

# Strike slip tectonic controls on the East African Rift System

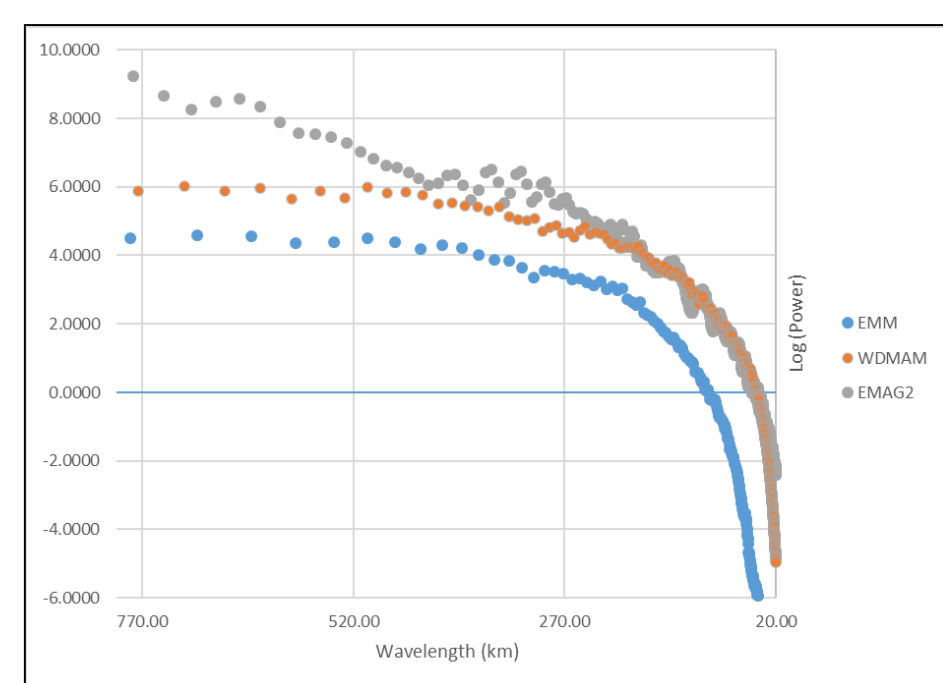
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## Introduction

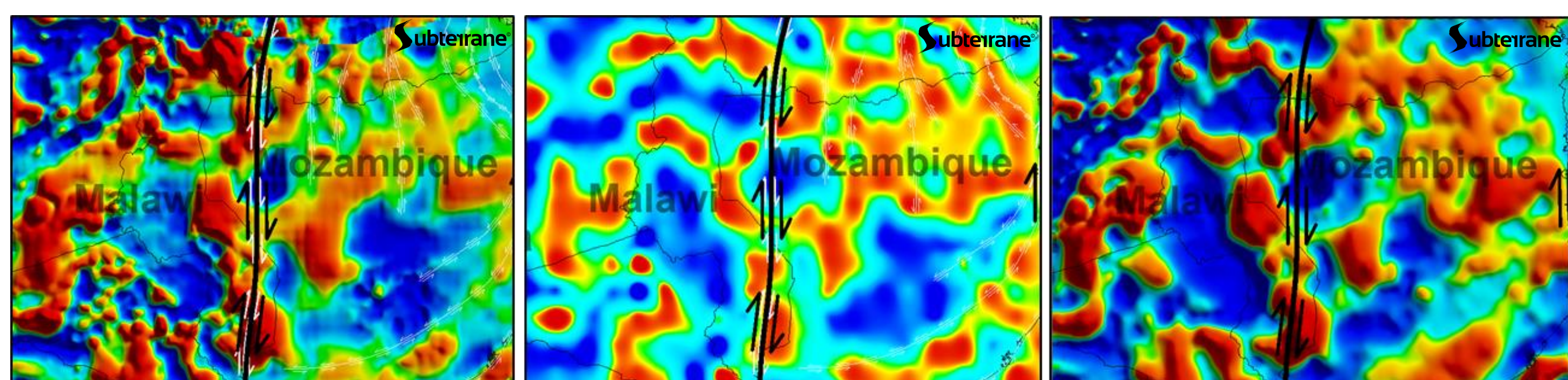
Evidence of major strike slip intraplate structure that bound the East African continental-oceanic margin (Long, 2017), opens the gateway to explore further regional strike slip structural controls that have spatially and temporally deformed the African continent through geological time. The oldest known rifting phase dated Permian to Triassic ('Karoo') preceded the early Jurassic breakup of Gondwana. The onset of Jurassic rifting was accompanied by the initiation of the Bouvet Plume and associated volcanism along the axis of the Lebombo monocline. The late Jurassic rifting and extension offshore East Africa is associated with an almost orthogonal stress field to that of Karoo rifting. The Cretaceous rifting is defined by yet another change in the regional stress field. It is demonstrated how strike slip tectonics has influenced the development of rifts across the East African Margin up to the onset of onshore Tertiary East African Rifting. Further examples of significant intraplate faults have since been discovered, (e.g. Carjaval-Arenas and Mann, 2018), this work, and recently a new unifying tectonics and plume hypothesis has been developed (Long (3), 2018), based on mapped strike slip systems controlling the rift phases since Gondwana's accretion in the NeoProterozoic era, and other plate evolutions across the world.

## Method

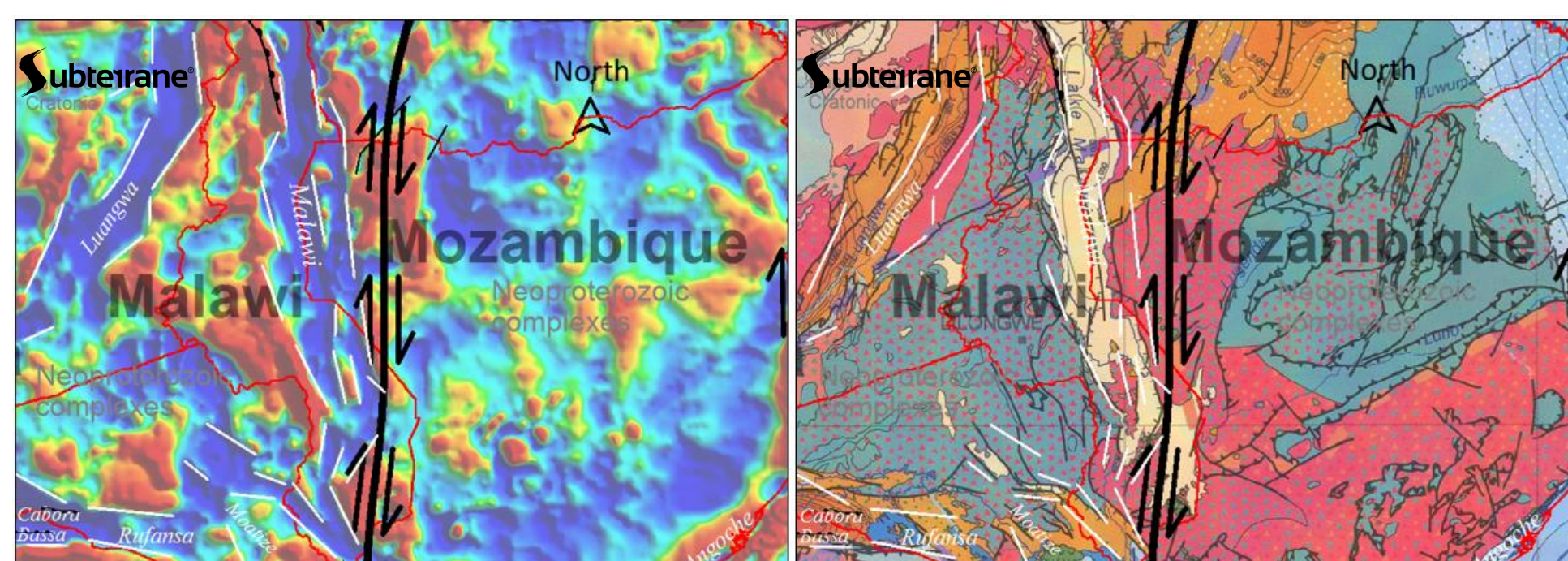
High resolution, shallow residual gravity and low resolution magnetics has previously been demonstrated to provide a correlative basis for interpreting regional geological structure (Long and Cameron 2016, Long, 2017, Long 2018 (1), (2) and (3)). **Figure 1** shows a comparison of the relevant 1D spectra for different magnetic datasets available over the East African margin. Clearly the coherence of the Enhanced Magnetic Model (EMM) at wavelengths greater than 56km is better than EMAG2 version 3, as demonstrated by the smooth curve of the profile. Furthermore, the variable energy at short wavelengths evident in the EMAG2 profile are testament to the interpolation of shiptrack profile lines over 10s to 100s kms and presented at 2 arc minute resolution (approximately 4km). Noise in 1D power spectra are indicative of low signal to noise ratio and insufficient sampling. One key difference between the EMM 2015, and the EMAG2 v3 is their method of construction. Both the EMM and EMAG2 are constrained by various satellite, shipborne and airborne magnetic observations, however the EMM is constructed using spherical harmonic expansion, versus the EMAG2 which is interpolated via a kriging algorithm. Onshore, there is good correlation between satellite magnetics due to reasonable survey coverage to constrain the magnetic models, refer **Figure 2 (top)**. However offshore, in regions of sparse shiptrack data, the models differ owing to the low signal to noise at wavelengths less than 56km. For further discussion, refer Long, 2018 (1). **Figure 2 (bottom)** shows the equivalent residual gravity and geological bedrock from Milesi et al (2010).



**Figure 1:** 1D power spectrum comparison of East African satellite magnetic datasets: EMM, Enhanced Magnetic Model 2015 (used in this study), WOMAM, World Digital Magnetic Anomaly Map (Quesnel et al, 2009), EMAG2 version 3 (Meyer et al, 2017).

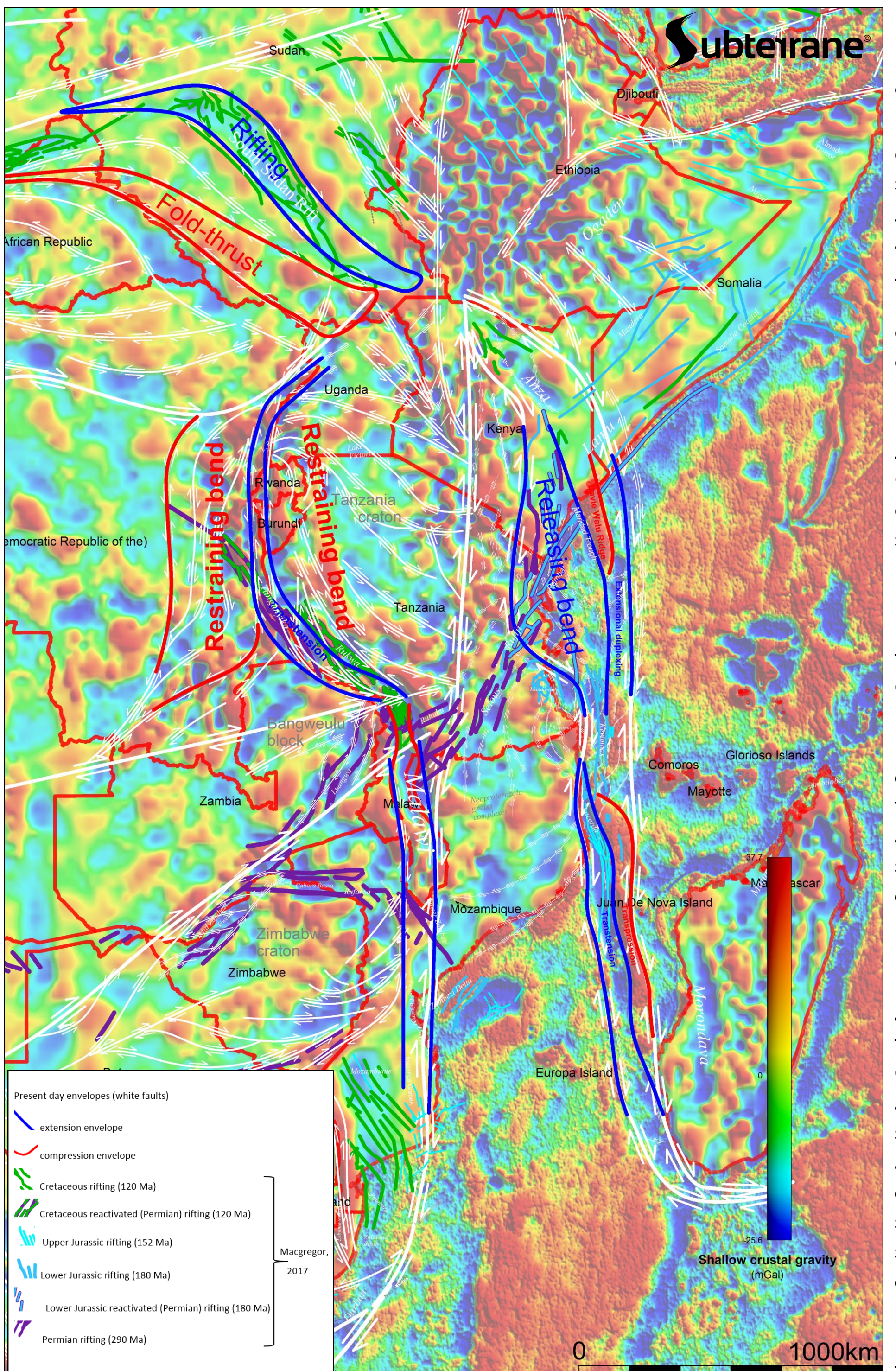


**Figure 2. (top)** Onshore comparison of satellite magnetics (residual, reduced to pole) along the border of Malawi and Mozambique between the EMAG2 version 3 (Meyer et al, 2017), (left), EMM, Enhanced Magnetic Model 2015 (Chulliat et al, 2015) (centre) and WOMAM, World Digital Magnetic Anomaly Map (Quesnel et al, 2009) (right). Note the correlation of the Caborra Bassa trough (south west corner), and reworked Neoproterozoic deformed basement east and west of the western bounding strike slip fault of the East African transform margin (black).



**Figure 2. (bottom)** shallow crustal residual gravity with Karoo and EARS rift trends mapped on edge of accompanying gravity troughs bound at depth to the western margin of strike slip corridor (left), refer figure 3 in Pavlis et al, 2012 for gravity measurement control on EGM2008. Right: Tectonic map of Africa, CGMW, Milesi et al 2010.

Shallow strike slip fault structure has much deeper linkage to mantle structure, as demonstrated by Teyssier and Tikoff, 1998; they are transferred from deeper shear structure within the mantle. Storti et al, 2003, later expanded this to infer the influence of strike slip tectonics in regions of convergent and divergent plate margins. Utilizing shallow residual gravity derived from satellite gravity (Sandwell et al, 2014 and Grace data, Tapley et al, 2005) and long wavelength satellite magnetics derived from the Enhanced Magnetic Model (Chulliat et al, 2015), EMAG2 v3 (Meyer et al, 2017) and WDMAM (Quesnel et al, 2009), together with bedrock geology (Milesi et al, 2010) we demonstrate the control of strike slip tectonism on the development of the East African Rift System, and earlier rift phases.

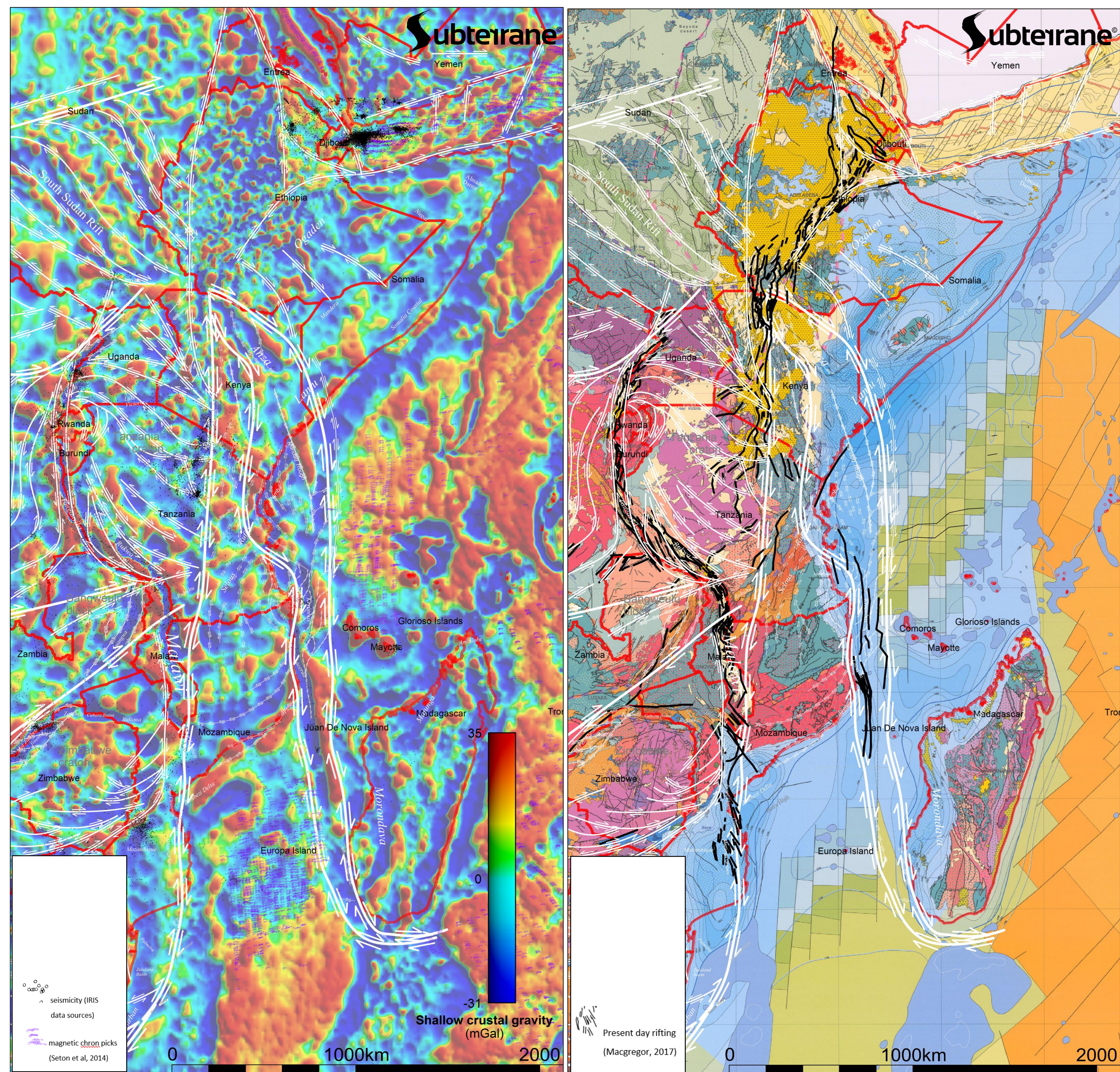


**Figure 3.** Shallow crustal residual gravity derived from Grace et al, 2005 and Sandwell et al, 2014 with faults (Subterrane ongoing research 2018) and coloured faults from MacGregor, 2017.

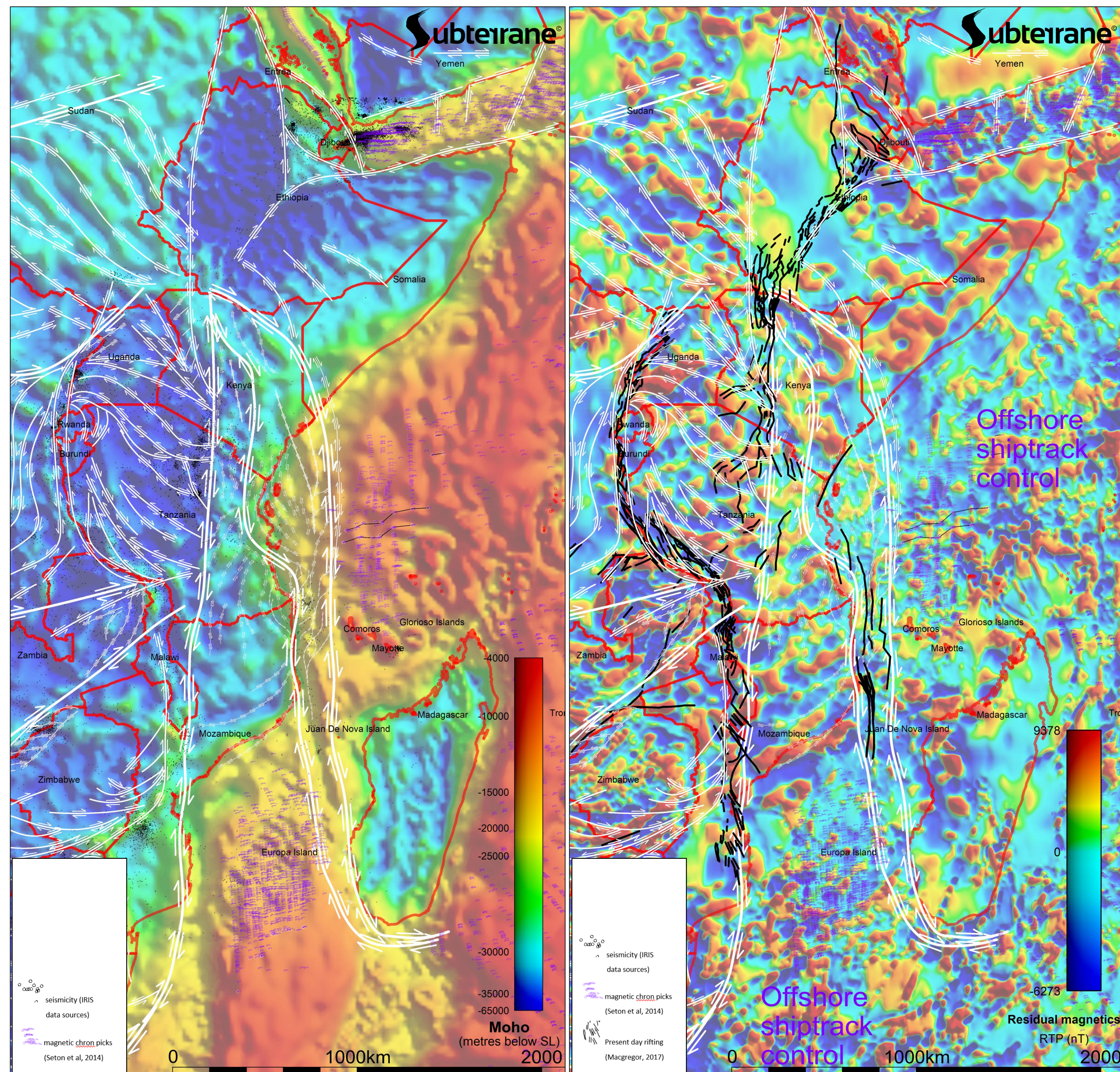
The older north east striking Karoo rift trend (purple faults, MacGregor 2017) indicated from the seismic fault compilation is seen to still be active today (figures 4 and 5). It is postulated the compressional Davie Walu structure formed coevally to the oblique rifted margin of offshore Lamu. The axial fold plane defined by the Pemba-Zanzibar island has subsequently been reactivated in the releasing bend of the intraplate strike slip system defined by Long 2018 (2). Further south we see reactivation of the Jurassic transtensional Lacerda graben (figure 3) in present day rift structure (figures 4 and 5), and how this is bound within the strike slip corridor defining the Davie Transform Margin.

## Coeval extension and compression

Recent research has shown evidence of coeval compressional and extensional structures in the northern Norwegian Atlantic margin ((Kristensen et al, 2018), and the region of Abu Dhabi, (Sirat et al 2016) for example. When we observe the present day structure of East Africa, we can use a variety of dating methods to constrain initial fault propagation, and reactivation to unravel the four major rifting episodes that have deformed Africa since the consolidation of Gondwana in the Neoproterozoic Era. By correlating the present day enveloping strike slip faults mapped from gravity/magnetics to the rift phases mapped by MacGregor, 2017, it is possible to unravel how the structures have developed through the Palaeozoic, Mesozoic and Cenozoic eras. Woodcock and Fischer, 1986 introduced strike slip duplexes and how compressional and extensional duplexes form thrusts and normal dip-slip faults respectively. They noted how these are best imaged in map rather than section view. In figure 3 (left) present day strike slip envelopes in the north indicate the Cretaceous rift has remained relatively undeformed since its initial propagation following easterly Late Jurassic extension in Ethiopia (152 Ma faults, MacGregor 2017). The Cretaceous rift is an excellent example of an extensional duplex segment. Further south Karoo rifting between the Congo and Tanzanian cratons were reactivated during Cretaceous rifting, and subsequently again in the Tertiary as seen in Figures 4 and 5. The present day configuration shows how the Tertiary rift major bounding faults have reactivated compressional duplexes to the west and east of the western branch of EARS, in a deformed Neoproterozoic belt, and the Tanzanian craton, respectively.



**Figure 4:** Left, residual gravity (1 degree Subterrane shallow crustal gravity product 2018 derived from Sandwell et al, 2018) with present day seismicity (IRIS data sources), marine magnetic chron picks (Seton et al 2014), and present day strike slip structure (faults, from Long, 2017, sigmoids after Long 2018 (3)). Right: CGMW Bedrock geology (Milesi et al 2010) with present day (0 Ma) faults from MacGregor, 2017.



**Figure 5:** left, gravity derived Moho (Subterrane) with present day seismicity (IRIS seismicity), marine magnetic chron picks (Seton et al 2014), and present day strike slip structure (sigmoids after Long 2018 (3)). Right: residual magnetics, reduced to pole (Quesnel et al, 2009) with present day (0 Ma) faults from MacGregor, 2017.

## Onshore Tertiary East African Rifting and offshore fault reactivation

Figures 4 and 5 show an overview of the present day regional structure combined with MacGregor's 2017 regional fault compilation set for 0 Ma (present day), utilizing a variety of gravity, magnetic, geological and a Moho base. Offshore, present day faulting is related to the Tertiary onset of reactivation of the intraplate strike slip system that propagated the Jurassic breakup of Madagascar as previously presented (Long, 2017, 2018(2)). Onshore the eastern branch of the E.A.R.S. is bound by the confines of the western and central bounding dextral faults of this reactivated Jurassic system, whereas the western branch of the East African Rift System is constrained by narrow transtensional rift channels utilizing weaker crust between the Tanzanian craton, Bangweulu Block and Congolese Neoproterozoic crust.

To the north, the Cretaceous Pan-African rift system is truncated to the west of Sudan by the north-south striking fault bounding Tertiary EARS flood basalts and EARS propagation along a NE striking fault. Offshore in the Indian Ocean, seismicity is related to Tertiary reactivation of faults within the strike slip corridor that straddles offshore Mozambique and Tanzania. Both the Turkana and Malawi rifts have developed within the constraint of a western bounding strike slip fault, that propagated between Precambrian cratonic regions, utilizing weaker Neoproterozoic crust, initiated in early Jurassic times. It is further observed the older Permo-Triassic rifting axis, has been broadly deformed by right lateral shear onshore Tanzania, and correlates to offsets seen between the western Luangwa Karoo rift, and eastern Selous and Ruhuhu rifts.

Further south, the EARS corridor narrows an echelon from Lake Malawi into southern Mozambique bound by the Zimbabwe craton to the west, and the major bounding fault of the intraplate system to the east adjacent to northern Mozambique NeoProterozoic terrain.

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