Seismic and geodetic evaluation of earthquake and volcanic hazards in East Africa

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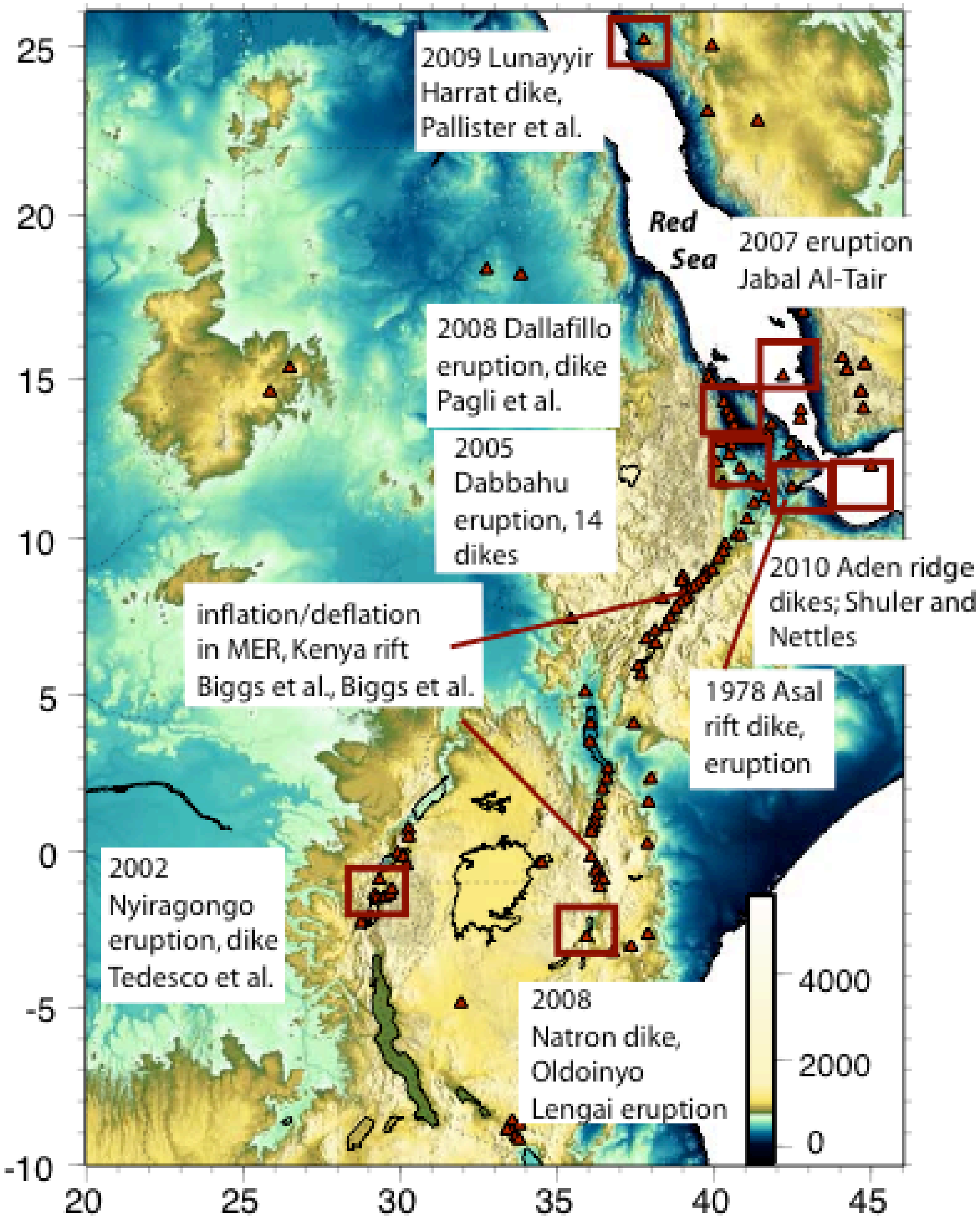


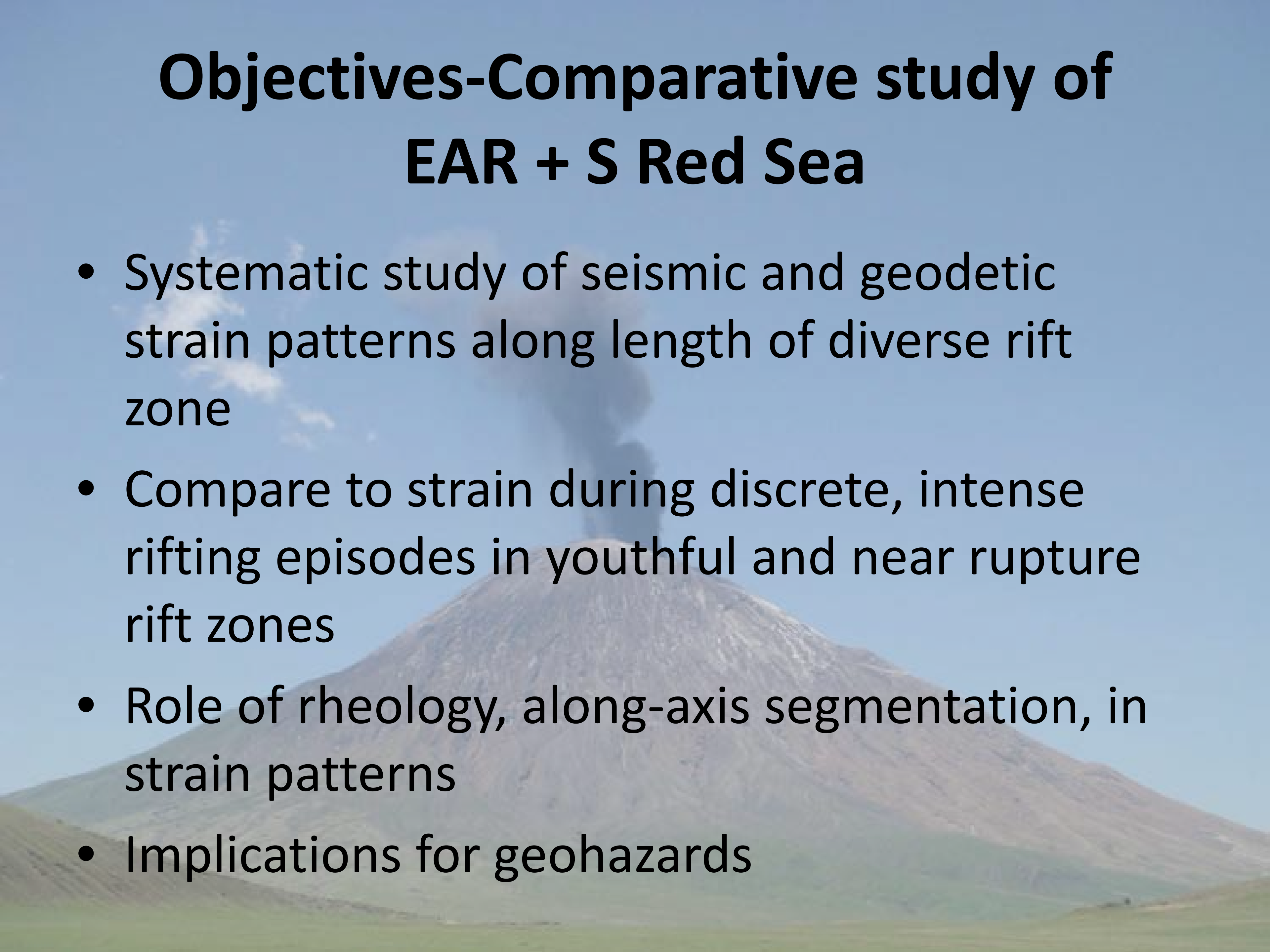
22 dike intrusions accompanying volcanic eruptions or volcano-tectonic rifting crises in East African, Red Sea and Gulf of Aden rift zones since 1978 (red boxes) and 9 'breathing' volcanoes. Fatal EQ swarms in Mozambique, Malawi, DRC, Tanzania

Aseismic deformation – 99-80%.

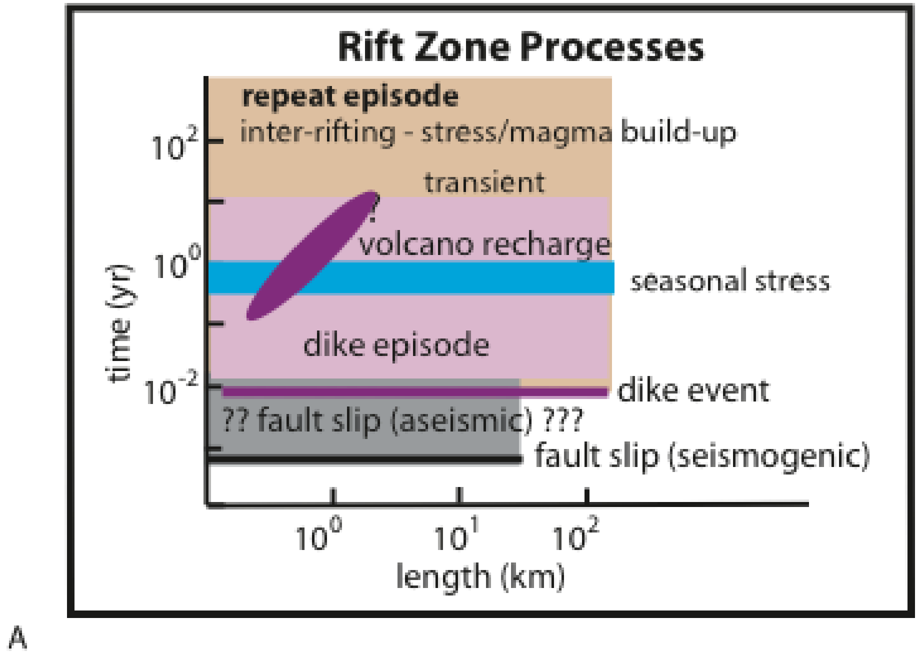
Significant property damage, deaths in 2007 Jabal Al-Tair event.

How does our growing knowledge of frequency and magnitude of magmatic rifting influence hazards?

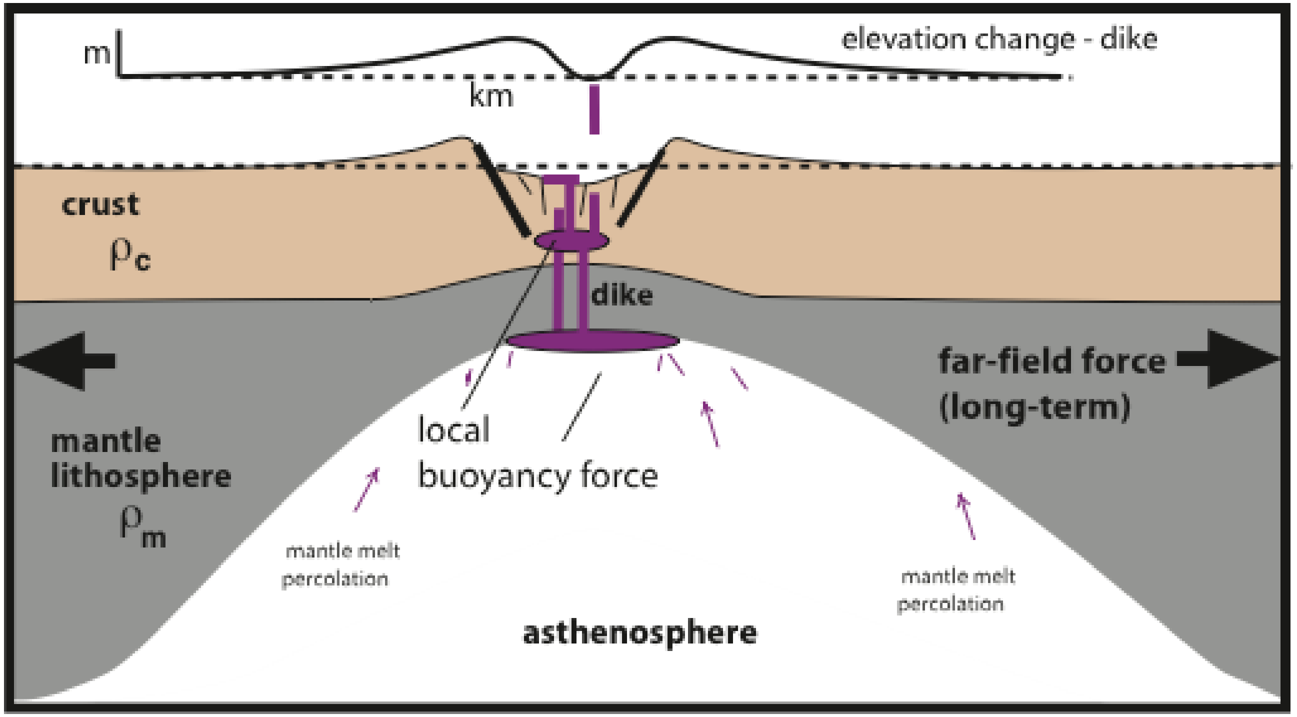
Objectives-Comparative study of EAR + S Red Sea



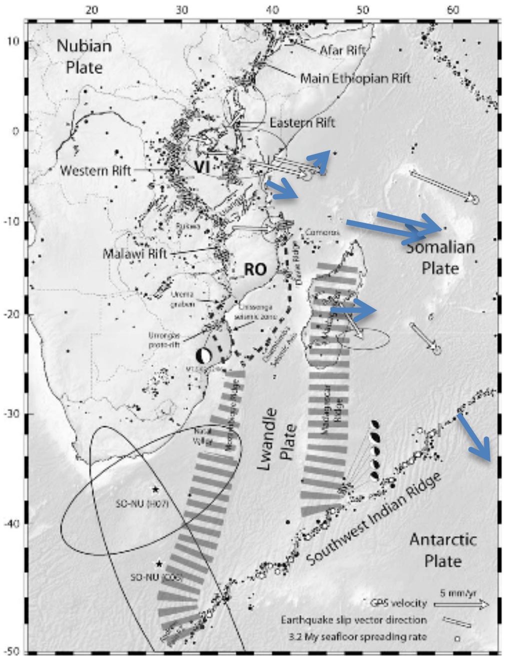
- Systematic study of seismic and geodetic strain patterns along length of diverse rift zone
- Compare to strain during discrete, intense rifting episodes in youthful and near rupture rift zones
- Role of rheology, along-axis segmentation, in strain patterns
- Implications for geohazards



Multiple time and length scales of process –
EAR - short historic record of damaging EQs and explosive volcanism



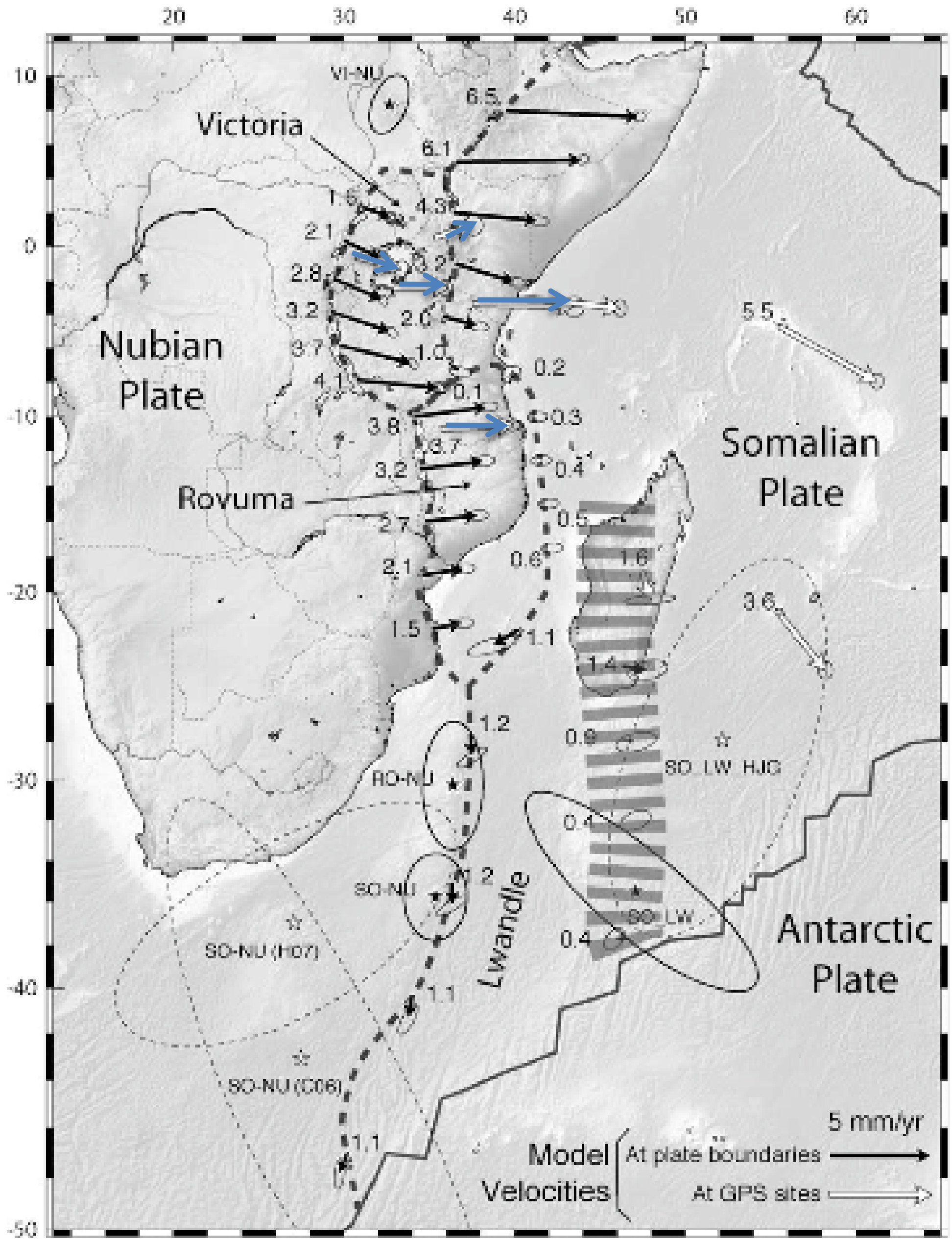
Strain accommodated by fault slip in brittle crust, magma intrusion, ductile deformation in deeper hotter layers



Stamps, Calais et al. GRL 08

vs Gordon 2000 – broadly distributed plate boundary deformation.

Blue vectors are constraints from sparse continuous GPS. Need more CGPS data!!!



Seismic moment : Relates brittle energy release to faulting process

$$M_0 = \mu A s$$

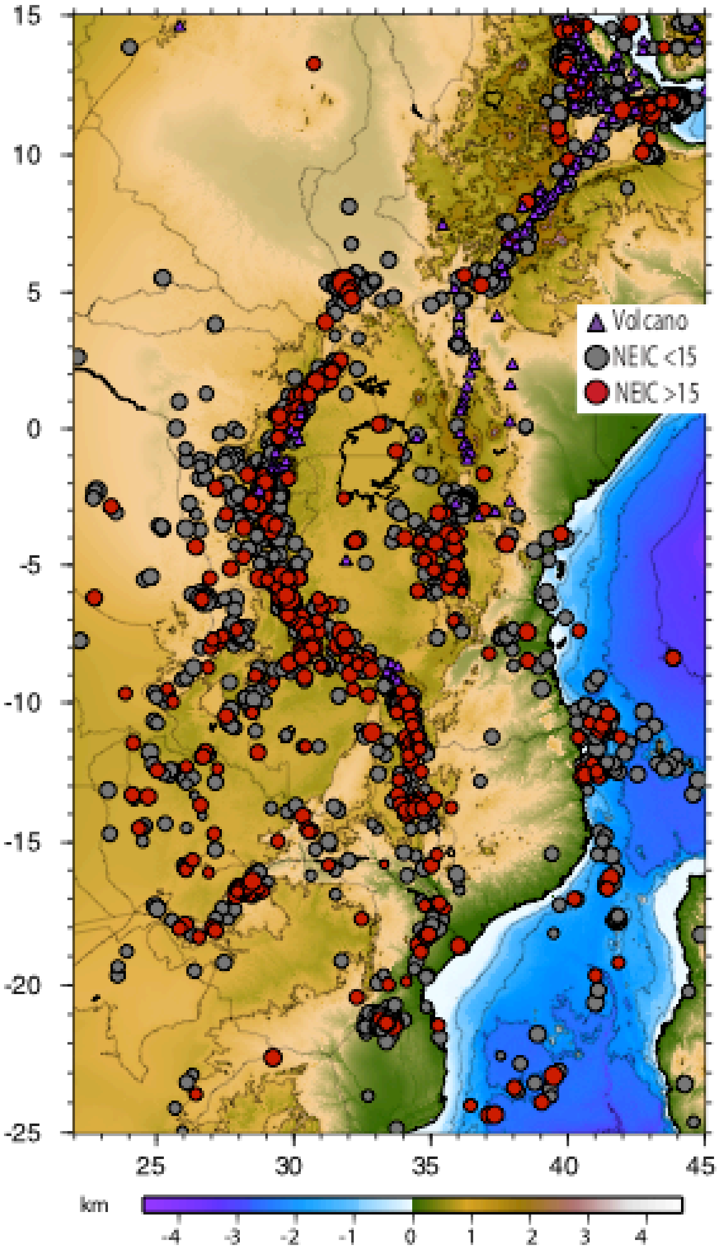
where is shear modulus of rock at EQ source, and A is area of fault plane, and *s* is slip.

Energy dissipated scales with rupture length, fault height

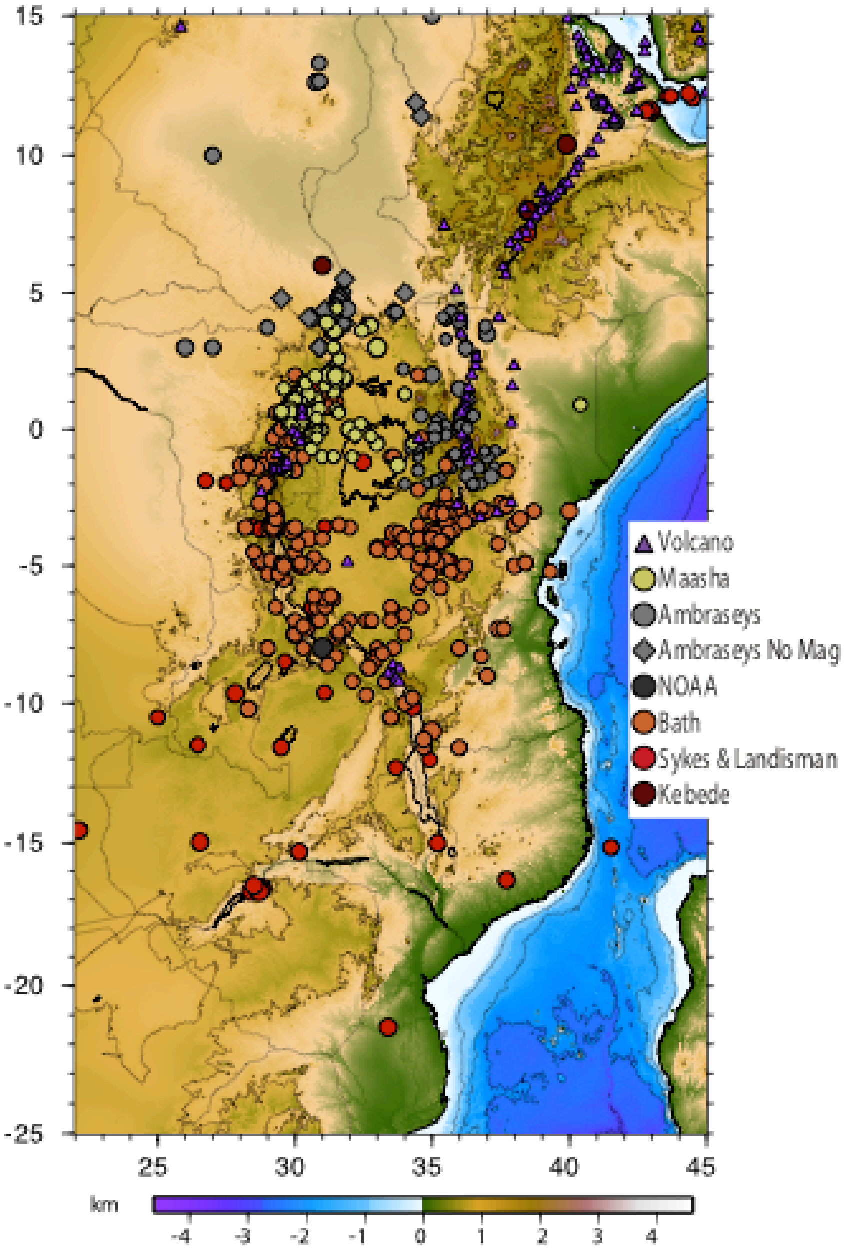
- Seismic moment rate: $\Sigma\, M_0$ /time
- Geodetic moment rate: $= 2\mu L_1 L_3 v/k$

L_1 is length of deforming area, L_3 is seismogenic layer thickness (max depth of EQs) v is velocity from GPS, k relates to distribution of randomly oriented fractures 0.75-1 in Basin and Range, Andes

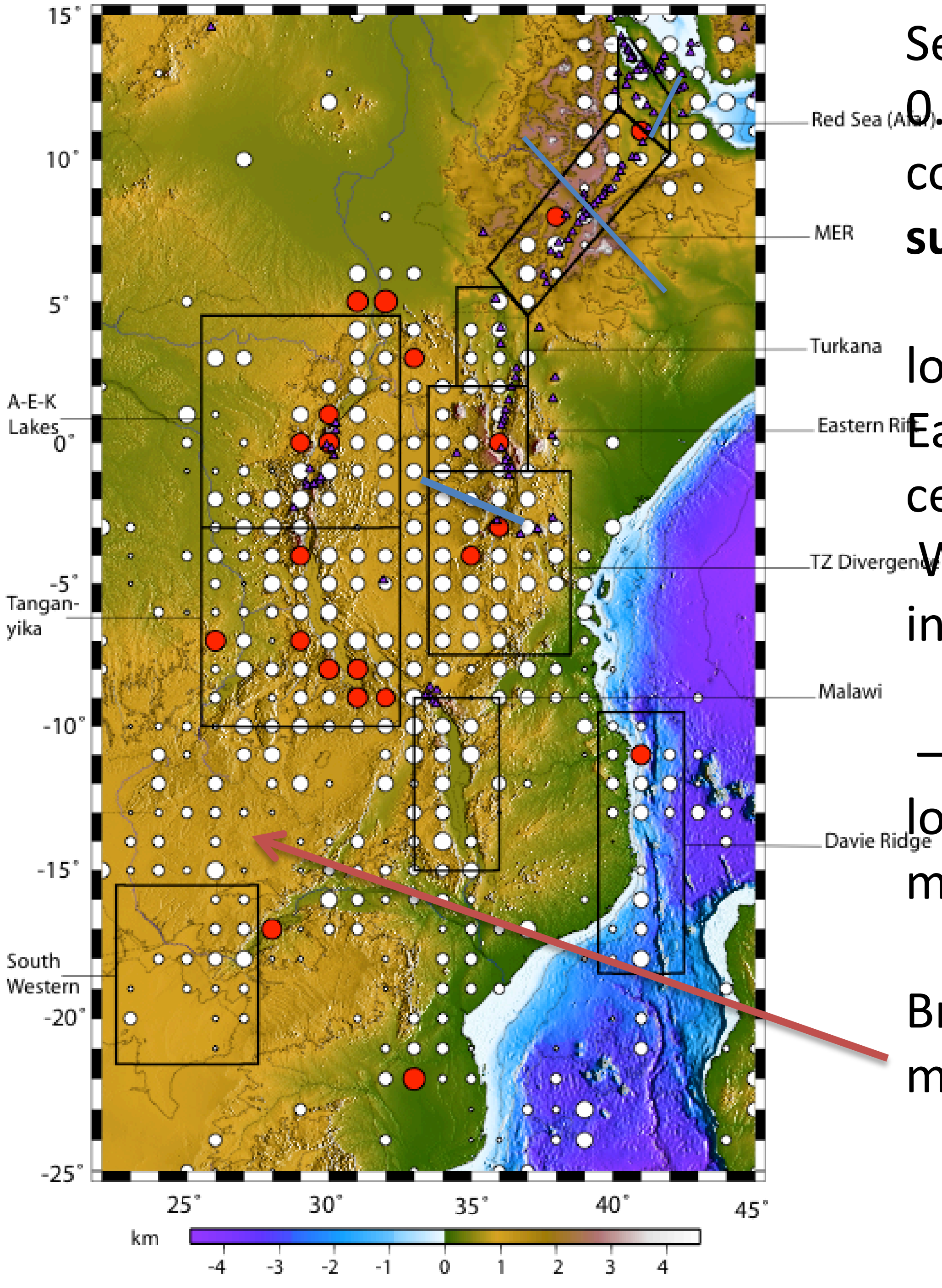
Ratio S:G gives estimate of strain partitioning between brittle failure and aseismic (magma, creep)



1973-present. Note many deep events



Validated historic records –spatial bias

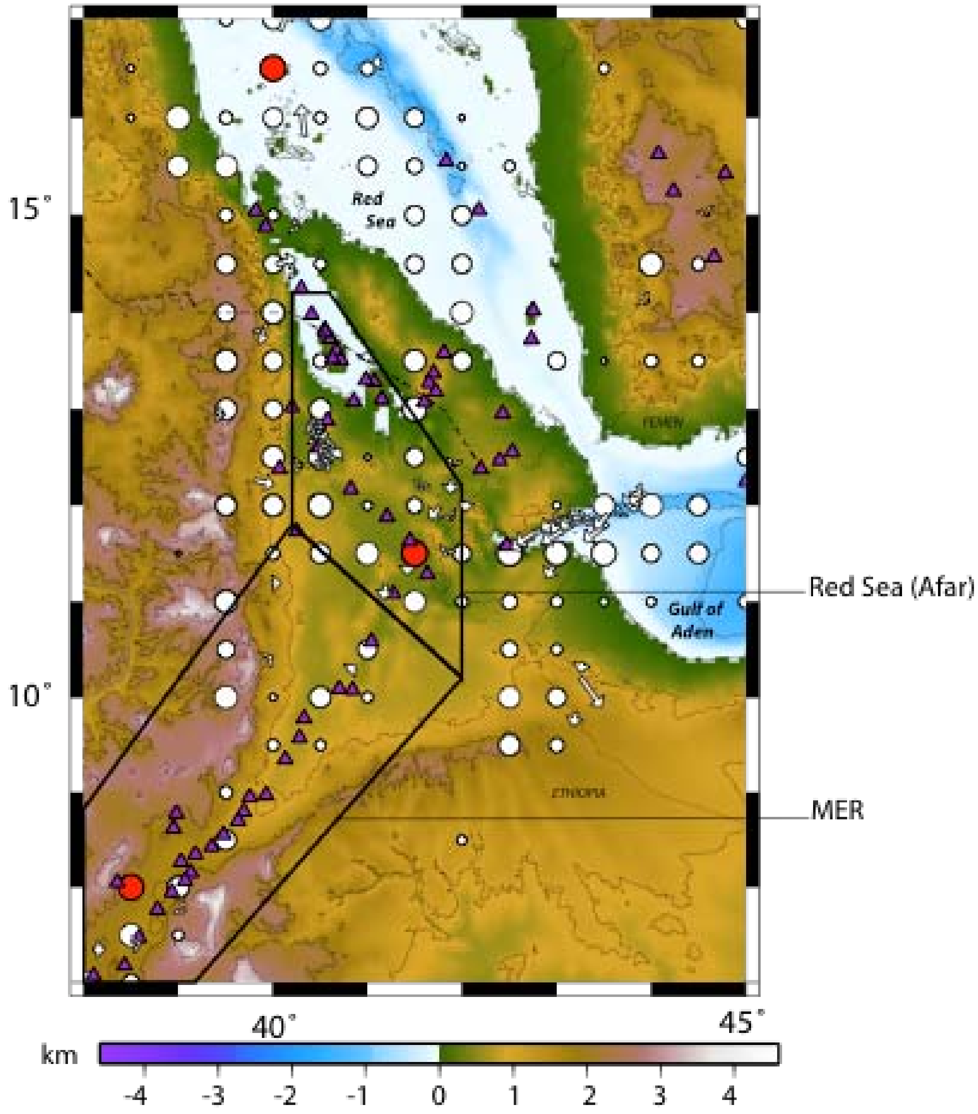


Seismic moment release summed in 0.5* bins (NEIC + historic catalogues, complete to ~ ML 5) –Lindsey **et al. submitted**

low seismic moment release in Eastern rift and MER - eruptive centers in central rift valley vs Western rift - eruptive centers in inter-segment transfer zone

– CO_2-rich volatile degassing, but lower He suggesting lithospheric mantle + mantle degassing

Broad zone of deformation – mantle metasomatism in progress?



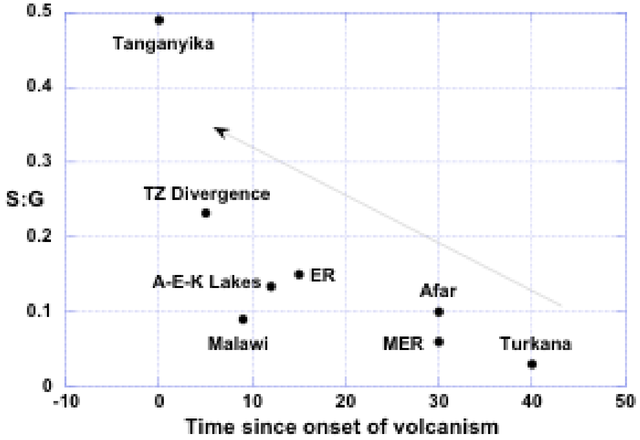
Extensional velocities 16- 22 mm/yr in S Red Sea moving south from pole of rotation – Vigny et al. 2006, McCluskey et al., 2011.

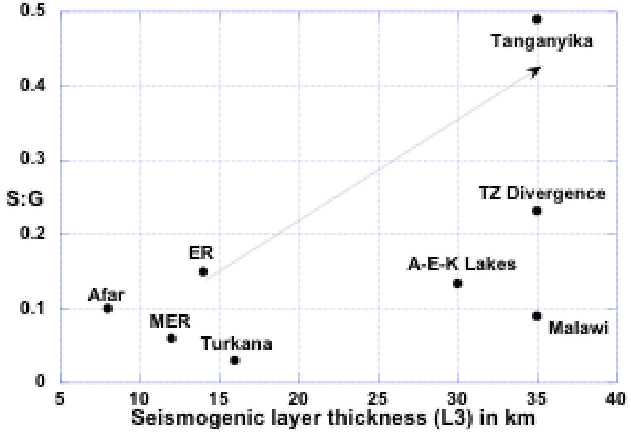
Most of the seismicity in zones of magmatism where intense episodes of plate boundary deformation occur – aseismic deformation is .1 to 10% of total opening.

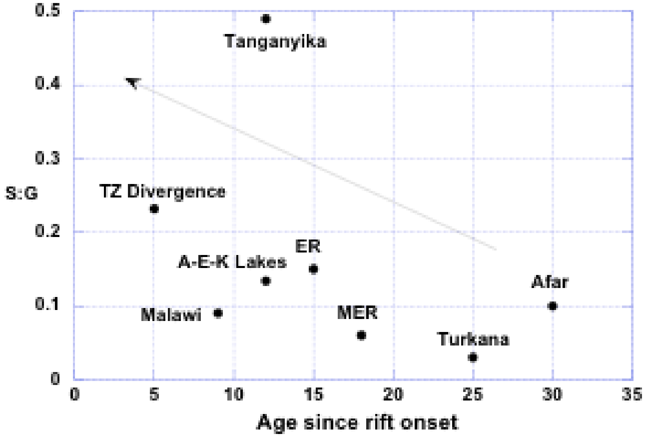
Pattern of largest EQs matches microseismicity patterns from local arrays

Comparisons between seismic moment rate and geodetic moment rate

- Geodetic moment is everywhere > 2 times seismic moment rate
- Strain rates, ext velocities from inversion of EQ moment tensors is everywhere << values from rigid plate model of Stamps et al.
- Some patterns emerge when comparing with age of rift sector, time duration of magmatism, and seismogenic and effective elastic layer thickness – proxies for plate rheology





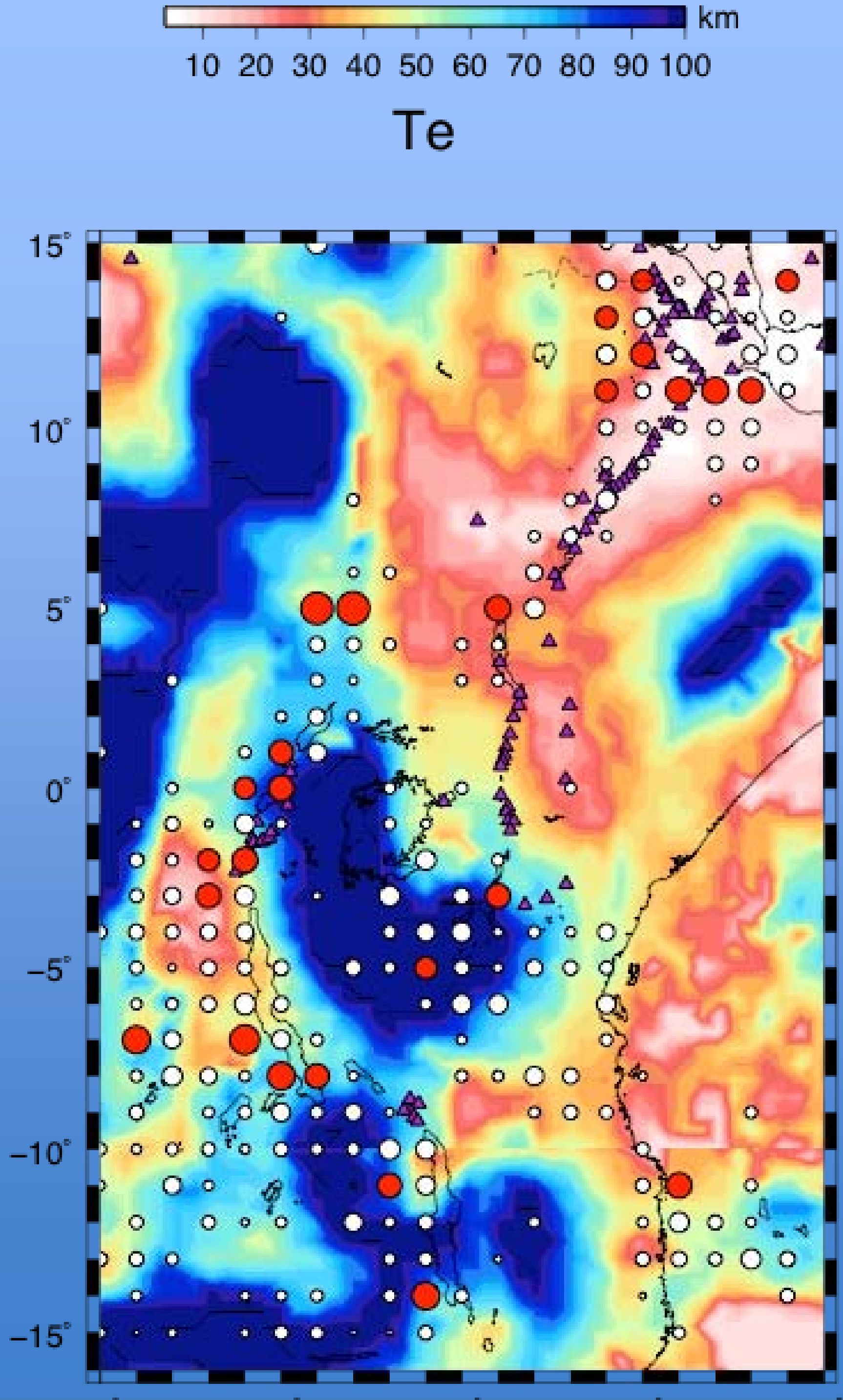


Exclude Davie ridge (oceanic crust); SW rift (too few data)

Increase in seismic to geodetic strain release (decrease in aseismic strain) as Tseis/Te increases, and as time period of magmatism decreases.

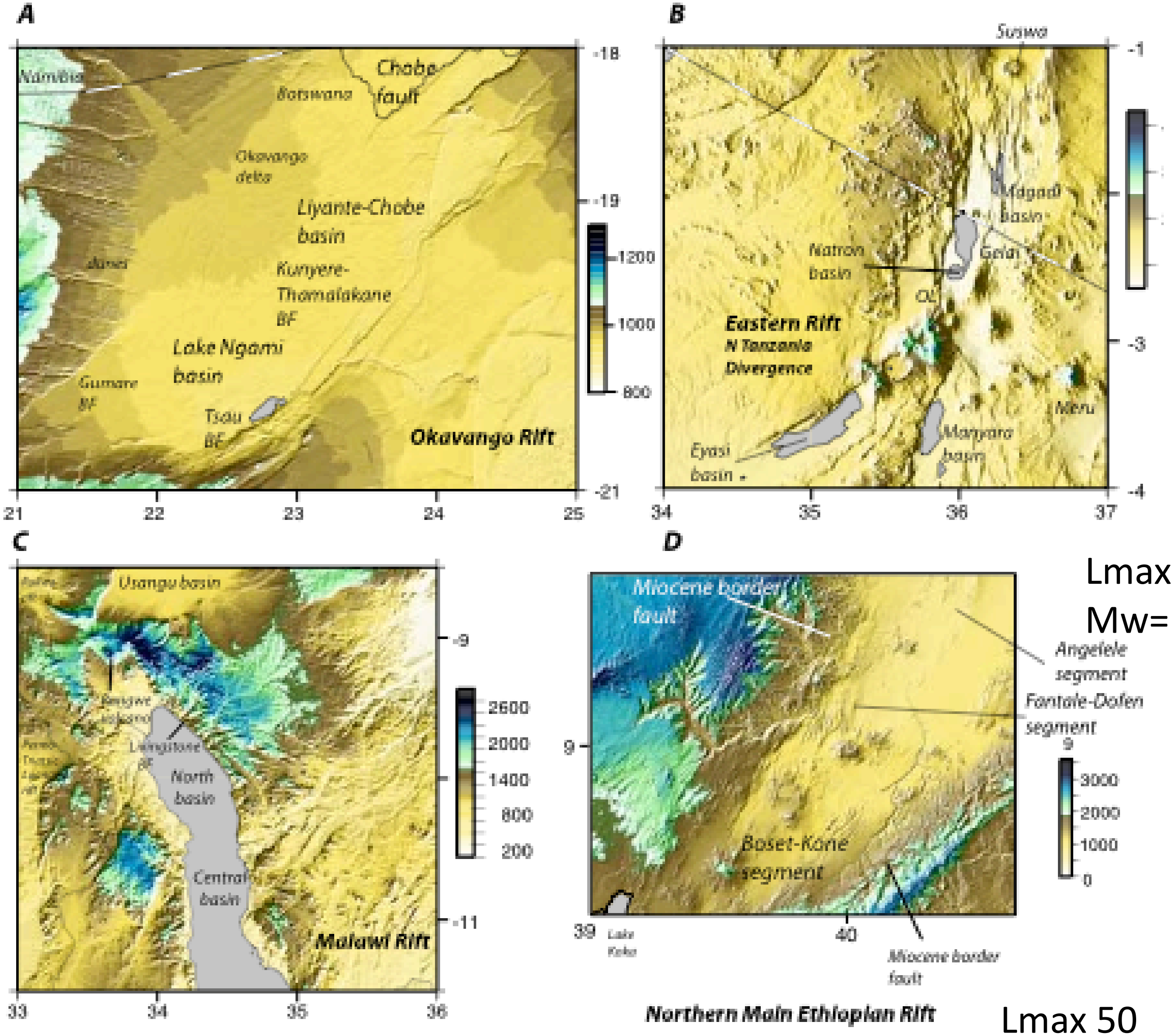
Magma volume and time period of heating and extension lead to an increase in the aseismic component of plate boundary deformation – matches S:G .1 to 10% for discrete intrusion events.

Young rifts in cratons may have larger EQ magnitudes, but longer repeat times.



Comparison of cumulative seismic moment release (NEIC + historic) vs effective elastic thickness (Te in km) – grid of Te from Perez-Gussinyé et al. (2008). Higher moment release along edges of tectonic domains/Te provinces

Lmax = 120
Mw= 8

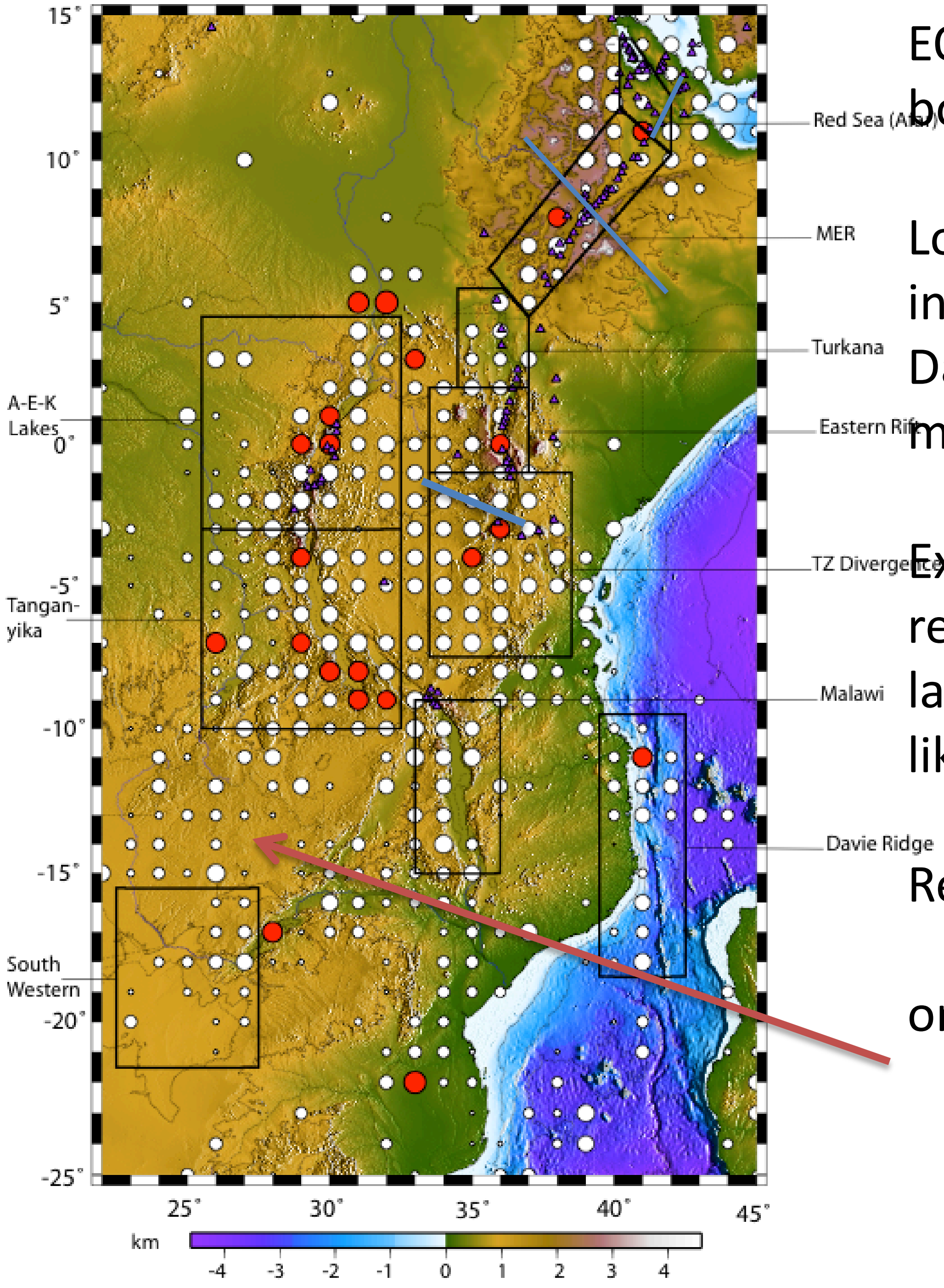


Lmax 80
Mw= 7.7

Malawi
Mw= 7.8

Lmax 50
Mw= 7.1

Ebinger and Scholz 2012



EQ hazards extend well outside fault-bounded rift valley

Localized strain in zones of magma intrusion within Ethiopian plateau; Davie ridge – smaller magnitude but more frequent EQs

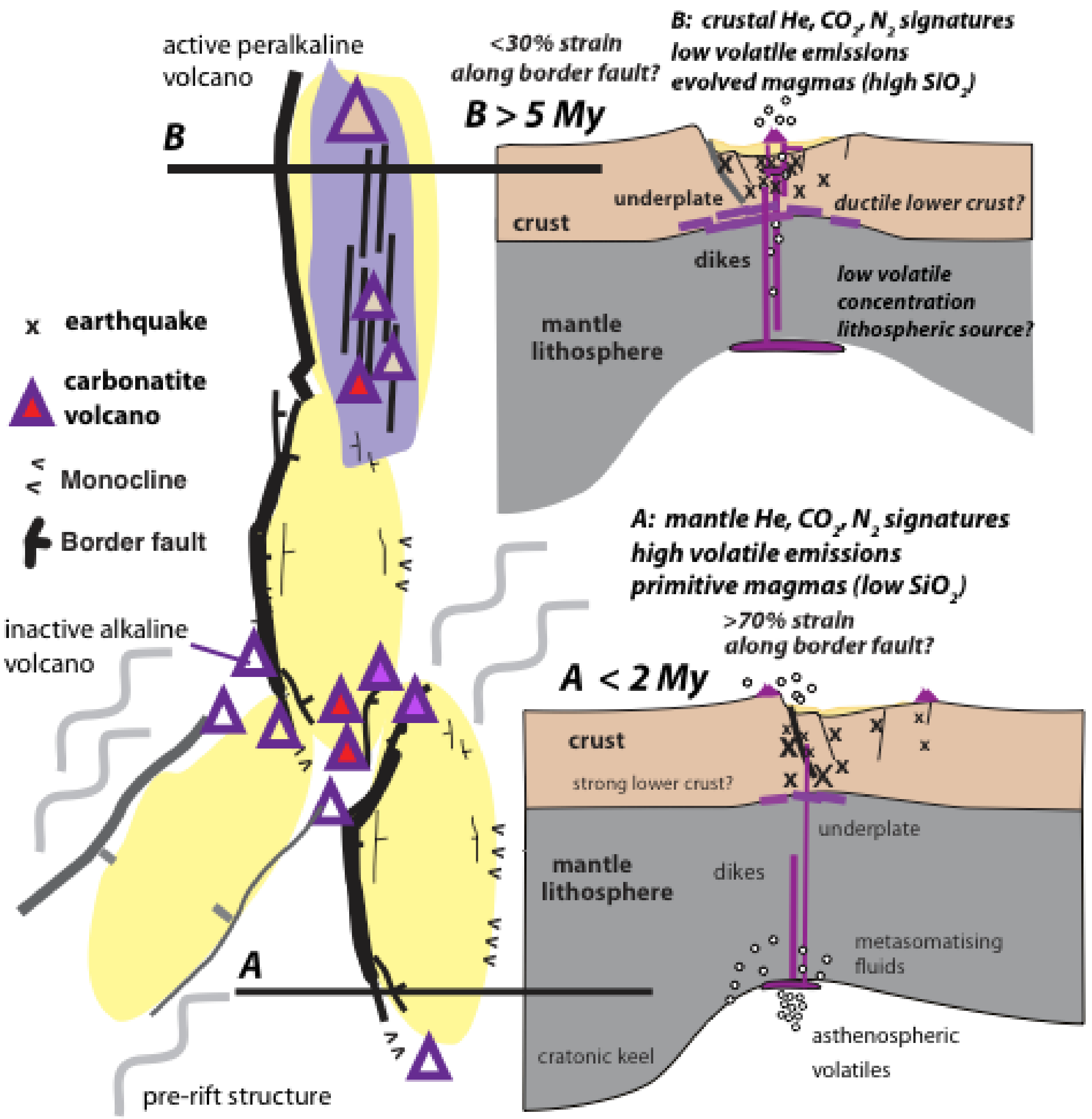
Expect larger magnitude, but longer repeat time EQs in SW rift arm, with lateral heterogeneities in rheology likely zones of strain concentration

Repeat times - Little calibration

only 2 paleotrenching studies in EAR

Conclusions

- Diffuse plate boundary deformation occurs over zones much broader than the fault bounded rift valleys, extending into the deeply rooted cratons.
- Davie ridge sector on oceanic lithosphere shows localized deformation and efficient seismic energy release.
- Increase in aseismic deformation with greater volume/time span of magmatism. Magma intrusion + creep
- Opening velocities estimated from inversion of sparse CMT data provide strain rates and extensional velocities an order of magnitude or more lower than those predicted by rigid plate models of geodetic data.
- Long faults Young and amagmatic sectors of the rift zone have a greater risk of large magnitude earthquakes than zones of magma intrusion, but repeat times may be << less th. The Southwestern rift zone, the Tanganyika rift, the Tanzania Divergence and the Davie ridge may pose the greatest earthquake and tsunami/seiche hazards.

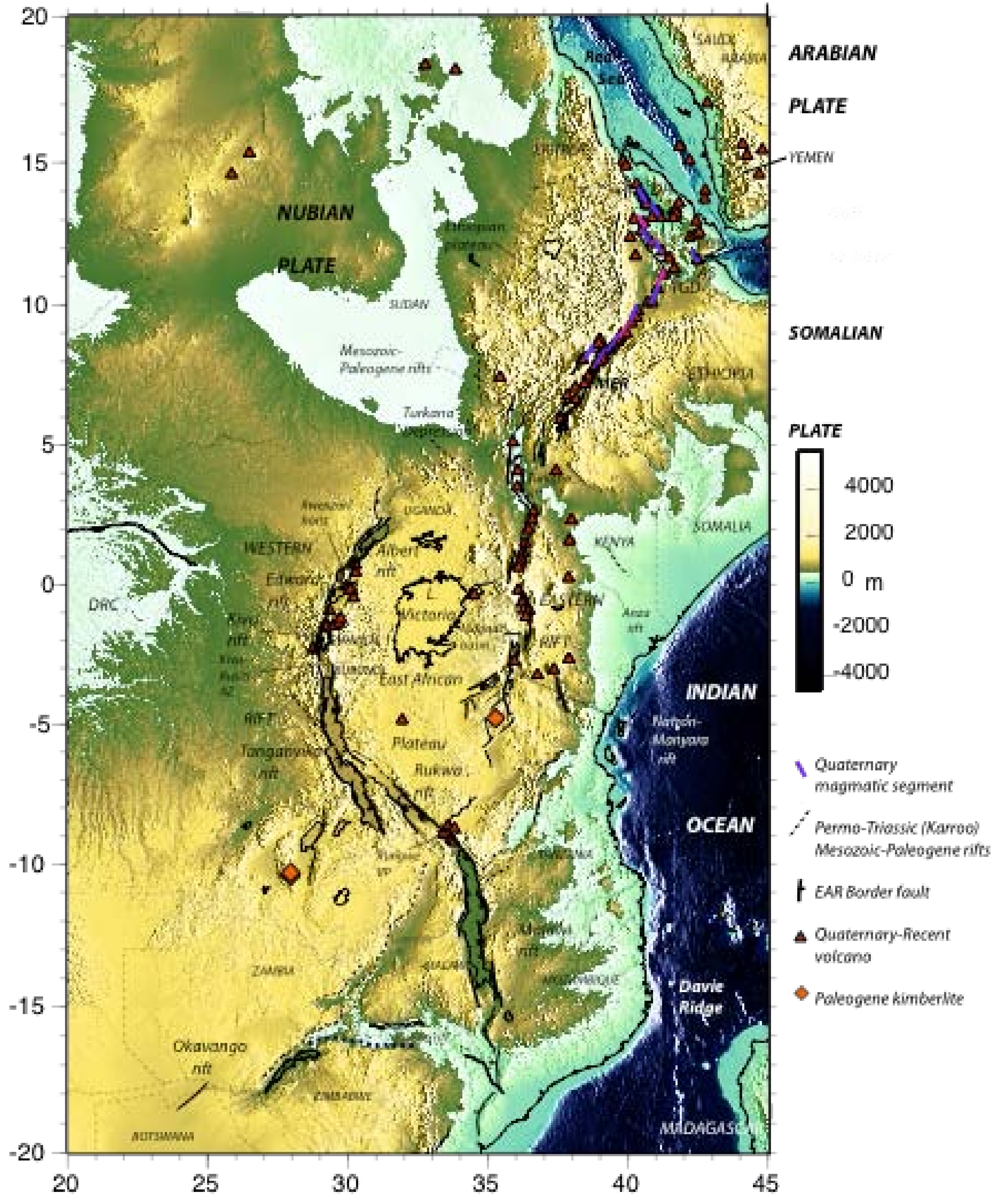


Bialas et al. 2010 : < 100 km-thick, strong continental lithosphere can be rifted if magma is present.

Yet – rift in NE Tanzania - lithosphere > 100 km in thickness (Ritsema et al., 1998).

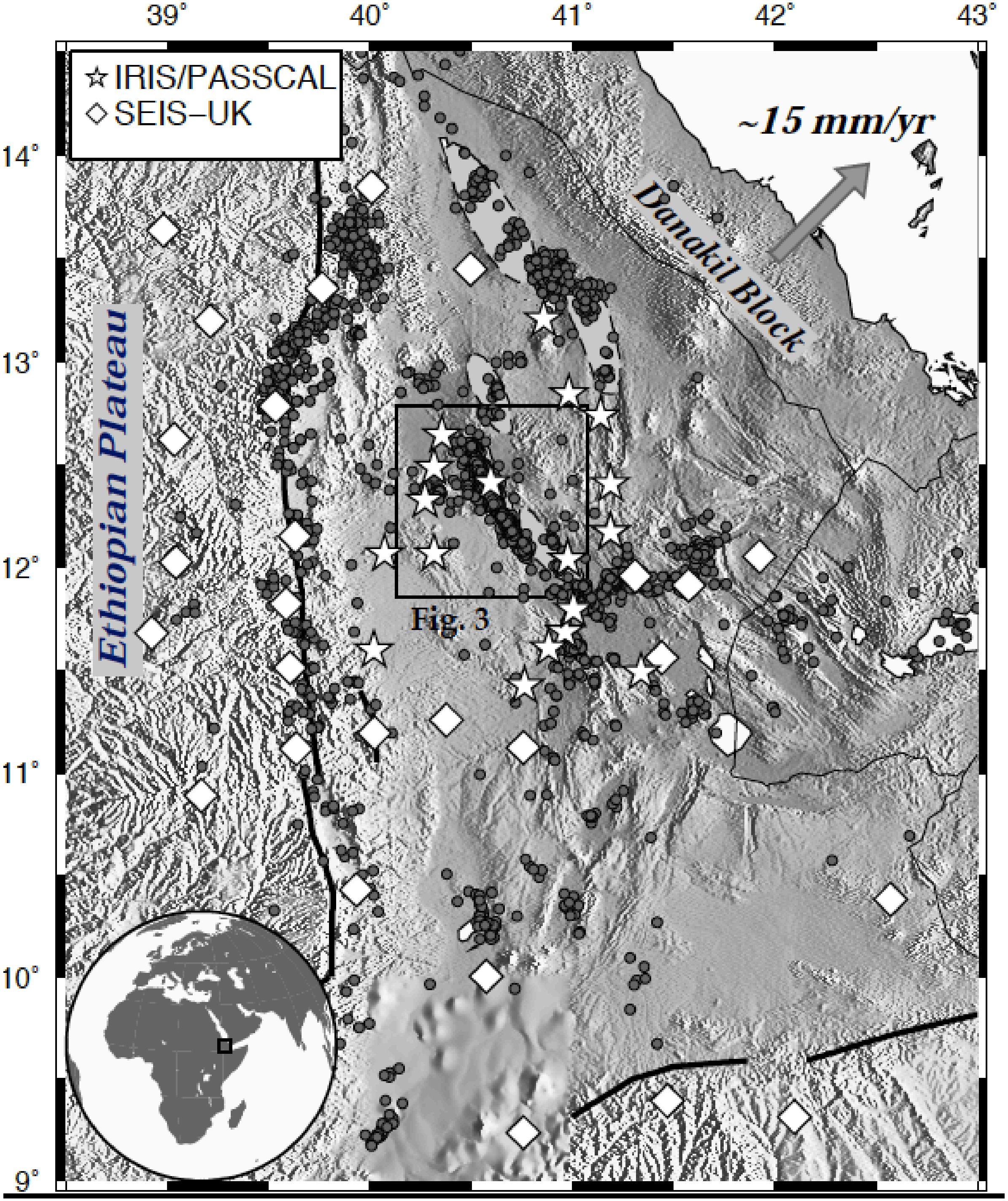
Carbonatite volcanoes and volatile emissions - volatiles/metasomatism may precondition lithosphere (e.g.,Fischer et al., 2009; Rooney et al., 2009)

Use strain distribution as an indicator volcanoes.



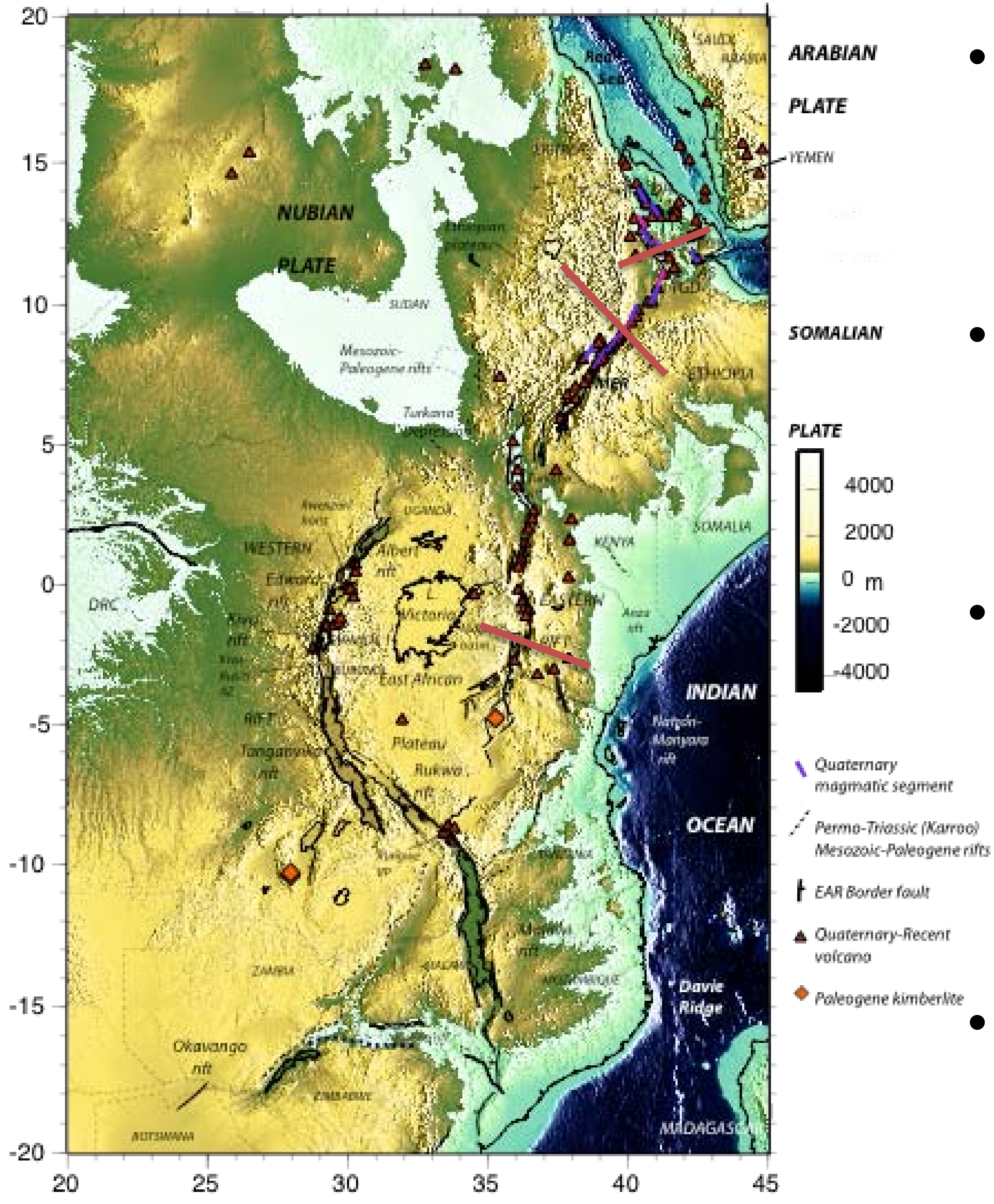
1) Seafloor spreading in Red Sea north of 14N
2) Seafloor spreading in Gulf of Aden propagates westward into Afar depression
3) Oldest volcanism in Ethiopia-Yemen – 40 Ma – kimberlites emplaced (orange)
4) Initial rifting of S Red by 28 Ma; initial rifting in Turkana by 25 Ma
5) Magmatism and faulting young southward
6) Rifts are strain localizations in Proterozoic-Panafrican orogenic belts around Tanzania, Congo, Zimbabwe, Bangweulu block

EAR encompasses a wide range of rift sectors – with without magmatism, strong/weak lithosphere, ages



Seismicity 2005/6; 10.2007 to 10.2009 PASSCAL+Seis UK arrays

Belachew et al., JGR, 2011



- Use sparse active source seismic profiles and MT data to constrain volume of intrusives
- Use geochron and plate kinematic constraints to estimate minimum intrusion rates
- Compare with magma production rates from 2005-2010 diking episodes in Afar – 0.4 km^3 yr^{-1}; 1.5 km^3 in ~3 days
- Compare with arc magmatism rates