The 3-D Seismic Structure Beneath Madagascar

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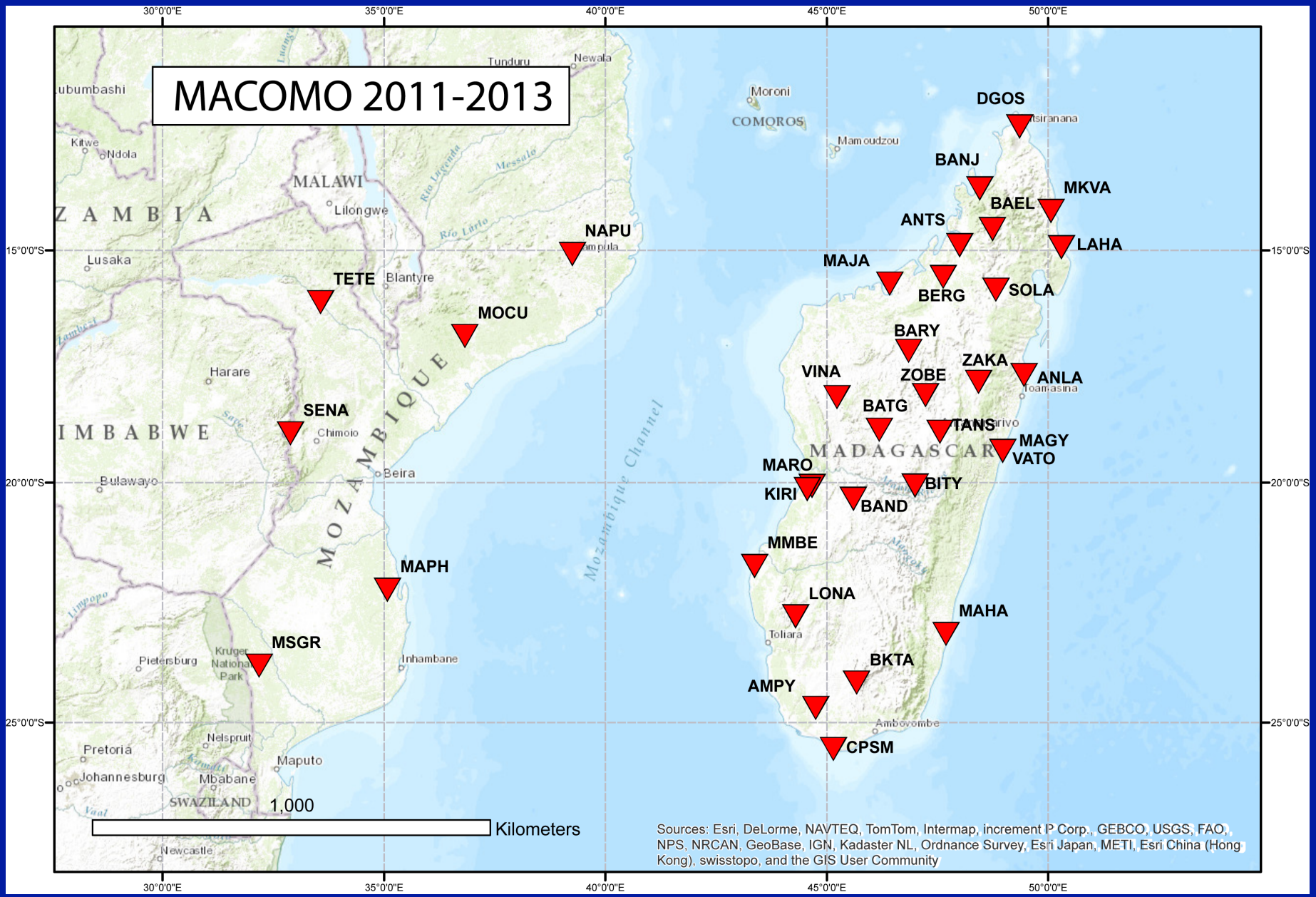
MACOMO 2011-2013
DGOS
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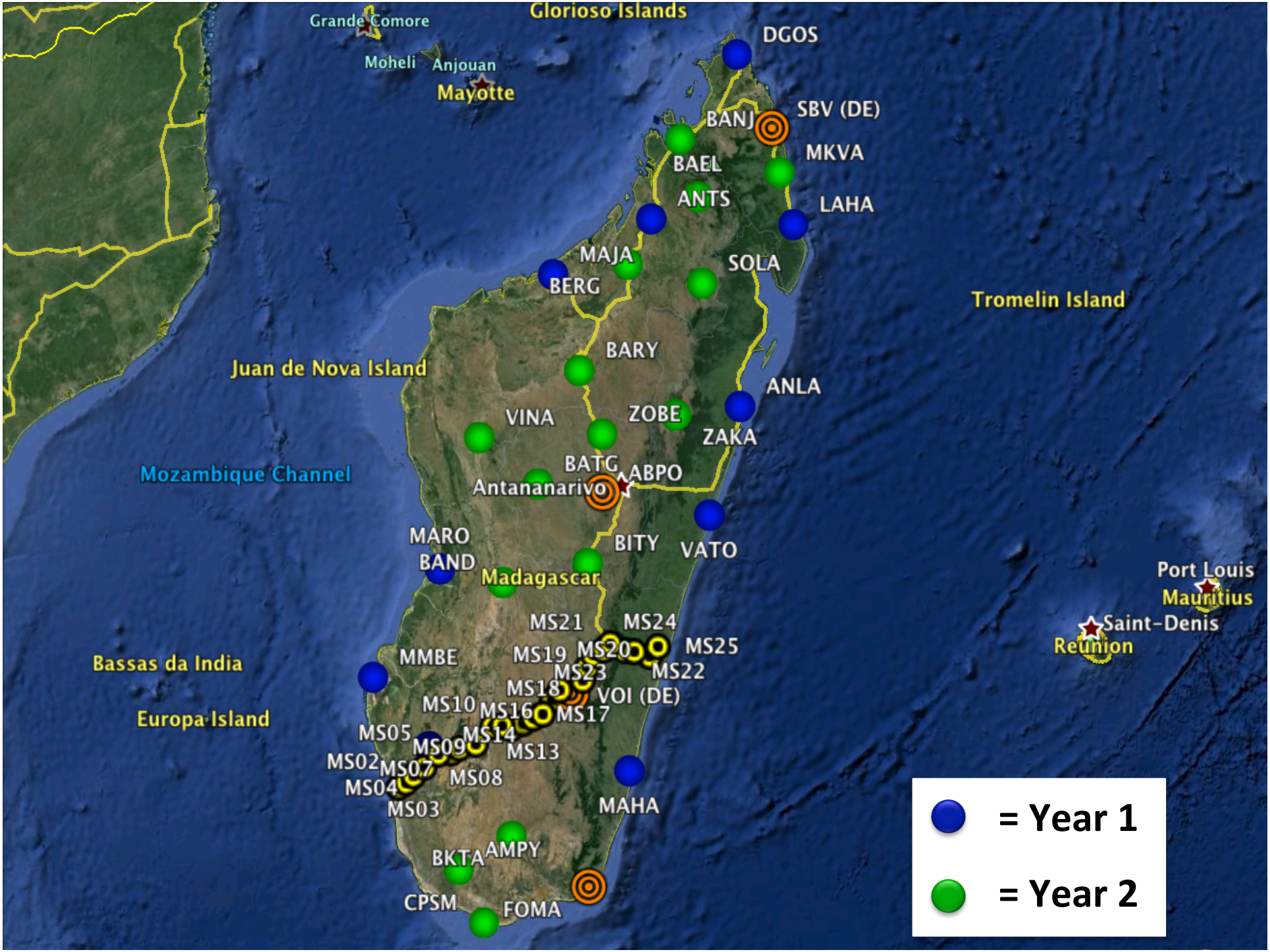
VATO
MARO
KIRI
BITY
BAND
MMBE
LONA
MAHA
BKTA
AMPY
CPSM
NAPU
TETE
MOCU
SENA
MAPH
MSGR
MALAWI
ZAMBIA
MOZAMBIQUE
MADAGASCAR
COMOROS
Moroni
Mamoudzou
Tunduru
Newala
Lilongwe
Lusaka
Blantyre
Harare
Chimoio
Beira
Bulawayo
Inhambane
Toliara
Ambovombe
Pietersburg
Kruger National Park
Nelspruit
Pretoria
Johannesburg
Mbabane
SWAZILAND
Maputo
Newcastle
Mozambique Channel
30°0'0"E
35°0'0"E
40°0'0"E
45°0'0"E
50°0'0"E
15°0'0"S
20°0'0"S
25°0'0"S
1,000
Kilometers
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community


Grande Comore
Glorioso Islands
DGOS
Moheli
Anjouan
Mayotte
SBV (DE)
BANJ
MKVA
BAEL
ANTS
LAHA
MAJA
SOLA
BERG
Tromelin Island
Juan de Nova Island
BARY
ANLA
VINA
ZOBE
ZAKA
BATG
ABPO
Mozambique Channel
Antananarivo
MARO
BAND
BITY
VATO
Madagascar
Port Louis
Mauritius
Saint-Denis
Reunion
MS21
MS24
MS25
MS19
MS20
MS23
MS22
MMBE
Bassas da India
MS18
VOI (DE)
MS10
MS16
MS17
Europa Island
MS05
MS14
MS09
MS13
MS02
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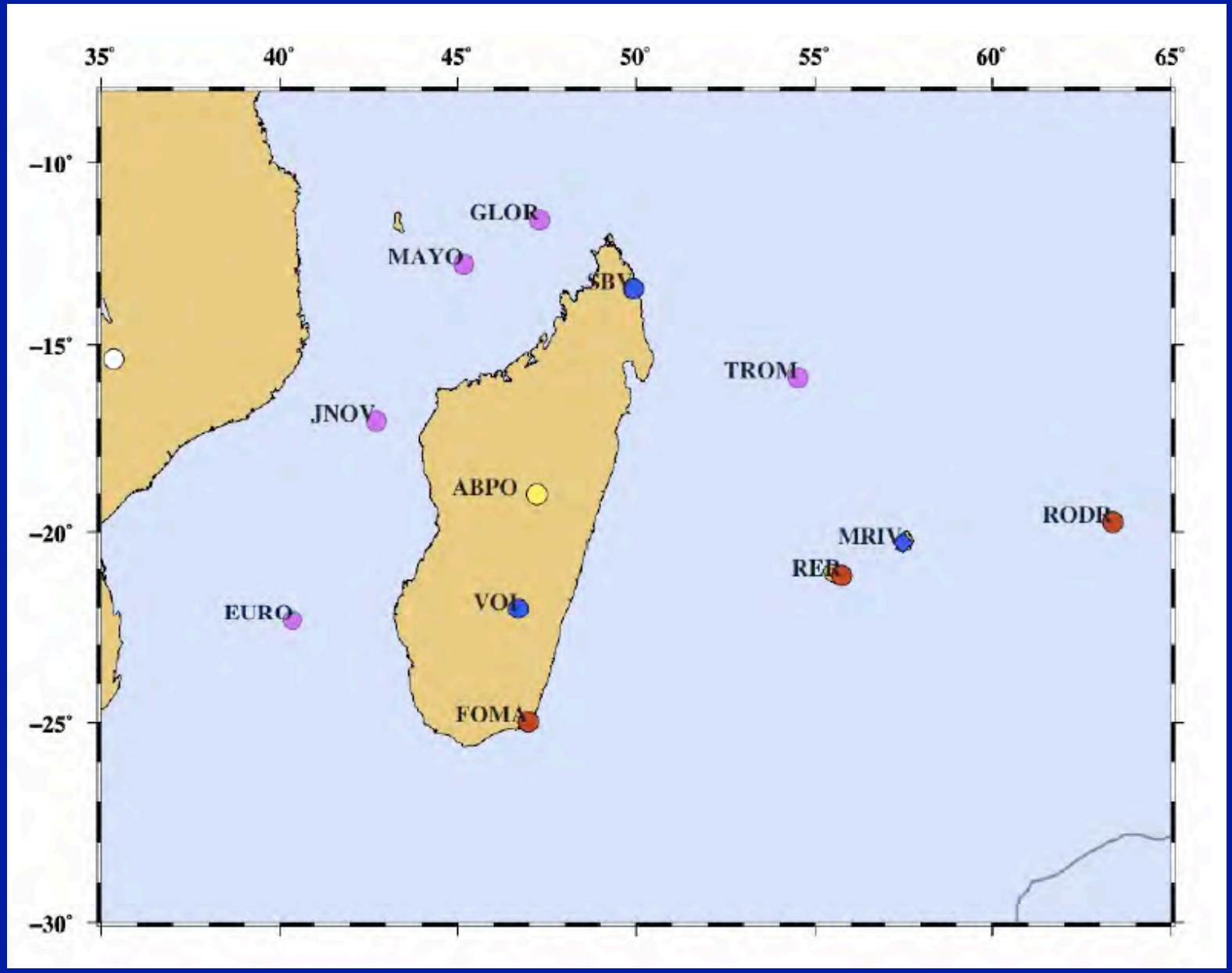
MS04
MS03
MAHA
AMPY
BKTA
CPSM
FOMA
= Year 1
= Year 2

Mission Iles Esparses: Guilhem Barruol, Fabrice Fontaine, Karin Sigloch



RHUM-RUM:
Réunion Hotspot Upper Mantle – Réunions Unterer Mantel

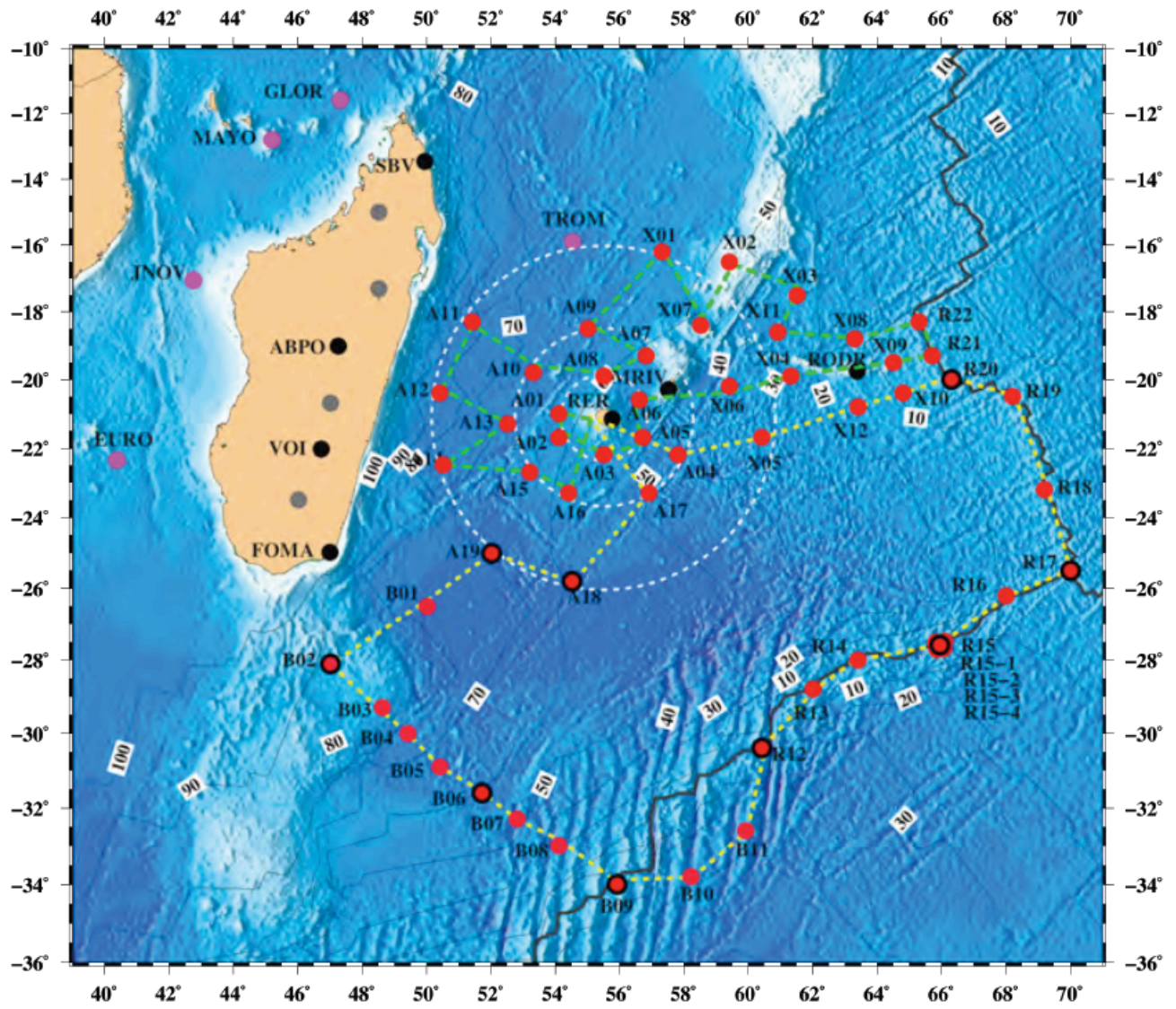
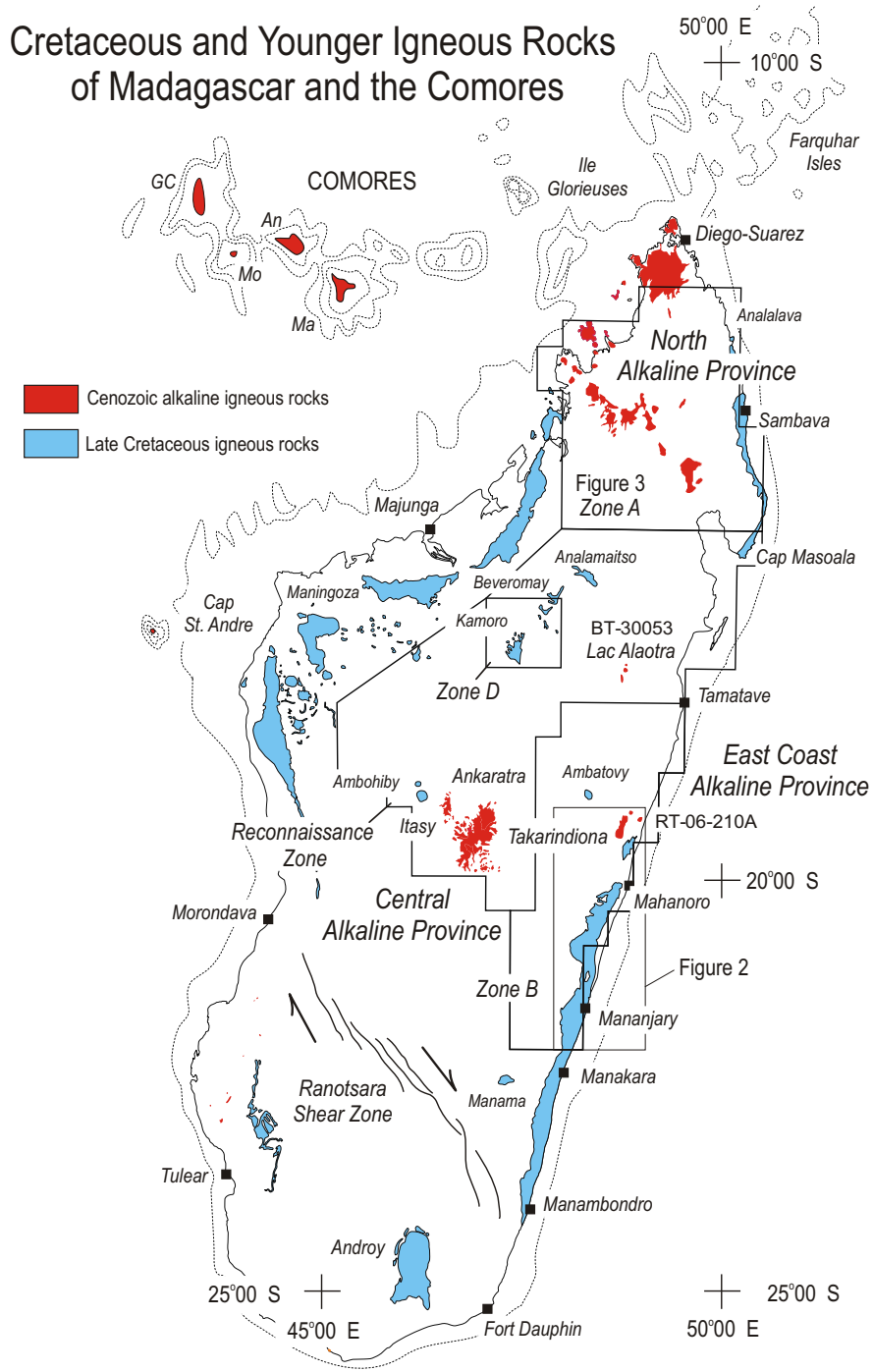
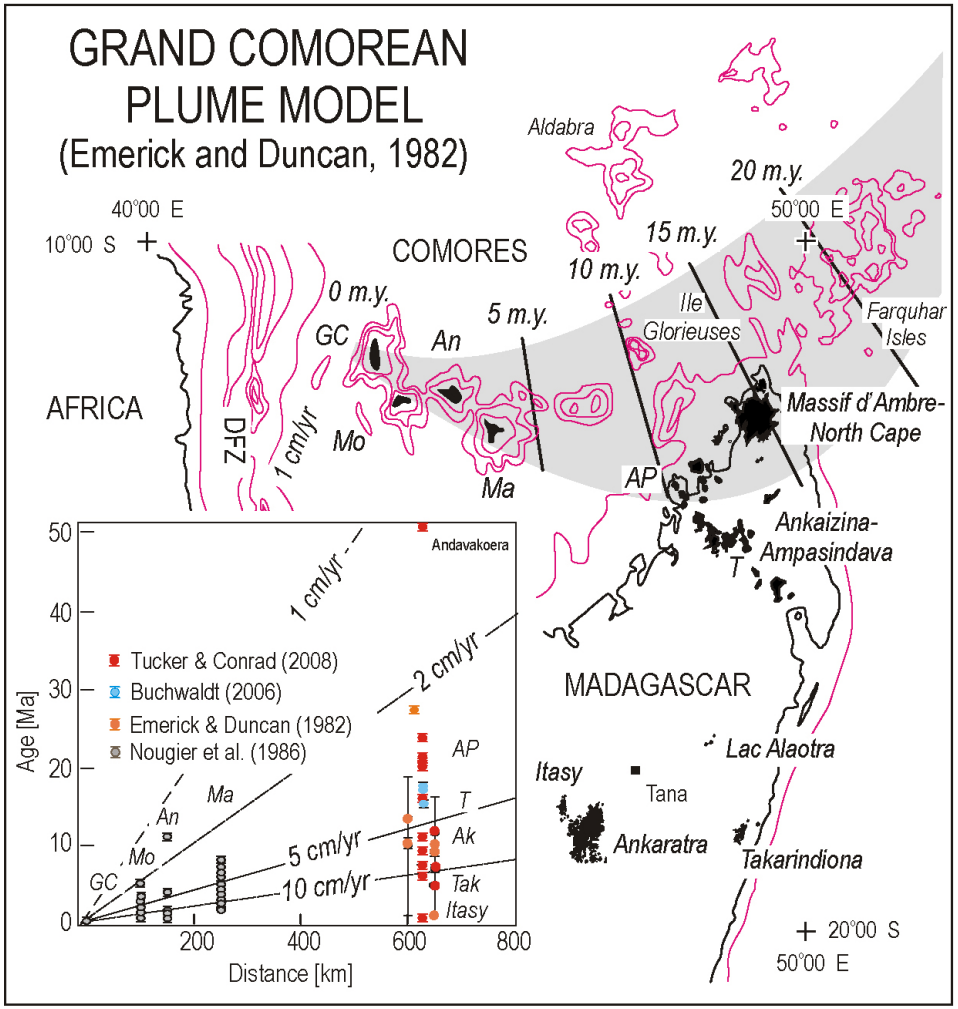


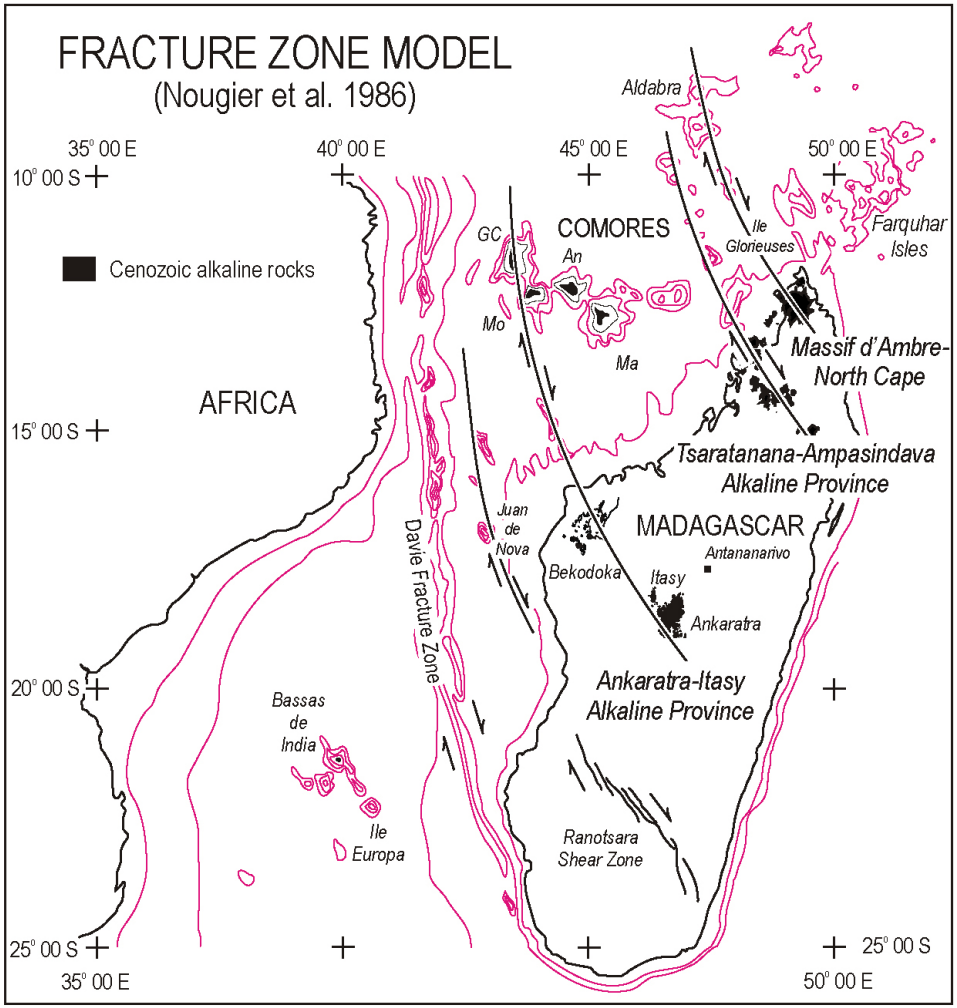
Figure 8: Ocean-bottom seismometer locations for the RHUM-RUM proposal. Leg1 track is indicated by the green dashed line, Leg2 by the yellow dashed line. Red & black circles indicate the location of the 9 INSU OBS which are true broadband seismometers. White circles represent the distance of about 150, 300 and 500 km from La Réunion. Permanent stations are indicated by the black dots. Pink dots: planned deployments in the Iles Eparses. Grey dots: planned deployment in Madagascar

Recent (<1 Ma ago) volcanism has occurred within Madagascar



Two hypotheses for the recent intraplate volcanism within Madagascar: Grand Comorean plume model, or Fracture Zone Model





Question: Is surface volcanism connected to the sub-African LLSVP? (Large low-velocity shear velocity province)

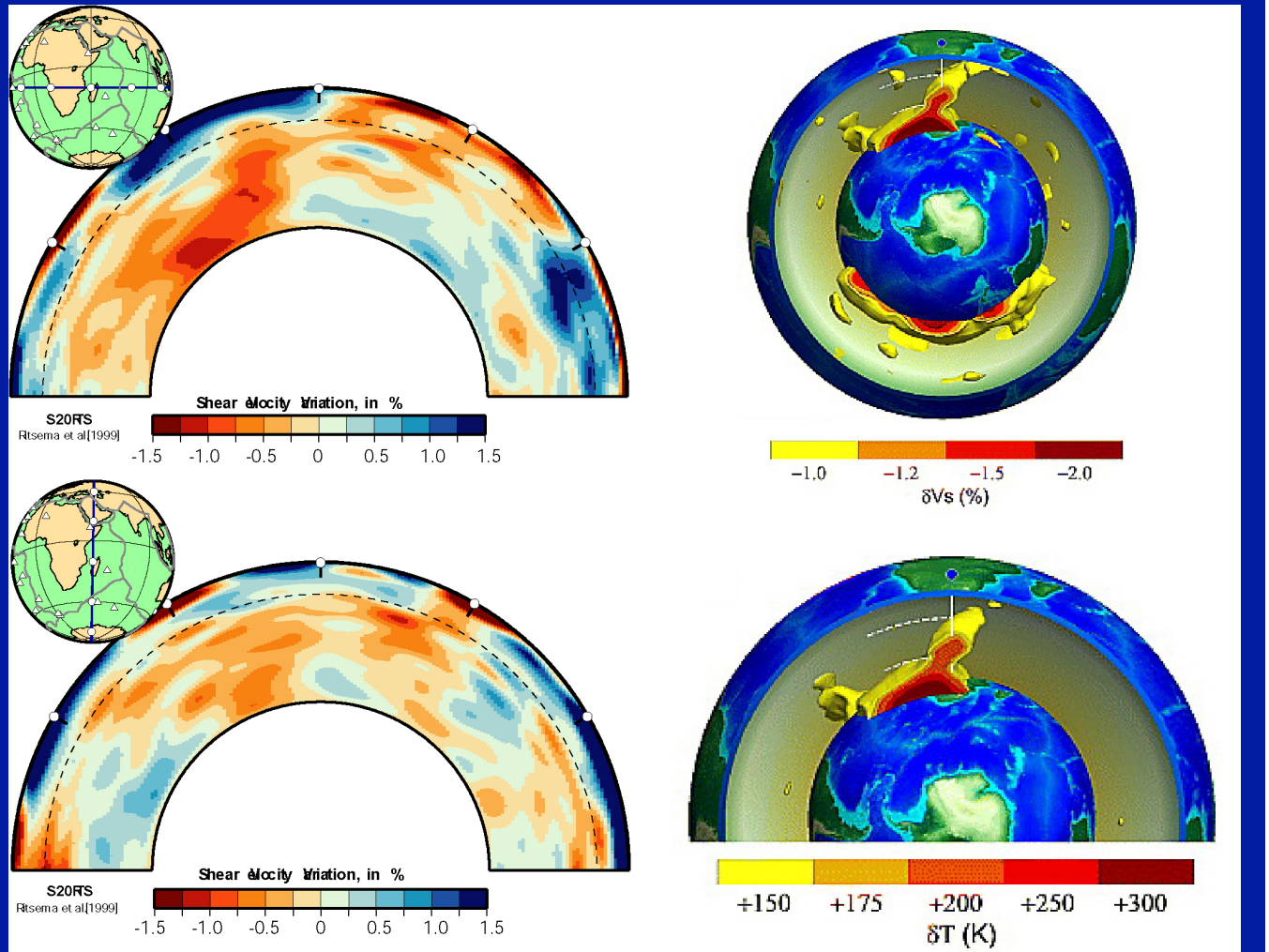
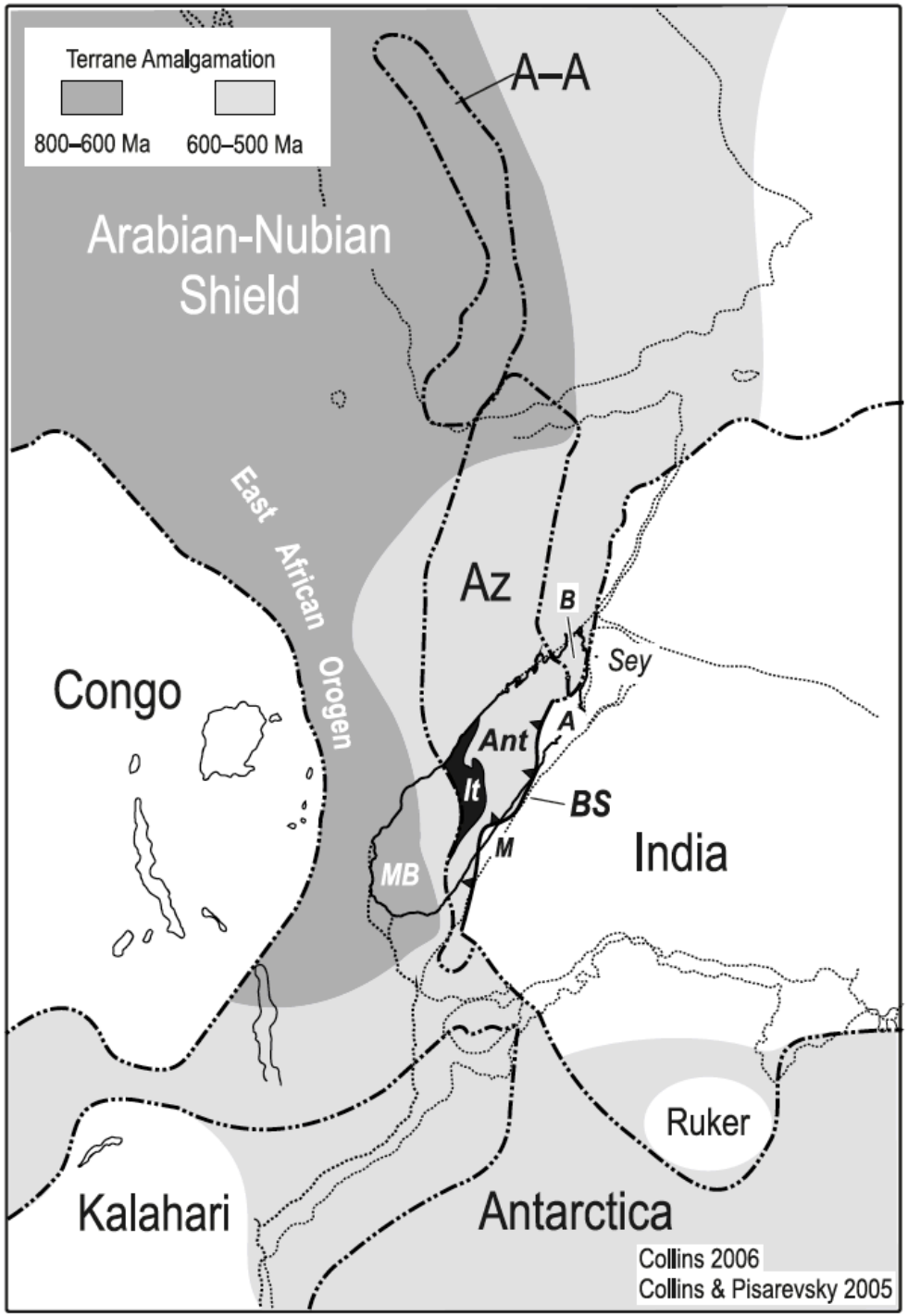


Figure 1. Shear-wave tomographic models of *Ritsema et al.* [1999] (*Left*) and *Simmons et al.* [2007] (*Right*), showing the structure of the African LLSVP (Large Low Shear Velocity Province). (*Left*) The cross-sections are centered on Madagascar, so that the small white dot corresponds to the location of northern Madagascar, the site of continuing Cenozoic intraplate volcanism. (*Right*) The top shows the shear-wave velocity anomaly and the bottom shows the calculated temperature anomaly. In all figures, notice how the LLSVP extends beneath east-central Africa, but also bends eastward toward Madagascar.

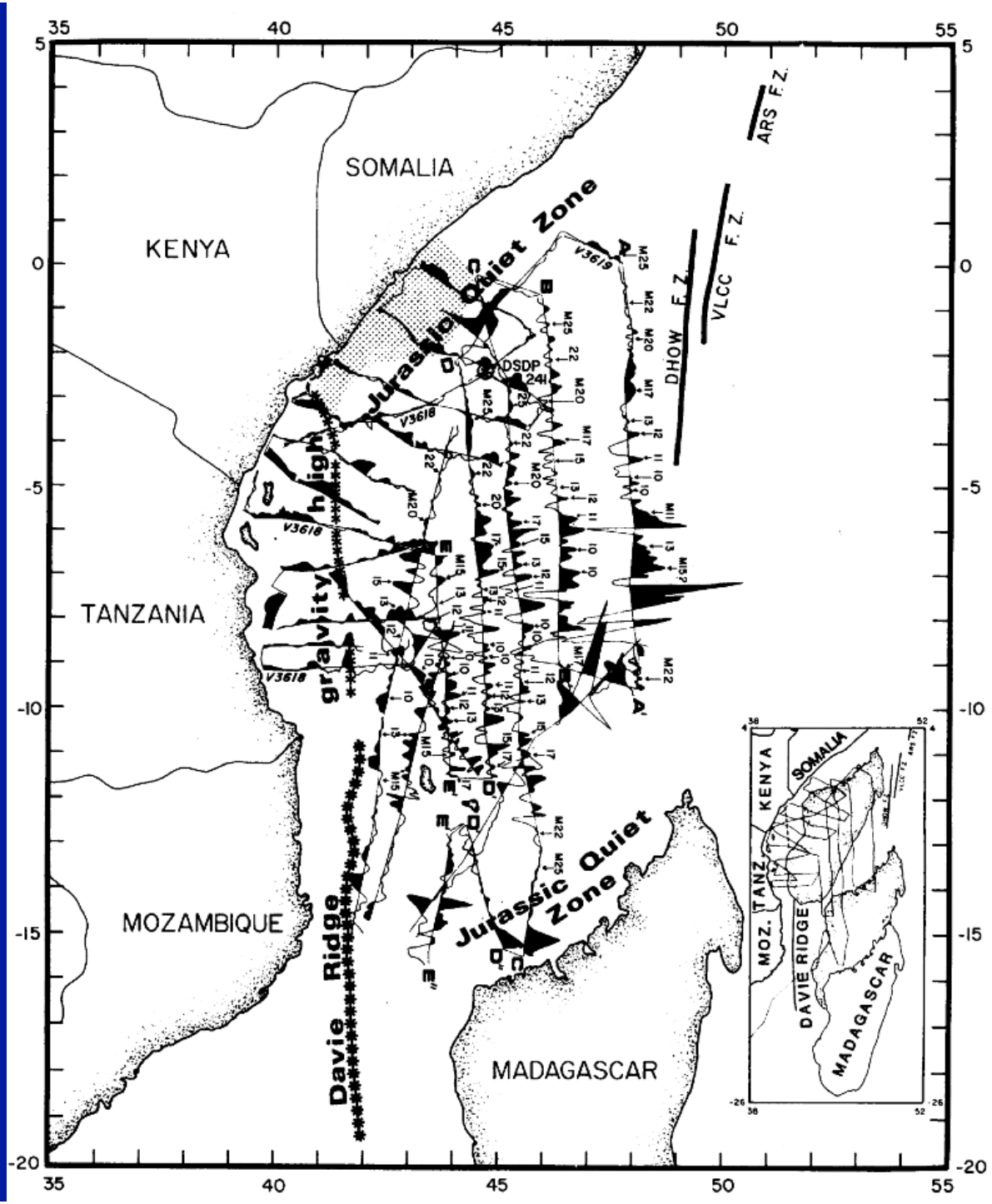


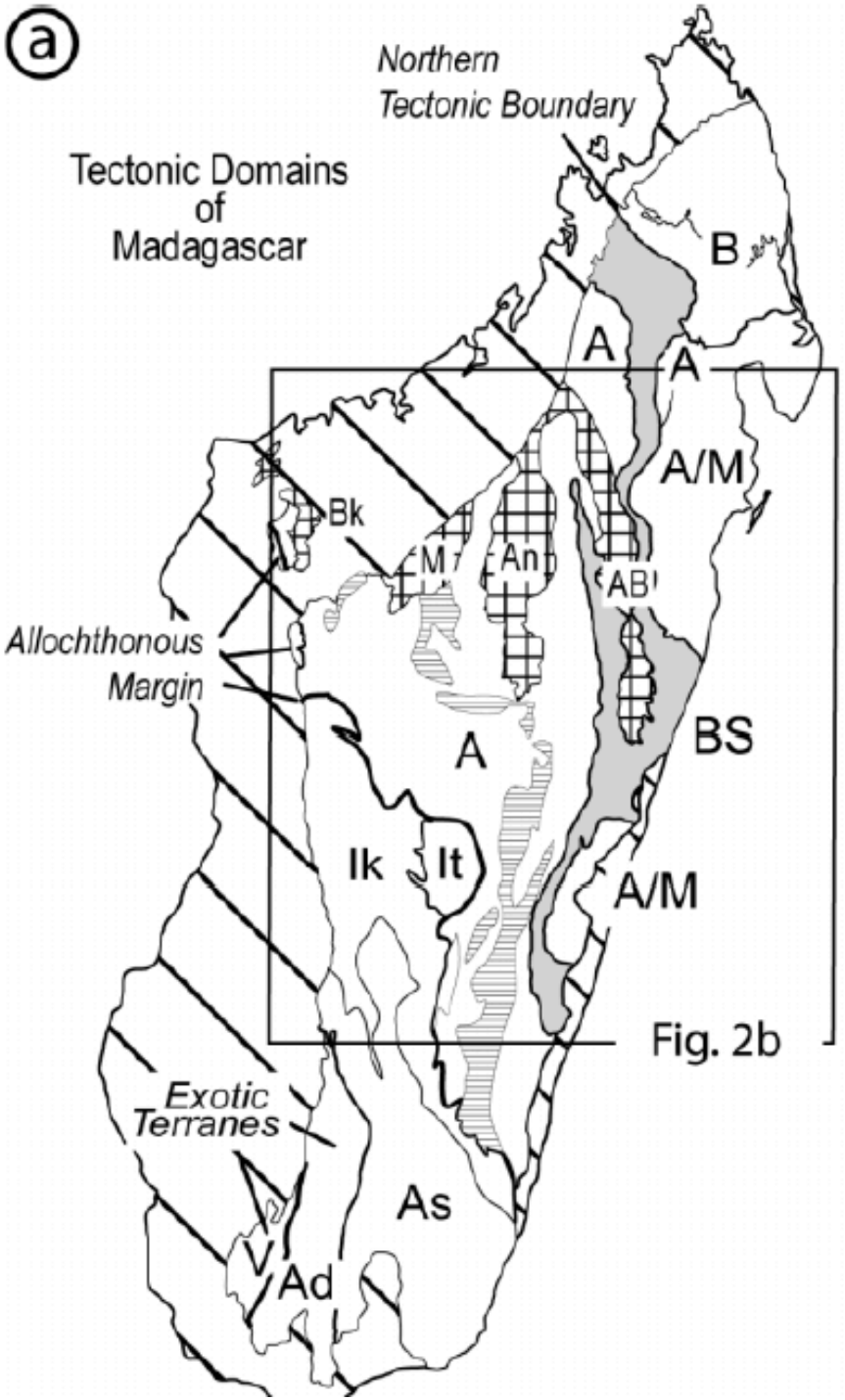
Reconstruction of the position of the microcontinent Azania within Gondwana

(Tucker et al., 2010)

Fig. 1. The microcontinent of "Azania" (Az) and its position within Gondwana (after Collins and Pisarevsky 2005 and Collins 2006). The "Betsimisaraka suture" (*BS*) is interpreted as the Neoproterozoic site of the India–Azania collision, and a provenance boundary between terranes derived from East Africa (*It*, Itremo; *Ant*, Antananarivo) and the Dharwar Craton of India (*A*, Antongil; *M*, Masora). A–A, Afif–Abas terrane; *B*, Bemarivo domain; *MB*, Mozambique belt (accreted southern terranes of Androyen and Vohibory); *Sey*, Seychelles.

Madagascar broke away from Africa during 165-120 Ma ago (Rabinowitz et al., 1982), so the NW part of Madagascar is an ancient rift zone




a
Northern
Tectonic Boundary
Tectonic Domains
of
Madagascar
B
A
A
A/M
Bk
M
An
AB
Allochthonous
Margin
A
BS
Ik
It
A/M
Fig. 2b
Exotic
Terranes
As
V
Ad

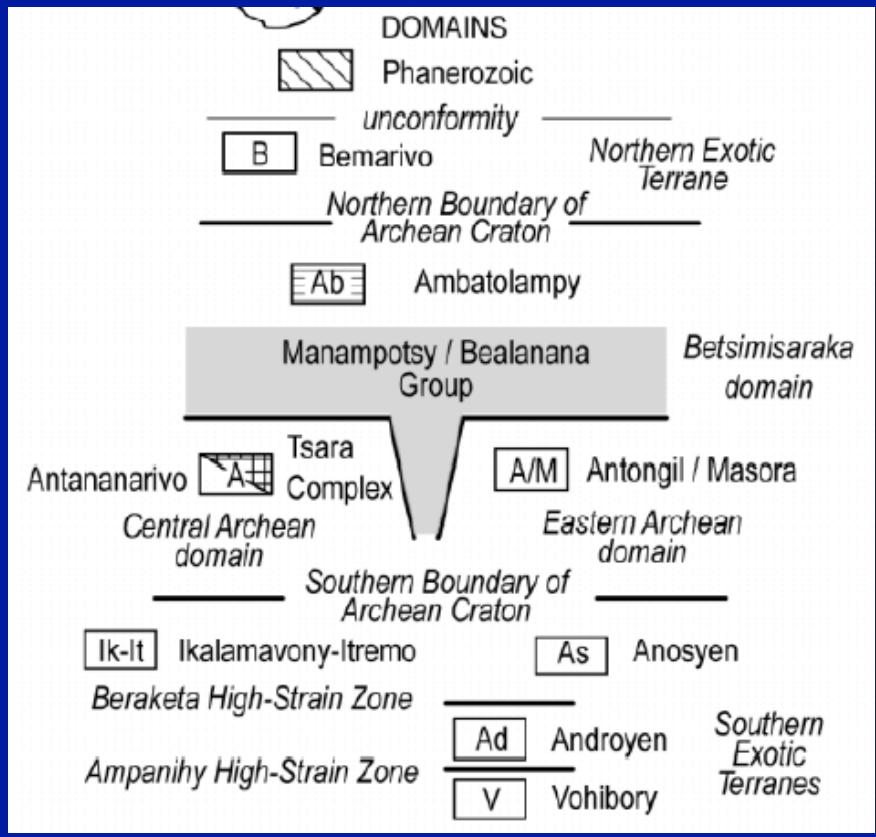
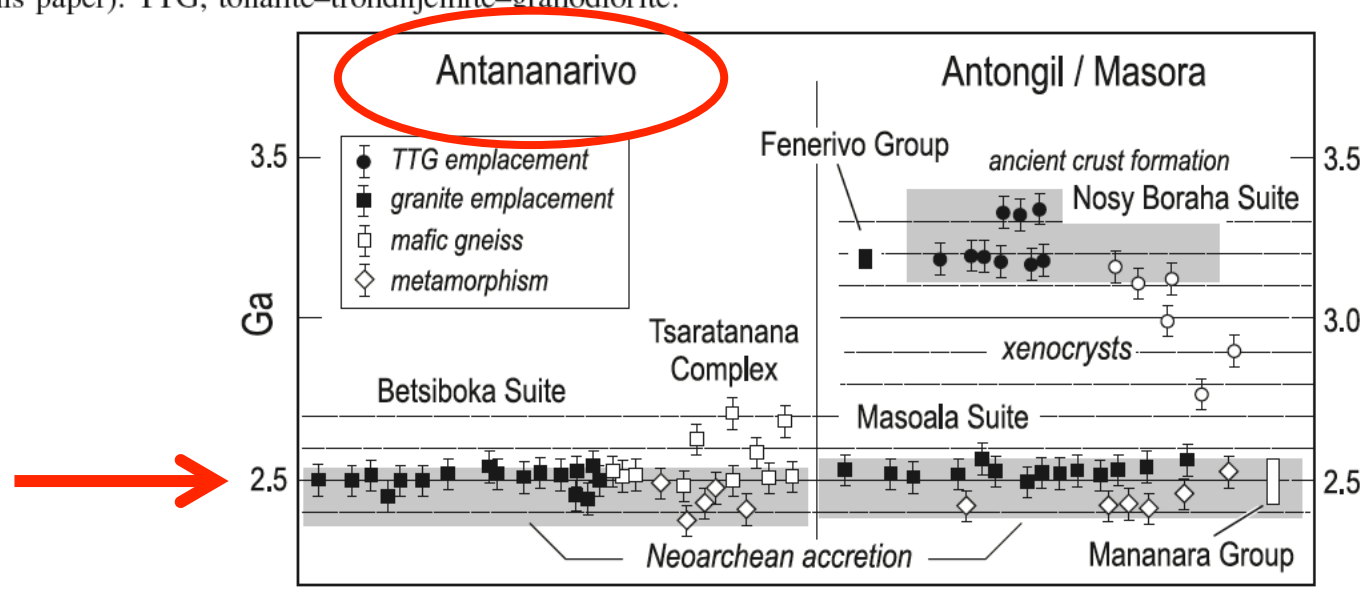

DOMAINS
Phanerozoic
unconformity
B
Bemarivo
Northern Exotic
Terrane
Northern Boundary of
Archean Craton
Ab
Ambatolampy
Manampotsy / Bealanana
Group
Betsimisaraka
domain
Antananarivo
A
Tsara
Complex
A/M
Antongil / Masora
Central Archean
domain
Eastern Archean
domain
Southern Boundary of
Archean Craton
Ik-It
Ikalamavony-Itremo
As
Anosyen
Beraketa High-Strain Zone
Ad
Androyen
Ampanihy High-Strain Zone
V
Vohibory
Southern
Exotic
Terranes

Fig. 3. Chronogram of Archean events across the Antananarivo and Antongil–Masora domains. The data are from published work (cited in the text), as well as information from the report of consultants (presented with permission from the PGRM, Madagascar). Also shown are the major periods of Archean sedimentation and volcanism for the Mananara Group (DeWaele et al. 2008) and the newly defined Fenerivo Group (this paper). TTG, tonalite–trondhjemite–granodiorite.



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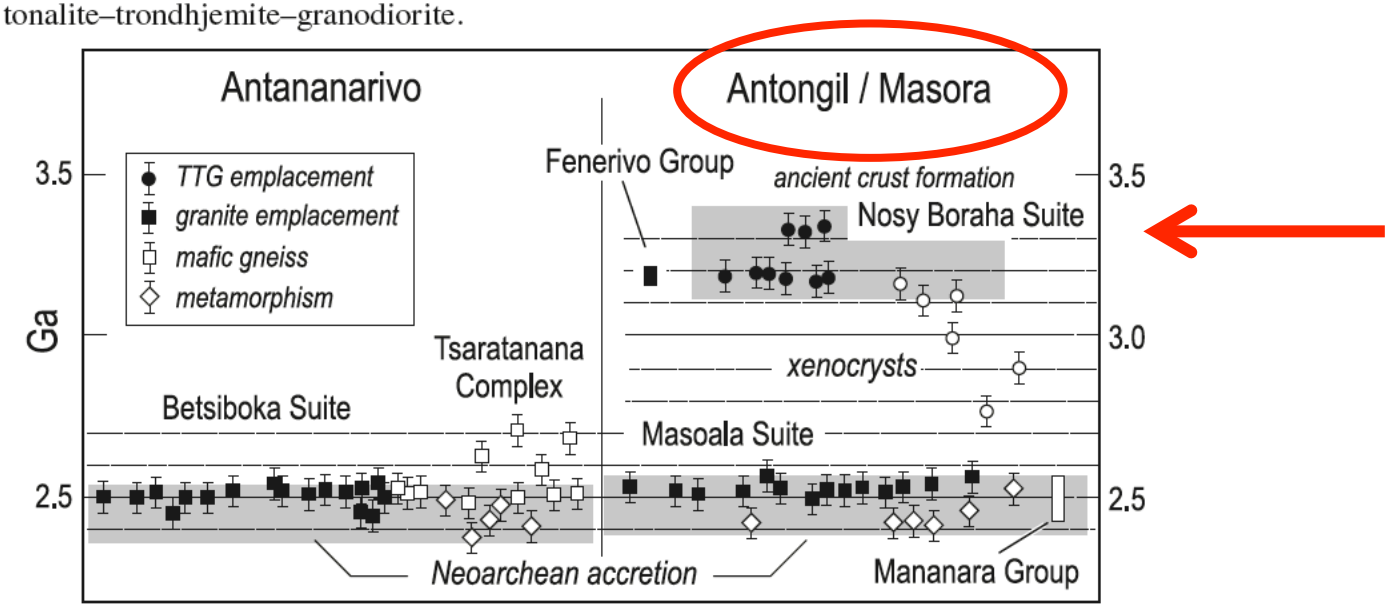
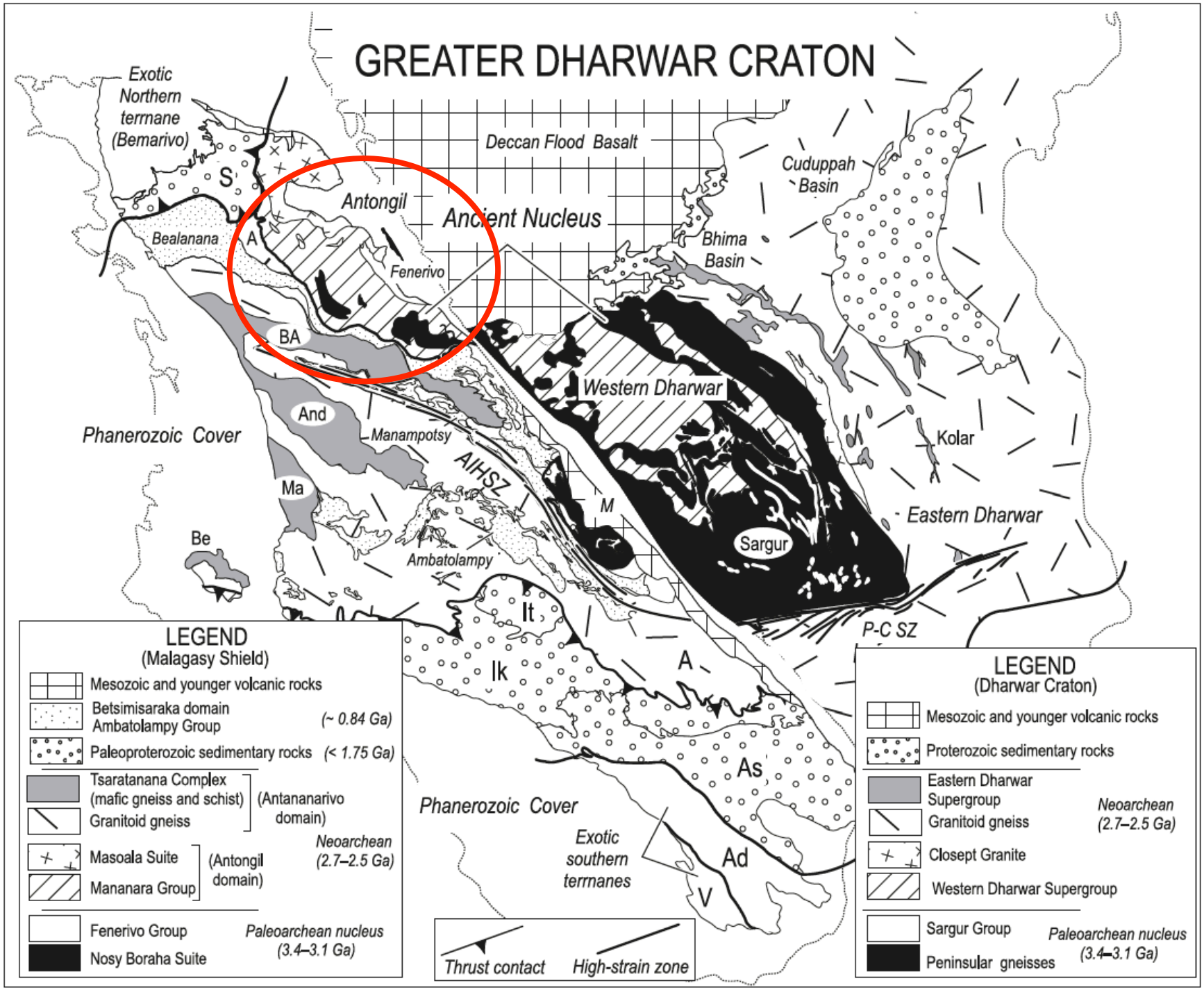
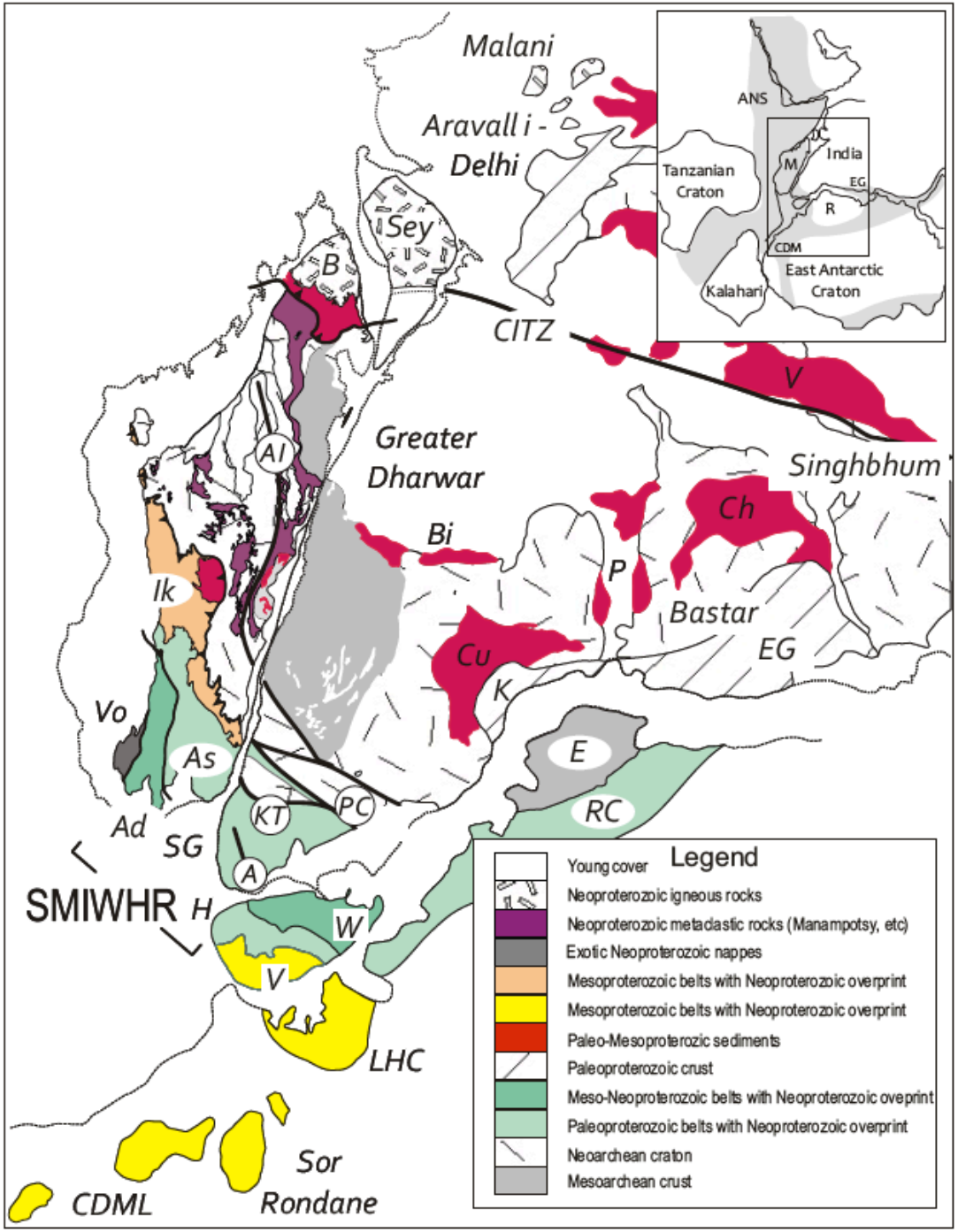



GREATER DHARWAR CRATON
Exotic Northern termane (Bemarivo)
Deccan Flood Basalt
Cuduppah Basin
Antongil
Ancient Nucleus
Bealanana
Bhima Basin
Fenerivo
BA
Western Dharwar
And
Phanerozoic Cover
Manampotsy
Kolar
AlHSZ
Ma
M
Eastern Dharwar
Be
Sargur
Ambatolampy
It
P-C SZ
Ik
A
As
Phanerozoic Cover
Exotic southern terrnanes
Ad
V
Thrust contact
High-strain zone
LEGEND
(Malagasy Shield)
Mesozoic and younger volcanic rocks
Betsimisaraka domain Ambatolampy Group (~ 0.84 Ga)
Paleoproterozoic sedimentary rocks (< 1.75 Ga)
Tsaratanana Complex (mafic gneiss and schist)
Granitoid gneiss
(Antananarivo domain)
Neoarchean (2.7–2.5 Ga)
Masoala Suite
Mananara Group
(Antongil domain)
Fenerivo Group
Nosy Boraha Suite
Paleoarchean nucleus (3.4–3.1 Ga)
LEGEND
(Dharwar Craton)
Mesozoic and younger volcanic rocks
Proterozoic sedimentary rocks
Eastern Dharwar Supergroup
Granitoid gneiss
Neoarchean (2.7–2.5 Ga)
Closept Granite
Western Dharwar Supergroup
Sargur Group
Peninsular gneisses
Paleoarchean nucleus (3.4–3.1 Ga)


Malani
Aravalli -
Delhi
Sey
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CITZ
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Greater
Dharwar
Singhbhum
Ch
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Bastar
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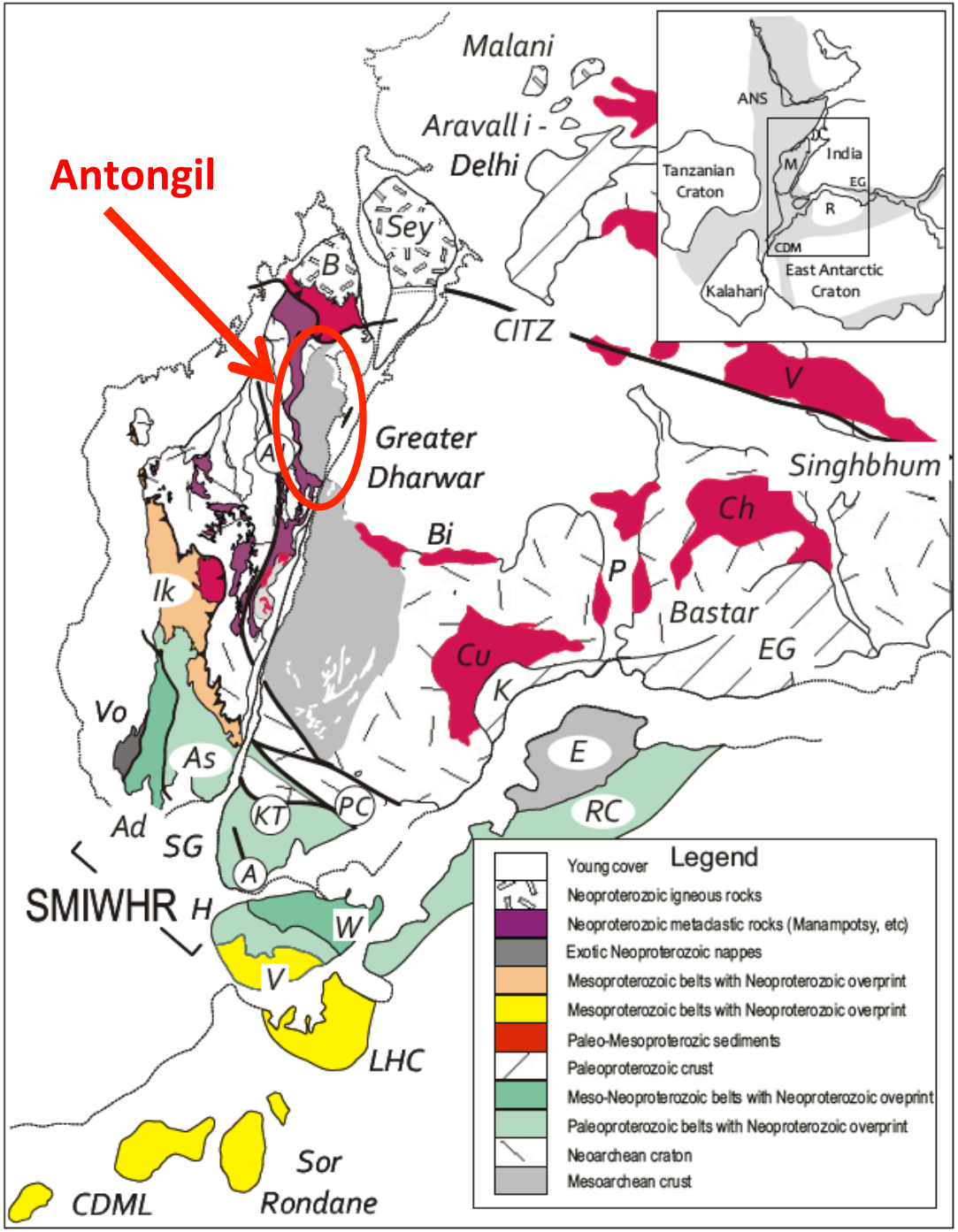
Sor
Rondane
CDML
ANS
India
Tanzanian
Craton
M
EG
R
CDM
East Antarctic
Craton
Kalahari
Legend
Young cover
Neoproterozoic igneous rocks
Neoproterozoic metaclastic rocks (Manampotsy, etc)
Exotic Neoproterozoic nappes
Mesoproterozoic belts with Neoproterozoic overprint
Mesoproterozoic belts with Neoproterozoic overprint
Paleo-Mesoproterozic sediments
Paleoproterozoic crust
Meso-Neoproterozoic belts with Neoproterozoic oveprint
Paleoproterozoic belts with Neoproterozoic overprint
Neoarchean craton
Mesoarchean crust


Antongil
Malani
Aravalli -
Delhi
Sey
B
CITZ
V
Greater
Dharwar
A
Singhbhum
Ch
Bi
P
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Bastar
EG
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LHC
Sor
Rondane
CDML
ANS
India
Tanzanian
Craton
M
EG
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CDM
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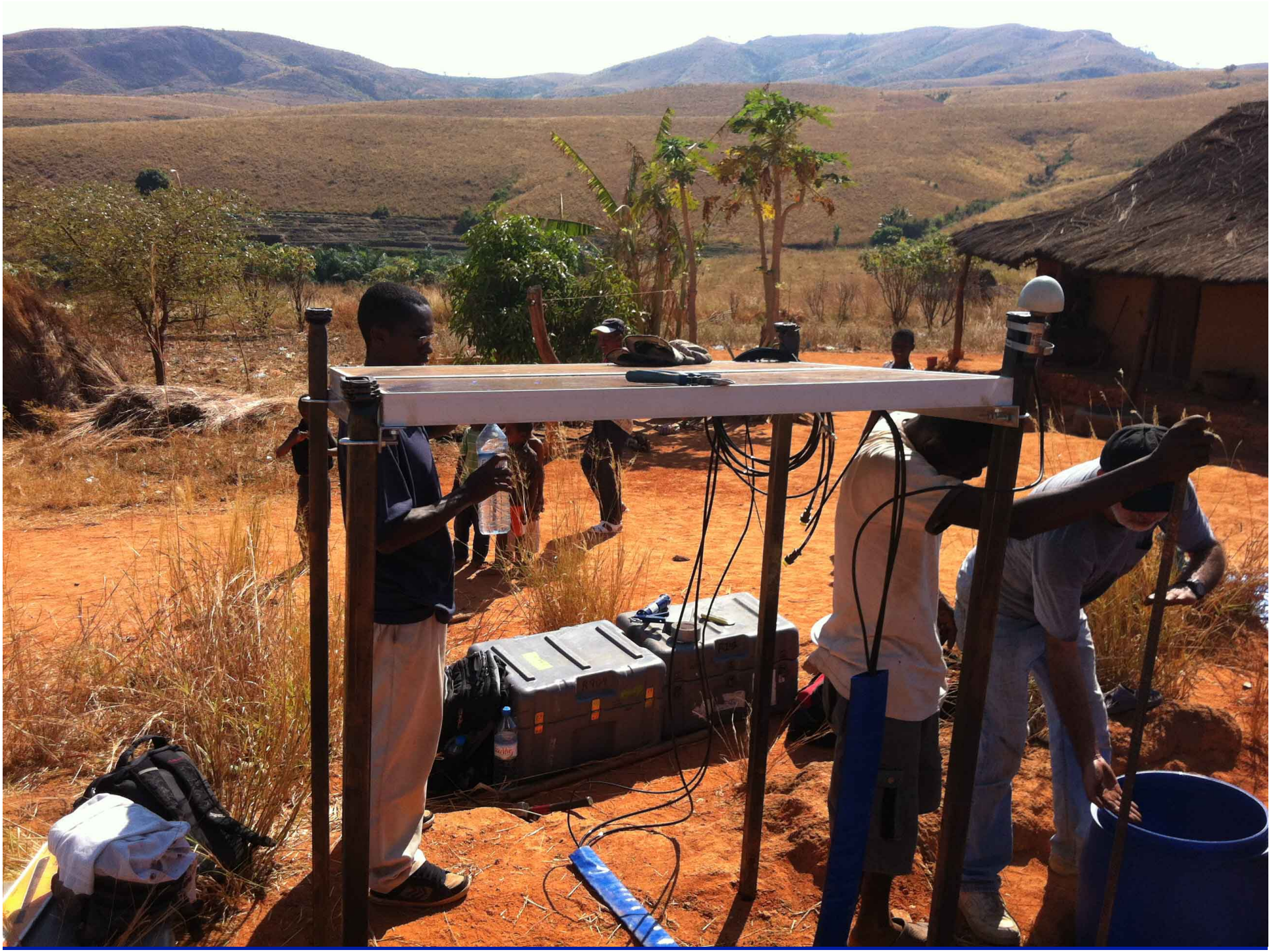
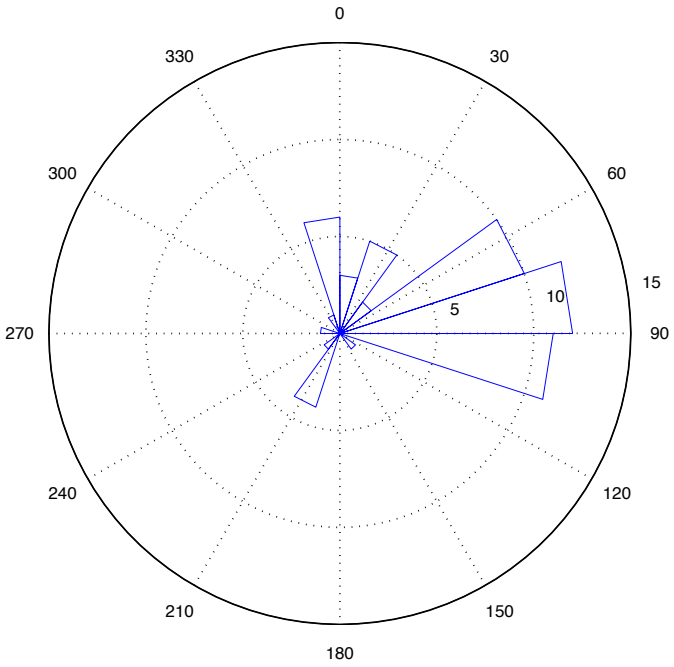
Paleoproterozoic crust
Meso-Neoproterozoic belts with Neoproterozoic oveprint
Paleoproterozoic belts with Neoproterozoic overprint
Neoarchean craton
Mesoarchean crust

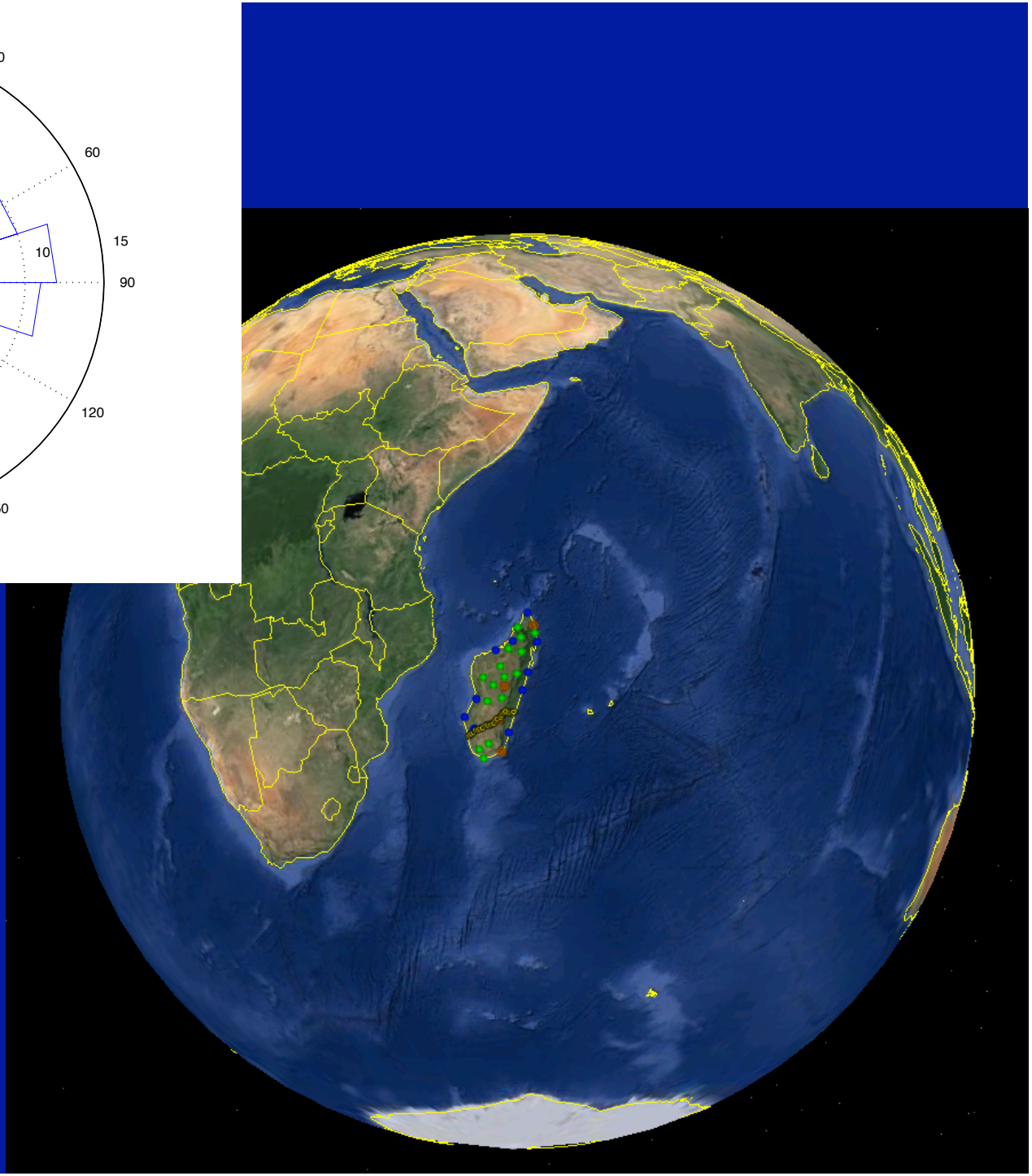
Many MACOMO seismometers were colocated at Missouri Botanic Garden research sites



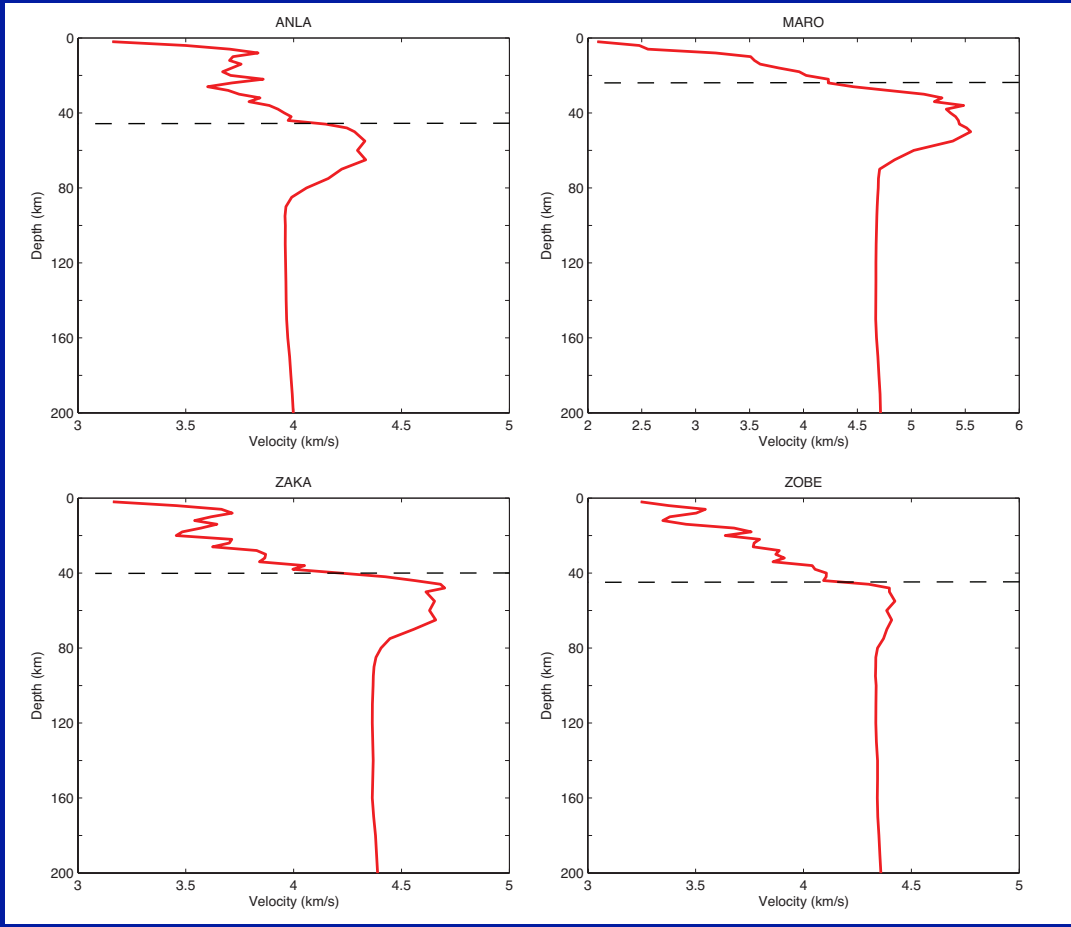

LAND CRUISER
9978
TAD



Rose diagram for data coverage for preliminary receiver function study of crustal thickness

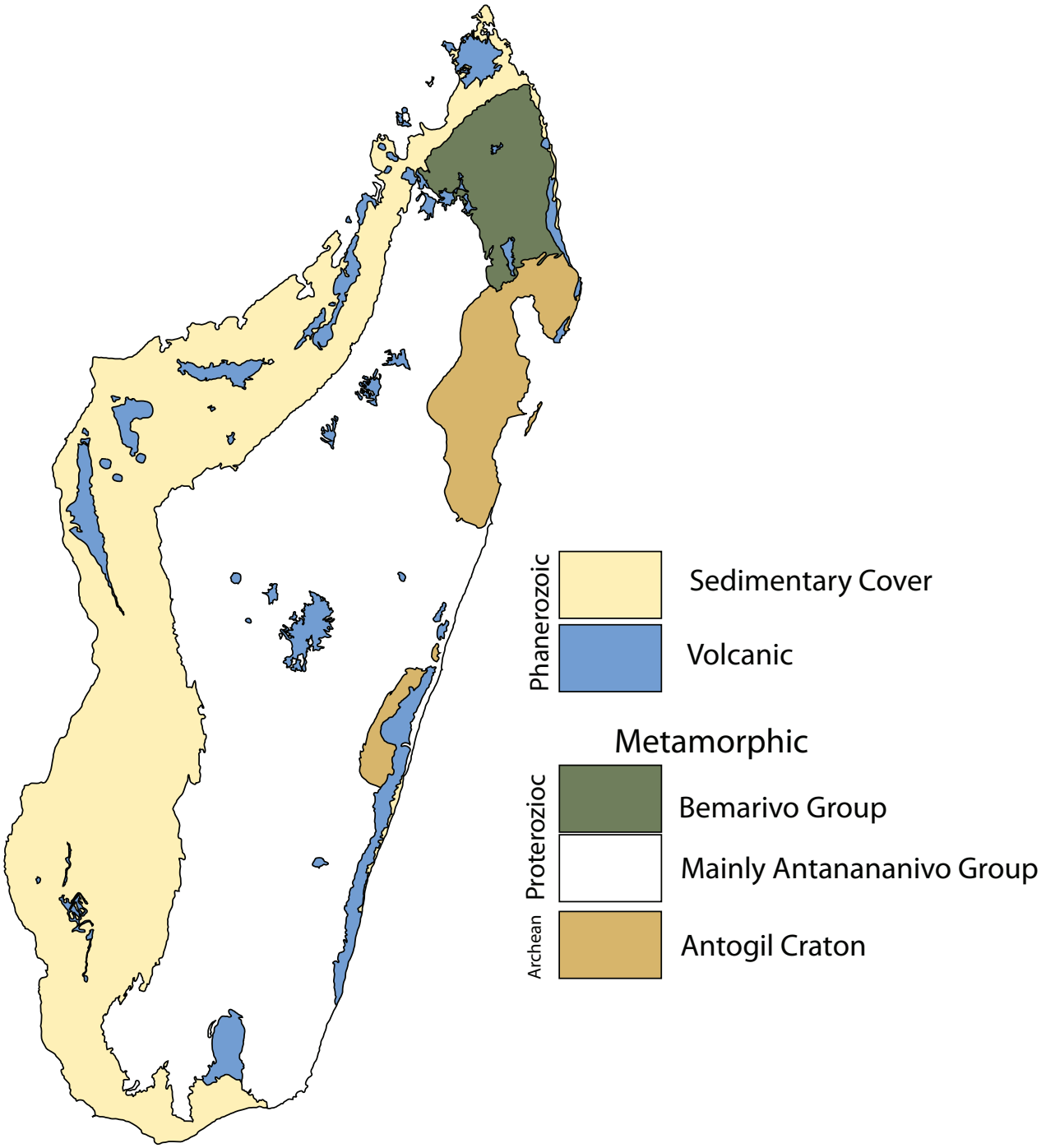


Examples of depth profiles from receiver functions for four stations



- Codes by Herrmann & Ammon (2002)
- 57 events of direct P arrivals
- Iterative deconvolution used to generate radial and transverse receiver functions
- Only radial receiver functions that recreated 80% of the original signal were used in the inversion.

Simplified version of 2012 geologic map



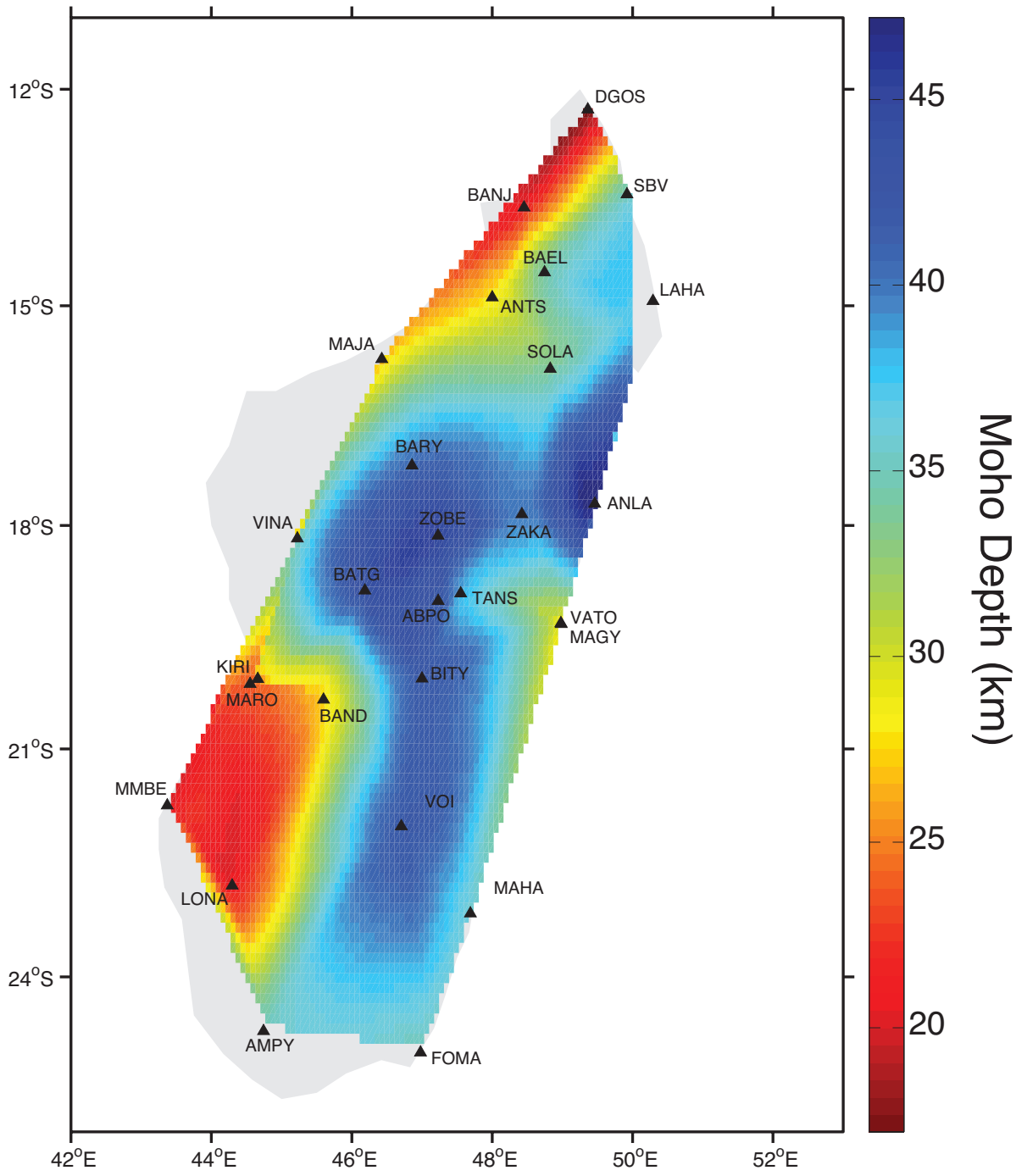
Crustal Thickness:

~ 40 km along the spine of the Proterozoic Antananarivo Group

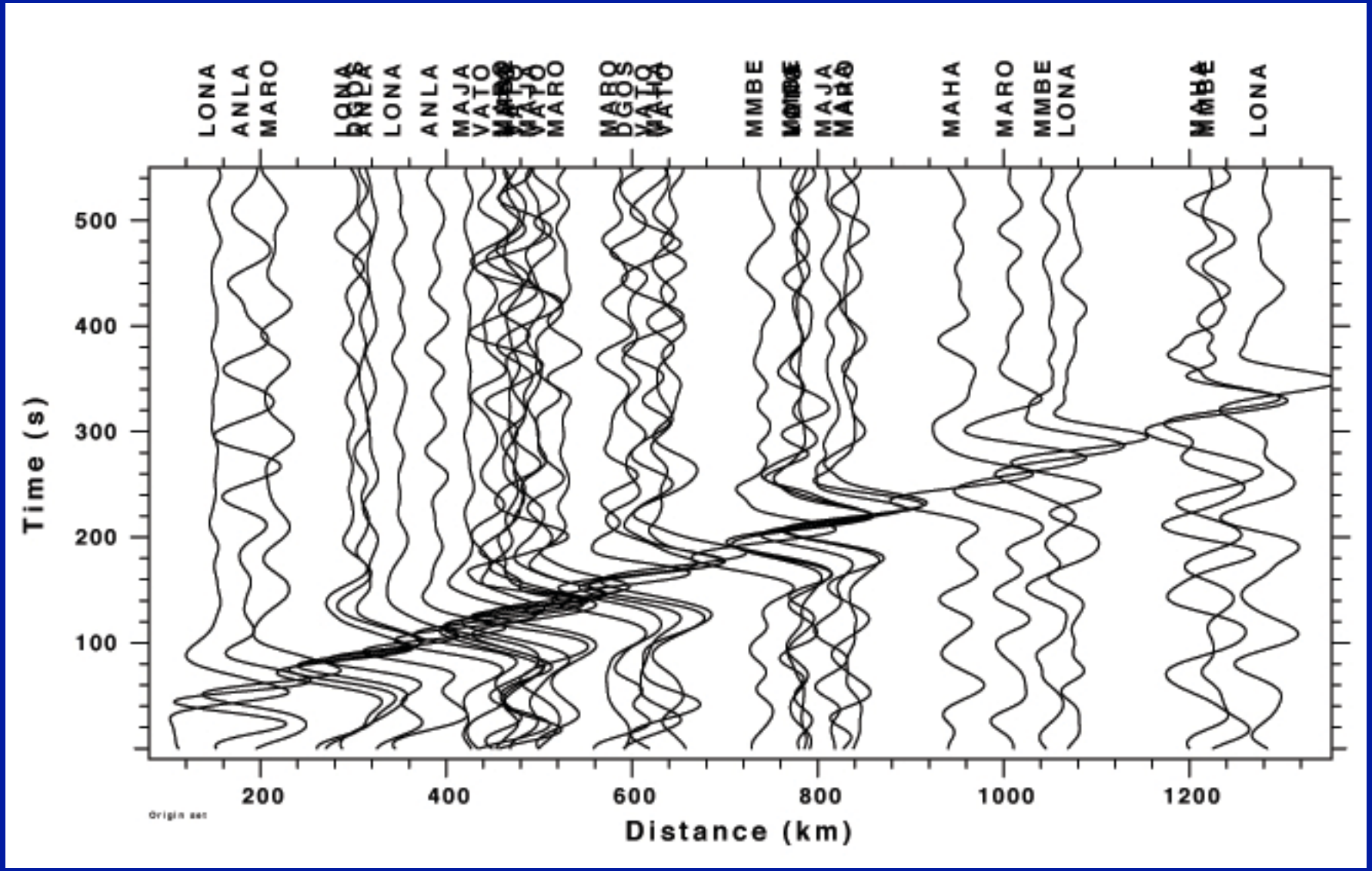
Thins to ~20 km to the rift zone at the northwest

Thins to ~20 km to the orogenic belt to the SW

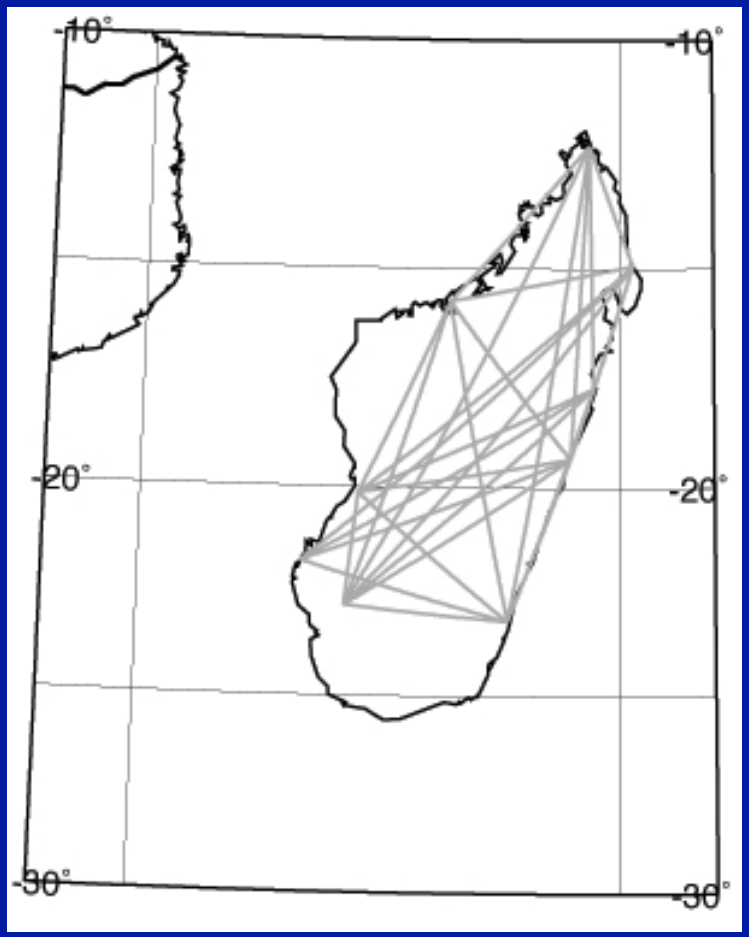
Thickens to ~45 for the Antongil craton to the east

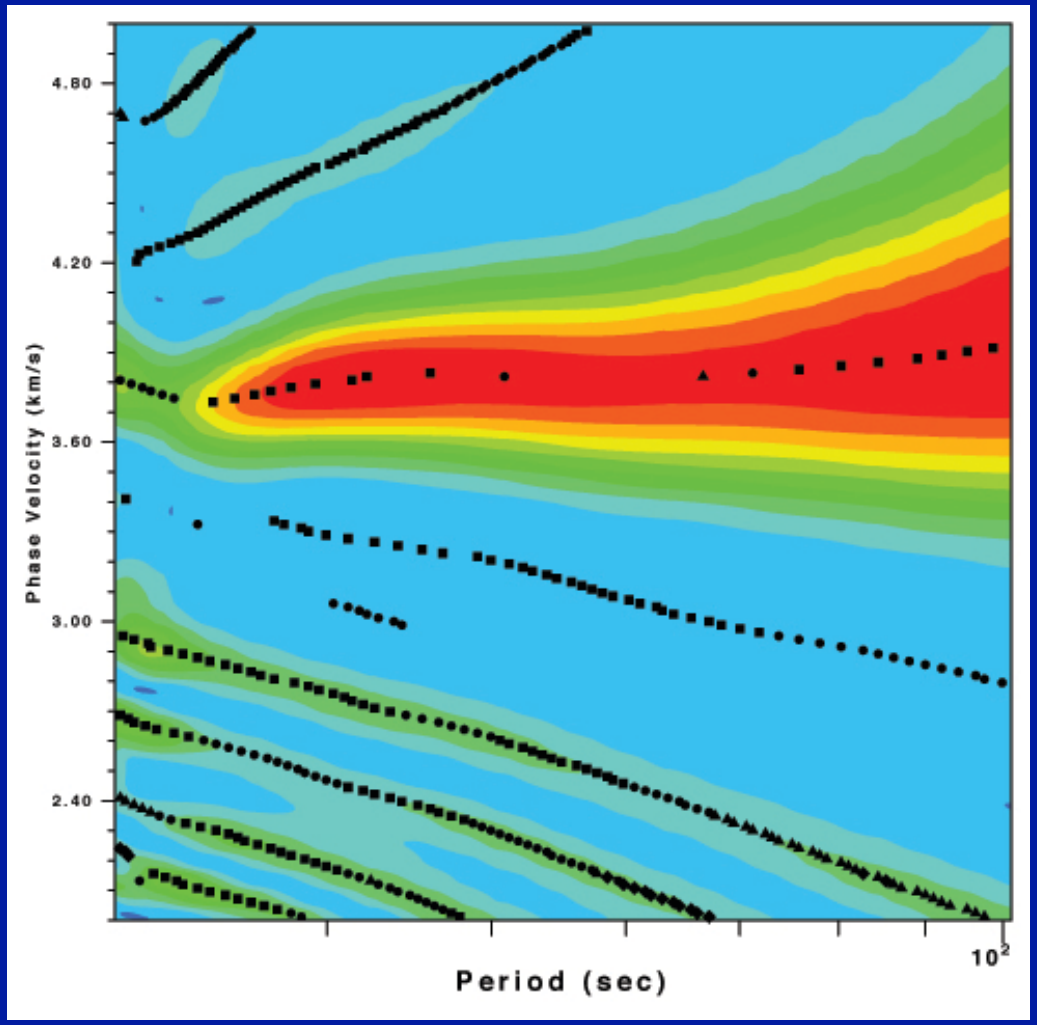


Preliminary 2-station Green's Functions for 1st-yr Madagascar stations



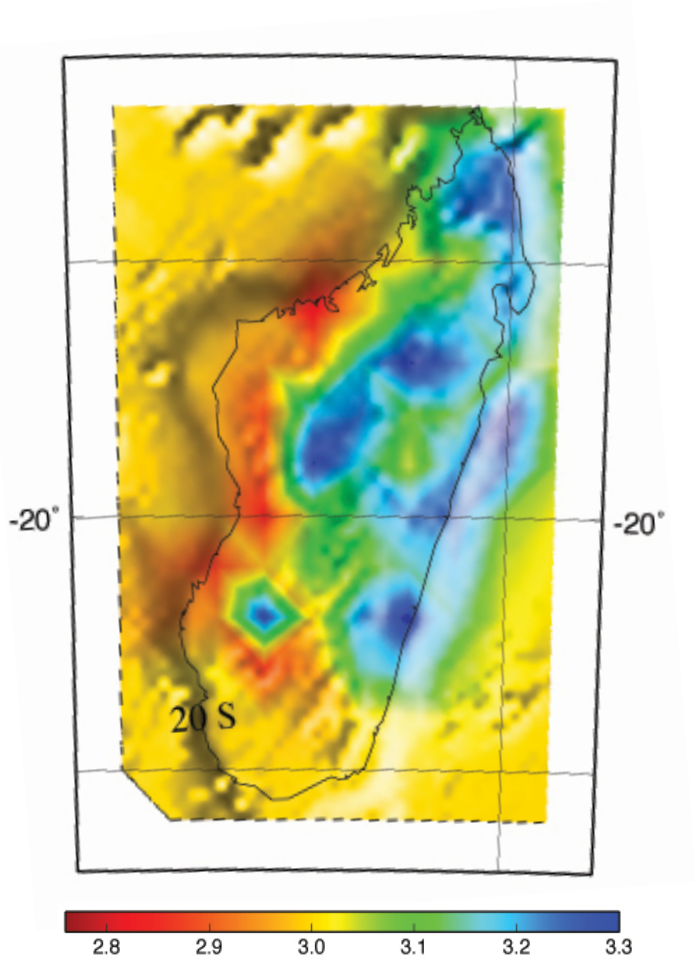
Paths for 1st-year 2-station Green's Functions





Example of a phase velocity map, calculated using the P-omega method for a 2-station noise Green's Function

Preliminary Seismic Noise Tomography using Rayleigh Wave Group Velocities



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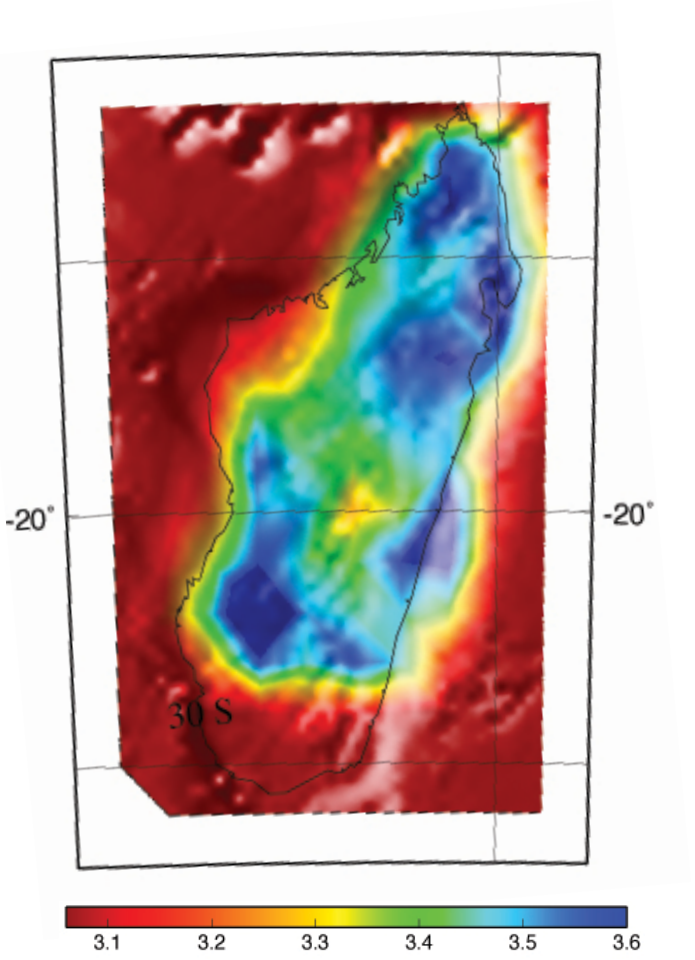

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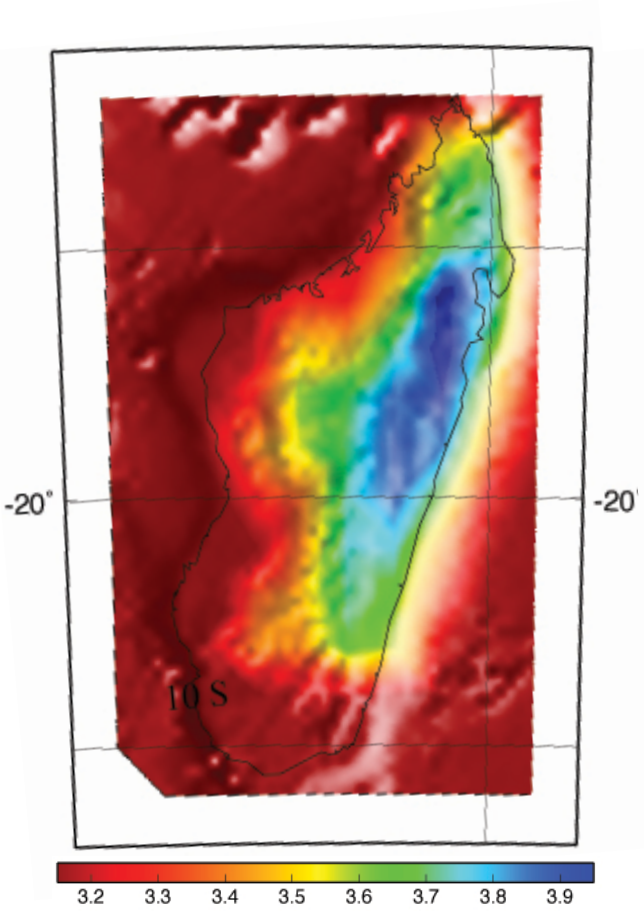
Preliminary Seismic Noise Tomography using Rayleigh Wave Phase Velocities



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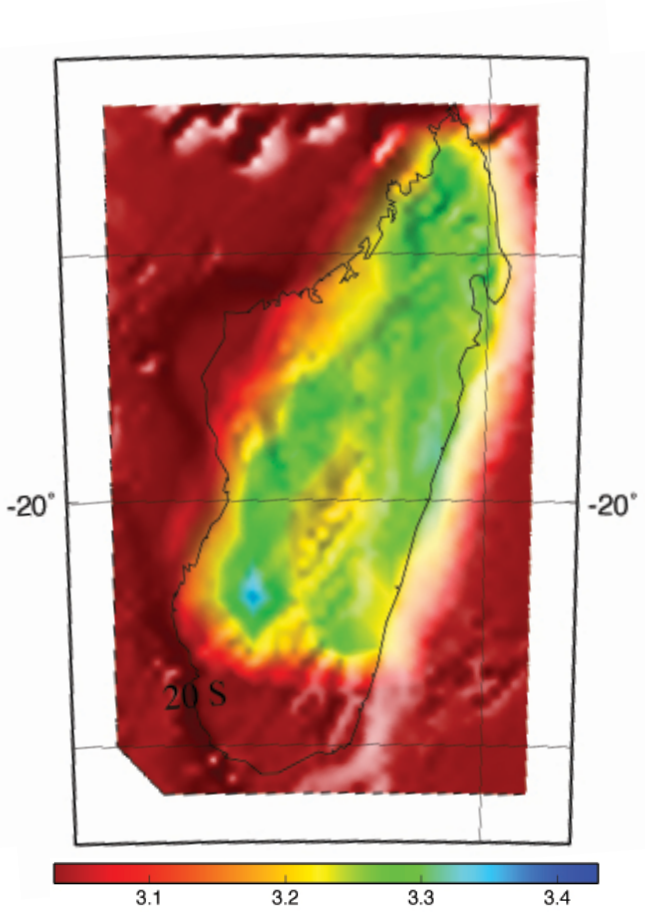

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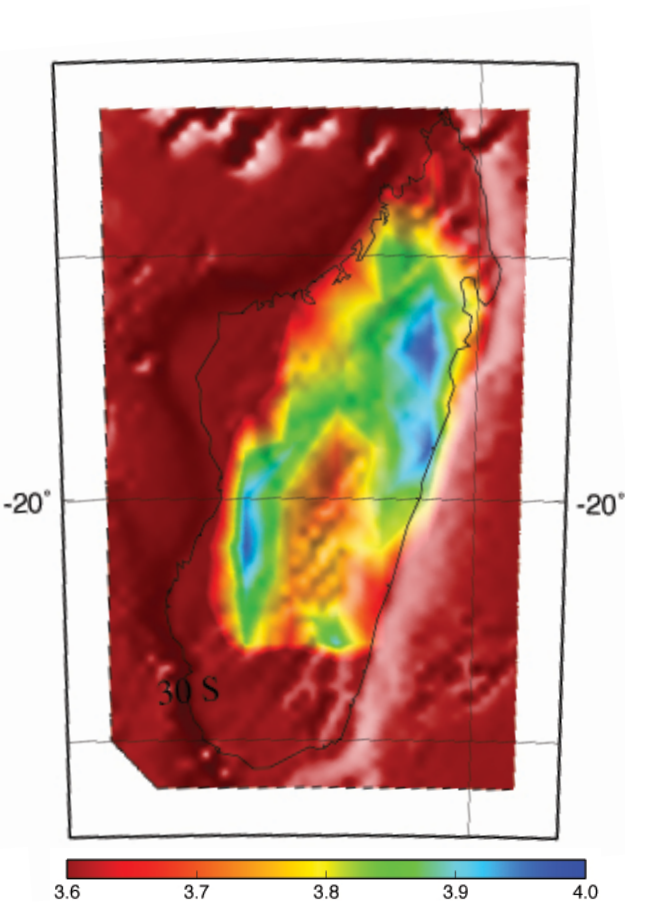

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