Rift linkage processes in areas of incipient oceanic spreading: examples from Afar

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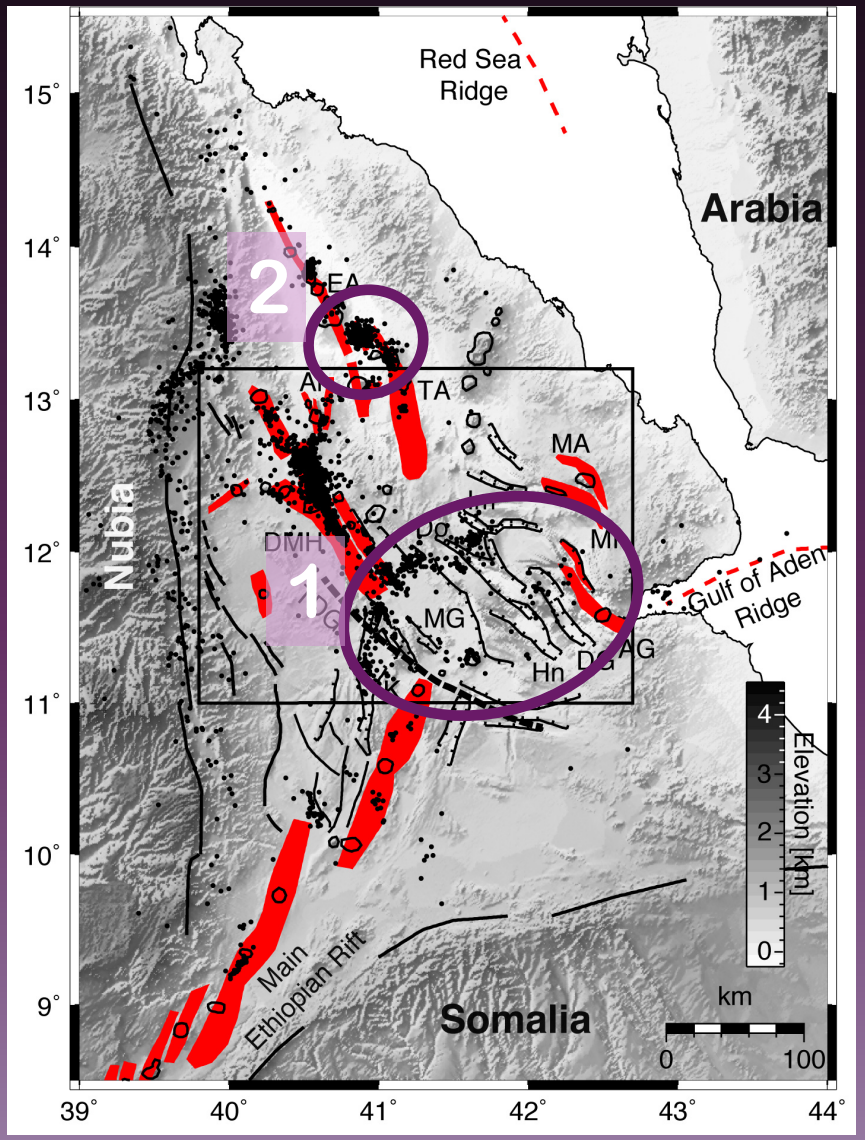
The Afar rift

We use Seismicity and InSAR to study the kinematics of rift segment linkage in two different offsets of the Afar rift:

1. The first order linkage zone between the Red Sea and Gulf of Aden rifts

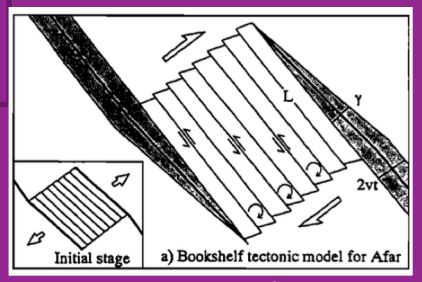
2. The second order linkage zone between the Erta Ale and Tat Ali rifts



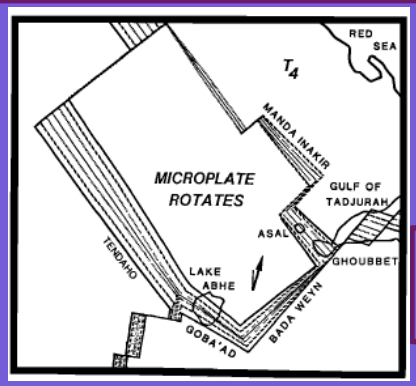
Red Sea-Gulf of Aden linkage

The different rift linkage models proposed:

1) Bookshelf faulting



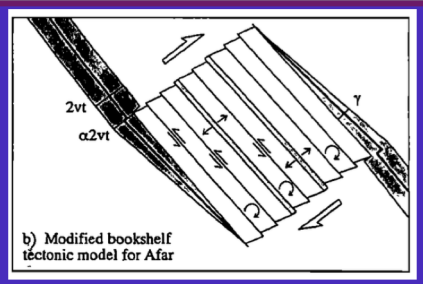
Tapponier et al., 1990



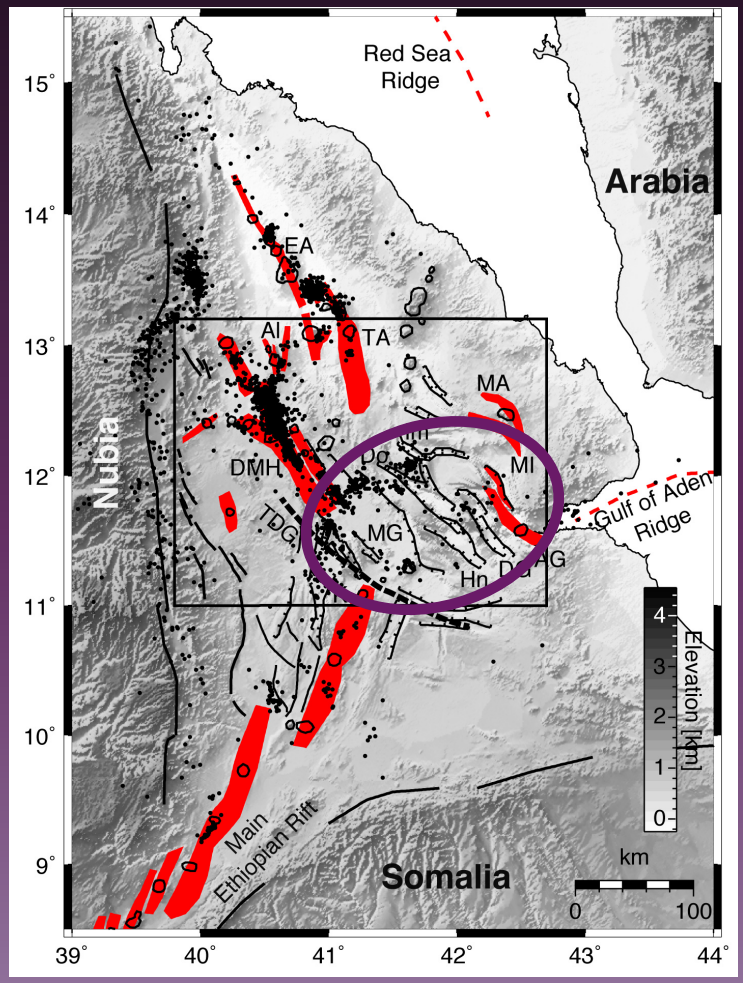
Acton et al., 1991

2) Microplate rotations

3) Bookshelf with extension



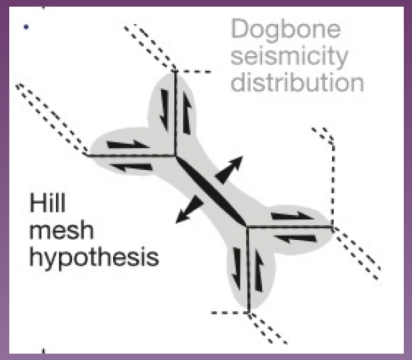
Sigmundsson et al., 1992



Seismicity data

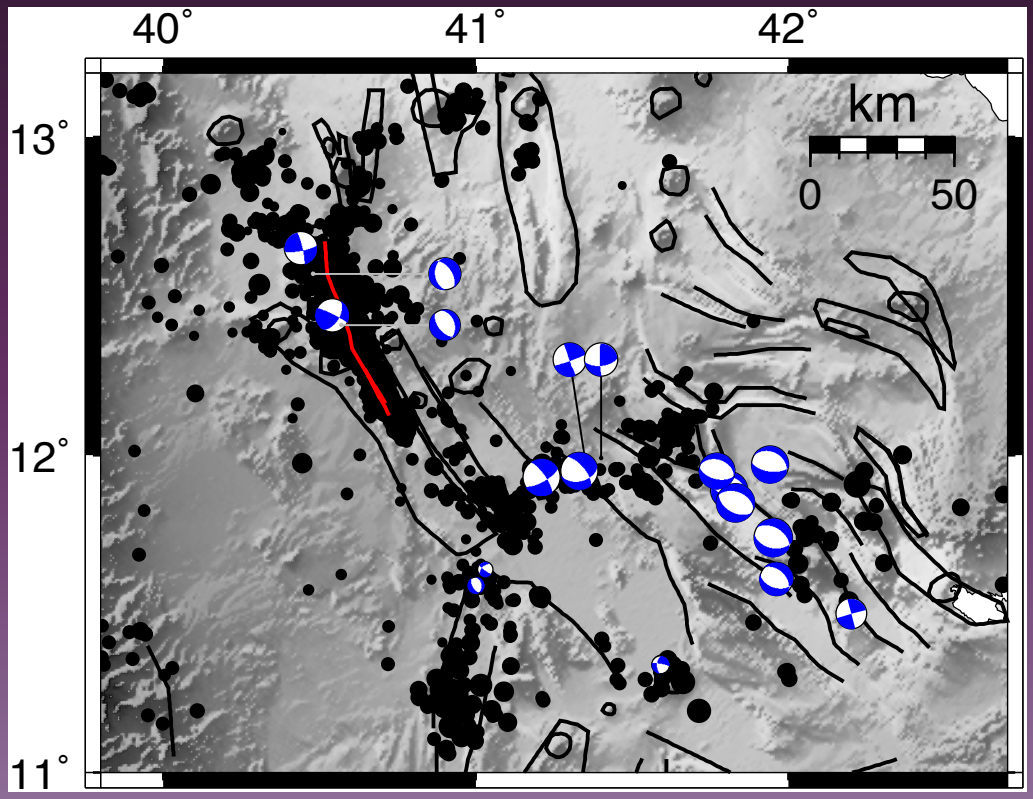
- Seismicity data from local network Oct 2005-Oct 2009

- What governs the seismicity distribution and why strike-slip earthquakes?
  - ✓ Long-term Tectonics
  - ✓ Transient Dogbone seismicity distribution



Toda et al., 2002

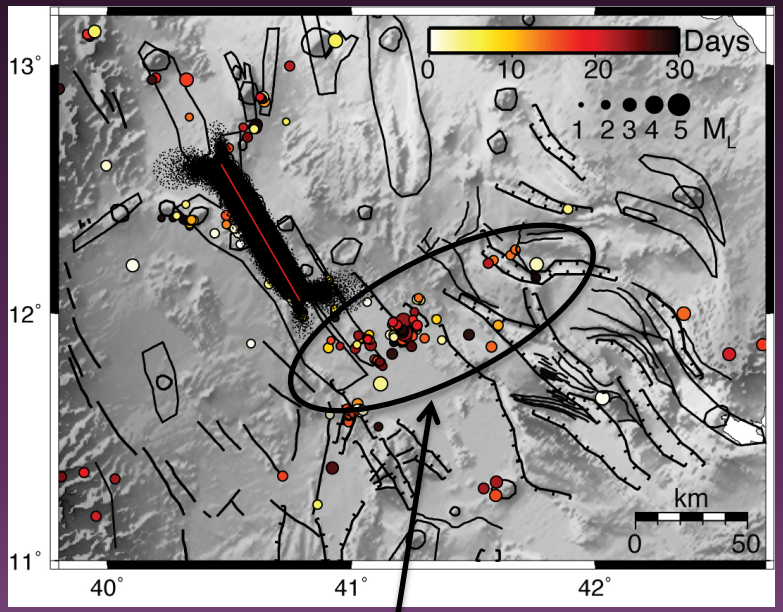
14 intrusions in Dabbahu-Manda Hararo



Pagli et al., Geology, 2019

Dogbone Modeling

Co-intrusive and modeled seismicity



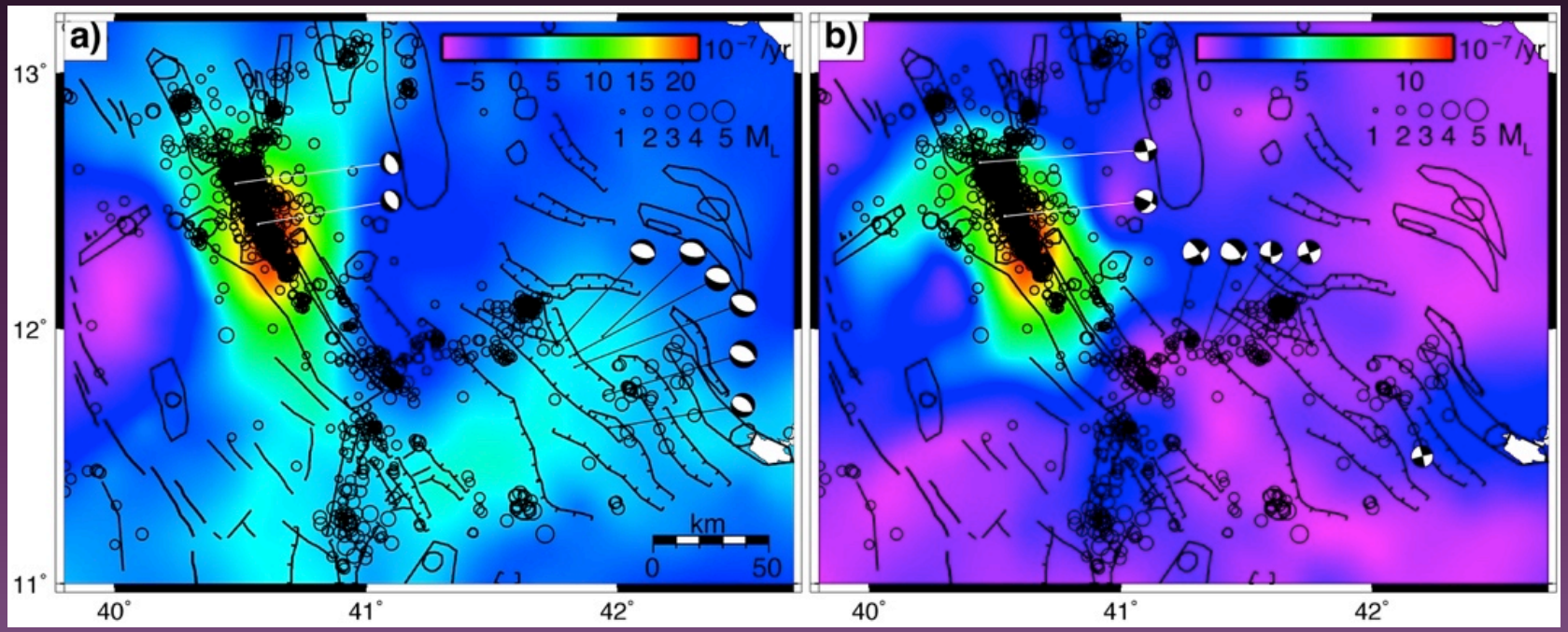
Pagli et al., Geology, 2019

Seismicity caused by tectonic stresses rather than dike-induced

- Model the seismicity as increase in Coulomb stress induced by repeated diking in Dabbahu, using boundary element method
- 70 km long area of diking N150E Local faults with same orientation dipping 60 degrees towards the rift axis

Horizontal Strain Rate maps from inversion of InSAR and GPS

First Invariant strain rate (dilatation) Max shear strain rate



Pagli et al., Geology, 2019

- Dabbahu: along-rift extension and shear coupled with seismicity
- Central Afar rifts: extension and normal faulting in the central parts of the rifts and no distributed zone of shear => no bookshelf faulting

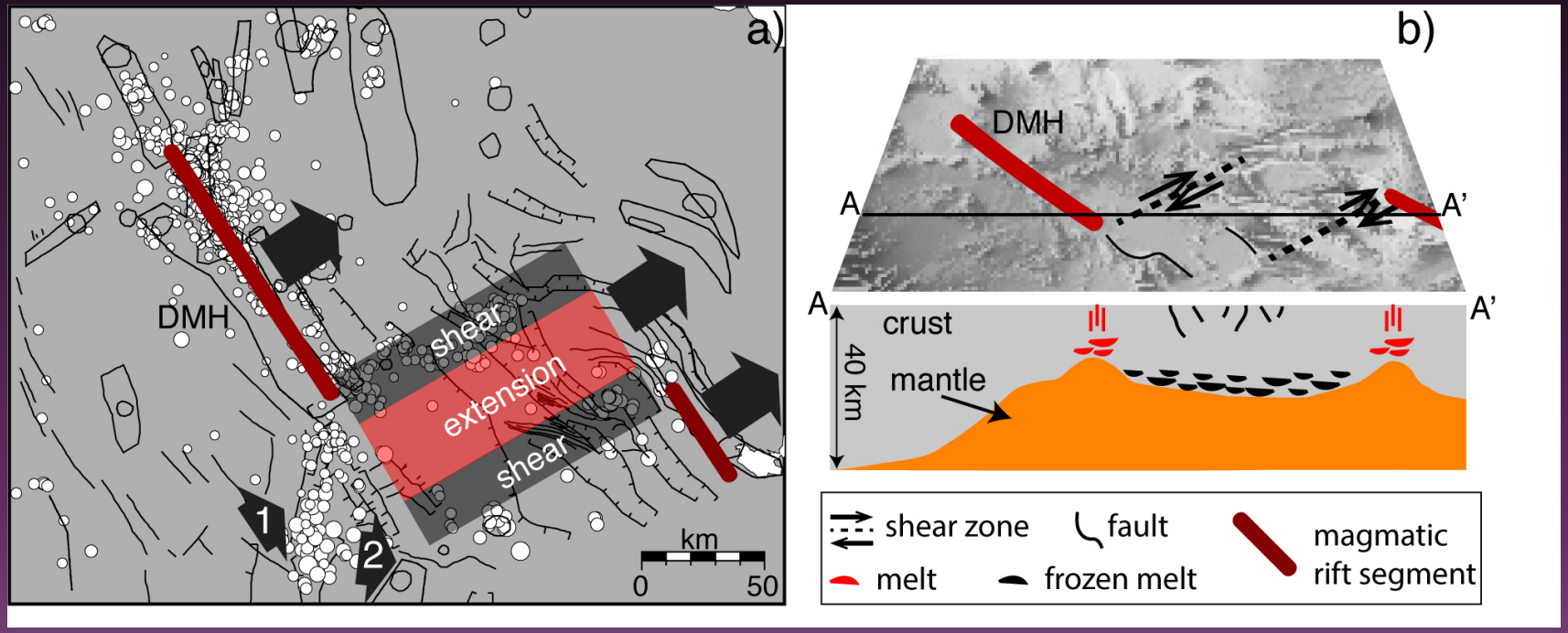
Red Sea-Gulf of Aden linkage

- Seismicity off the Dabbahu-Manda Hararo rift caused by long-term tectonic stresses rather than transient dogbone

- Central Afar rifts dominated by extension rather than distributed shear as shown by normal faulting earthquakes, strain rate maps and presence of grabens

=> suggests new plate boundary kinematics

New plate boundary model

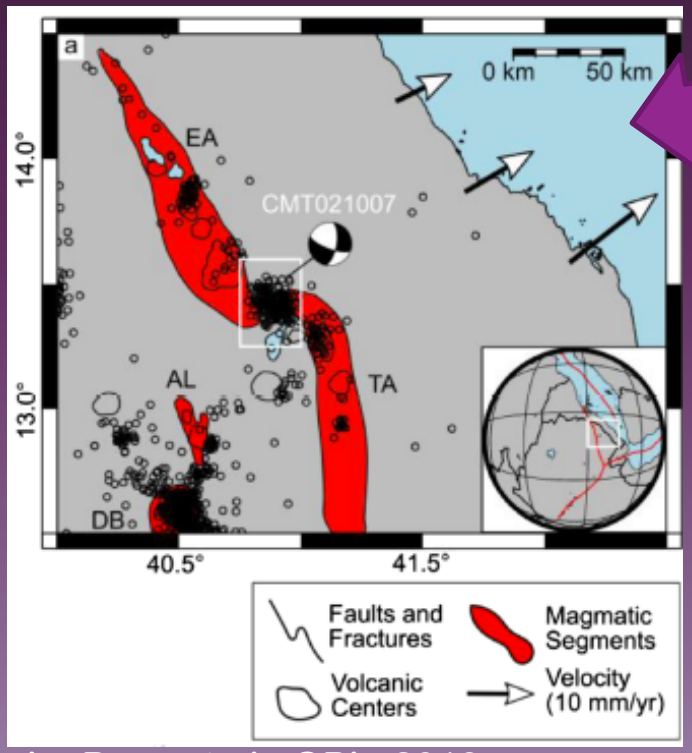


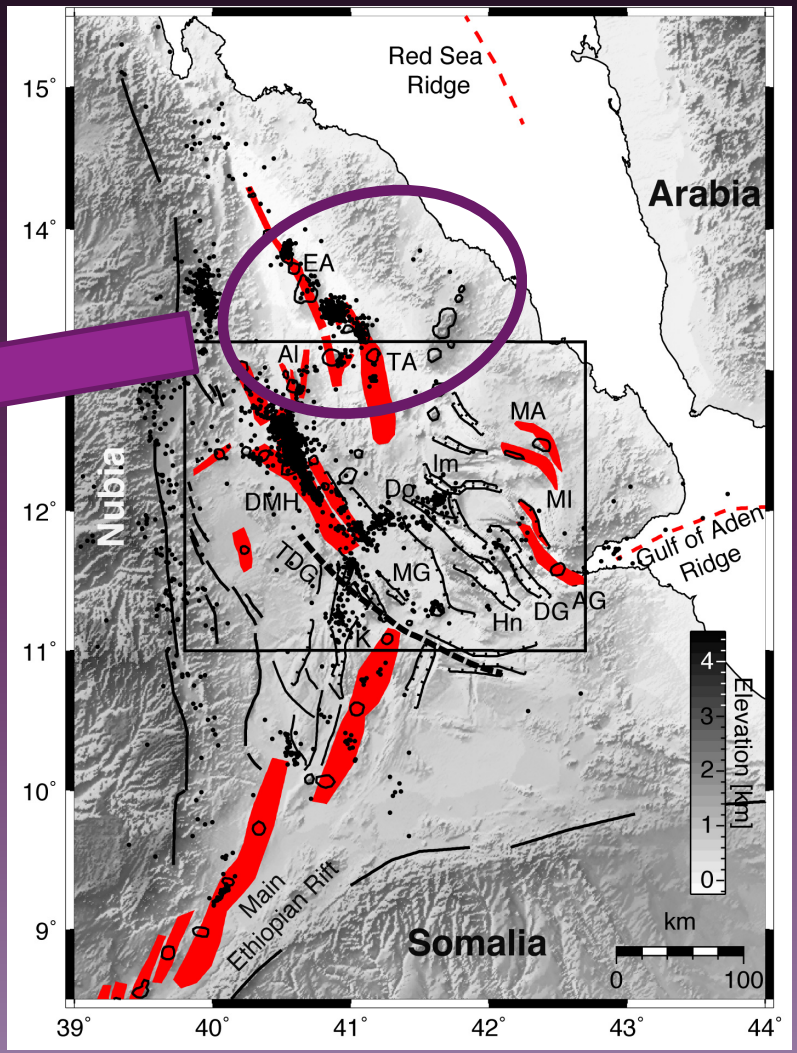
Pagli et al., Geology, 2019

- Left-stepping of the plate boundary from Gulf of Aden to Dabbahu-Manda Hararo
- Extension in the central parts of the rifts and shearing at the edges =>where the extension terminates against less stretched lithosphere

The Erta Ale-Tat Ali linkage zone

- 20-km-wide offset dissected by faults with continuous seismicity
- M_L 5.1 earthquake on 2 October 2007

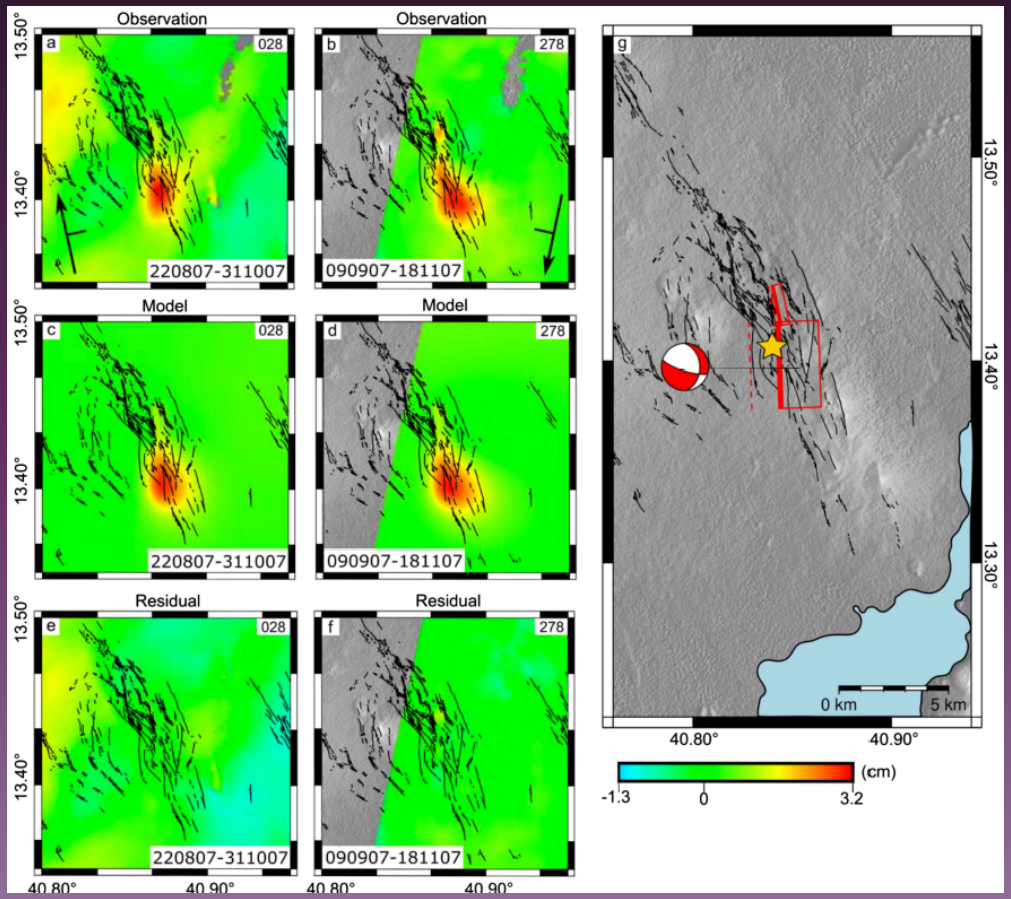


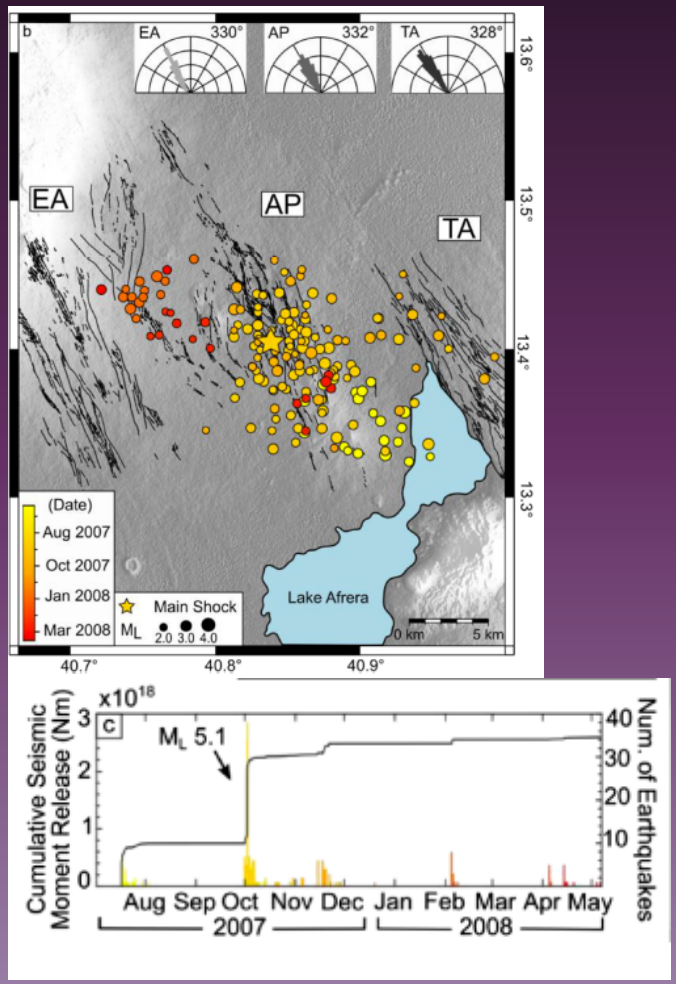


La Rosa et al., GRL, 2019

InSAR and seismicity

InSAR modelling of the 2007 earthquake shows: Oblique left-lateral slip along a ~N-S fault

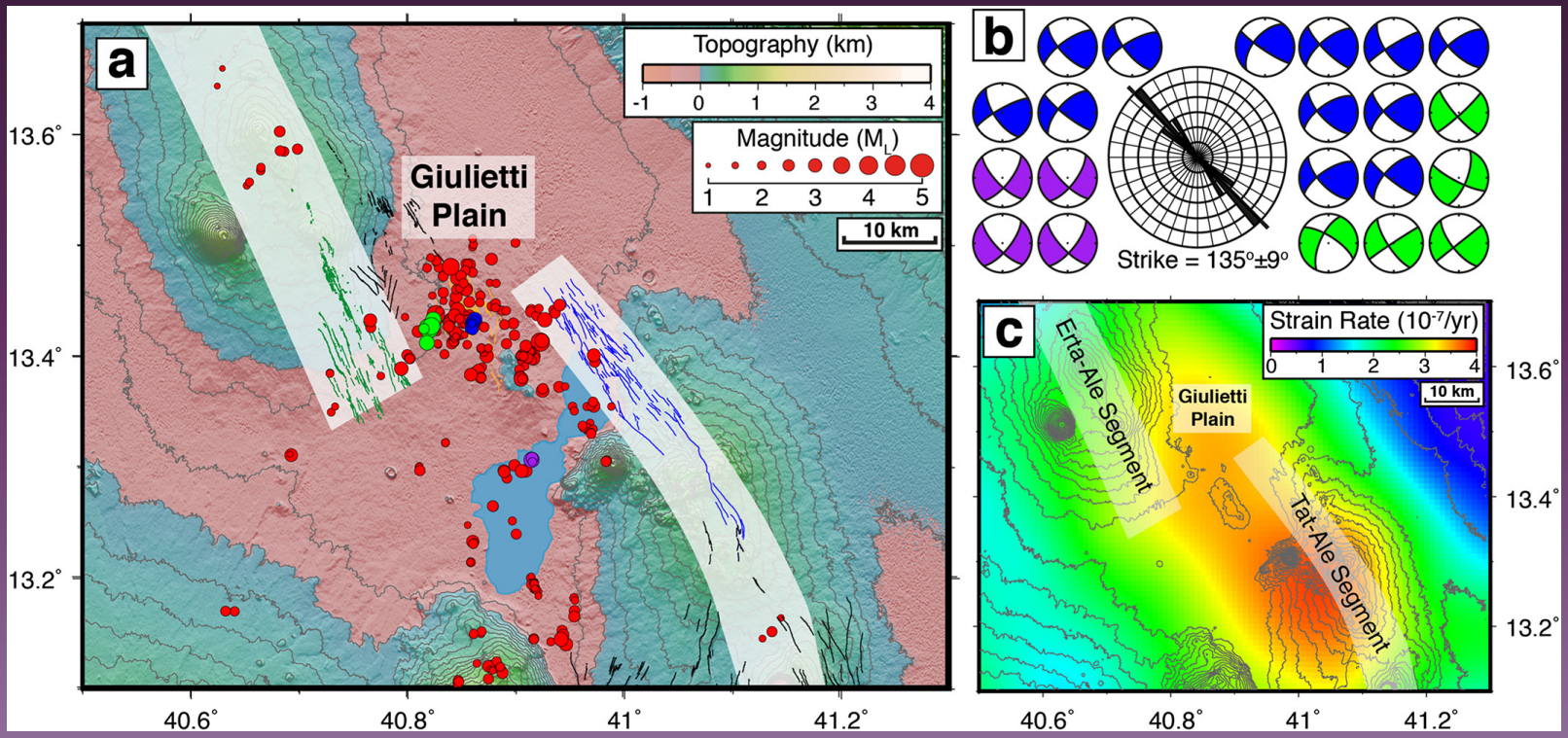




La Rosa et al., GRL, 2019

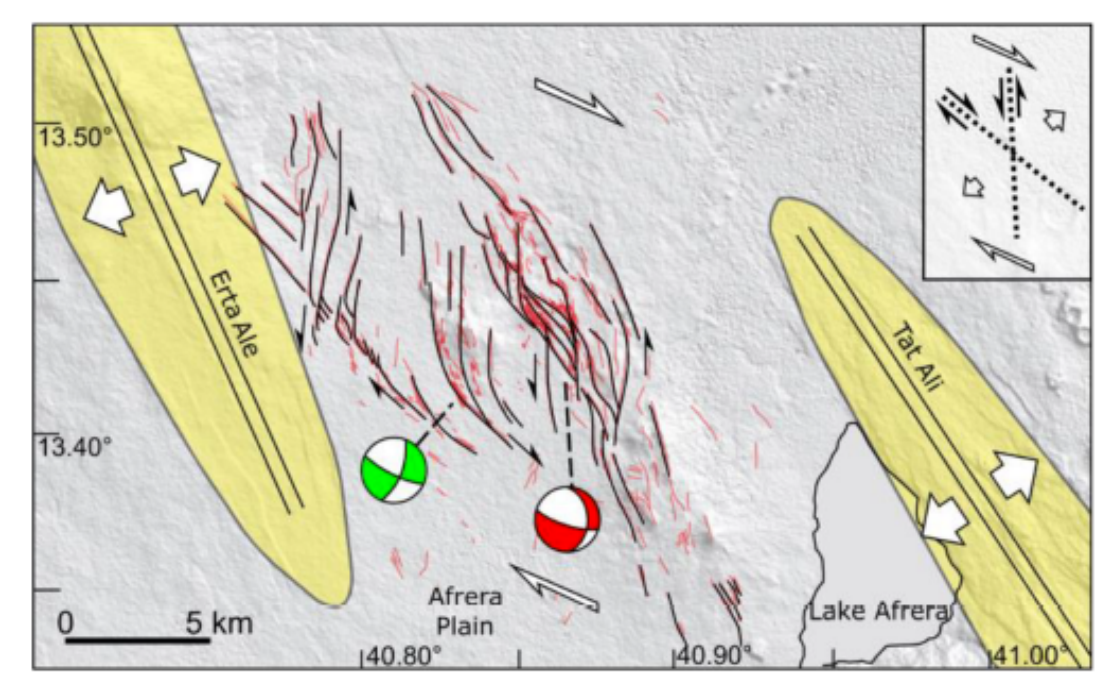
Conjugate system also active

Seismicity 2011-2013 observes right-lateral along NW-SE faults



Illsley-Kemp et al., Gcubed, 2018

Rift linkage model with formation of conjugate fault systems



La Rosa et al., GRL, 2019

Conclusions

- Our results provide evidences that offset rift segments during continental breakup can be linked by a variety of strain types including:

- Distributed extension inducing shear at the rift tips in the Red Sea-Gulf of Aden linkage zone

- Rotation of the extension due to development of a linkage zone and formation of a conjugate set of faults at the surface