The East African Transform Margin: *a major new interpretation using potential fields geophysics*

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William Smith Meeting 2017: Plate Tectonics at 50, 3-5 October 2017

Introduction

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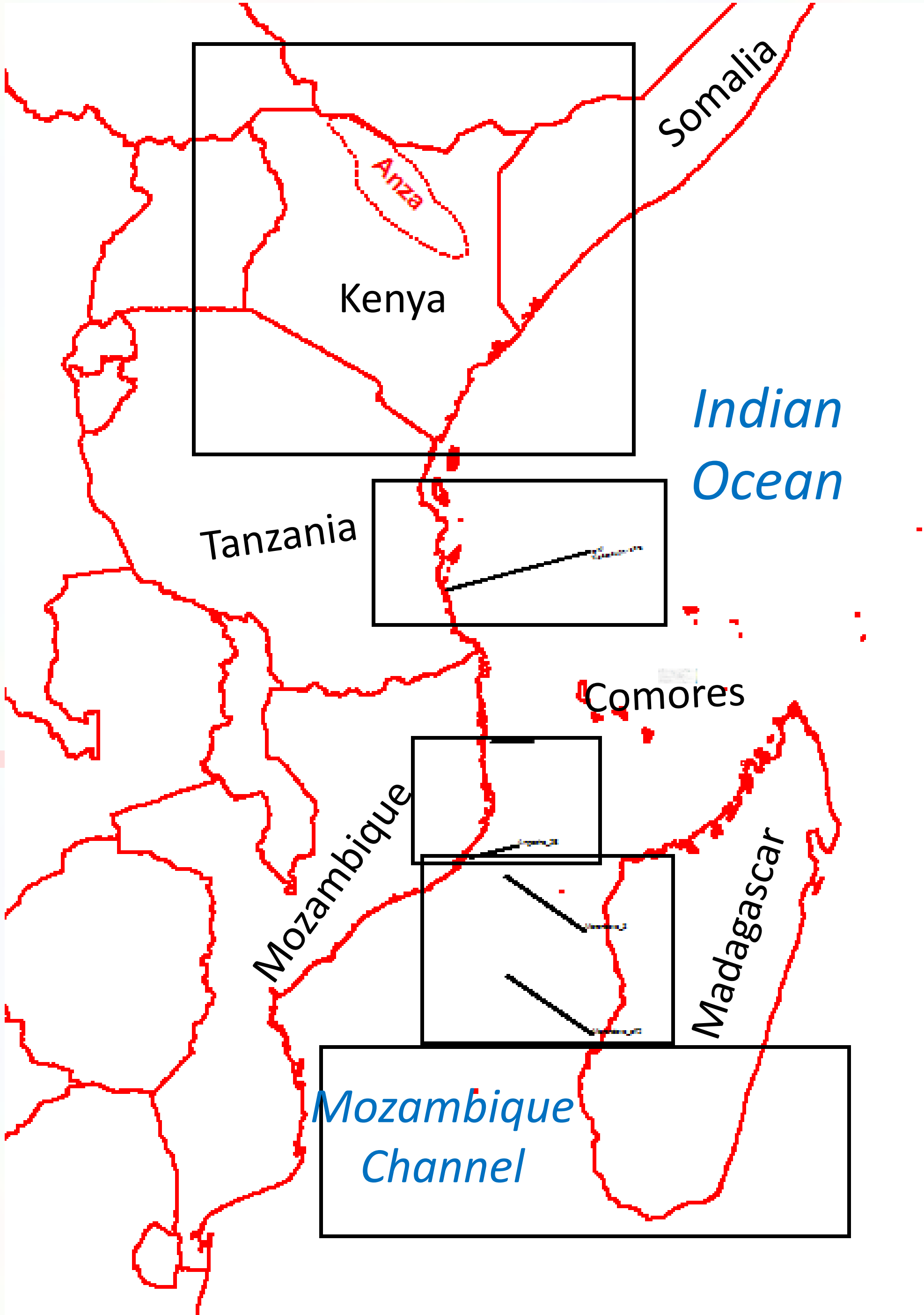


Data description

Following the release of the **Enhanced Magnetic Field model (EMM, Chulliat et al, 2015)**, a vast improvement in **resolution down to 56km** is achieved by increasing degree and order 720, versus the earlier World Magnetic model that had spherical harmonic representation to order 12, resolving the magnetic field at 3000 km wavelength. The EMM incorporates recent *ESA swarm satellite data providing good infill coverage of interpolated areas in other satellite magnetic products such as EMAG2 and WDMAM*. This has presented an excellent opportunity to re-interpret regions of the world previously poorly surveyed by magnetics. **Processed for IGRF correction, reduced to pole and amplitude gain corrected to enhance crustal magnetizations, and remove internal field.**

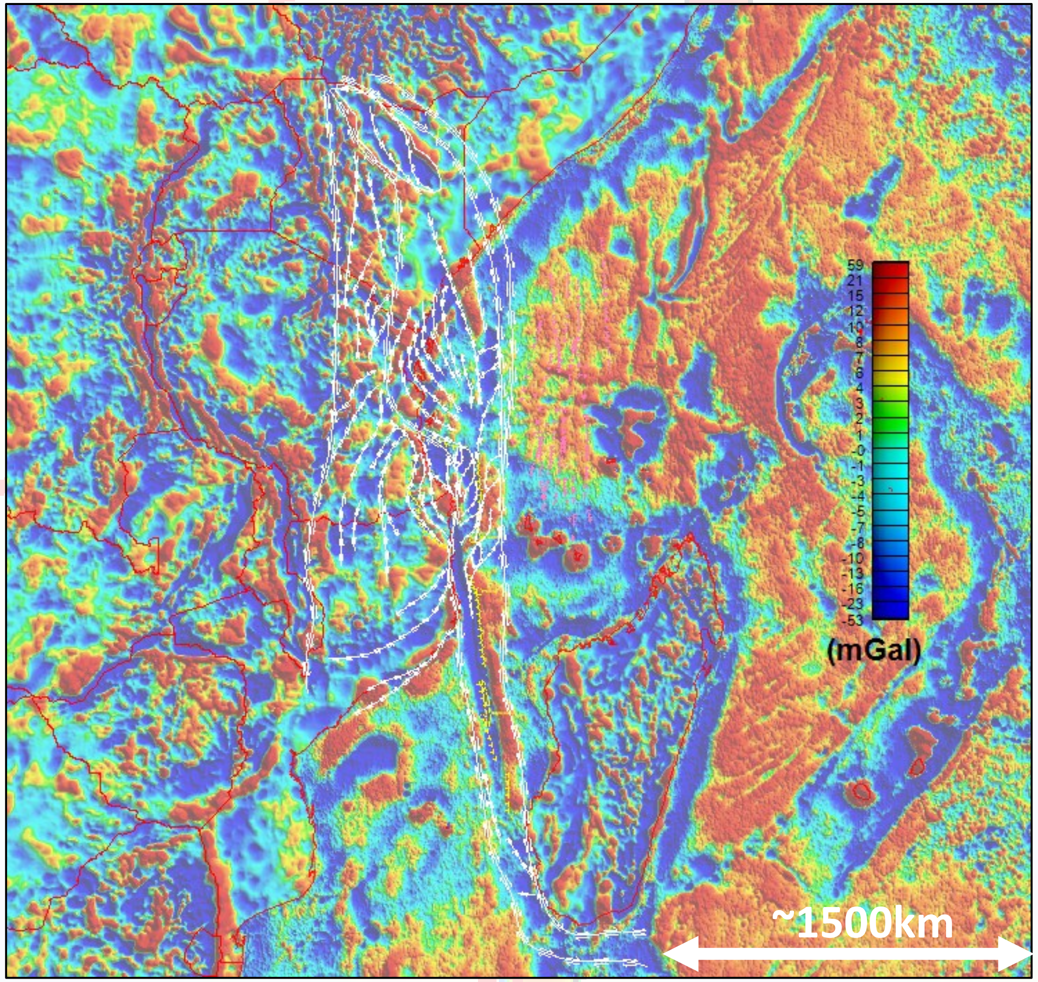
Sandwell Free Air Gravity (**Sandwell et al, 2014**), presented at **1 minute offshore resolution** has been processed and a decompensative correction applied to yield residual gravity. The new residual gravity products provide better control crustal structure and correlates well with the EMM processed magnetics. Furthermore slight corrections to the offshore Bouguer density, plus the depth of sea-level compensation in the Airy-Heiskanen isostasy model have improved resolution of high frequency, shallow gravity anomalies. **Processed and *corrected for Free Air, Simple Bouguer, terrain, Bullard Earth curvature, Airy isostasy, and residual taken from upward continuation to 40km)***

Use of Sandwell Free Air Gravity

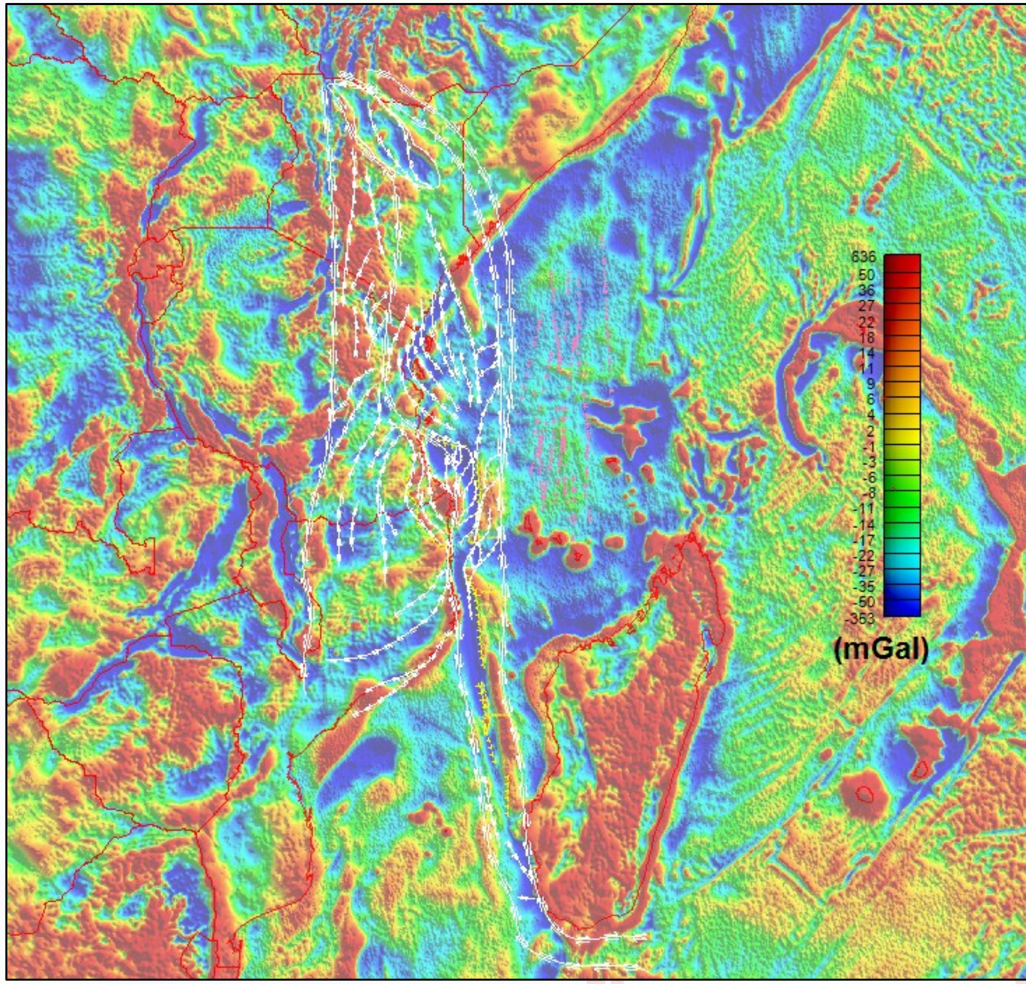
Free air gravity correlates with topo-bathymetric relief, neither geology, nor shallow crustal density variation

Free air gravity must be correctly processed to yield useful residualized products for interpretation

Let the data speak for itself- *do not model raw potential fields to support a preconceived model*



Left: Decompensative gravity (*corrected for Free Air, Simple Bouguer, terrain, Bullard Earth curvature, isostasy, and residual taken from upward continuation to 40km)*



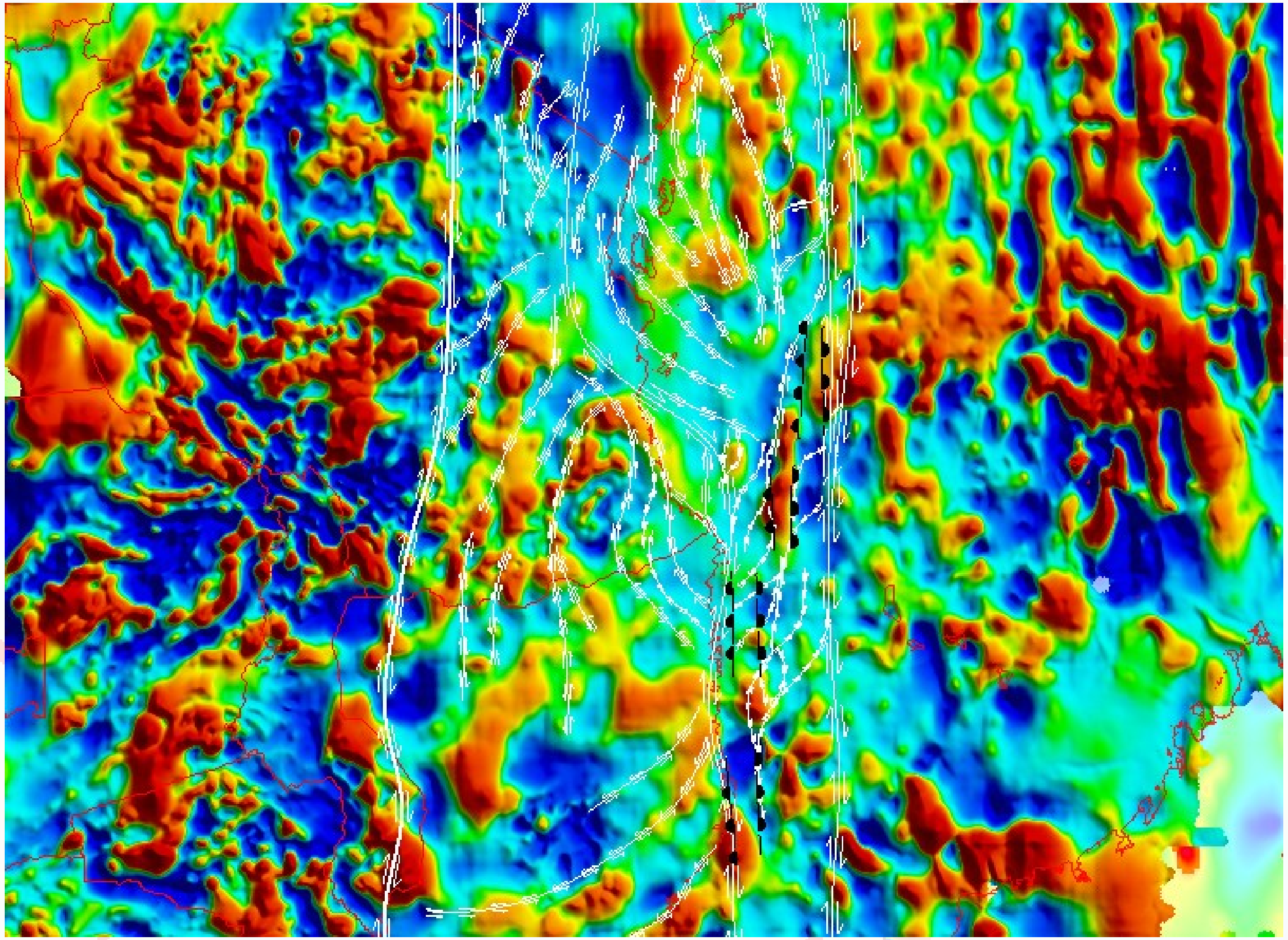
Right: Sandwell's v23 Free Air Gravity, *correlates to topo-bathymetric relief (***Sandwell et al, 2014***)*

Use of EMAG2 version 3

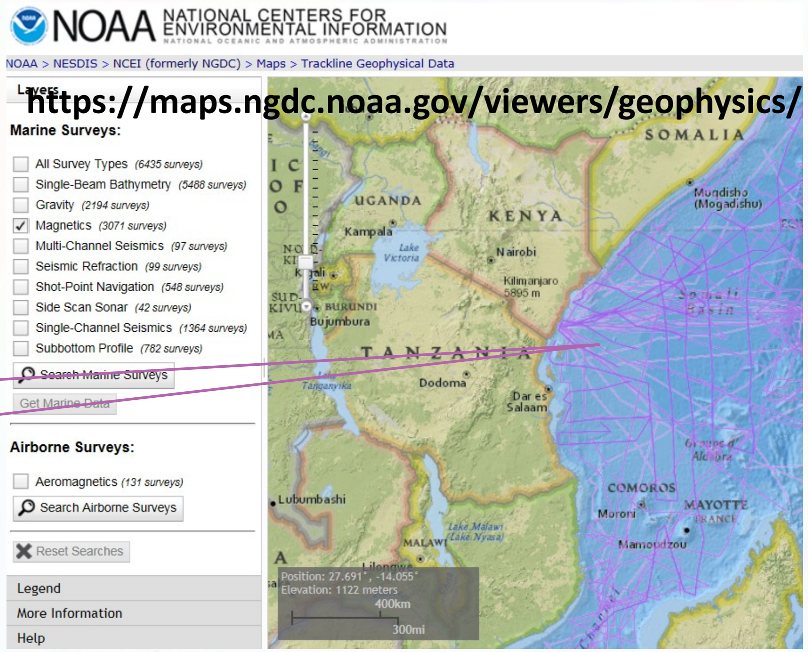
Krigged (i.e. interpolated) in areas of sparse shiptrack data

Not spatially homogeneous and continuous sampling of total field

Below: EMAG2 (**Maus et al 2009**) IGRF corrected, reduced to pole



https://maps.ngdc.noaa.gov/viewers/geophysics/



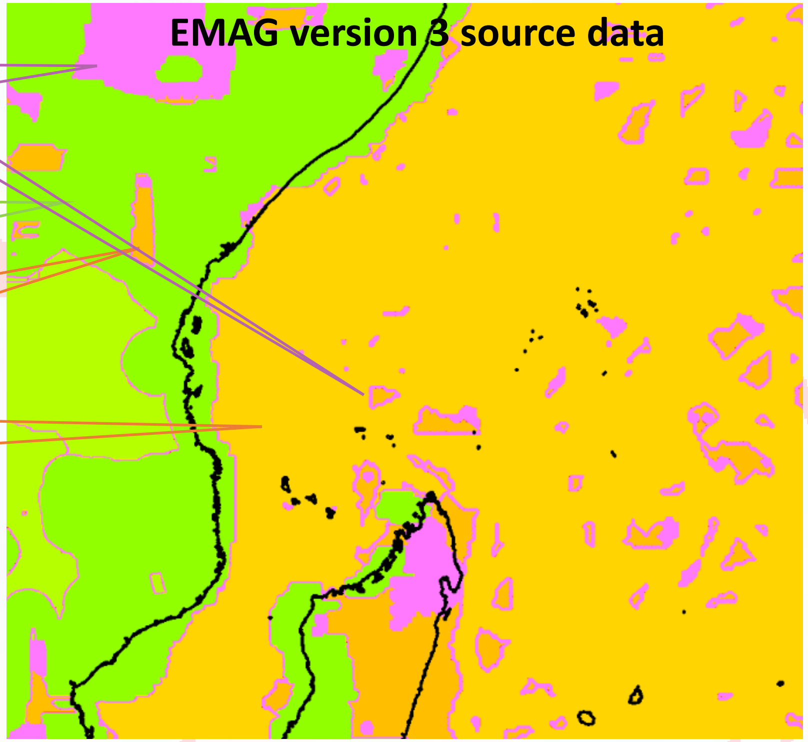
Sparse offshore shiptrack

No data

Getech

Arabian aeromag

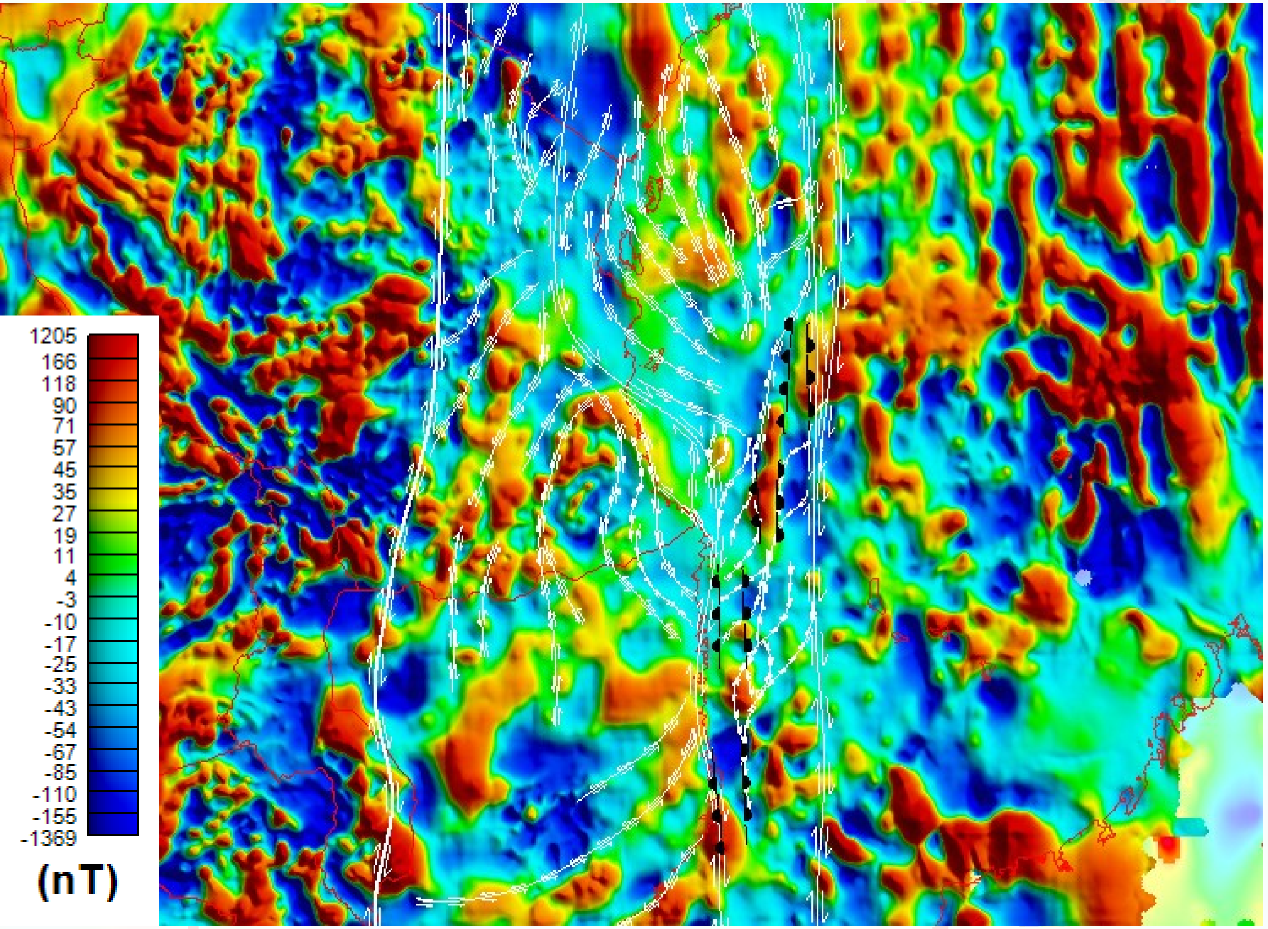
Arabian offshore

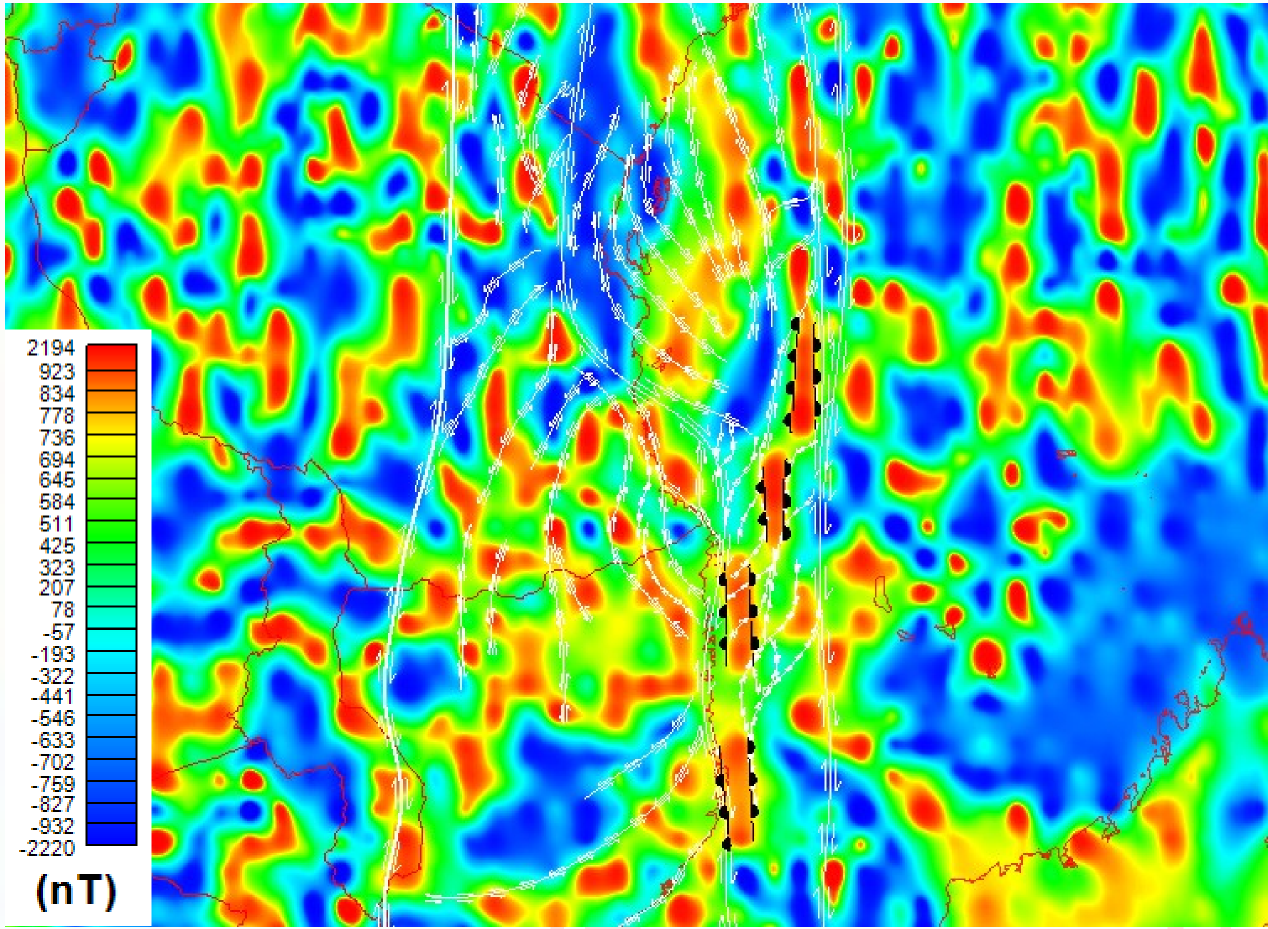


EMAG2 version 3 (left) versus EMM2015 (right)

Krigged (i.e. interpolated) in areas of sparse shiptrack data, **better onshore correlations** where higher resolution aeromagnetic surveys exist

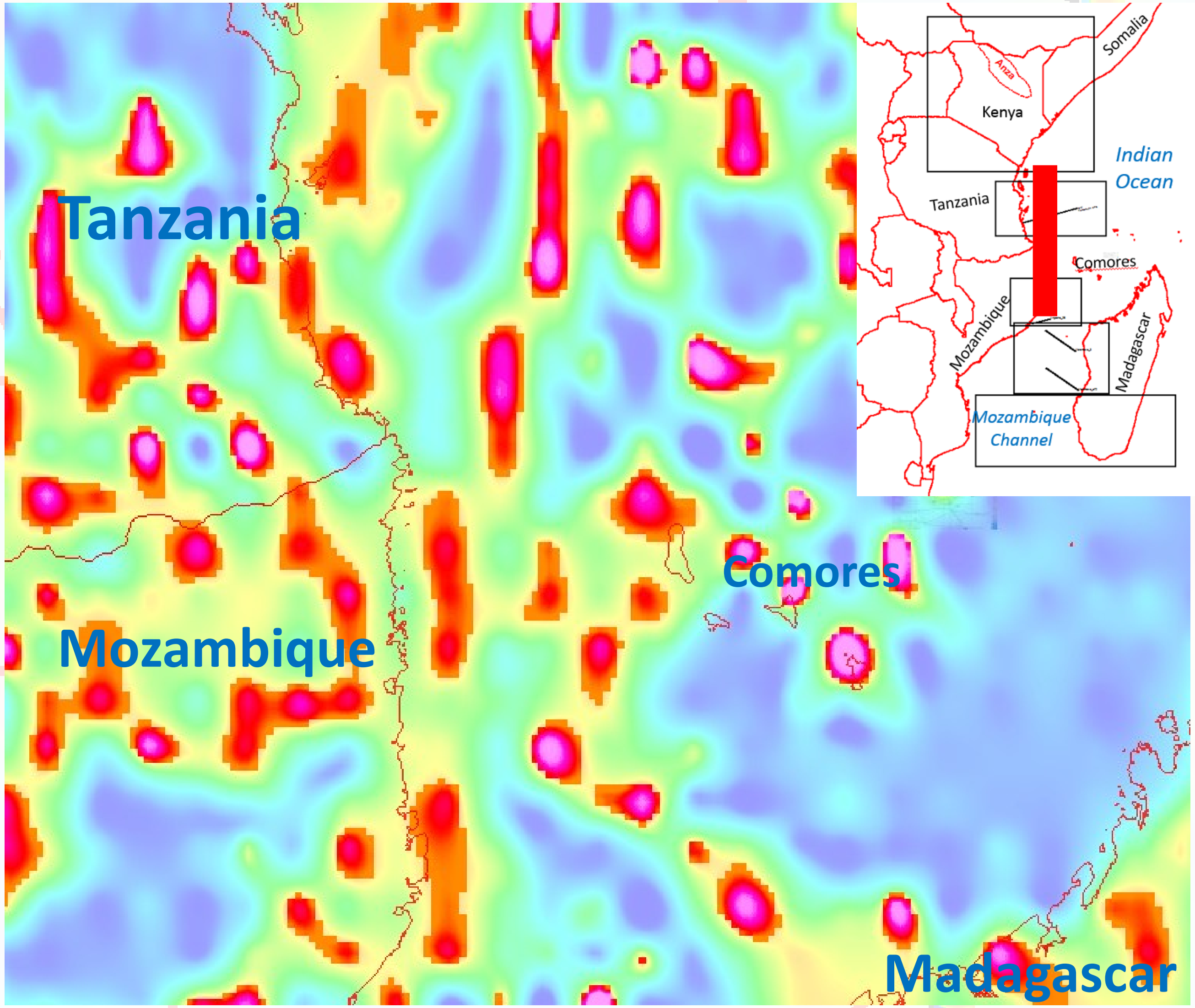
Not spatially homogeneous and continuous sampling of total field, versus EMM 2015

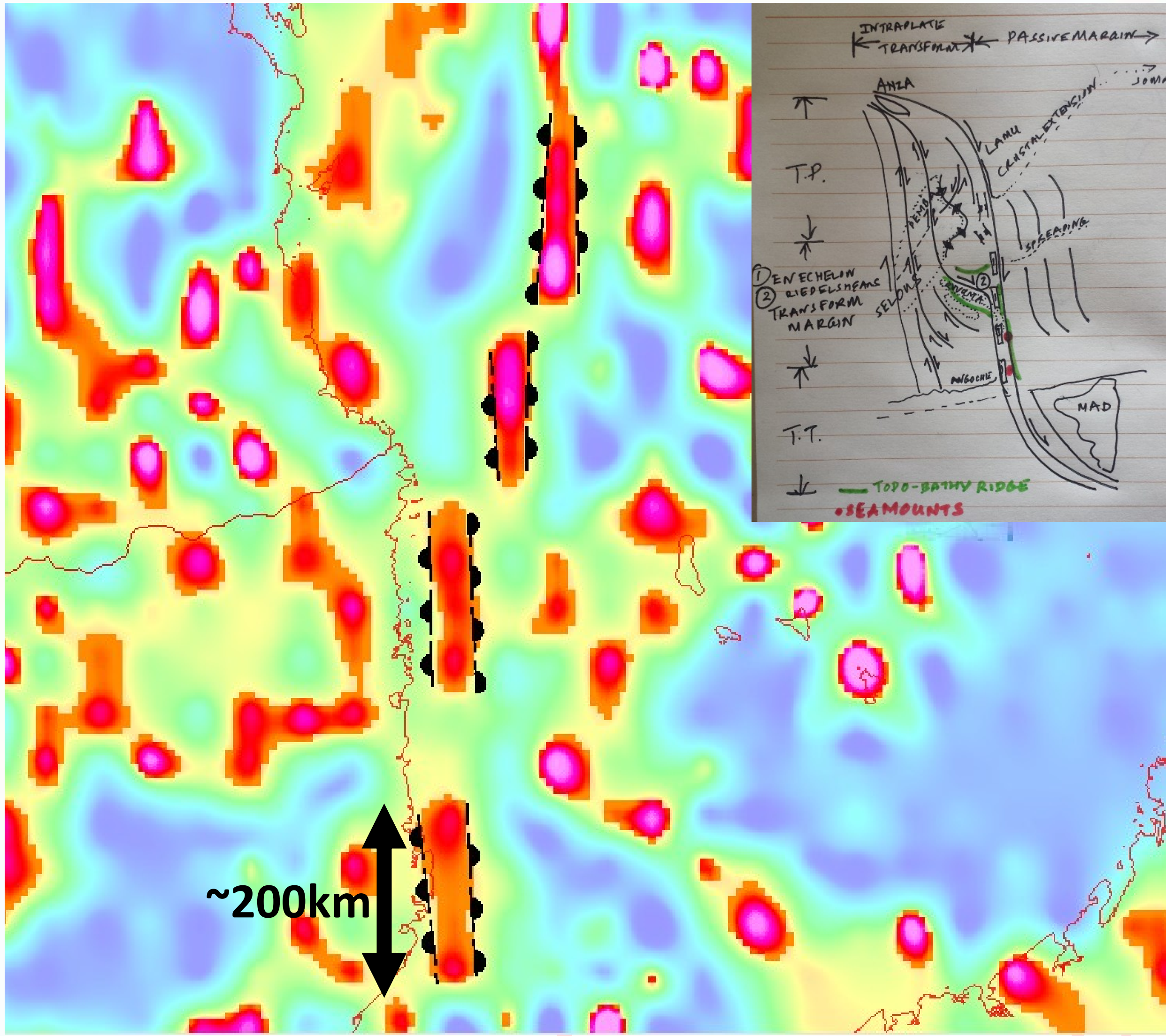




EMM2015 magnetics - Echelon crustal blocks

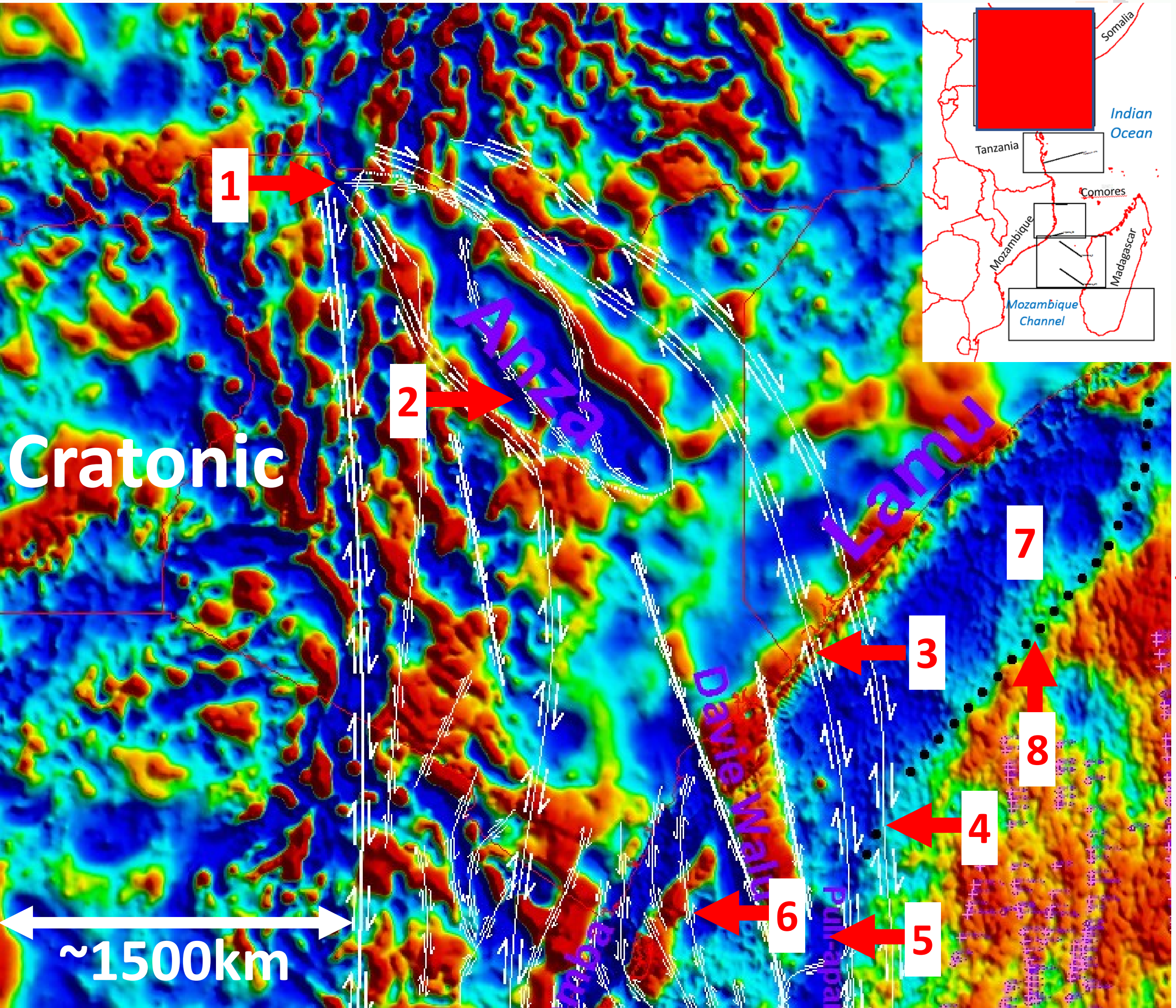
In a dextral strike slip setting, strongly suggestive of duplexing (e.g. **Woodcock and Fischer, 1986**)





Anza – the northern strike slip closure by rotation

Below: Decompensative gravity, *below right*: IGRF corrected, reduced to pole magnetics



Correlative strike slip fault offsets, transform margin, crustal extension, and oceanic boundary

Storti et al, 2003 - On intraplate strike slip tectonics:

"During divergence, they act as transfer zones that segment rifts, passive continental margins and, ultimately, oceanic spreading ridges… form major persistent zones of apparent weakness whose influence may be felt over many hundreds or even thousands of million years."

1 Closure by rotation

2 Seismic evidence of Neogene inversion + earlier

3 Main transform margin

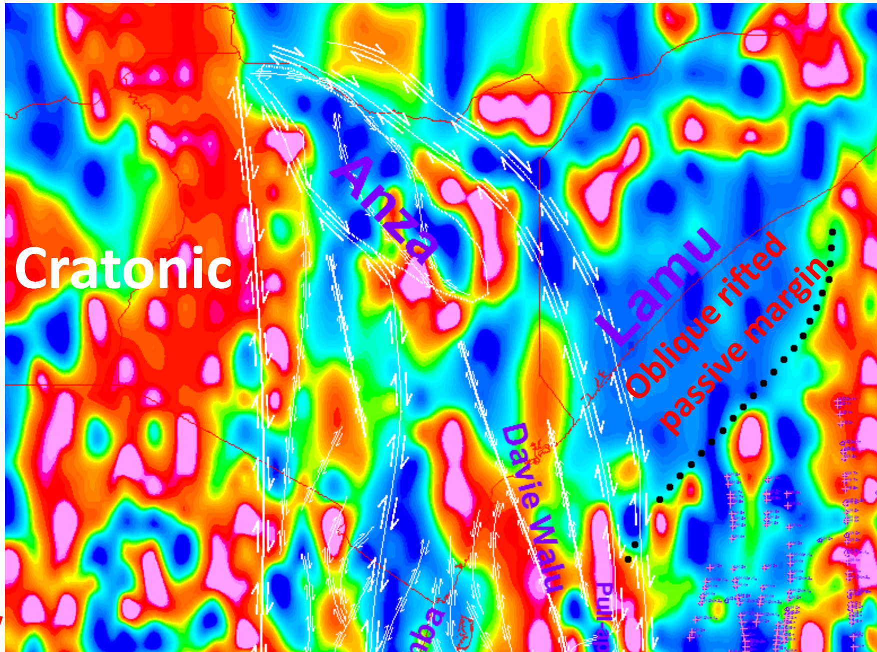
4 Oceanic transform segment

5 Seismic evidence of Jurassic pull-apart basin

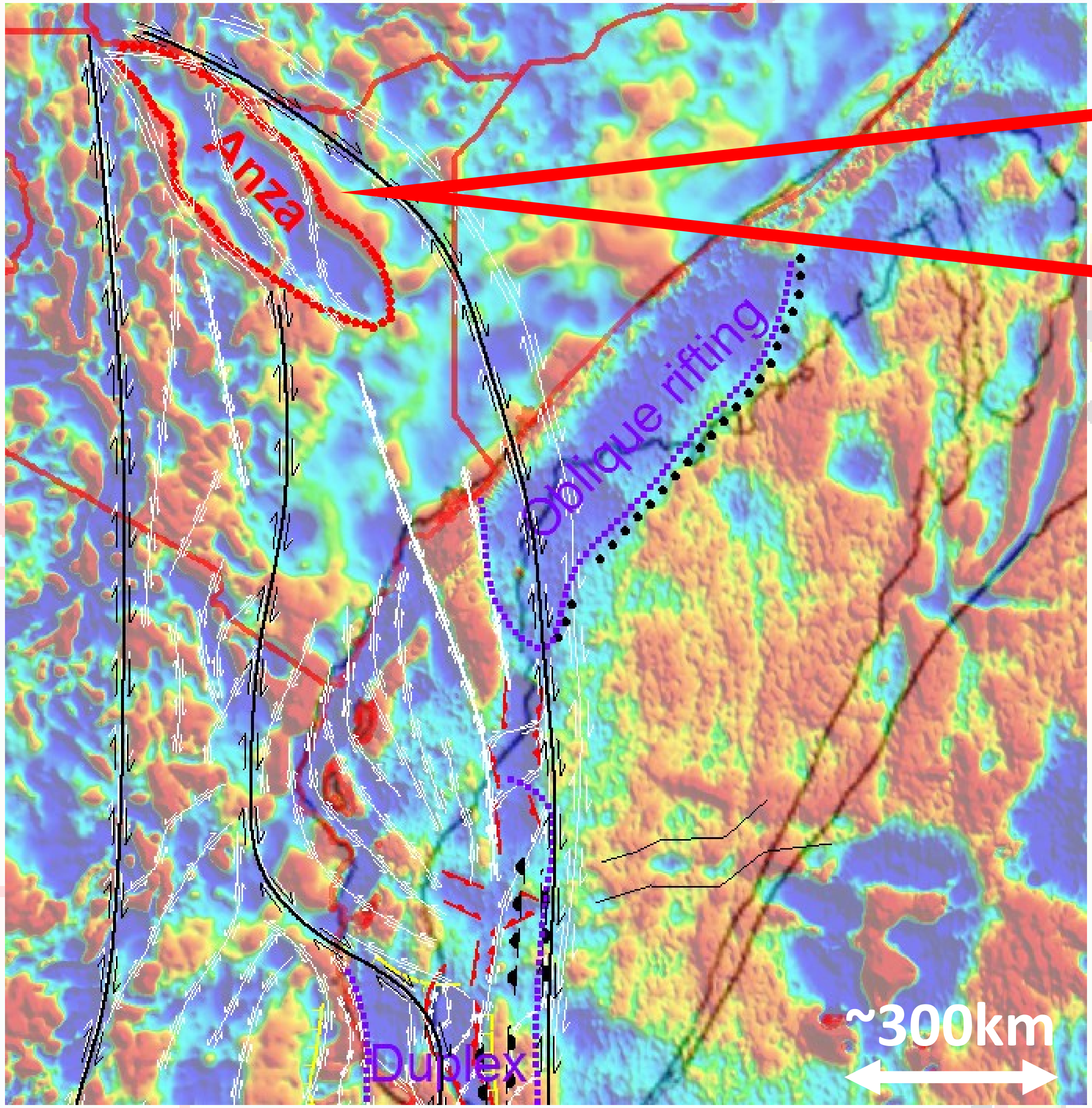
6 Transpression, several episodes

7 Oblique rifted passive margin

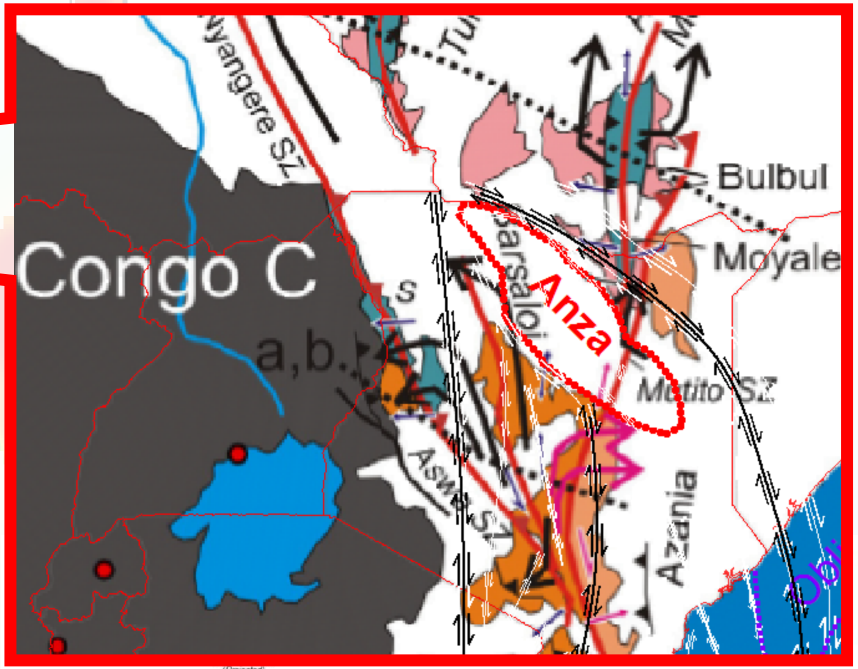
8 Continent-Ocean boundary

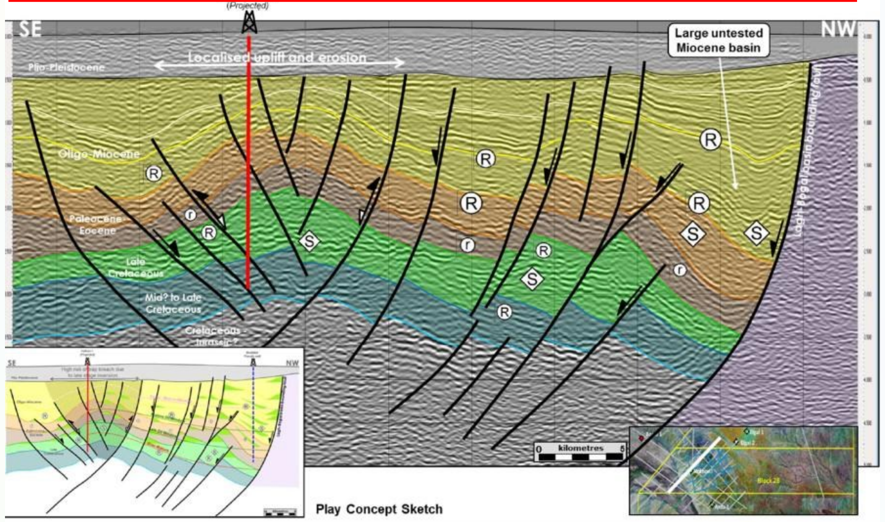


Precambrian Suture (E-W Gondwana) to Anza Neogene inversion:



Above: Decompensative gravity residual overlain by **David Boote's Triassic Karoo reconstruction**, 2017, based on rigorous well correlations



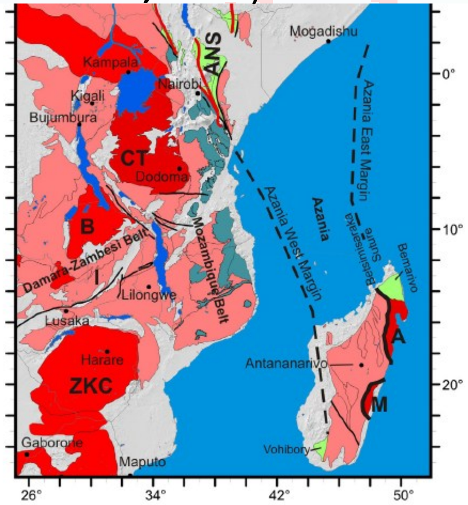


Above: Palaeogene- Neogene inversion

Left: After Fritz, 2013. Anza occupies Neoproterozoic Barsaloi suture between the Congo cratonic margin and the relic Anzania margin as part of the East African Orogen.

Relic faults and sutures remain lines of weakness, note western cratonic strike margin.

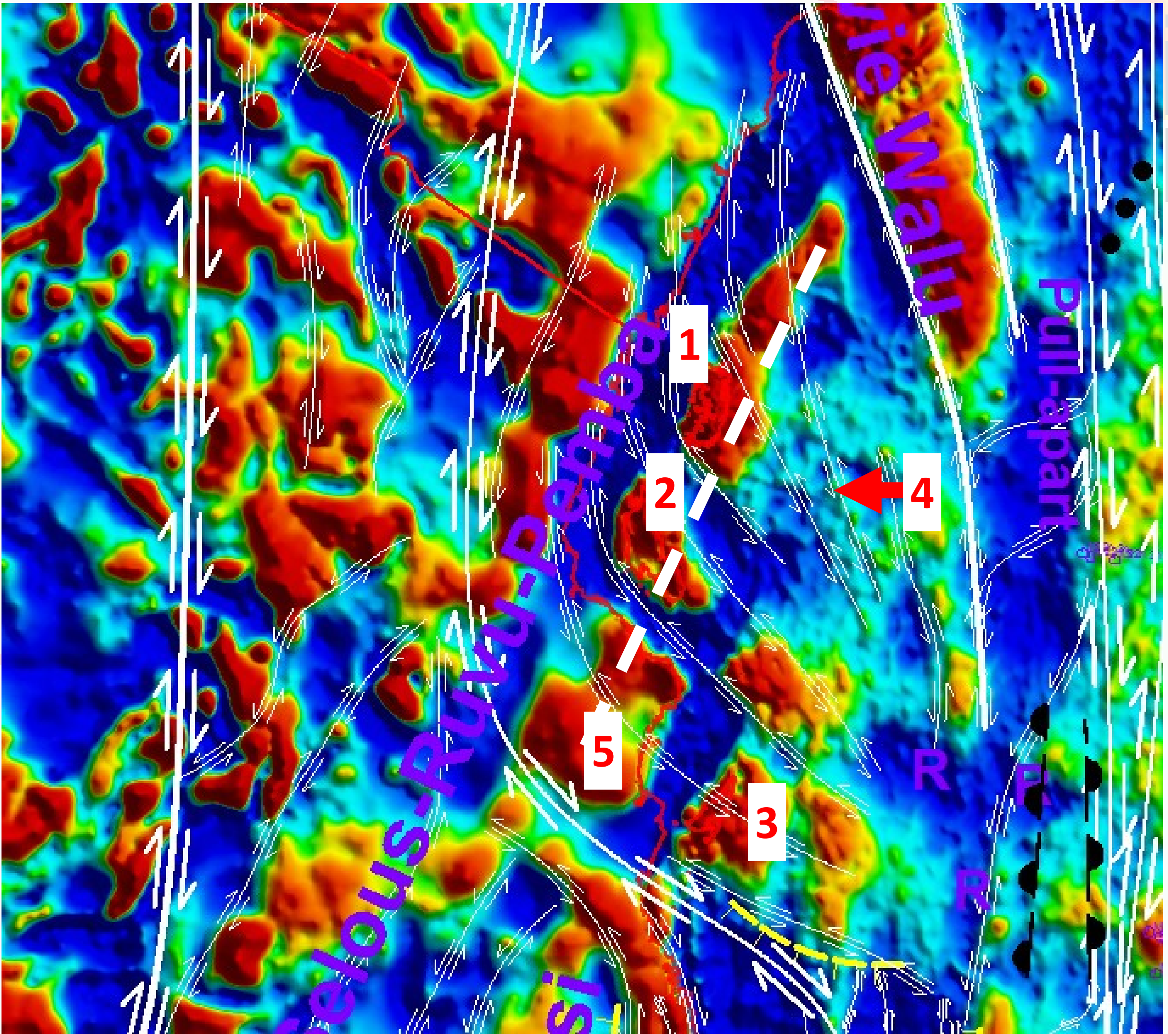
Below: Azanian western margin is found in Madagascar (**Fritz et al , 2013**):

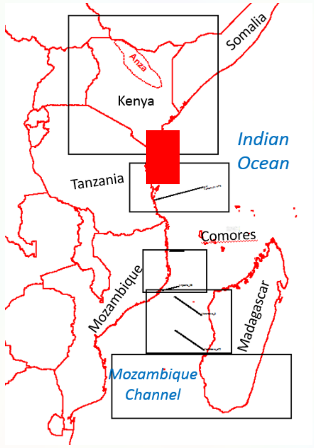


Mafia-Zanzibar-Pemba restraining bend

Compressional bend – 'horsetail splay', folding and synthetic sinistral strike slip faulting gives way to dextral extension east of Davie Walu Axis

Below: Decompensative gravity





1 Pemba High

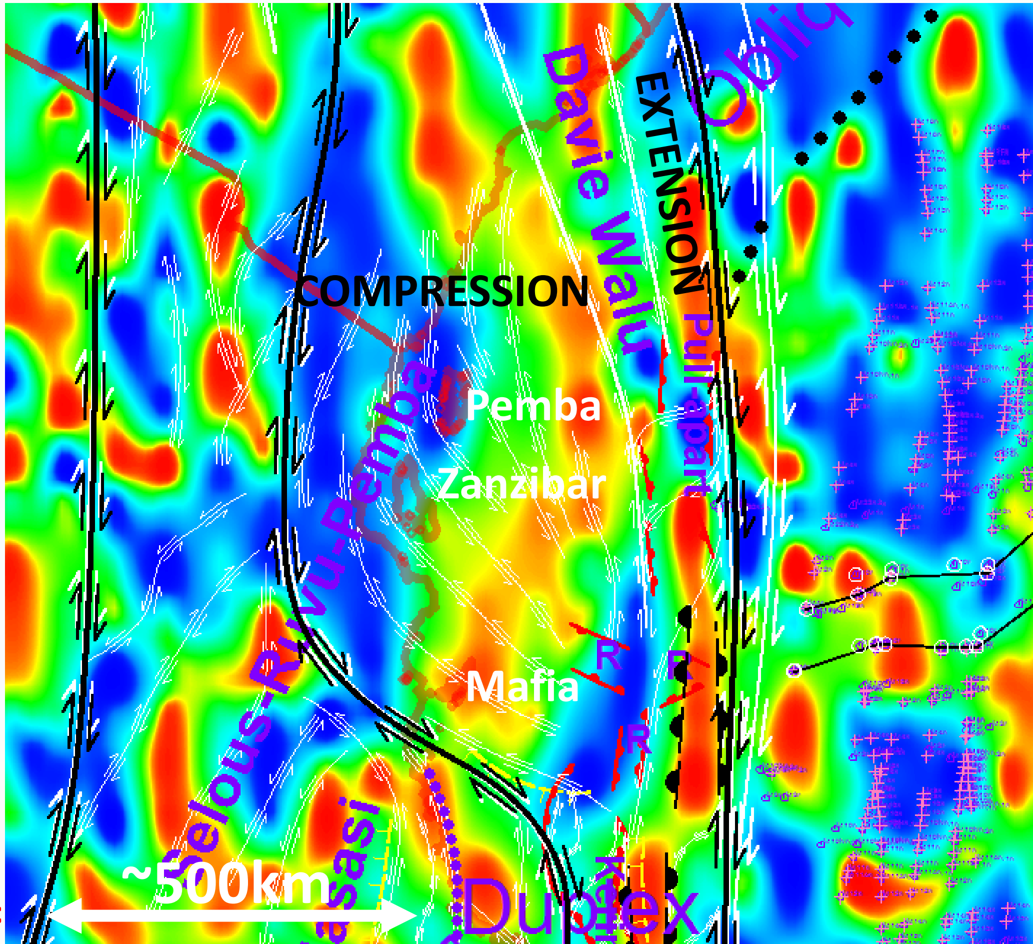
2 Zanzibar High

3 Mafia High

4 Synthetic strike slip faulting

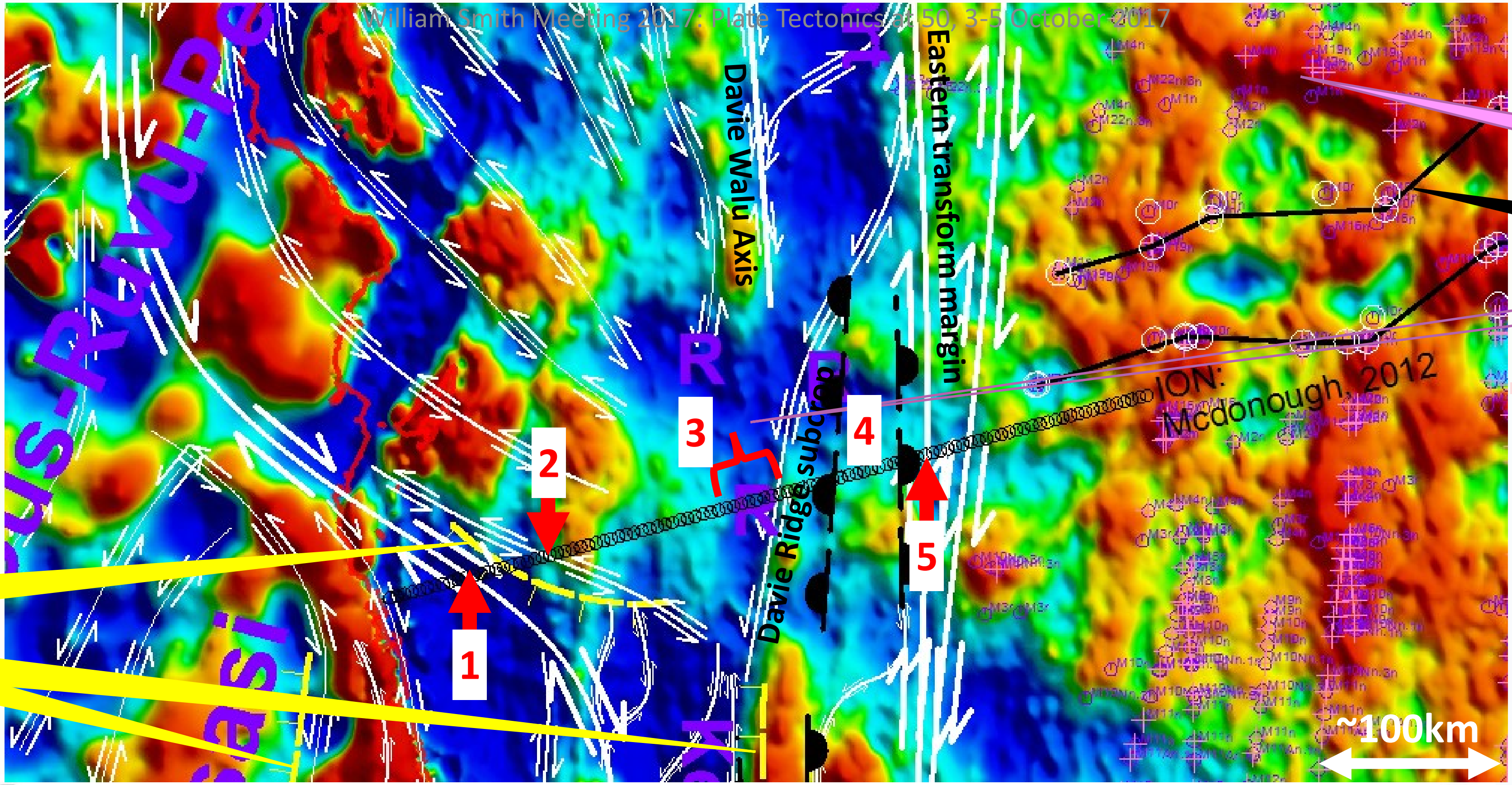
5 Oblique fold axis correlates with seismic

Below: IGRF corrected, reduced to pole magnetics



Offshore Tanzania, failed rifting and onset of early extensional duplexing

Tertiary EARS uplift

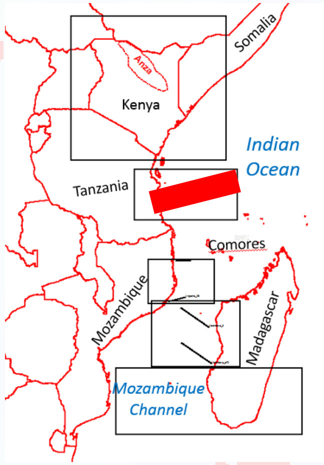


Left: Decompensative gravity

Published magnetic chron picks

Davis, 2016, M0 trace

Triple R failed aulacogen on M0 axis



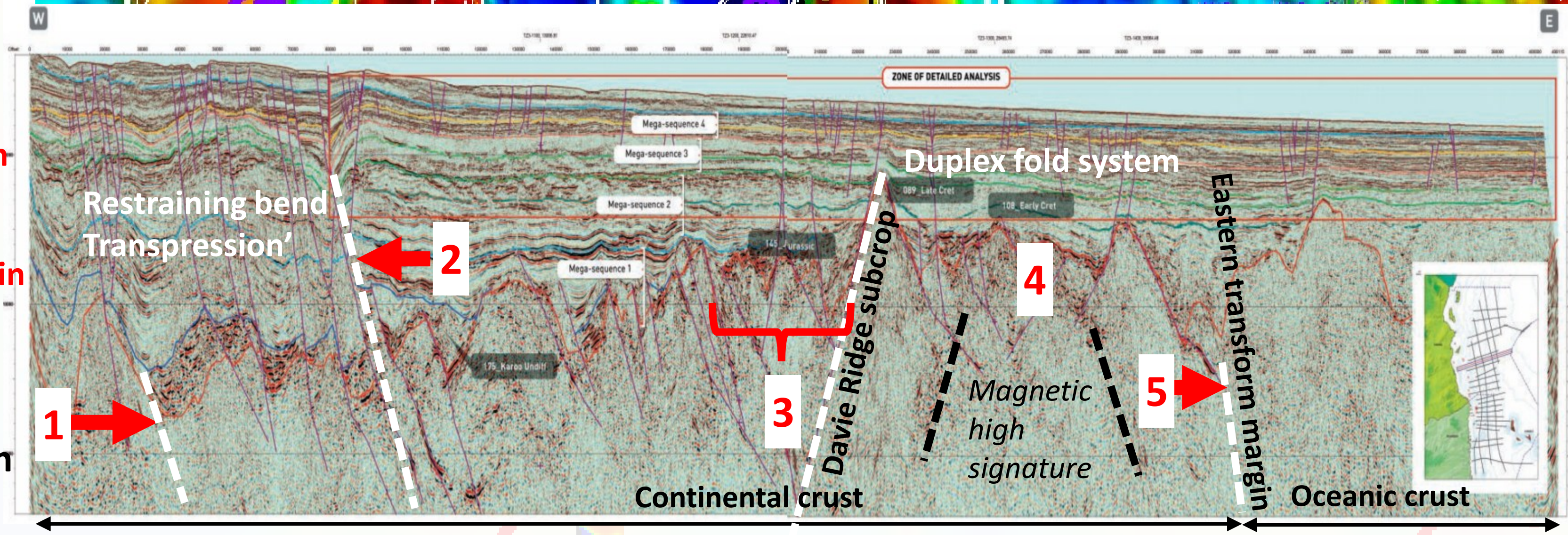
1 Transpression restraining fault

2 Transpression restraining fault

3 Failed triple R aulacogen

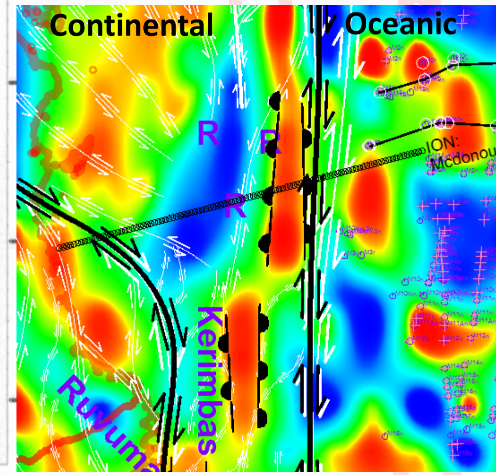
4 Outer high

5 Eastern Transform Margin

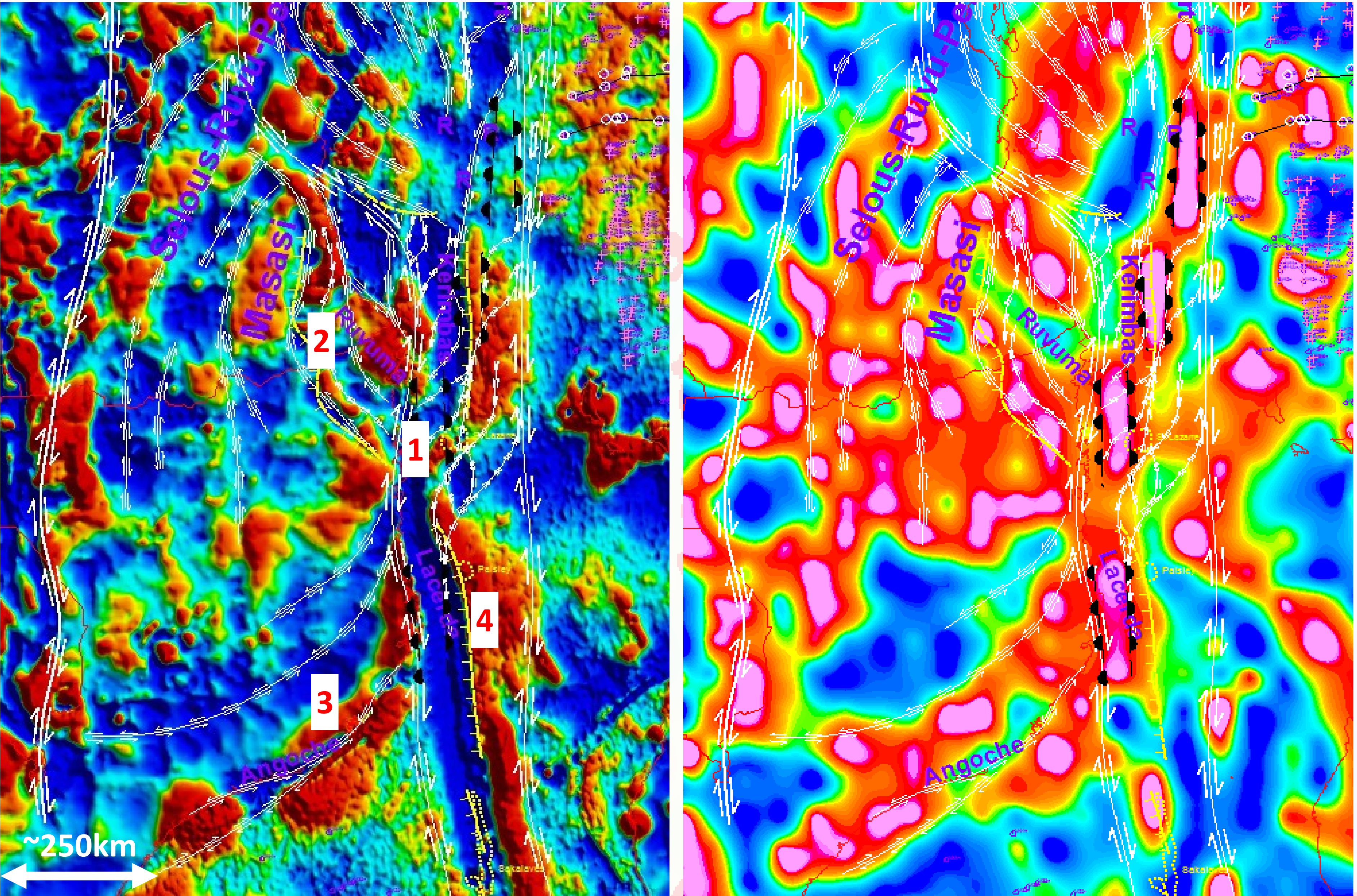


Right: ION line: *TZ3-2700 after* **McDonough et al, 2012**

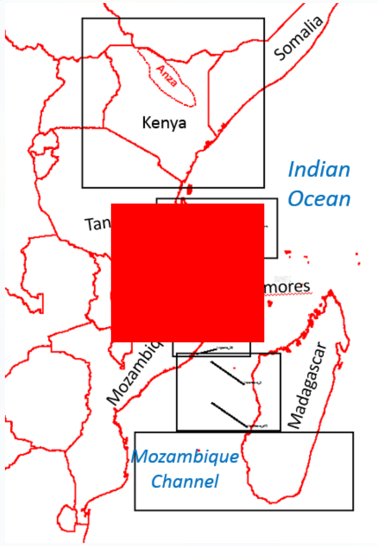
Below: IGRF corrected, reduced to pole magnetics



Kerimbas-Lacerda duplex to transtension



Left: Decompensative gravity
Right: EMM, IGRF corrected, reduced to pole



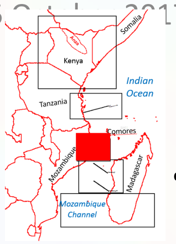
1 Southern onset of narrow transtensional zone

2 Rotation of Rovuma

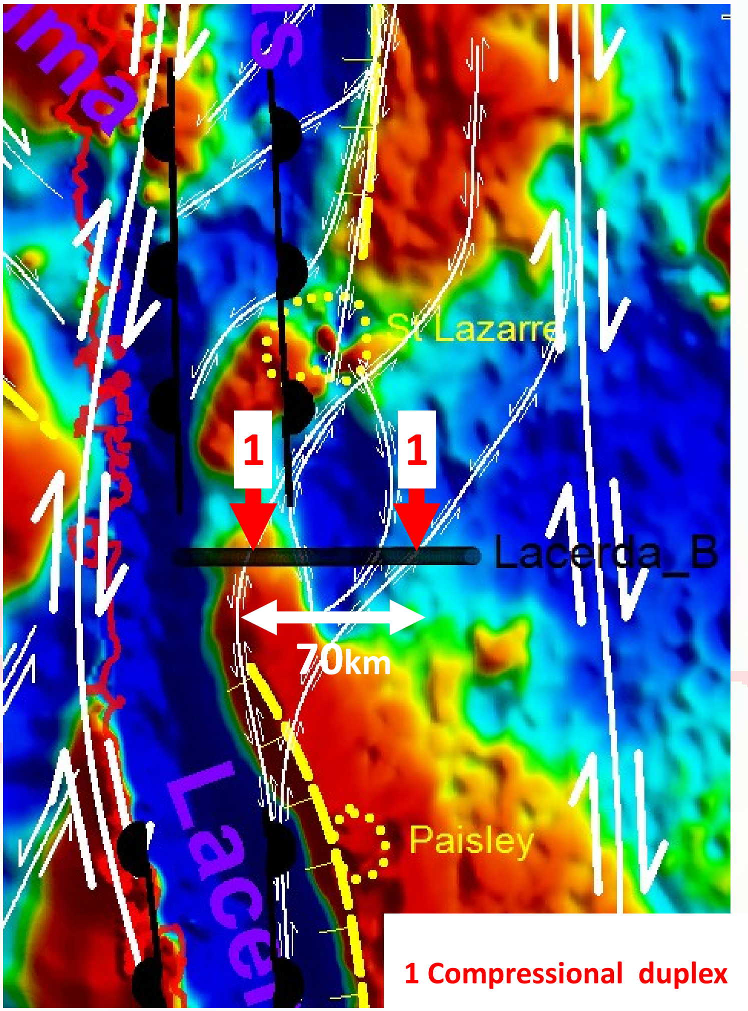
3 Angoche pull-apart, antithetic fault zone

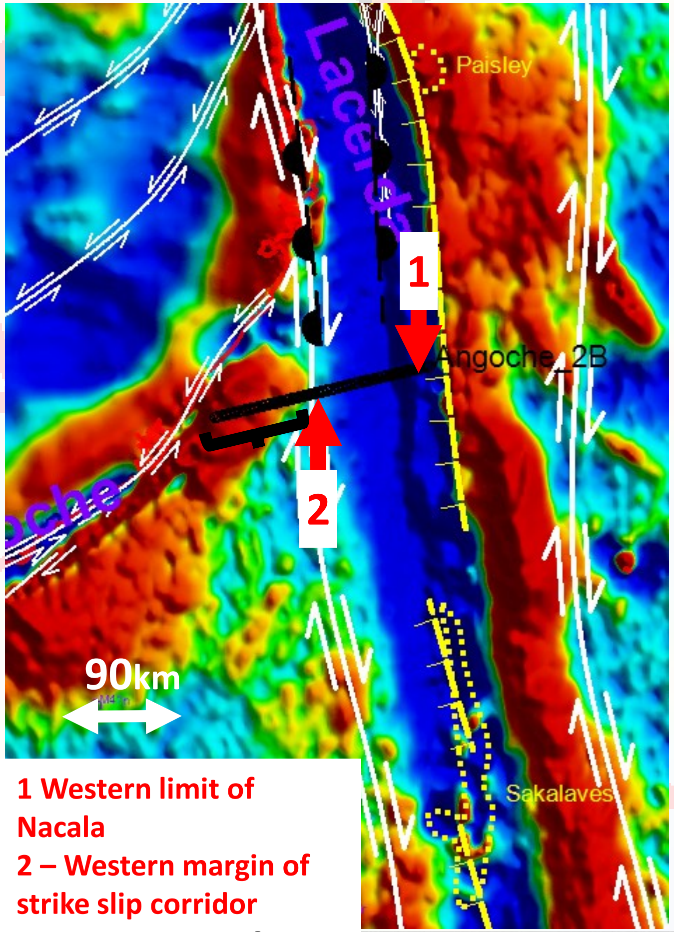
4 Offshore EARS overprint - easterly bound by deep basement blocks, form bathymetric ridges (yellow lineaments)

Lacerda-Angoche transtension + EARS



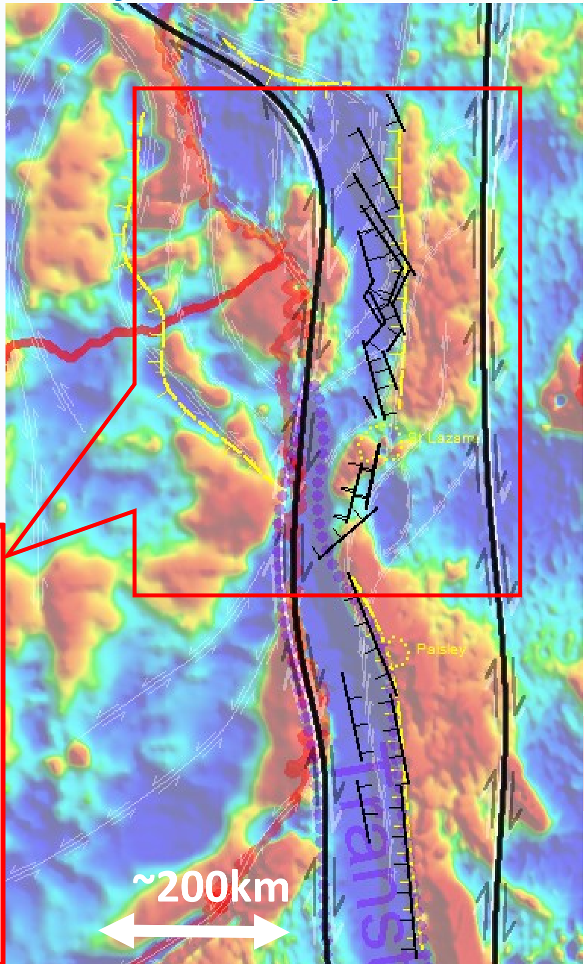
The strike slip corridor, in extension, narrows, and south of St Lazarre seamount transitions from the duplex system to a narrow, deep, extensional system, bound to the east by the tightly folded Davie Ridge.

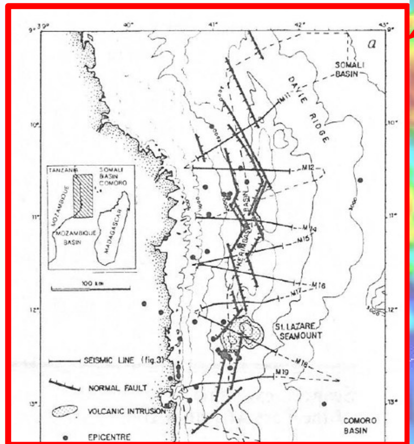


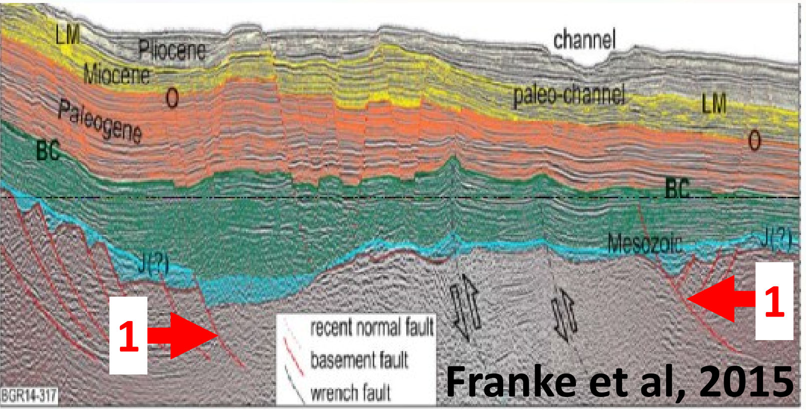


1 Western limit of Nacala
2 – Western margin of strike slip corridor

Right and below:
Mougenot et al, 1986 mapped en echelon synthetic Riedel shears, these are related to EARS propagation, as can be seen they straddle the bathymetric ridge

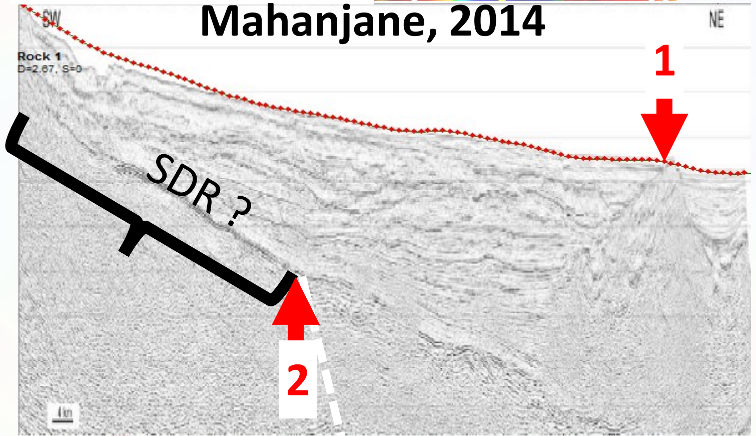




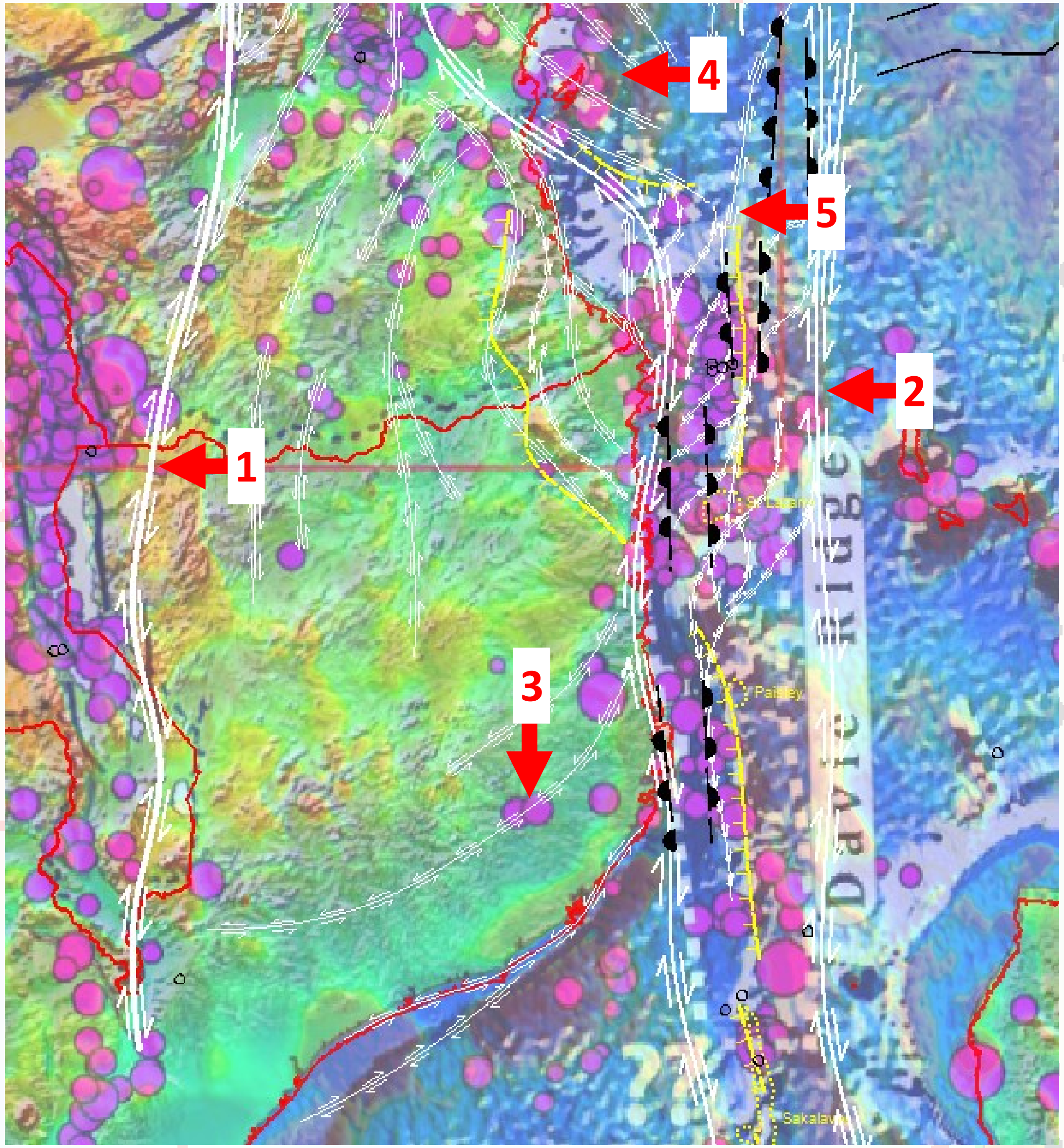


Franke et al, 2015

Mahanjane, 2014



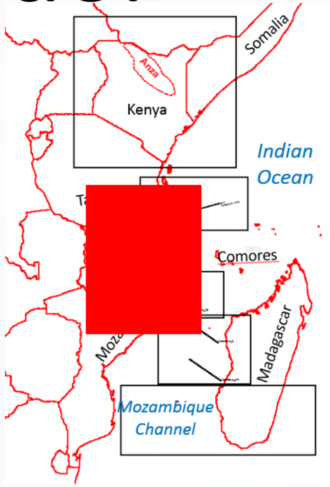
EARS and Seismicity locked by strike slip corridor



Modified after Mulibo et al, 2016

Left: Seismicity (Mulibo et al, 2016) over decompensative gravity

The transform margin and associated strike slip zones have influenced the development of later rift systems. Focal solutions for the seismicity support the strike slip fault configuration, *below right* (refer Mulibo et al, 2016) and indicate the transform margin is still active.



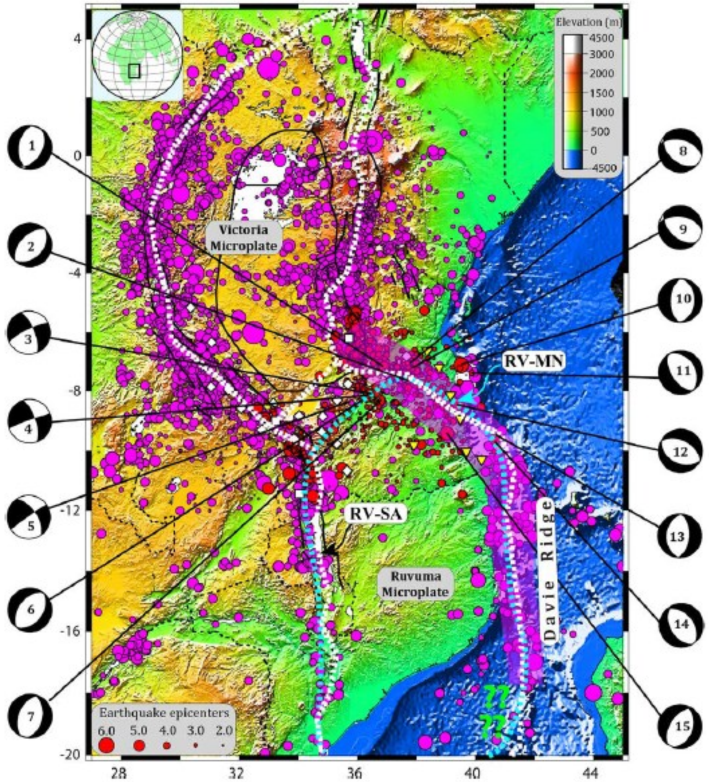
1 Western branch of East African Rift System, and associated seismicity, locked by western intraplate strike slip

2 Transform margin locks offshore EARS

3 Associated seismicity along Riedel antithetic fault

4 Seismicity associated with sinistral movement in zone of transpression

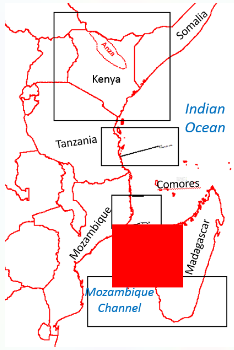
5 Present topographic ridges mark the northern extent of the offshore EARS

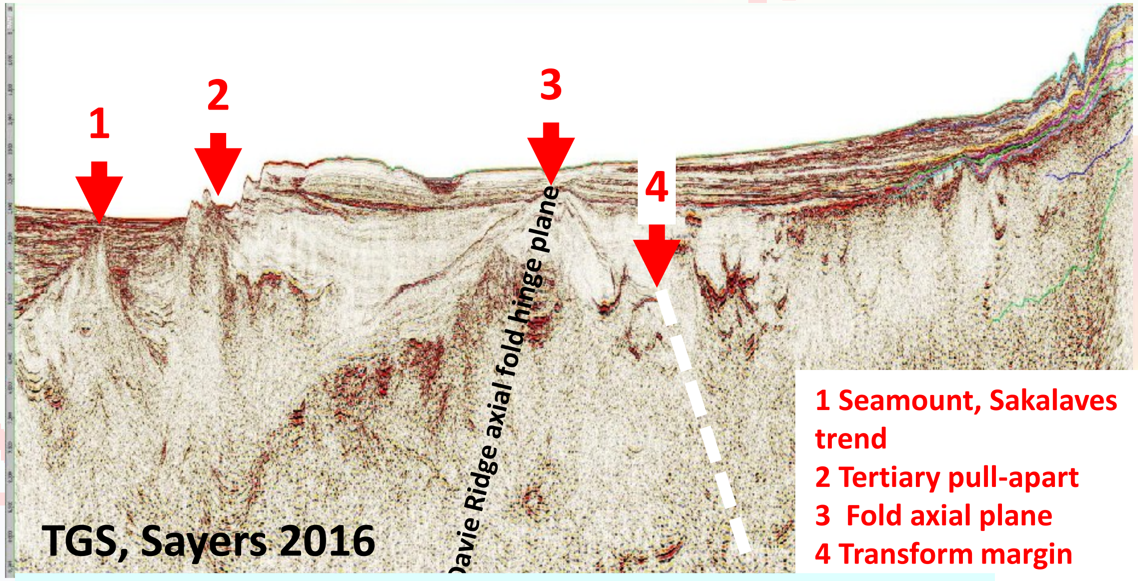


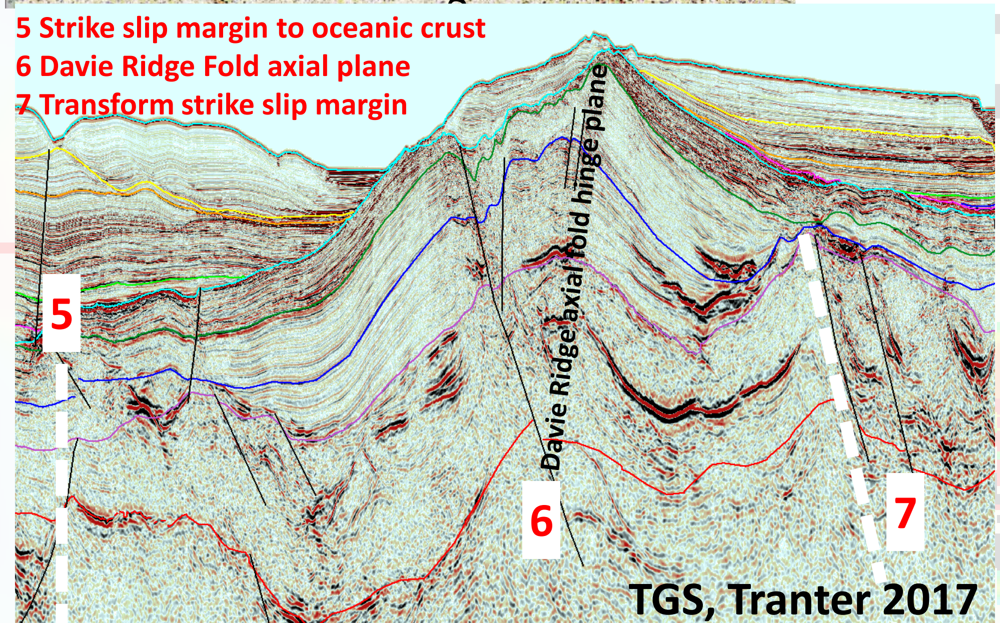
Mulibo et al, 2016

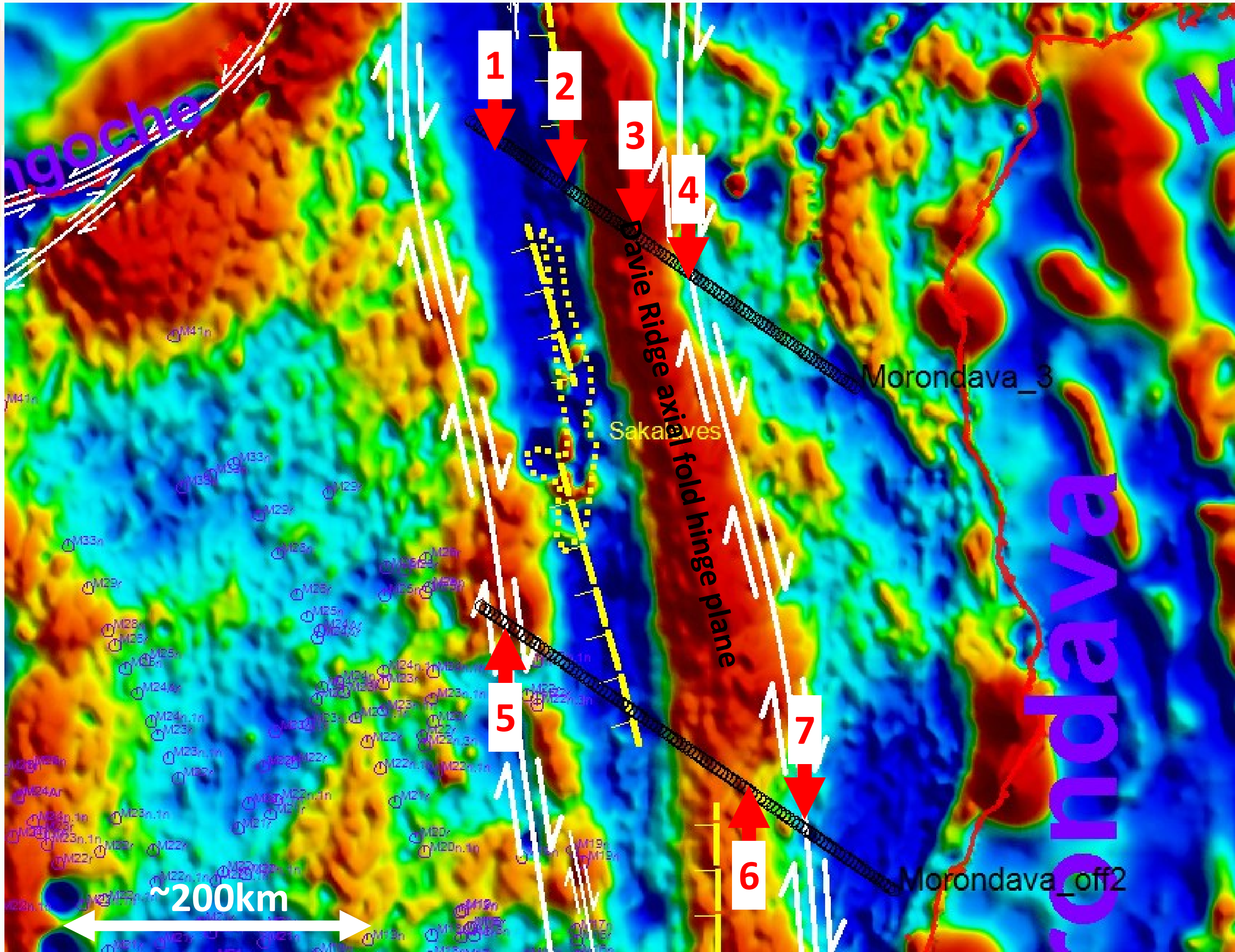
Morondava- compression

North of Sakalaves, the TGS line shows the major fold axis of the Davie Ridge, evidence of compressional strike slip reactivation, further south EARS related pull-apart deformation dissipates and the strike slip zone is clearly defined





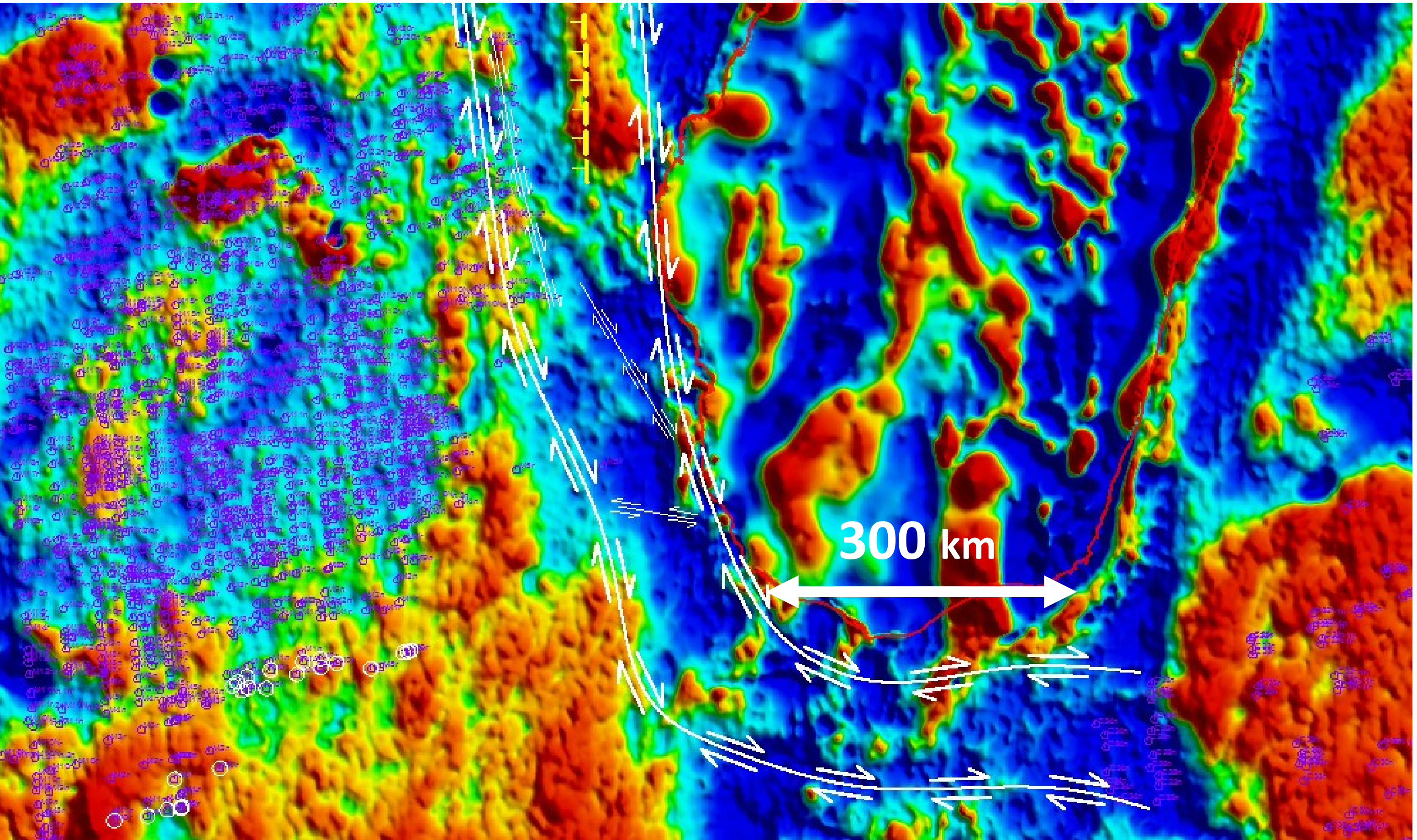


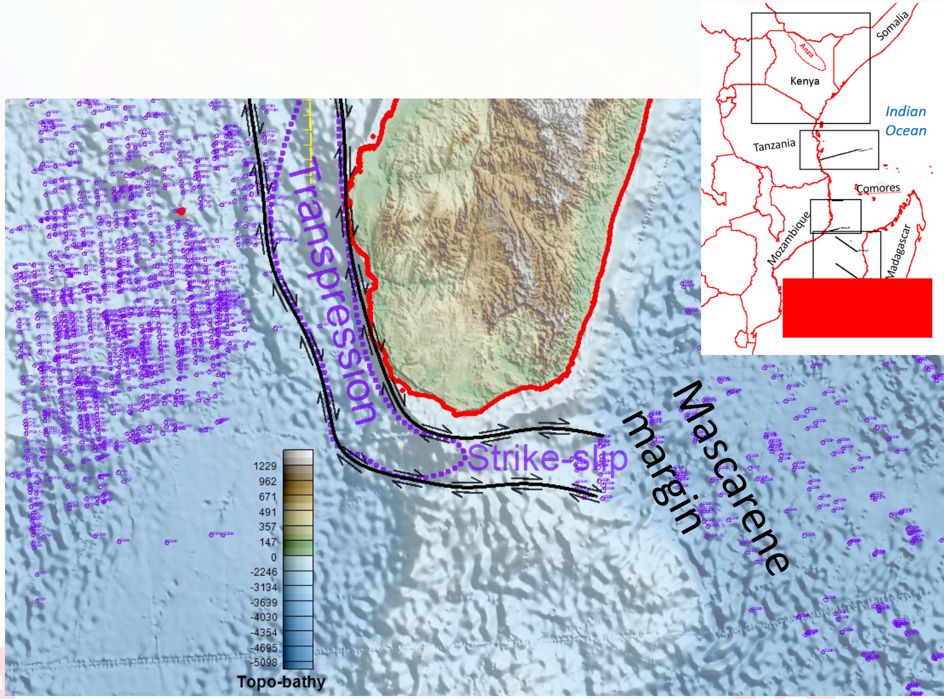


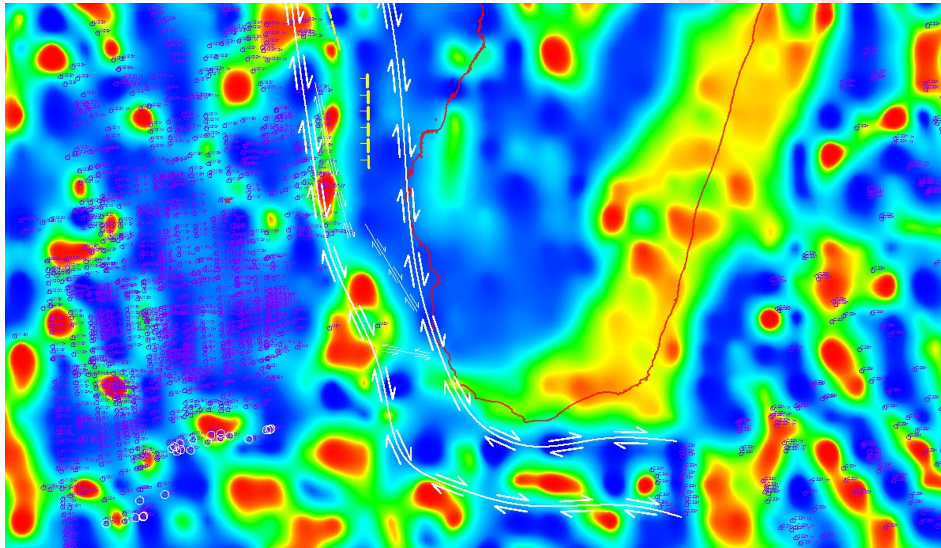
Cap St Marie – strike slip termination at Mascarene margin

The youngest part of the transform margin, diverts east south of Cap St Marie, termination in active strike slip, with associated margin uplift

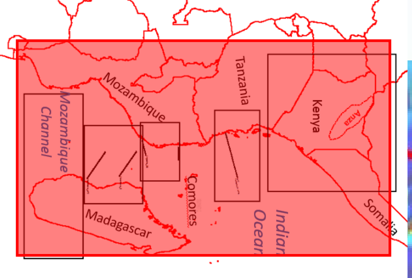
Below: Decompensative gravity, ***Above Right:*** SRTM topo-bathymetry ***Below Right***: EMM, IGRF corrected, reduced to pole

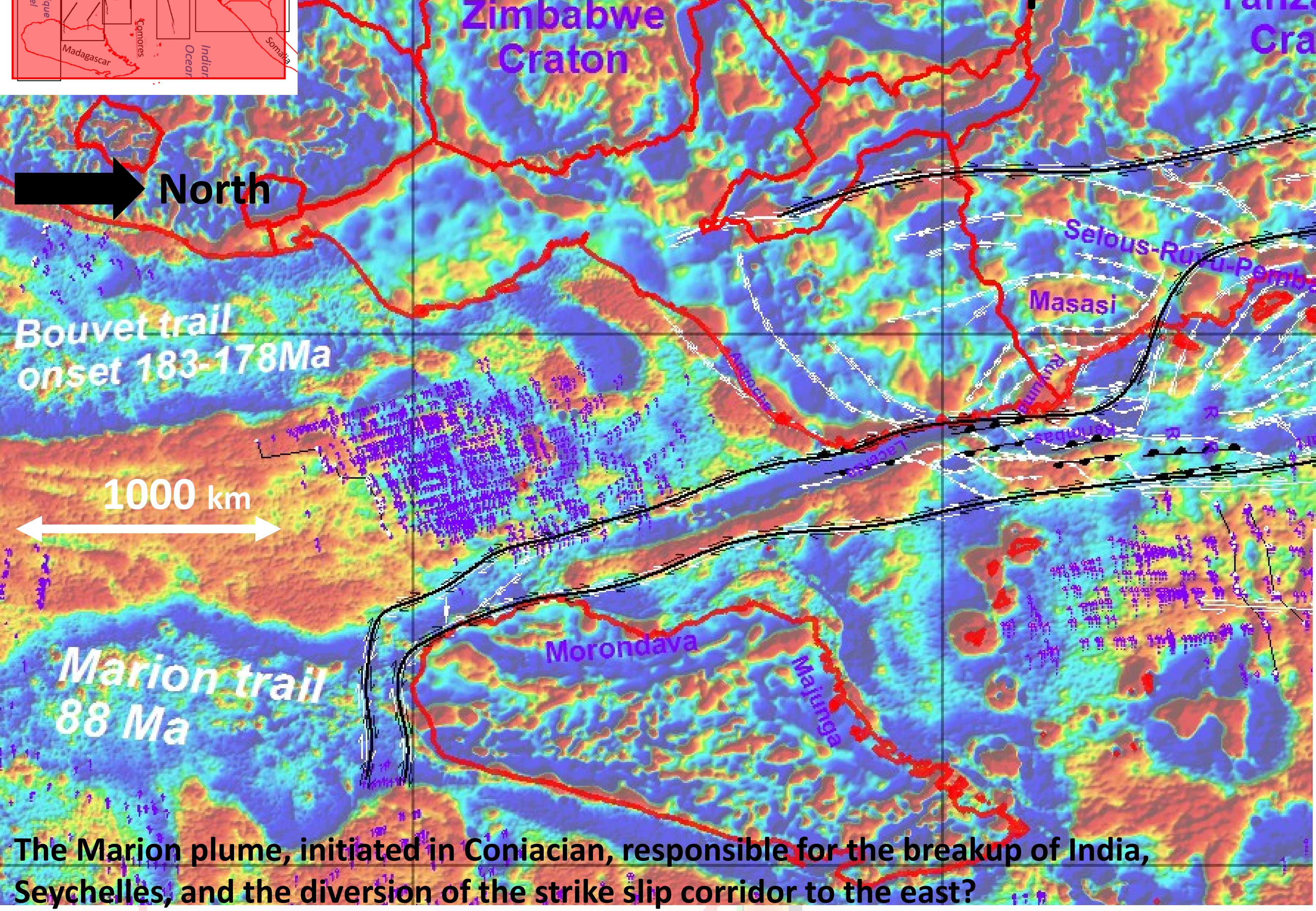


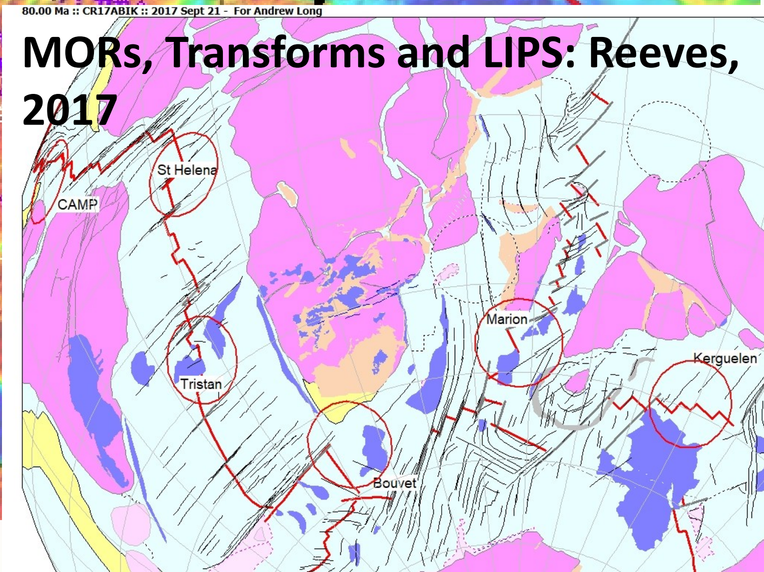




Influence of plumes







MORs, Transforms and LIPS: Reeves, 2017

The Marion plume, initiated in Coniacian, responsible for the breakup of India, Seychelles, and the diversion of the strike slip corridor to the east?

Conclusions

Correctly processed and derived potential fields data correlates to geological structure without the need to perform intricate modelling, providing a robust regionally consistent framework to examine and assess this reactivated transform margin.

A combination of residual gravity highlighting shallow crustal density variation, with residual magnetics highlighting deeper crustal magnetization serves to reveal real geological structure.

The transform margin has evolved from a Jurassic extensional dextral strike slip system into a sigmoidal complex system defined by many common structures associated with strike slip tectonics, spanning over 4,000km arcuate length. The margin propagated from as far north west as Anza, which is believed to overlie the original Neoproterozoic suture between West Gondwana cratonic centre and Azania, East Gondwana.

East African Transform Margin extends much further east into the Indian Ocean, this has important consequences for deepwater exploration of extractive resources. It's western margin is defined by the West Gondwana cratonic front, comprising the Zimbabwe, Tanzanian and Congo cratons.

Tertiary EARS offshore has been locked by the strike slip corridor, and modern seismicity indicates that fault movement is still active in several zones of the transform margin.

East Africa Transform Margin Geological Summary

Early (onset Carboniferous?) Karoo rifting

Early Jurassic **onset of Gondwana breakup**, **Lamu oblique rifting** accompanied by **propagation of transform margin development and shear**, inboard **compression and uplift**, outboard **extensional dextral strike slip transform**

Later, onset of **Somali basin spreading** (*outboard of margin*) and **aulacogen** (*failed rifting inboard of the margin*)

Early Cretaceous **compression, Davie Ridge uplift**, transpressional and duplex structures inboard Davie Ridge, associated volcanism

Late Cretaceous **Marion plume**, associated **volcanism** and **breakup of India**, **Seychelles**, (*diversion of transform?)*

Tertiary EARS localized **uplift** and **extension**. Late Tertiary reactivation of transform shear margin as compressional dextral strike slip

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