Active deformation of Malawi Rift's North Basin hinge zone modulated by reactivation of Precambrian shear zone fabric

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BACKGROUND

- The magma-poor Cenozoic Malawi Rift constitutes the southern segment of the Western Branch of the East African Rift System (Fig. 1A), where the eastward motion of the Rovuma Plate away from the Nubian Plate is being accommodated by tectonic extension.
- Malawi Rift largely consists of distinct half-grabens (Fig. 1B) bordered by major faults on one side and en echelon intrabasin faults on tilted hanging-wall blocks. The half grabens switch polarity along strike of the rift.
- Recent seismicity within the Malawi Rift (e.g. 2009 Karonga earthquake swarm) occurred in the North Basin half graben located at the northernmost part of the rift (Fig. 1C-D).
- The M_w6.0 2009 Karonga earthquake swarm affected the Karonga area which is the shoaling side (hinge zone) of the North Basin. The event resulted in destruction of >2000 buildings, several injuries and fatalities.
- The Karonga area is underlain by sheared granites and gneisses of the Precambrian Mughese Shear Zone (MSZ), overlain by Mesozoic and Cenozoic rift sediments (Fig. 1C).
- In this study, we investigate the role of pre-existing Precambrian structures in modulating (1) strain accommodation and active breaking-up of the hinge zone of the basin, and (2) subsequent ruptures leading to moderate-sized seismic events within the rift.

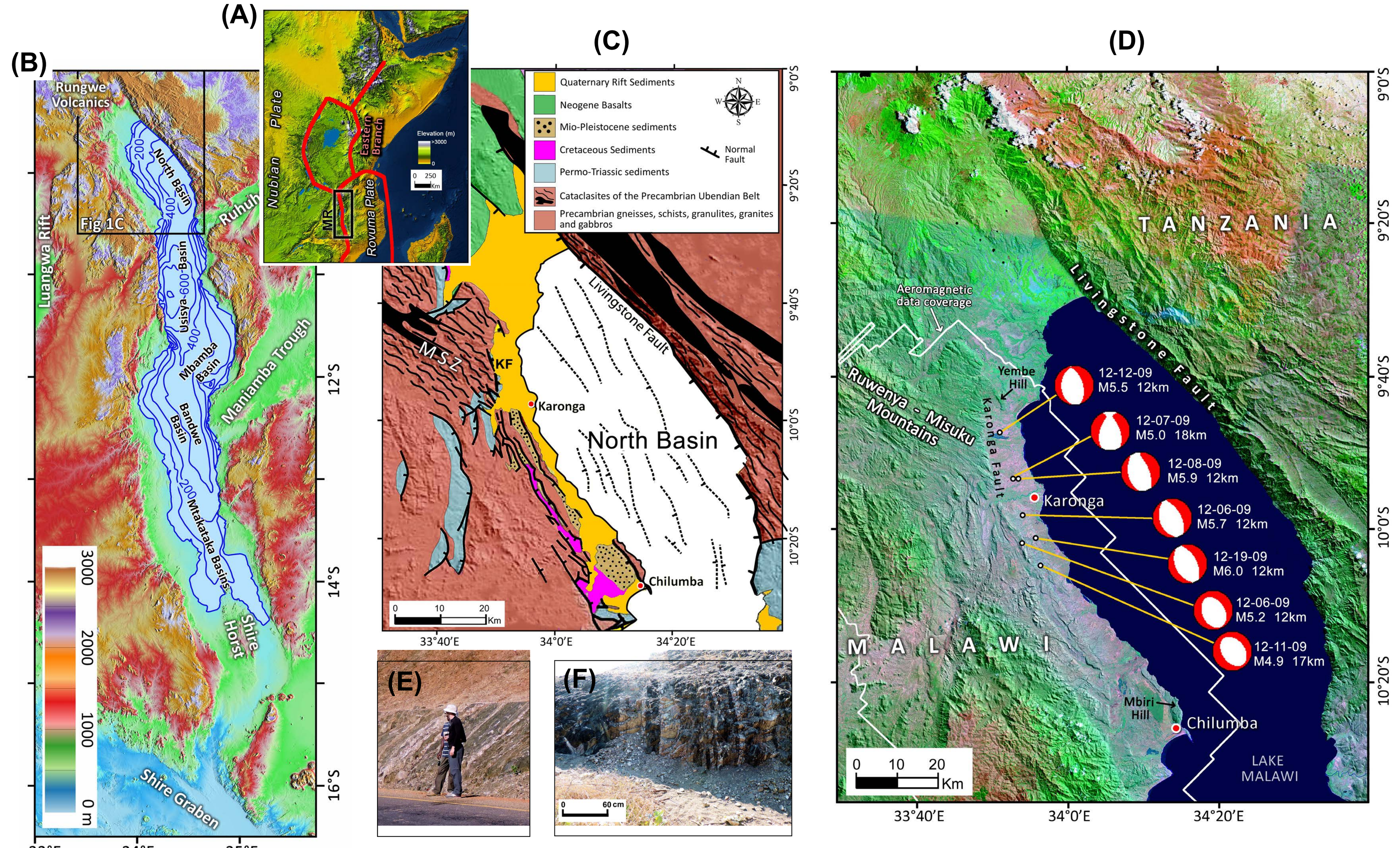

Fig. 1 (A) Location of the Malawi Rift within the East African Rift System. **(B)** SRTM DEM of Malawi Rift, showing the different segments along the rift. **(C)** Geological map of the North Basin, Malawi Rift modified after [1]. KF = Karonga Fault, MSZ = Mughese Shear Zone. **(D)** Landsat TM image draped over SRTM-DEM of northern Malawi showing major rift-related morphotectonic features and location of focal plane solutions and depths of $M_w \geq 4.9$ earthquakes associated with the December 2009 Karonga earthquake swarm from Global Centroid Moment Tensor database. White polygon represents the area covered by aeromagnetic data in Figure 2. **(E - F)** Photographs of outcrops of MSZ southwest of Karonga town.

ACKNOWLEDGEMENTS

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DATA AND METHODOLOGY

- **High resolution pre- (1985) and post- (2013) earthquake aeromagnetic data** (for mapping basement structures).

1985 data- 120 m flight elevation along NE–SW lines with 1 km spacing; 10 km tie-line spacing.

2013 data- 80 m flight elevation along NE–SW lines with 250 m spacing; NW–SE tie lines with 5 km spacing.

* Processed with Oasis Montaj© to produce derivative filtered maps.

* Applied derivative filters (Dx, Dy, Dz and tilt) to the reduced to pole (RTP) aeromagnetic grid.

- **Surface rupture locations** were obtained from [2] and [3].
- **Earthquake Epicenter locations** were obtained from the Geological Survey of Malawi.

RESULTS

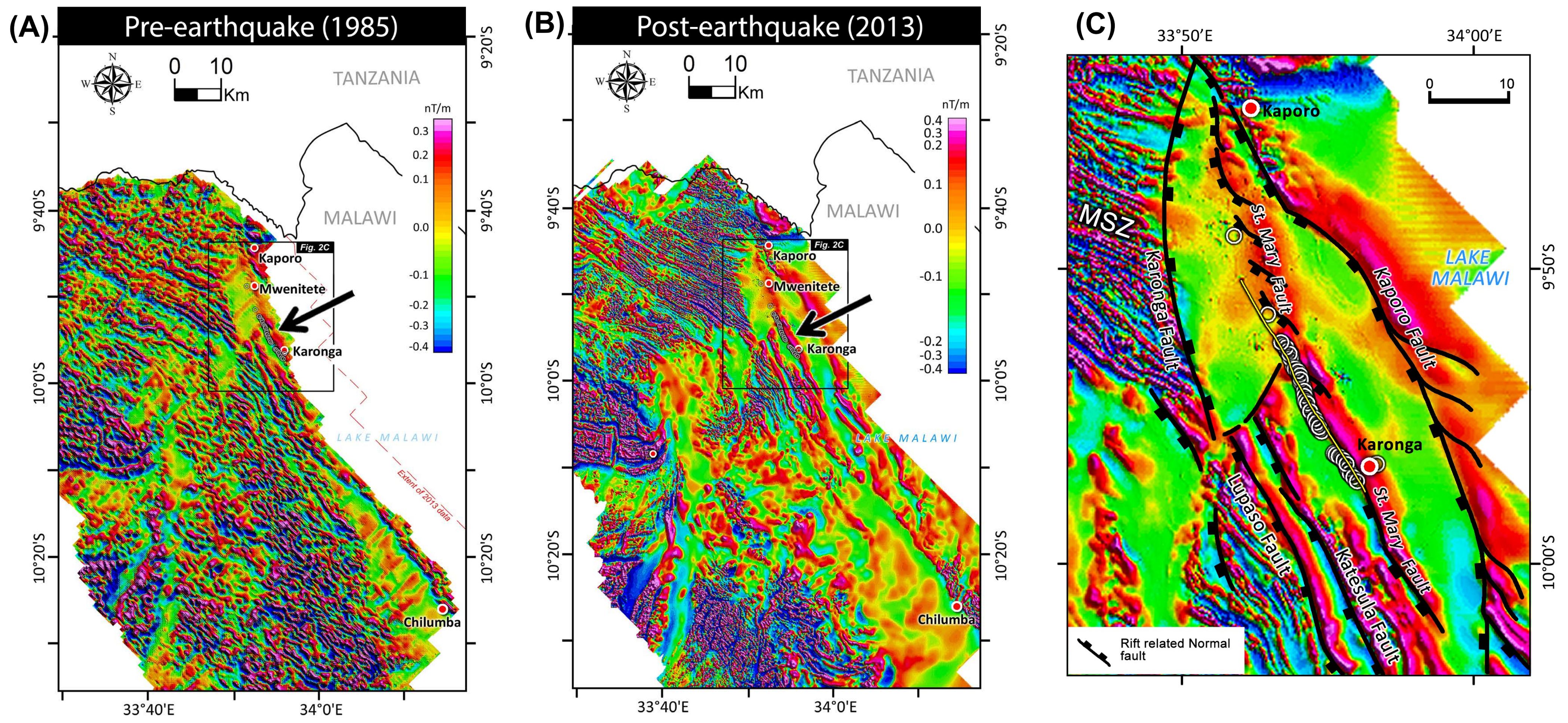

Fig. 2 (A-B) First vertical derivatives (Dz) of the RTP pre– and post– earthquake aeromagnetic grids of NW Malawi, overlaid with earthquake surface rupture locations (white circles). Black arrow points at prominent magnetic lineament. **(C)** The 2013 aeromagnetic grid showing interpreted buried basement-rooted faults. Yellow line represents InSAR fault model by [1] and [2].

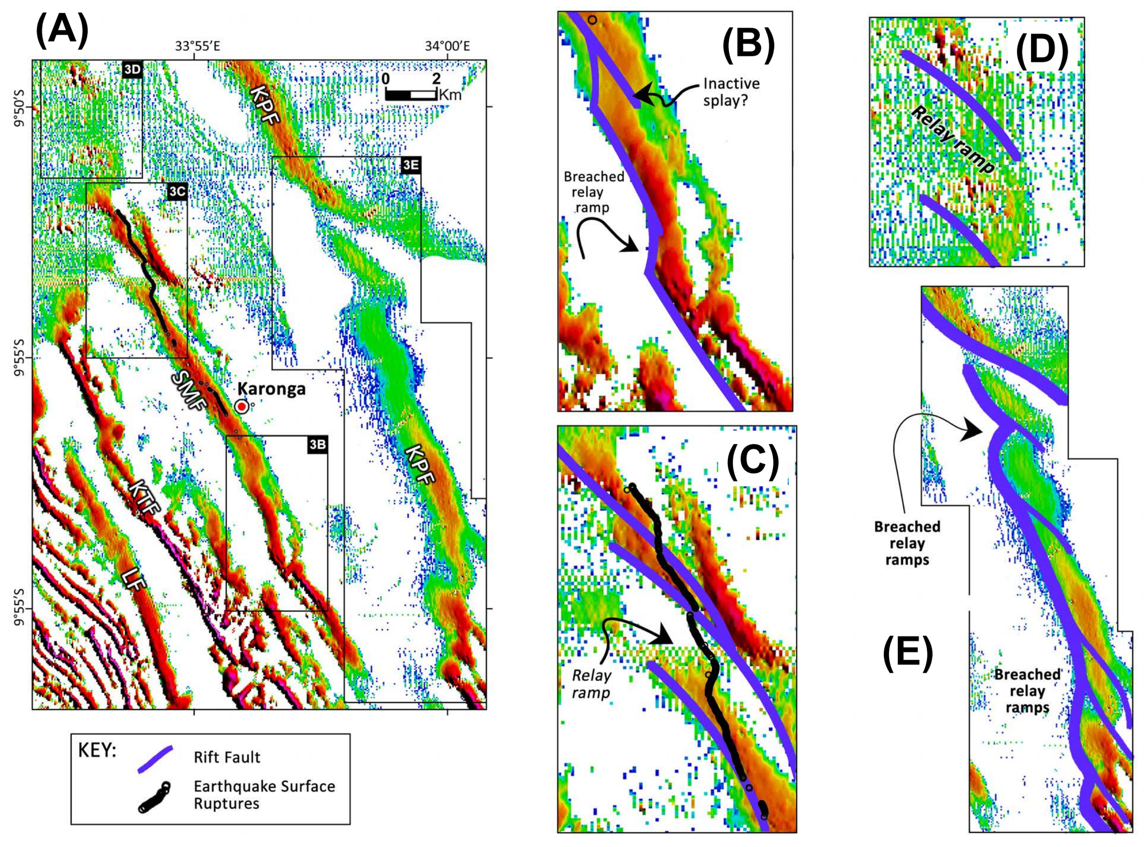

Fig. 3 (A) Filtered (1st order Dx of Dz) aeromagnetic grid of the Karonga area showing detailed along-strike geometry of the ruptured fault (SMF - St. Mary Fault) and other buried faults in the area (KPF – Kaporo Fault, KTF – Katesula Fault, LF – Lupaso Fault).
(B) Fault interpretation showing that the southern segment of SMF is dominated by coalesced fault segments.
(C) North of Karonga town, the SMF is characterized by overlapping segments (soft-linked). Earthquake surface ruptures propagate across the relay ramp. **(D)** Farther north, SMF segments show soft-linking with wider relay gap.
(E) The Kaporo Fault (KPF) also exhibits series of hard-linked and coalesced fault segments.

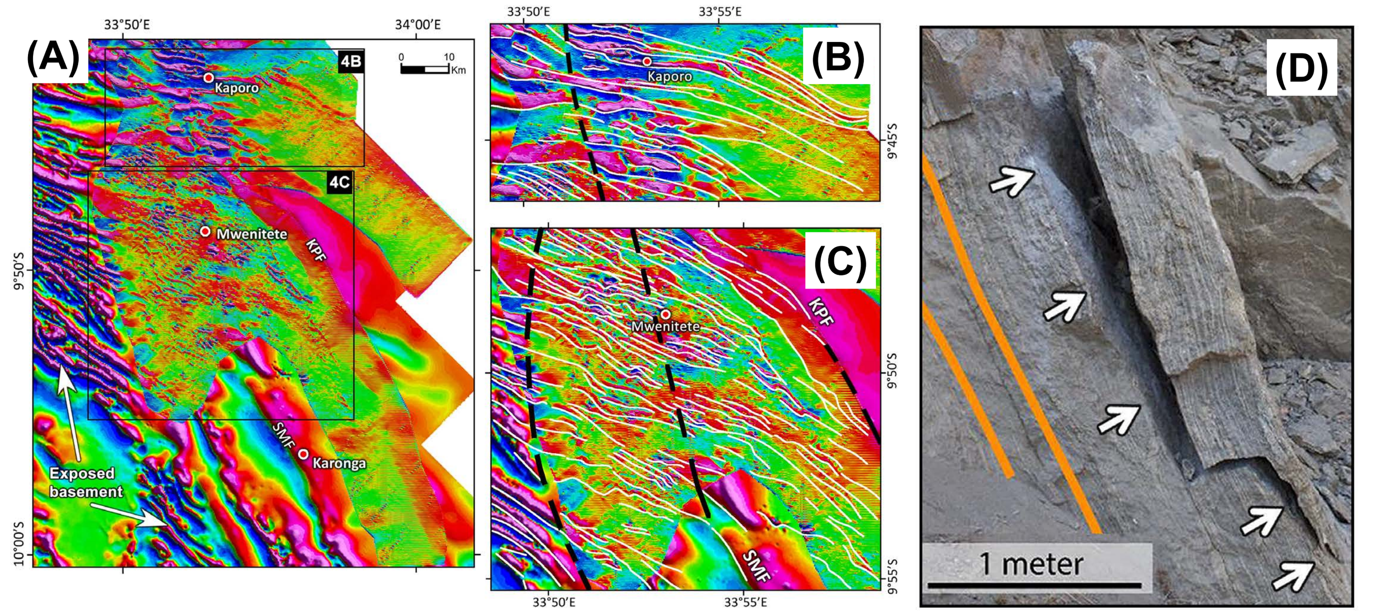

Fig. 4 (A-C) Aeromagnetic (Dz) map of Karonga area overlaid with DxDy of the tilt magnetic grid, showing edge-enhanced basement fabric beneath sedimentary cover. Solid white lines = basement MSZ fabric. Black dashed lines = the segments of buried faults that appear to cut across the MSZ fabric.

(D) Photograph of an outcrop of the MSZ southwest of Karonga town, showing a mesoscale down-dip hard-linking of fault segments. Orange line represents steep dip of the shear zone foliation, and white arrows point to fault reactivated along the contact between felsic and mafic bands.

DISCUSSION

- Propagation of the earthquake surface ruptures across soft-linked SMF segments north of Karonga town , and dominance of soft-linked segments farther north (Fig. 3A-D) suggest that the recent earthquake is associated with active coalescing of SMF segments and northward progression of the fault growth.
- Segments of basement-rooted blind faults coincide with Precambrian shear zone fabric (Fig. 4A-C), and coalesce along strike of shear zone to form faults that appear to cut shear zone obliquely (Fig. 5A).
- Plots of the earthquake epicenters (Fig. 5B-C) show that active deformation is localized within the hinge zone of the half graben where Precambrian fabric is being reactivated.
- We present a model for the 3-dimensional (3-D) reactivation of the steeply-dipping MSZ fabric into normal faults with more-gentle dips along the North Basin hinge zone (Fig. 5D).

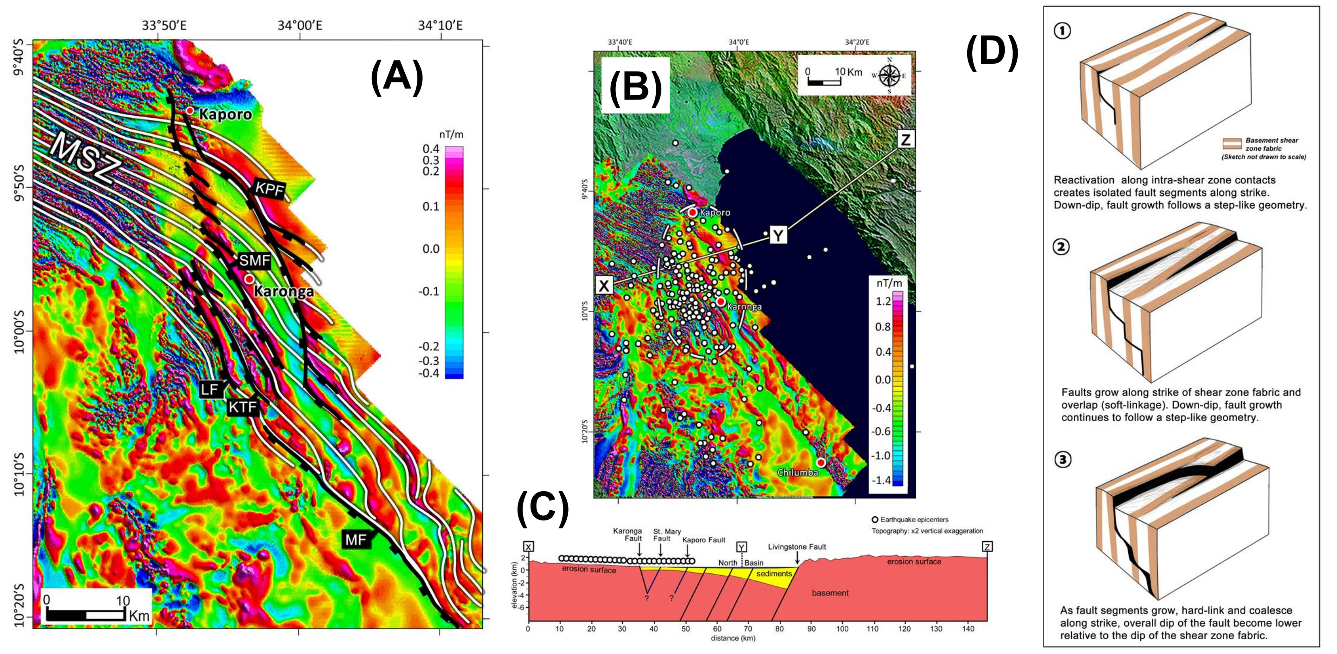

Fig. 5 (A) Superposition of blind faults (black solid lines) on the trend of the MSZ fabric (white solid lines). **(B)** Dz Aeromagnetic map of Karonga area overlaid with earthquake epicenters. **(C)** Cross-section across the North Basin, modified after [1]. **(D)** Our model for 3-dimensional (3-D) reactivation of the MSZ fabric along the North Basin hinge zone. SMF = St. Mary Fault, KPF = Kaporo Fault, KTF = Katesula Fault, LF = Lupaso Fault, MF = Mbiri Fault, MSZ = Mughese Shear Zone.

CONCLUSIONS

- We provide evidence highlighting the role of pre-existing basement shear zone structures in strain accommodation leading to moderate-sized earthquake generation within rift systems.
- We also showed that the structural development of the hinge zone of Malawi Rift's North Basin half graben is actively modulated by the underlying pre-existing shear zone fabric.

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