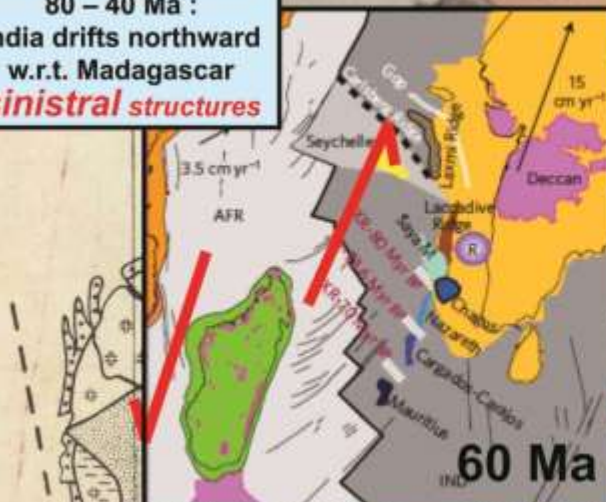


Morondava Basin, SW Madagascar:

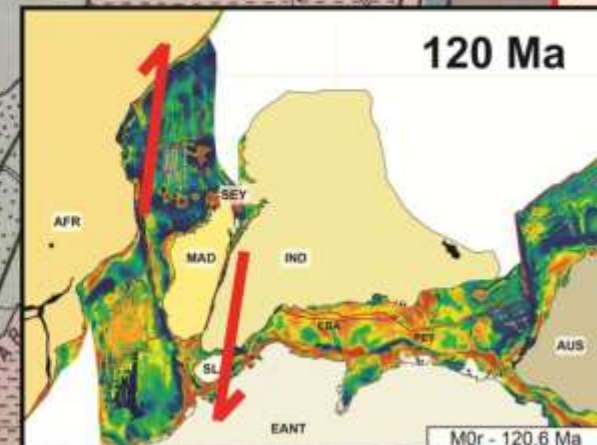
Trans-tensional pull-apart structures in Permian - Eocene sedimentary rocks record changes in plate kinematics during Gondwana break-up

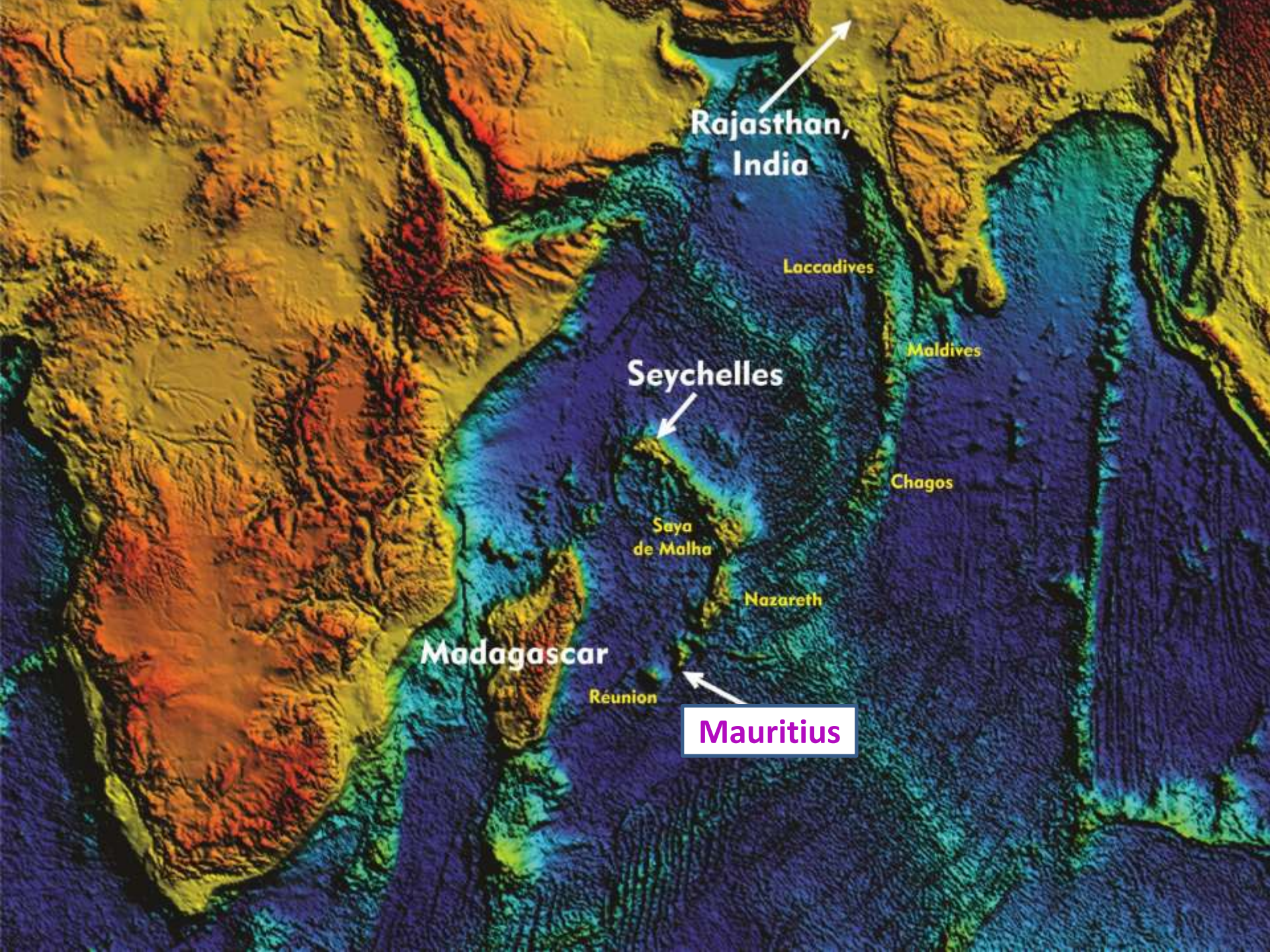


80 – 40 Ma :
India drifts northward
w.r.t. Madagascar
sinistral structures



180 – 120 Ma :
Mad + India + Antarctica
drift southward w.r.t. Africa
dextral structures





Rajasthan,
India

Laccadives

Maldives

Seychelles

Chagos

Seya
de Malha

Nazareth

Madagascar

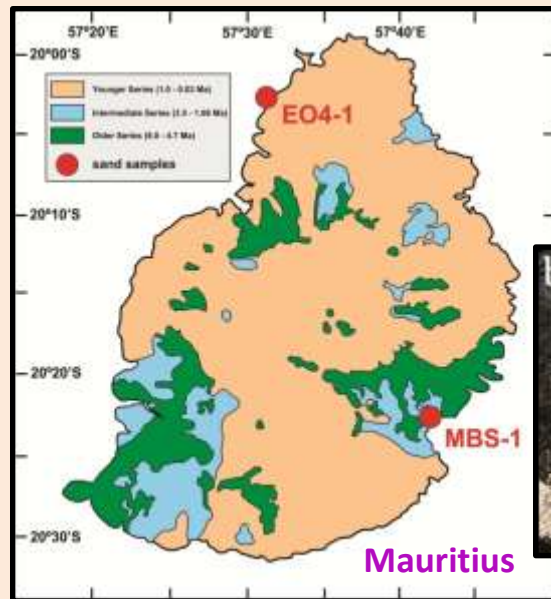
Réunion

Mauritius

Mauritius & Hidden Continents



- 2-day layover *en route* to India
- Bjørn collects Miocene basalt sample
- Recovers Permian zircons in Oslo labs
- Submits *Nature* paper (luckily rejected)

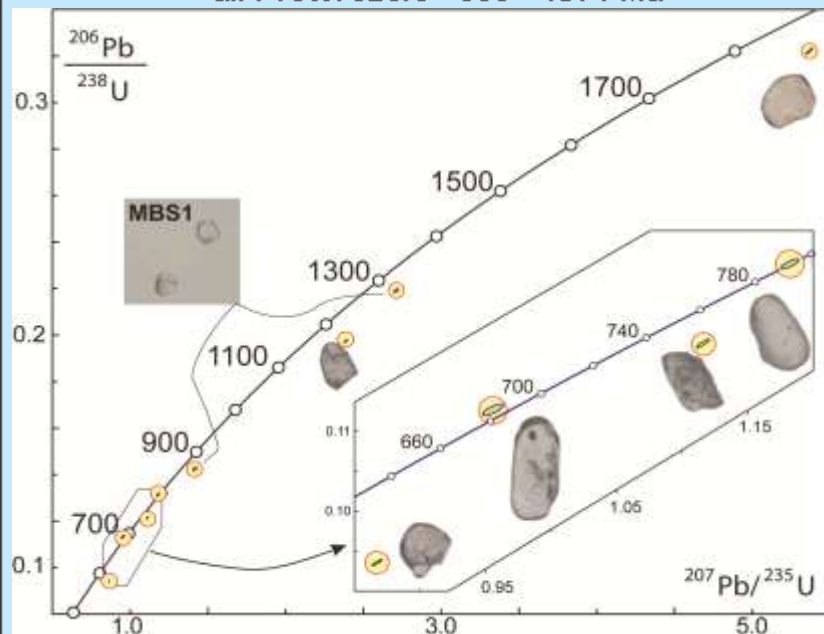


Zircons from sand samples

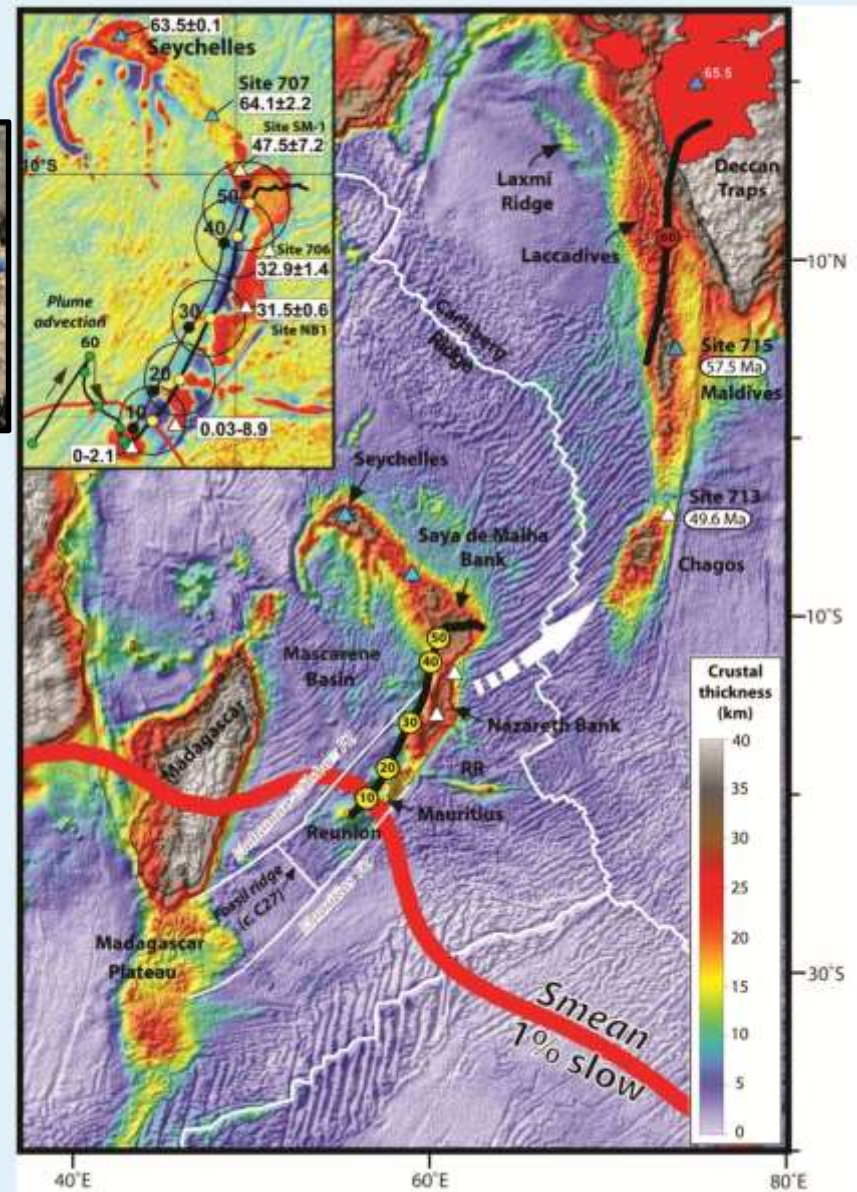
Ebbe Hartz
Hans Amundsen



TIMS analyses of 20 grains by Fernando Corfu:
all Proterozoic-- 660 - 1971 Ma

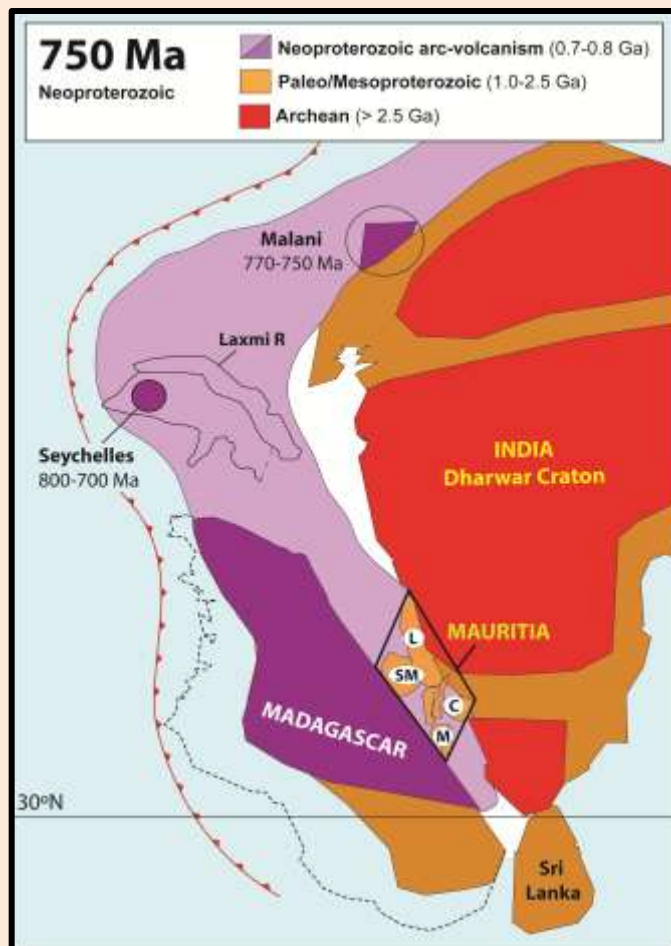


Gravity inversion modelling by Nick Kusznir to infer crustal thickness



A Precambrian microcontinent in the Indian Ocean

Trond H. Torsvik^{1,2,3,4,5,*†}, Hans Amundsen⁶, Ebbe H. Hartz^{1,7}, Fernando Corfu⁴, Nick Kuszniir⁸,
Carmen Gaina^{1,2,4†}, Pavel V. Doubrovine^{1,2†}, Bernhard Steinberger^{1,2,9}, Lewis D. Ashwal⁵
and Bjørn Jamtveit¹ (2013)

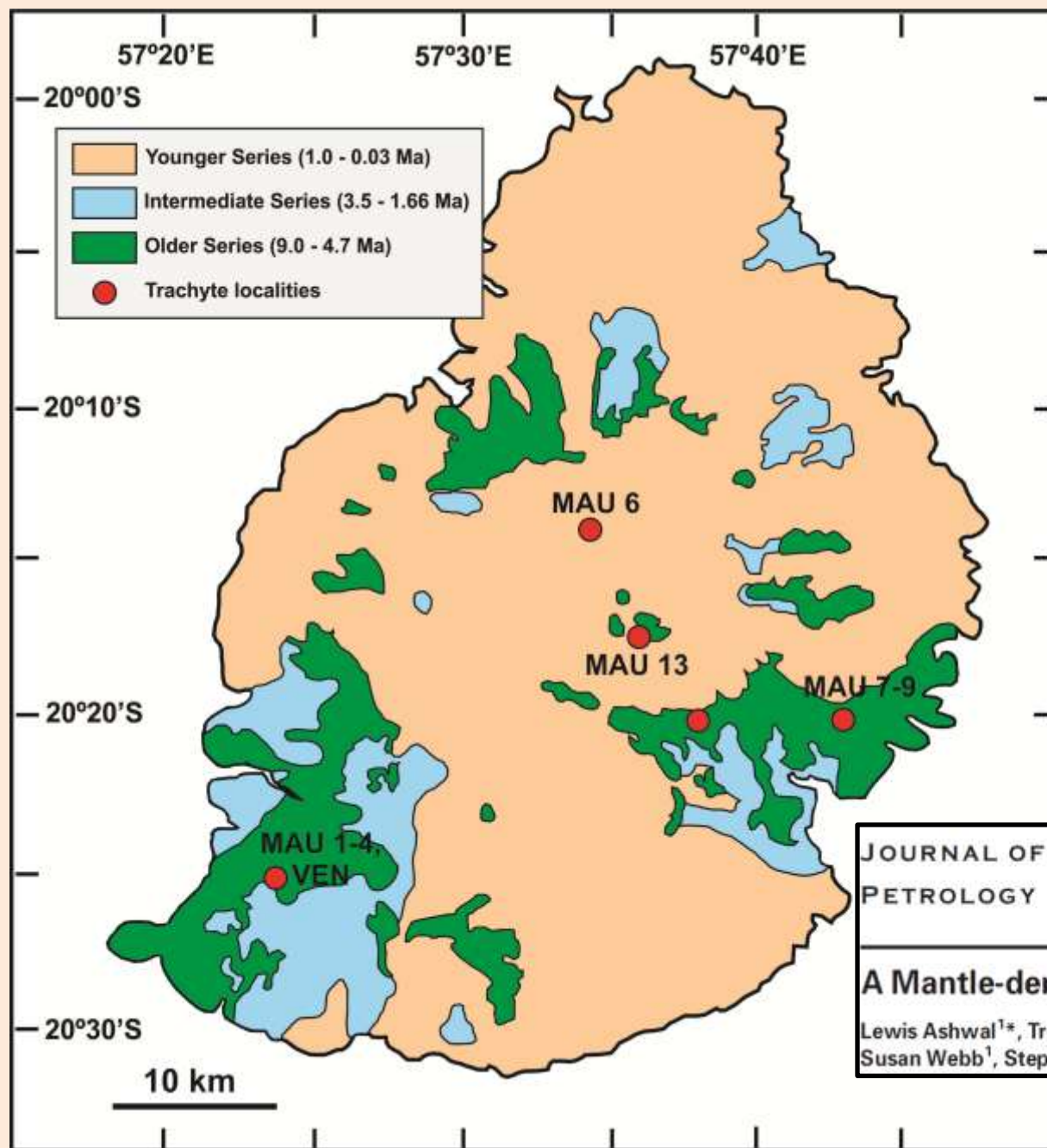


Mauritia = Precambrian microcontinent including Mauritius, Cargados-Carajos, Nazareth Banks, Saya de Malha, Chagos & Laccadives

Criticism by reviewers & sceptics:

zircons transported from elsewhere by:

wind ? ocean currents ?
birds ? pumice ?
footwear ? tires ?



Trachyte:

alkali-rich volcanic rock
commonly showing
alignment of feldspar
crystals due to
magmatic flow



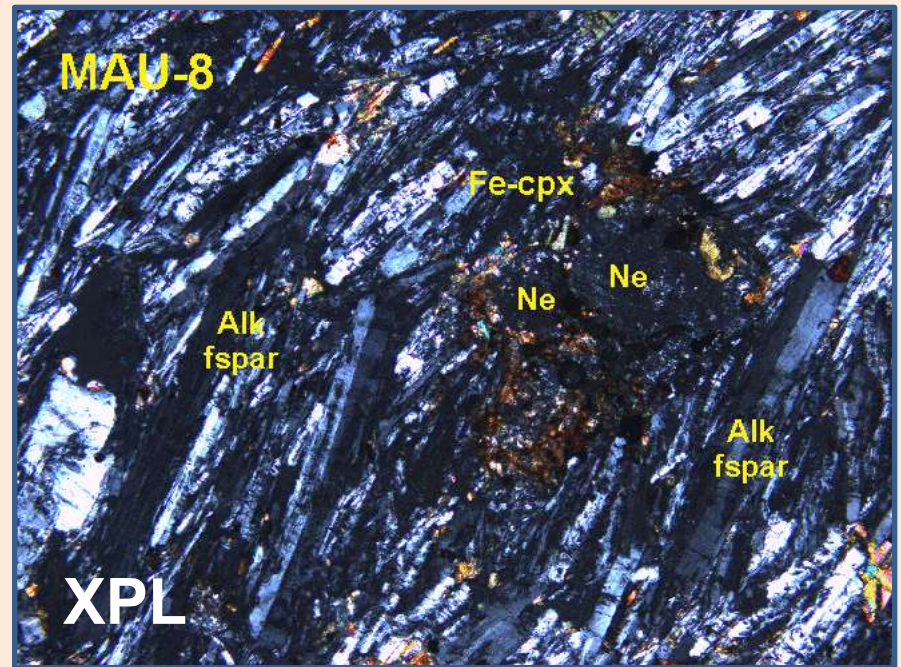
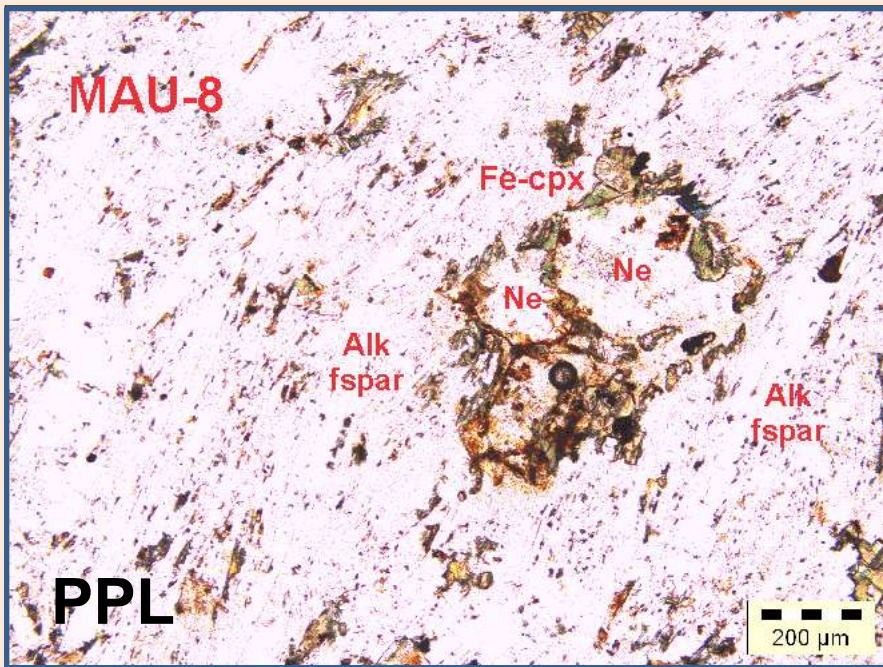
JOURNAL OF
PETROLOGY

(2016)

Journal of Petrology, 2016, Vol. 57, No. 9, 1645–1675
doi: 10.1093/petrology/egw052
Advance Access Publication Date: 23 October 2016
Original Article

A Mantle-derived Origin for Mauritian Trachytes

Lewis Ashwal^{1*}, Trond Torsvik^{1,2}, Péter Horváth¹, Chris Harris³,
Susan Webb¹, Stephanie Werner² and Fernando Corfu⁴



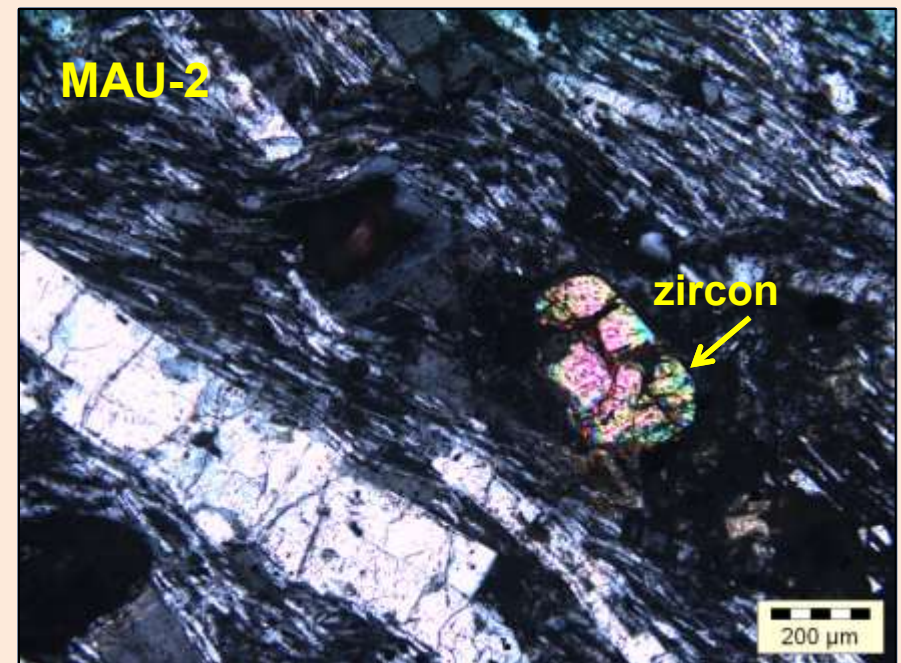
Mauritius trachytes

Zr = 830 – 1497 ppm
average = 1307 ± 204 ppm

MAU-8: Zr = 1165 ppm

Recovered 13 zircon grains from
1 sample (MAU-8), in GFZ Potsdam lab,
using metal rolling pin.

No crushing or grinding equipment used



Secondary Ion Mass Spectrometer (SIMS) instrument at GFZ, Potsdam, Germany



10 young grains

- all featureless, with no visible internal structures in BSE or CL
- no traces of inherited components

49 spot analyses
by SIMS (Cameca 1280-HR)
at GFZ Potsdam:

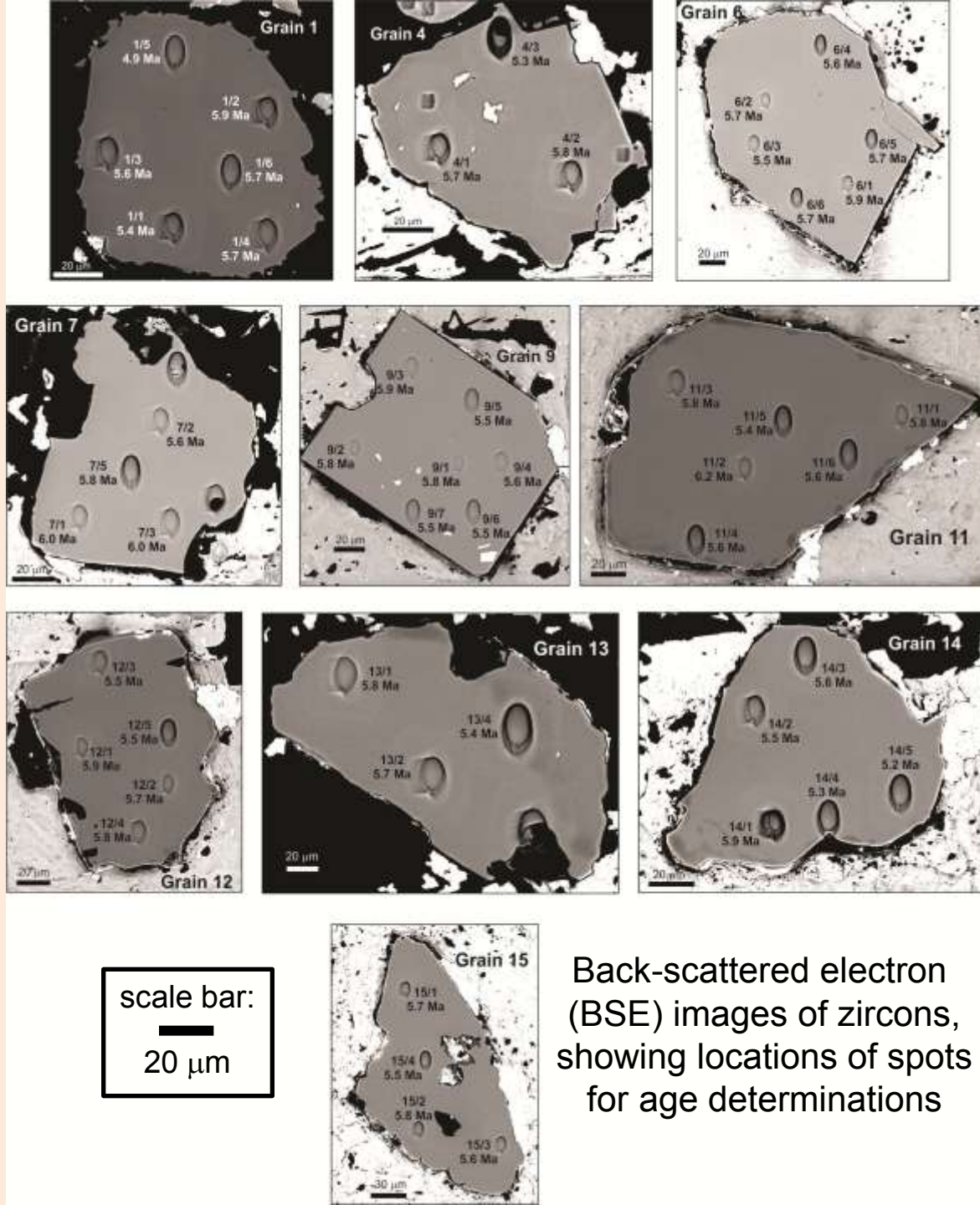
All have late Miocene
 $^{206}\text{Pb}/^{238}\text{U}$ ages of:

4.9 ± 0.1 Ma
to

6.2 ± 0.1 Ma

average = **5.7 ± 0.2 Ma**
(1 sd, n = 49)

Consistent with association of
trachytes to Older Series basalts
(9.0 – 4.7 Ma)



Back-scattered electron (BSE) images of zircons, showing locations of spots for age determinations

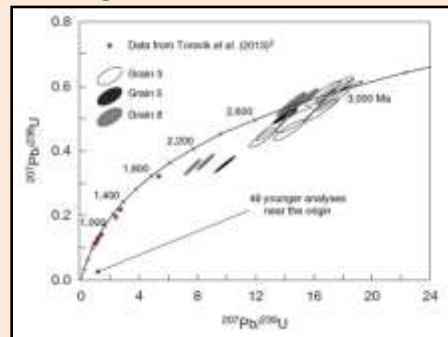
3 old grains recovered

- BSE & CL show complex internal structures- metamict cores, partly resorbed idiomorphic banding
- Mineral inclusions: quartz, K-feldspar, monazite

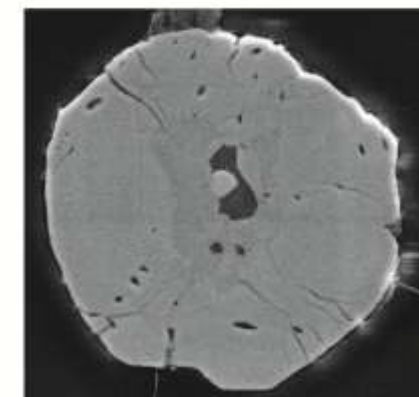
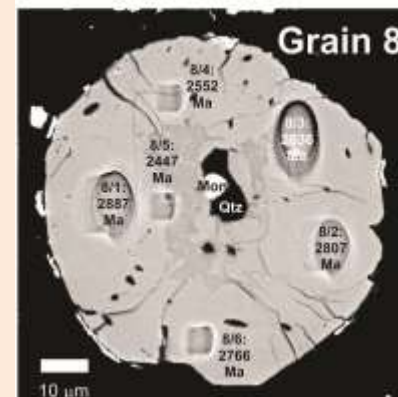
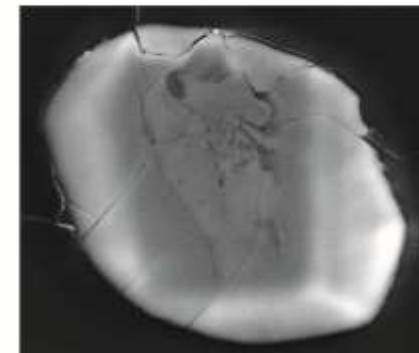
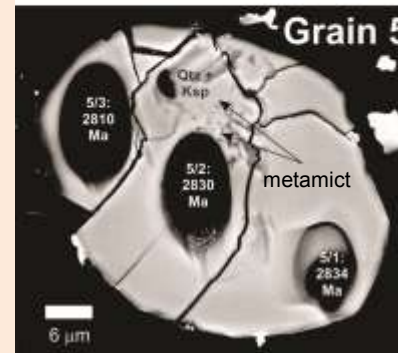
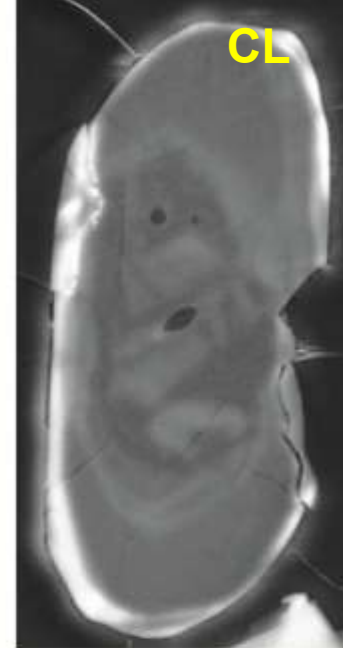
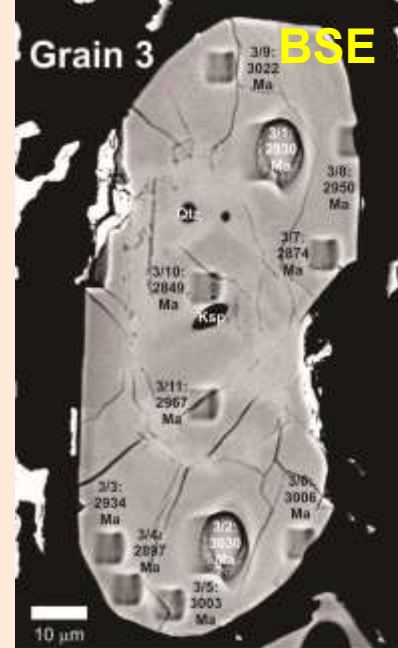
20 individual spot analyses:

$^{207}\text{Pb}/^{206}\text{Pb}$ ages range from:

**2522 ± 11 Ma
to
 3030 ± 5 Ma**

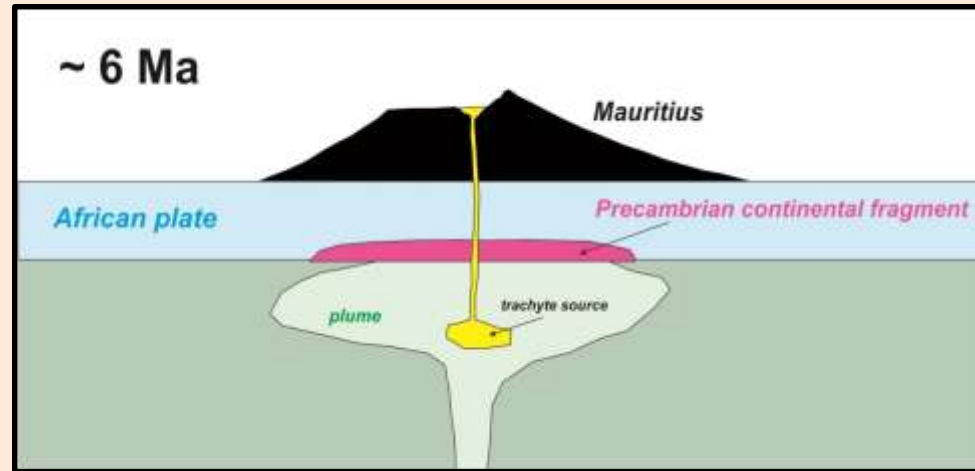


- most concordant to near-concordant
- young overgrowths looked for, but not found



Mauritius trachyte:

- 2500 – 3000 m.y. U-Pb zircon ages
- **oldest such ages in ANY young volcanic rock**
- can only have come from **continental** crust



We suggest:

- At ~9 Ma, a fragment of ancient continent was located **by chance**, at a place where the Mauritian volcano began to erupt
- Continental fragment was blanketed and buried by lavas.
- At ~6 Ma, trachyte magmas passed through & picked up zircons from fragment, delivering them to the surface.



Forbes

The New York Times

POPULAR
SCIENCE
THE FUTURE NOW

THE HUFFINGTON POST

NBC NEWS

CNN

CHINA TOPIX

Latest Nigerian News
All news in one place

NATIONAL
GEOGRAPHIC

The CHRISTIAN SCIENCE
MONITOR

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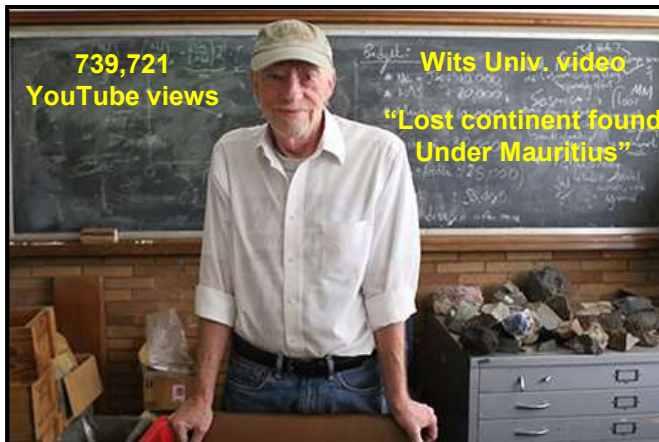
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Scientists have discovered a lost continent
at the bottom of the Indian Ocean

And they're calling it 'Mauritia'

By [Jess Edwards](#)
Feb 6, 2017



Possible continental fragments in the Indian Ocean:

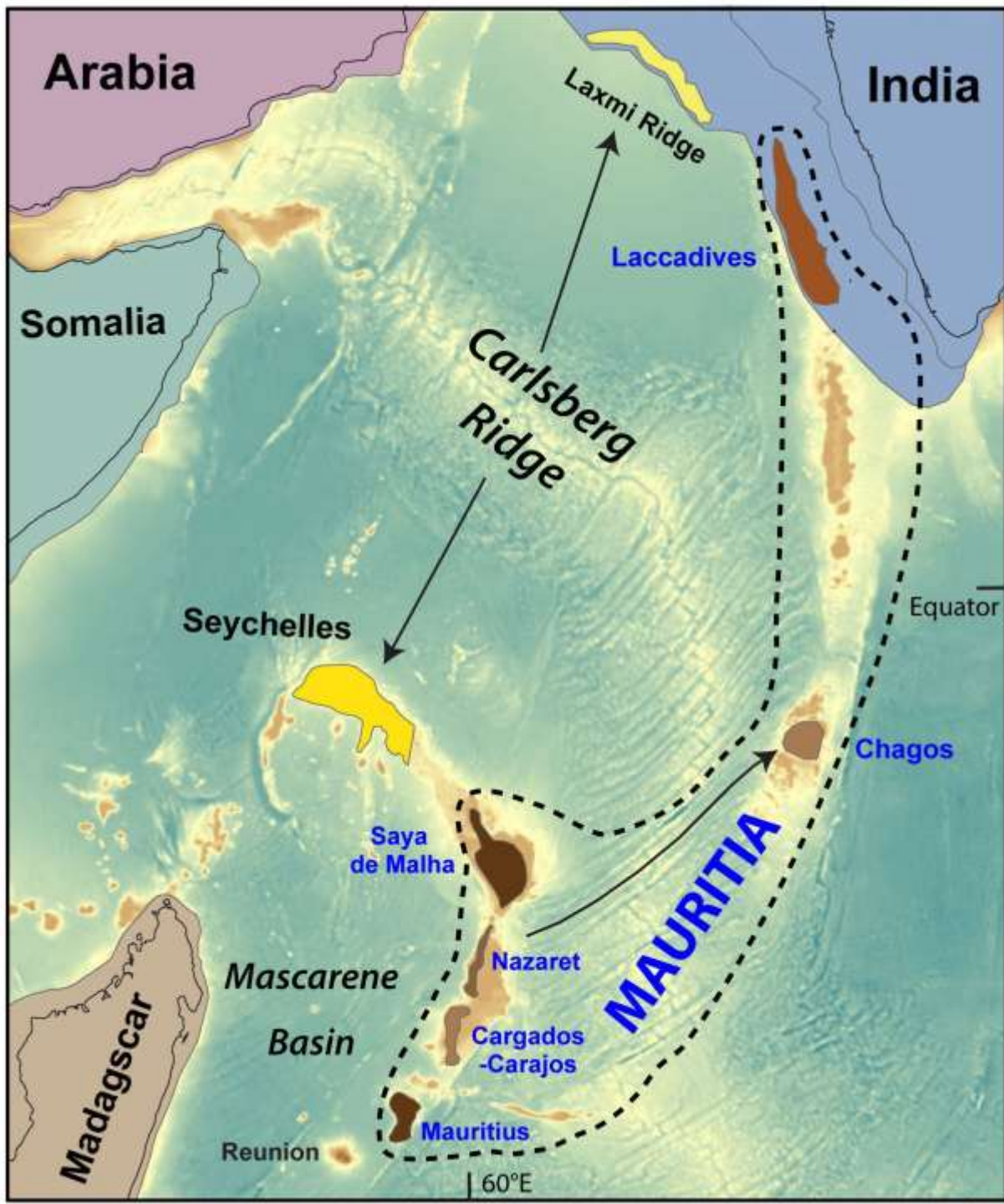
Mauritia (brown)

Mauritius
Cargados-Carajos
Nazareth Banks
Saya de Malha
Chagos
Maldives
Laccadives

Seychelles (yellow)

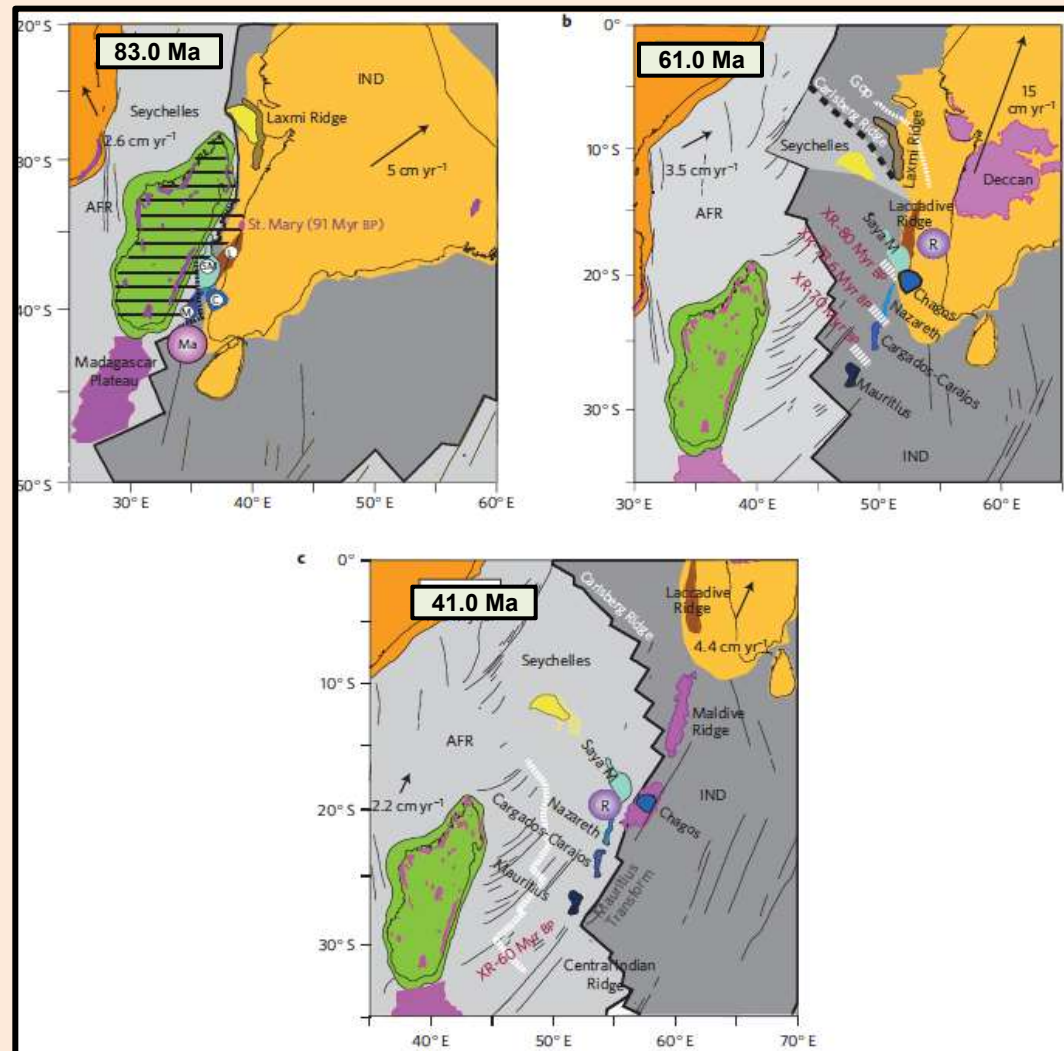
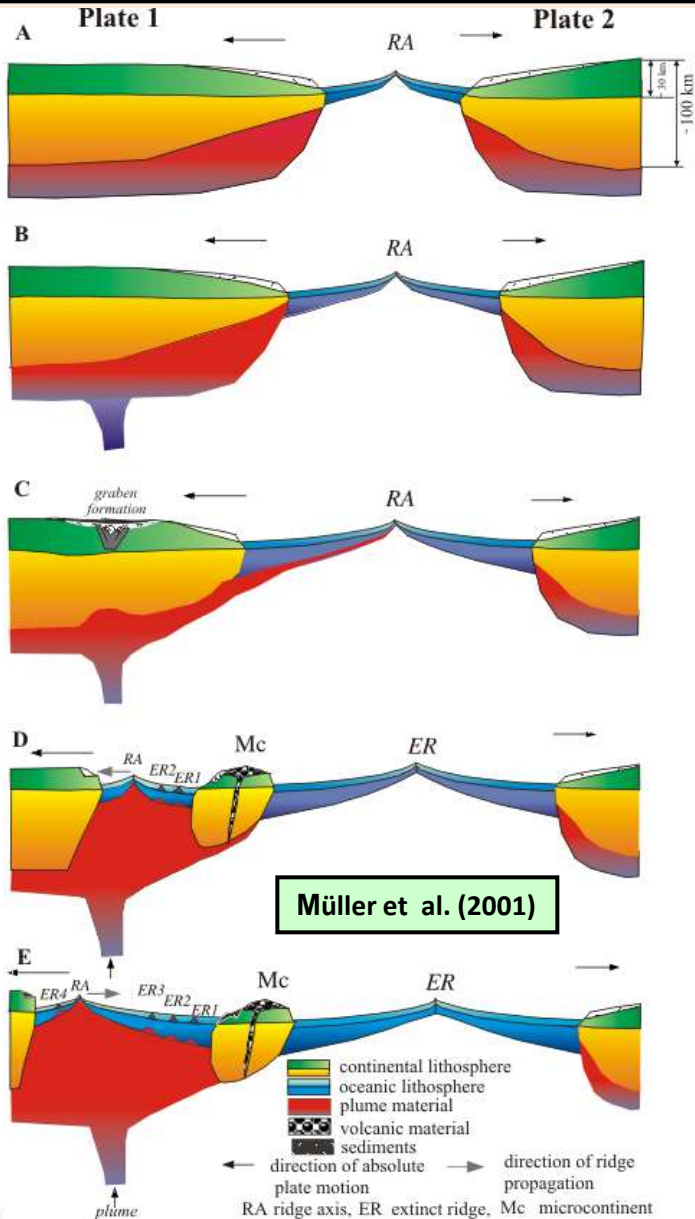
Laxmi Ridge (yellow)

*But how do these scattered
“microcontinents” form?*



Microcontinent formation by mid-ocean ridge relocation (“ridge jumps”)

Example: transfer of Seychelles microcontinent from Indian to African plate by ridge jump at 61 Ma



Can the spectrum of U-Pb ages for old Mauritian zircons be **correlated** with exposed Precambrian terranes in nearby continental entities?

Seychelles?

- Undeformed granitoids—
- almost all are 750 ± 5 Ma
- **IMPLAUSIBLE**

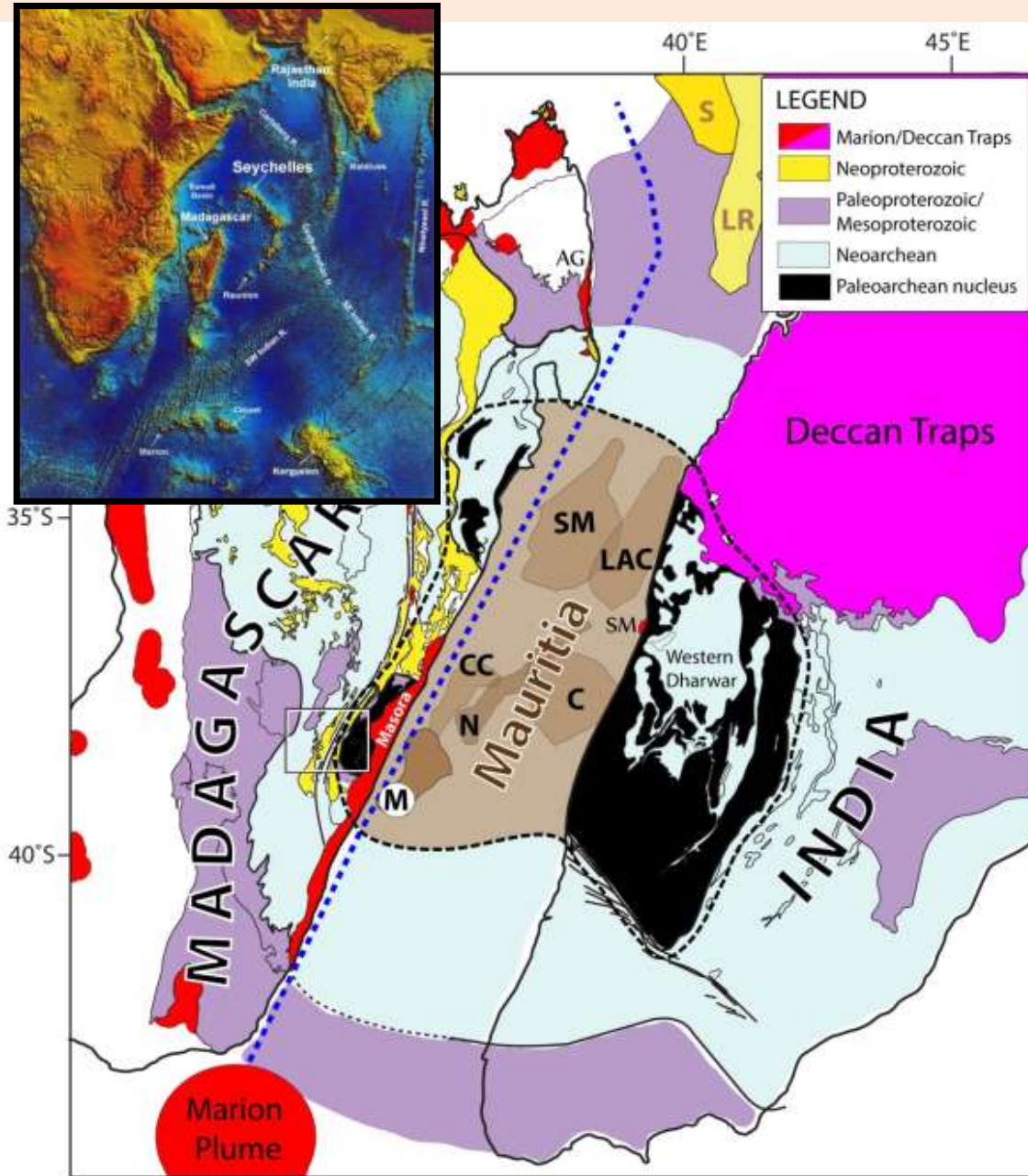
Dharwar Craton of India?

- Palaeoarchaeoan nucleus of (3.4 – 2.5 Ga) orthogneisses, flanked by:
- Neoarchaeoan (2.7 – 2.5 Ga) granitic gneisses
- Neoproterozoic rocks rare
- **UNLIKELY**

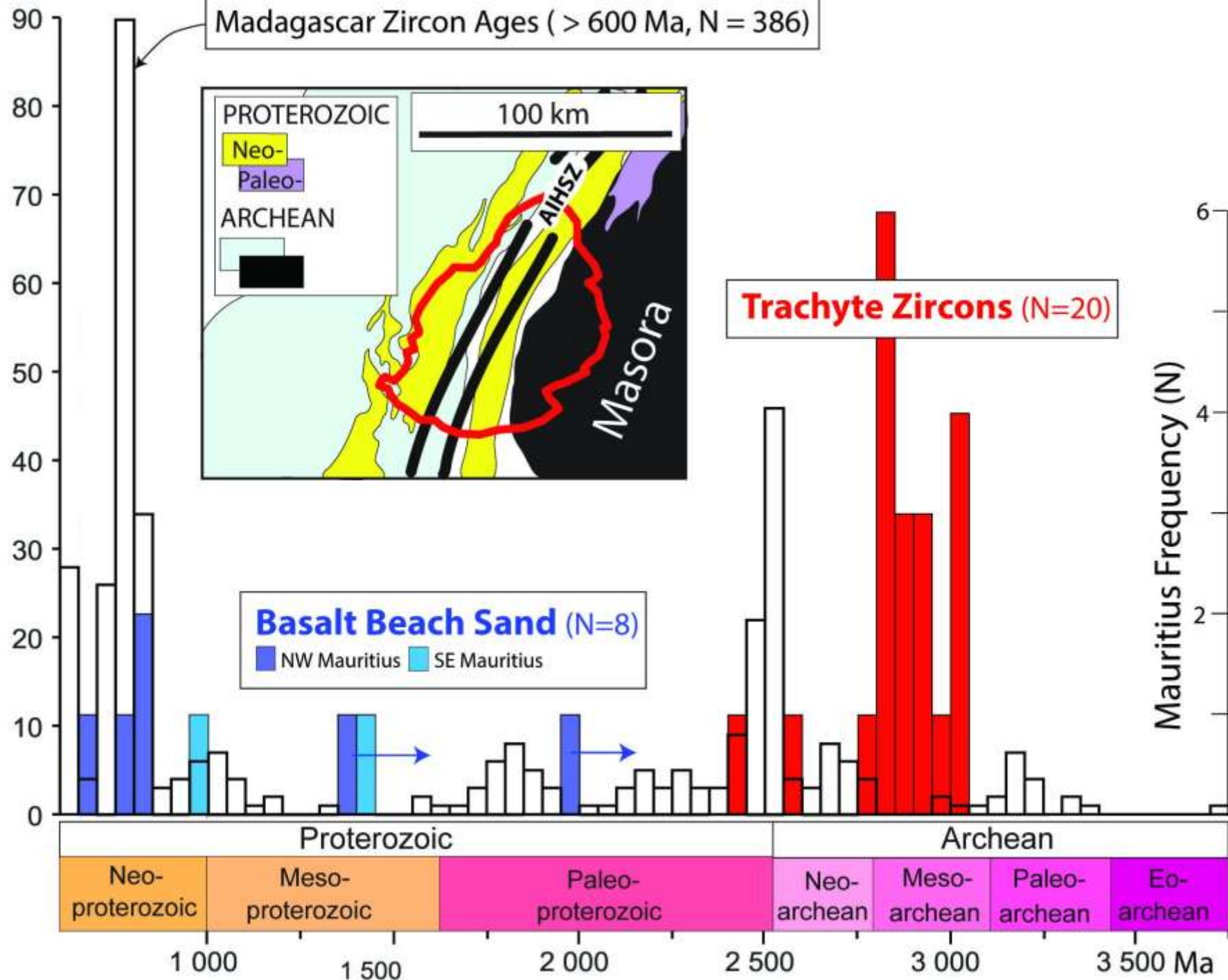
Madagascar?

- Palaeo- Mesoarchaeoan gneisses, (correlated to Dharwar)
- Abundant Neoproterozoic (0.85 – 0.70 Ga) gabbro – granite
- **BEST MATCH**

90 - 85 Ma reconstruction of Madagascar & India, with intervening continental fragment of Maurititia



Madagascar Zircon Ages (> 600 Ma, N = 386)



Implications:

- Refined Gondwana reconstruction
 - **Mauritia** = “buffer zone” between Mad & India
 - **accounts for:**
 - paucity in India of ~90 Ma LIP products from Marion plume
 - difficulty in detailed correlations between Madagascar & India
- (revise exploration models ?)

Nature of basement underlying continental fragments:

Mauritius & Mauritia:

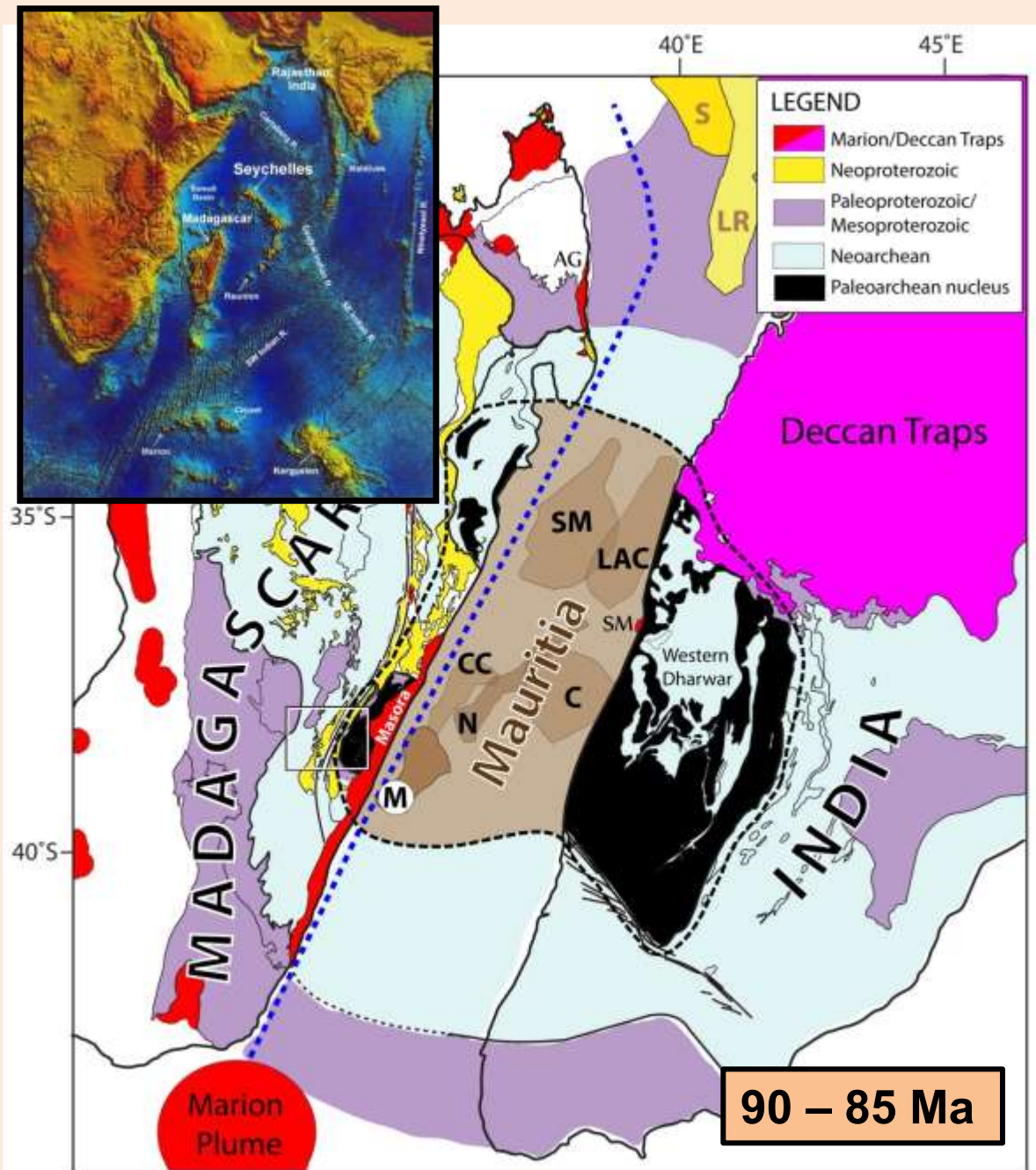
Archaean – Neoproterozoic,
as in E-central Madagascar

Seychelles & Laxmi Ridge:

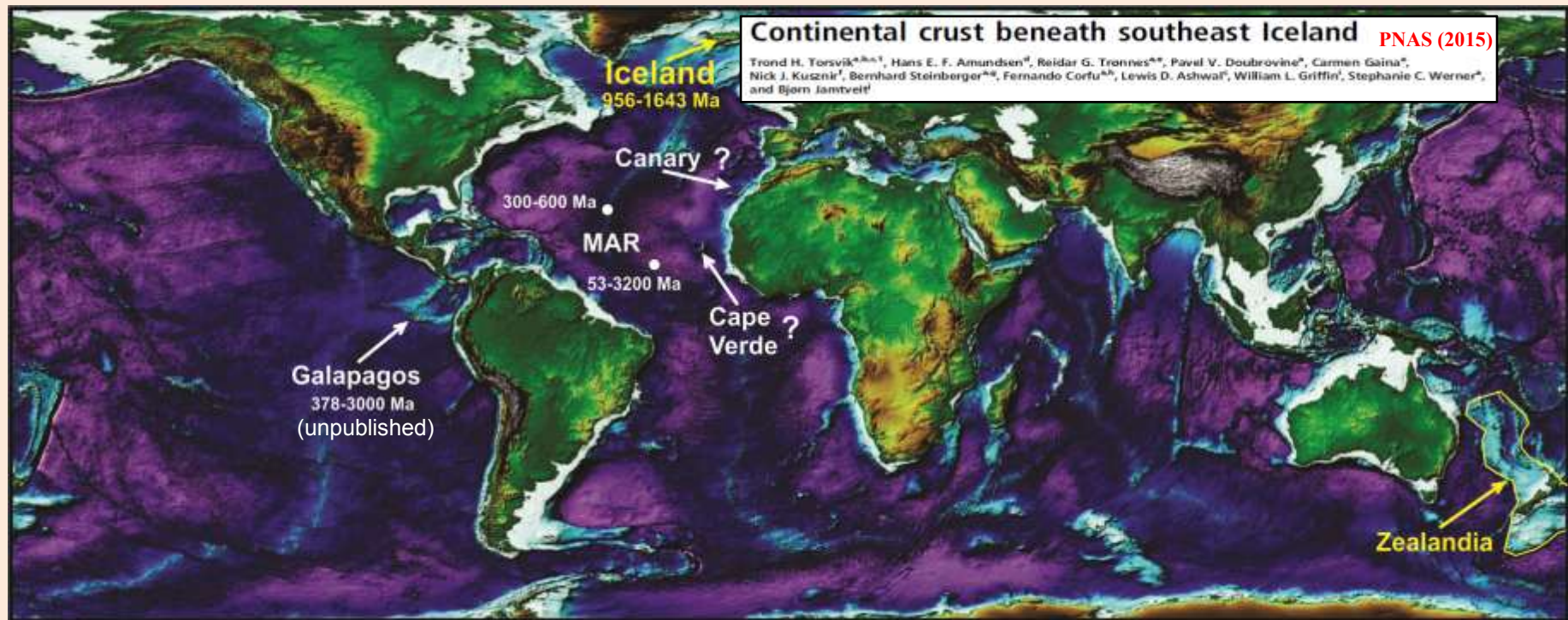
Paleo – Mesoproterozoic,
as in N Madagascar

Continental break-up is messy:

- can leave the ocean floor “littered” with continental fragments of variable sizes



Other “hidden” continents?



talk is almost over !

Iceland:

Torsvik et al. (2015) *PNAS*

Mid-Atlantic Ridge:

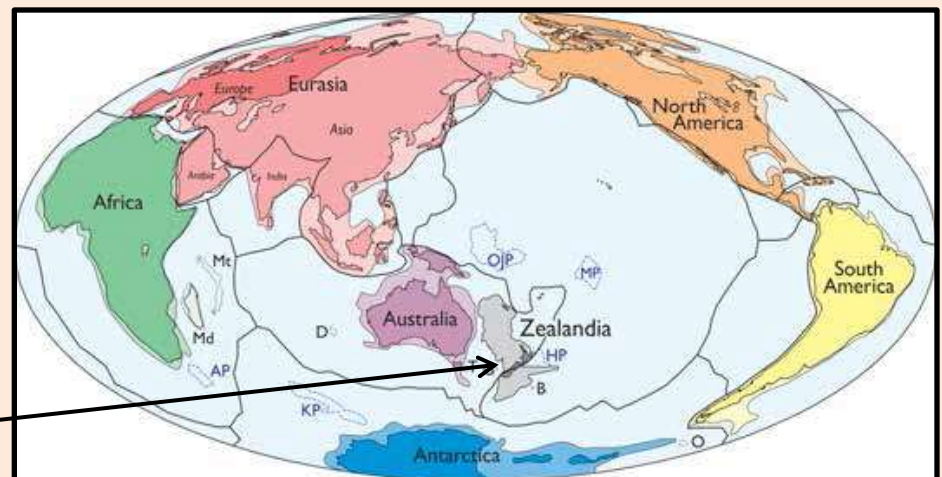
Pilot et al. (1998) *Nature*

Skolotnev et al. (2010) *Geotectonics*

Galapagos:

Rojas-Agramonte et al. (2016) *IGC abstr.*

“**Zealandia**: Earth’s Hidden continent”
Mortimer et al. (2017) *GSA Today*



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