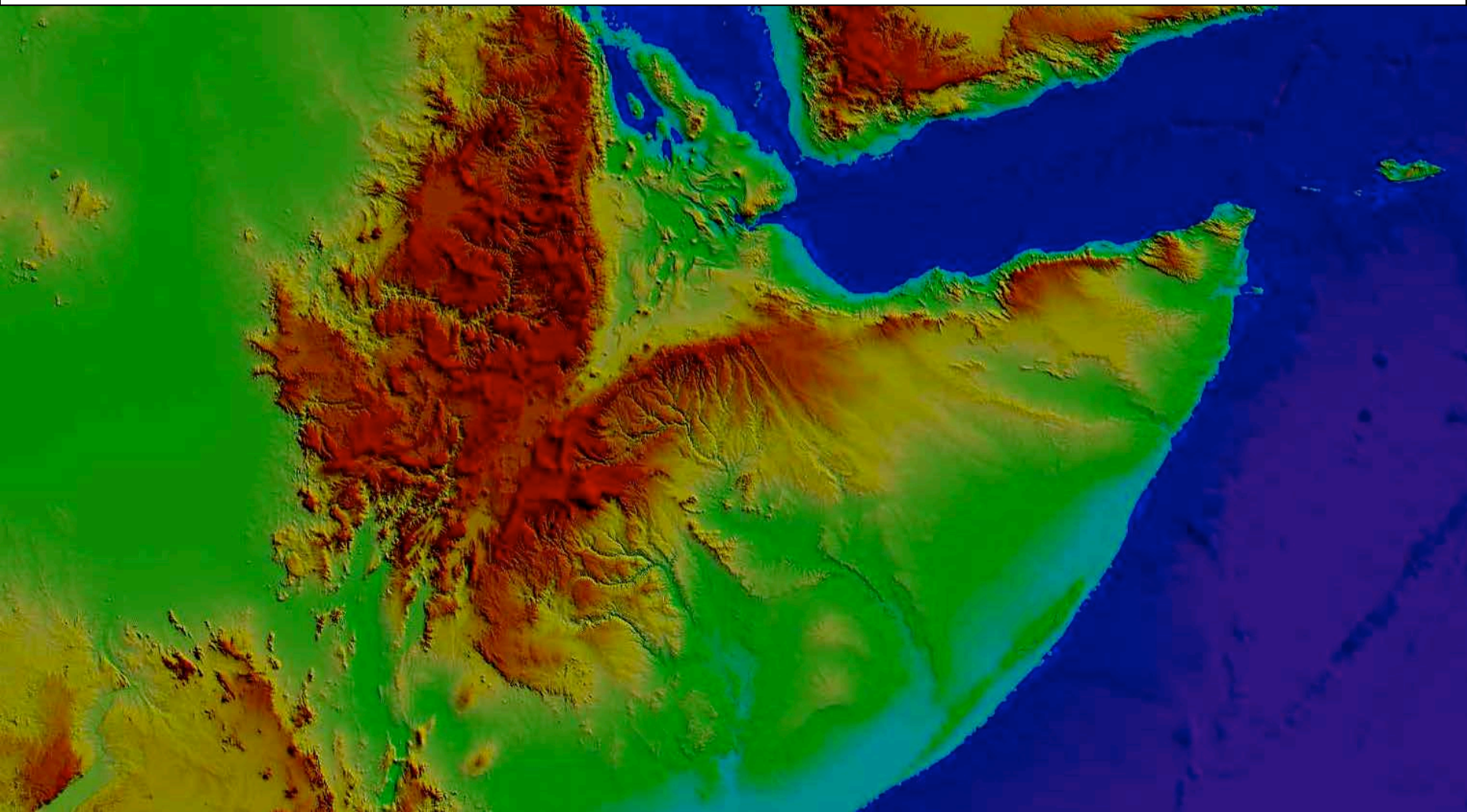
GeoPRISMS RIE Workshop 2010

Rift initiation - East Africa and Afar

Derek Keir - University of Leeds



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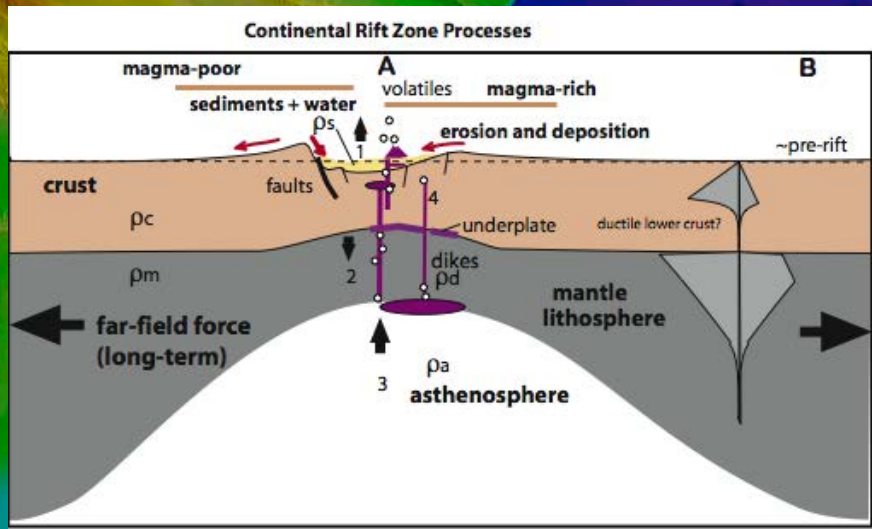
Conclusions

- Currently deforming rifts offer a window to understanding extensional processes in space and time

- Plate rheology - temperature, composition, pre-existing structures
- Deformation - mechanical and magmatic
- Rift architecture at a plate scale
- Mantle dynamics - magma supply

- Achieved via multidisciplinary approach to earth observation and modeling



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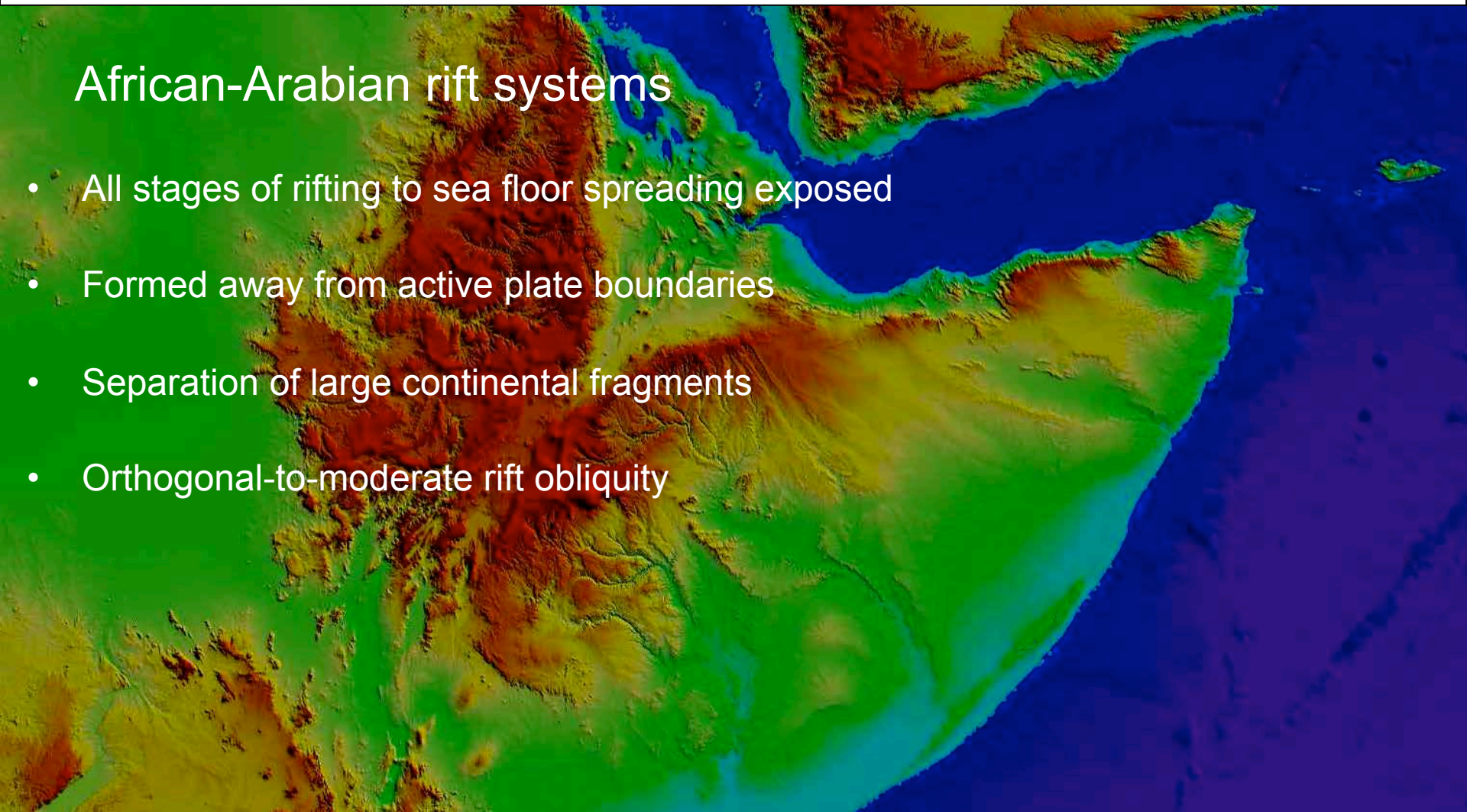

African-Arabian rift systems

- All stages of rifting to sea floor spreading exposed
- Formed away from active plate boundaries
- Separation of large continental fragments
- Orthogonal-to-moderate rift obliquity

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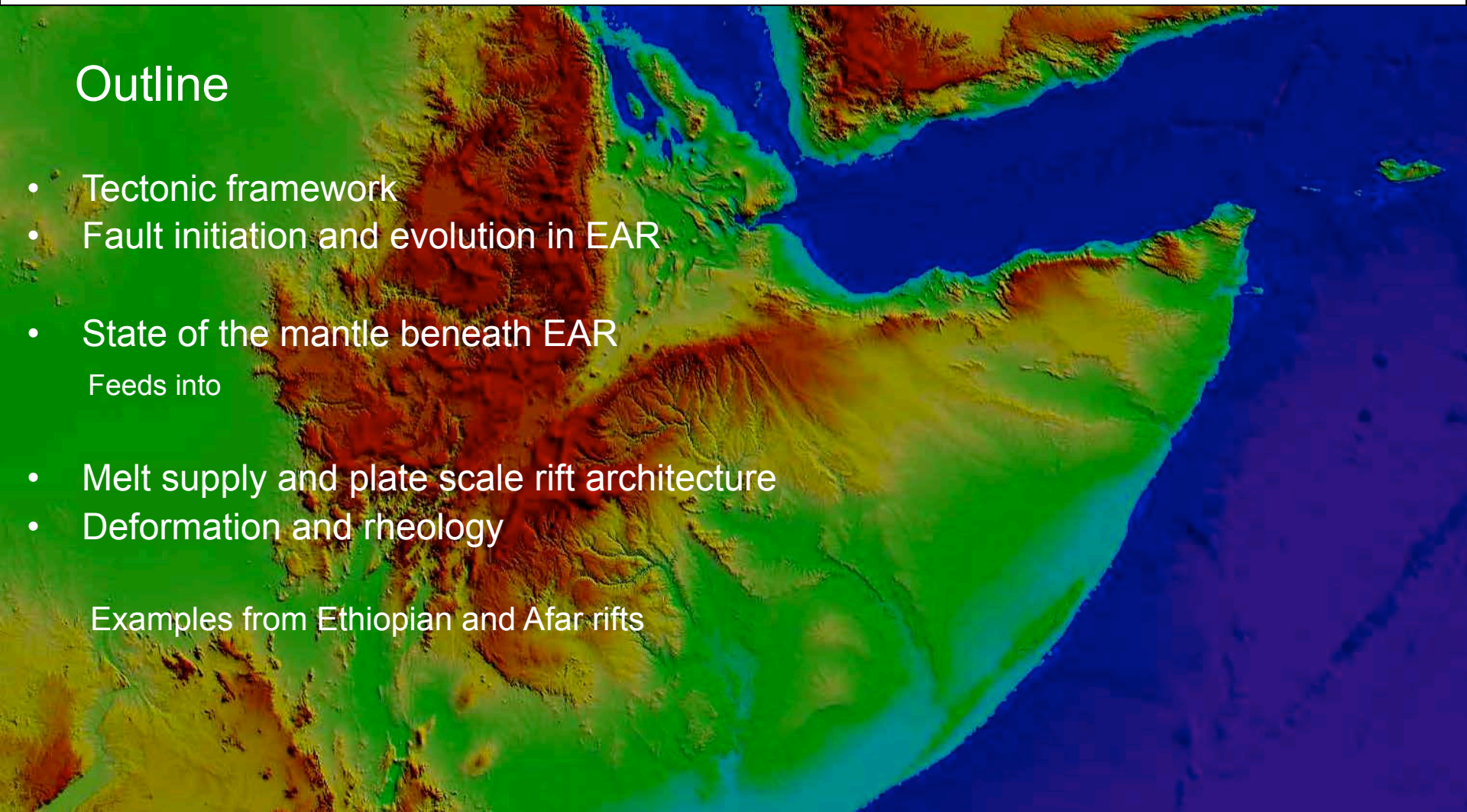


Outline

- Tectonic framework
- Fault initiation and evolution in EAR

- State of the mantle beneath EAR

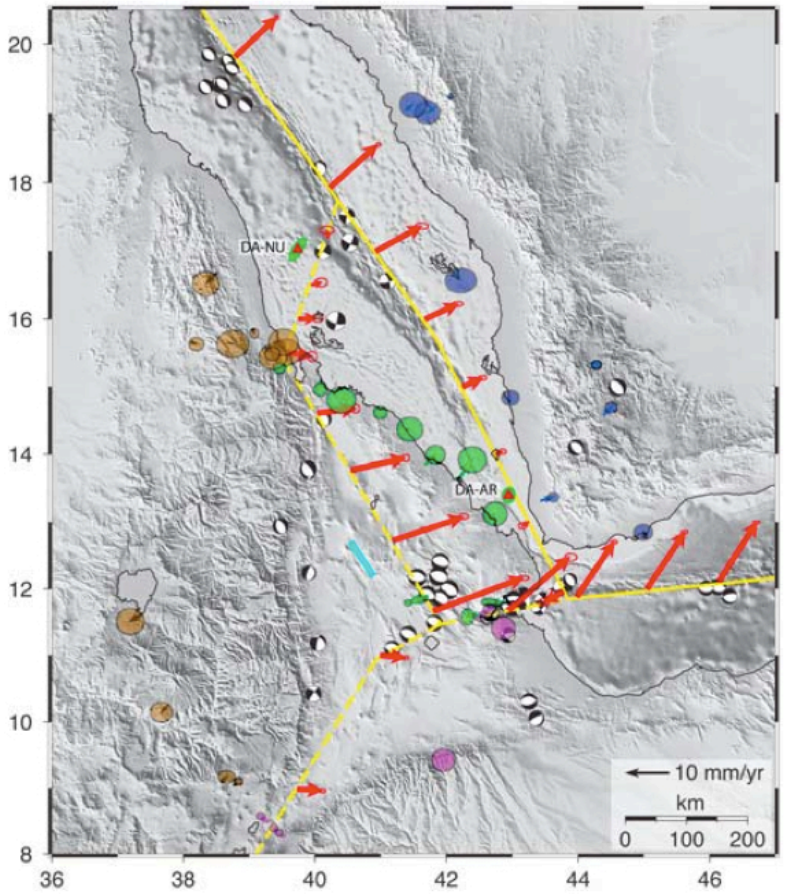
Feeds into

- Melt supply and plate scale rift architecture
- Deformation and rheology

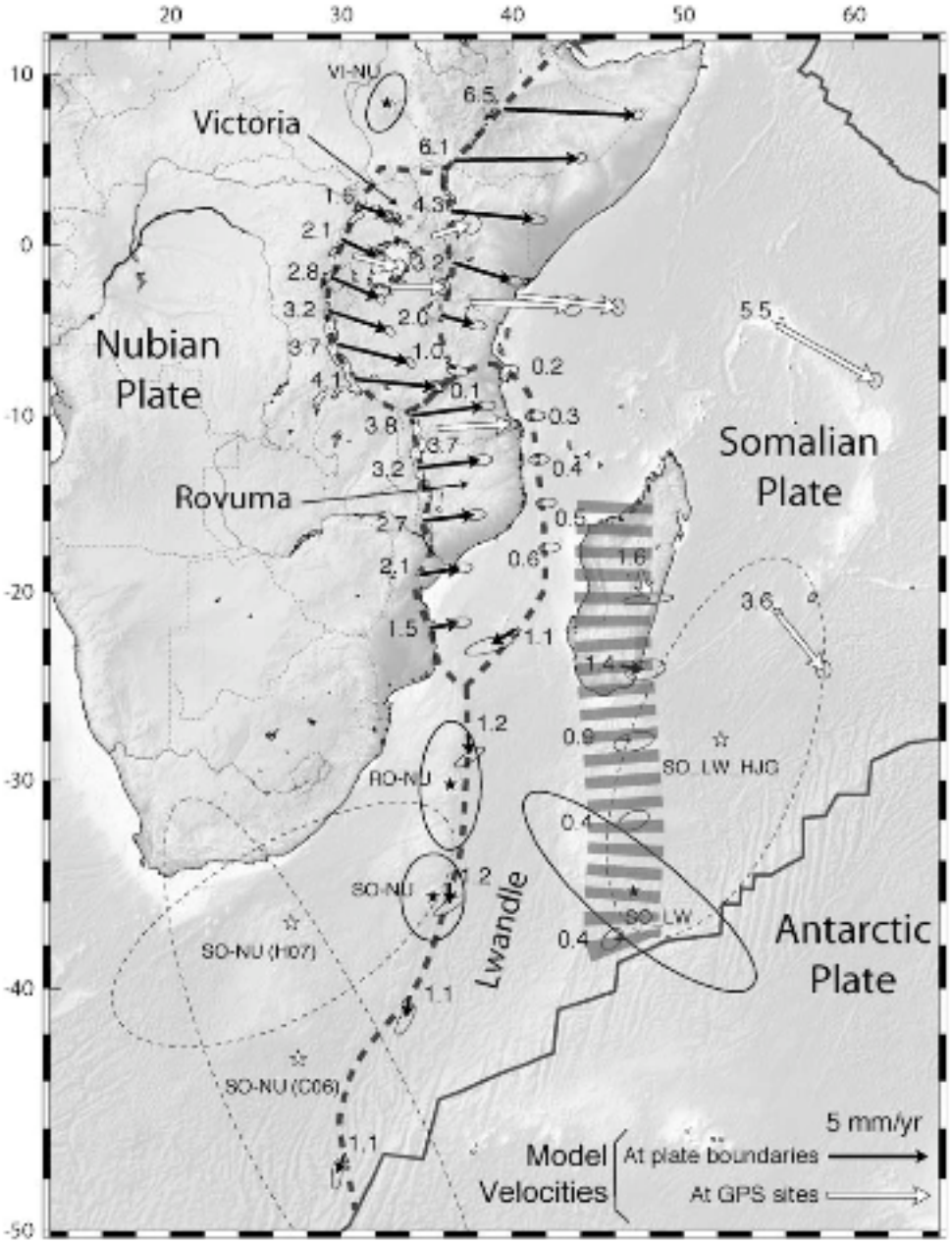
Examples from Ethiopian and Afar rifts

Tectonic framework

- Plate separation
- Rift initiation youngest in south
  ~29 Ma in Afar to <1 Ma in Okavango
- Rifting propagates south



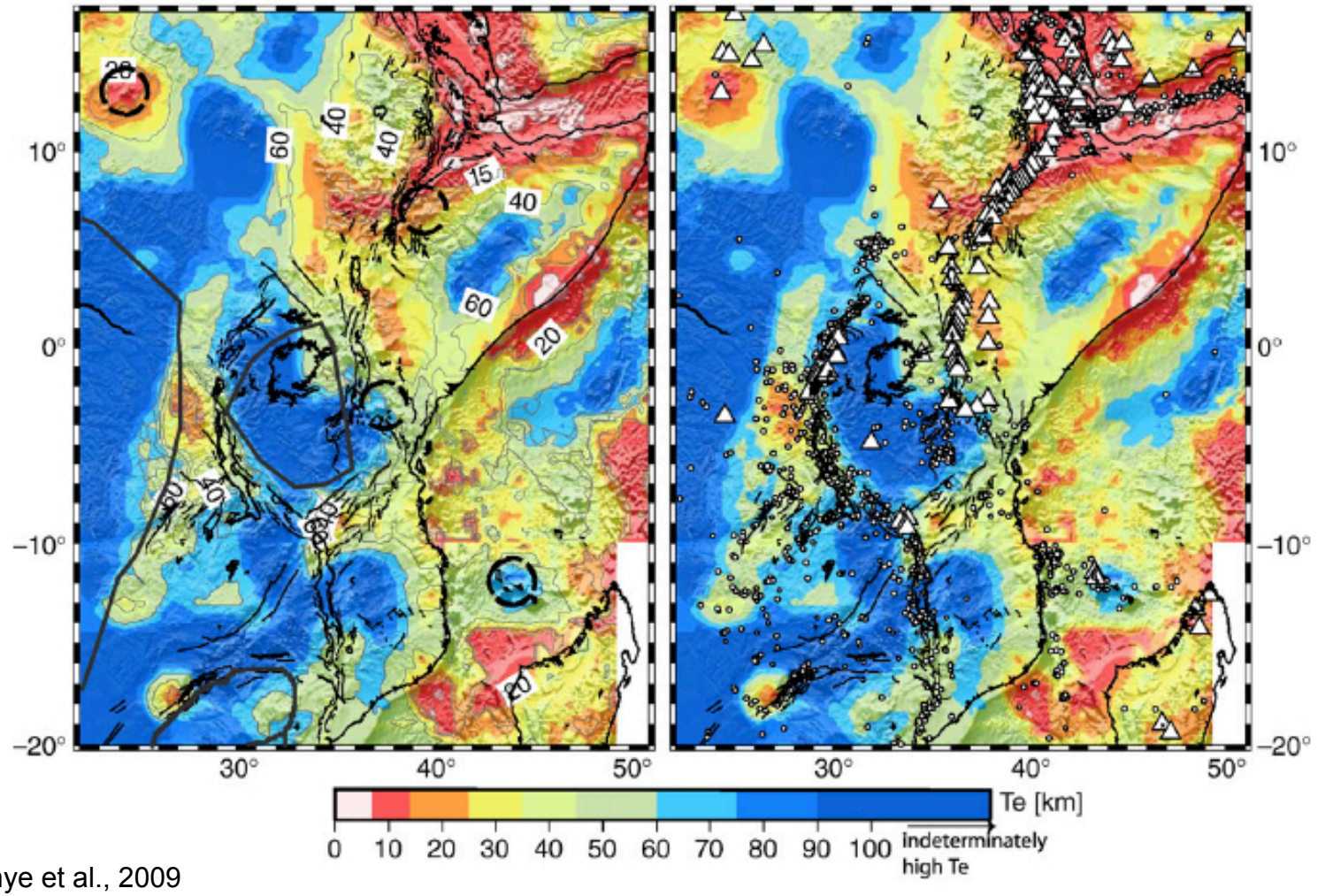
McClusky et al., 2010



Stamps et al., 2008

Tectonic framework

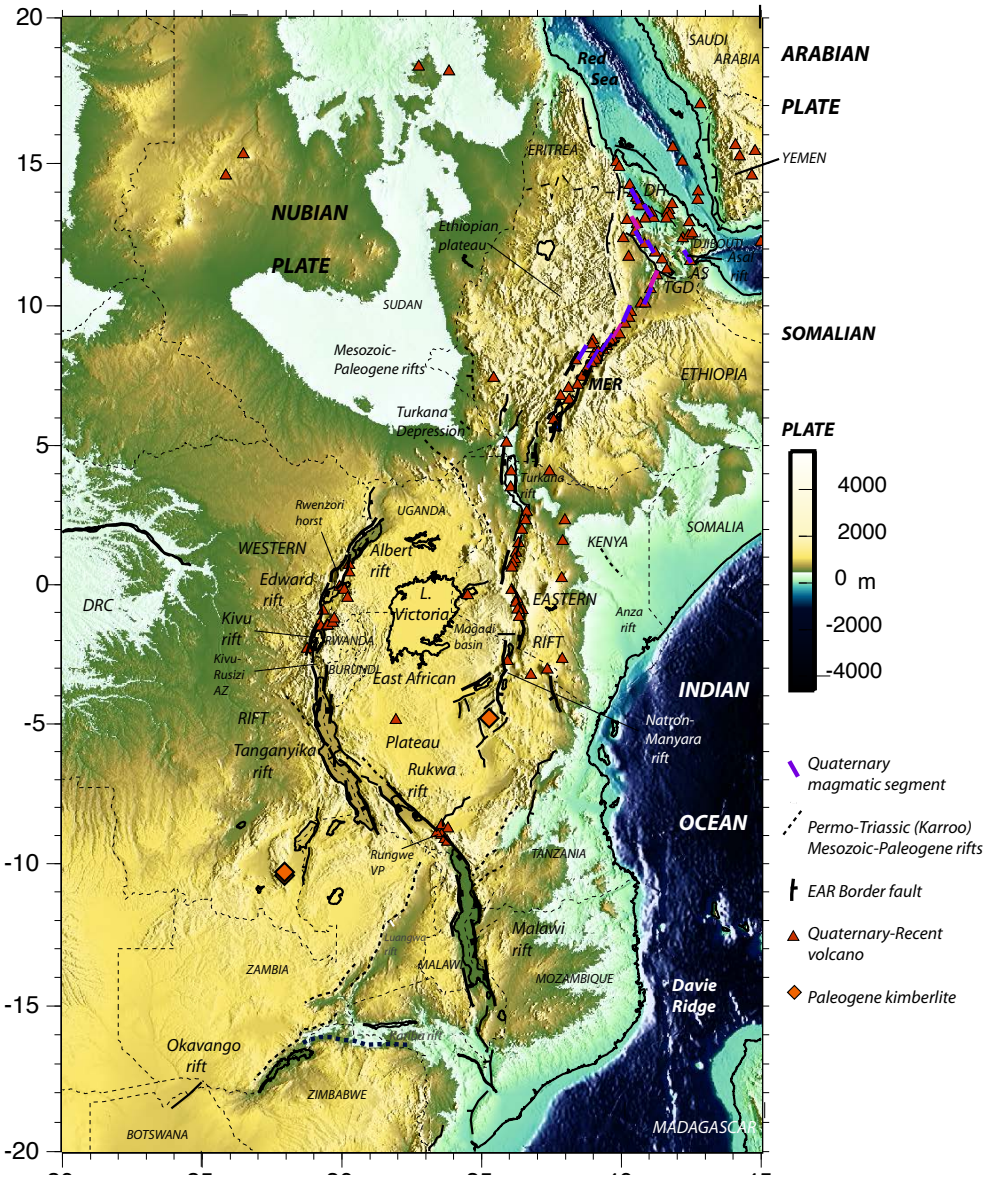
- Plate strength
- Volcanism
- Seismicity
- Fault architecture



Perez-Gussinye et al., 2009

Fault initiation and evolution

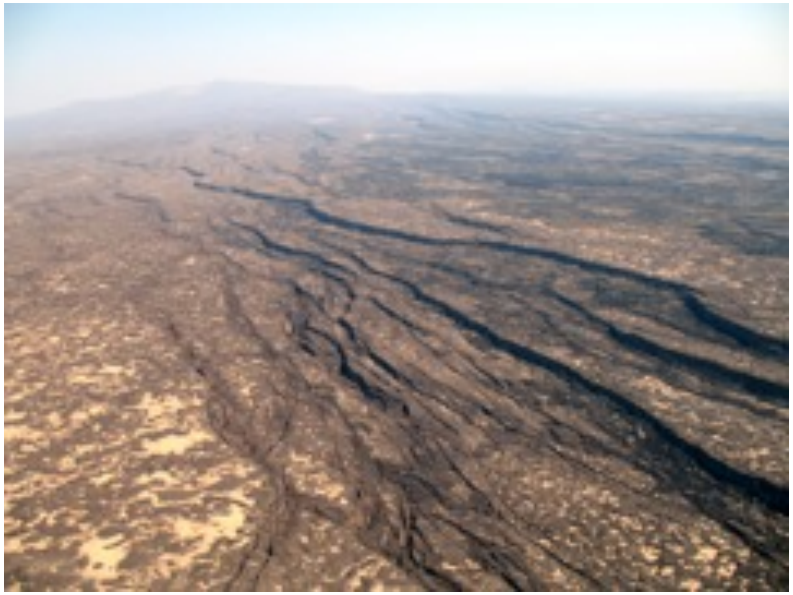
- Much of rift superbly exposed
- Variability in fault architecture
- Rift initiation <1 My in Okavango
  ~100-km-long fault

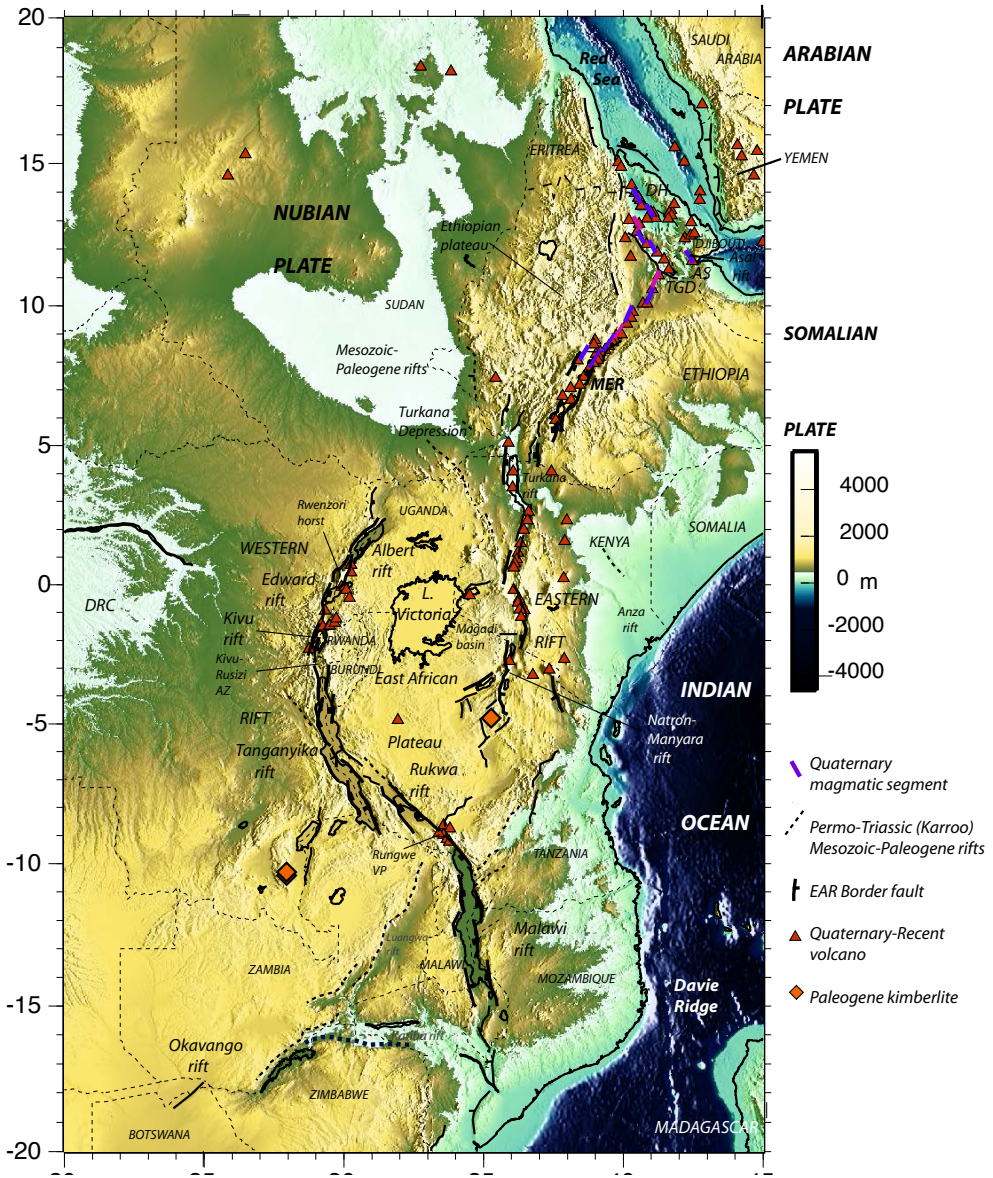


Fault initiation and evolution

- Much of rift superbly exposed
- Variability in fault architecture
- Rift initiation <1 My in Okavango
  ~100-km-long fault
- Faulting during late stage rifting
  lots of short faults above dikes

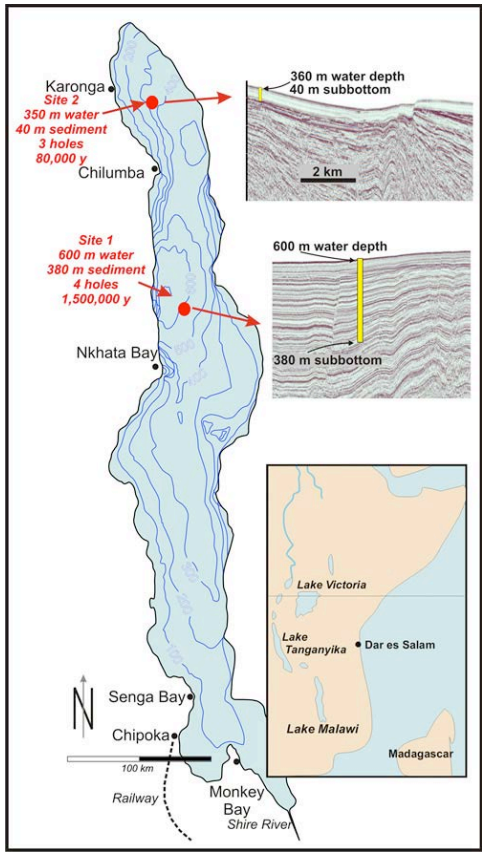
- Recent examples of deformation
  Karonga, Oldoinyo-Lengai, Dabbahu

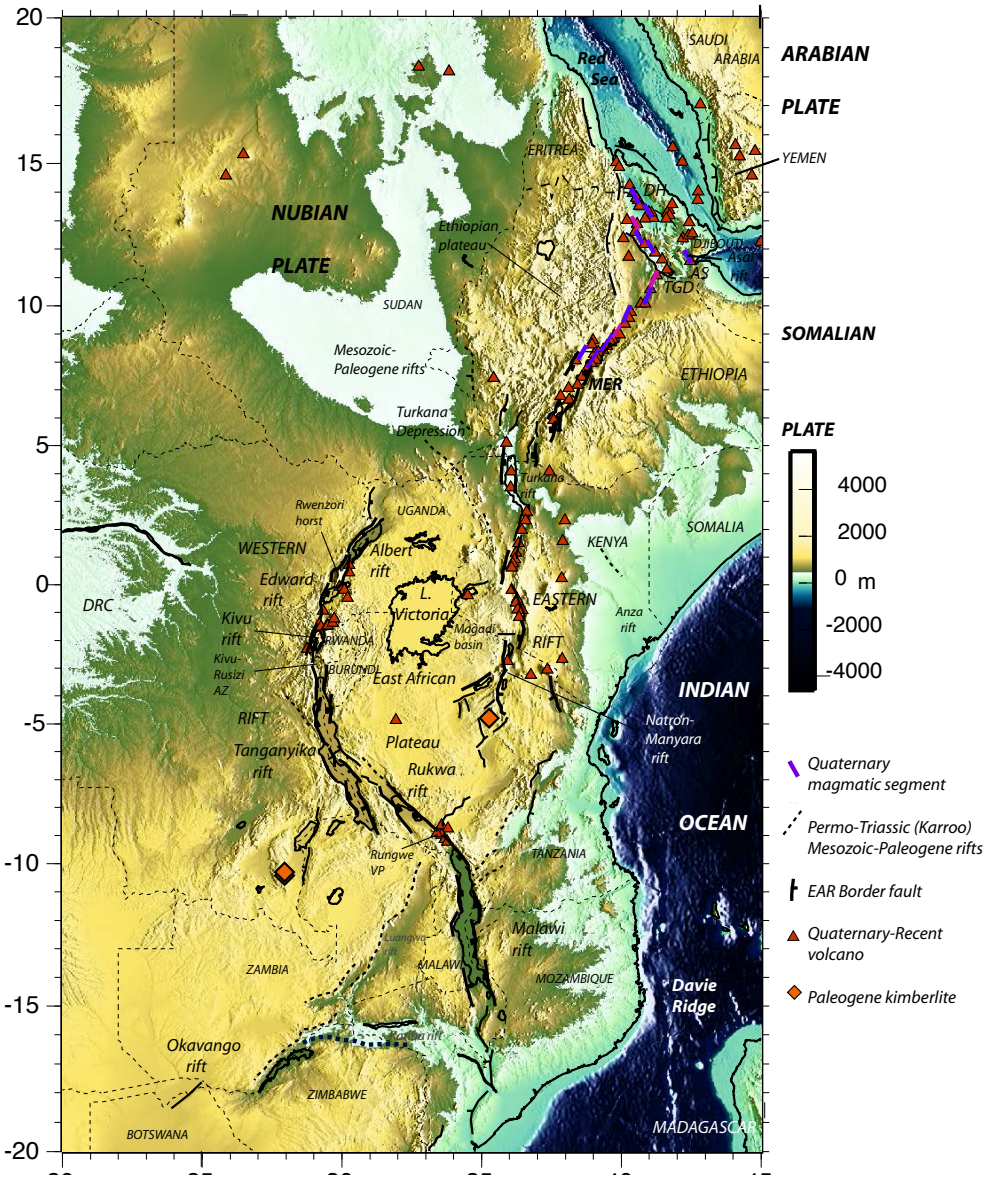




Fault initiation and evolution

- Much of rift superbly exposed
- Variability in fault architecture
- Rift initiation <1 My in Okavango ~100-km-long fault
- Sedimentary record in lakes records tectonics and climate change

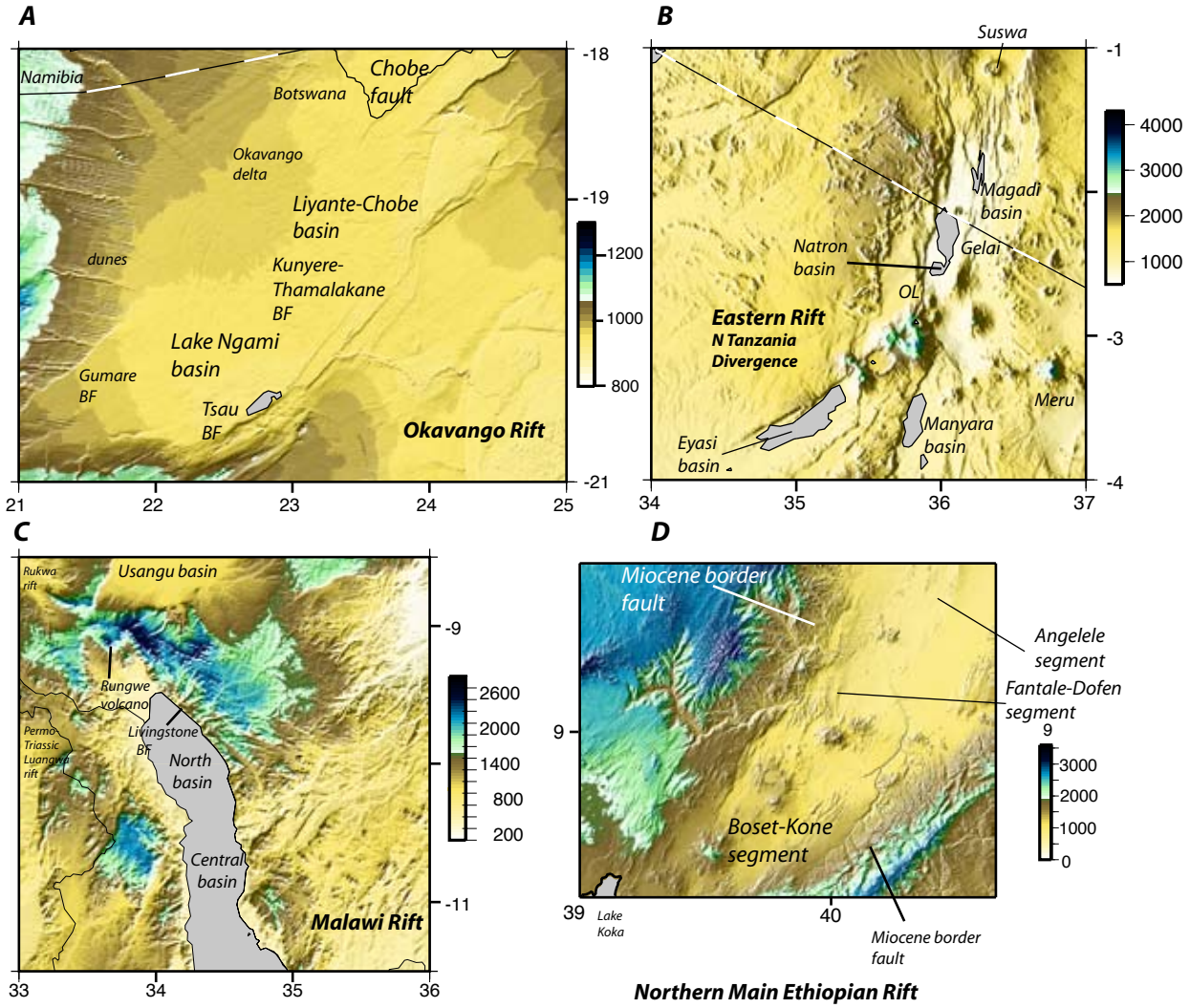




Scholtz and Cowen

Fault initiation and evolution

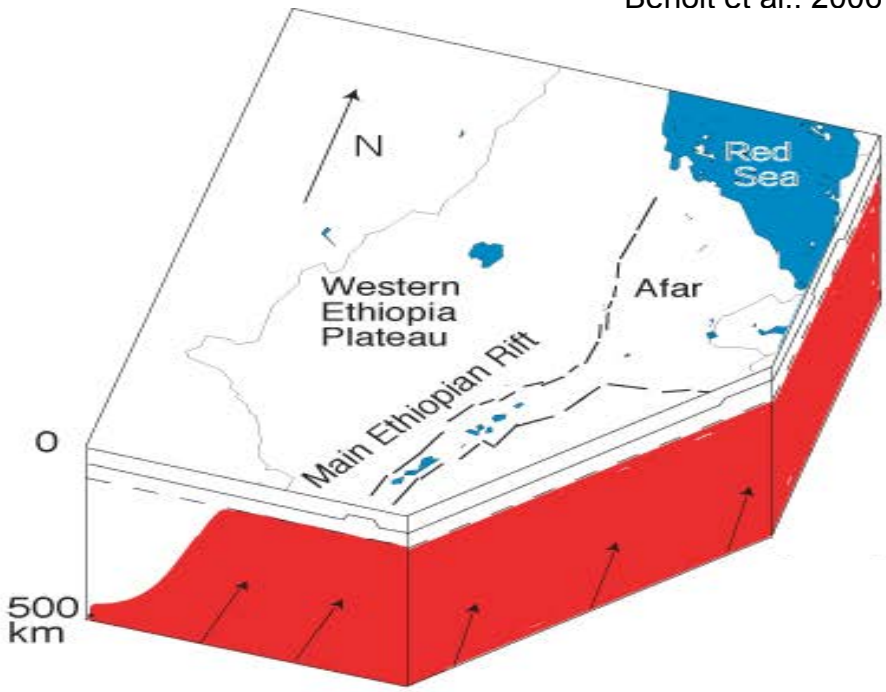
- White papers
- A: Atekwana, C: Gaherty & Shillington, D: Reilinger and Bendick
- Border fault dimensions scale with plate strength
- Magma intrusion?

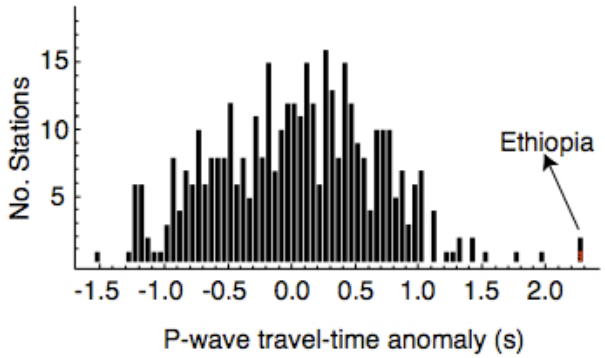


State of the mantle

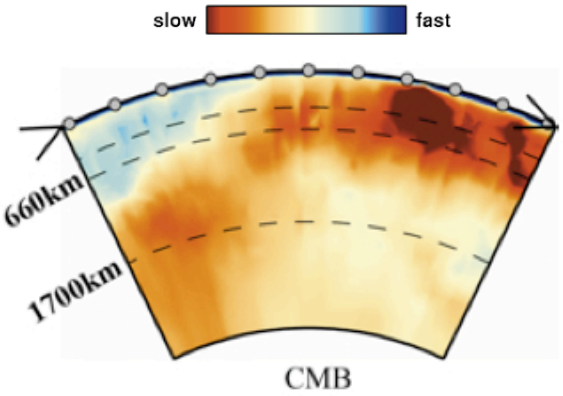
- Broad thermal upwelling beneath Ethiopia
- Slowest / hottest mantle on Earth

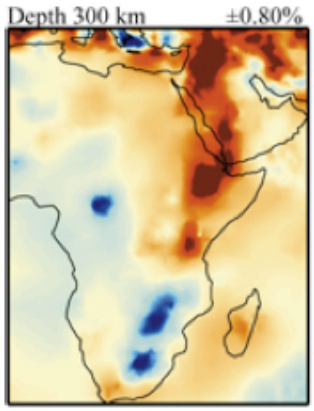
Benoit et al.. 2006

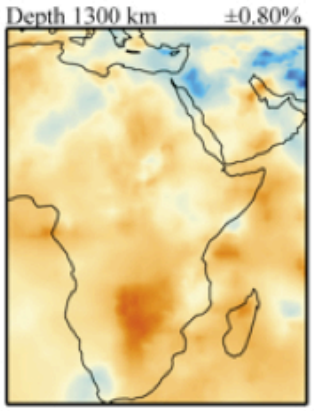


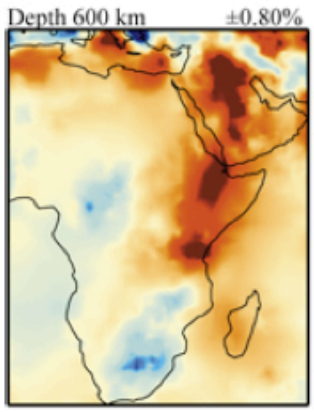


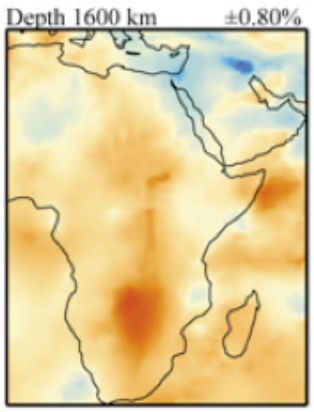
Poupinet et al., 1979







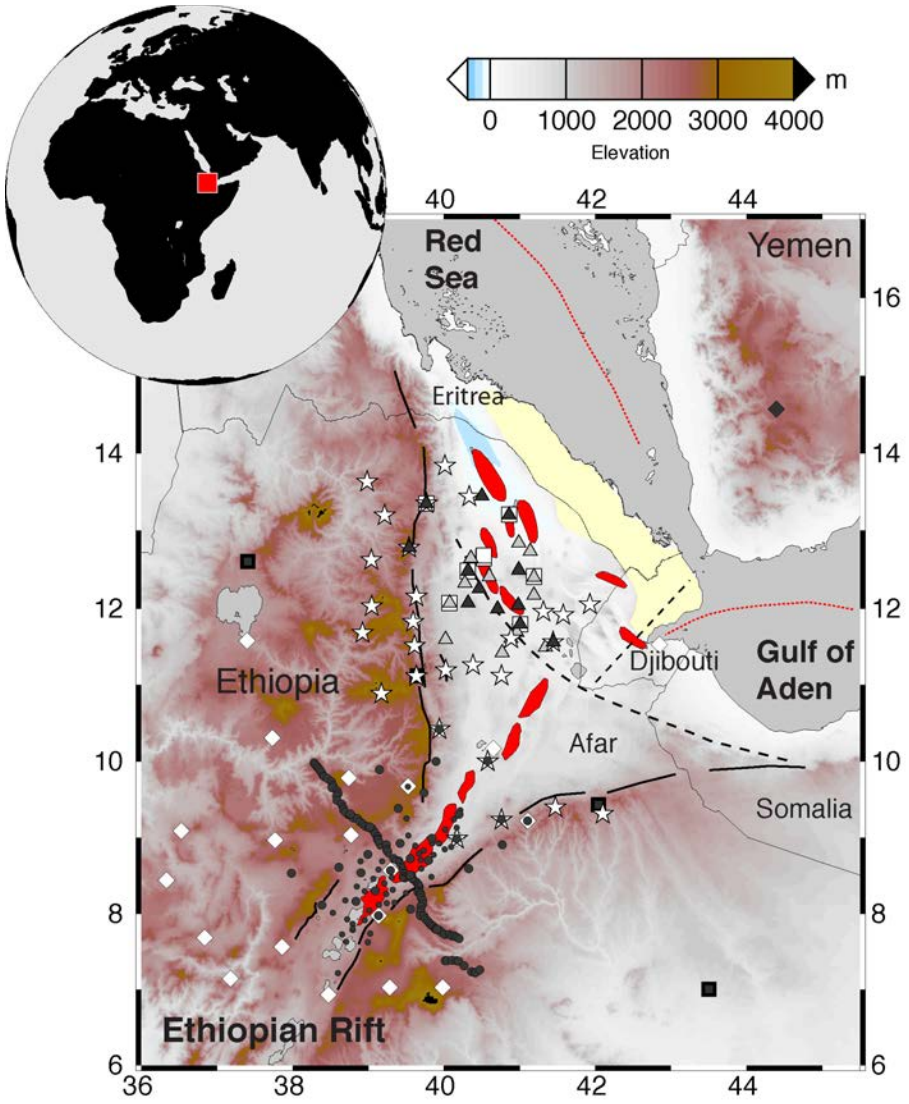


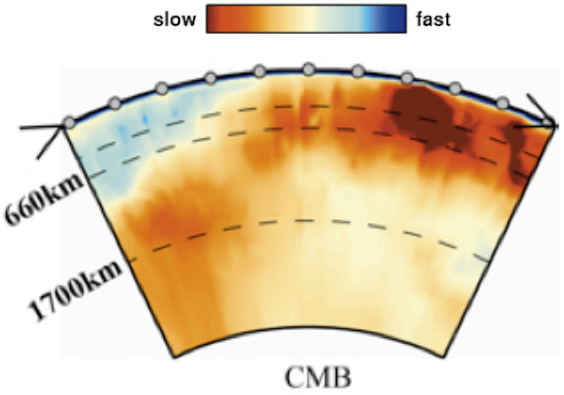


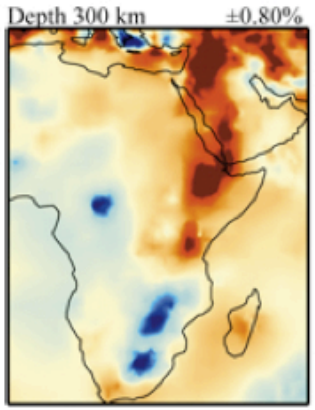
Li et al., 2008

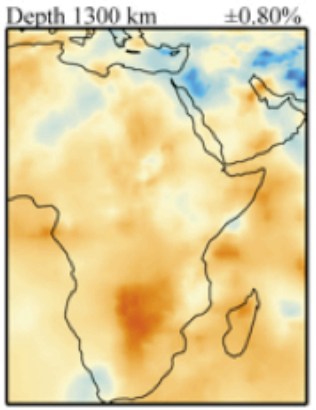
Mantle dynamics - melt supply

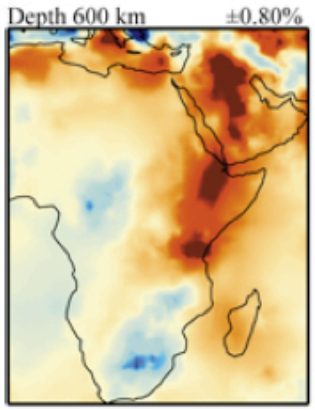
- Broad thermal upwelling beneath Ethiopia

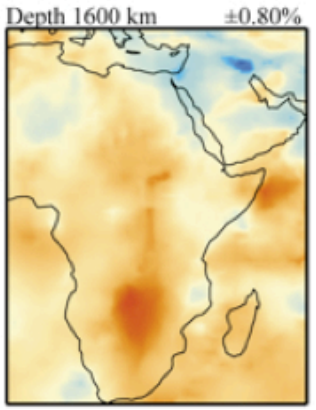












Li et al., 2008

Mantle dynamics - melt supply

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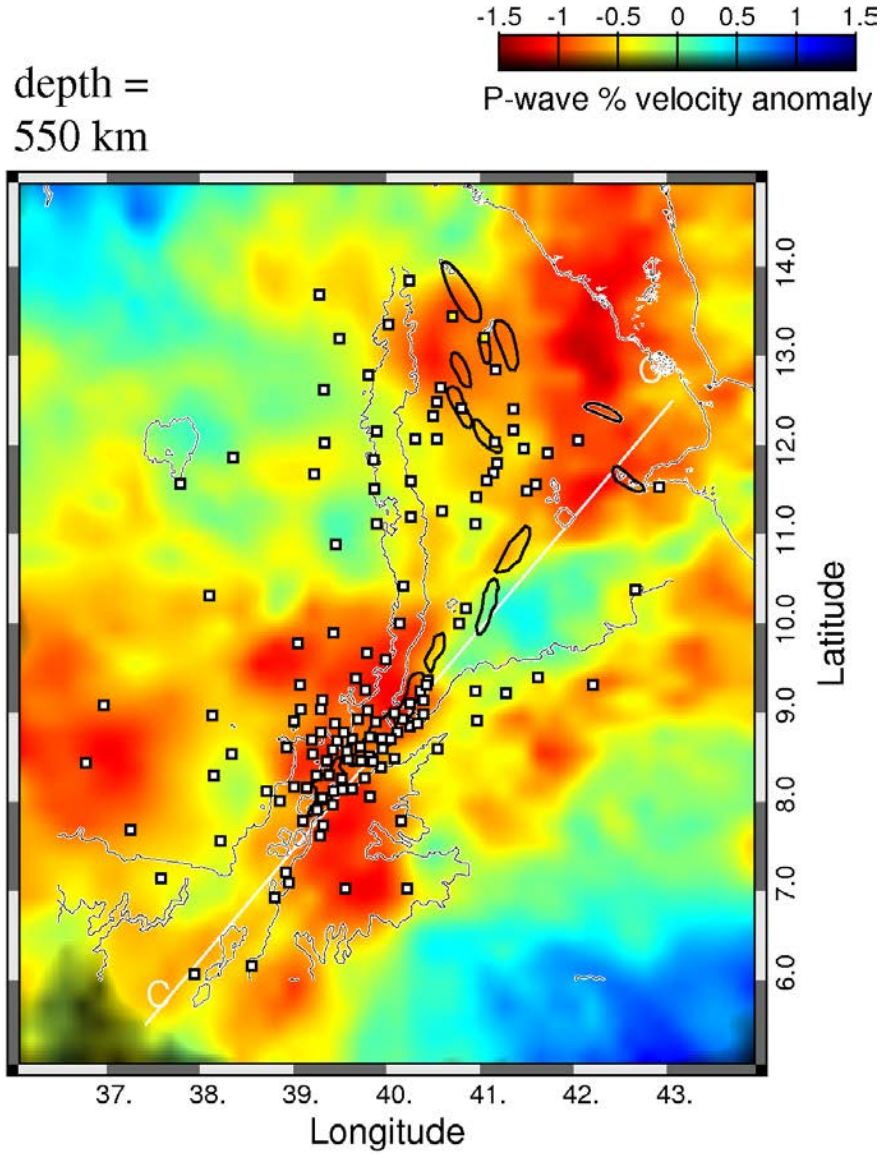
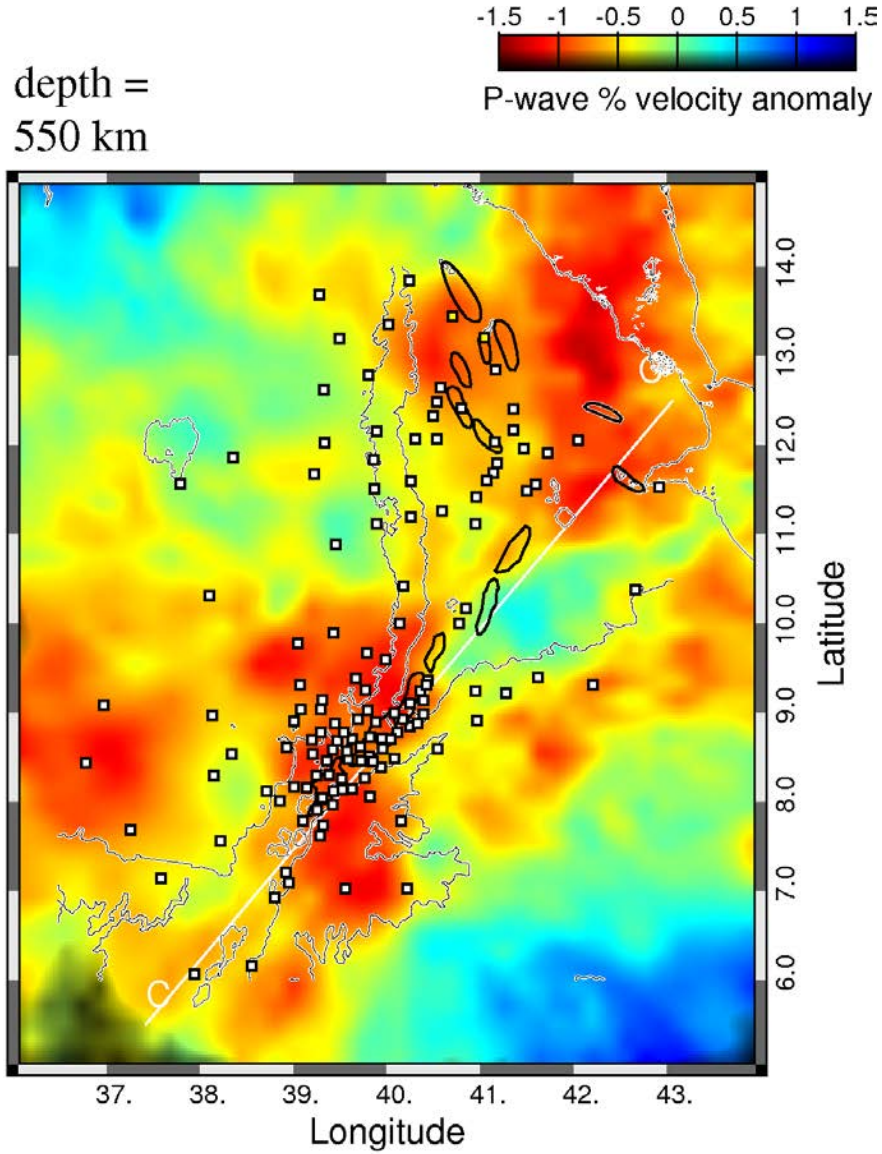


Image from James Hammond, Bristol

Mantle dynamics - melt supply

- Low velocity anomalies offset towards border faults



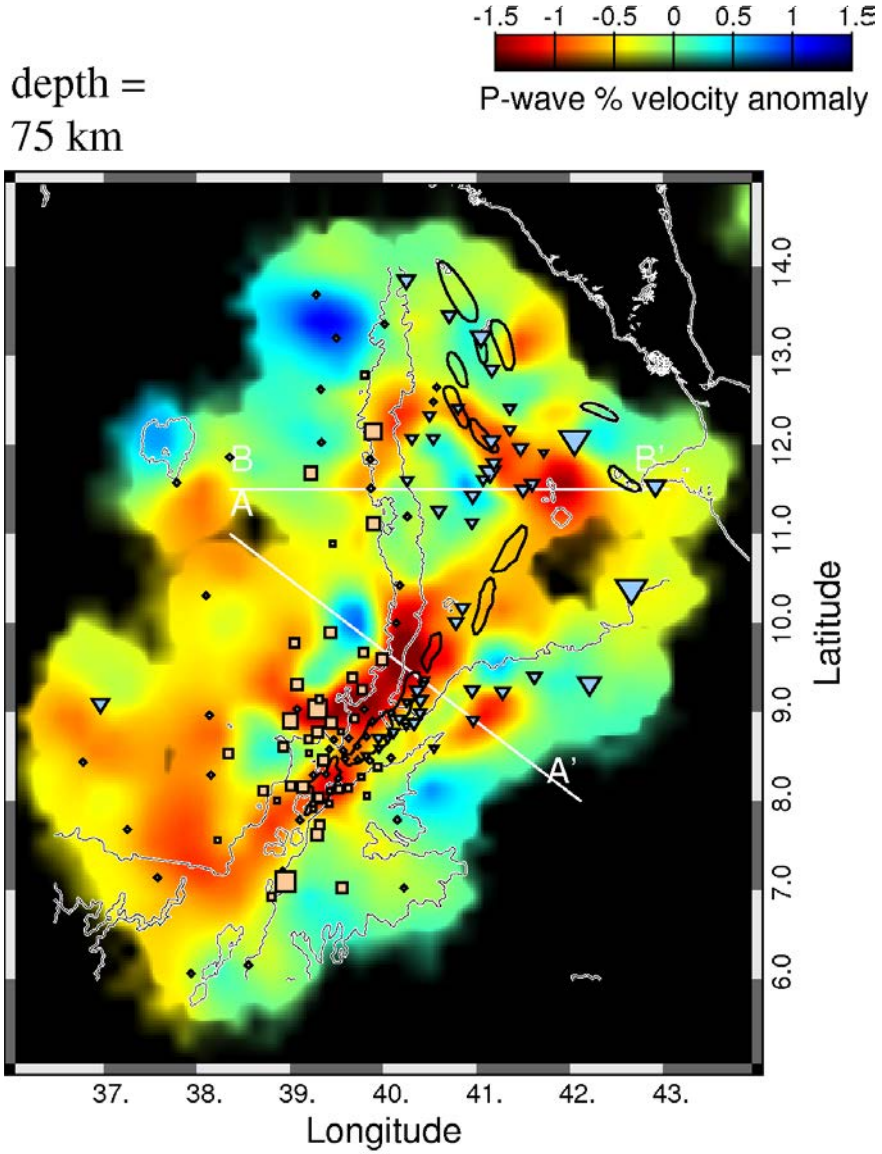
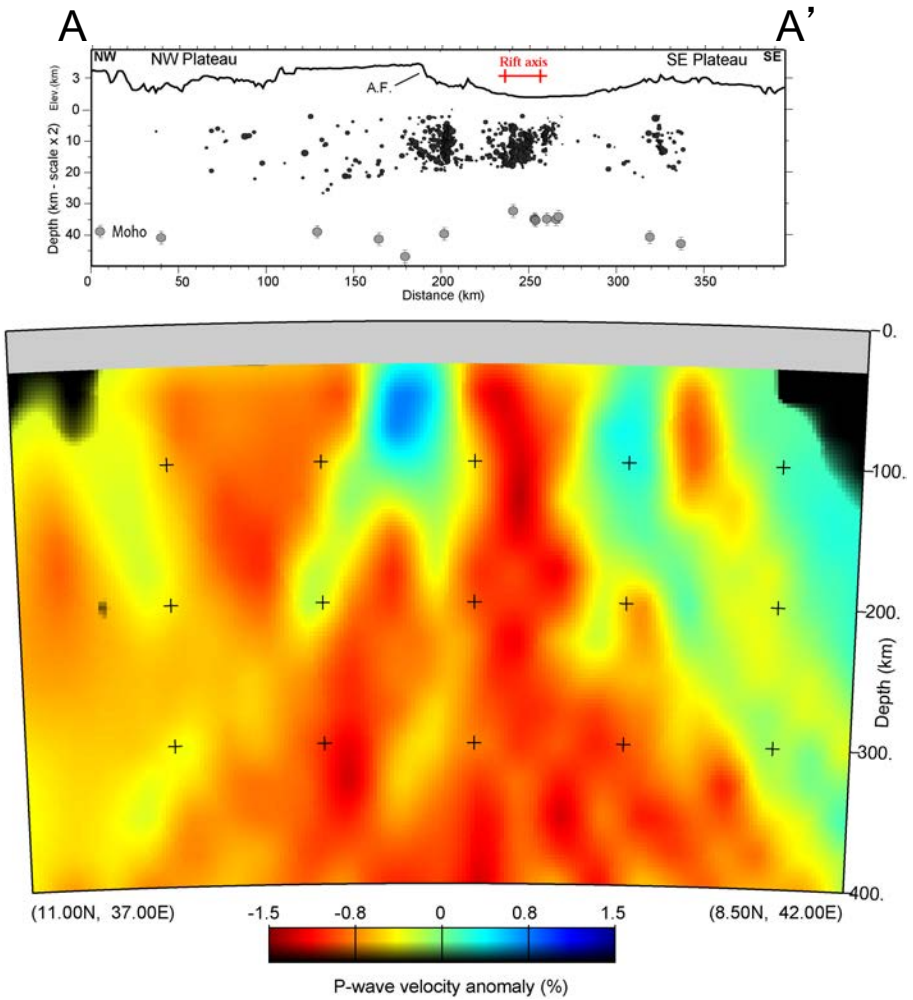
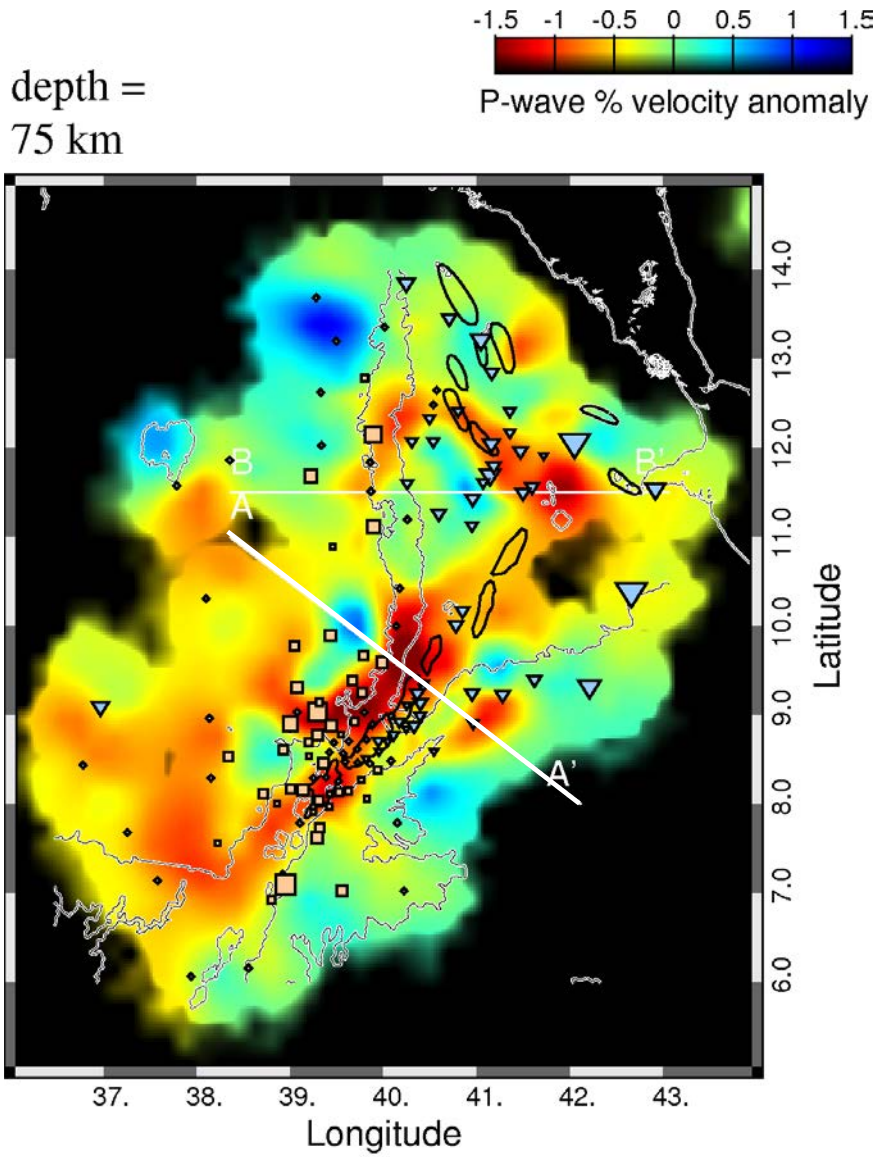


Image from James Hammond, Bristol

Mantle dynamics - melt supply

- Low velocity anomalies offset towards Miocene border faults
- Decompression melts focused along LAB
- Mechanical structure of lithosphere from early stretching influences melt migration





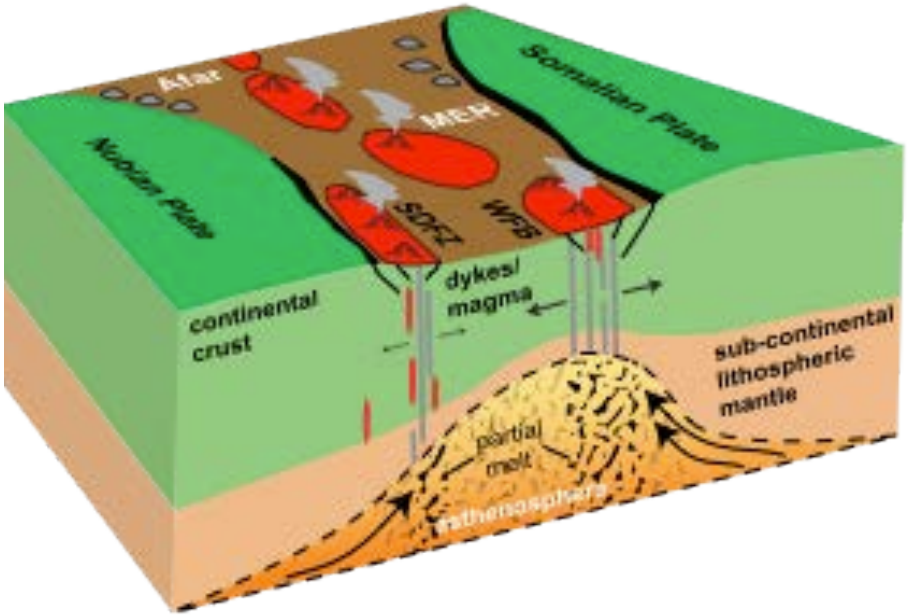
Keir et al., 2009; After Bastow et al., 2008

Image from James Hammond, Bristol

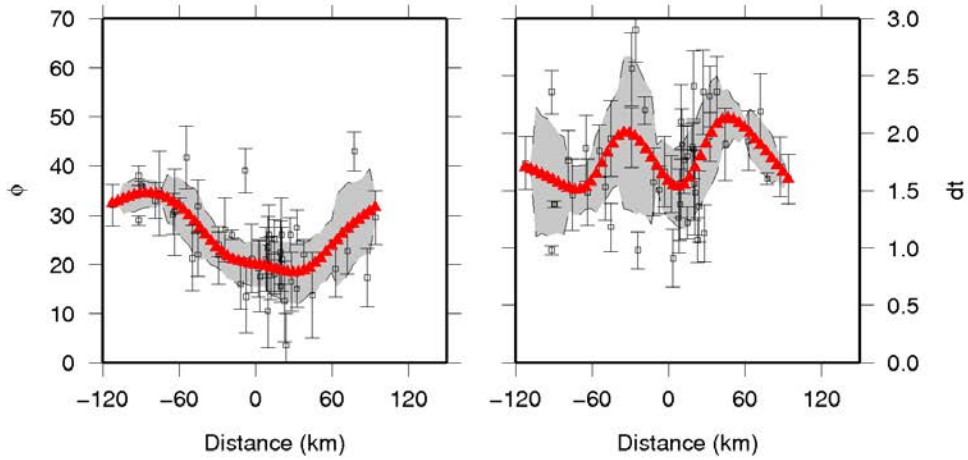
Mantle dynamics - melt supply

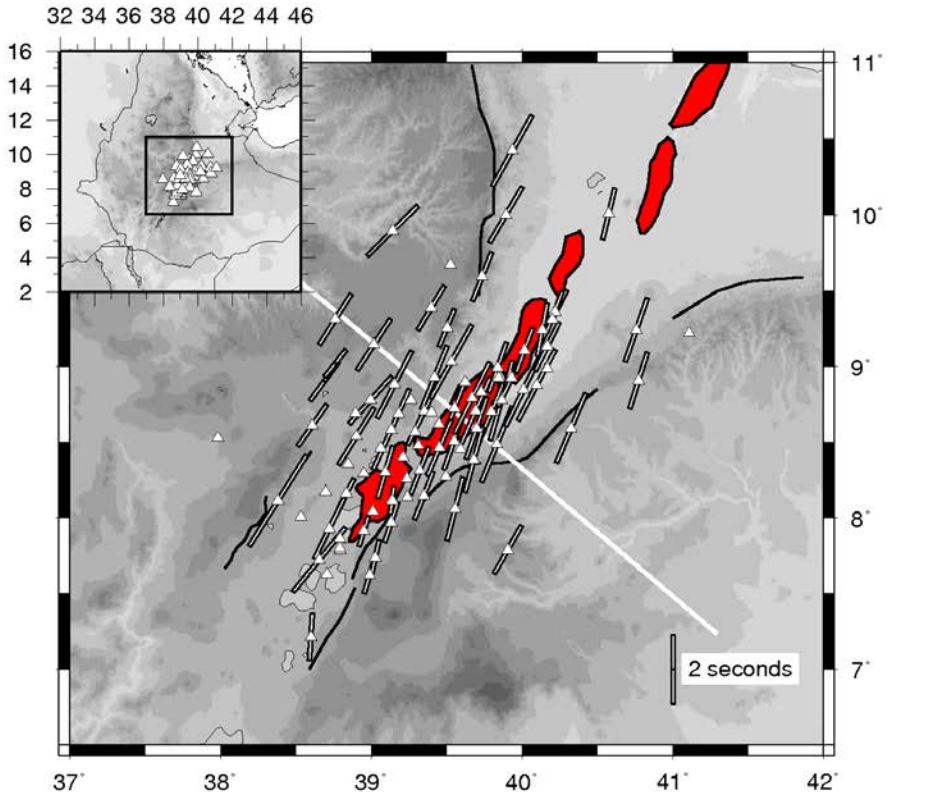
- Peak in SKS splitting beneath border faults
- Decompression melts focused along LAB
- Shape of lithosphere from early stretching influences melt migration
- Comparison of early stage rift - rupture to trace LAB modification during evolution

- Thermal / chemical erosion of lithosphere?
- Thermal and chemical heterogeneity from melt extraction?



Rooney et al., 2010





Kendall et al., 2005

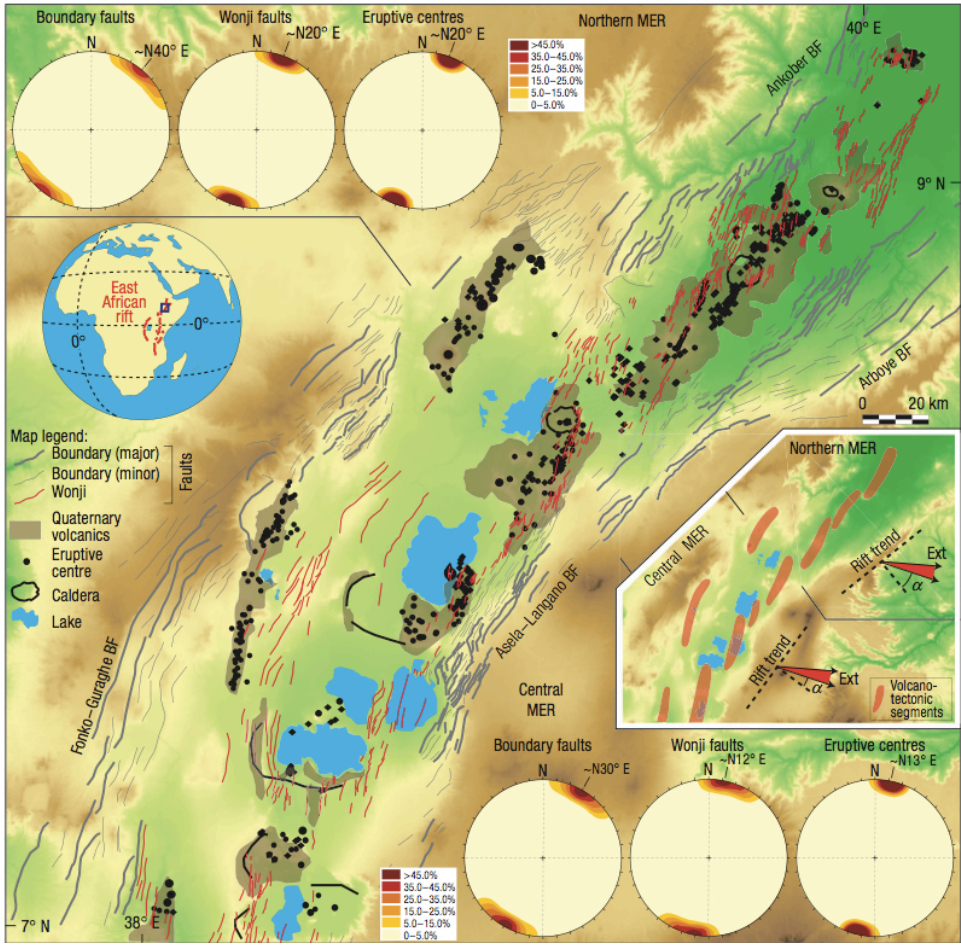
Deformation and rheology

- **Border faults - Miocene age**
- ~80-km-long fault segments
- <25 degrees obliquity to ~E-W opening
- Role of pre-existing structures not clear

- **Quaternary - Recent faults in axial graben**
- Shorter <15-km-long faults
- Strike orthogonal to rift opening
- Right-stepping en-echelon pattern

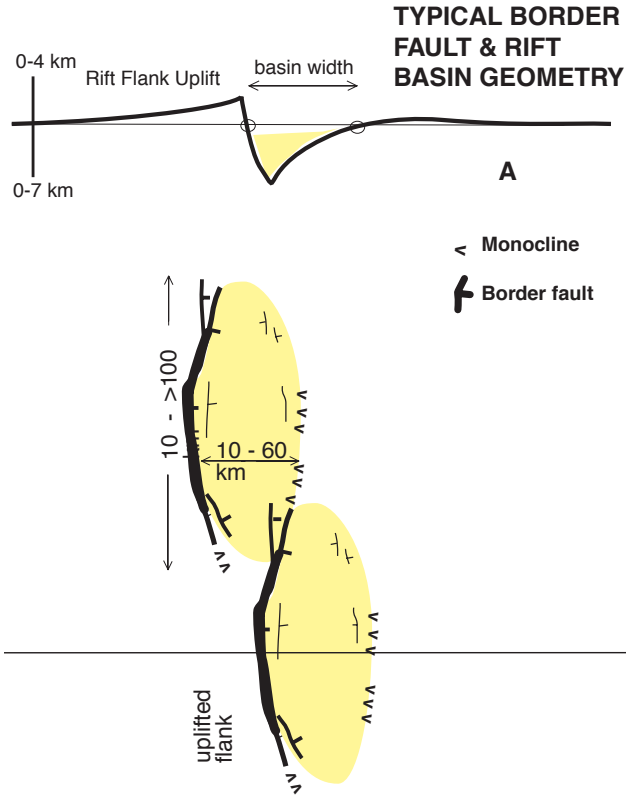
- **Faulting, magma intrusion, rheology and stress**

Corti 2008



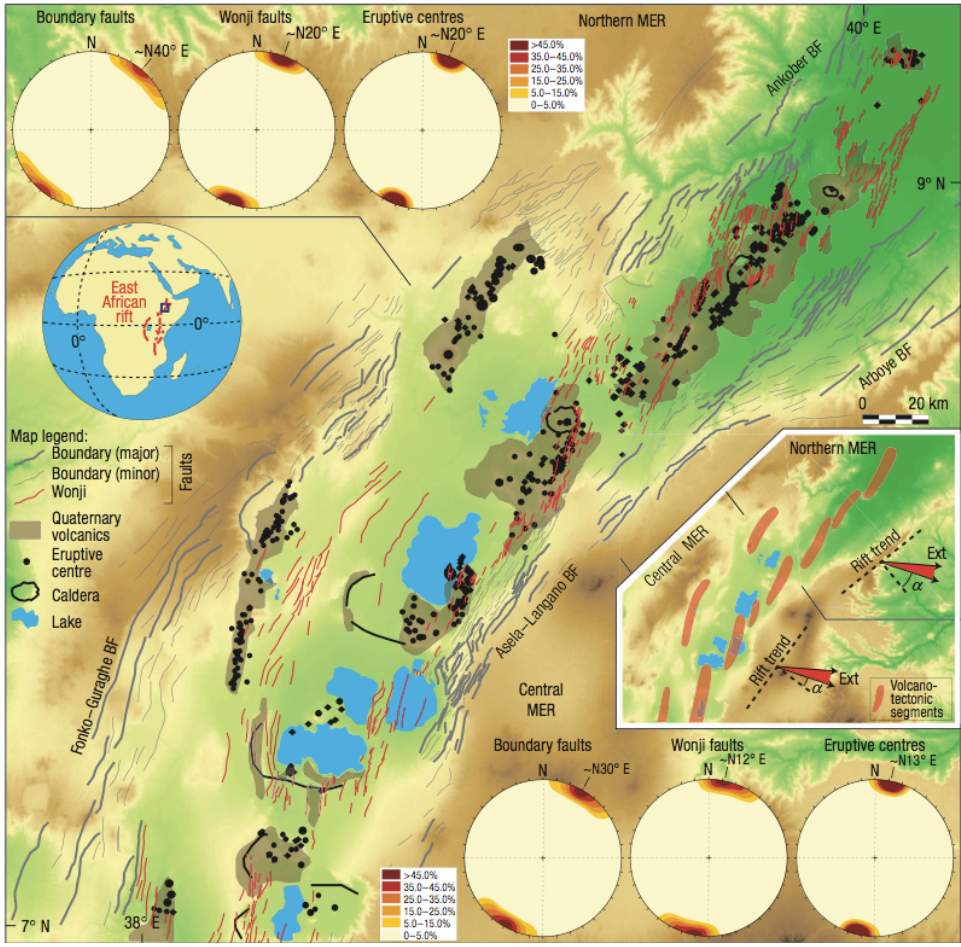
Deformation and rheology

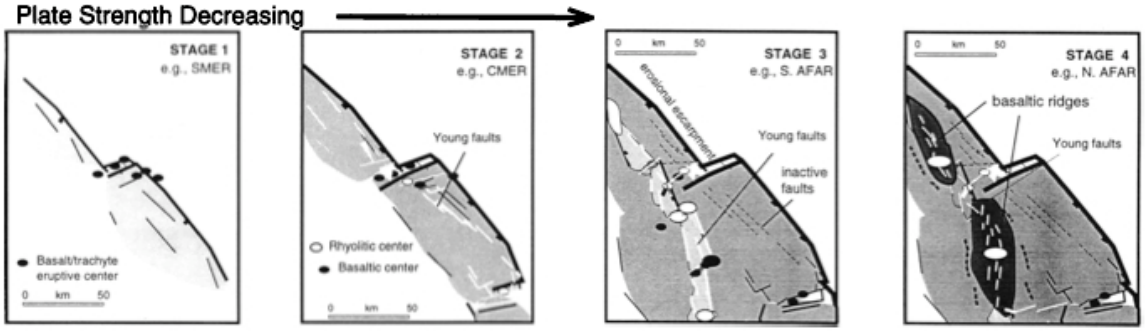
- Plate strength
- Reduction in fault length / basin width coincident with decrease in plate strength
- Influence of magma on strain, strength, and along-axis segmentation



Ebinger et al., 1996

Corti 2008





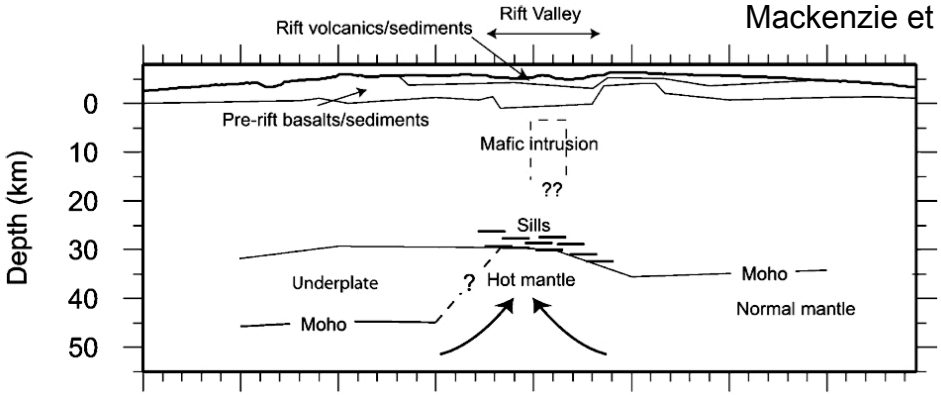
Deformation and rheology

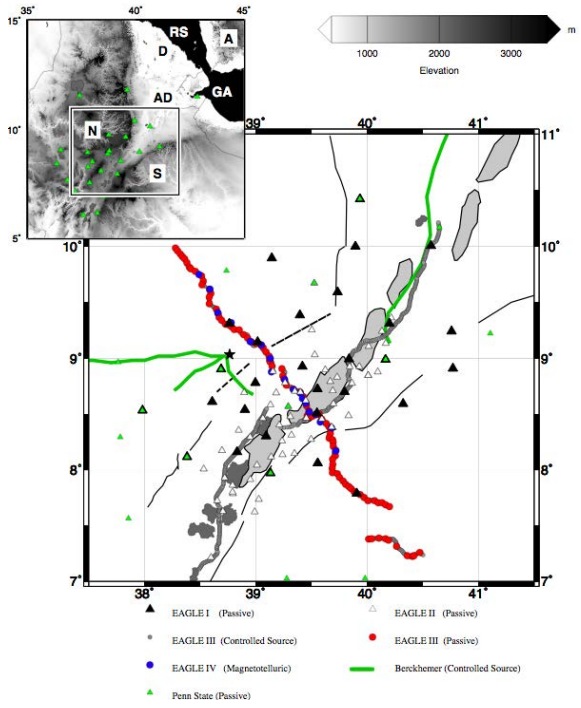
- Magma intrusion - EAGLE

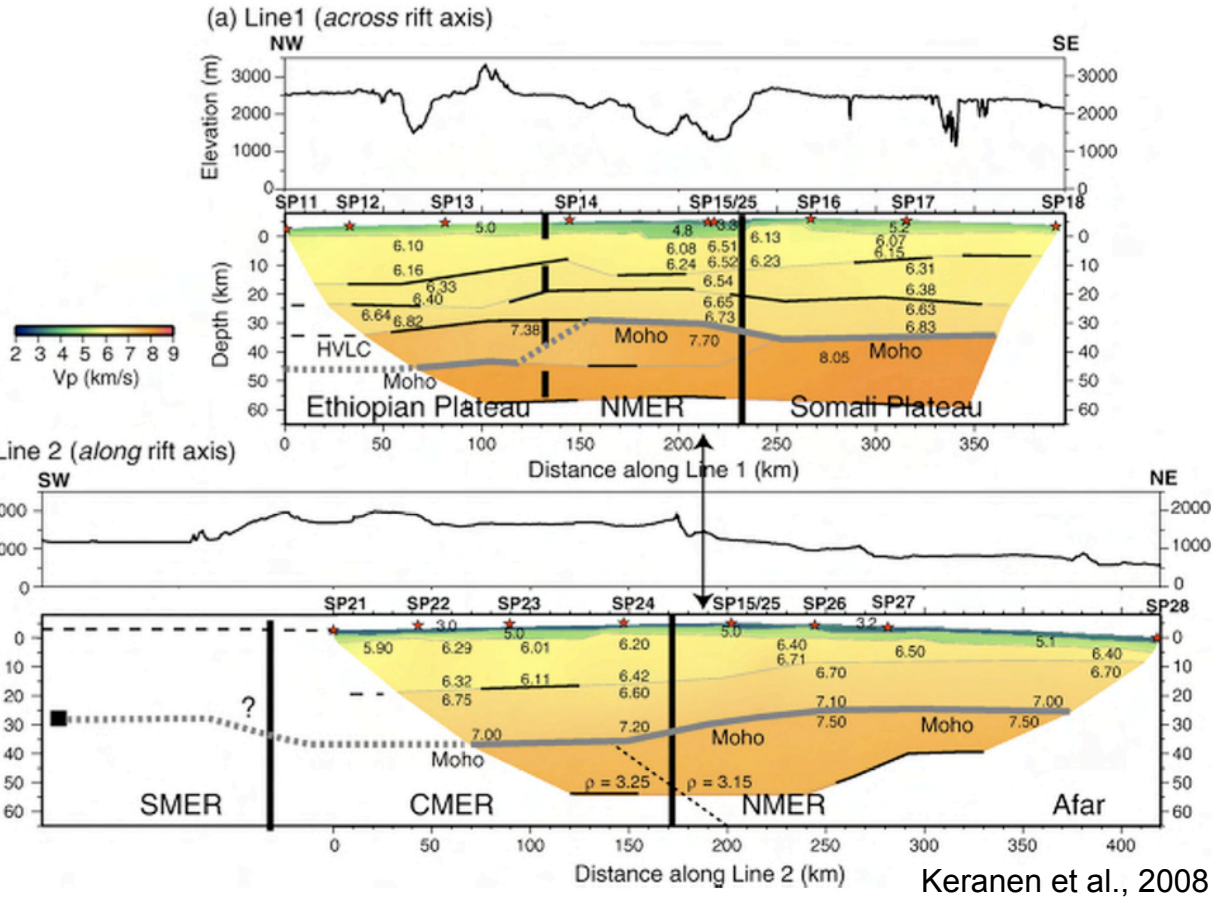
- HVLC beneath plateau - Oligocene?
- ~5 km crustal thinning beneath the rift - Miocene stretching

- High velocity crust beneath Quaternary - Recent segment
- Sill intrusion into lower crust
- Dike intrusion into mid-upper crust

Mackenzie et al., 2005





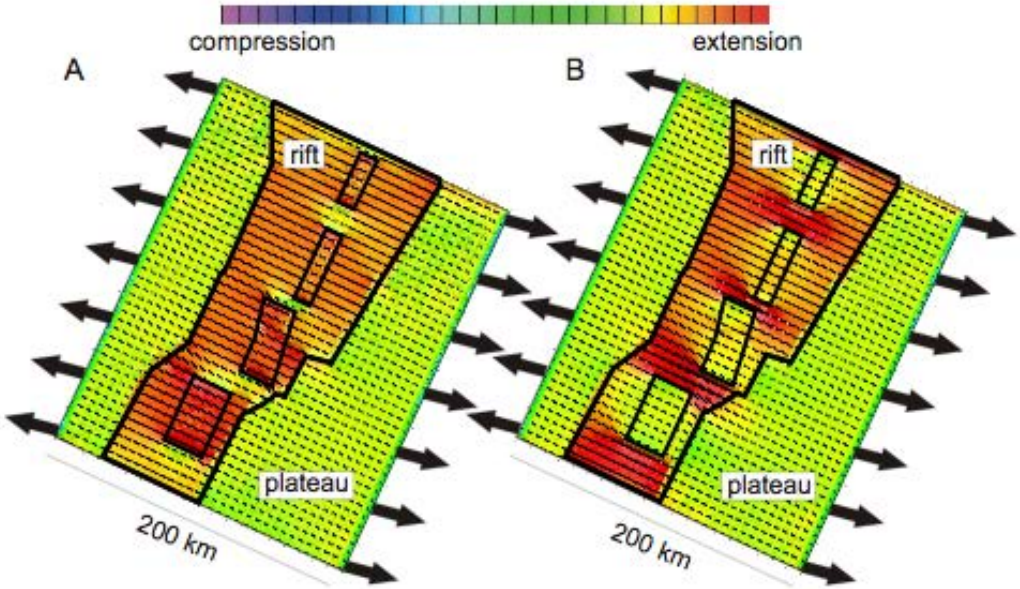


Keranen et al., 2008

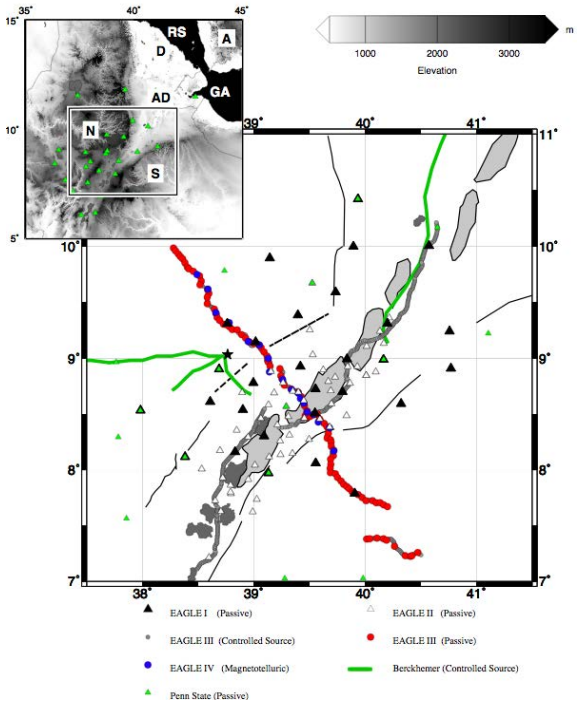
Deformation and rheology

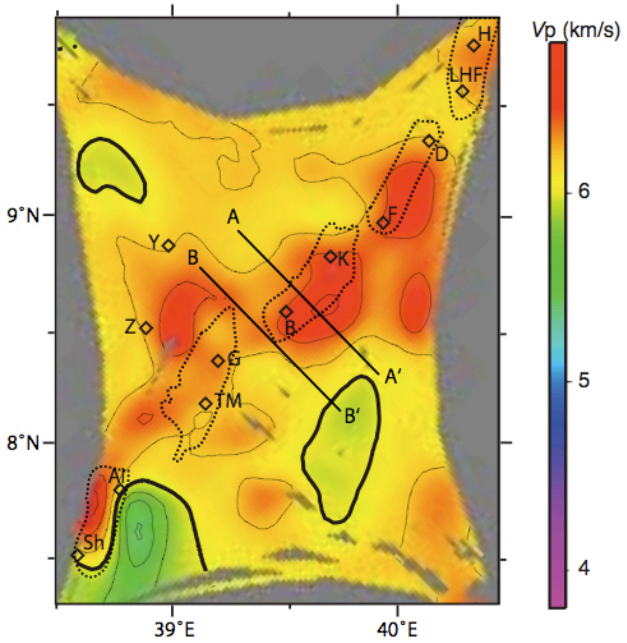
- Faulting, magma intrusion, rheology and stress

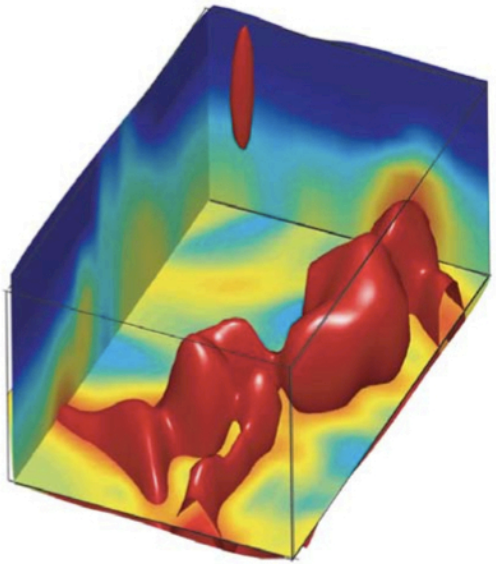
- Dense mafic intrusions in mid-crust
- ~20 km extension in ~3 My
- Magma production rate 90km^3 km^{-1} My^{-1}
- Solid intrusions strengthens lithosphere and causes localization of stress
- Partially molten intrusions weakens plate and localizes stress between segments



Beutel et al., 2010





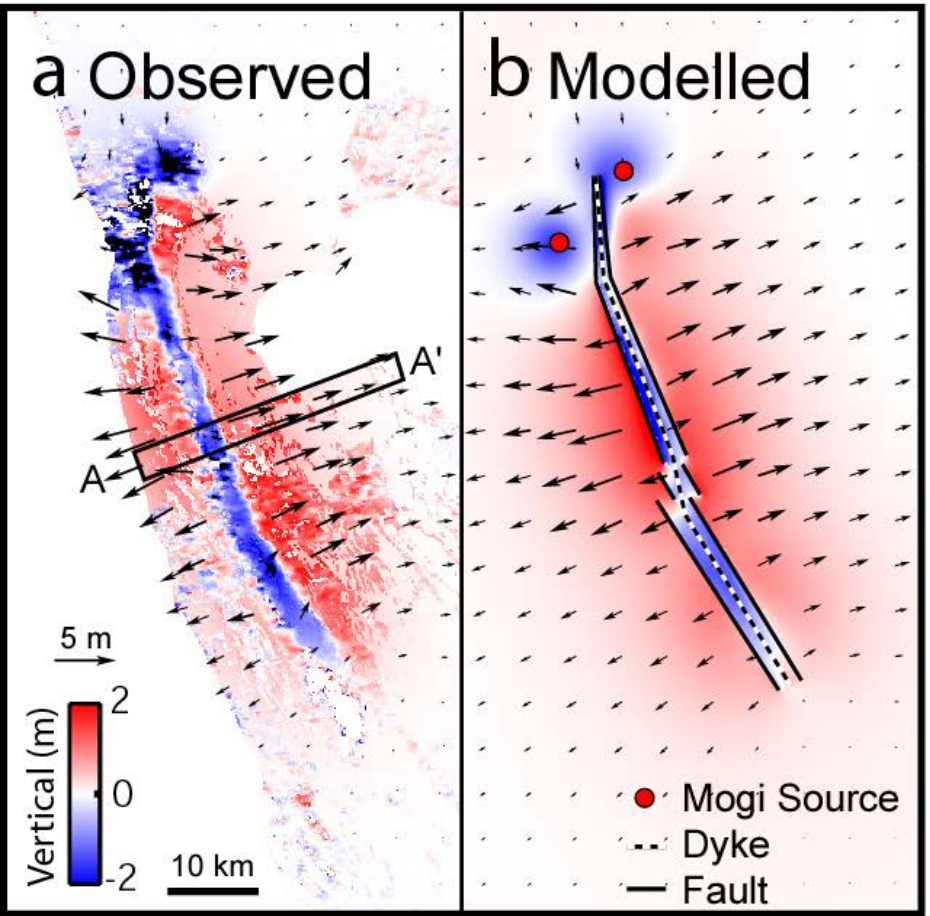


Kerenan et al., 2004

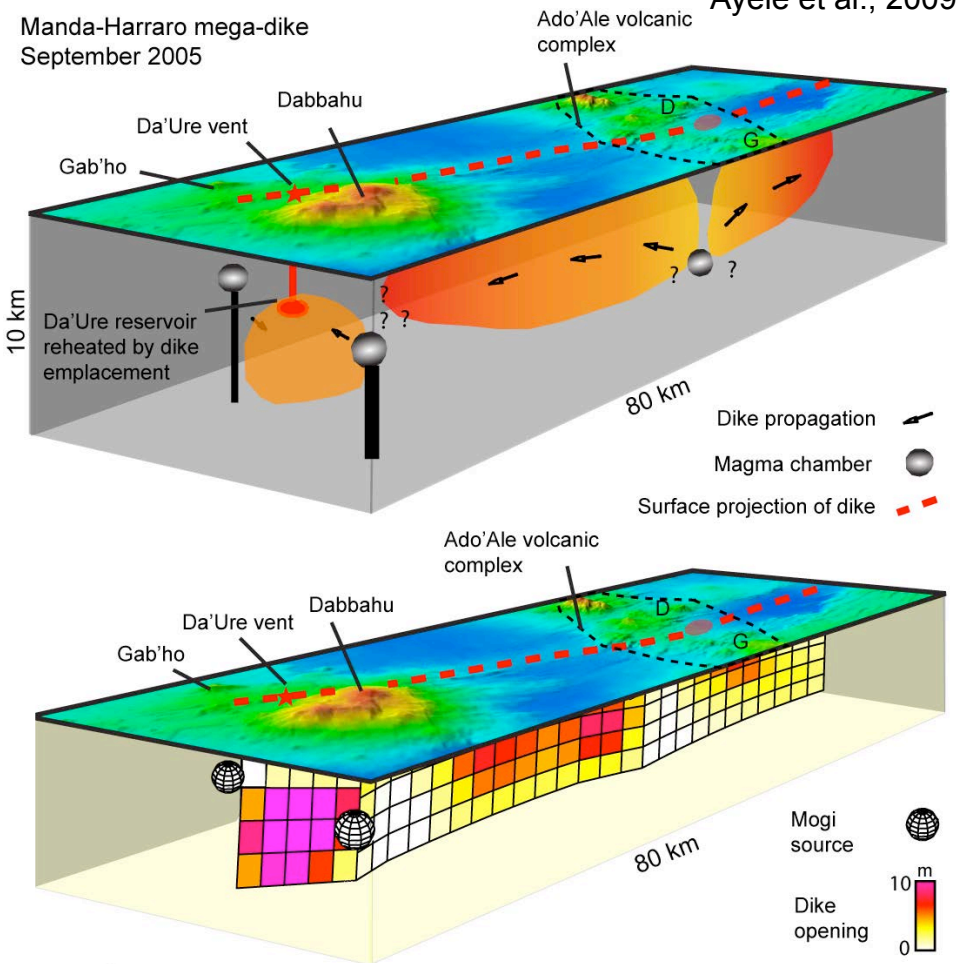
Dabbahu rifting episode

- Time-scales of magma intrusion
- Dike-induced faulting
- Maintenance of along-axis segmentation

Wright et al., 2006

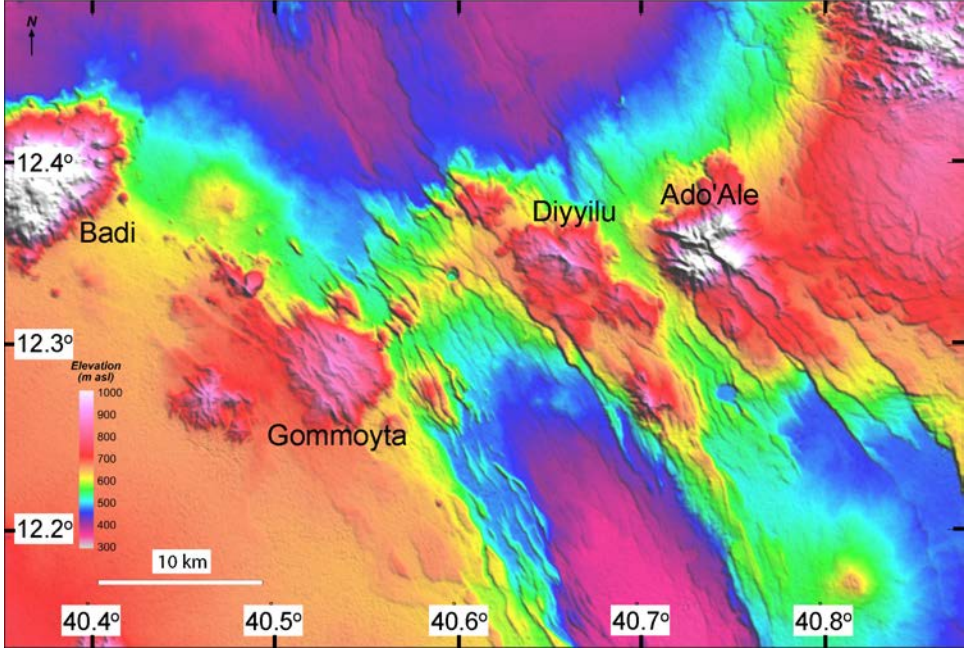


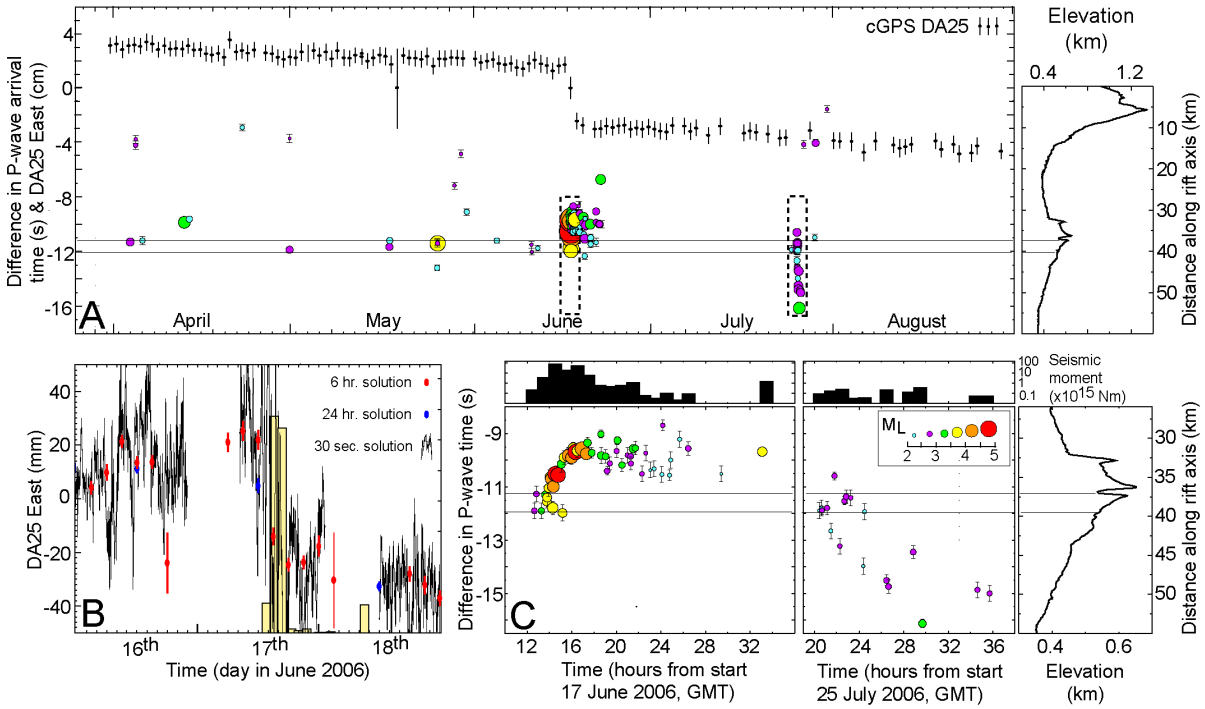
Ayele et al., 2009



Dabbahu rifting episode

- Seismic and aseismic deformation
- Time-scales of rifting processes

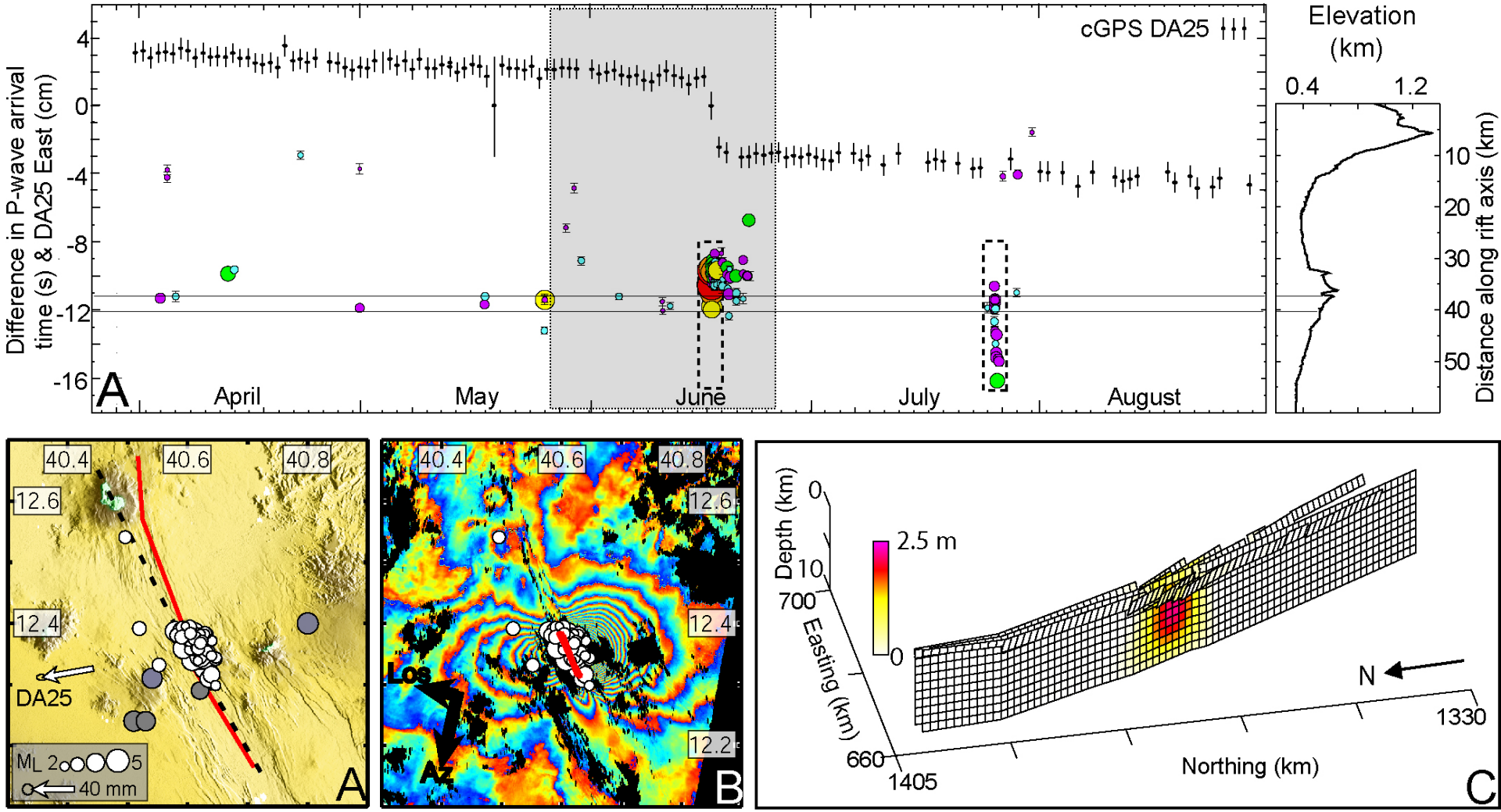




Keir et al., 2008

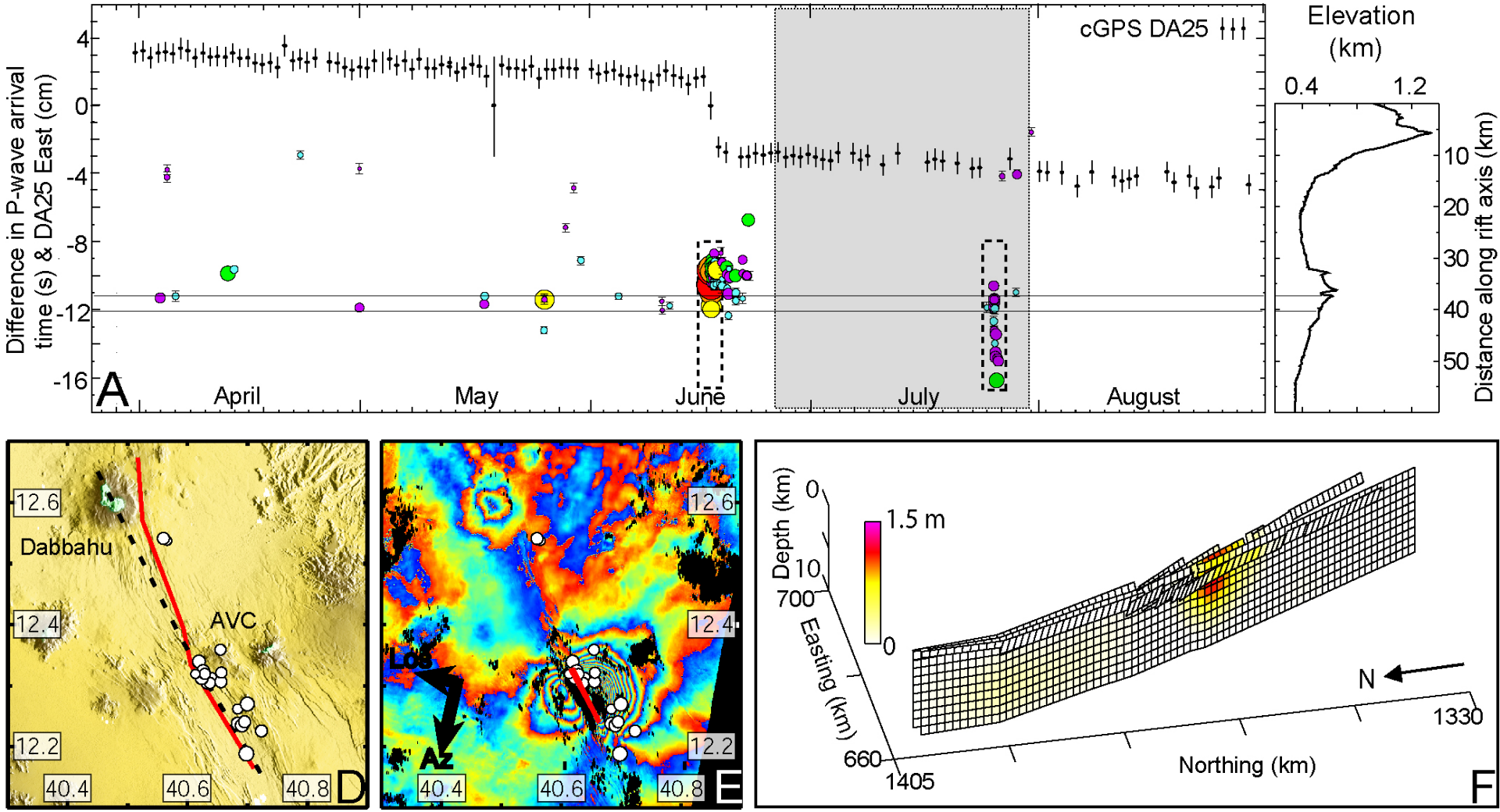
Deformation during dike intrusions

20 May - 24 June 2006



Deformation during dike intrusions

24 June - 29 July 2006



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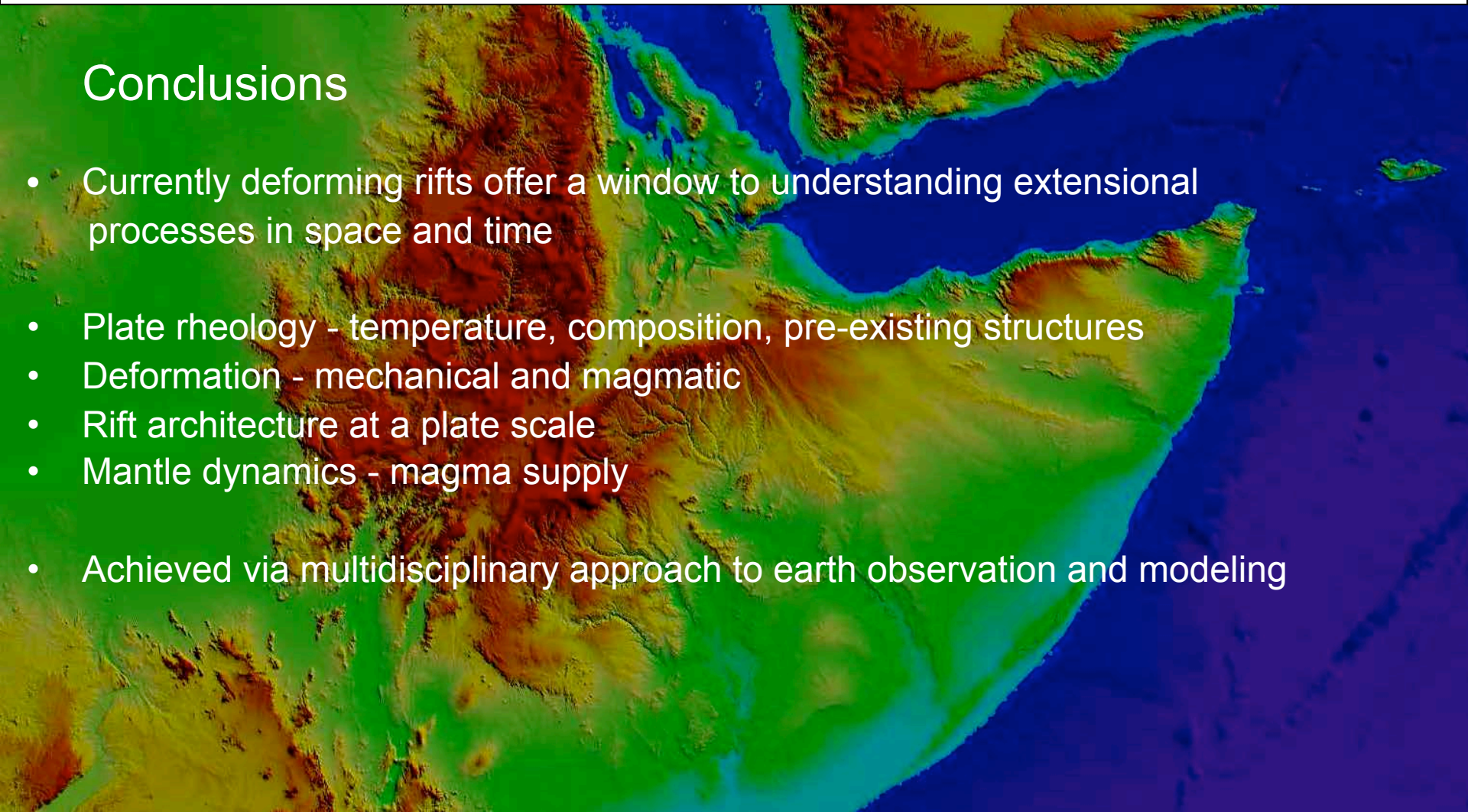
Rift initiation - East Africa and Afar

Derek Keir - University of Leeds

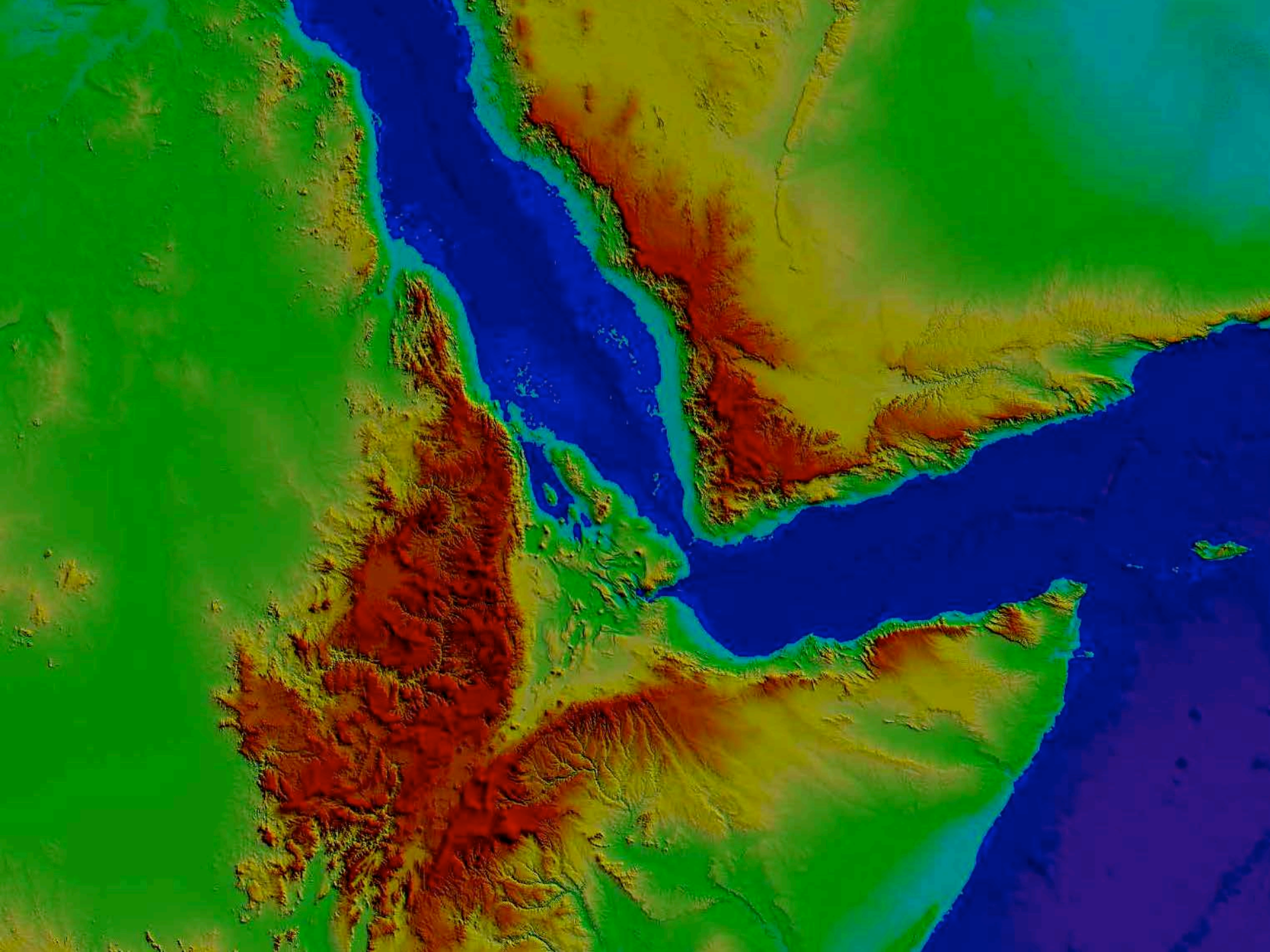


Conclusions

- Currently deforming rifts offer a window to understanding extensional processes in space and time

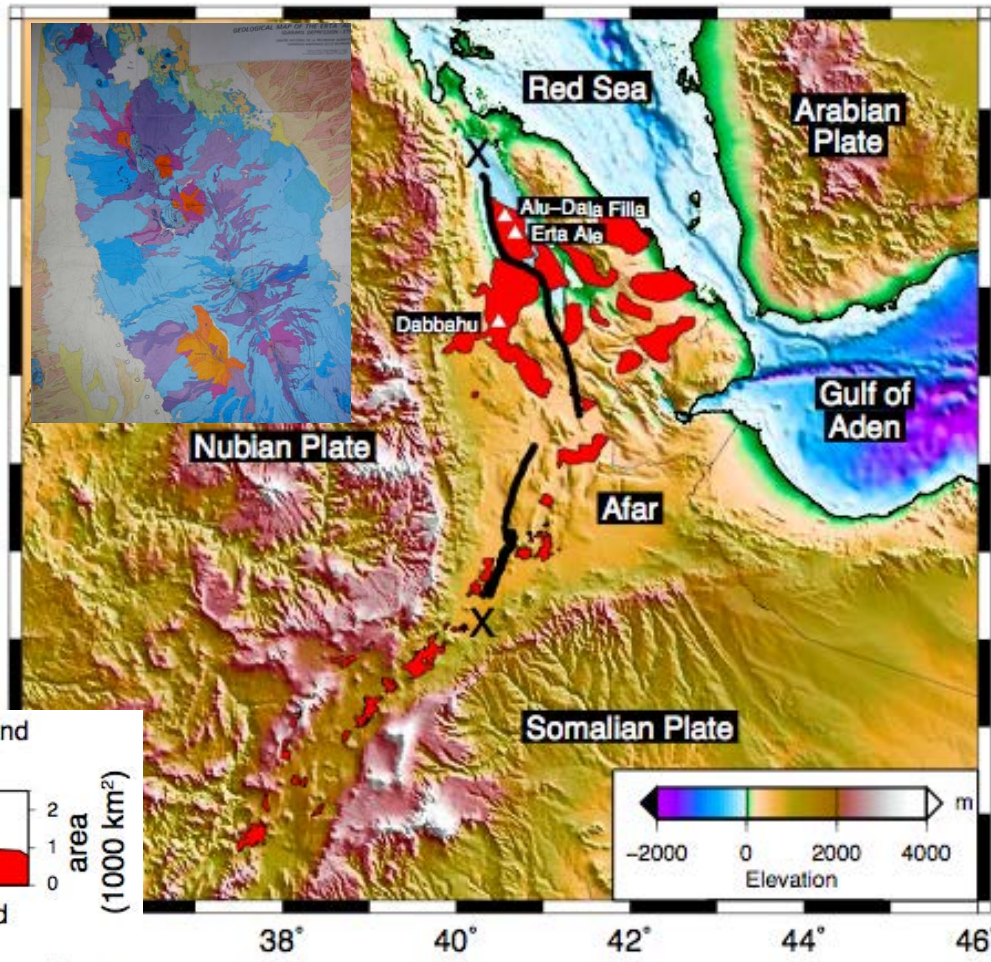
- Plate rheology - temperature, composition, pre-existing structures
- Deformation - mechanical and magmatic
- Rift architecture at a plate scale
- Mantle dynamics - magma supply

- Achieved via multidisciplinary approach to earth observation and modeling

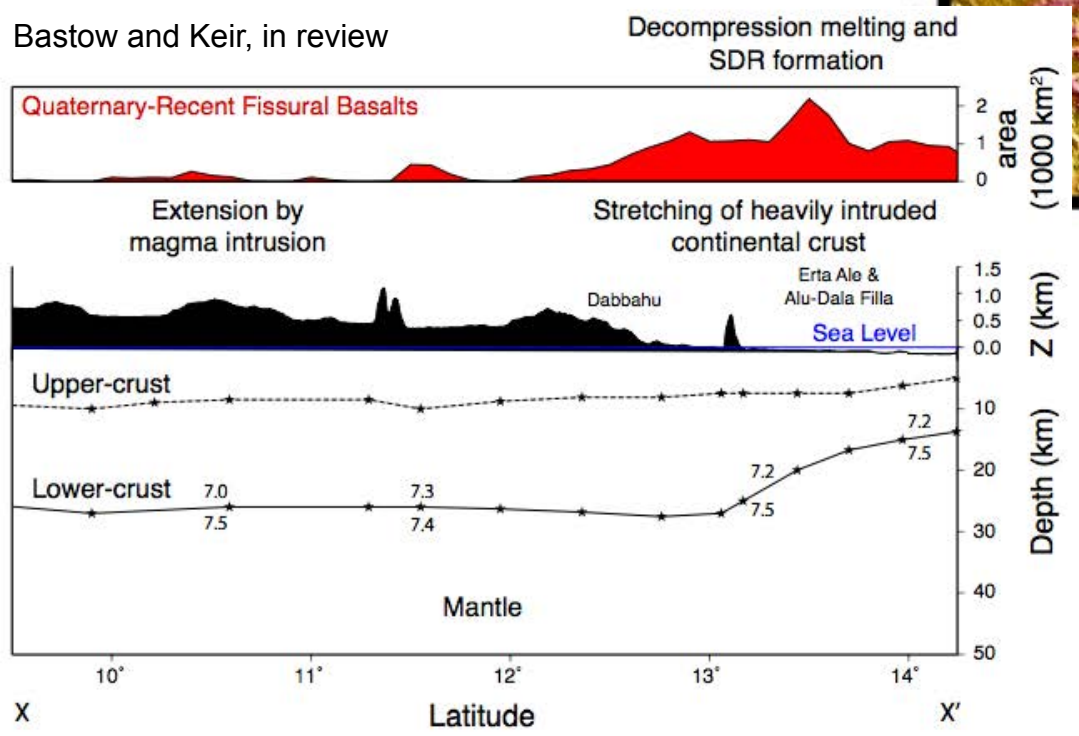


Basaltic volcanism at breakup

- Volcanism during late stage rifting
- Peak in Quaternary-Recent basaltic volcanism
- Subsidence of land towards sea-level
- Marked thinning of the crust

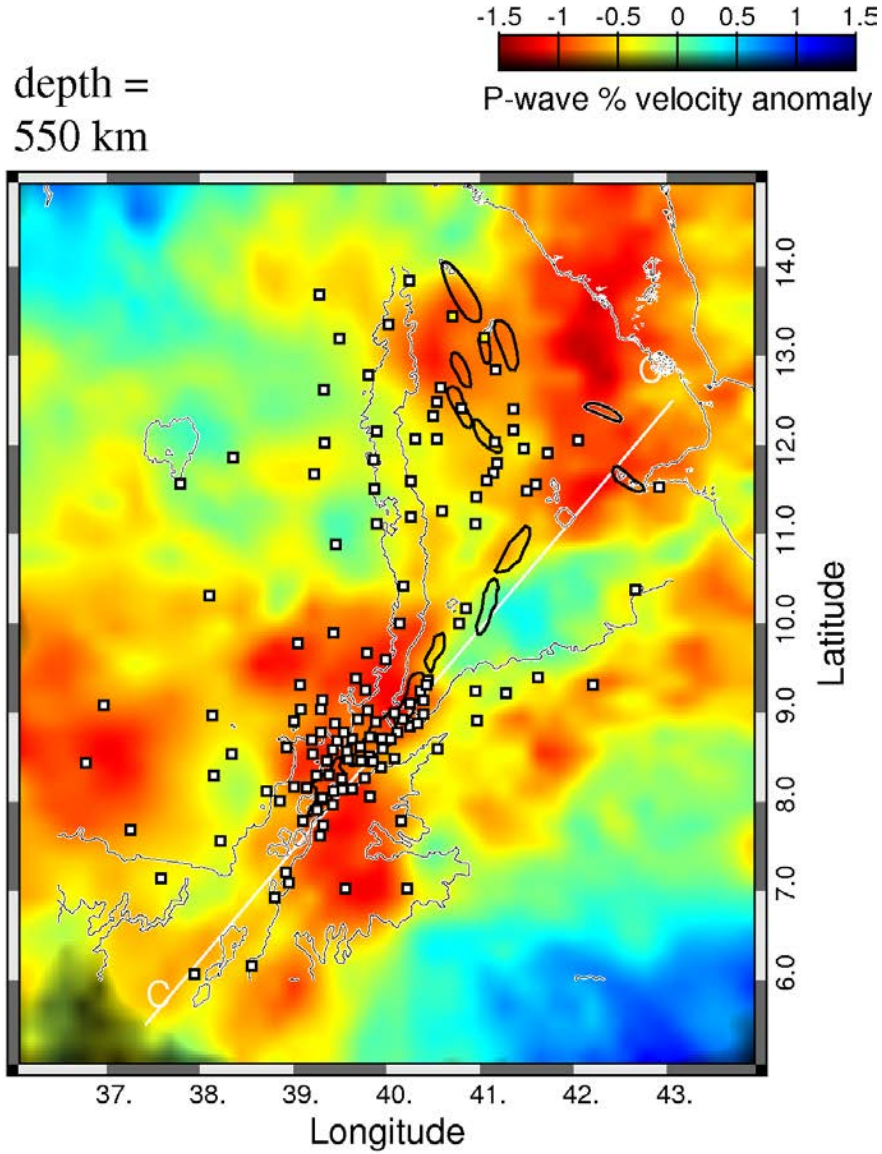


Bastow and Keir, in review



State of the mantle and rift initiation

- Broad thermal upwelling beneath Ethiopia



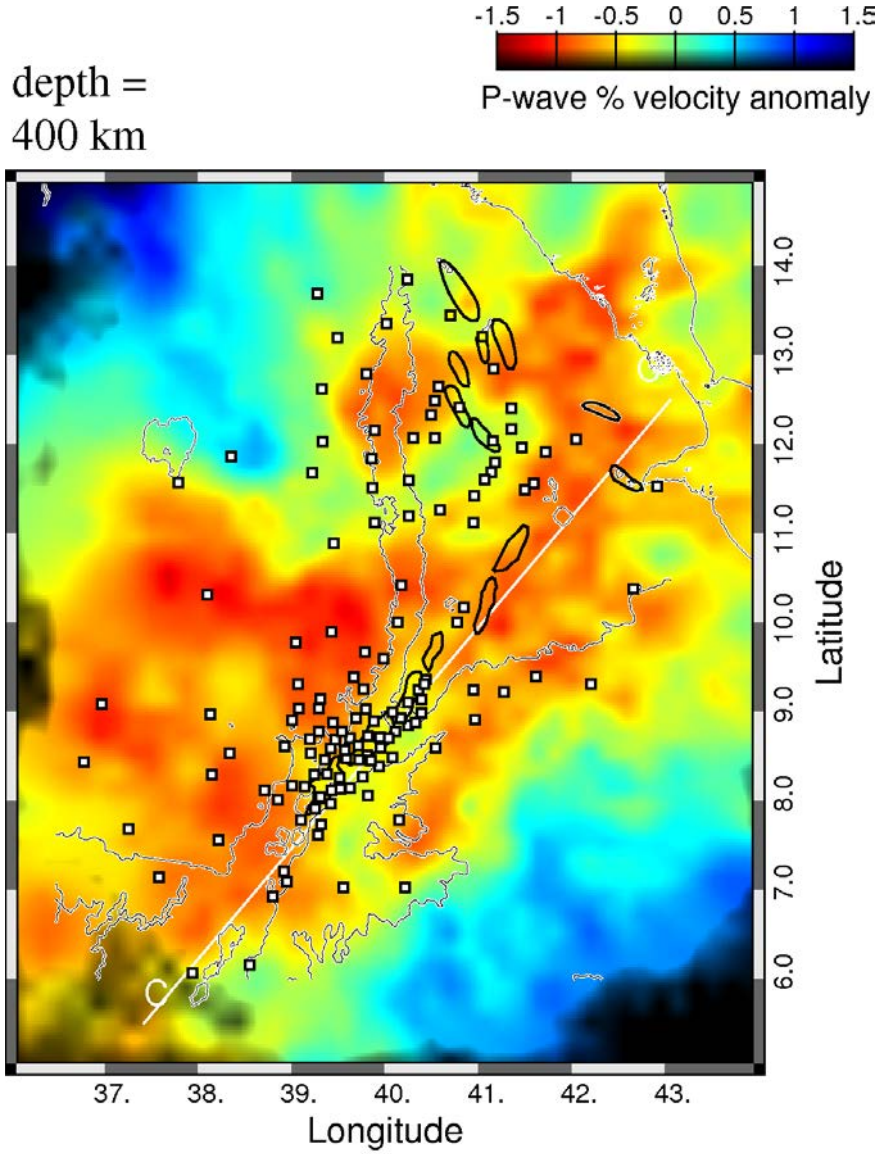


Image from James Hammond, Bristol

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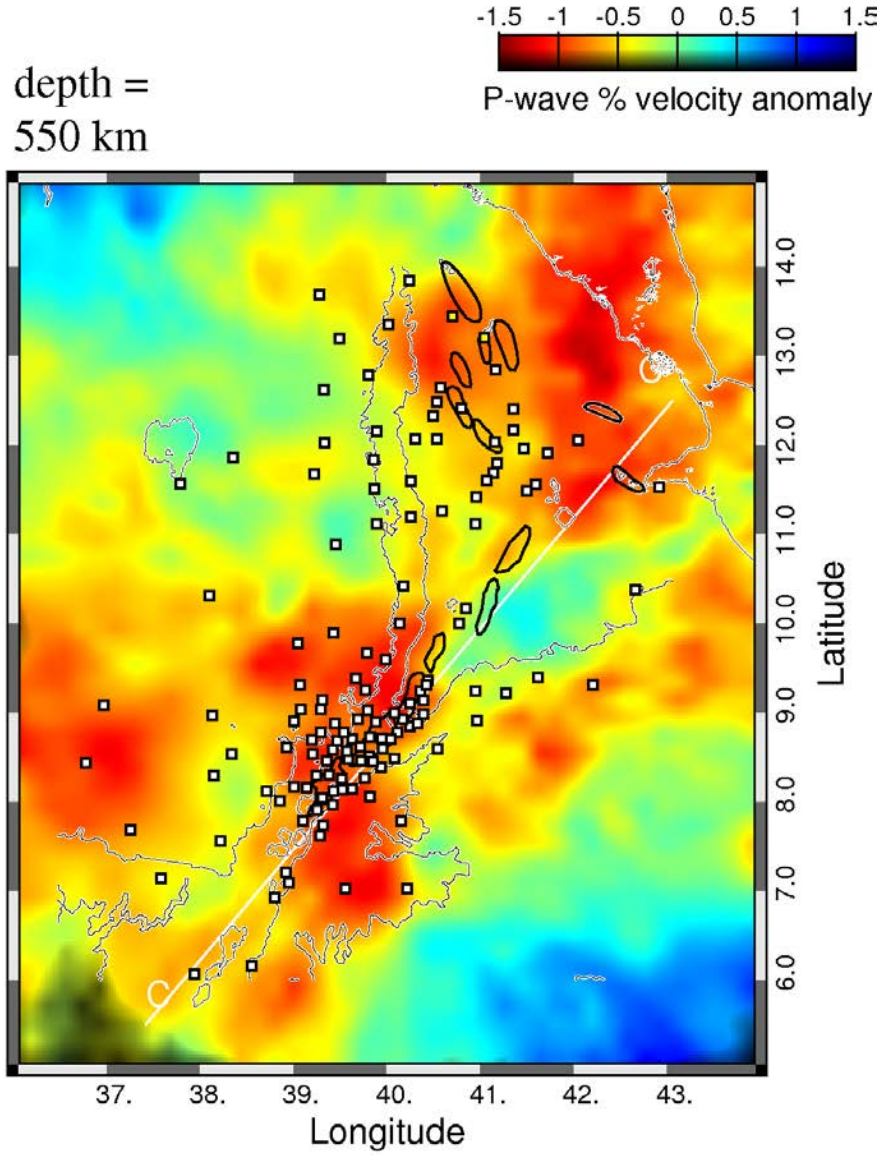

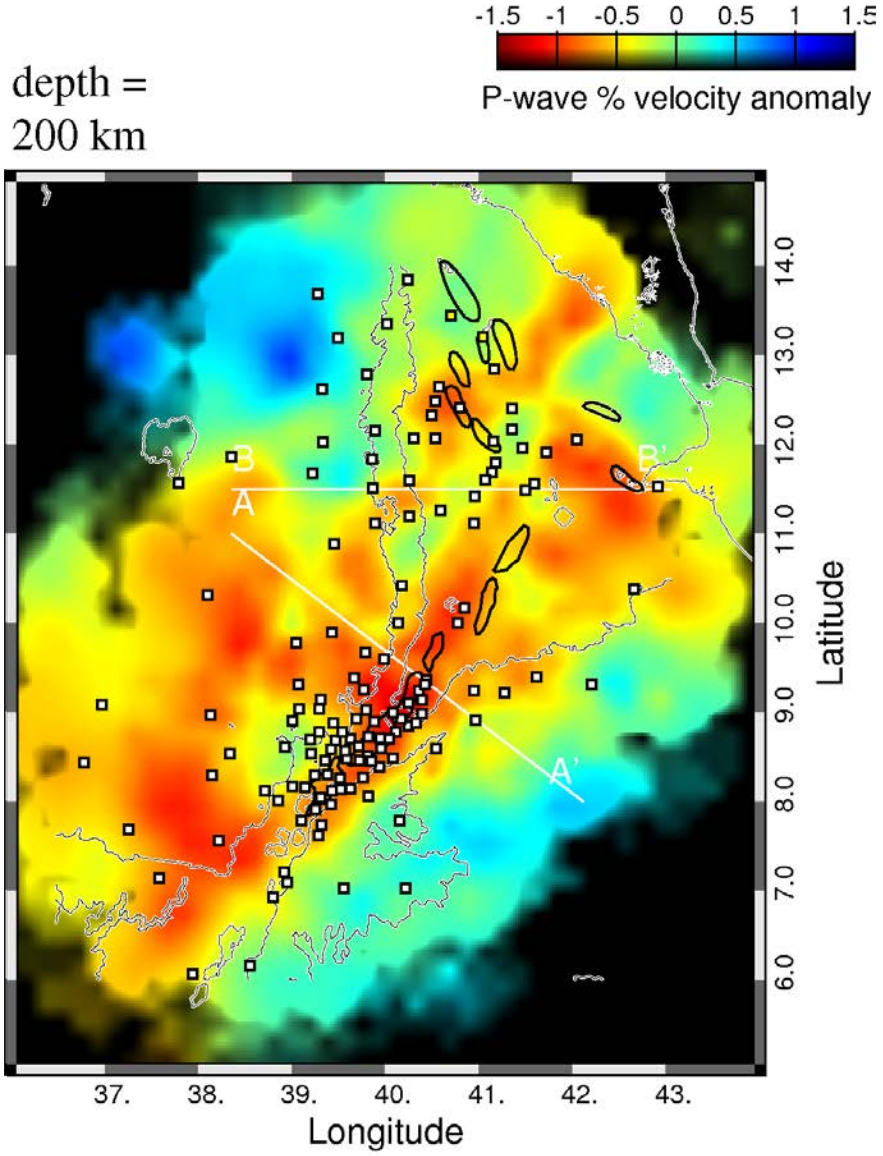

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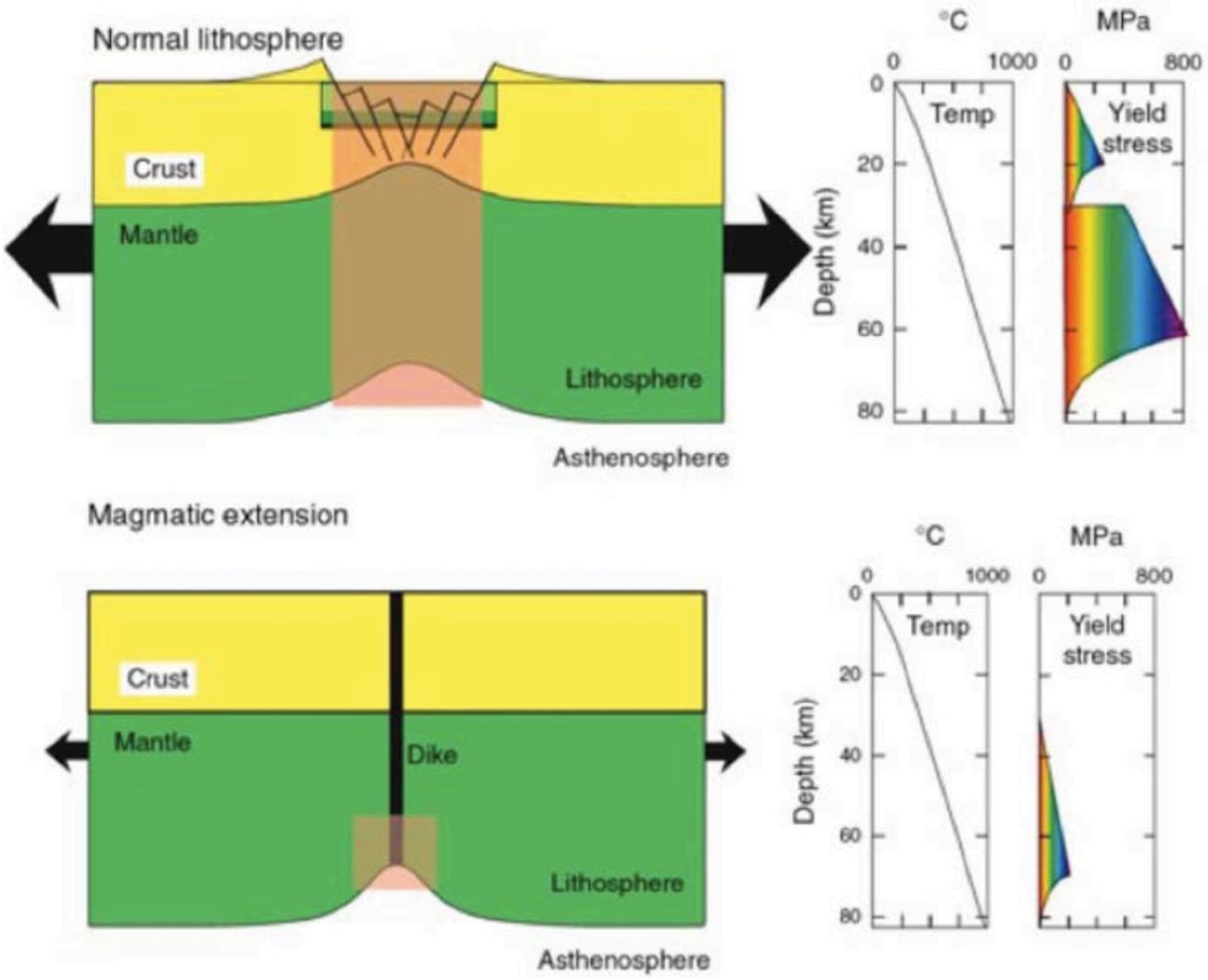
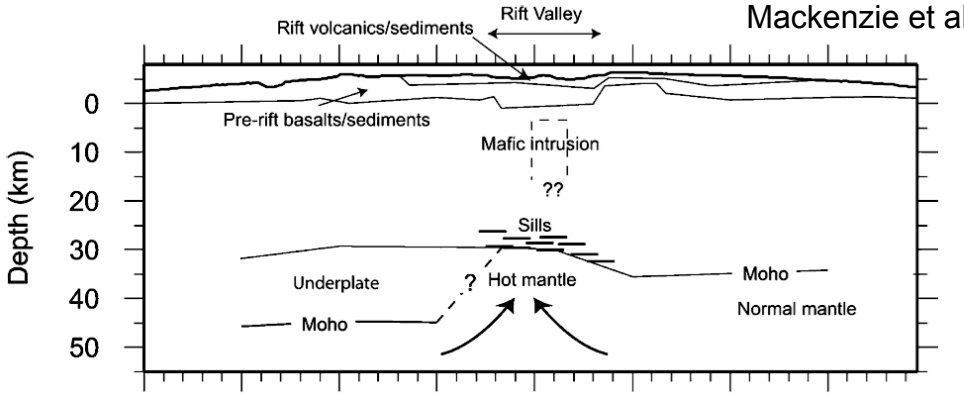
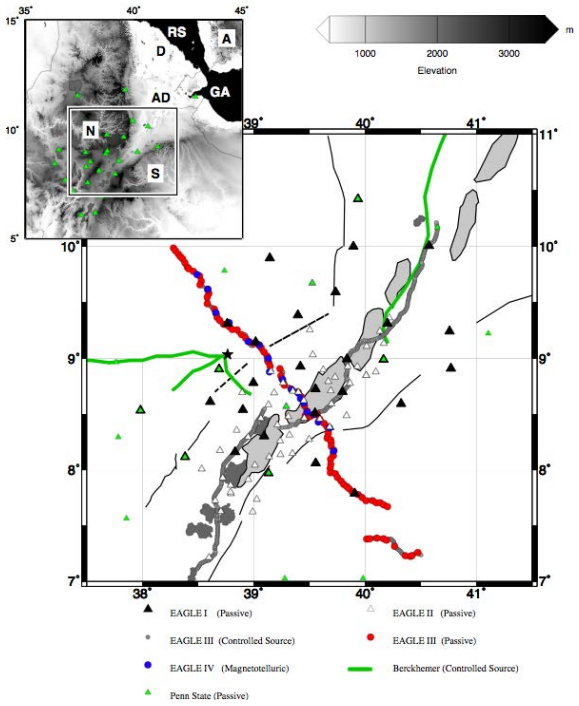

Normal lithosphere
Crust
Mantle
Lithosphere
Asthenosphere
°C
MPa
0
1000
0
800
Temp
Yield stress
Depth (km)
0
20
40
60
80
Magmatic extension
Crust
Mantle
Dike
Lithosphere
Asthenosphere
°C
MPa
0
1000
0
800
Temp
Yield stress
Depth (km)
0
20
40
60
80

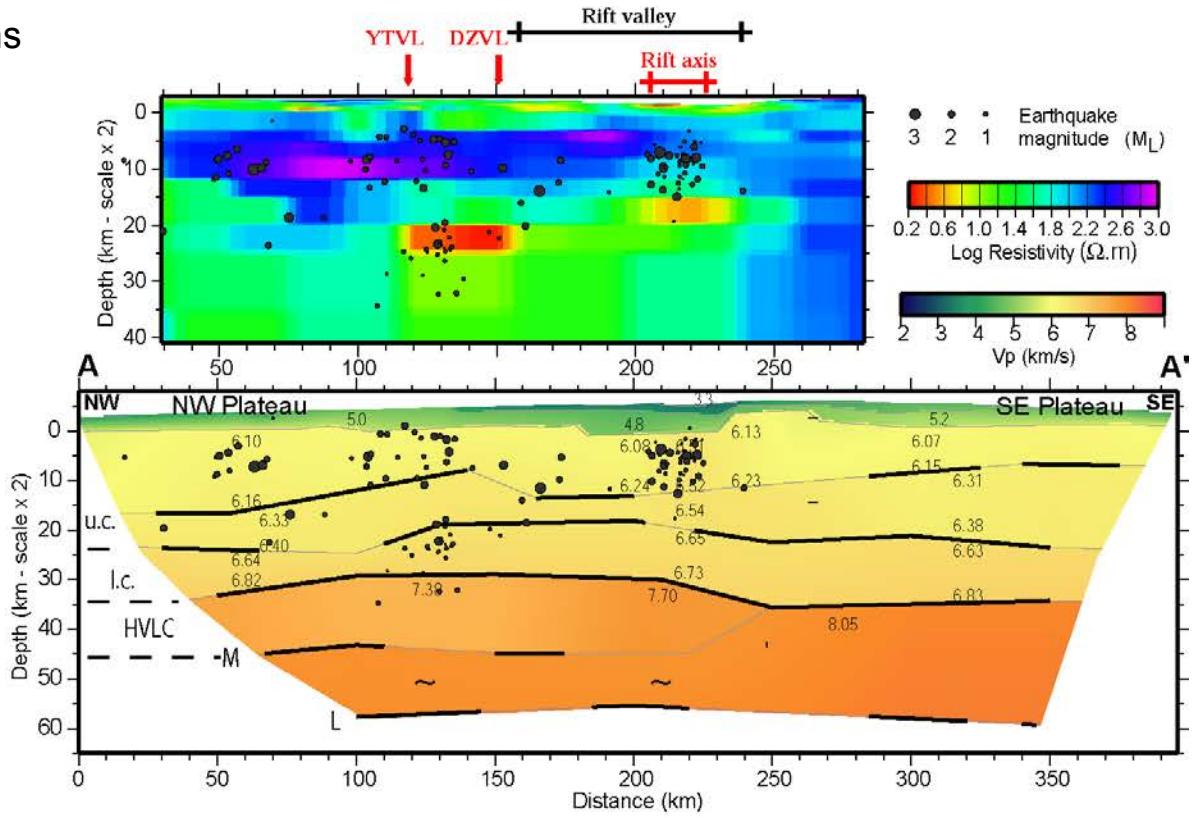
Deformation and rheology

- Magma intrusion - EAGLE
- ~20-30-km-deep earthquakes beneath rift marginal volcanic centers
- Evidence for ongoing magma intrusion into lower crust beneath border faults
- Fluid release from cooling intrusions

Mackenzie et al., 2005



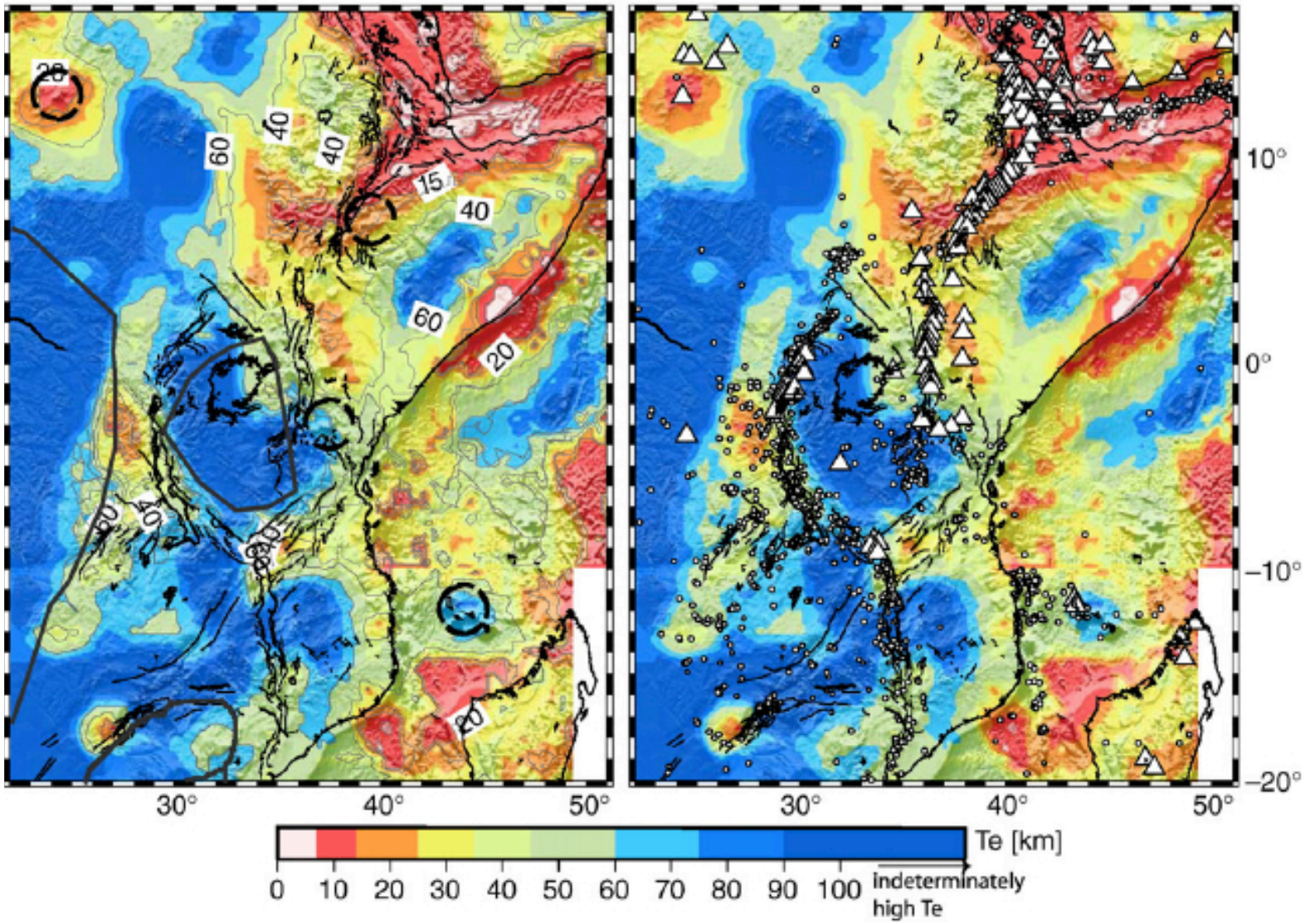




Keir et al., 2009

Rift initiation in East Africa

- Volcanism, seismicity, fault architecture and plate strength



Perez-Gussinye et al., 2009