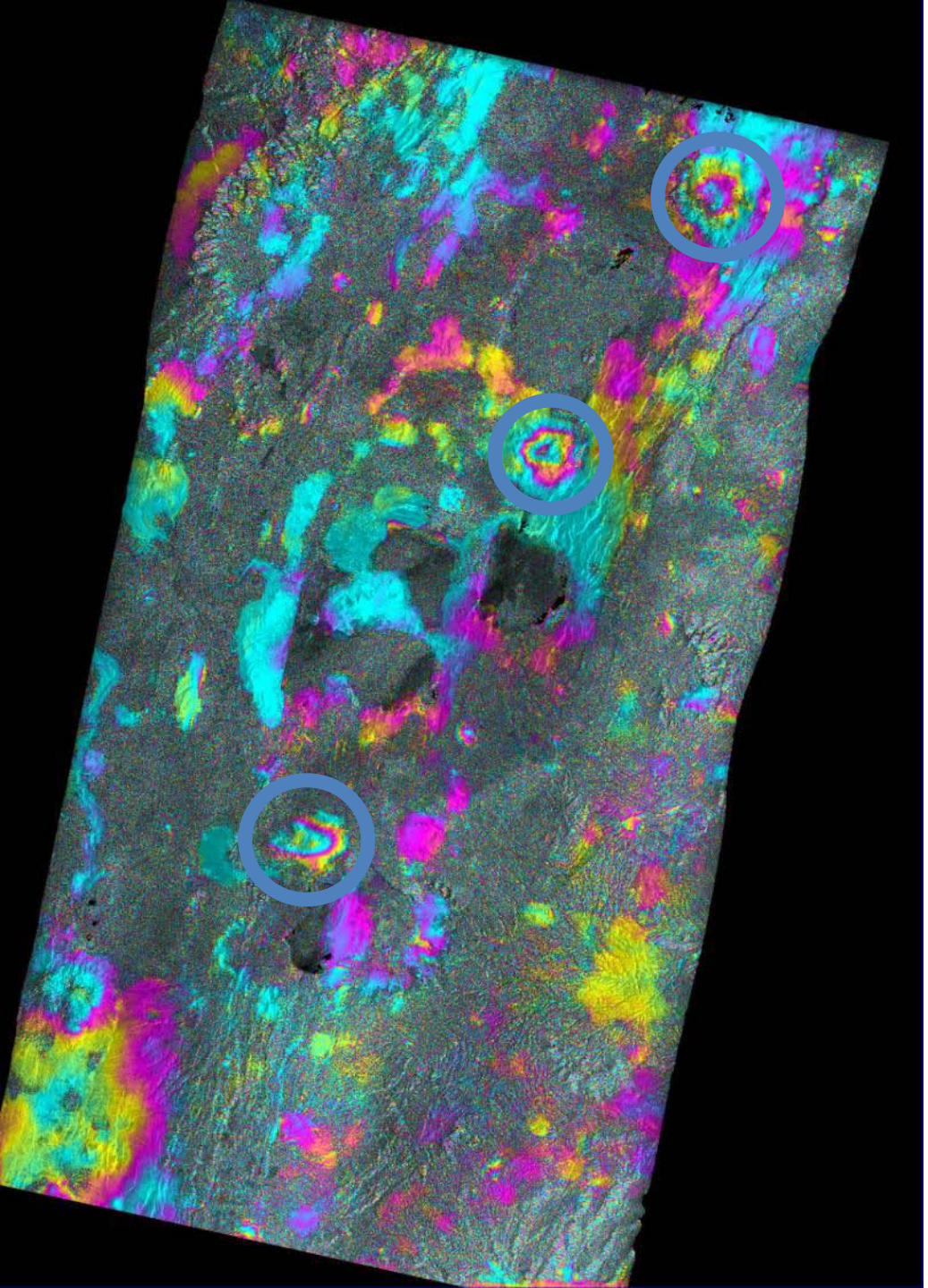


# Volcano Deformation in the Main Ethiopian Rift

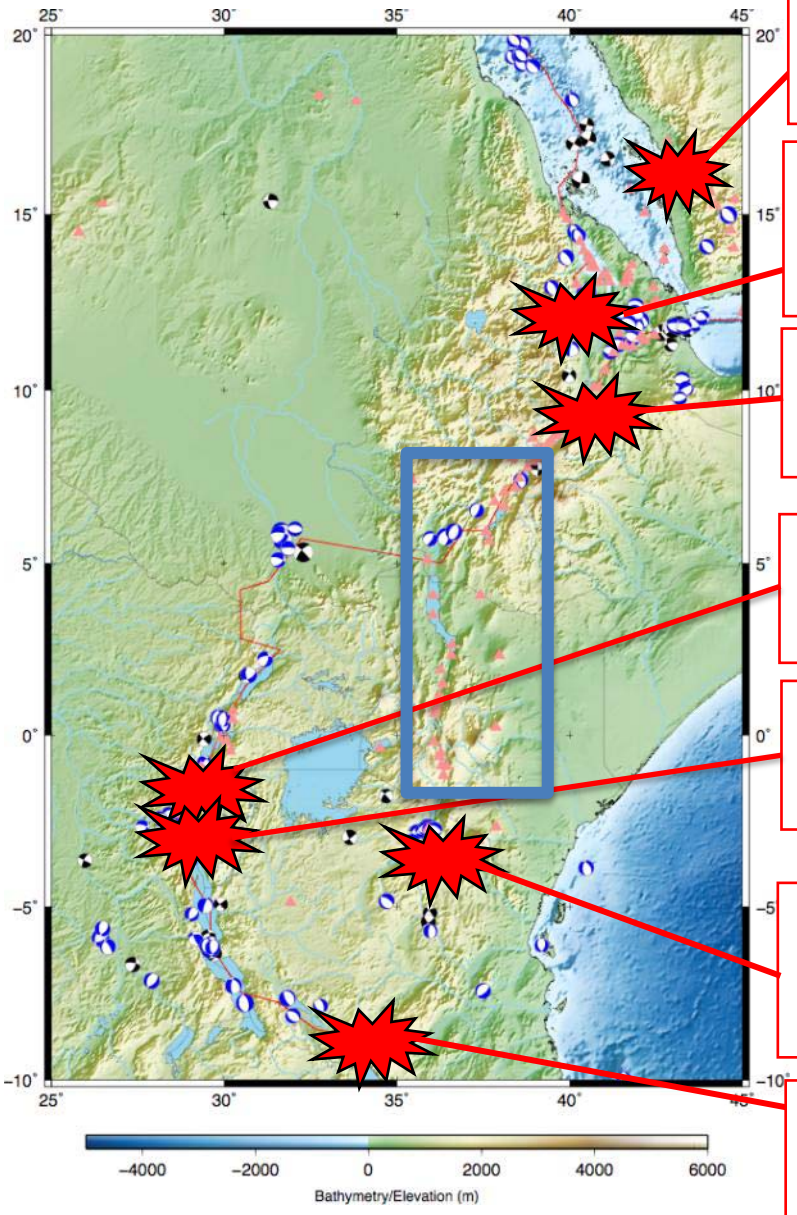

Juliet Biggs[1]; Ian Bastow[1], Derek Keir[2], Elias Lewi[3],

[1]University of Bristol;

[2]University of Leeds;

[3]University of Addis Ababa

# Seismic and Eruption Surface Deformation




## 2009: Saudi Arabia Dyke

Jonsson et al,. 2010, Baer et al, 2010.

## 2005- Afar Dykes & Eruptions

e.g. Wright et al, 2006; and many, many more….

## 2008: Ayelew-Amoissa Dyke

e.g. Keir et al 2011

## 2008: Nyamuragira Eruption

e.g. Cayol et al

## 2008: Bukavu Earthquake

e.g. d'Oreye et al, 2010

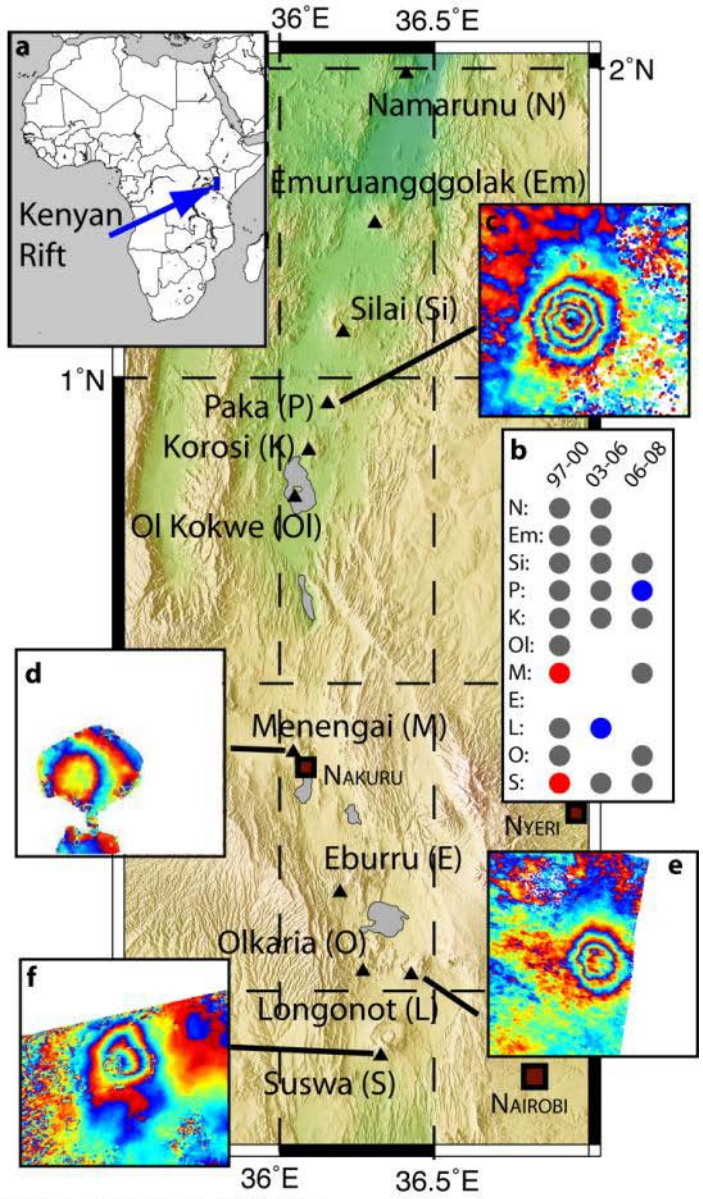
## 2007: Lake Natron Dyke

e.g. Calais 2009; Biggs et al, 2009; Baer, 2008.

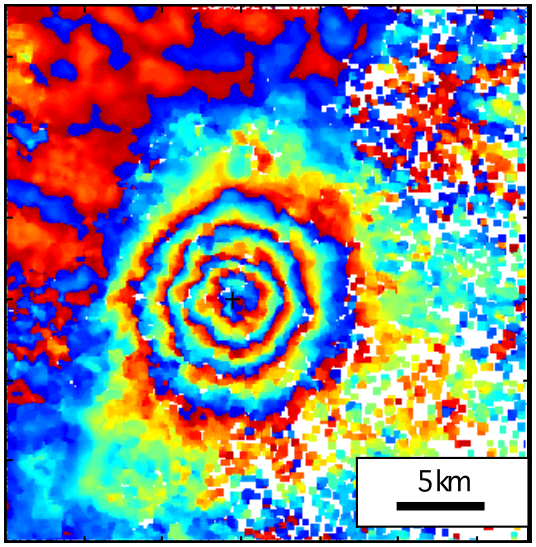
## 2009: Karonga Earthquakes

e.g. Biggs et al, 2010.

# Kenyan Rift Volcanoes 1997-2010




Biggs, J., Anthony, E.Y., Ebinger, C.J.
Figure 1. biggs_fig1.jpg

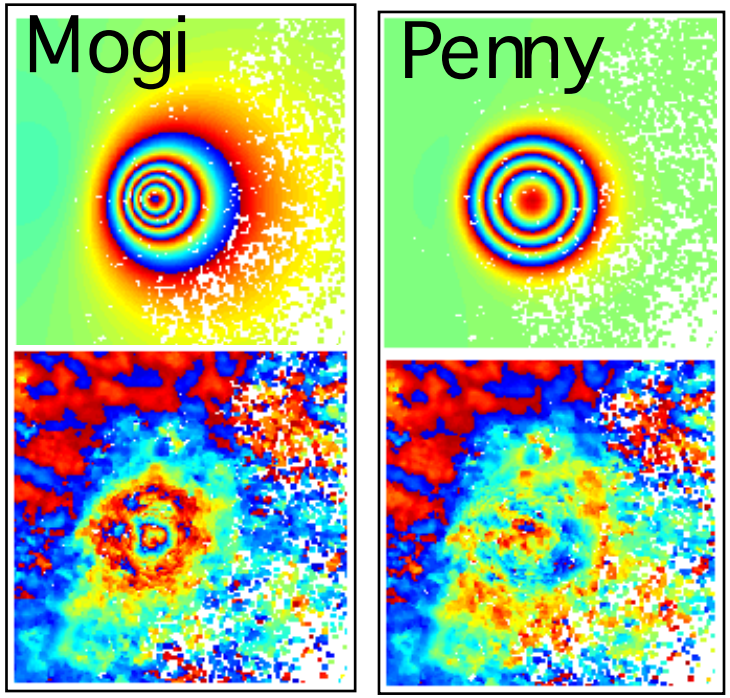



Paka

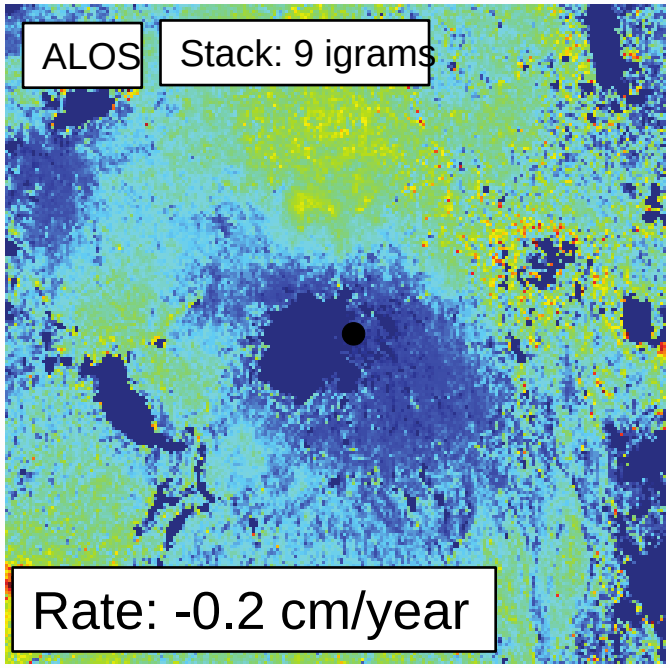
21.3 cm uplift

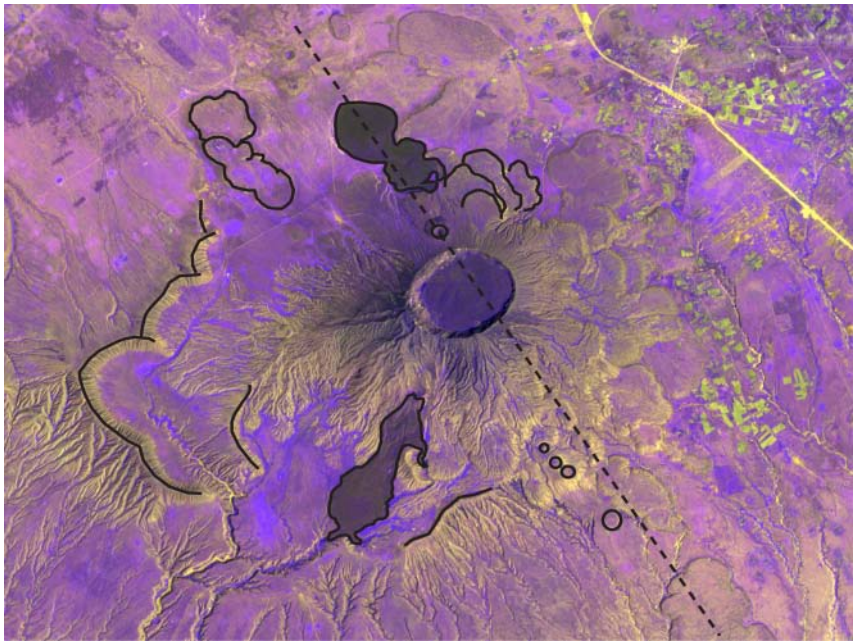
29 May 06 - 05 Mar 07

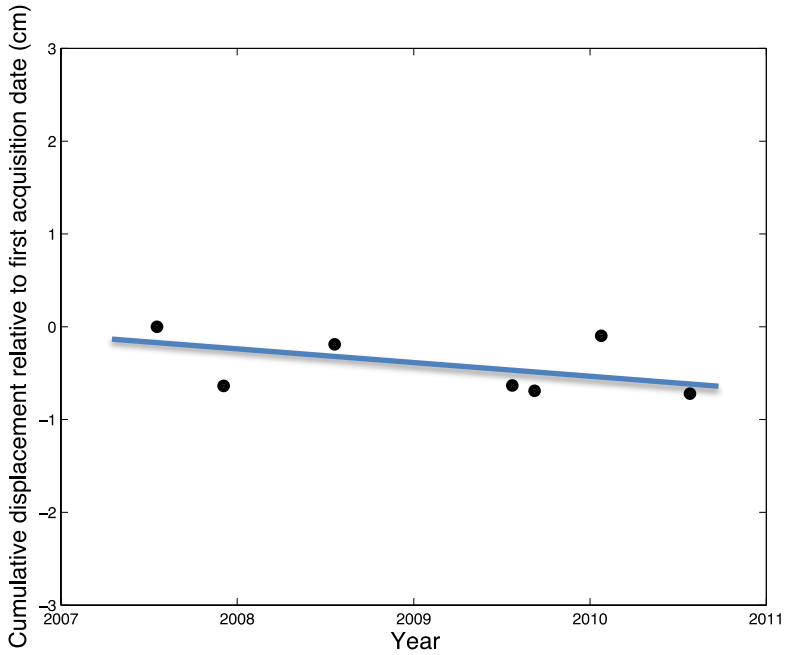
(9 months)




Depth 2.8 km
Radius 6.3 km

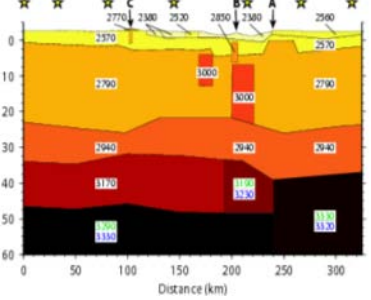


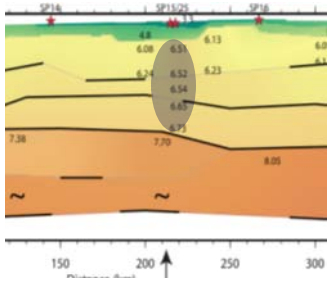



See Robertson et al Poster.

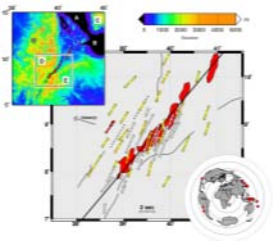
# Evidence for melt in the MER



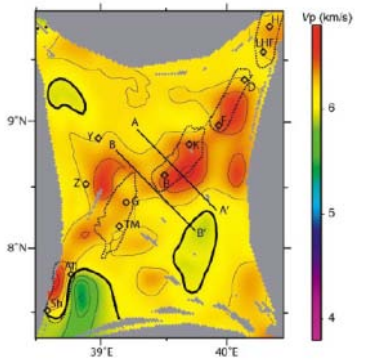

**Gravity**: Shallow high density body beneath Boset volcano (Cornwell et al, 2006)



**Seismic Refraction:** Velocities compatible with a cooled gabbroic body (Maguire et al, 2006)



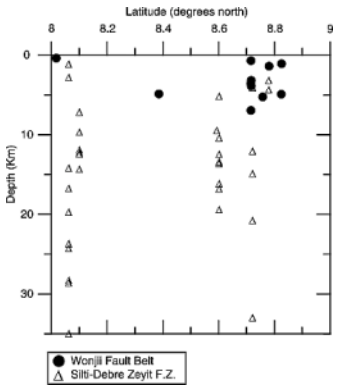
**Shear-wave splitting:** melt filled pockets in the top 90km of the  lithosphere (Kendall et al, 2005)




**Crustal Tomography:** high velocity mafic intrusions ~7km beneath the magmatic segments (Kerenan et al, 2004)

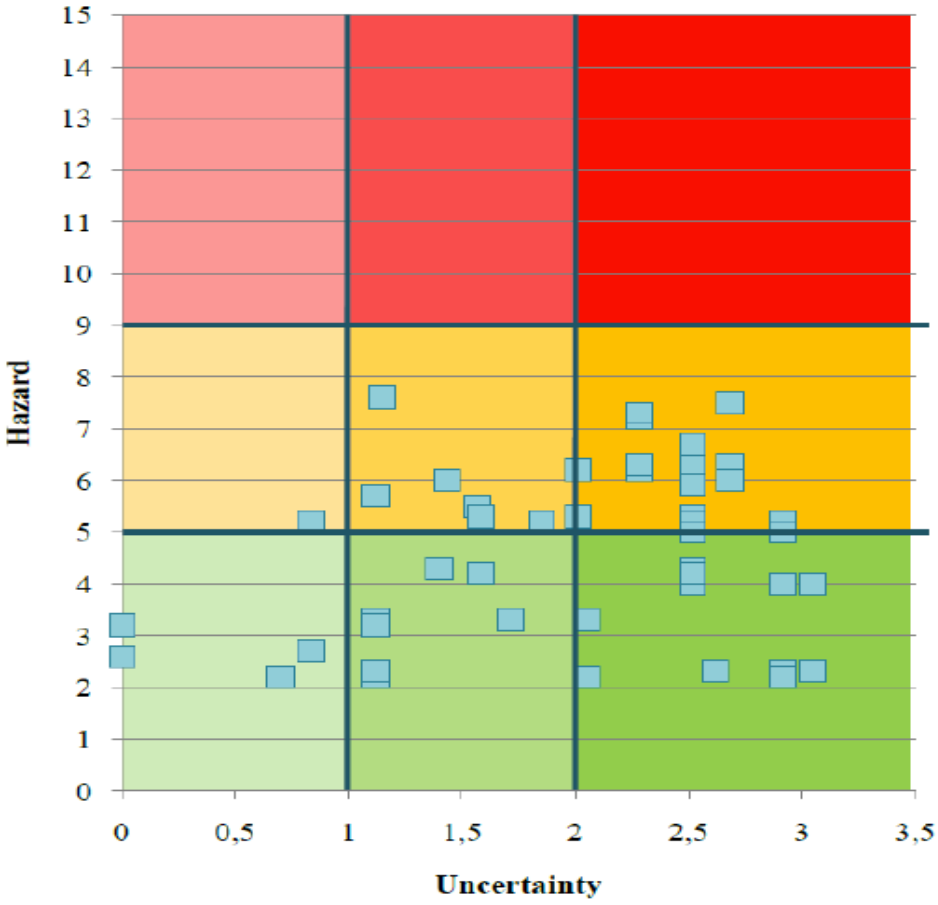
**Seismicity:** Ongoing microseismicity beneath Fentale-Dofen MS (Keir et al, 2006)

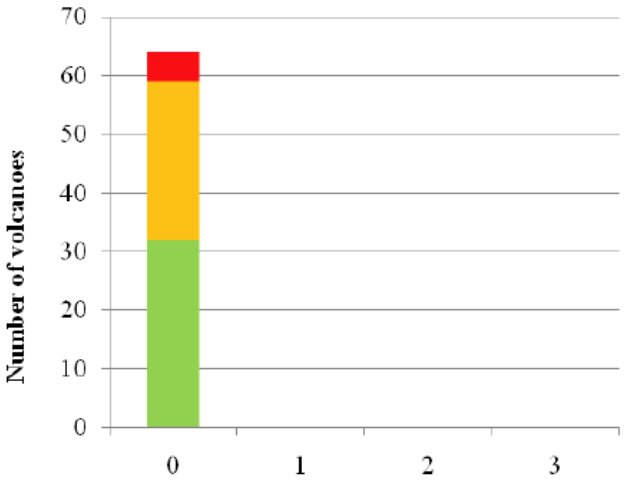
**Petrology:** Fractional crystallisation in the upper 5km (Rooney et al, 2007)



# Volcanic Hazard and Risk

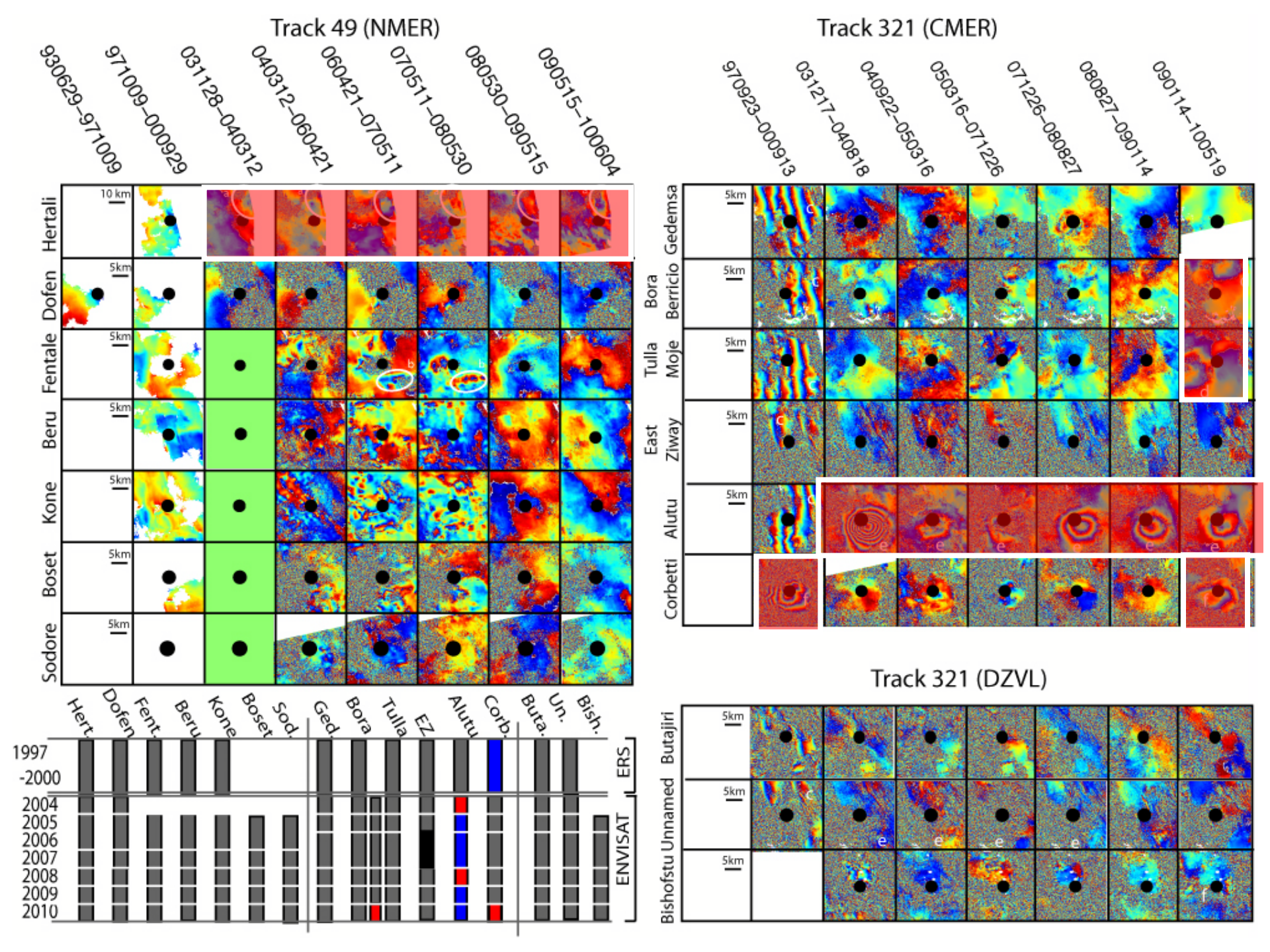
**No eruption since 1820's.**



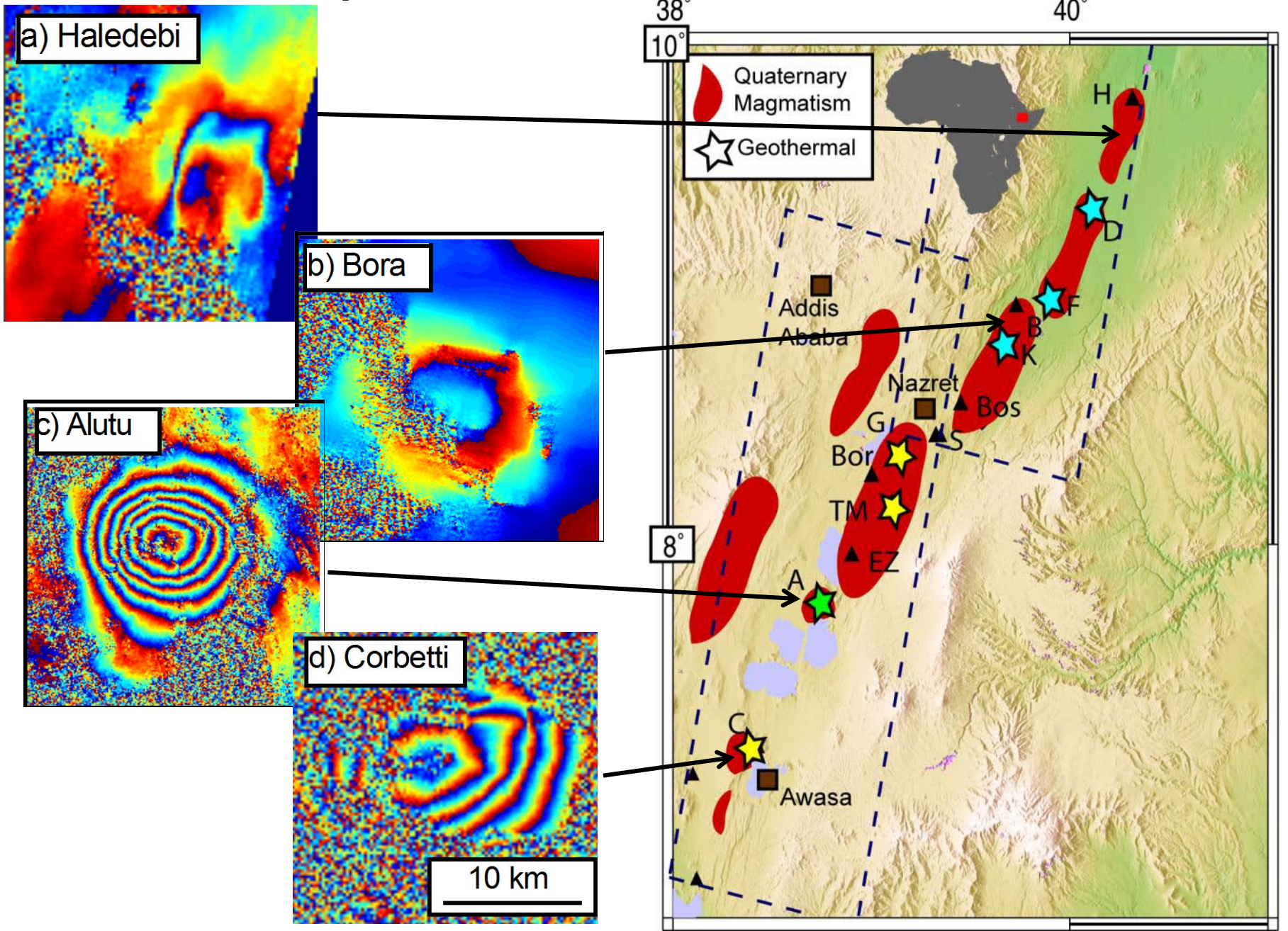




Monitoring Level

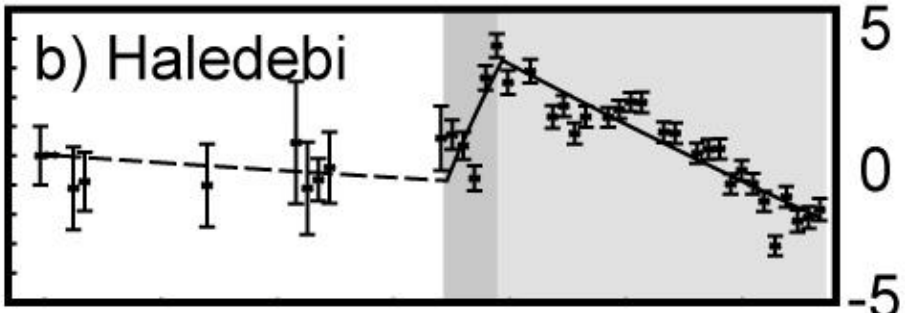
From: GFDRR World Bank Report

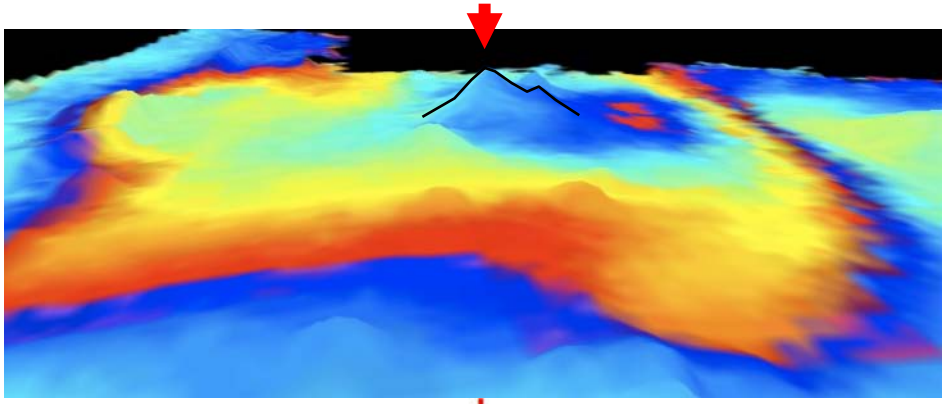

Track 49 (NMER)
930629–971009
971009–000929
031128–040312
040312–060421
060421–070511
070511–080530
080530–090515
090515–100604
Hertali
Dofen
Fentale
Beru
Kone
Boset
Sodore
10 km
5km
Track 321 (CMER)
970923–000913
031217–040818
040922–050316
050316–071226
071226–080827
080827–090114
090114–100519
Bora
Gedemsa
Berricio
Tulla
Moje
East
Ziway
Alutu
Corbetti
Track 321 (DZVL)
Butajiri
Unnamed
Bishofstu
Hert.
Dofen
Fent.
Beru
Kone
Boset
Sod.
Ged.
Bora
Tulla
EZ
Alutu
Corb.
Buta.
Un.
Bish.
1997
-2000
2004
2005
2006
2007
2008
2009
2010
ERS
ENVISAT

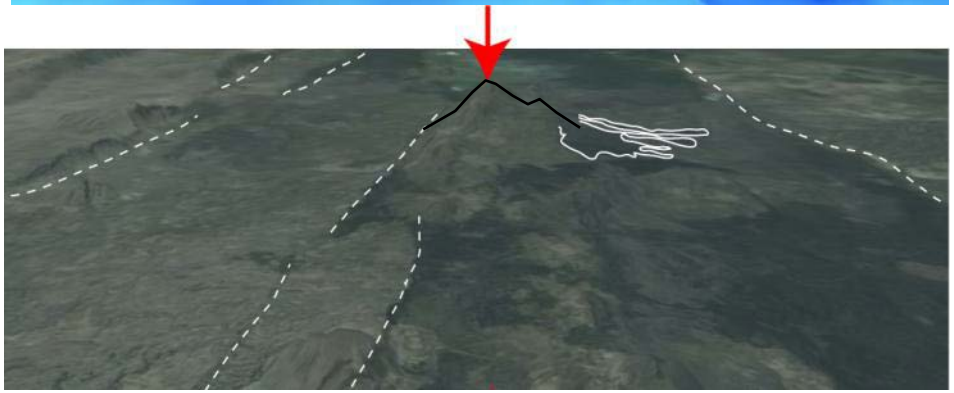
# Main Ethiopian Rift

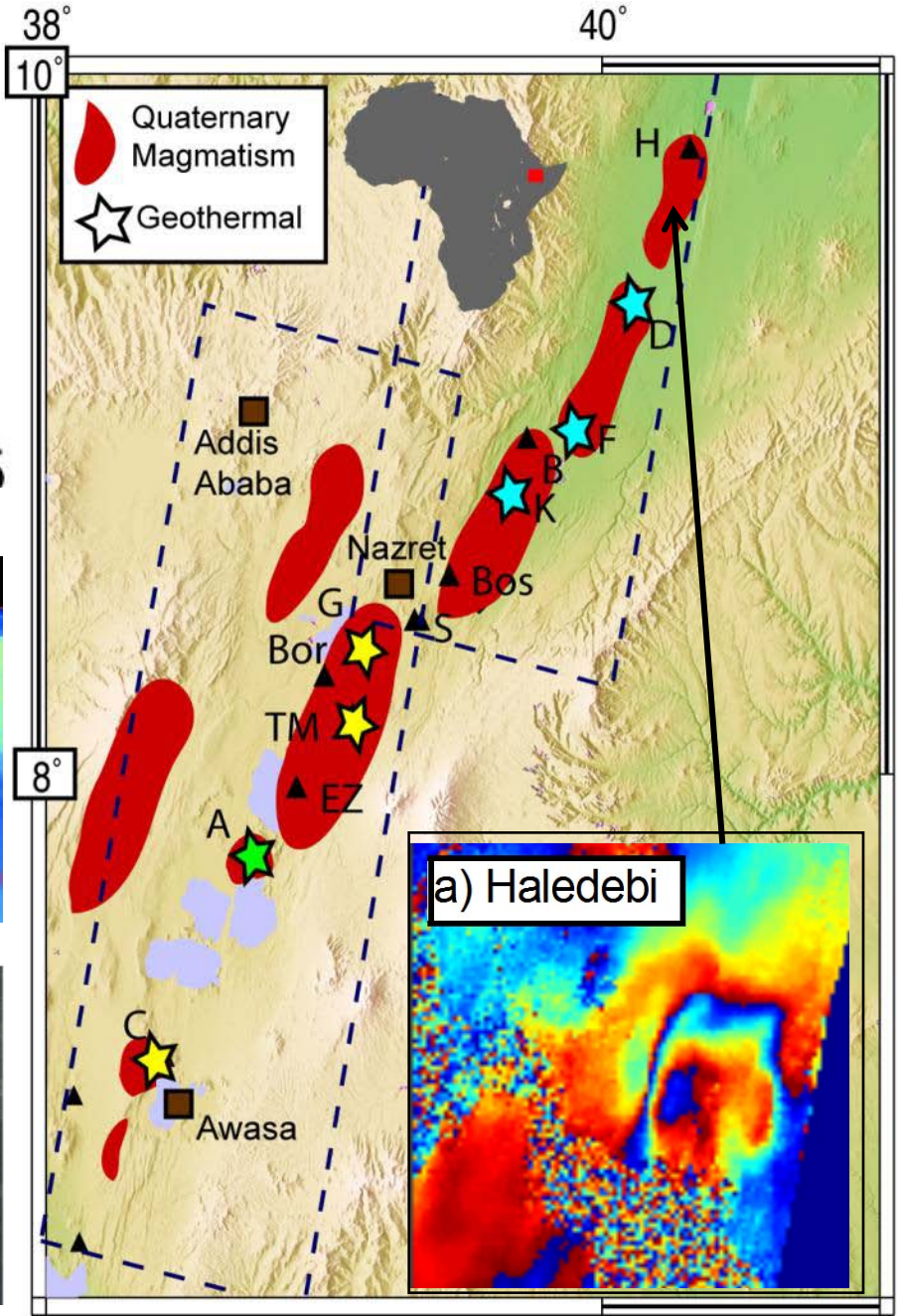


# Main Ethiopian Rift





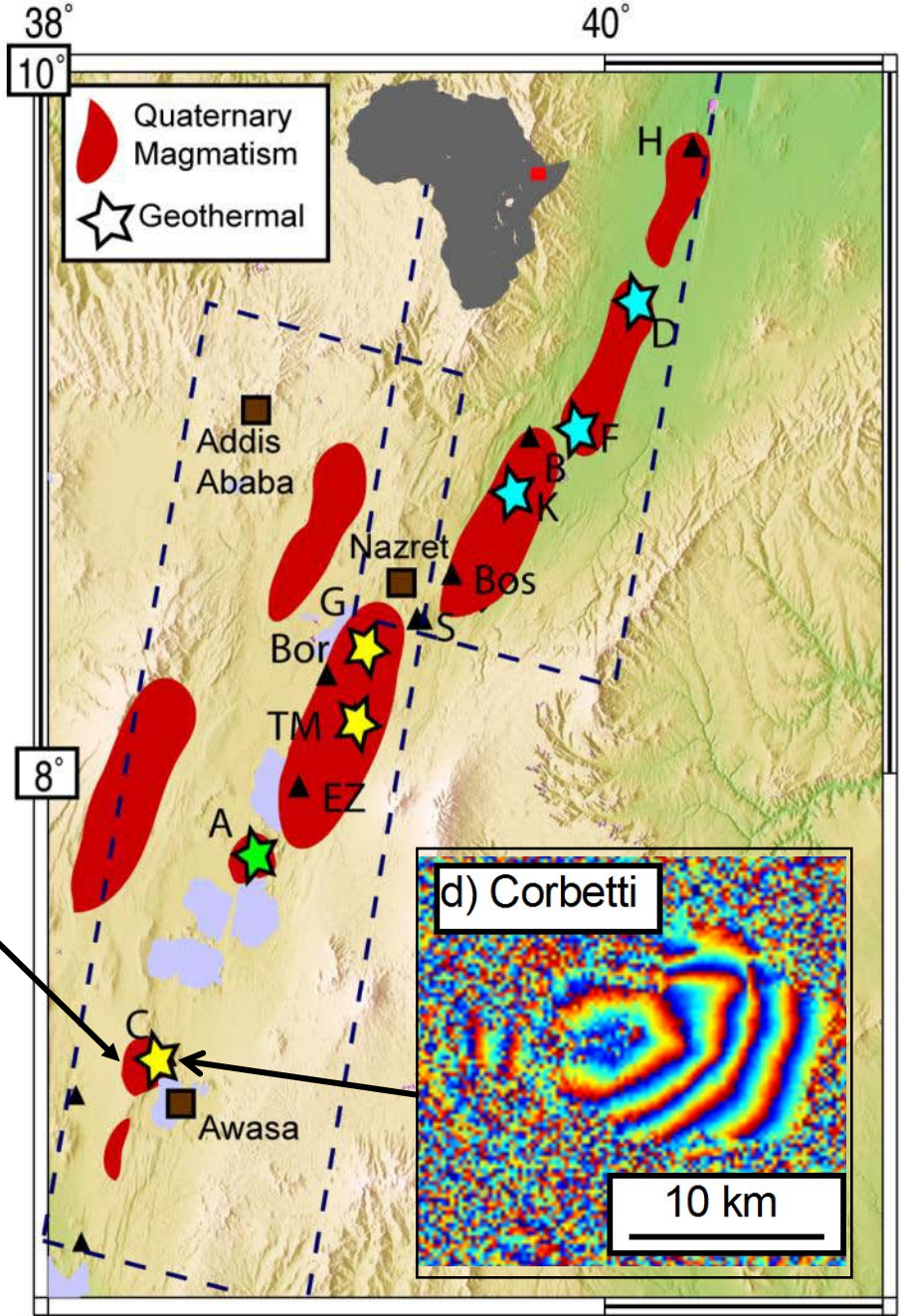


# Corbetti

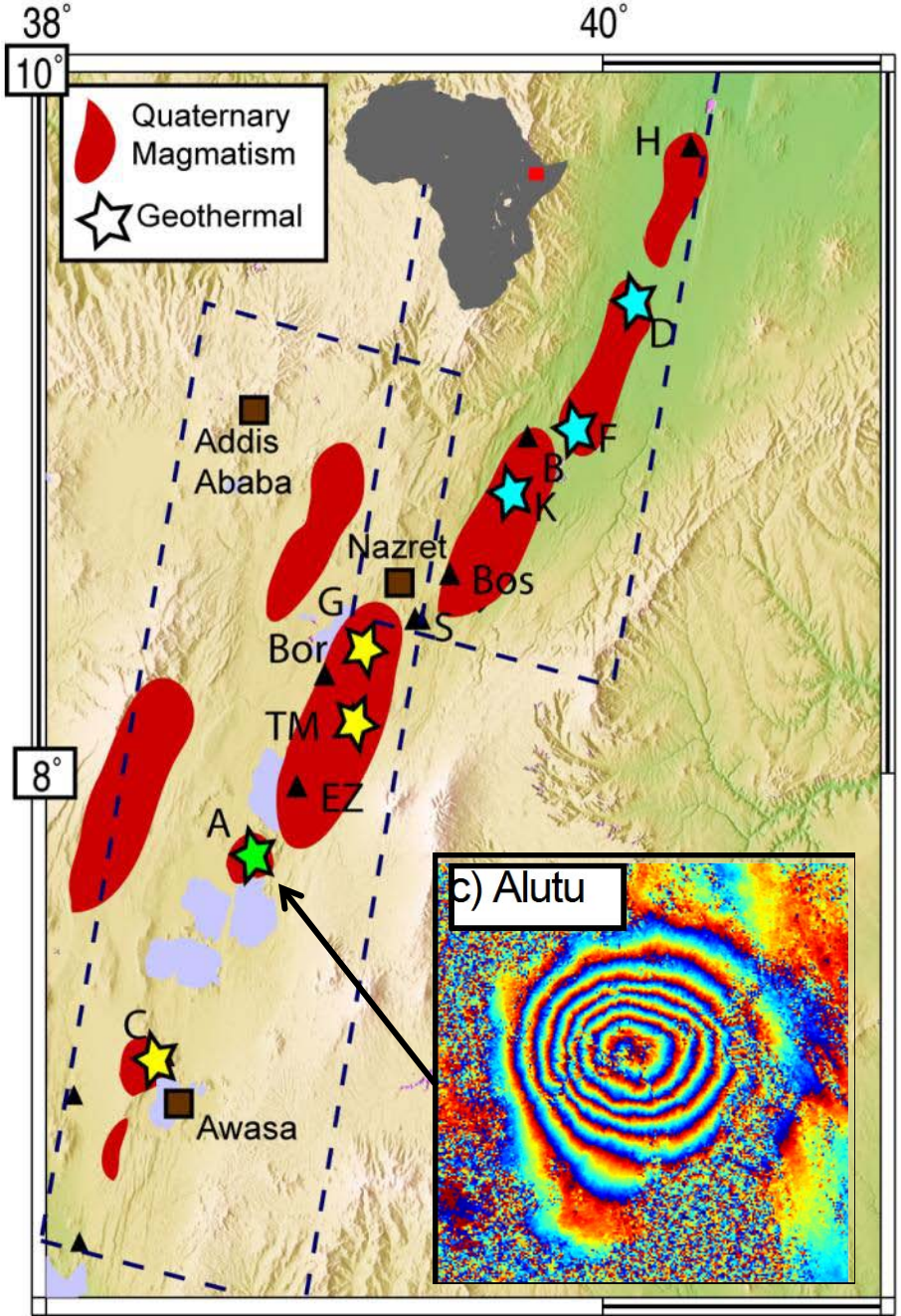
At least 14cm of subsidence between 1997 and 2000.

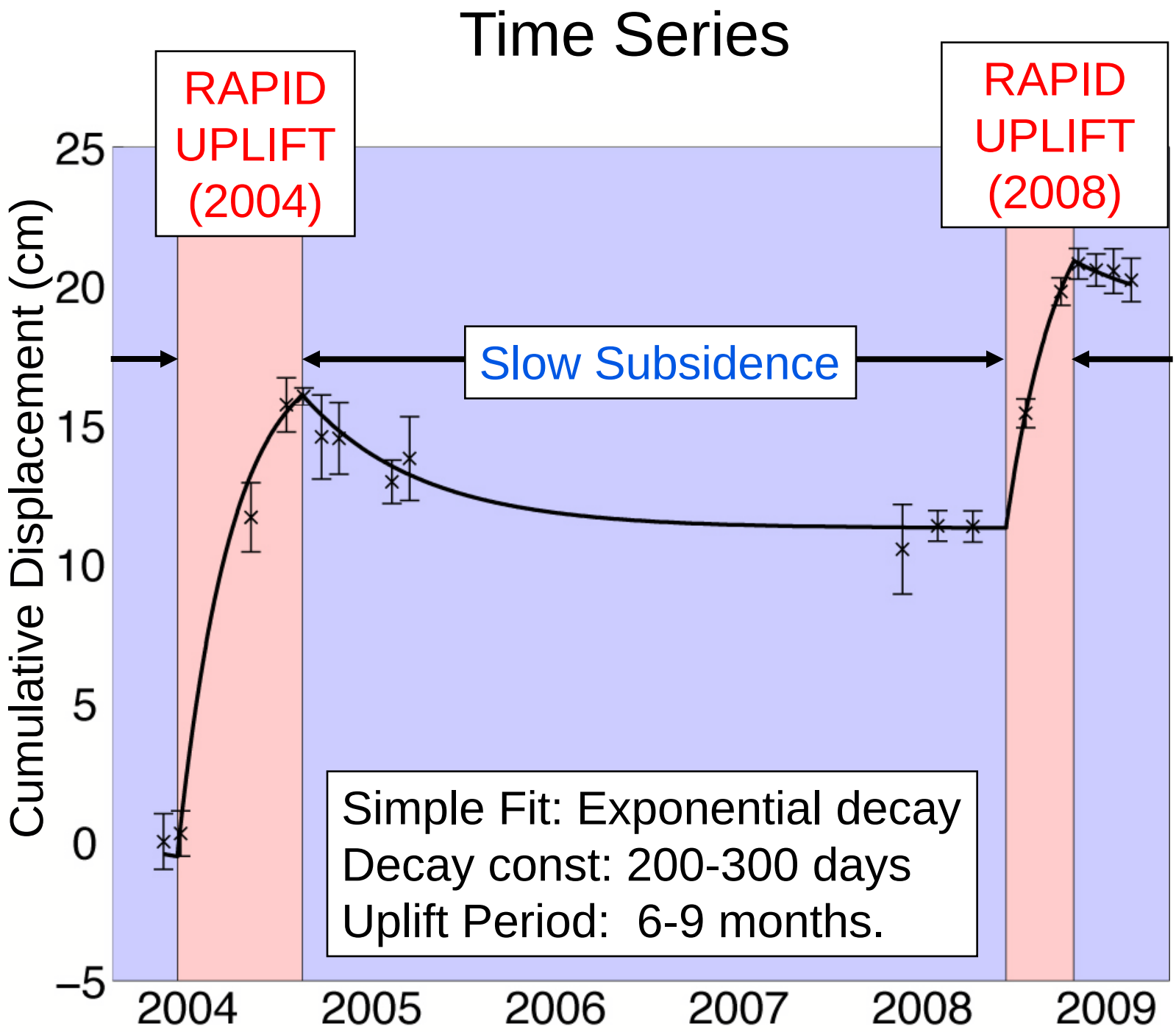
Ayelew et al, 2004

Rejuvenated uplift in 2010

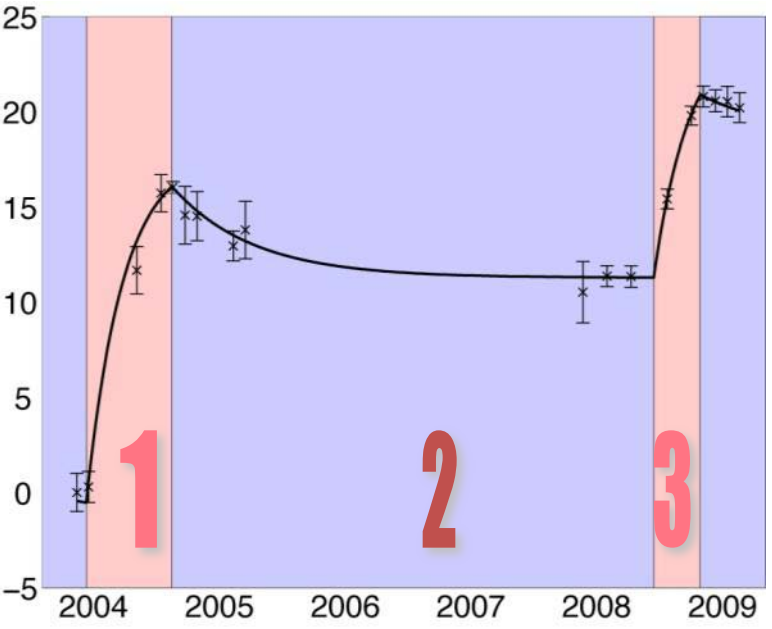


# Main Ethiopian Rift



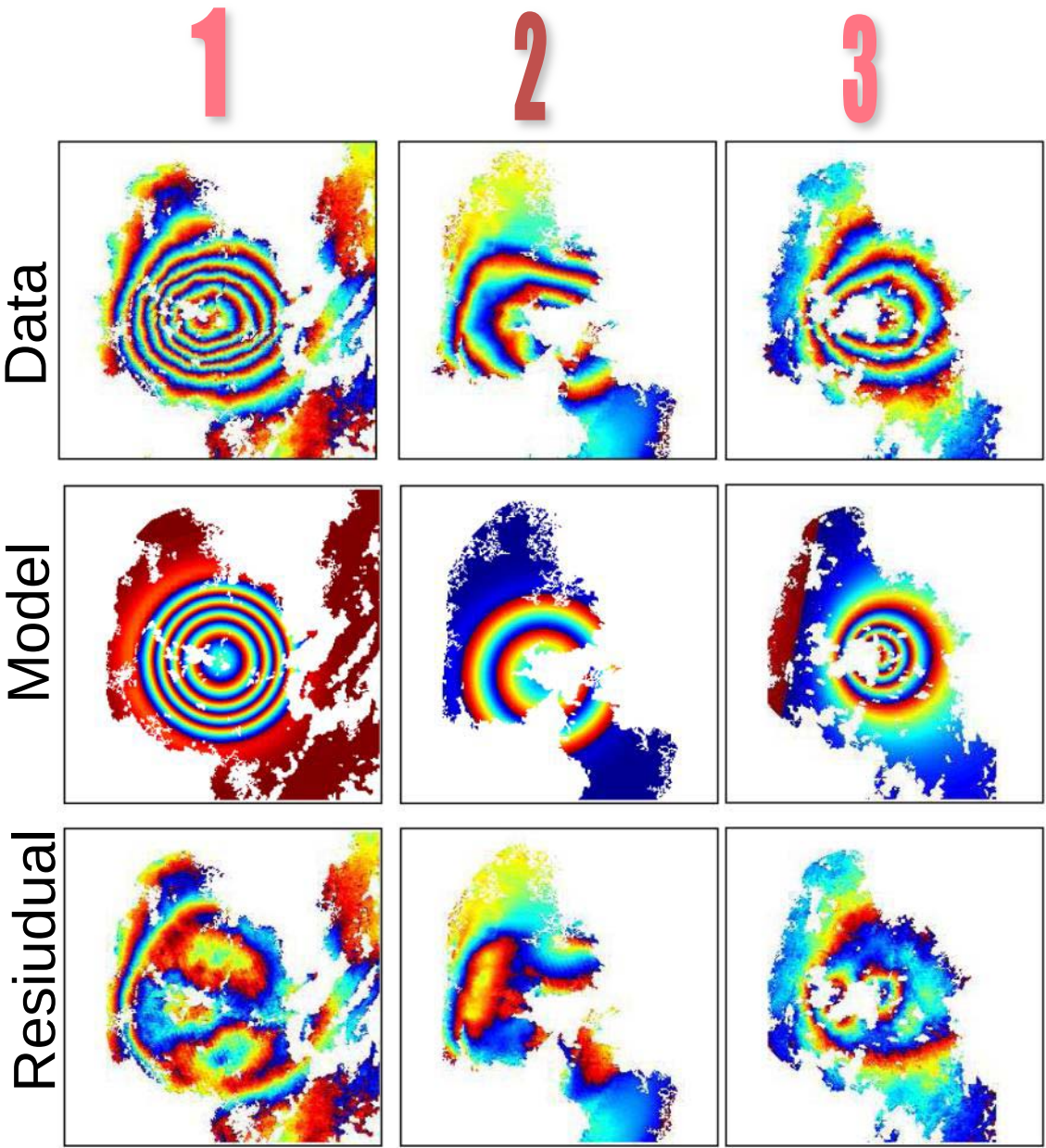

Time Series
RAPID UPLIFT (2004)
RAPID UPLIFT (2008)
Slow Subsidence
Cumulative Displacement (cm)
25
20
15
10
5
0
−5
2004
2005
2006
2007
2008
2009
Simple Fit: Exponential decay
Decay const: 200-300 days
Uplift Period: 6-9 months.

# Modelling: Penny Shaped Crack




Penny shaped crack

Depth: 0.7-2.5km;
Radius: 2.8-8.9 km



# Time Series and Source Modelling

Temporal Pattern

Source Geometry

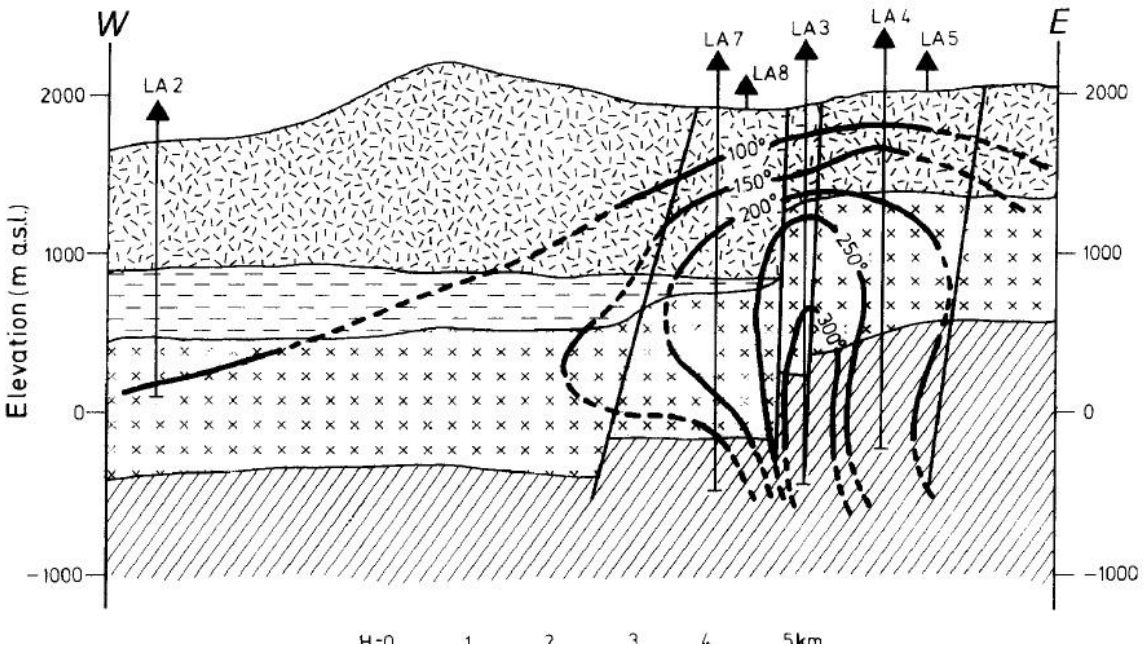
| | | Start | Displ. (cm) | Duration (days) | Decay (days) | Model Type | Depth (km) | Radius (km) |
|---|---|---|---|---|---|---|---|---|
| Alutu | Alutu | Dec 03 | +15 | 260 | 230 | Penny | 0.7-2.5 | 2.8-8.9 |
| | | Sep 04 | -4.7 | 1400 | 320 | Penny | 0.5-1.9 | 2.9-10 |
| | | Jul 08 | +9.9 | 150 | 230 | Penny | 0.7-2.4 | 4.0-8.2 |
| | | Dec 08 | <-4.3 | >750 | 320 | Penny | | |
| Bora | Bora | Feb 08 | +5.3 | 900 | 1600 | Penny | 0.9-1.3 | 4.7-8.1 |
| Corbetti | Corbetti | Feb 94-Jan 96* | >1.4 | - | - | - | - | - |
| | | Sep 97-Sep 00* | <14 | - | - | Mogi | 5.8-7.8 | 0 |
| | | - | -3.3 | >2100 | 1500 | - | - | - |
| | | Aug 09 | +4.2 | 290 | 1700 | Mogi | 3.3-5.3 | 0 |
| Hale. | Haledebi | Jun 07 | +4.1 | 170 | 630 | Dipping Sill | 2.7-8.8 | 5.8x8 |
| | | Dec 07 | -5.4 | >1000 | 6800 | Dipping Sill | 2.7-8.8 | 5.8x8 |

Rate:
Exponential decay at Alutu;
~ Constant rate at Bora, Corbetti, Haledebi.

Depth:
All depths are shallow (<10 km):
Alutu + Bora <3 km.

Shape:
Alutu, Bora, Corbetti fit a radially symmetric source; Haledebi is asymmetric/dipping.

# Alutu Langano Geothermal Field.




Gianelli and Teklemariam, 2003.

- T=350C at 2500m
- Primary aquifer at >1400m.

- Exploration drilling in 1980's
- 7.3MW power station installed in 1999; reactivated in 2009

- Currently installing a seismic network (ask Mike Kendall or Ian Bastow)
- MT Study (see Samrock Poster)

# EAR-Wide Perspective

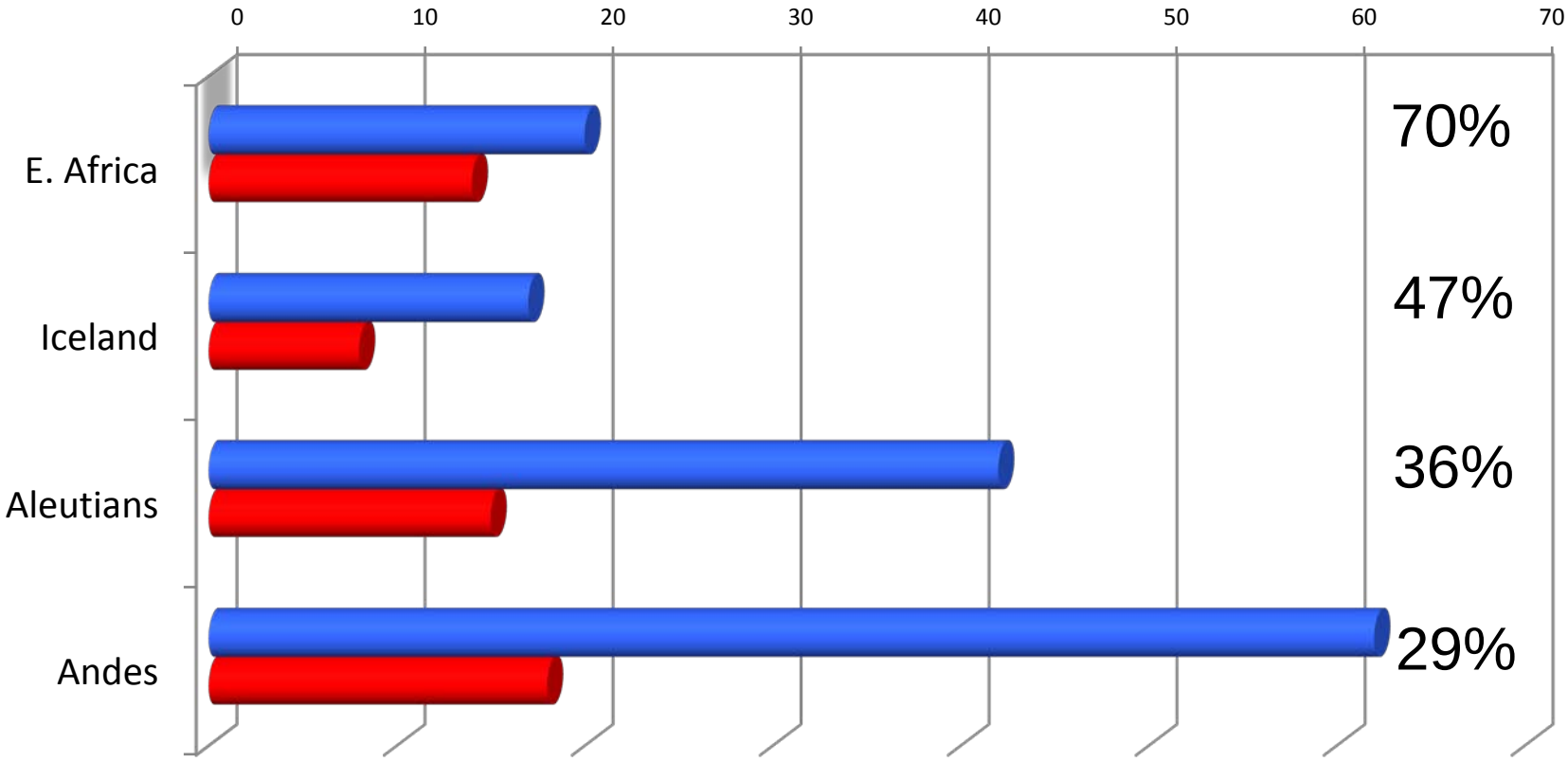
## Deforming Volcanoes

| | | |
|---|---|---|
| 1 | Nyamuragira | Cayol et al, 2007 |
| 2 | Nyiragongo | Poland and Lu, 2004 |
| 3 | Suswa | Biggs et al, 2009 |
| 4 | Longonot | Biggs et al, 2009 |
| 5 | Menengai | Biggs et al, 2009 |
| 6 | Paka | Biggs et al, 2009 |
| 7 | Silali | Robertson et al, poster |
| 8 | Ol Doinyo Lengai | Biggs et al, unpub. |
| 9 | Corbetti | Biggs et al, 2011 |
| 10 | Alutu | Biggs et al, 2011 |
| 11 | Hertali | Biggs et al, 2011 |
| 12 | Bora | Biggs et al, 2011 |
| 13 | Gada' Ale | Amelung et al, 2000 |
| 14 | Dabbahu/Gabho | Wright et al, 2006; Grandin et al etc. |
| 15 | Nabro | Pagli et al |
| 16 | Erta Ale | Pagli et al |
| 17 | Dallafilla | Pagli et al |
| 18 | Dallol | Wright el al |

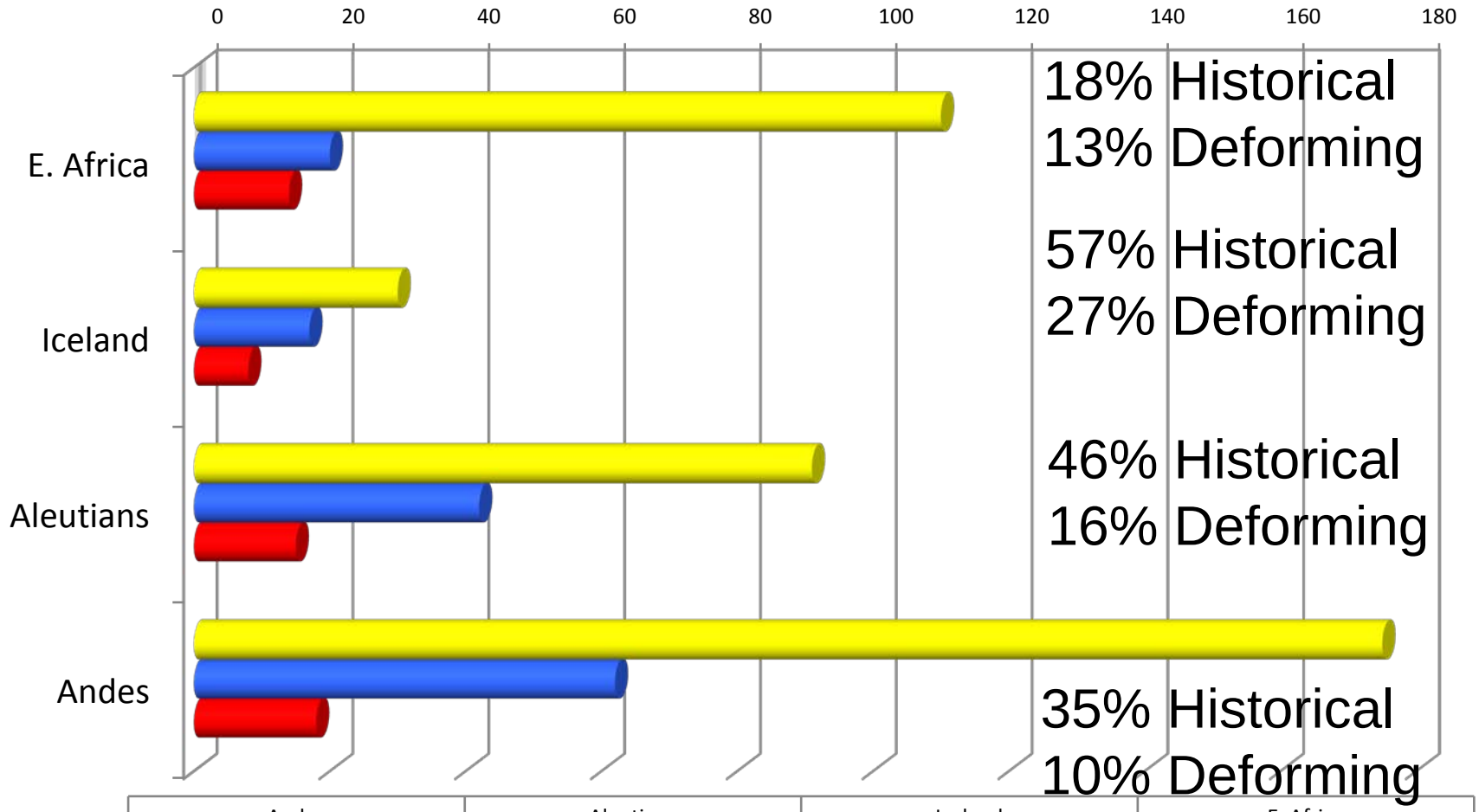
## Historical Eruptions

| | |
|---|---|
| 1 | Nyiragongo |
| 2 | Nyamuragira |
| 3 | Visoke |
| 4 | South Island |
| 5 | The Barrier |
| 6 | Oldoinyo Lengai |
| 7 | Meru |
| 8 | Kieyo |
| 9 | Fentale |
| 10 | Kone |
| 11 | Dallol |
| 12 | Dallaffilla |
| 13 | Erta Ale |
| 14 | Nabro |
| 15 | Dubbi |
| 16 | Alayta |
| 17 | Dabbauhu |
| 18 | Manda Harraro |
| 19 | Manda Inakir |
| 20 | Ardoukoba |

# Deformation Statistics




| | Andes | Aleutians | Iceland | E. Africa |
|---|---|---|---|---|
| Historical | 62 | 42 | 17 | 20 |
| Deforming | 18 | 15 | 8 | 14 |



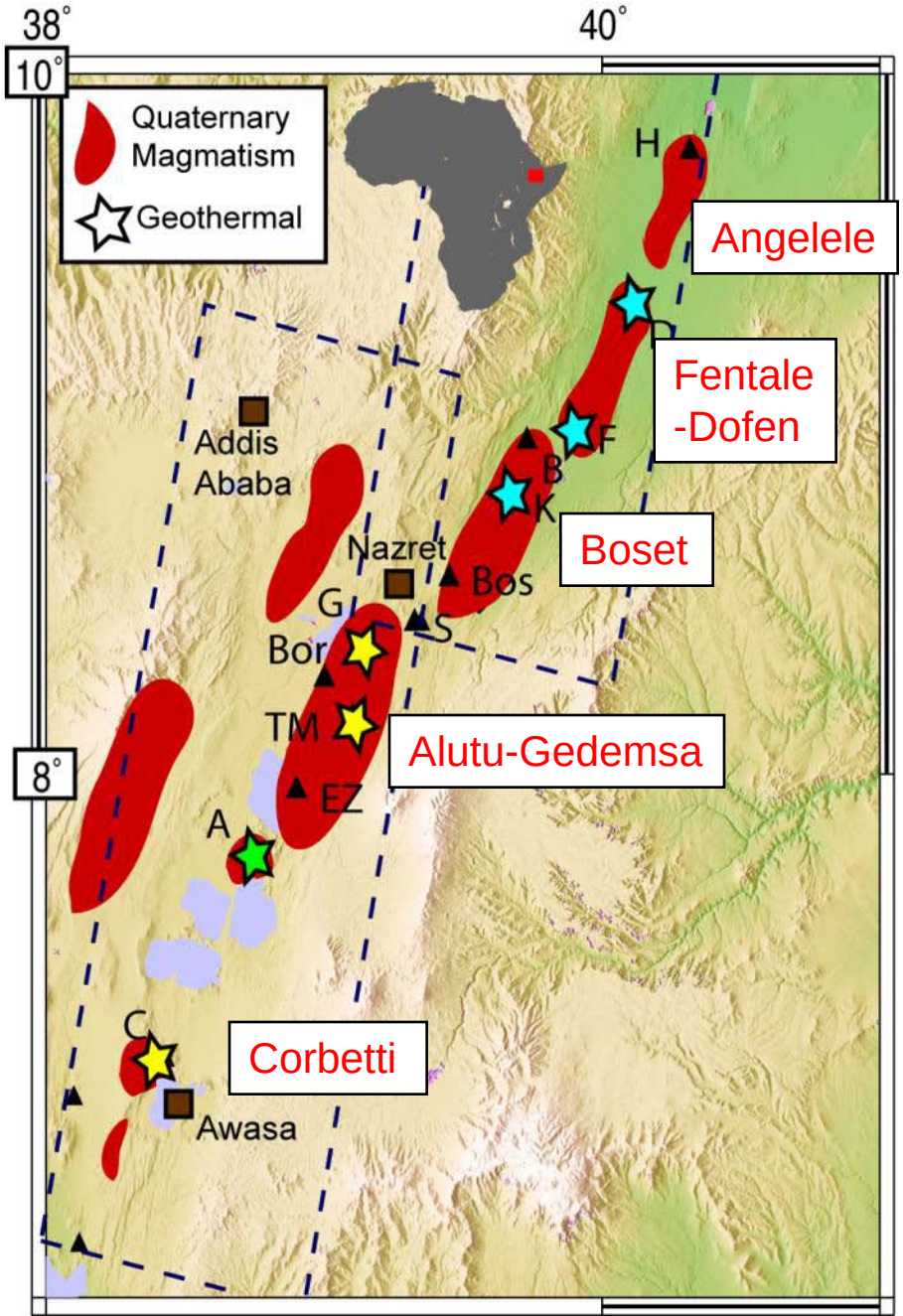

| | Andes | Aleutians | Iceland | E. Africa |
|---|---|---|---|---|
| Total | 175 | 91 | 30 | 110 |
| Historical | 62 | 42 | 17 | 20 |
| Deforming | 18 | 15 | 8 | 14 |

# Conclusions

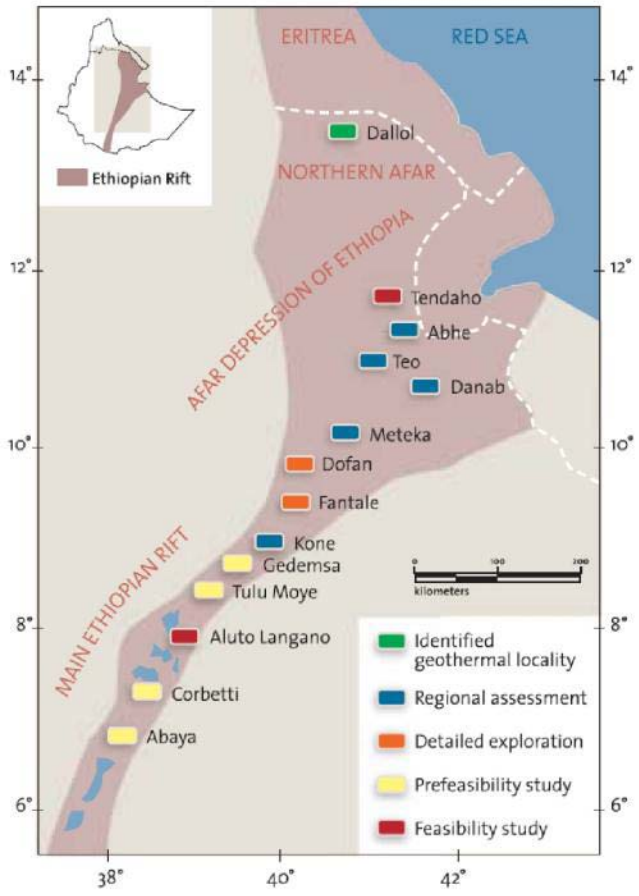
- Many of the volcanoes in the Main Ethiopian Rift and Kenyan Rifts are actively deforming despite few historical eruptions:
  - EAR is fundamentally different to other volcanic regions (including Iceland).
  - The historical record is incomplete
  - This is an abnormally quiet period.
- The deformation sources are shallow indicating shallow magma storage and interaction with hydrothermal systems.

# Main Ethiopian Rift

- Current Spreading Rate - 6.5 mm/yr
- Extension on Mid-Miocene border faults began ~18Ma.
- Since 12Ma, strain has progressively localized towards the magmatic segments.
- 80% strain now accommodated in the rift.



# Conclusions and Implications




Shallow melt storage beneath volcanic edifices in the Main Ethiopian Rift.

No surprise in terms of long-term rift development but raises questions about short-term interactions:

1. **Rifting:** how does this melt contribute to extension - potential to feed lateral dike intrusions?
2. **Volcanology:** dynamics of coupled magmatic-geothermal systems (4 yr cycles of uplift and subsidence)
3. **Resources**: geothermal reservoirs and mineral deposits.

# Coupled Magmatic and Hydrothermal processes