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A Rare Magmatic Event on the other side of the Red Sea: The 2009 Dyke Intrusion and Seismic Crisis in Harrat Lunayyir, western Saudi Arabia

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Thuwal, Saudi Arabia

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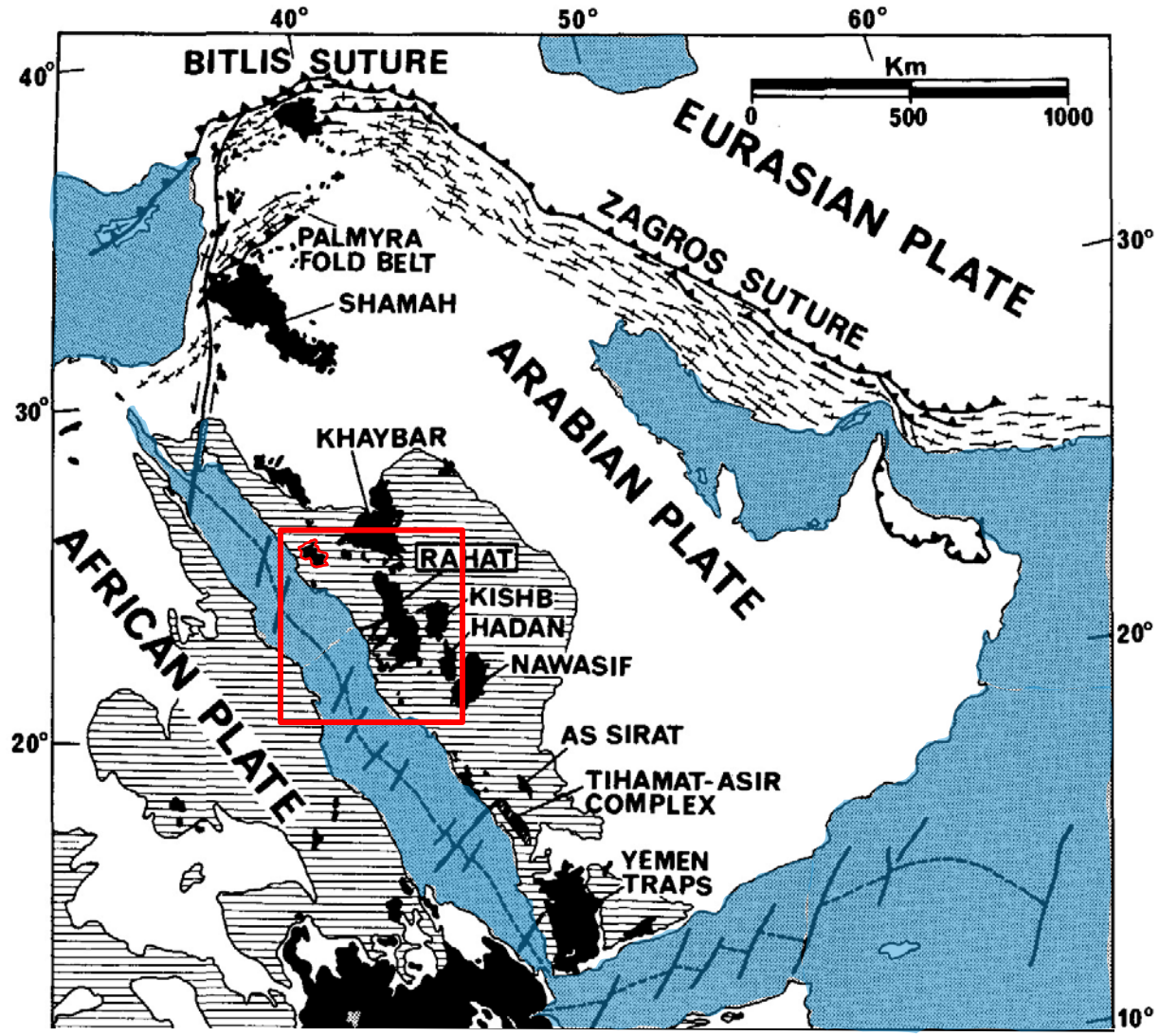
Lava Provinces in western Arabia

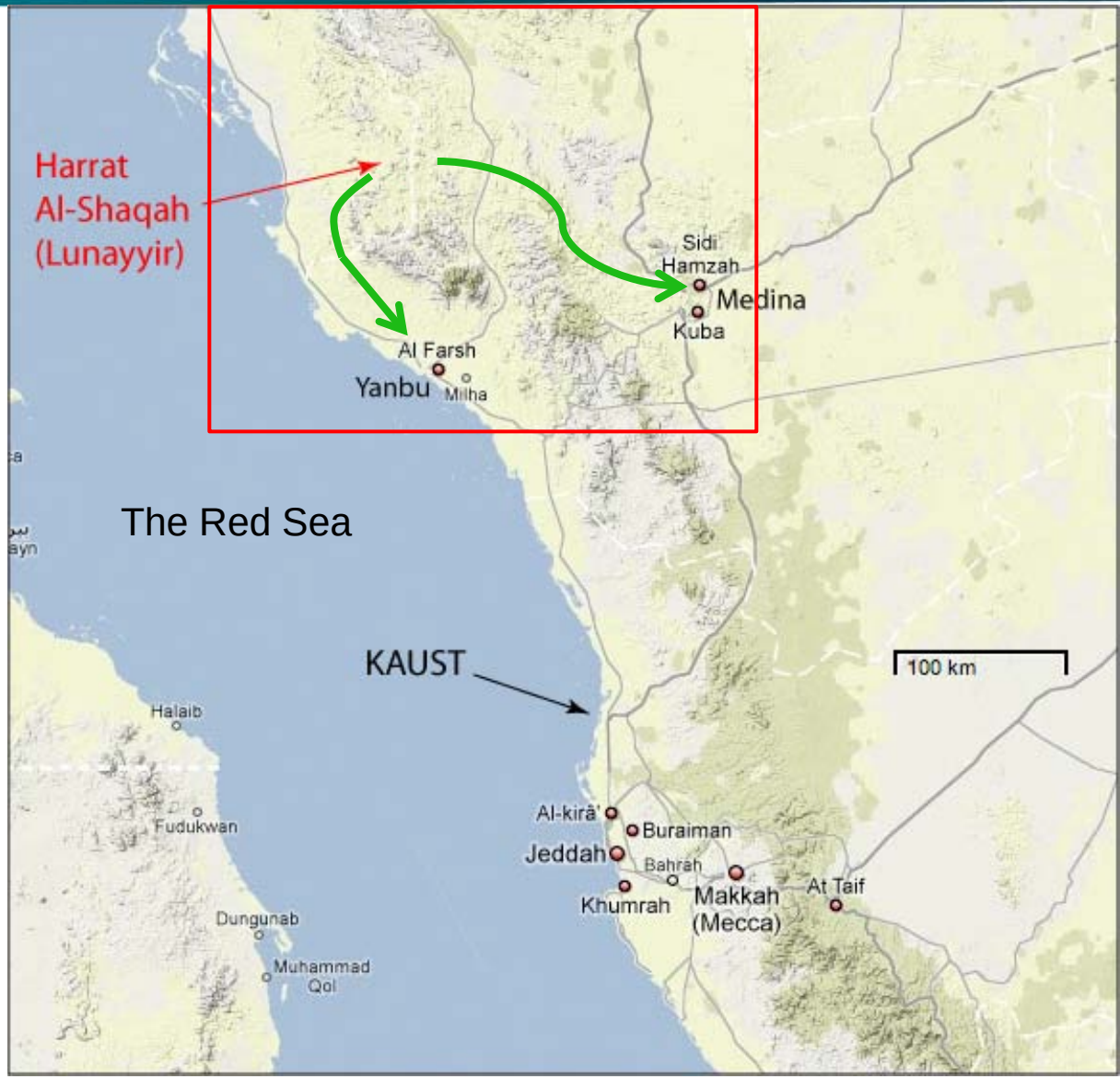


Camp et al., 1989

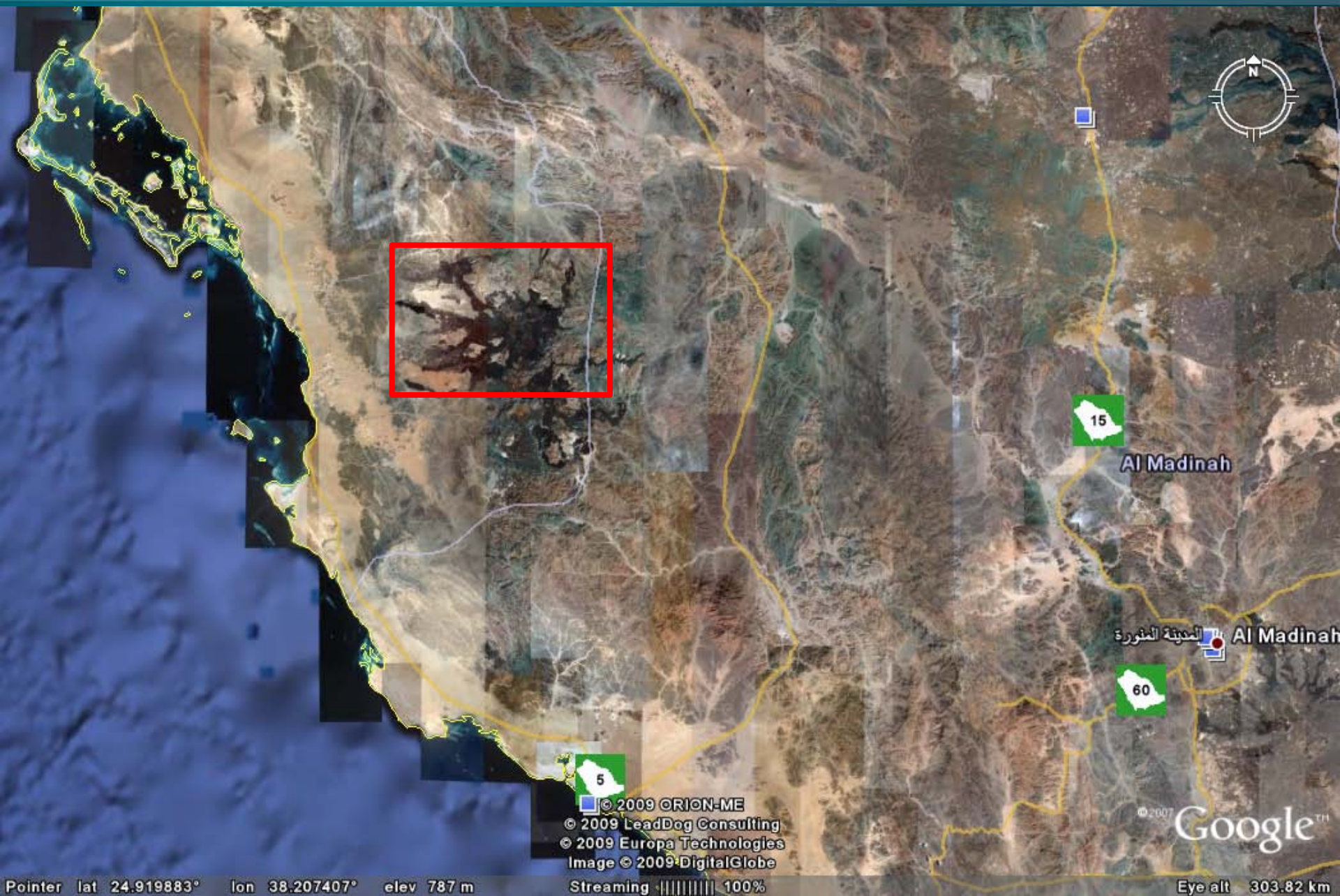
- Red Sea opening increases from 7 mm/yr in the north to 17 mm/yr in the south
- Volcanic provinces in Yemen, Saudi Arabia, Jordan, and Syria became active when Red Sea opening started, now cover 180.000 km^2 in Saudi Arabia alone
- Several historical eruptions, the best known is the 1256 Madinah event
- Harrat Lunayyir is a small lava province in north-western Saudi Arabia

The 2009 Seismic Crisis in Harrat Lunayyir

- Seismic activity started in mid-April and intensified steadily until mid-May
- Several magnitude 4.0-5.7 earthquakes in 17-19 May
- 3-40000 people evacuated! Stayed in Yanbu and Medina for weeks



Harrat Lunayyir

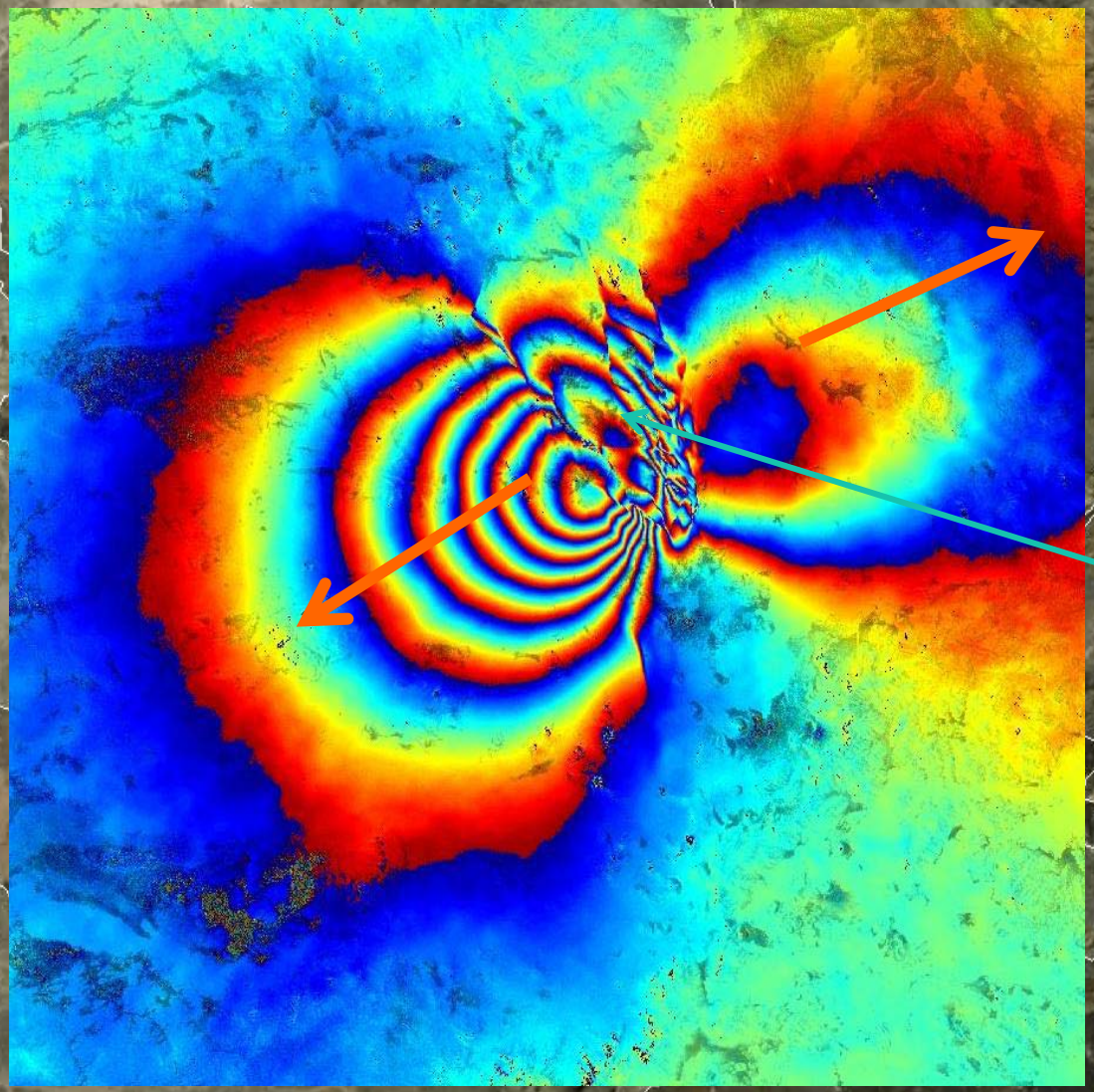


Harrat Lunayyir

Fresh-looking lavas and cinder cones

Most recent activity possibly ~1000 years ago

ALOS data spanning the 2009 EQ activity



20 km

Extension

Graben
Subsidence

© 2009 ORION-ME
Image U.S. Geological Survey
Image © 2009 DigitalGlobe
© 2009 LeadDog Consulting
25°12'24.06" N 37°52'51.25" E elev 885 m
©2009 Google
Eye alt 72.66 km

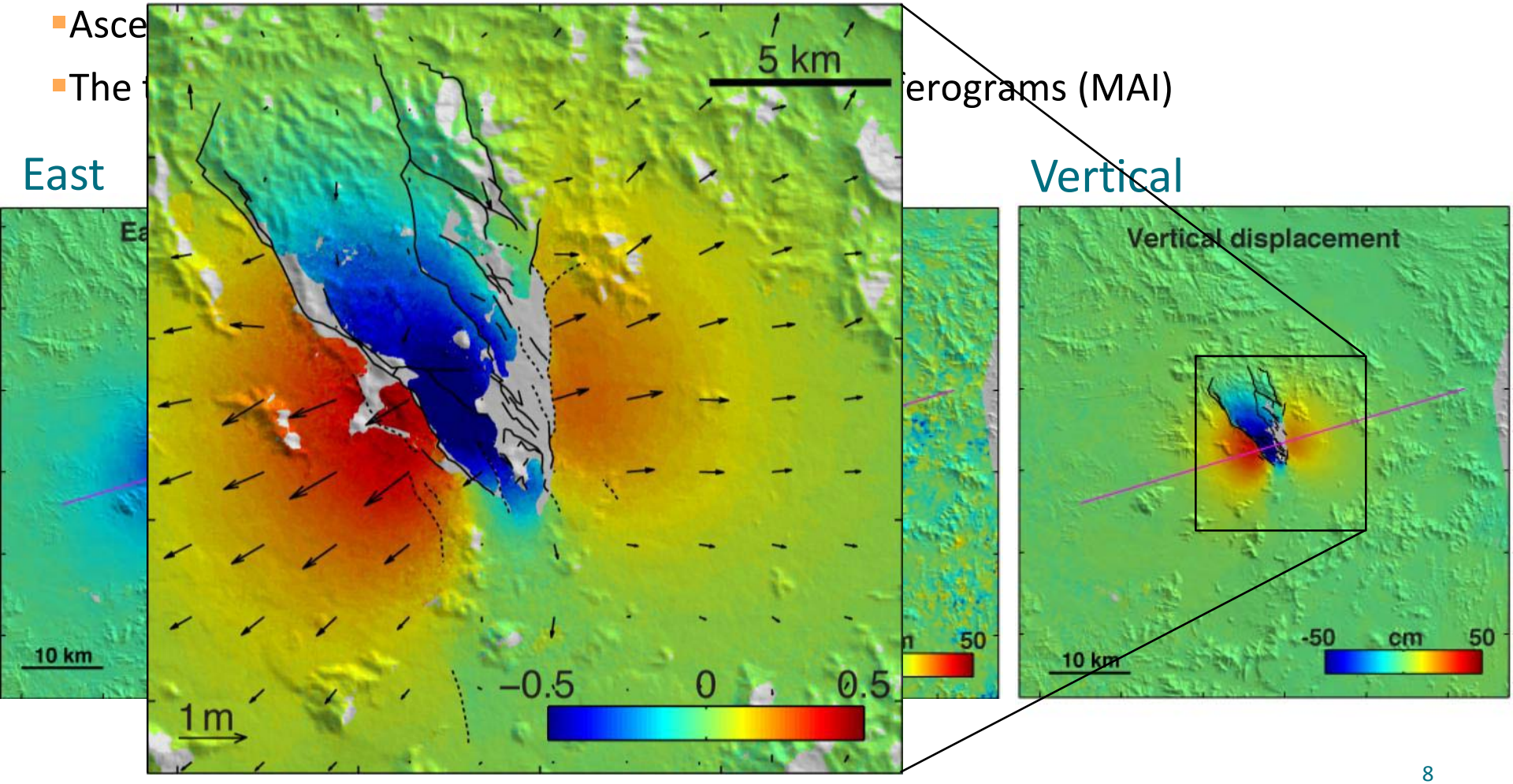
3D Ground Displacements

The 3D ground displacements were estimated from six different data sets:

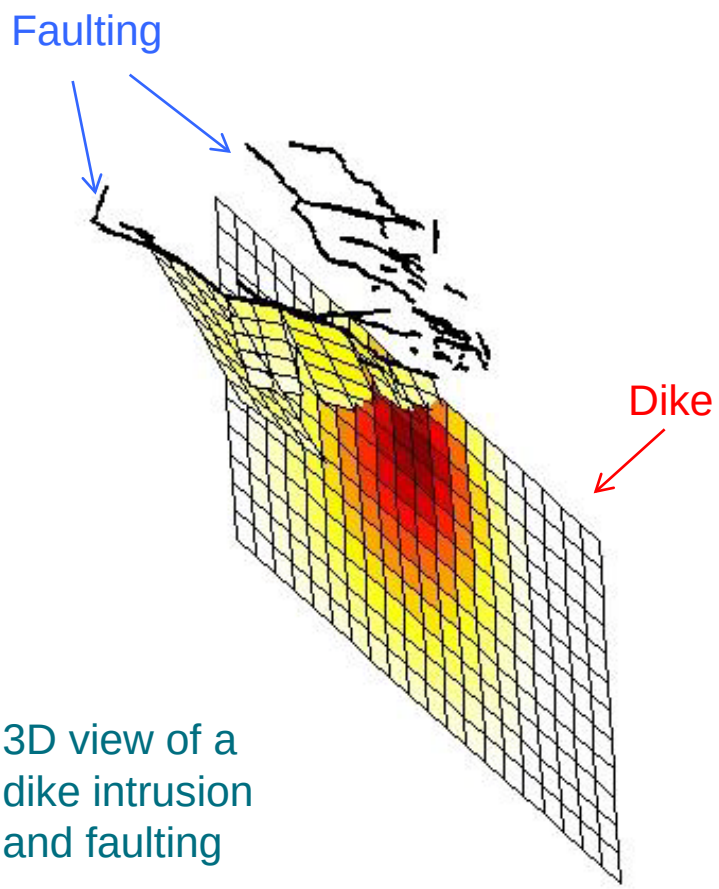
- Ascending and Descending Envisat InSAR
- Asce
- The t erograms (MAI)

East

Vertical



Dyke Model with Variable Opening / Faulting

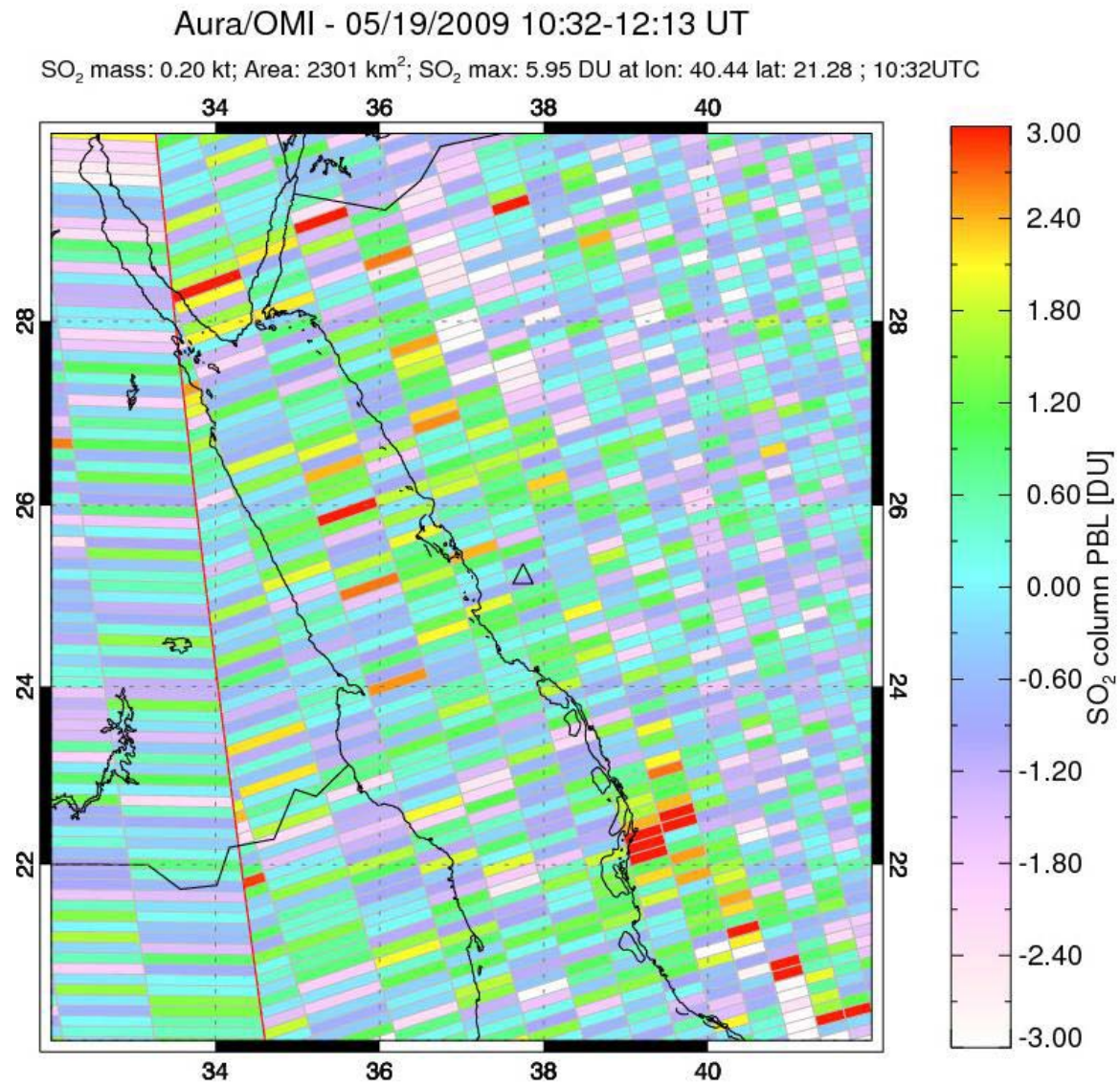


3D view of a dike intrusion and faulting

Main Findings

- Deformation well explained with ~10 km long dyke and graben-bounding faulting
- Depth to dyke top only 1-2 km
- Dyke opening 3-4 m
- Faulting over 1 m in places
- Volume ~ 0.1 km^3 (or ~40 kg for each person in the world)

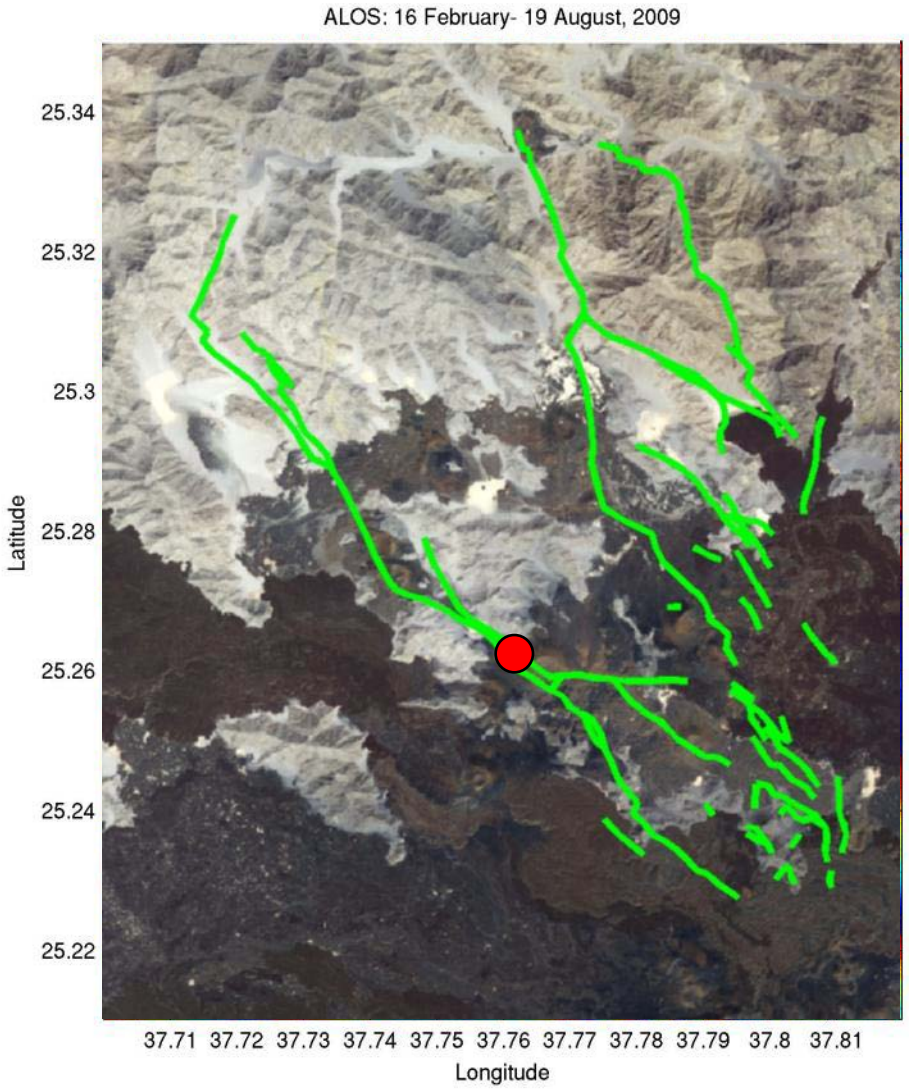
SO_2 Emissions on 19 May



From Nickolay A. Krotkov, NASA

- SO_2 emissions measured by the OMI instrument
- No signs of elevated SO_2 above the dyke intrusion in Harrat Lunayyir

ALOS InSAR data in the nearfield

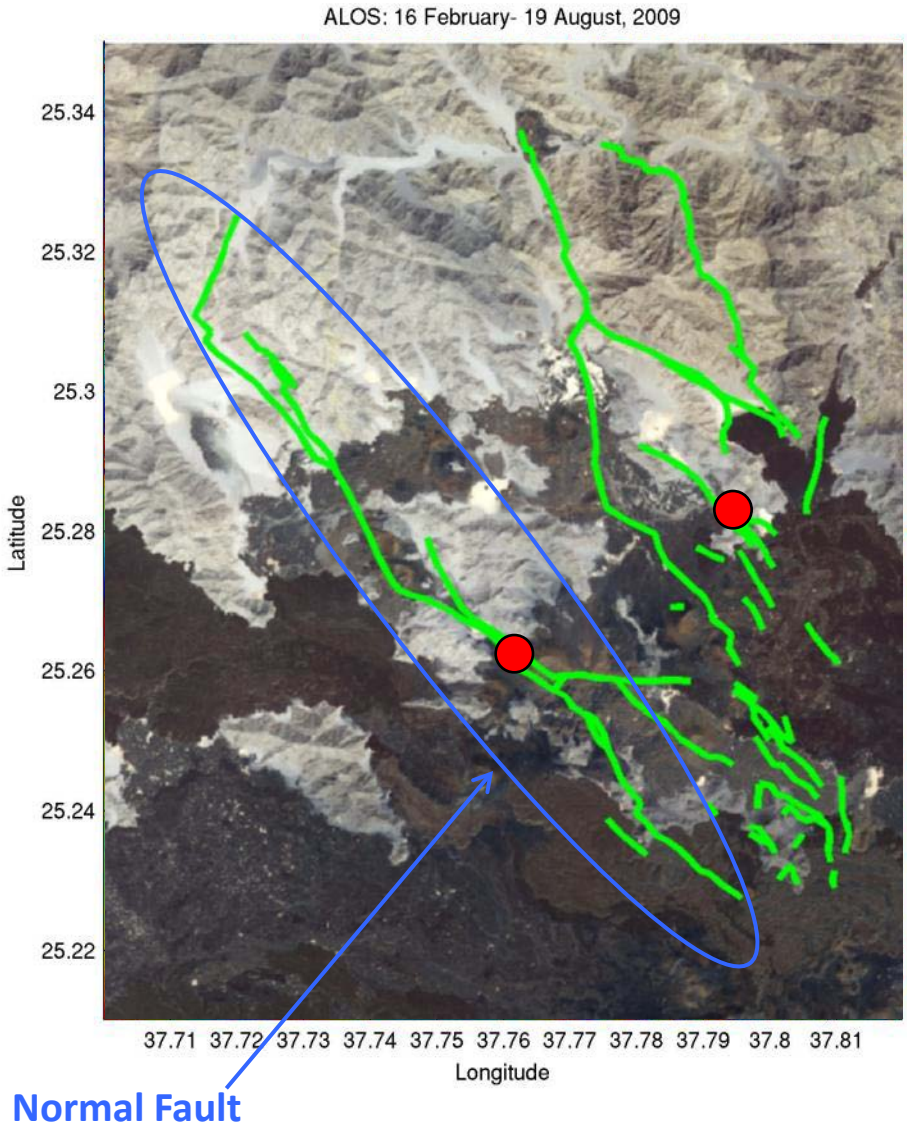


- Phase discontinuities clearly indicate fault offsets
- Main offset seen across the western graben bounding fault

Photo: Mark Rosa

Photo: Sabrina Metzger

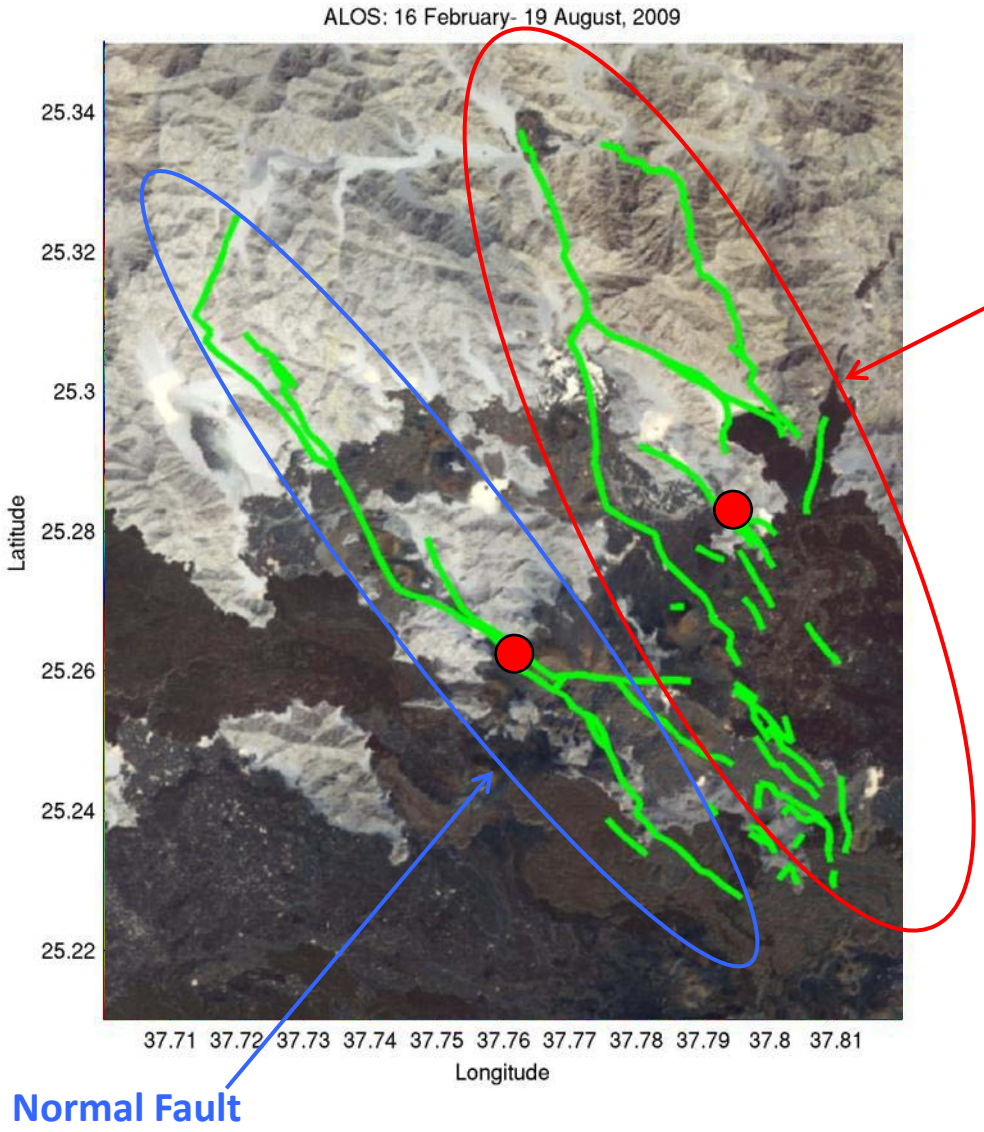
ALOS InSAR data in the nearfield

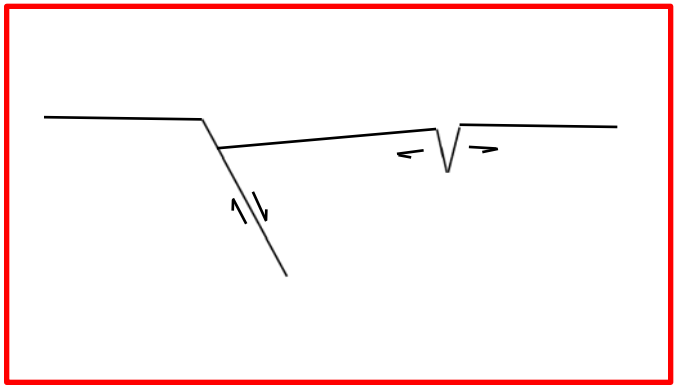


- Phase discontinuities clearly indicate fault offsets
- Main offset seen across the western graben bounding fault

Photo: Sabrina Metzger

Diking may have formed in a “Half-graben”





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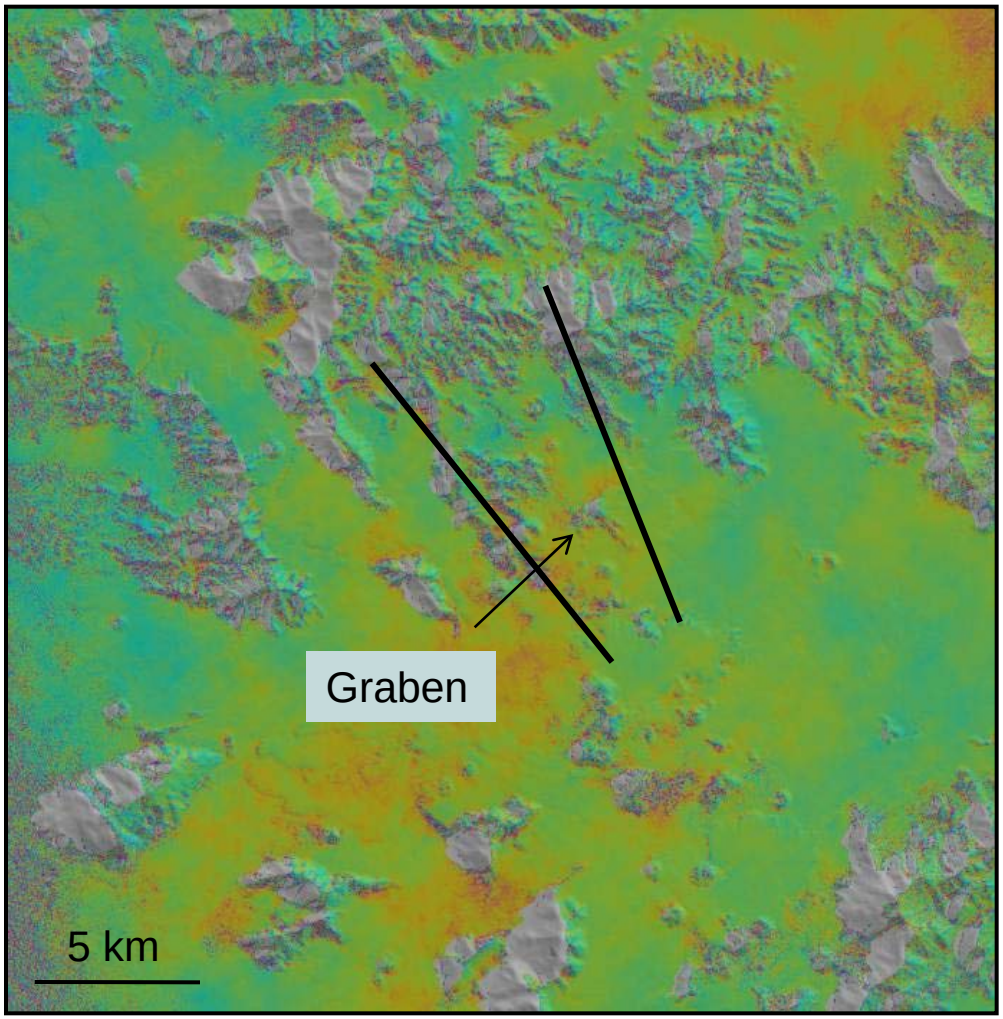
Where did the Magma come from?

No Uplift prior to the Intrusion!

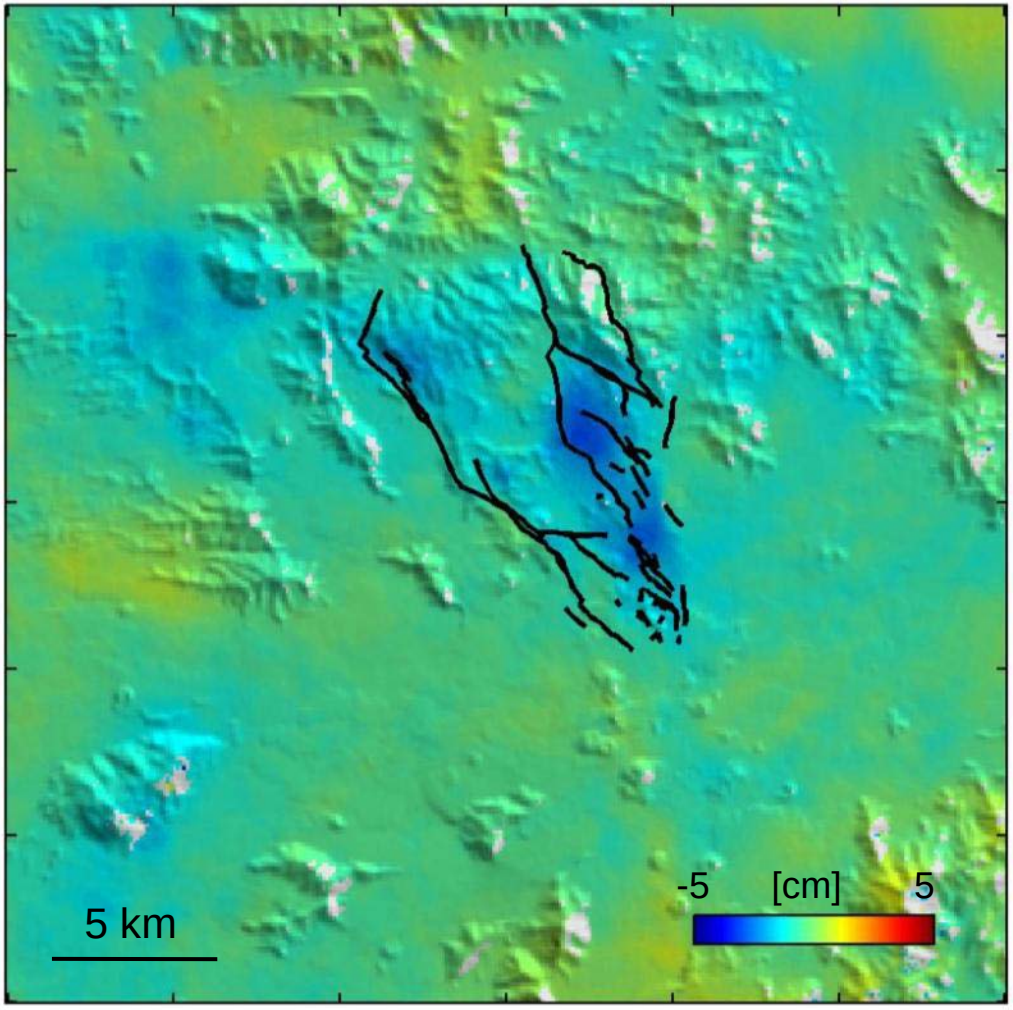
Oct 2006 - March 2008



- Other InSAR data also show no significant deformation between 2004 and May 8, 2009
- 0.1 km^3 volume change at 10 km depth would cause ~24 cm vertical displace-ment (or ~6 cm at 20 km depth)

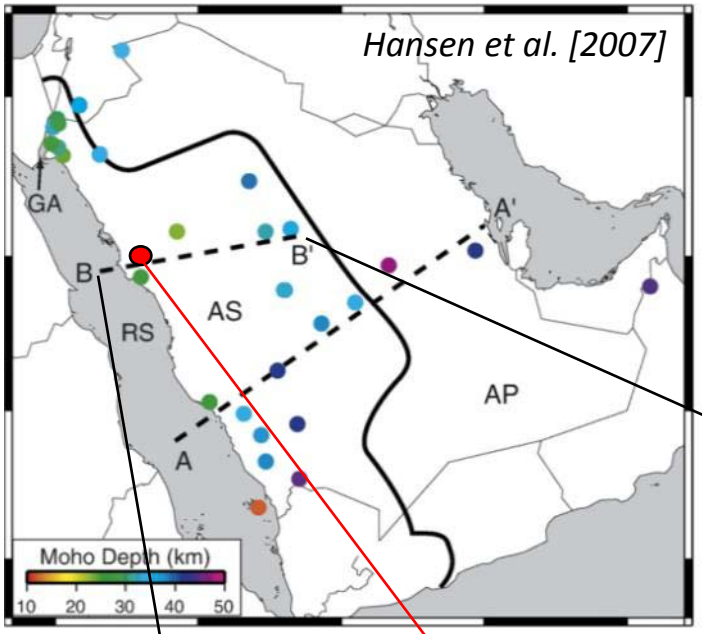
Also no Uplift after the Intrusion

Sept. 2009 - April 2010

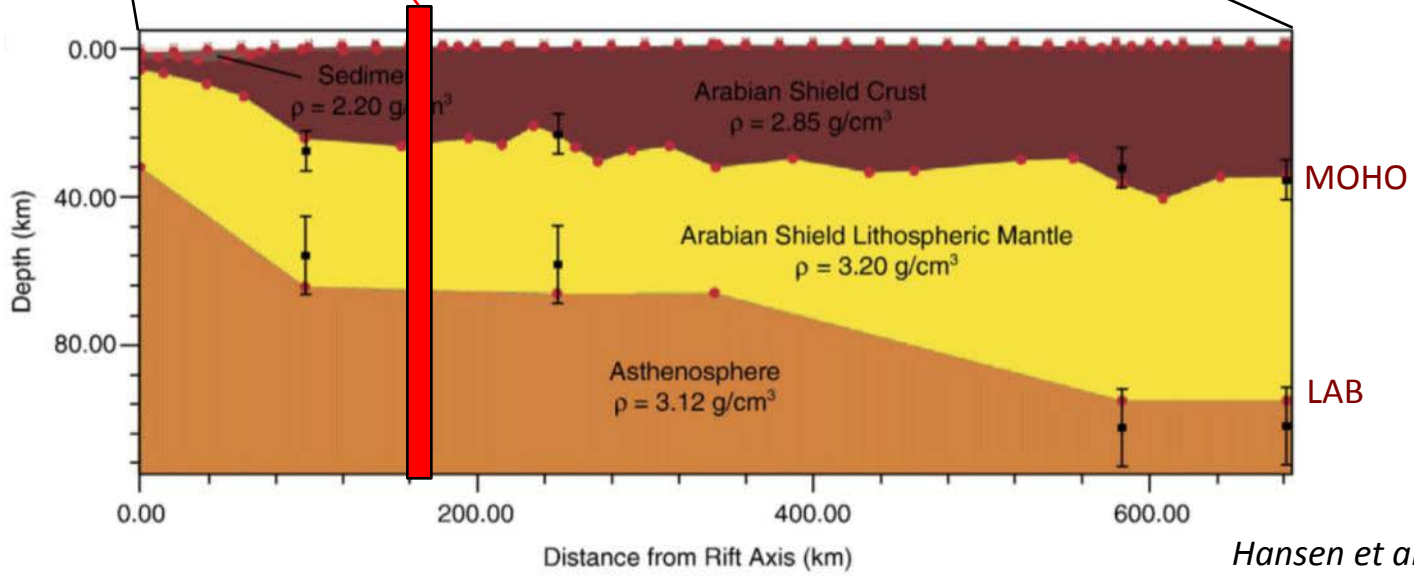


- Deformation transient associated with the intrusion was over in August 2009

Crustal Thickness and LAB

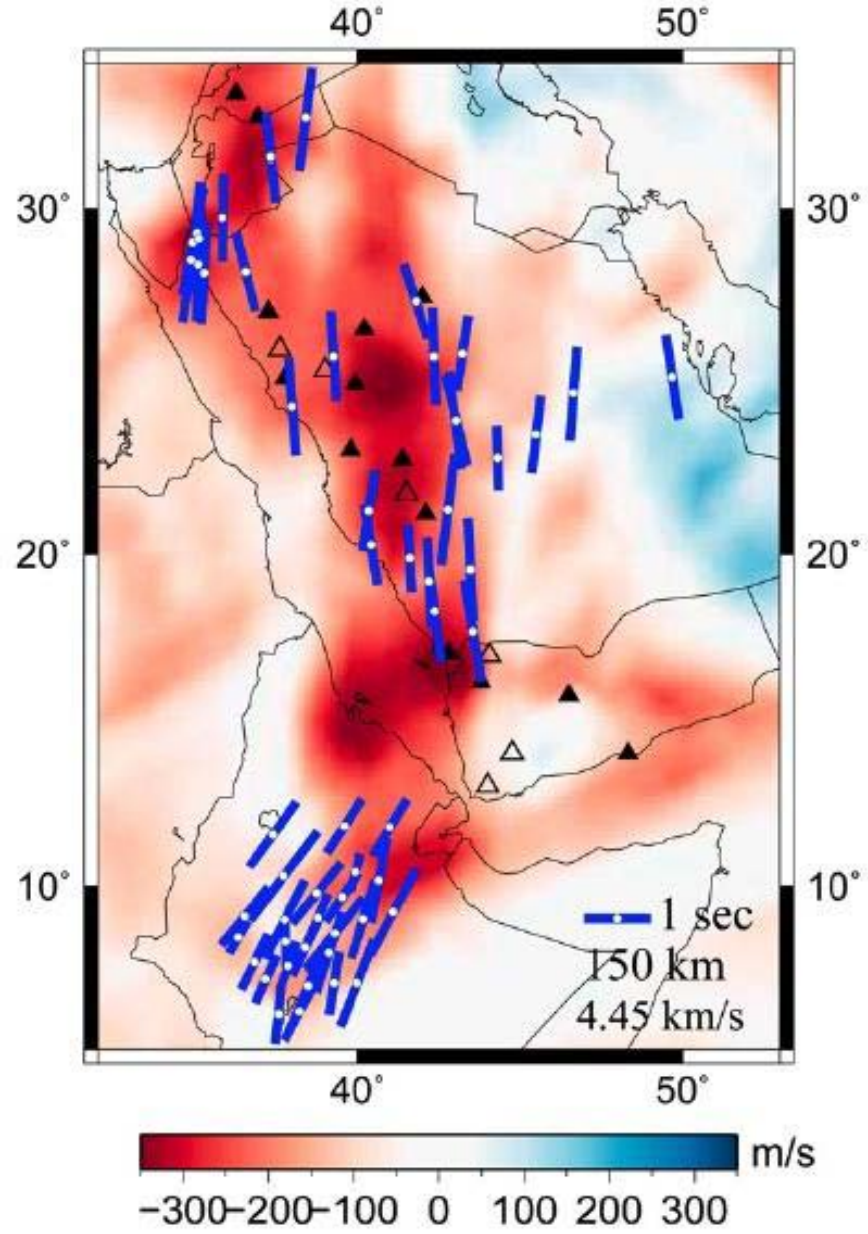


- Crust thickens away from the Red Sea towards east [Chang et al. 2011]
- Crustal thickness estimated ~25 km in the Harrat Lunayyir area



Hansen et al. [2007]

S-wave velocity and splitting



- S-wave velocity deviations at 150 km depth show slower velocities under Arabia, offset from the Red Sea [Chang et al. 2011]
- Shear-wave splitting shows fast N-S directions under western Arabia [Hansen et al., 2006].

From Chang et al. [2011] using results from Gashawbeza et al. [2004], Hansen et al. [2006],

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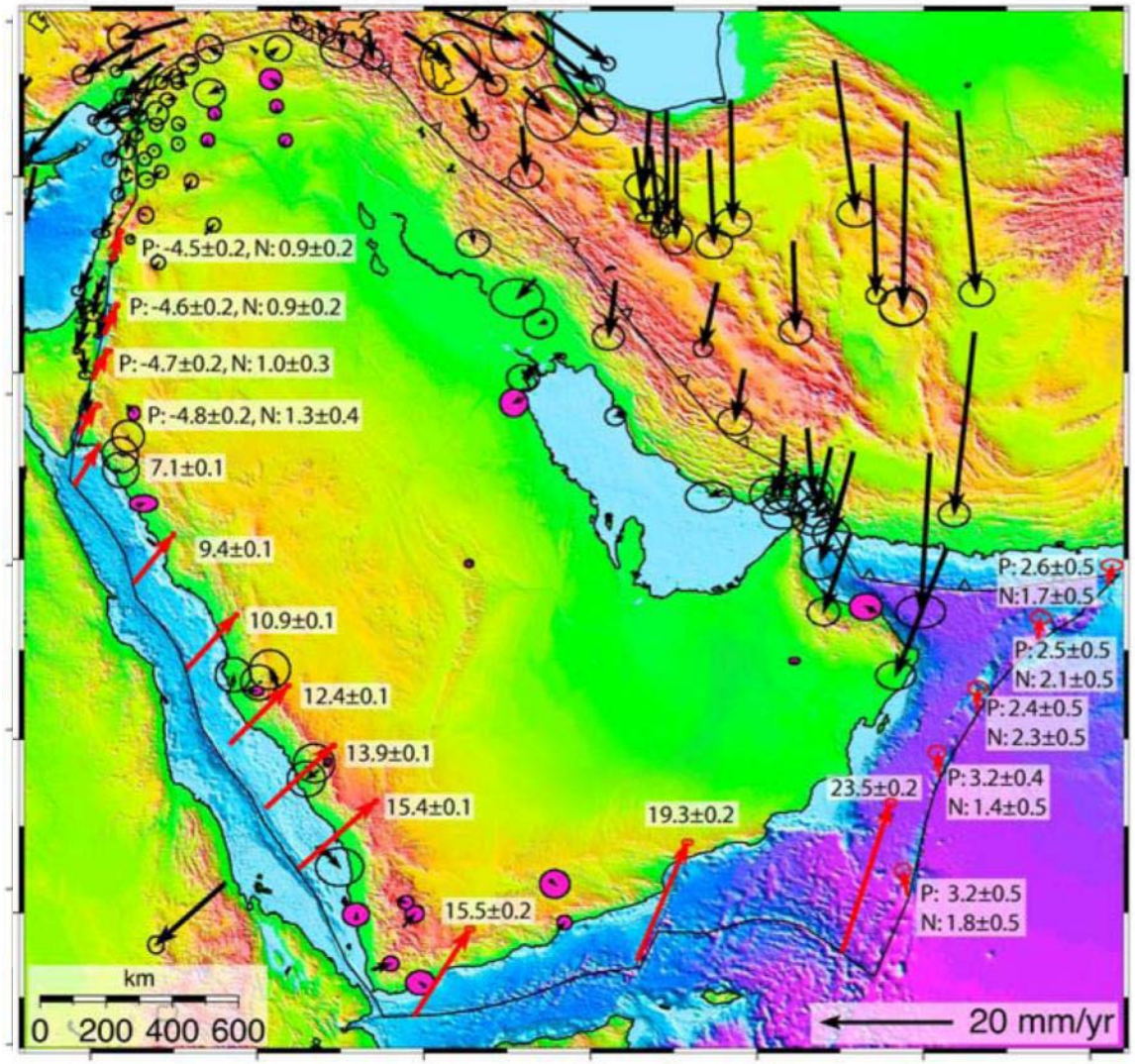
Western Arabia is a magmatically active “passive” margin:

What is the Extension Rate?

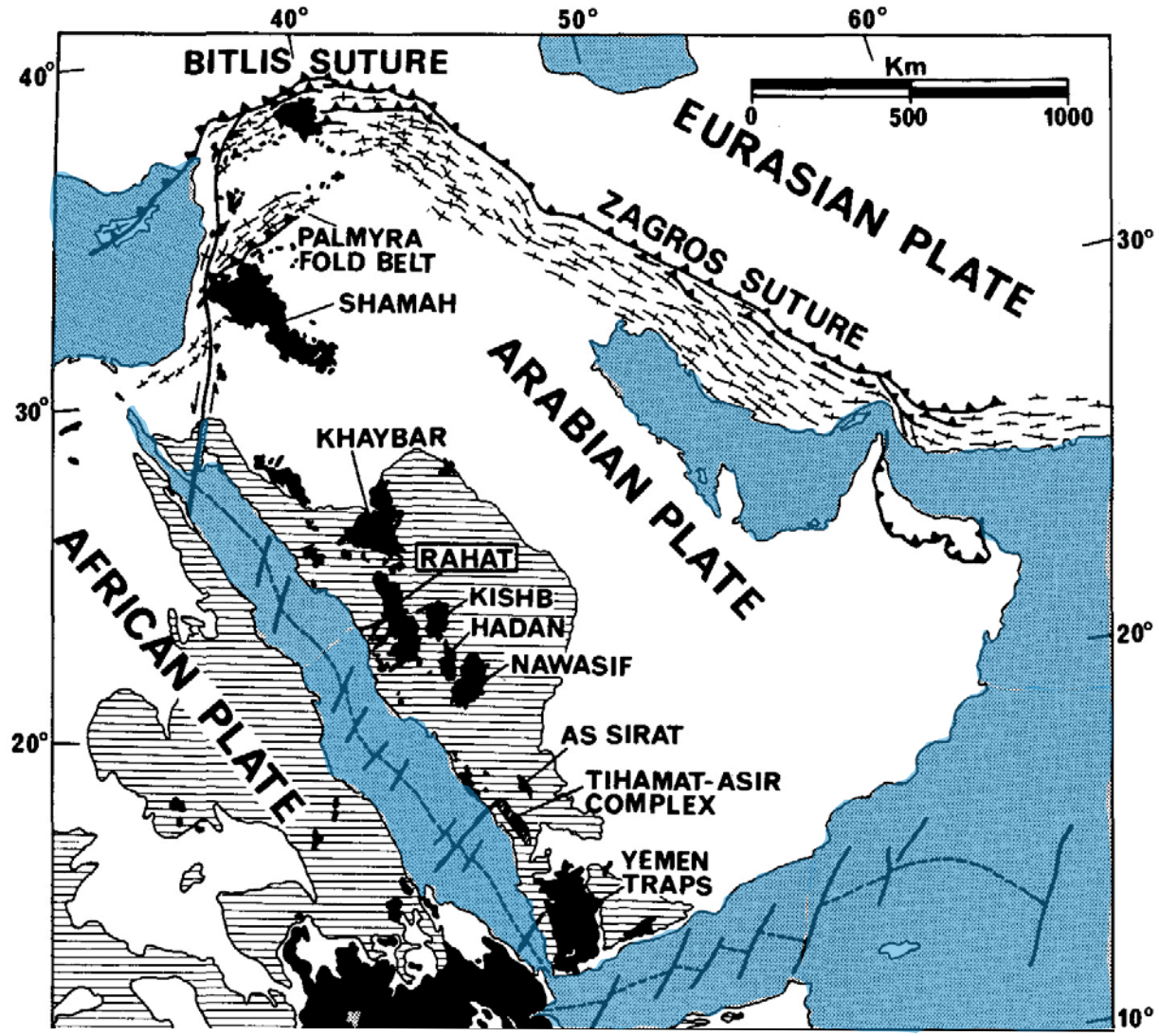
Limited Internal Deformation of Arabia



- Campaign and Continuous GPS measurements do not reveal any internal deformation of the Arabian plate
- Stations on the west coast move with the entire plate
- Confidence level is ~1 mm/year

Arrajehi et al., 2010

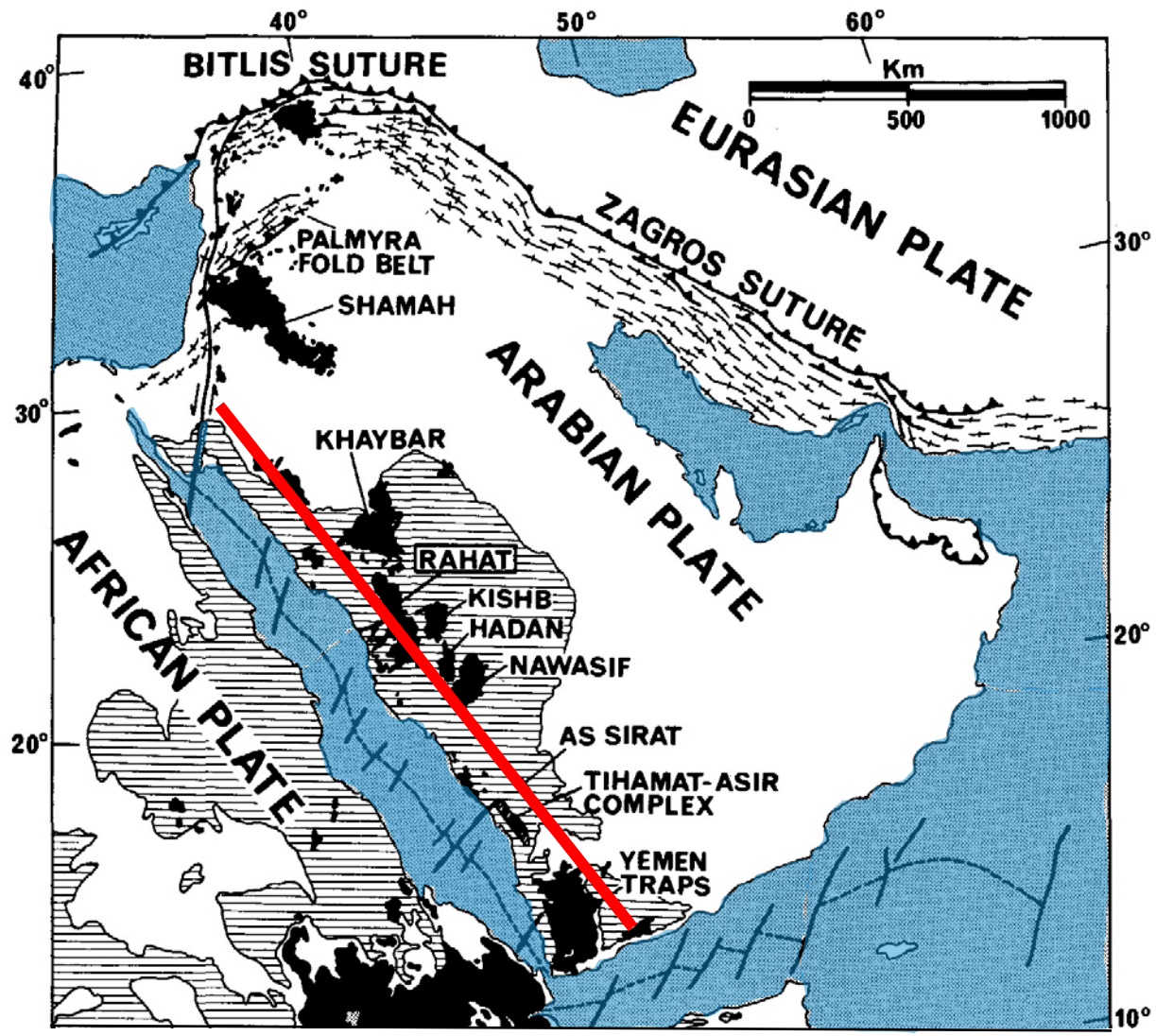
Eruptions & Intrusions in western Arabia



Camp et al., 1989

- 21 on-plate historical eruptions during the past 1500 years (Camp et al., 1987)
- Some eruptions were probably not detected
- Many intrusions may have been without eruptions (like in Harrat Lunayyir)

Possible Extension Rate in western Arabia



Camp et al., 1989

- Assuming HL-type of intrusion every 50 years,
- Intrusion production in the upper crust would amount to ~2 km^3 per 1000 years
- Along the 2000 km boundary it would mean an average extension rate of only 0.1 mm/year
- Even 5-10x higher production rate would result in undetectable extension.

Conclusions

- The observed meter-scale extension, faulting, and graben subsidence was caused by a ~0.1 km^3 dyke intrusion that came within only ~2 km of the surface
- The lack of pre- and post-event uplift suggests a deep magma source, no hint of any crustal magma chamber
- Assuming Harrat Lunayyir type of intrusions occur every 50 years (or even every 10 years) in western Arabia, it would correspond to an average extension rate that is still below the detection level of 1 mm/year
- However, the activity shows that the extension across the Nubian-Arabian boundary is broadly distributed and not entirely focused on the rift axis

Thanks!

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