The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2053-10

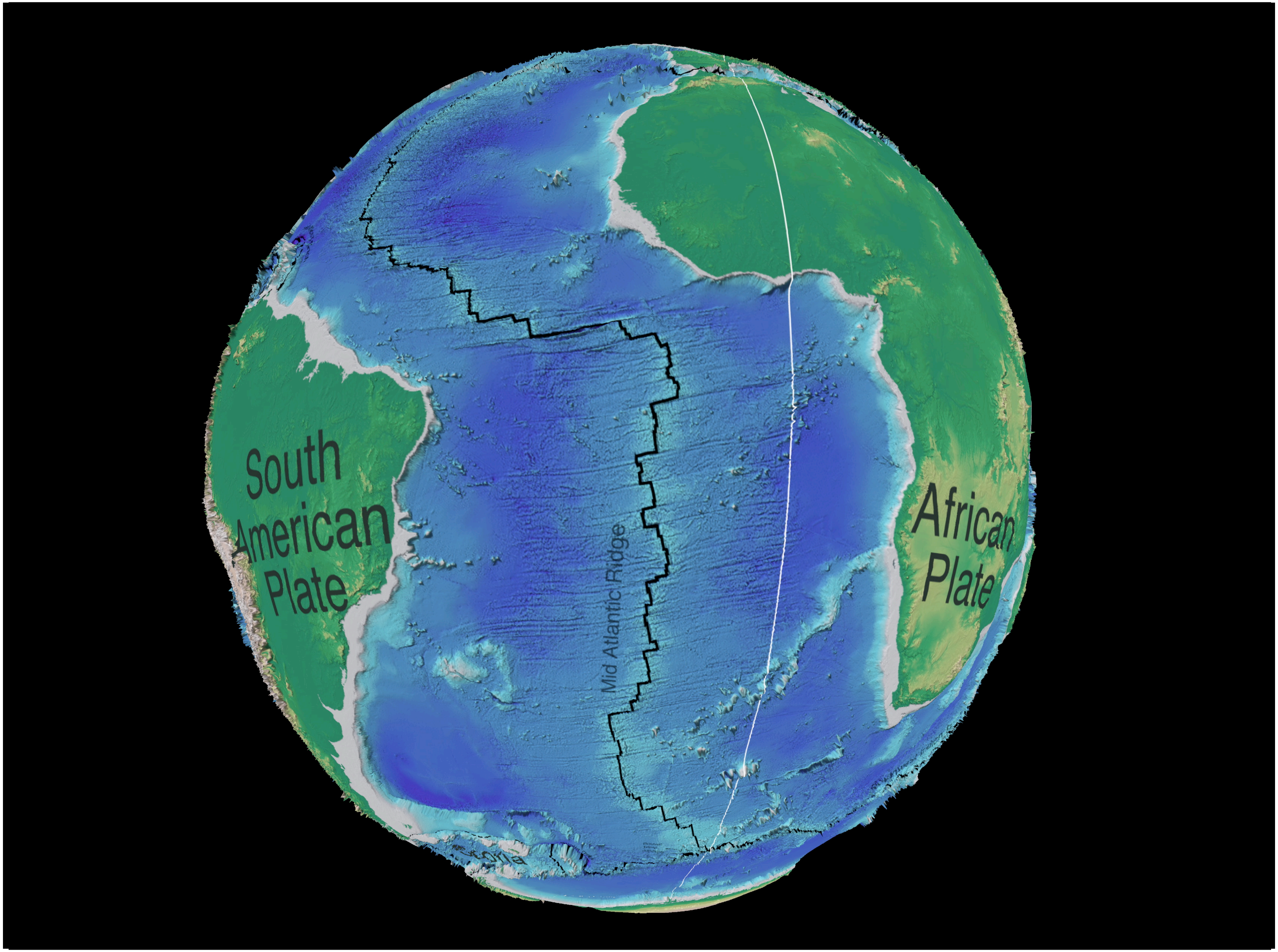
Advanced Workshop on Evaluating, Monitoring and Communicating Volcanic and Seismic Hazards in East Africa

17 - 28 August 2009

Time and length scales of deformation in the East African Rift: Implications for EQ and Volcanic hazards

Cindy Ebinger

University of Rochester
USA

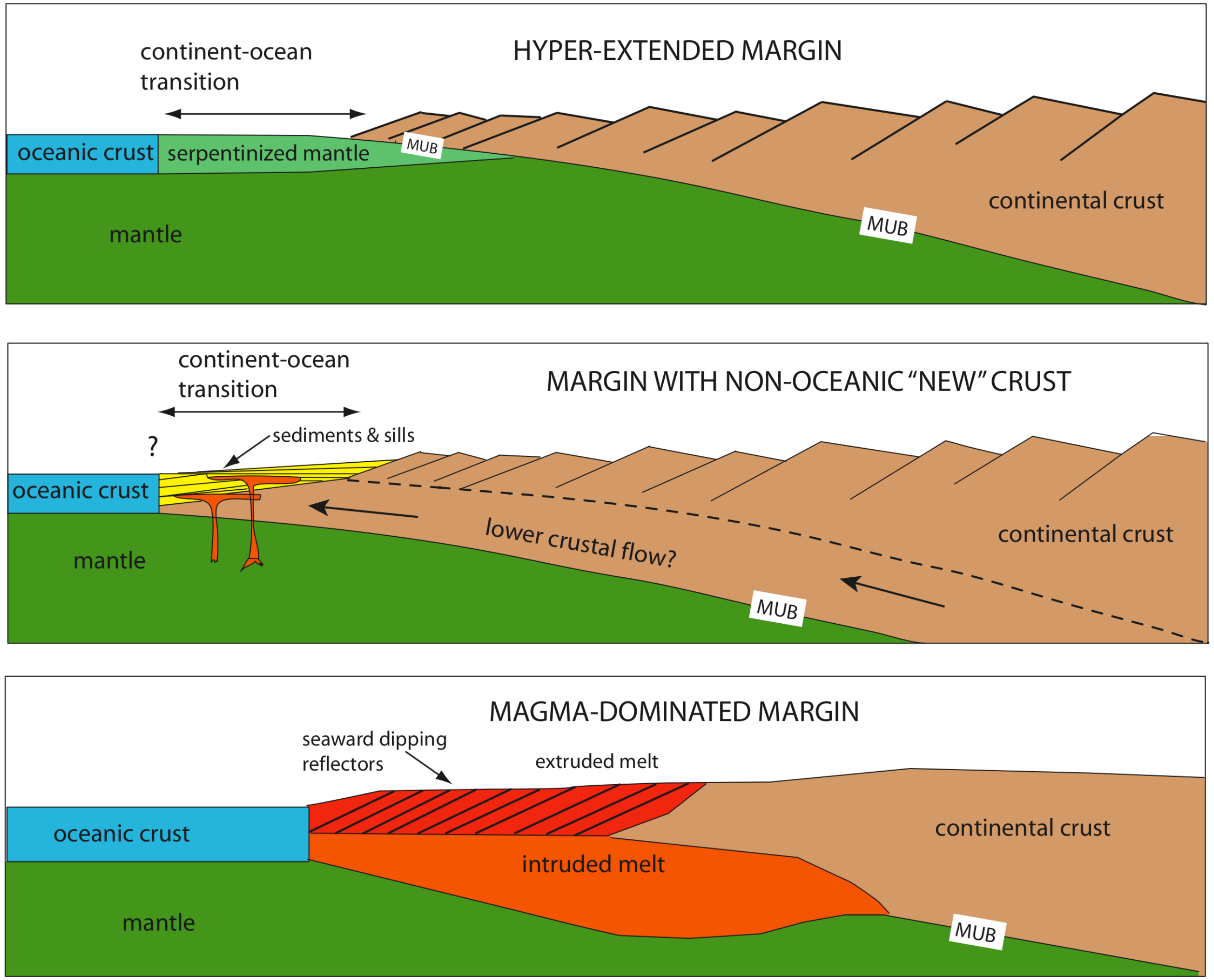

South American Plate
African Plate
Mid Atlantic Ridge

Time and length scales of faulting and magmatism within the East African rift system

Cindy Ebinger, University of Rochester

Work in progress from Manahloh Belachew and Dustin Coté

Current conceptual models for continental rupture



MUB = mafic-ultramafic boundary

Coffin et al., 2008

TEAMWORK – MULTIDISCIPLINARY STUDIES

Geodecists, structural geologists, petrologists, seismologists

Technical, software, hardware support from PASSCAL/Seis-UK, UNAVCO, AAU, UDSM, UCLAS, etc

HARD WORK

Science Communication

Implications for Rates

- Slow spreading – 3 -6 mm/yr in EAR south of triple junction; 20 mm/yr north
- During rifting crises, rates of ~m/day possible

- Implications – High instantaneous rates, plus growing population centers in rift increases seismic and volcanic risk to that of some subduction settings

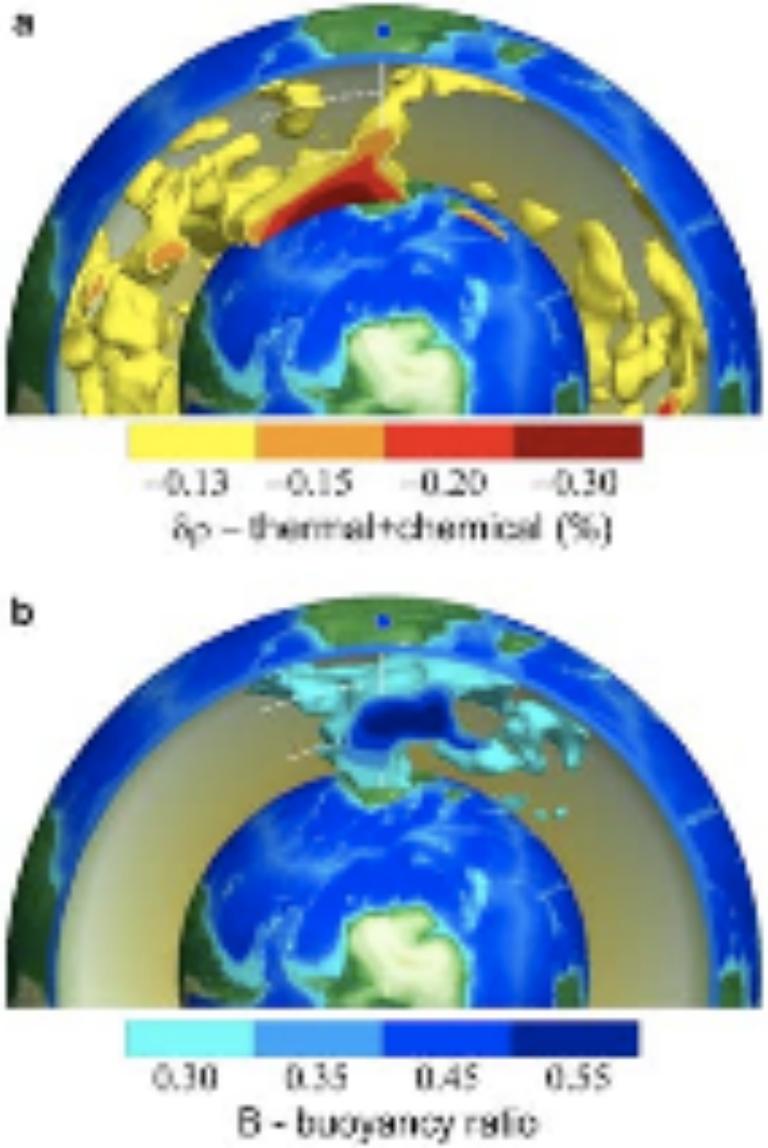
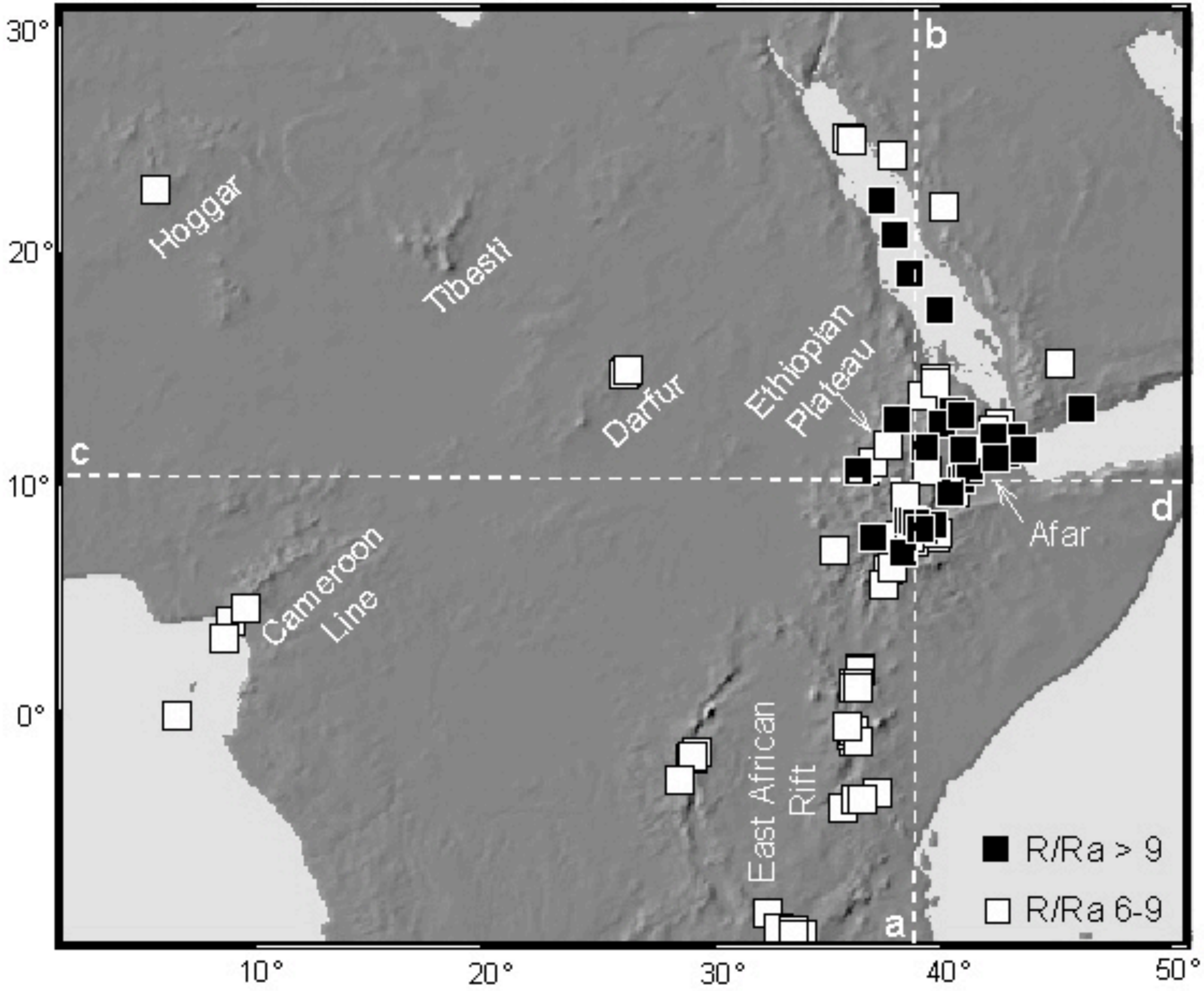
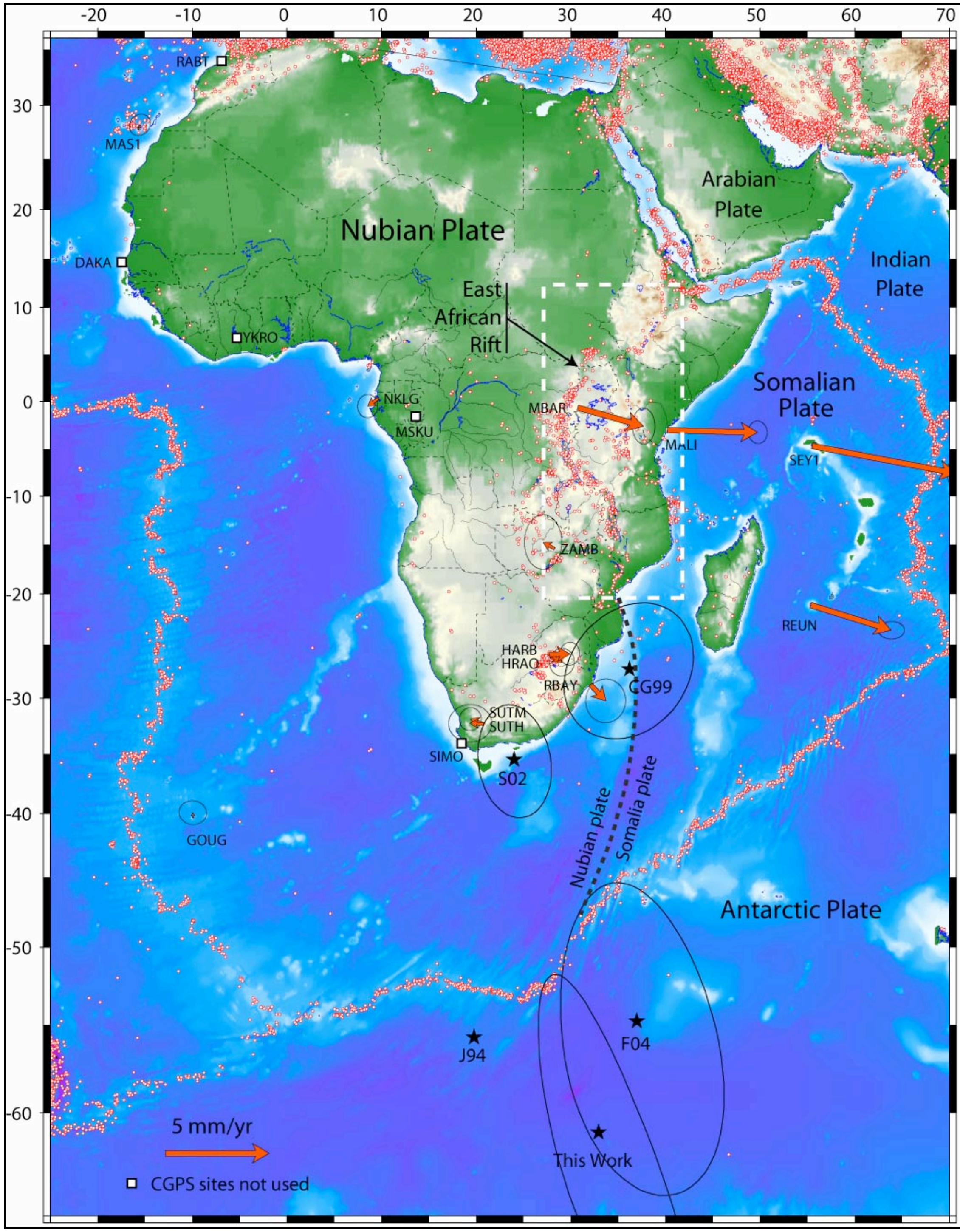


Figure 4. Total density perturbation field and buoyancy ratio $B = |\delta\rho^{chemical}/\delta\rho^{thermal}|$ within the African superplume region. (a) Summation of the thermally- and chemically-induced density fields yields negative density (positive buoyancy) of the superplume structure. (b) The buoyancy ratio field reveals that the superplume buoyancy is strongly reduced by the positive-density chemical component near 1800 km depth. The superplume structure appears to bend eastward within the same region as a response to buoyancy deficiency.

Simmons et al., 2007



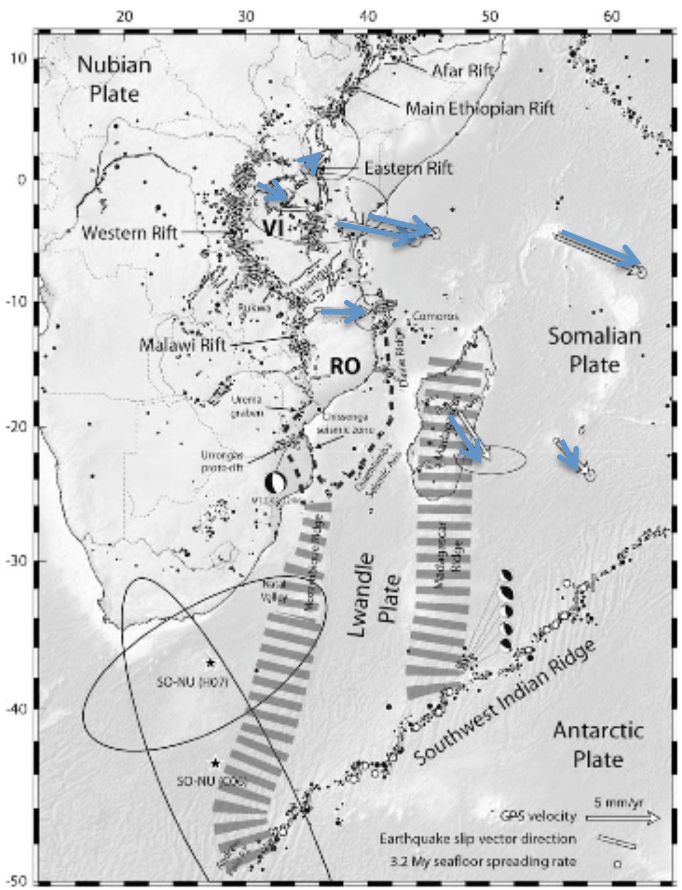
He anomaly patterns - Pik et al., 2006

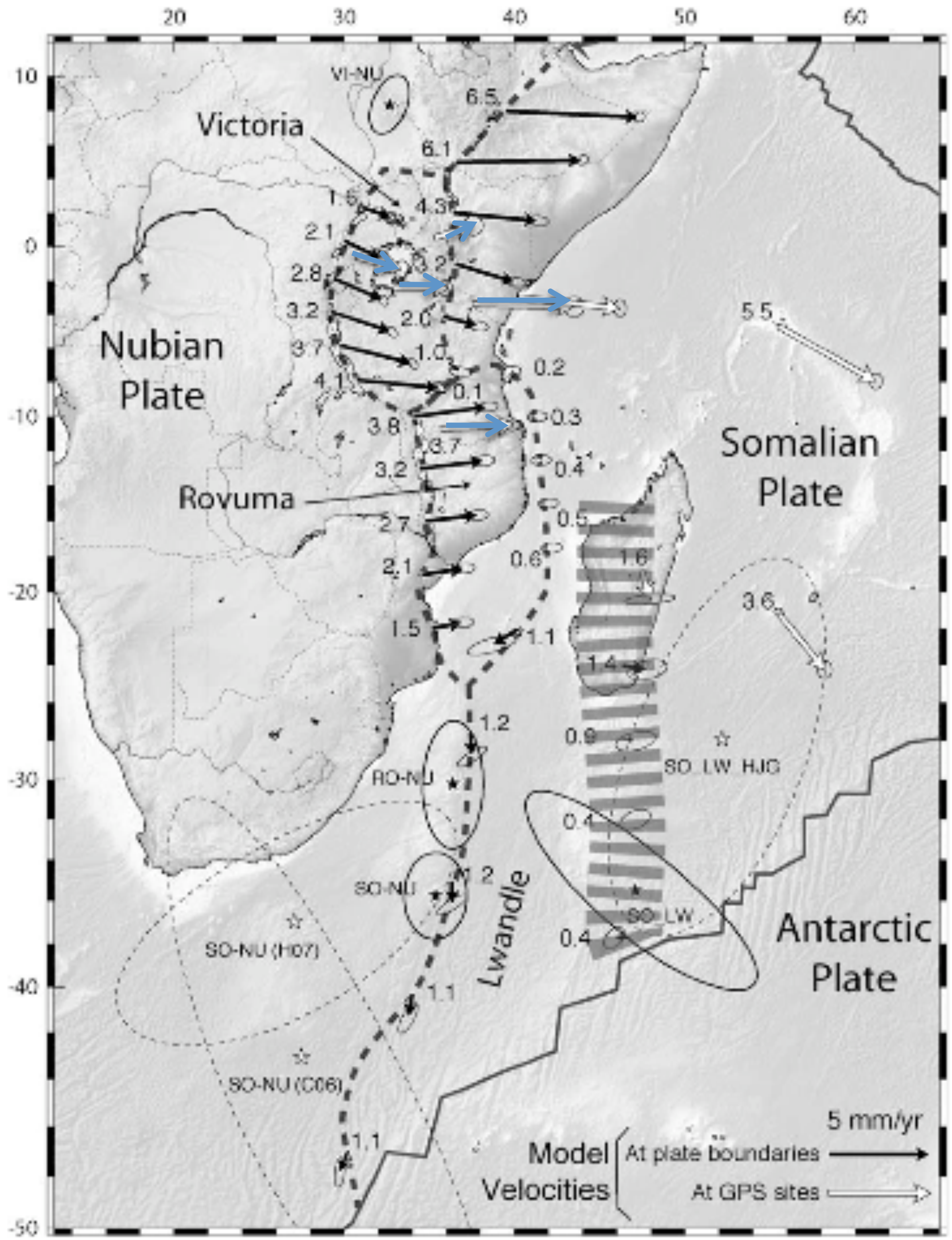


Chris Hartnady noted a

differential opening direction between WR and ER, and suggested that central Tanzania Archaean craton was a discrete microplate.

Fig. from Calais et al., 2006





Stamps, Calais et al. GRL 08

Time Scales of Rifting Cycle

- Far-field + body forces- decades to centuries - depends on inherent strength, lateral density contrasts, plate pull
- Fault slip, magma intrusion - minutes to months
- Viscous relaxation - years
- Isostatic compensation for the deformation - 10^4 years
- Aseismic slip – ????? need more collocated GPS + seismic

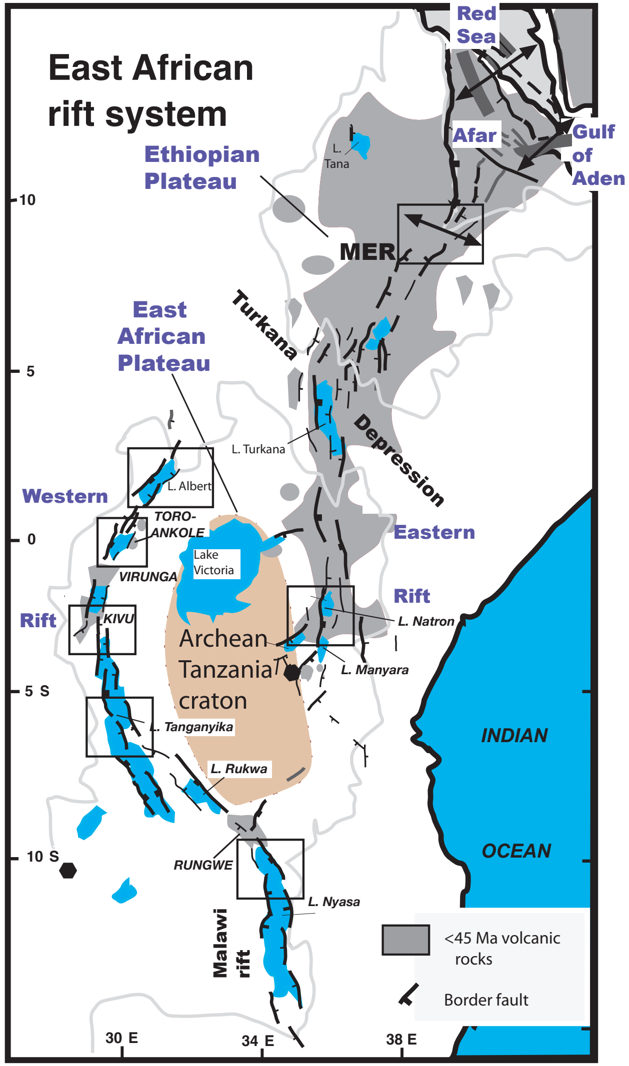
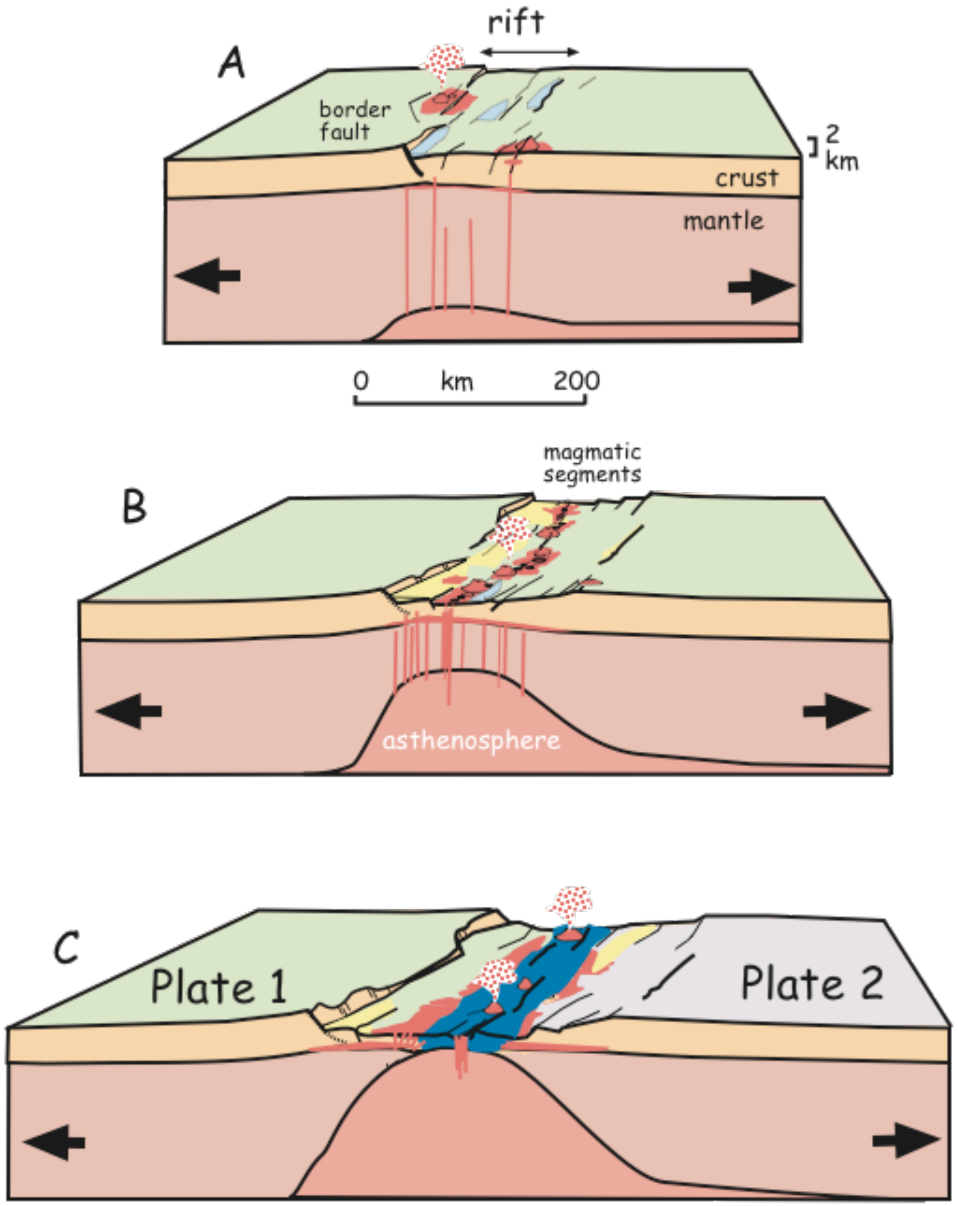


Fig. 5, Ebinger and Scholz



Rifting with Magma

Stage 1 - Thick lithosphere, long repeat times; large stored stresses.

Stage 2: Strain localization to zones of magma intrusion rather than older border faults

Stage 3: Onset of seafloor spreading similar to ultra-slow ridges - ridge jumps, 'off-axis' volcanism, and long repeat times.

Fig 3.

Consistent patterns – predictive model for rift basins worldwide

- *Interactions between magma and segmented large offset faults.*
- *How do they interact in space and time?*

Shillington talk later…

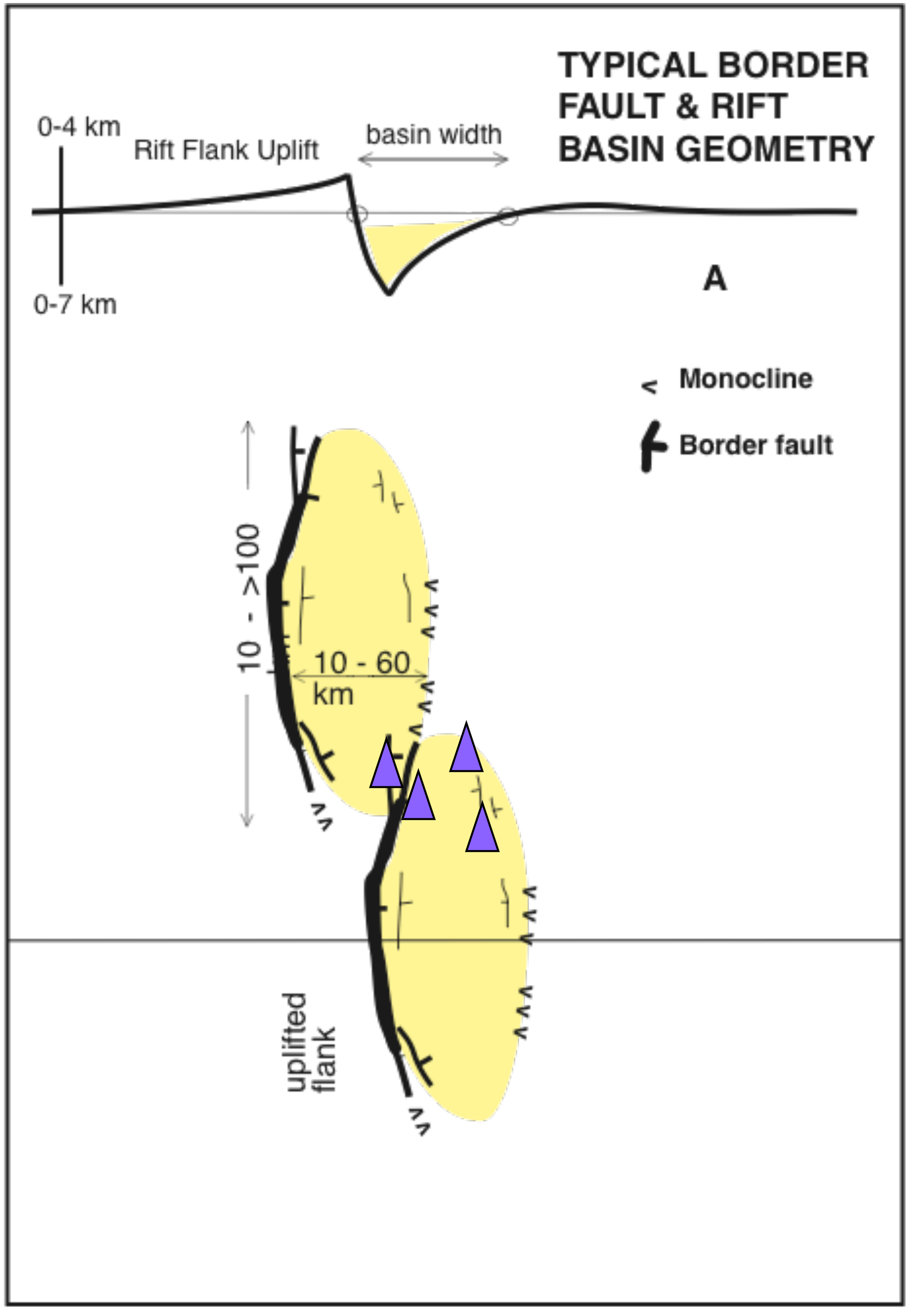
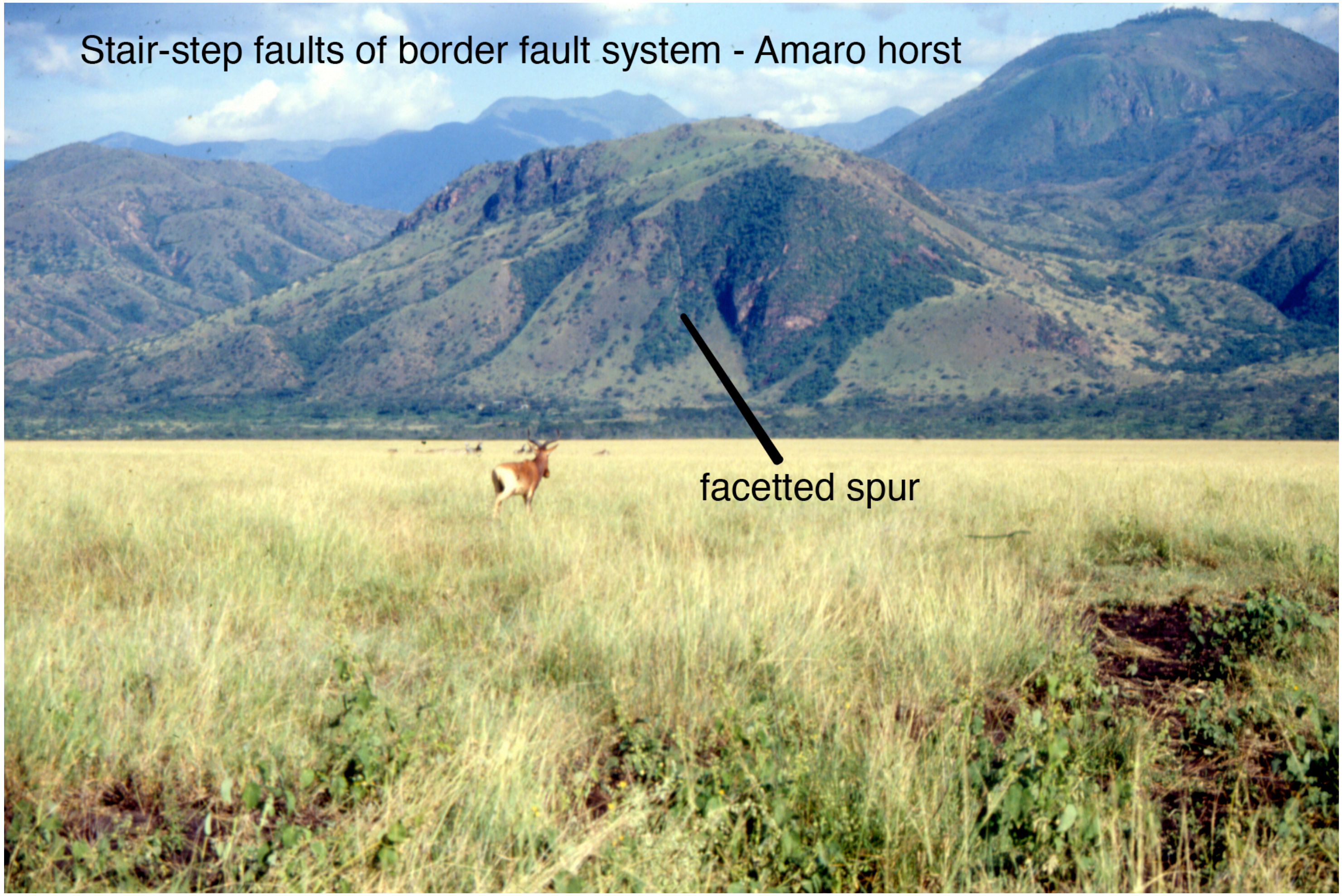
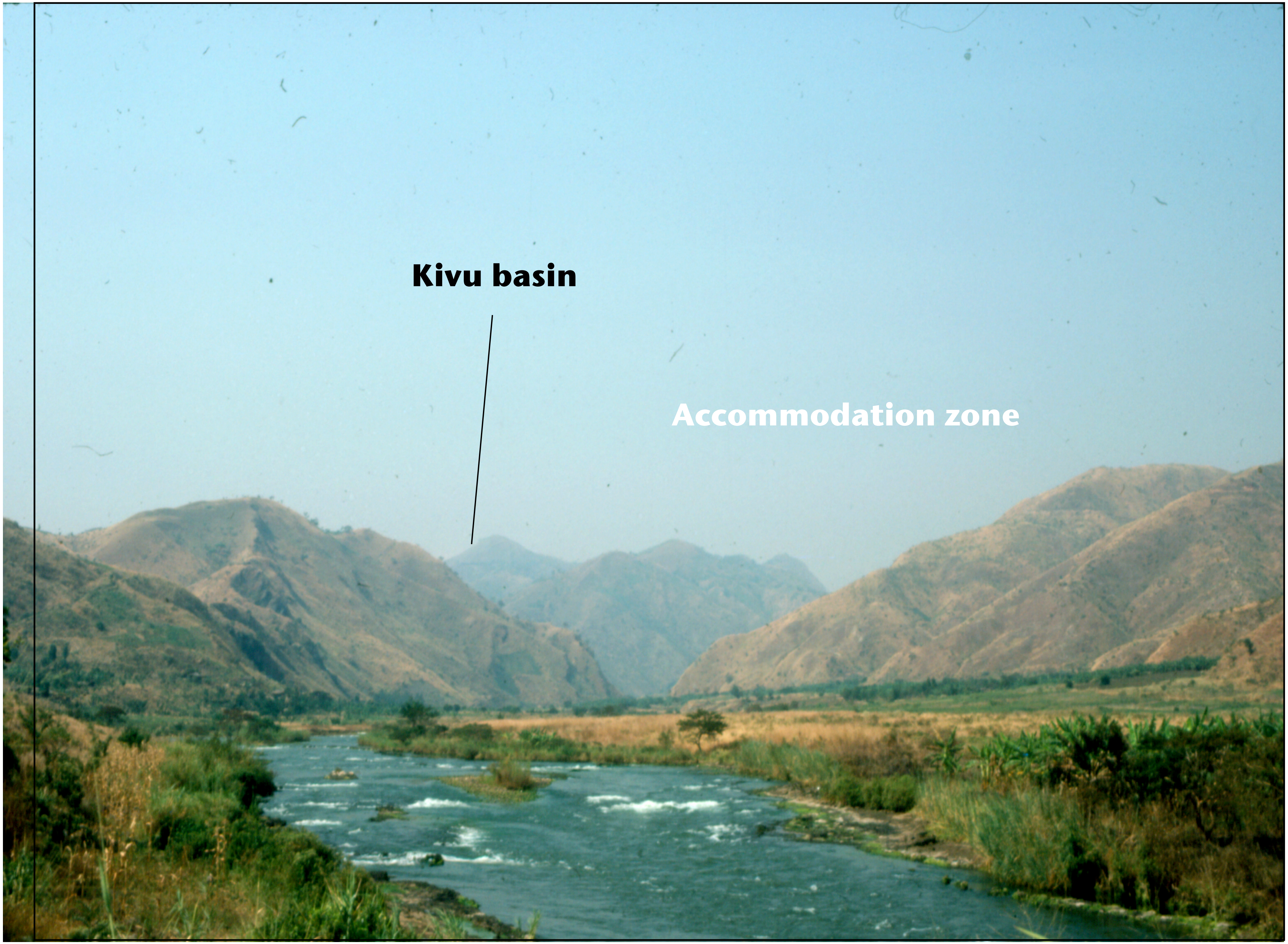
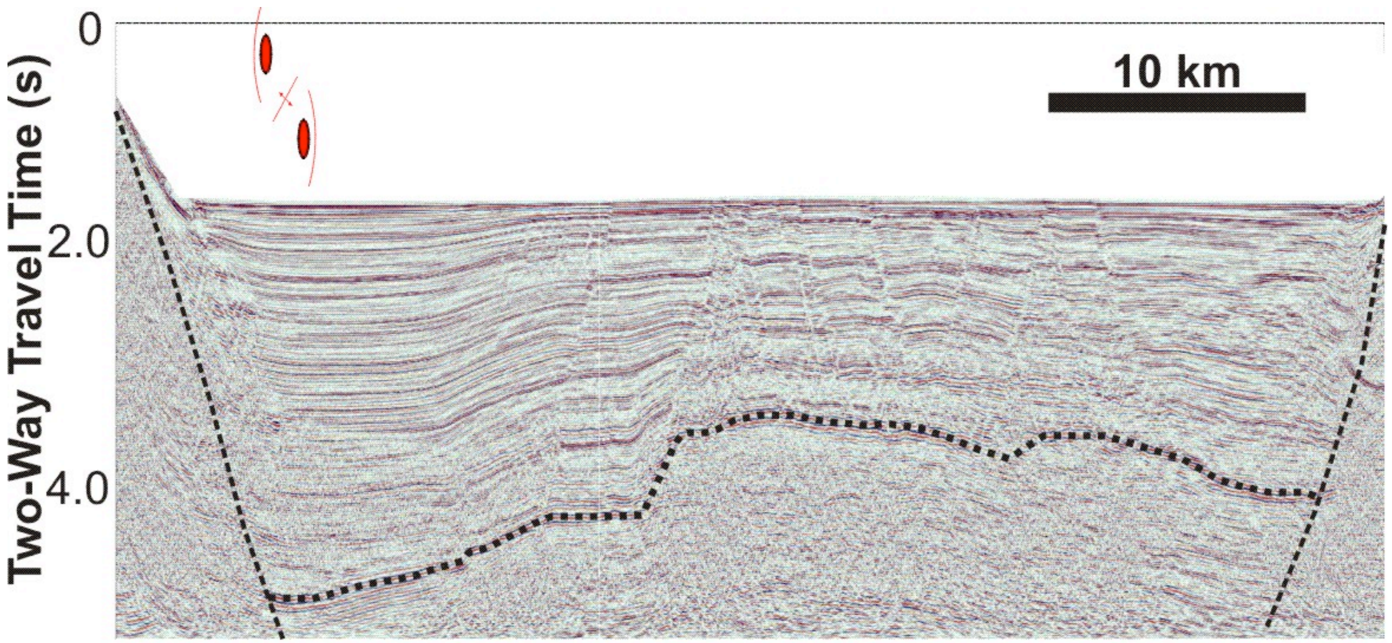
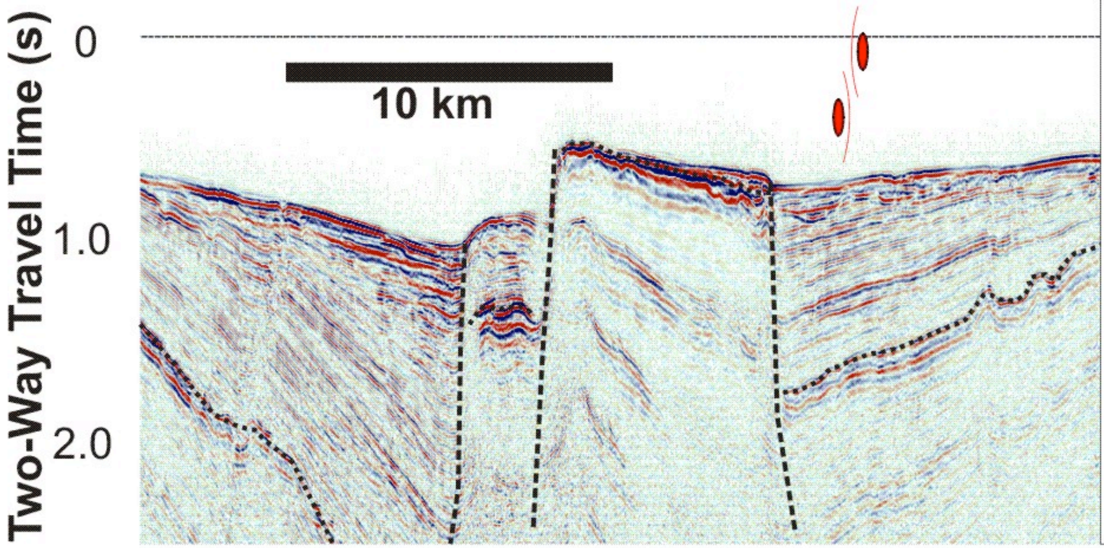


Figure 2. Ebinger et al.


Stair-step faults of border fault system - Amaro horst
facetted spur

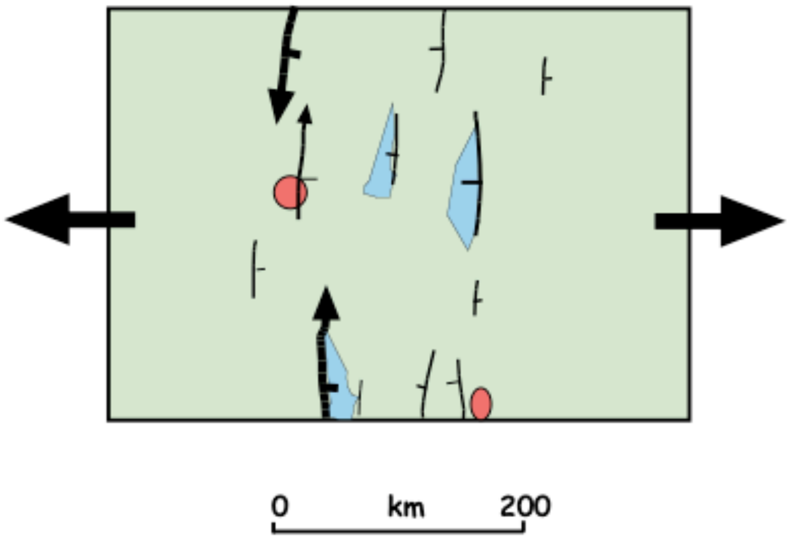

Kivu basin
Accommodation zone

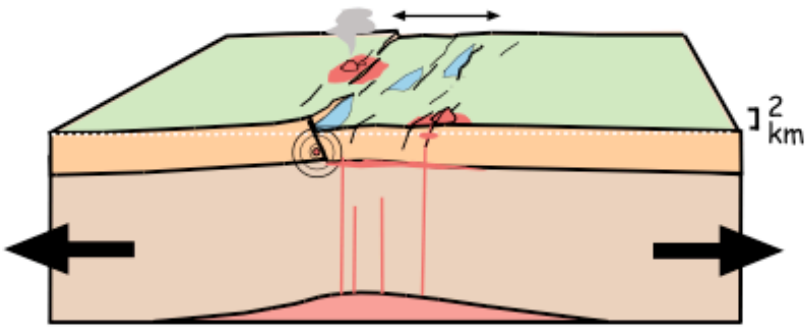




fault
map of
Tang.
rift here

Ebinger and Scholz, in Busby and Azor, Sedimentary Basins



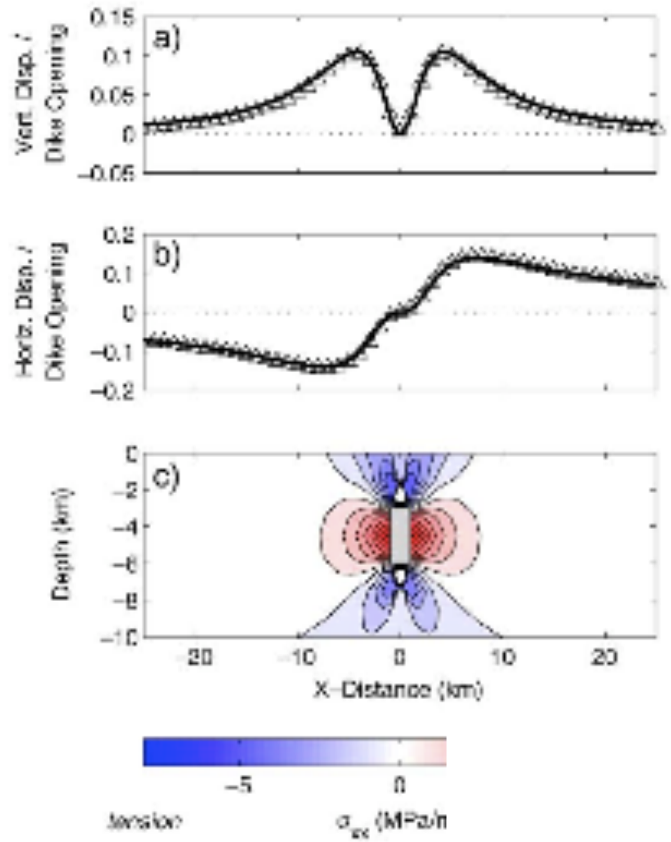


Front face ~ KRISP 94

Natron basin event, 2007 d'Oreye et al., Albaric et al.

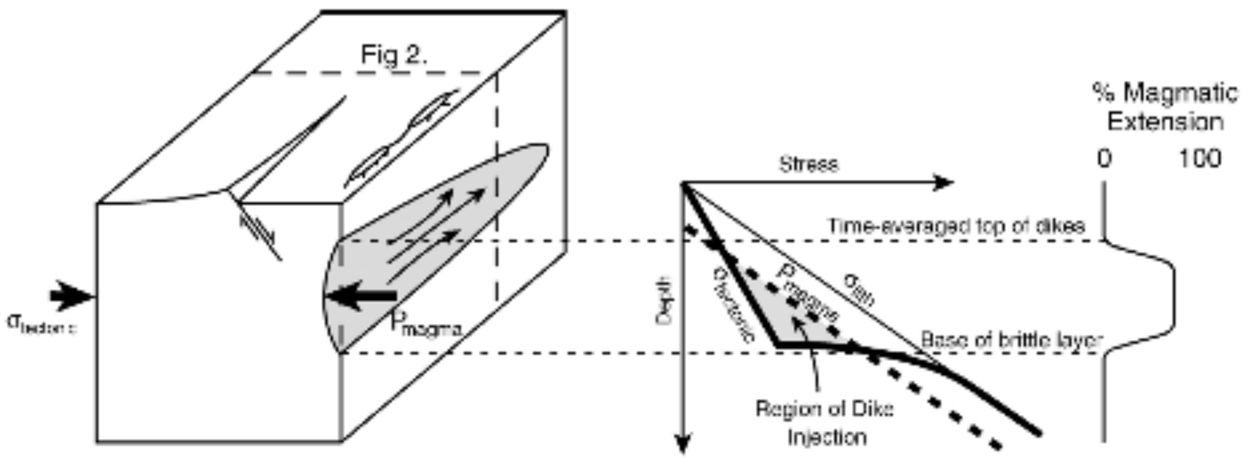
October 19 eruption of Ol Doinyo Lengai

Photo by Majura Songo, UDSM



Behn, Buck, Sacks,
EPSL, 2006

M.D. Behn et al. / Earth and Planetary Science Letters 246 (2006) 188–196 189



Implications for Hazards

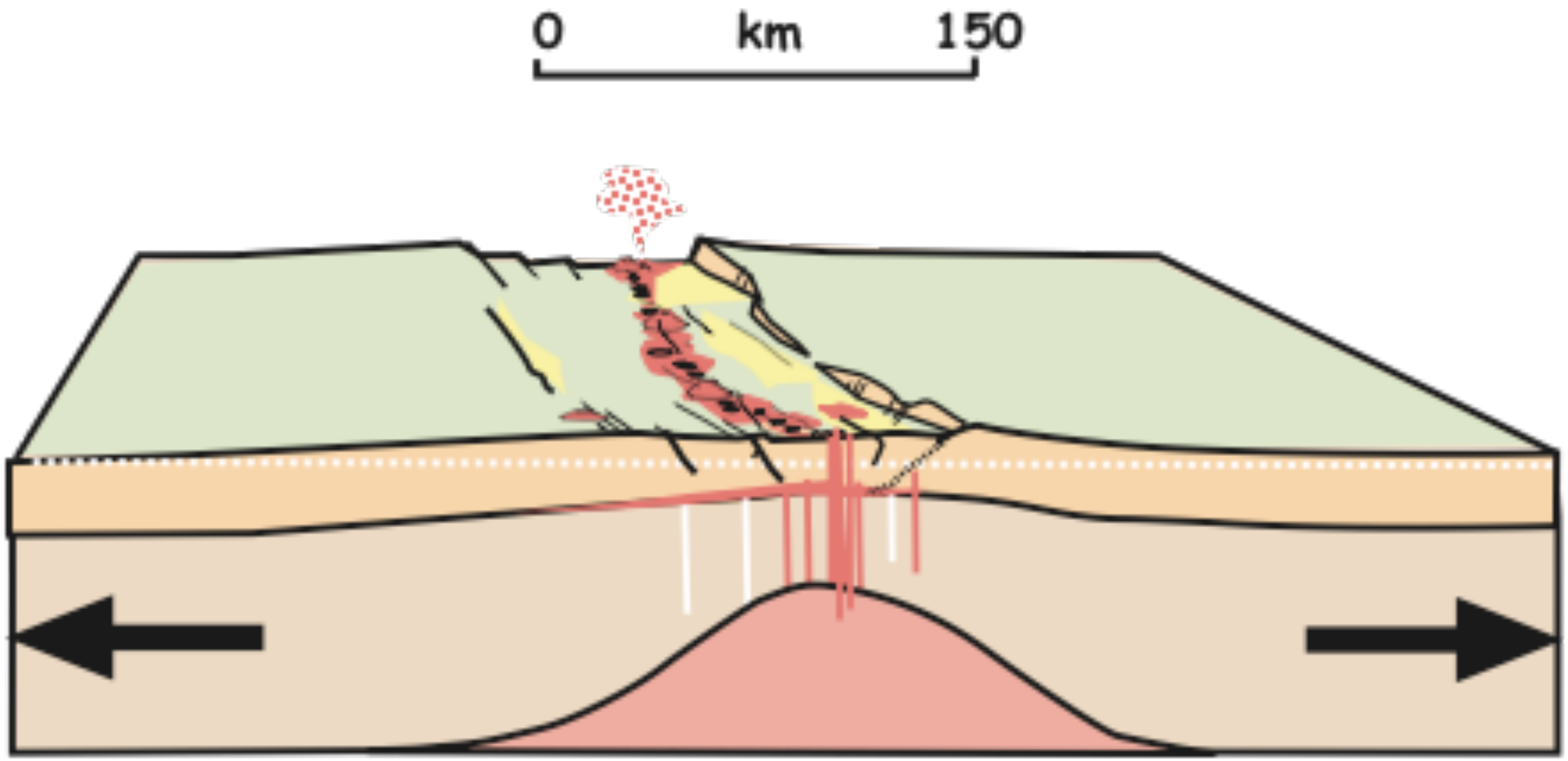
- Magma intrusion via ‘hidden’ subsurface dikes – hidden process

- Rifting crises, rates of ~m/day possible

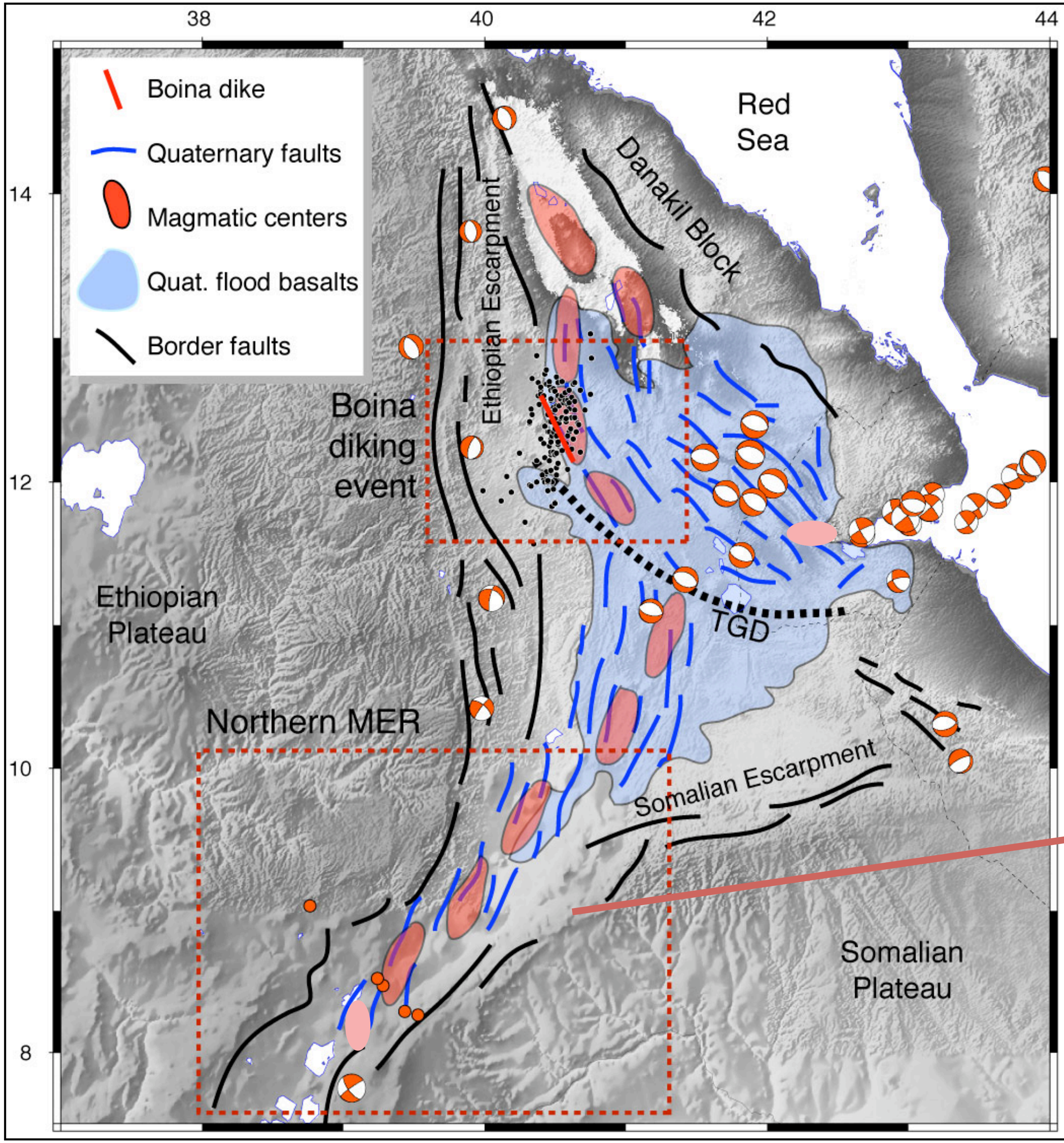
- Implications – High instantaneous rates, plus growing population centers in rift increases seismic and volcanic risk to that of some subduction settings

Length Scales of Rifting Cycle

- Regional magma-plate boundary situation 1000 km + scale
- Along-axis segmentation in both faulting and magmatism -50 to 100 km in EAR (may decrease with time)
- Entire segment may open during single episode - e.g., Dabbahu rifting episode; Malawi rift – Jackson and Blenkinsop example

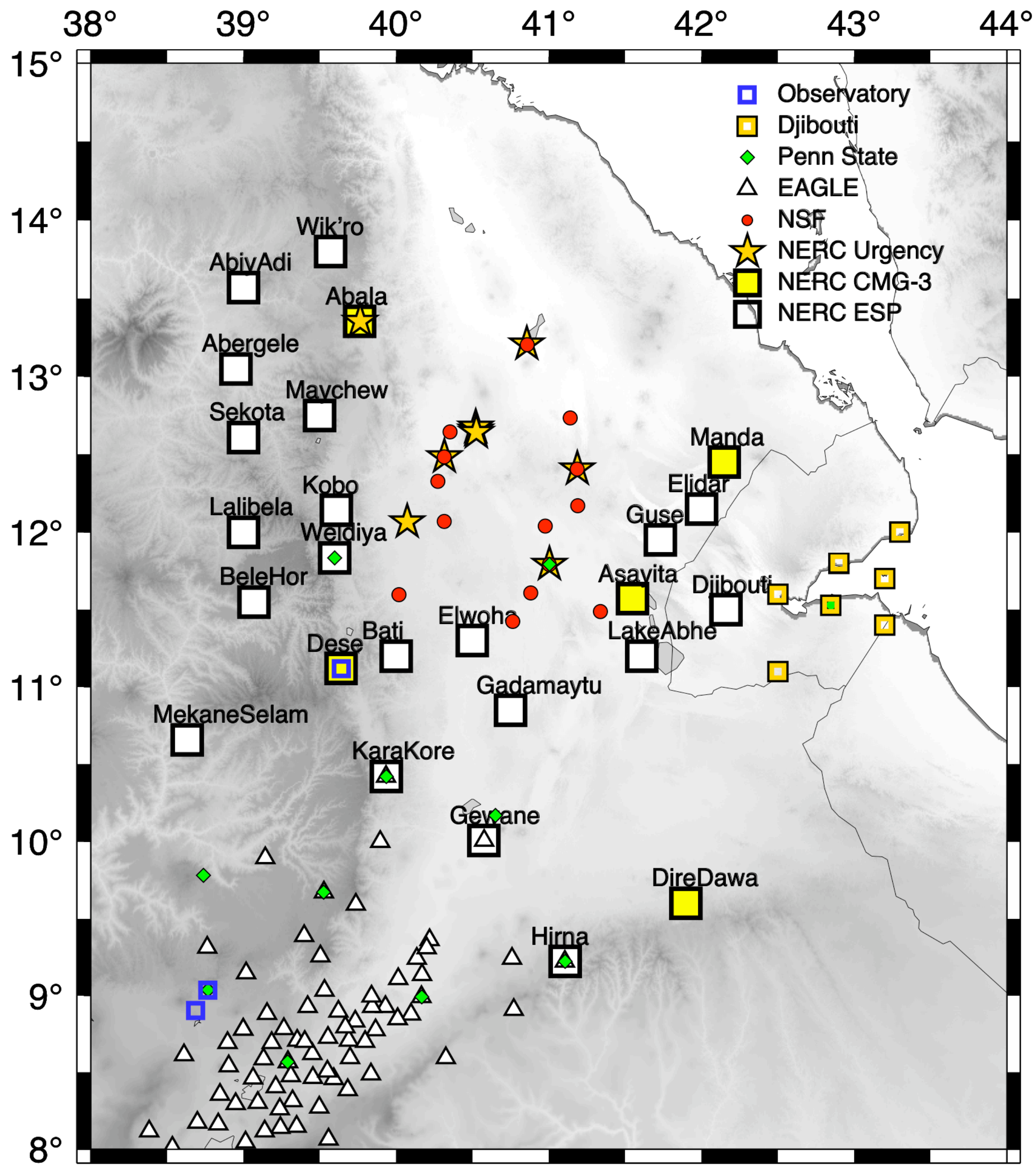


Minor crustal stretching, narrow zone of magma intrusion above mantle lithosphere thinned to <70 km = READY SUPPLY OF MELT

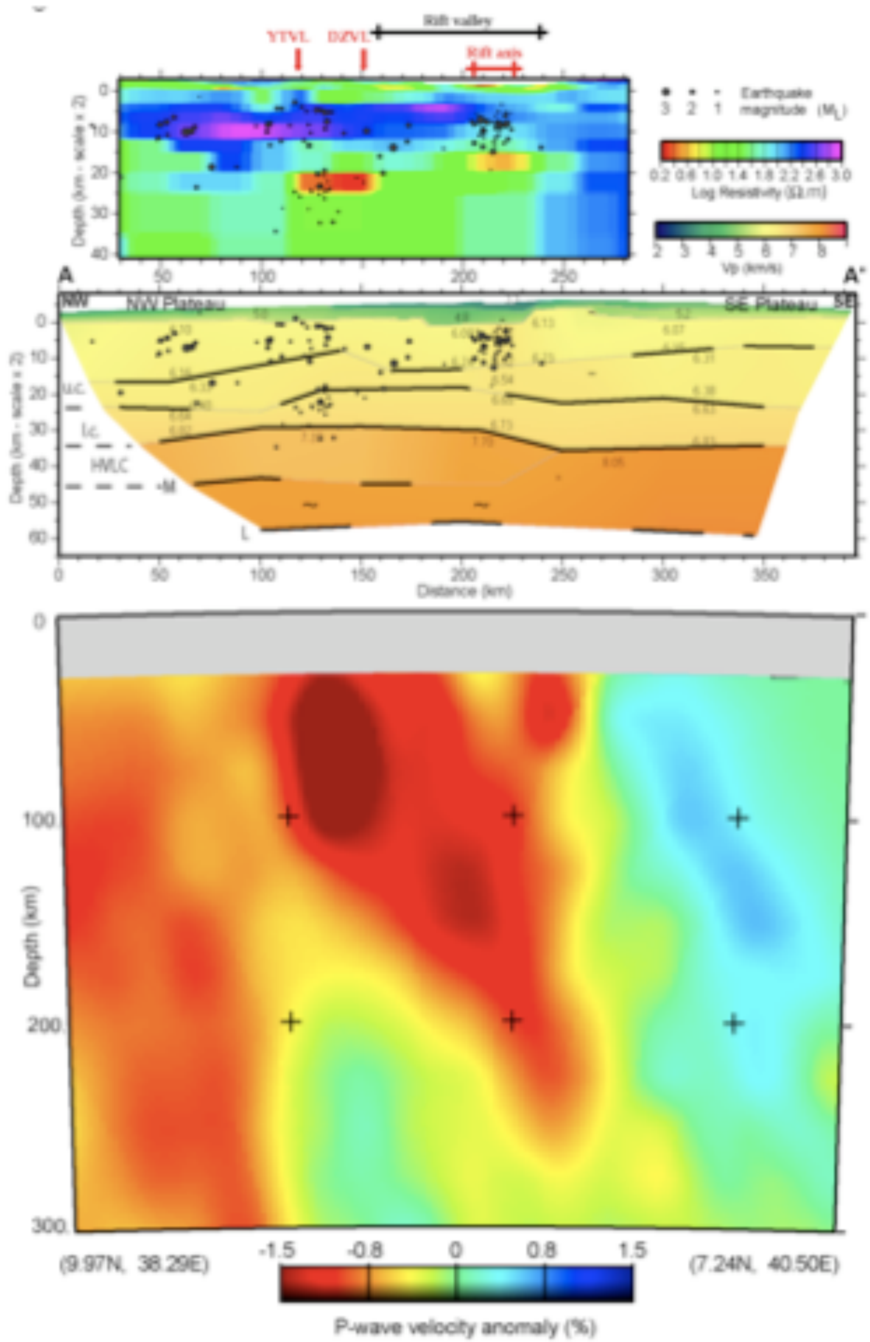


Quaternary strain localised to ~60 km long zones of fissures, aligned eruptive centres and faults - "magmatic segments "

EAGLE probed structure beneath magmatic segments - underlain by mafic intrusions and LVZ in thin mantle

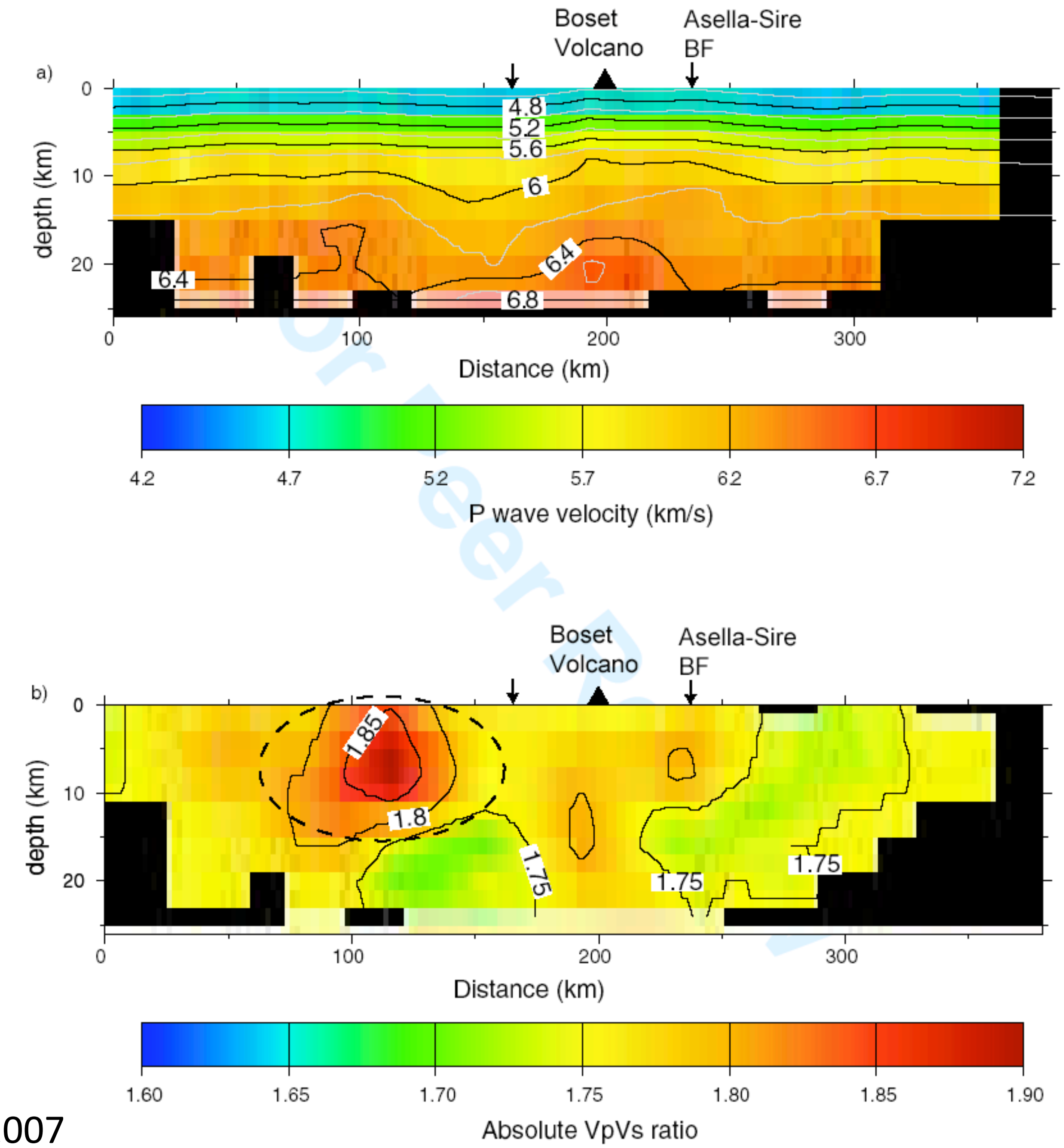


US-UK-Ethiopia partnership;
Triangles –
Data available for teaching, research;
Rest – work in progress – France, UK, US, Ethiopia, Djibouti

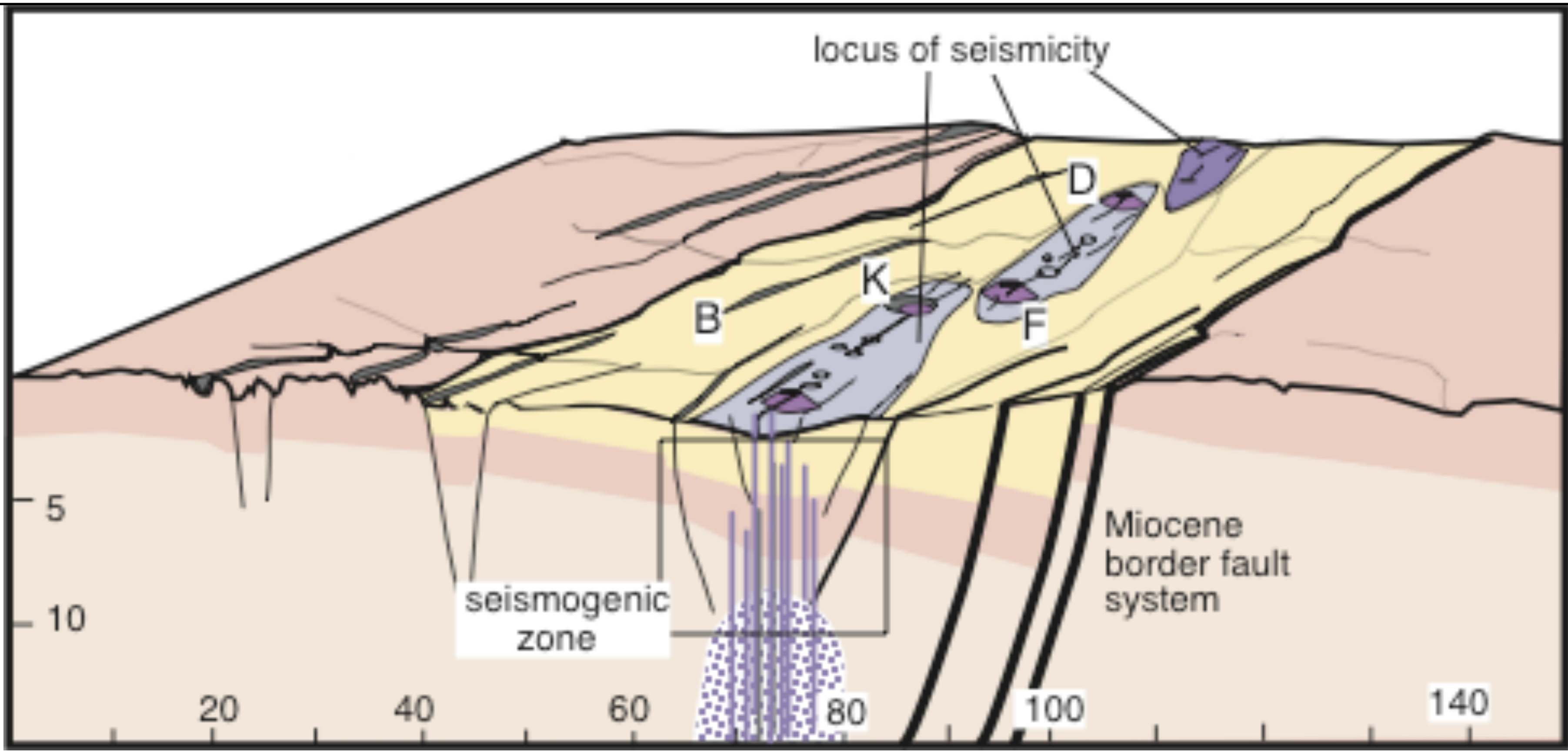


Keir, Bastow,
Cornwell, Whaler
Gcubed, 2009

617



Daly et al., GJI, 2007



Crustal segmentation defined by narrow zones of mafic intrusions that accommodate strain below 10 km; seismicity triggered by dike intrusions and dike-induced faulting. Steep faults; >50% have eruptive products along their length (<10 km- Casey et al., 2006).

Keir et al., JGR, 2006

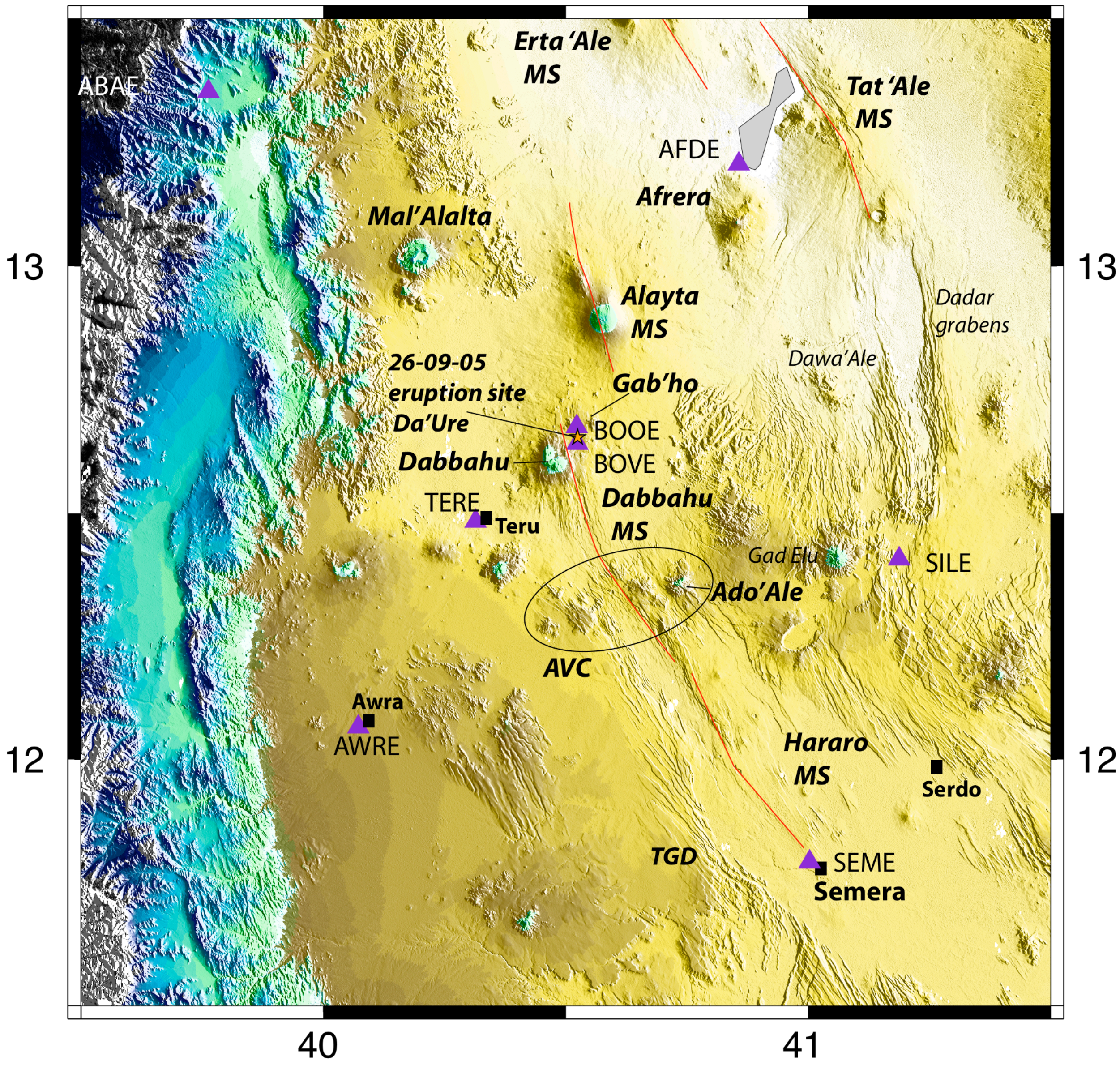
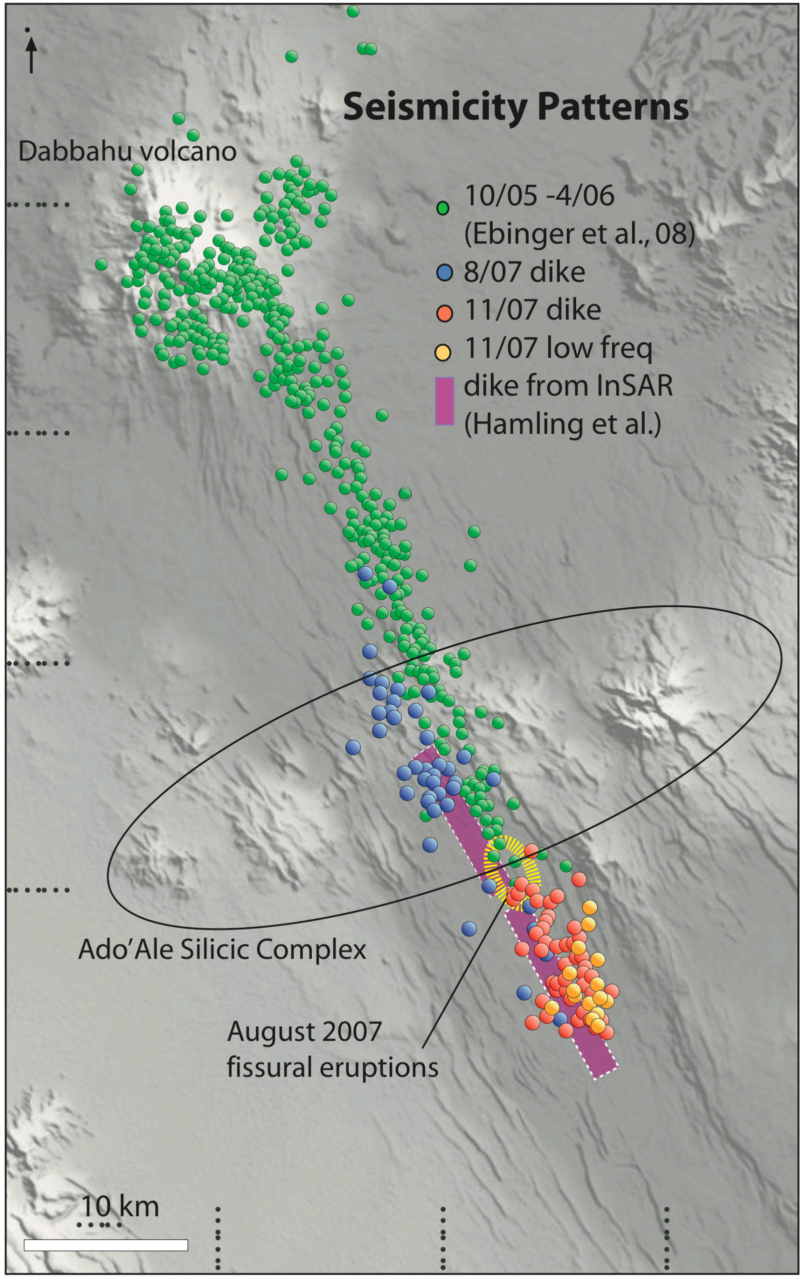


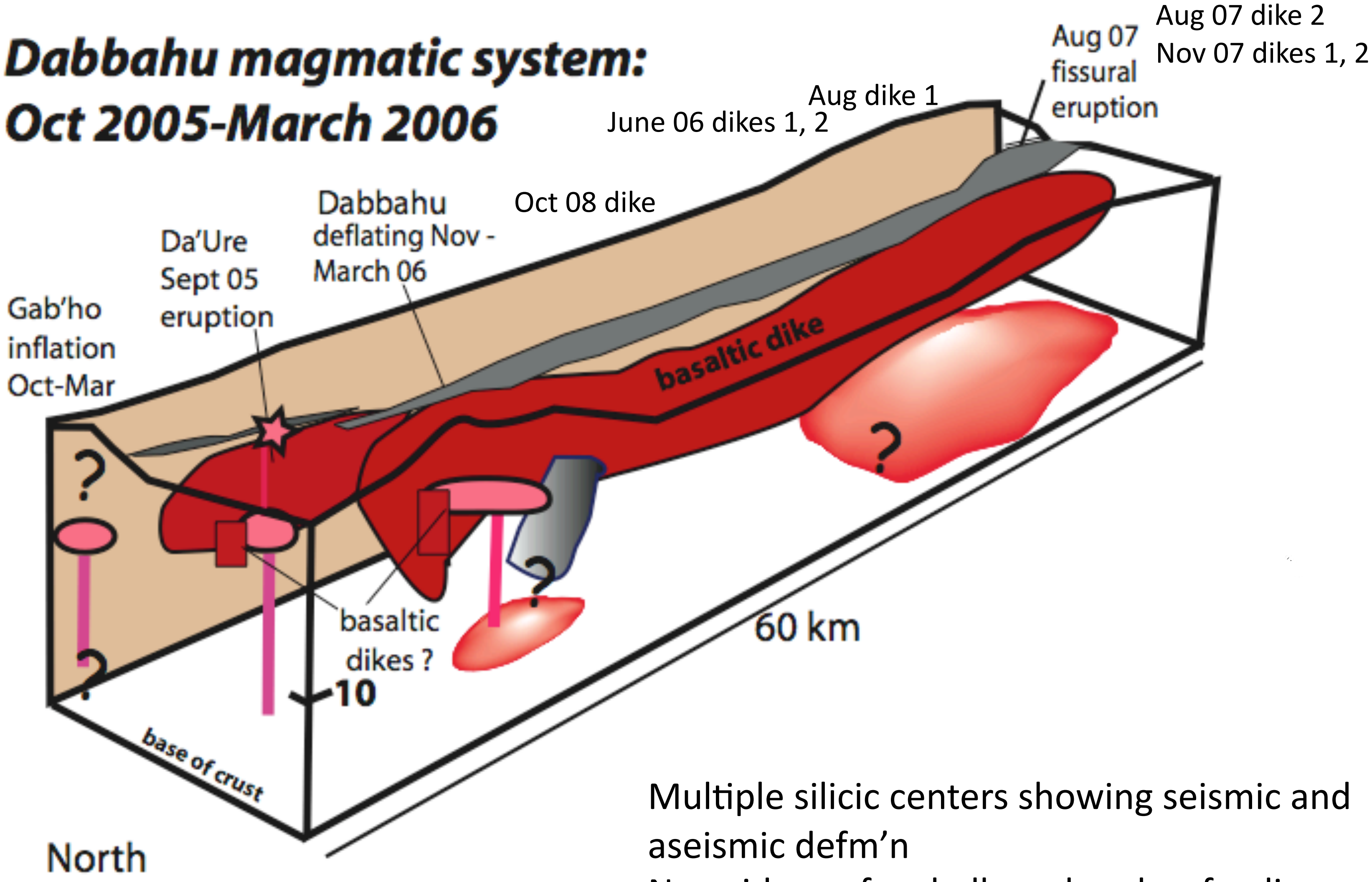
Figure 2. Ebinger et al. (revised)

March expedition to mid-segment. JRowland

3m-high white scarps - slip in July-Sept '06 - E Baker



Seismicity Patterns
Dabbahu volcano
10/05 -4/06
(Ebinger et al., 08)
8/07 dike
11/07 dike
11/07 low freq
dike from InSAR
(Hamling et al.)
Ado'Ale Silicic Complex
August 2007
fissural eruptions
10 km



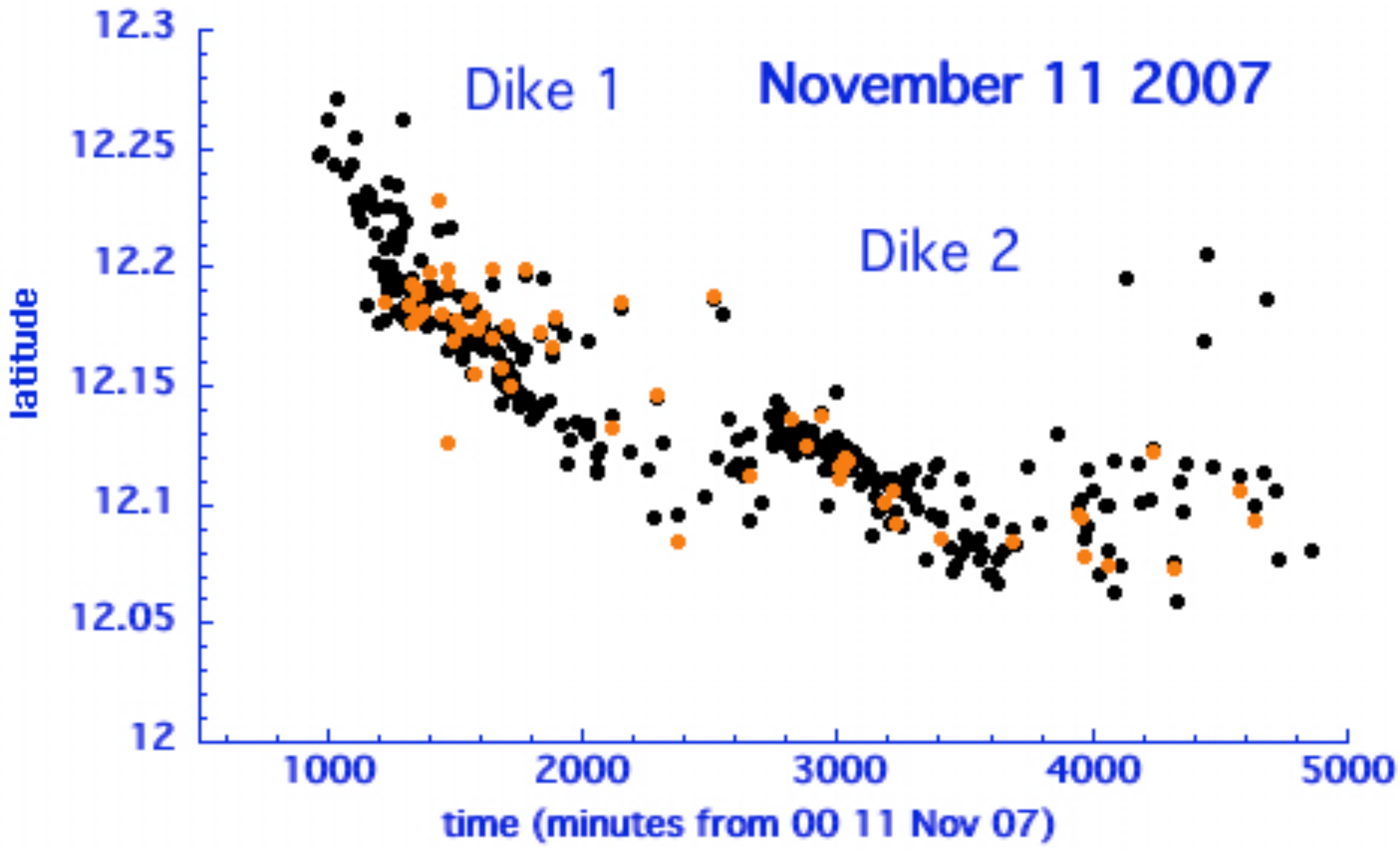
Multiple silicic centers showing seismic and aseismic defm'n

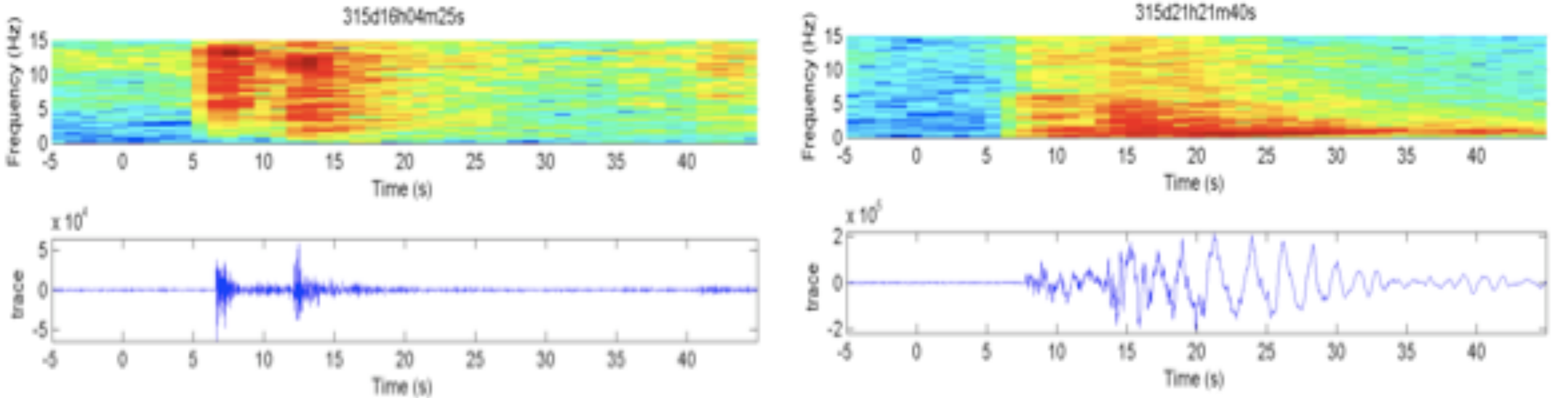
No evidence for shallow chamber feeding dikes

Ebinger et al. GJI, 08

- Centrally fed, ~60 km-long segment
- Dikes propagate northward and southward from segment center
- Shallow magma chambers with fractionated lavas at northern tip of segment where abuts ‘cold’ lithosphere (may have triggered rifting event- Ayele et al., 2009)
- Base crust/asthenospheric source zone from preliminary crustal tomography (no chamber shallower than 7 km)
- Time varying seismicity patterns reveal magma injection process

June 06, August 07, November 07 dikes are each multiple dikes – each 10-20 km





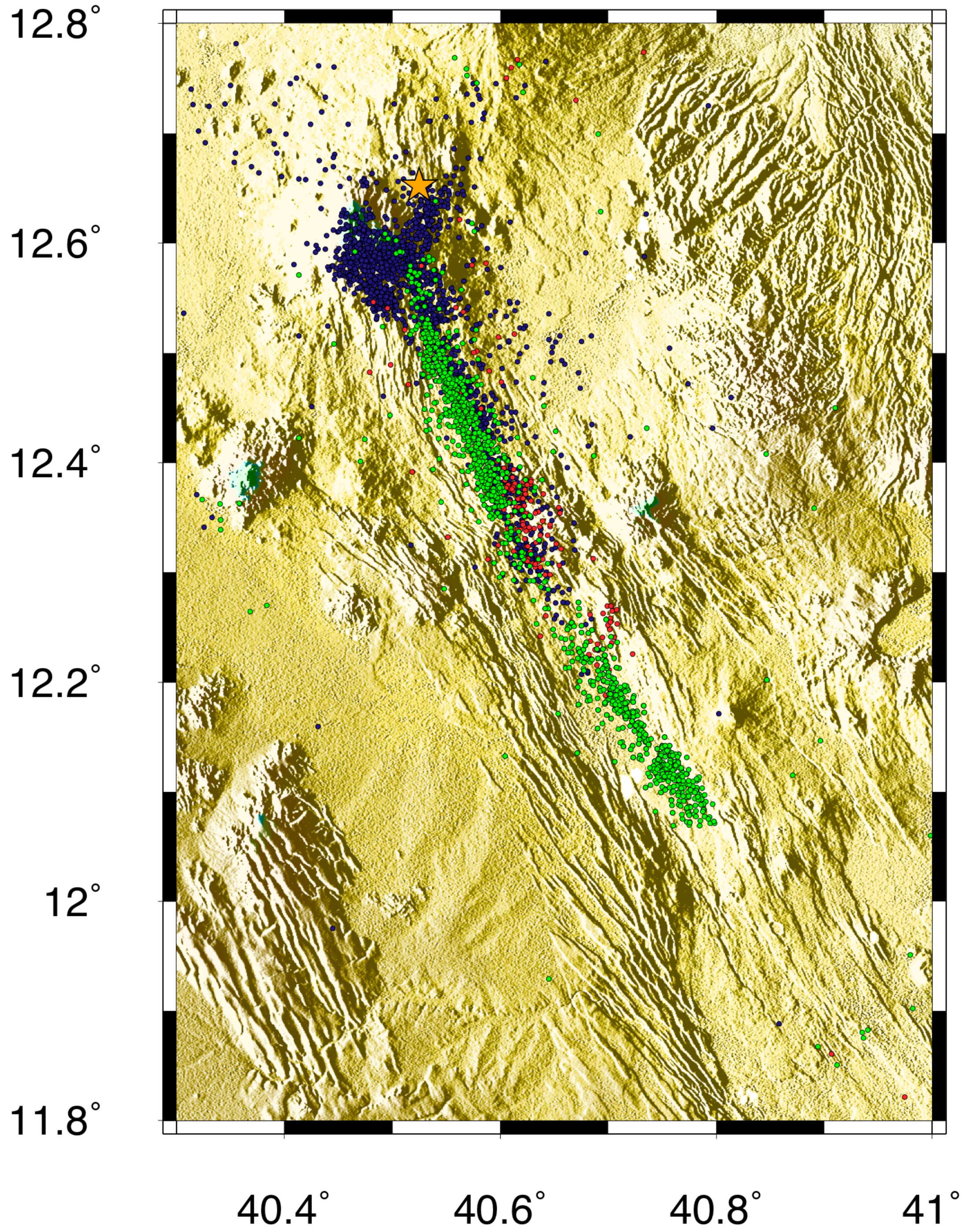
A comparison of a typical tectonic earthquake with a classic LF signal from the Nov 2007 swarm. The LF earthquake shows a clear 'P' onset that becomes superposed with a peak <0.5Hz signal.

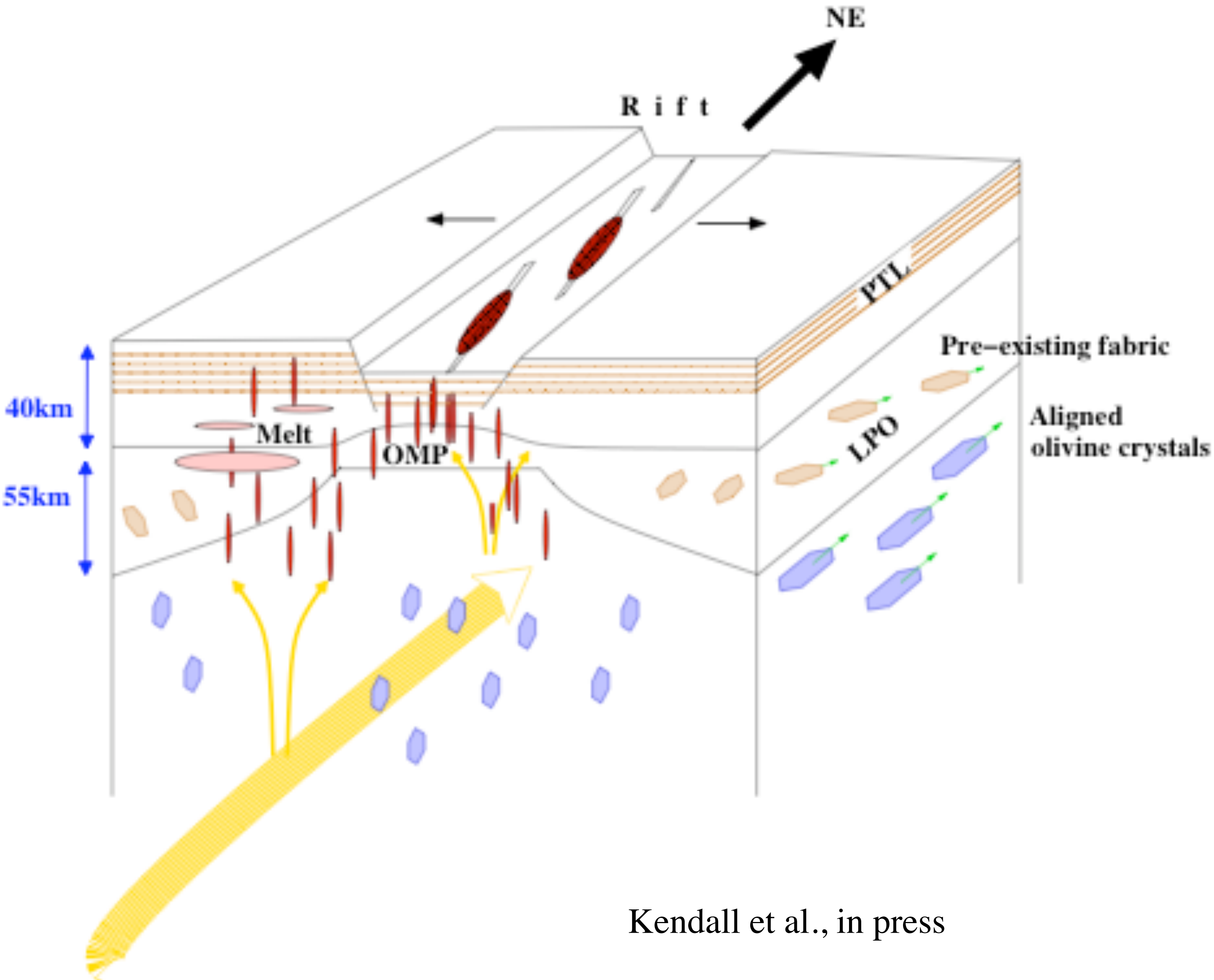
Dustin Cote, U Rochester

March 7 to
August ‘07

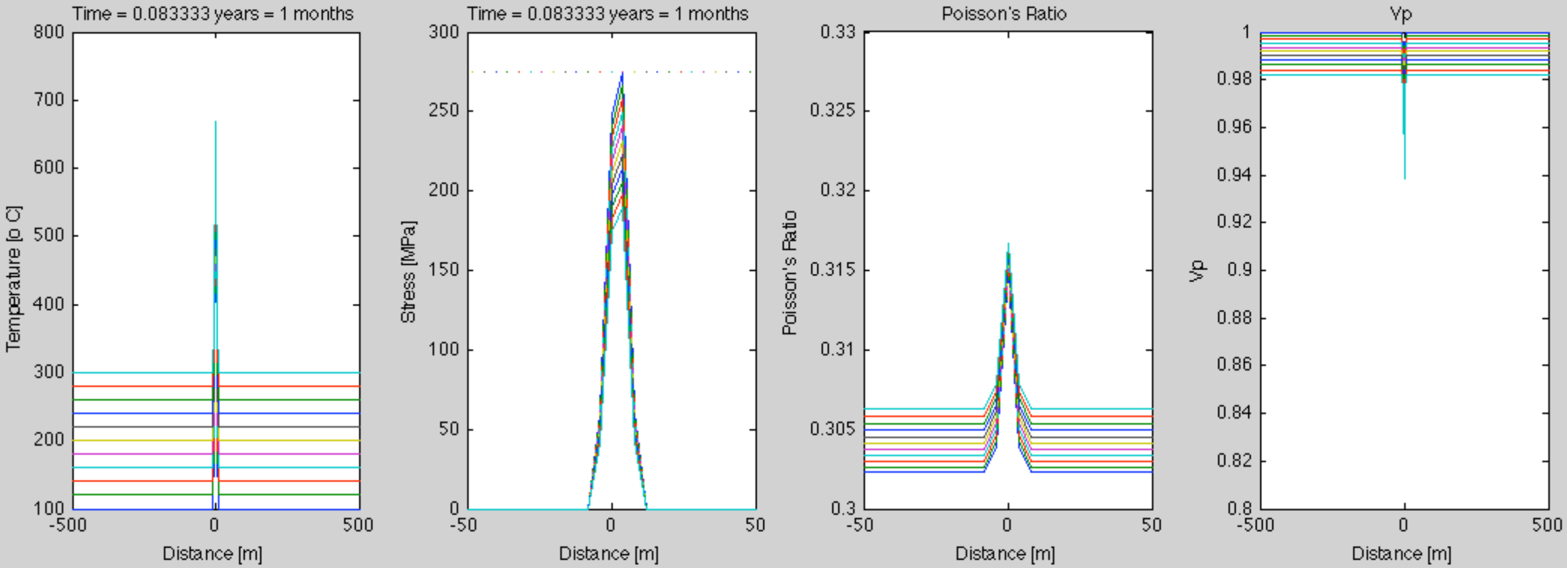
Note W, shift, S
propagation of
seismicity

A lot more to do!



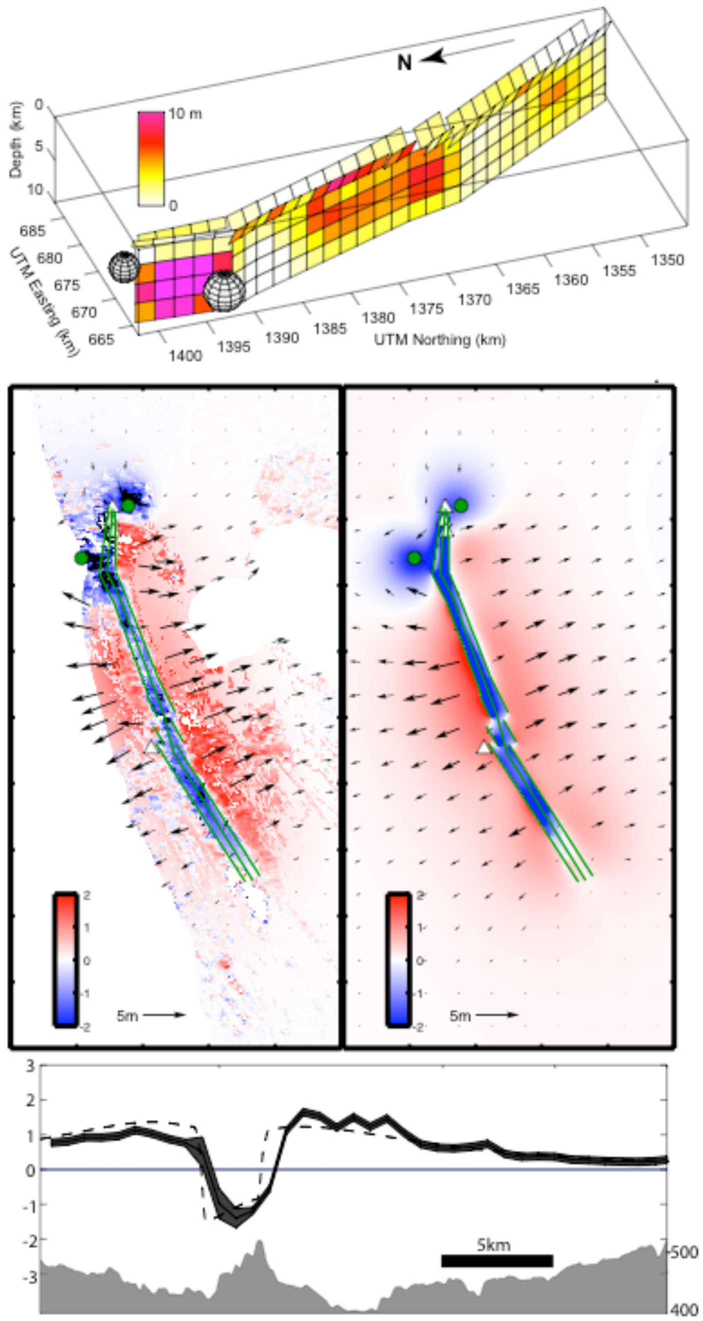


Kendall et al., in press


Time = 0.083333 years = 1 months
Temperature [p C]
Distance [m]
Time = 0.083333 years = 1 months
Stress [MPa]
Distance [m]
Poisson's Ratio
Poisson's Ratio
Distance [m]
Vp
Vp
Distance [m]

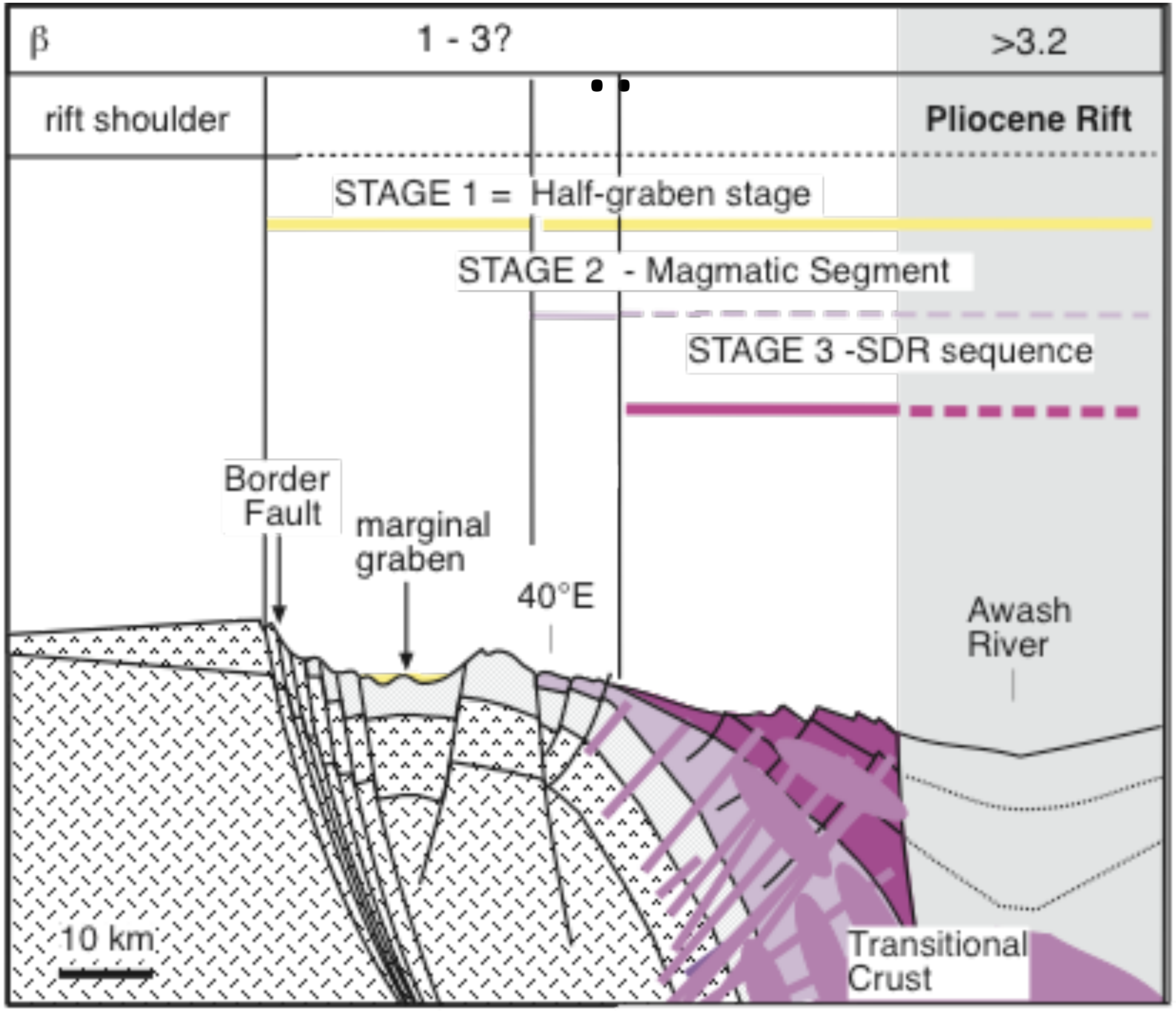
Infrastructure and capacity building – sustainable solutions may come from:

- Data archiving – resource and storage ?
- Software updates – sharing 'clones' ?
- Regular software training via internet/ training schools ?
- Visiting scholars ?
- Observatories as regional resources?
- Sandwich courses for PhD and MSc research?

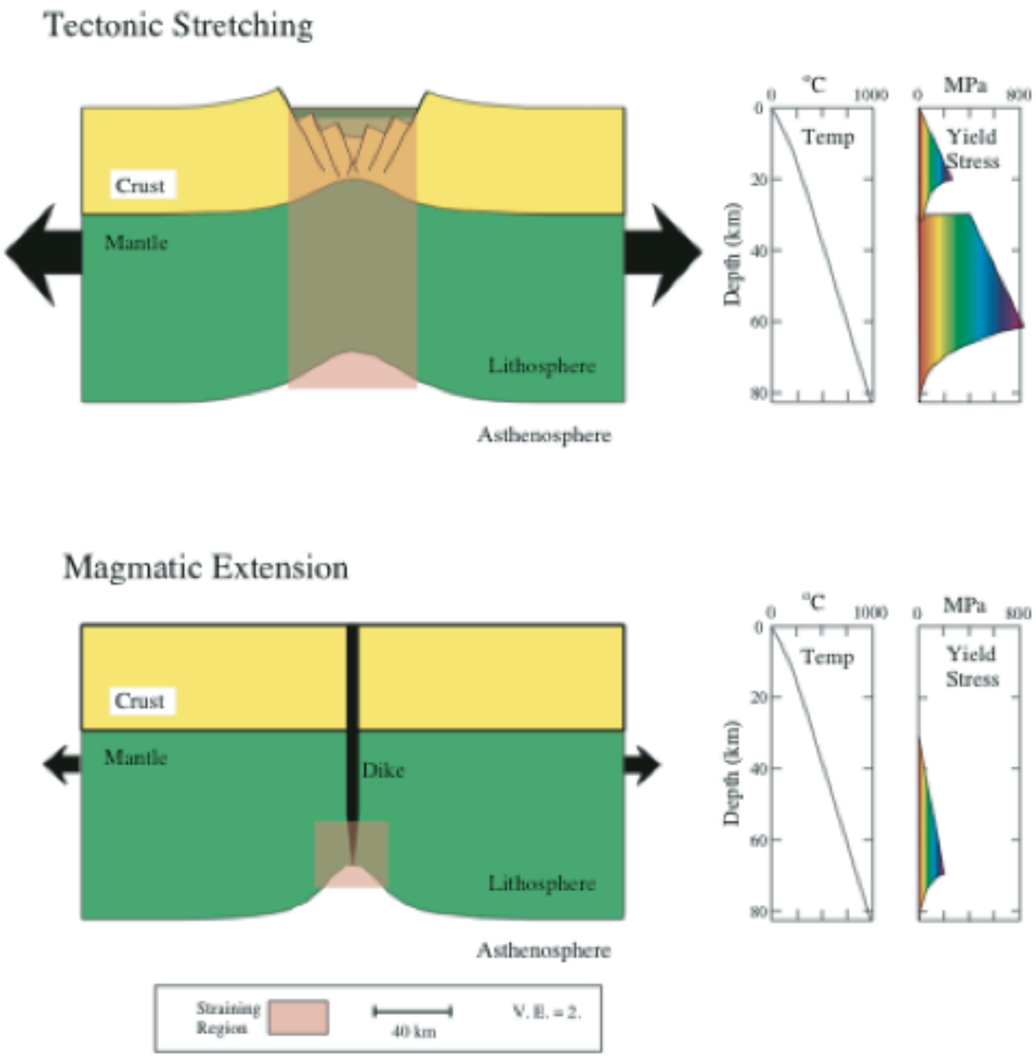


Wright et al., Nature, 2006

Model of interferometry
2 Mogi sources
~ 8 m opening, 60 km-long dyke, <30% sourced from shallow magma chambers beneaeth Dabbahu and Gabho



Wolfenden, 2003



Mechanical stretching - differences relate to rheology assumed.

Add the additional buoyancy force of magma intrusion and associated heating, and breakup can occur at 1/10 the force required for Class A.

After Buck, 2004

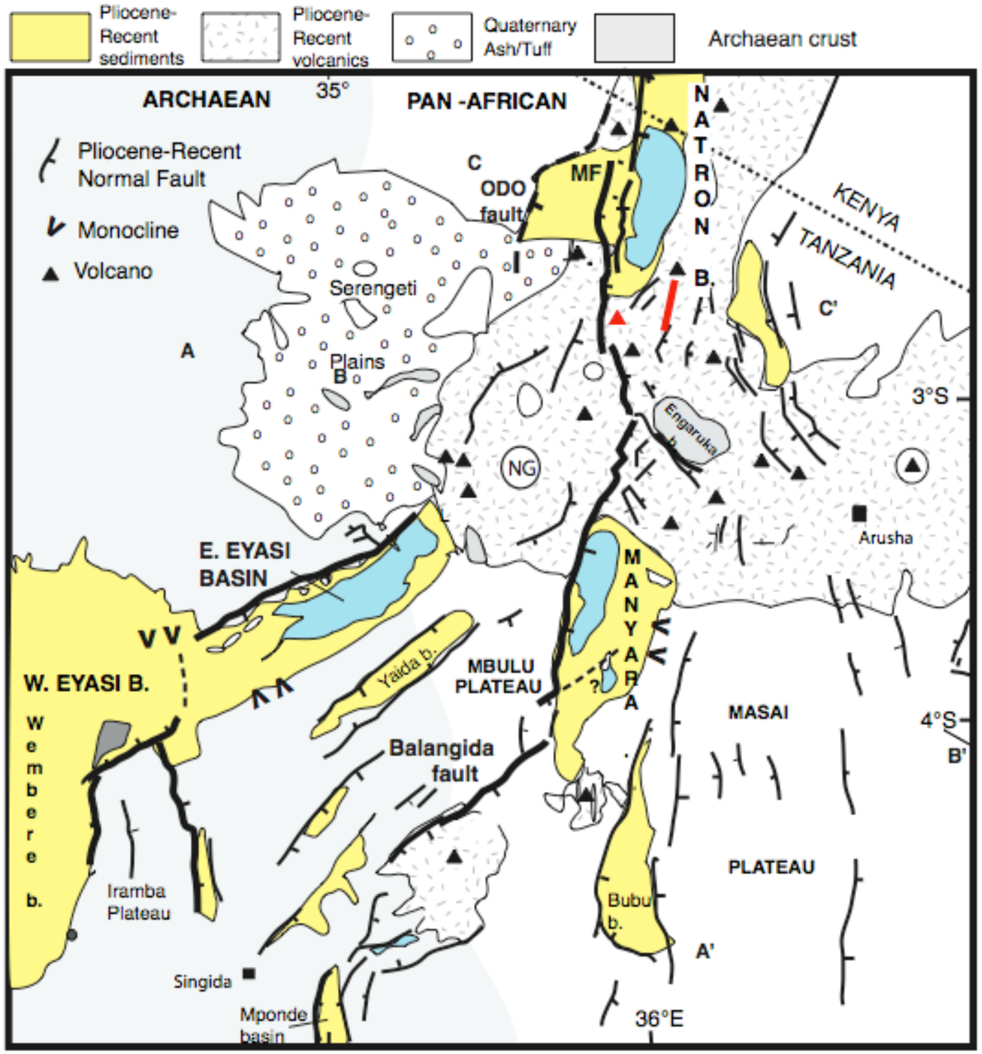
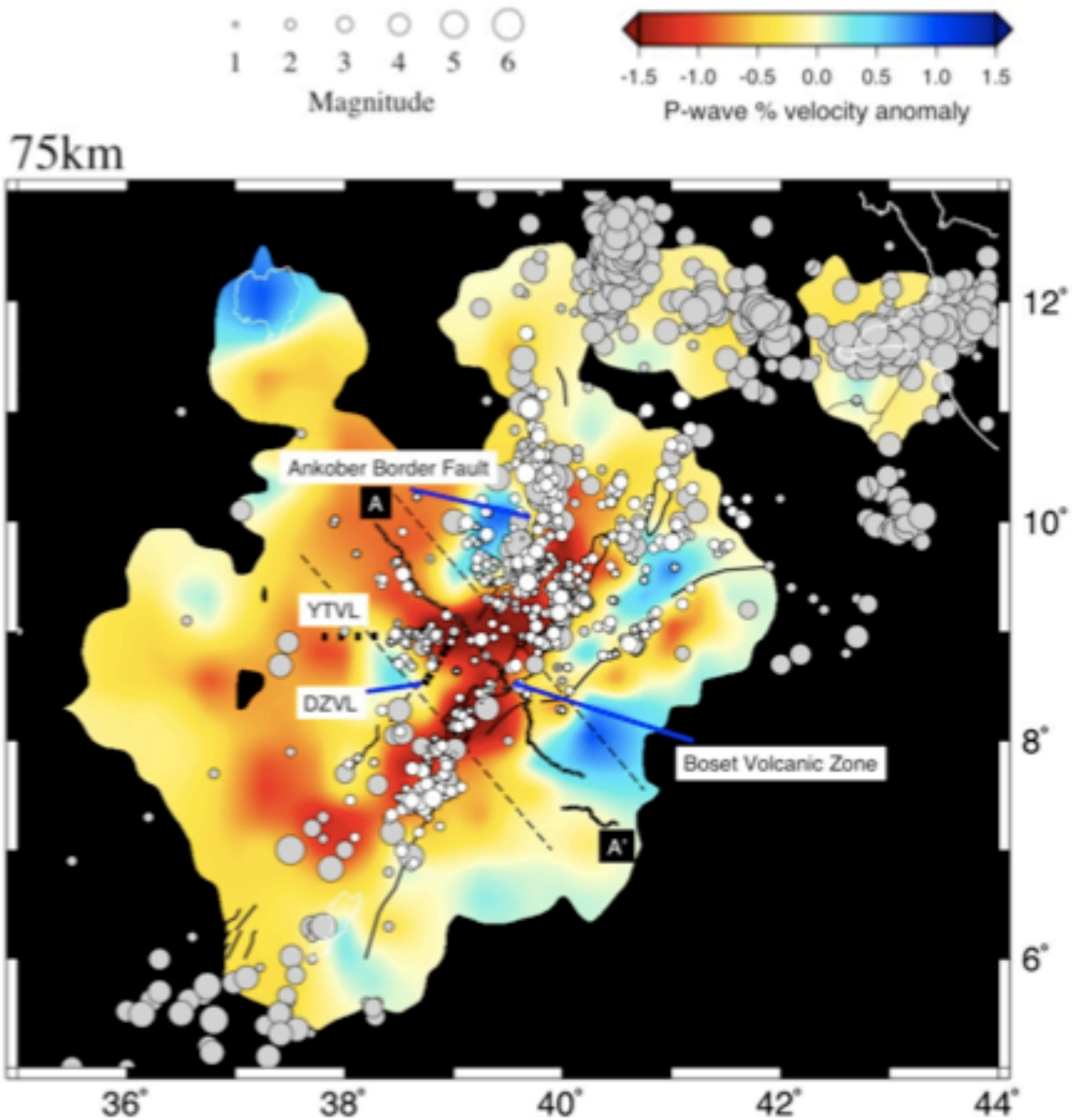


Figure 4. Ebinger et al.

Figure 2; Keir et al.



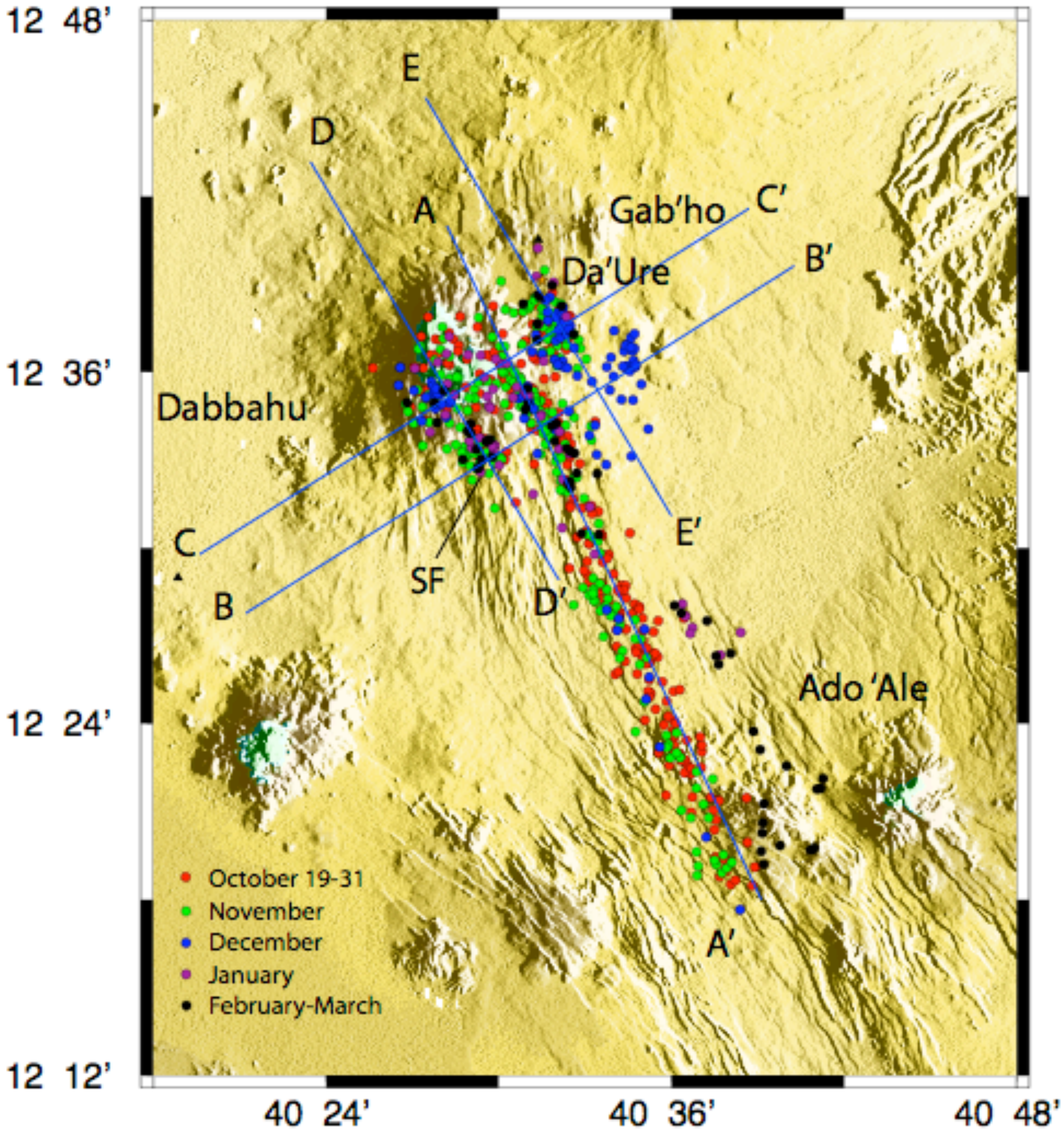
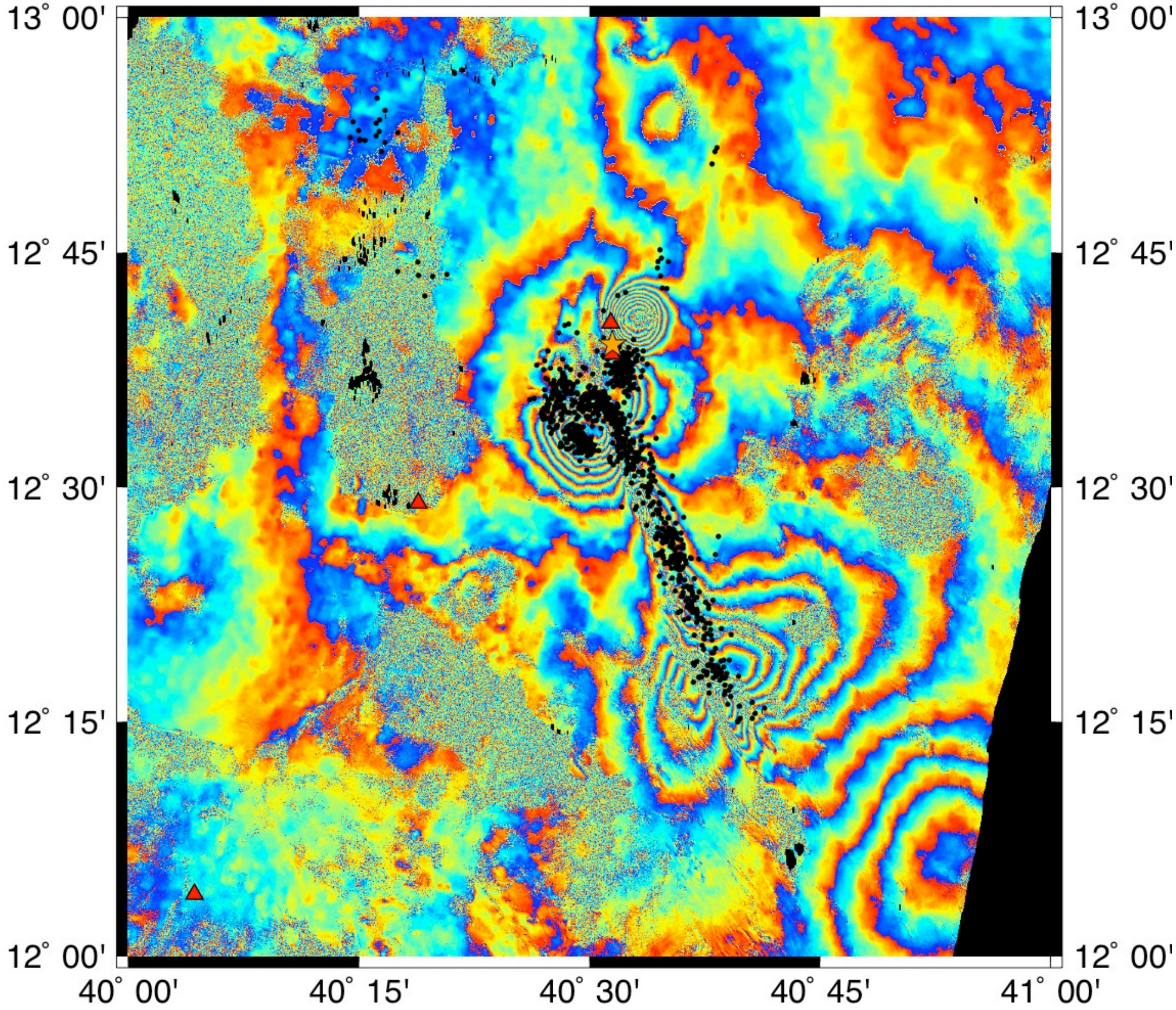


Fig. 3, Ebinger et al.



Seismicity 18/10-30/4/06

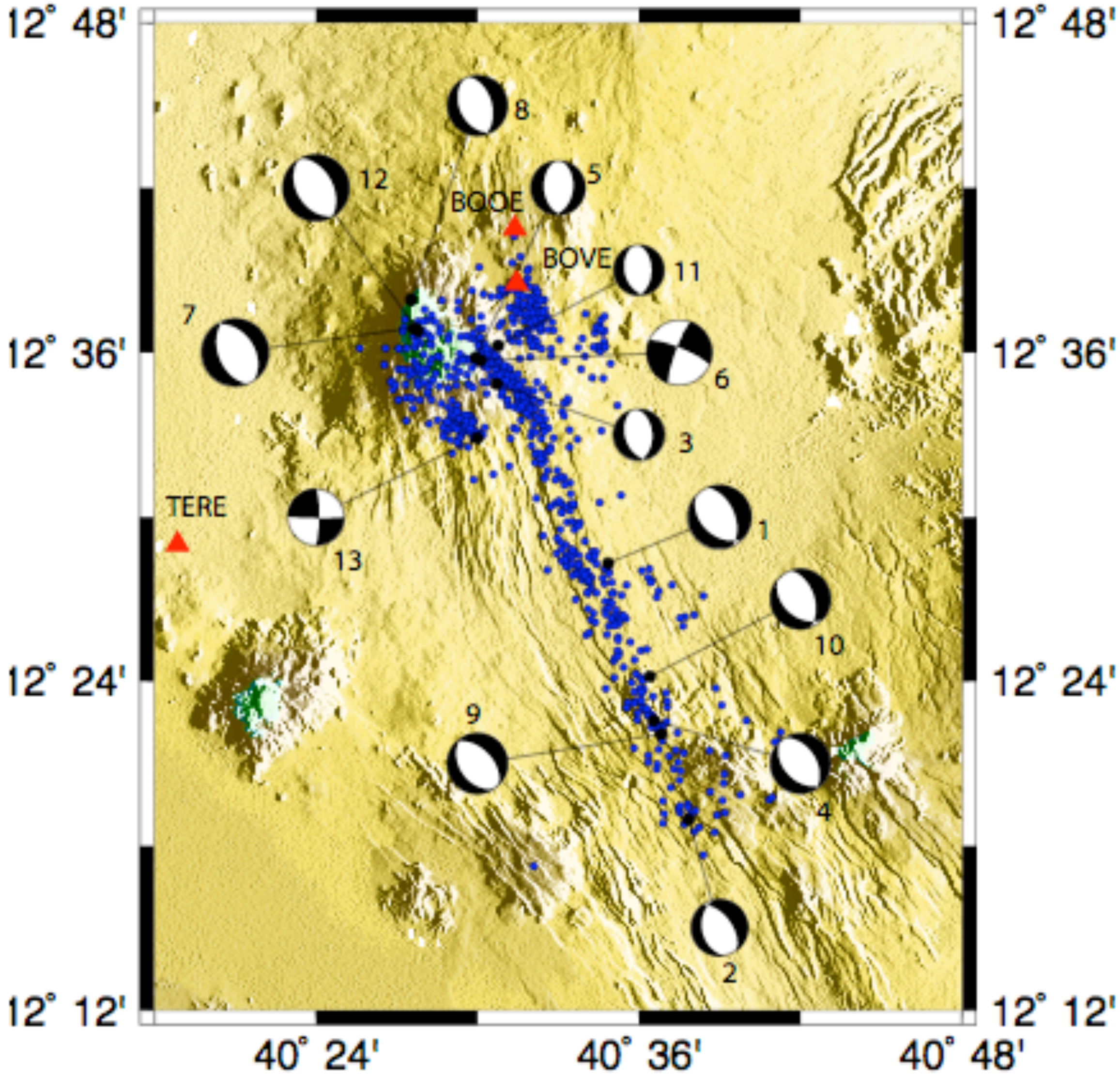
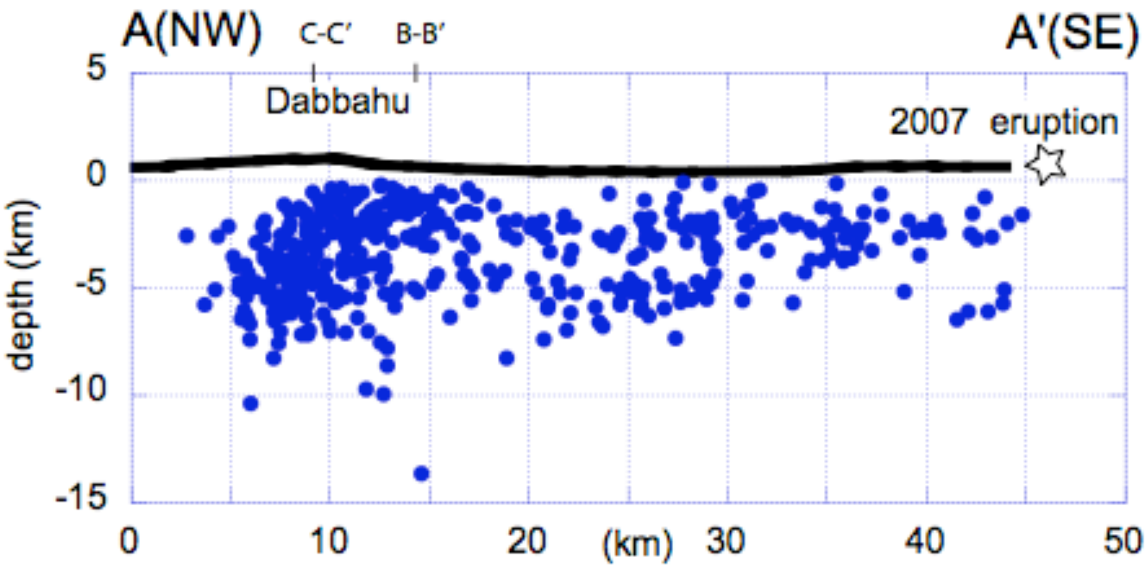


Fig. 5, Ebinger et al.

3 en echelon dikes?



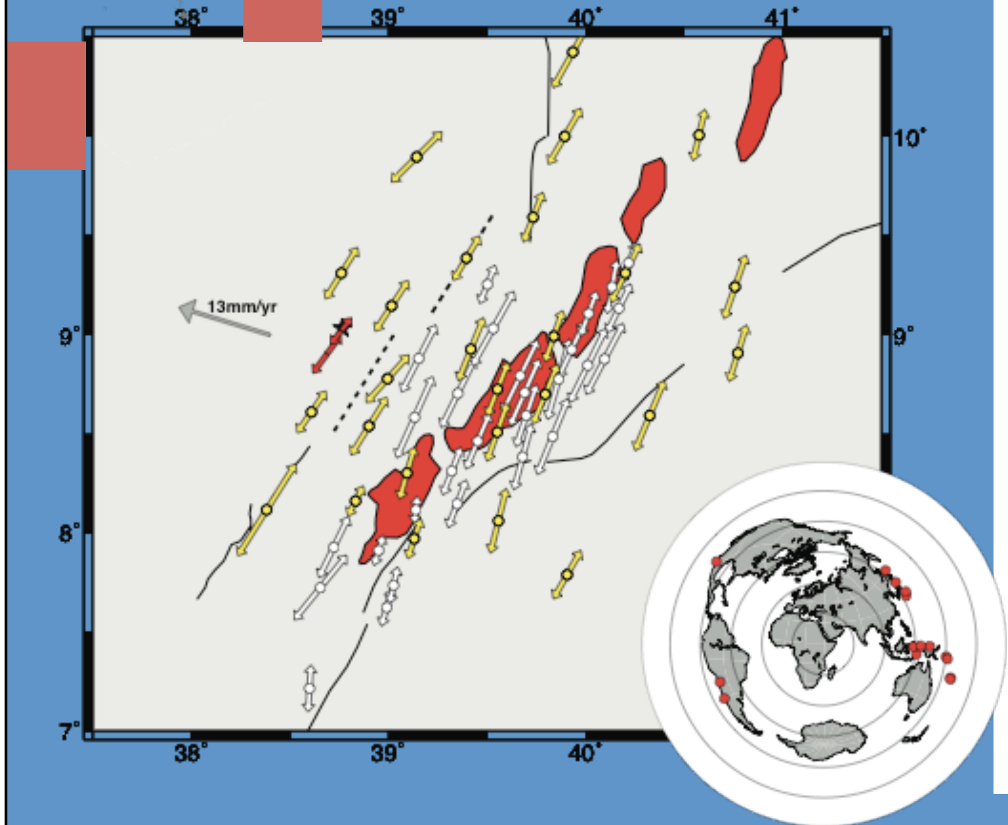
Post-intrusion seismicity
Thermal stress along dike walls; continued dike intrusion?

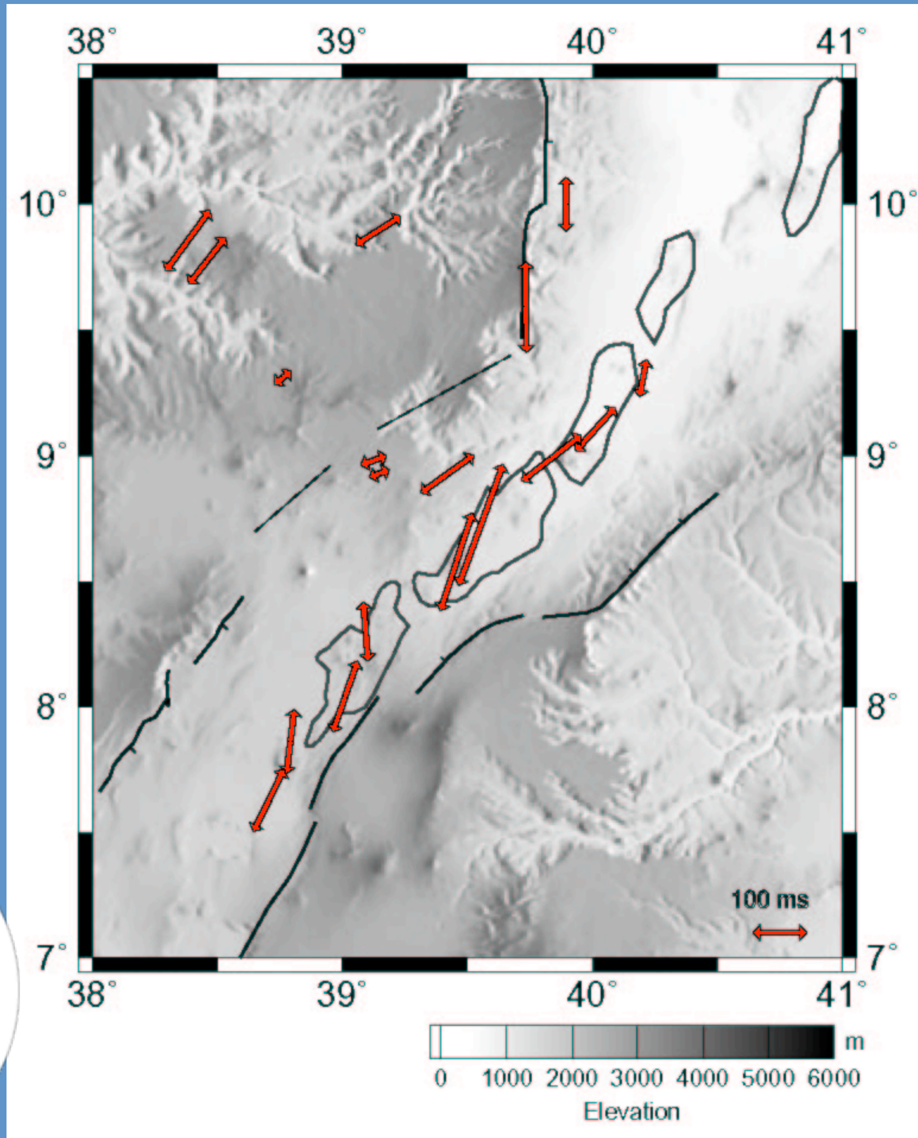
Figure 7, Ebinger et al.

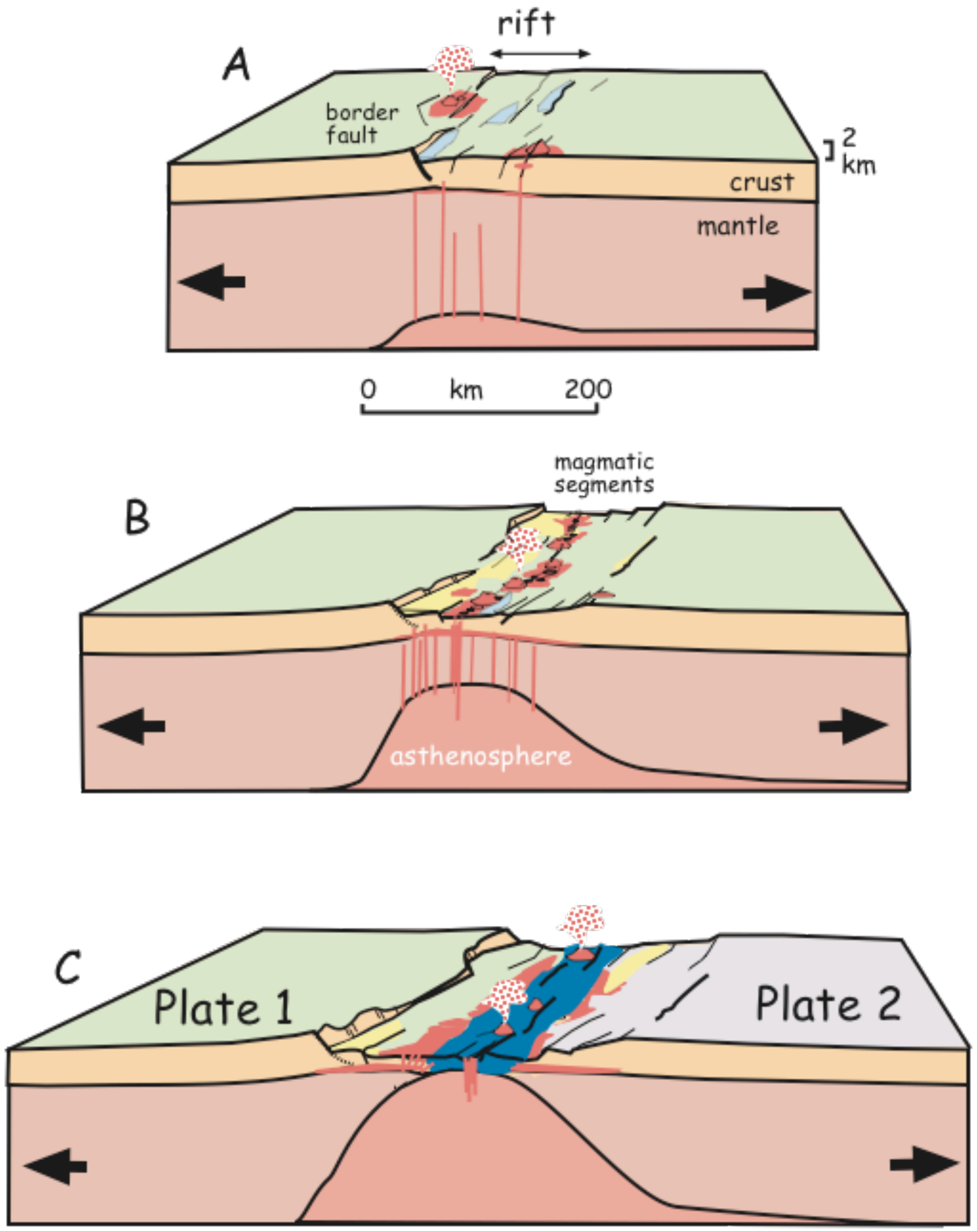
Shear-wave splitting indicates melt-filled cracks that penetrate plate

Kendall et al., Nature 05 - > 2 s SKS splitting

Keir et al. GRL '05 4-6% anisotropy







Rifting with Magma

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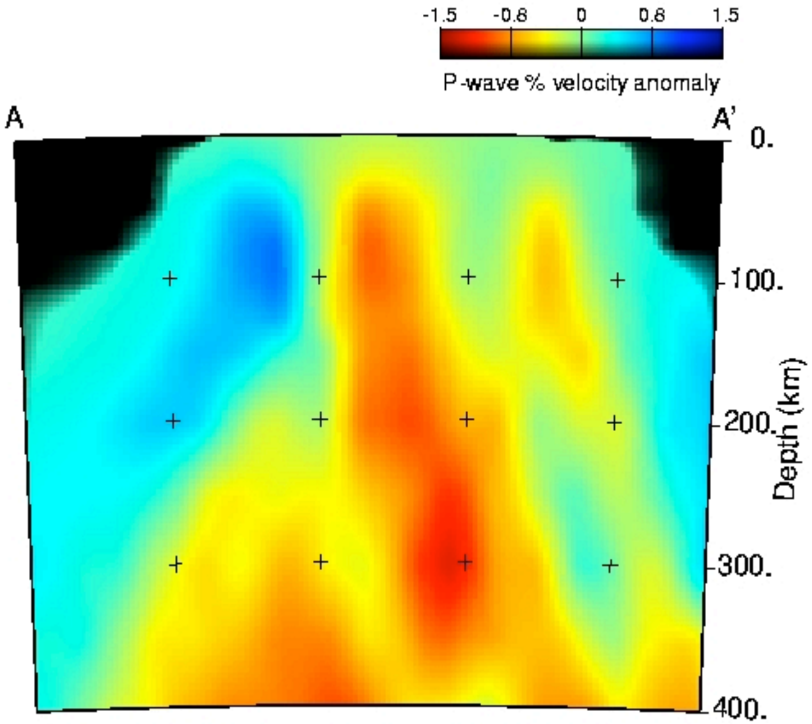
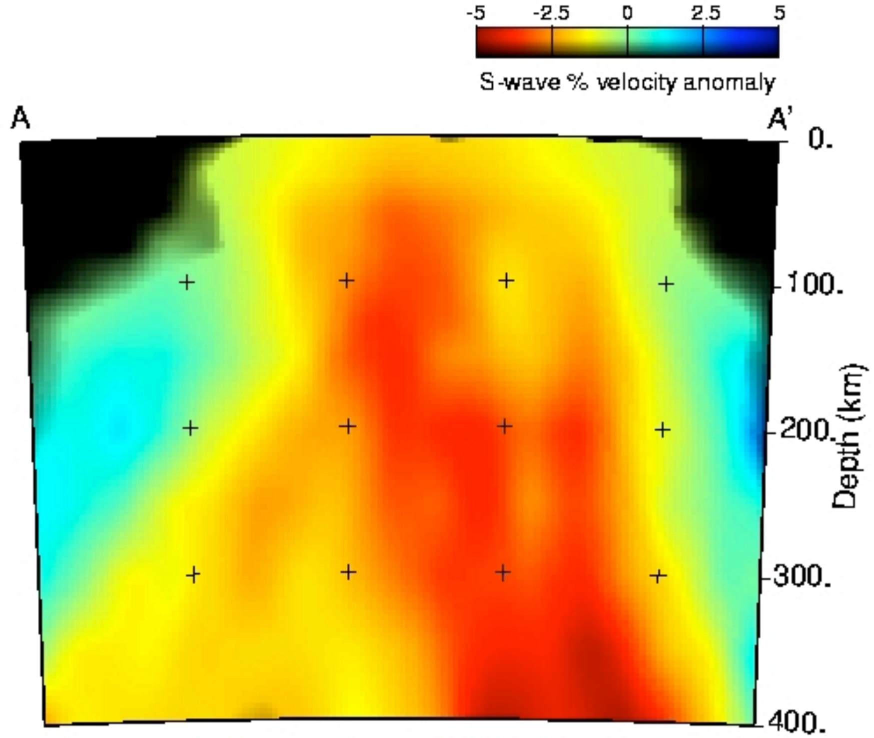
Fig 3.

P S



A:(11.00N, 38.00E) A':(8.50N, 42.00E)



A:(11.00N, 38.00E) A':(8.50N, 42.00E)

Ian Bastow, Graham Stuart, & Mike Kendall, U of Leeds

Bastow et al., GJI, 2005 – see also Benoit et al., 2006, Bastow et al., 2009

P S