Using seismic networks to explore for geothermal resources in western Saudi Arabia

Robert J. Mellors[1], Victor Camp[2], Eric Matzel[1], Abdullah Al-Amri[3] and David Harris[4]

[1]Lawrence Livermore National Laboratory

[2]Consultant

[3]King Saud University, Saudi Arabia

[4]Deschutes Signal Processing

40th GRC Annual Meeting
23-26 October, 2016
Sacramento, CA

LLNL-PRES-XXXXXX

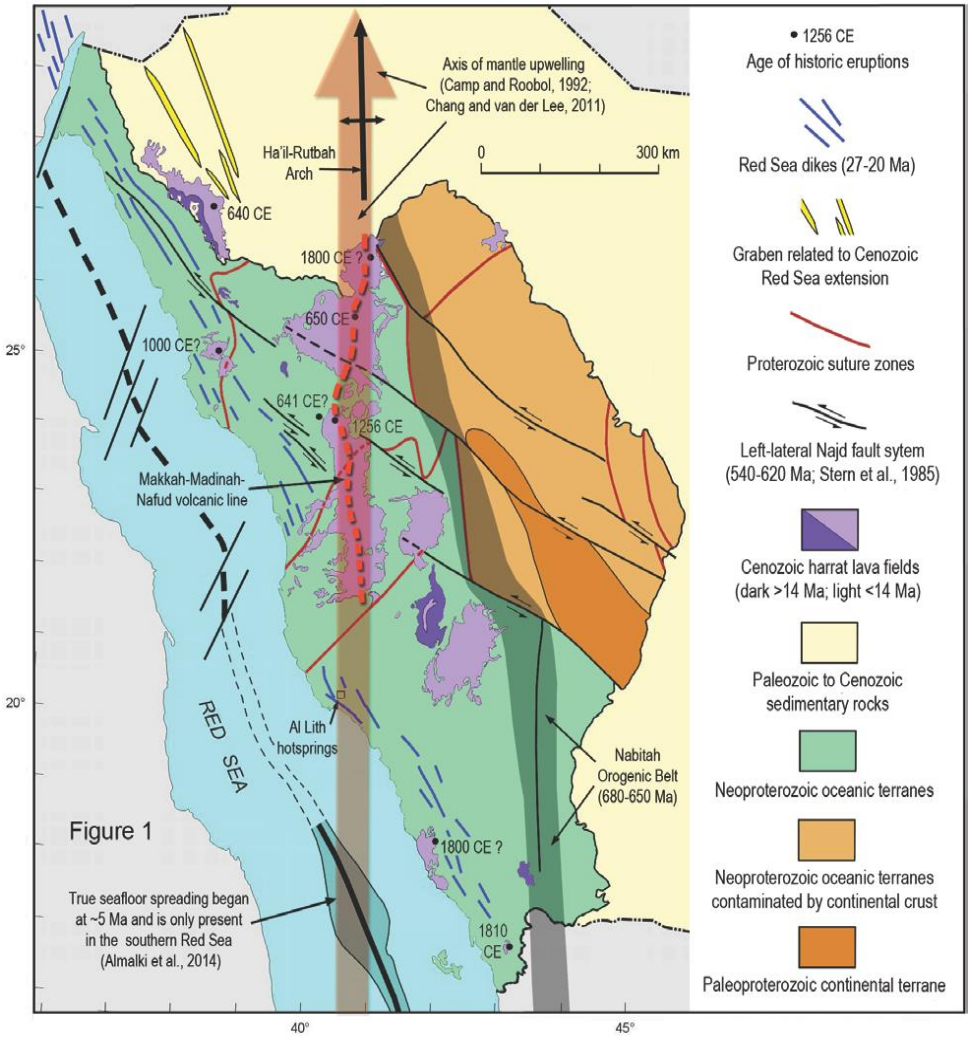
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

Overview

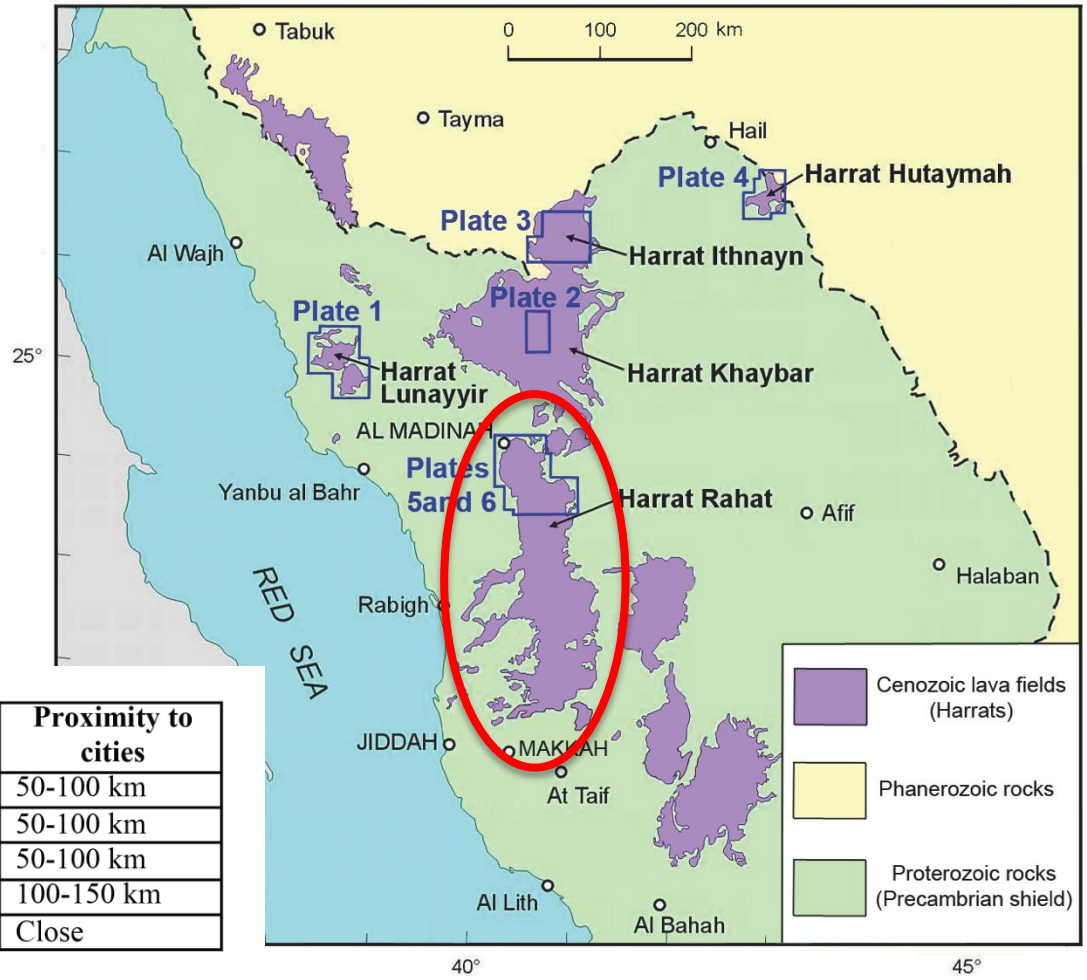
- Saudi Arabia lies in active tectonic area
- Potential geothermal in Saudi Arabia
  - Along Red Sea coast (e.g. Jizan)
  - Volcanic areas inland (harrats)
  - High heat generating granites in north (EGS potential?)
- Government favors growth of renewables

Roobol (2007)



Harrat Rahat

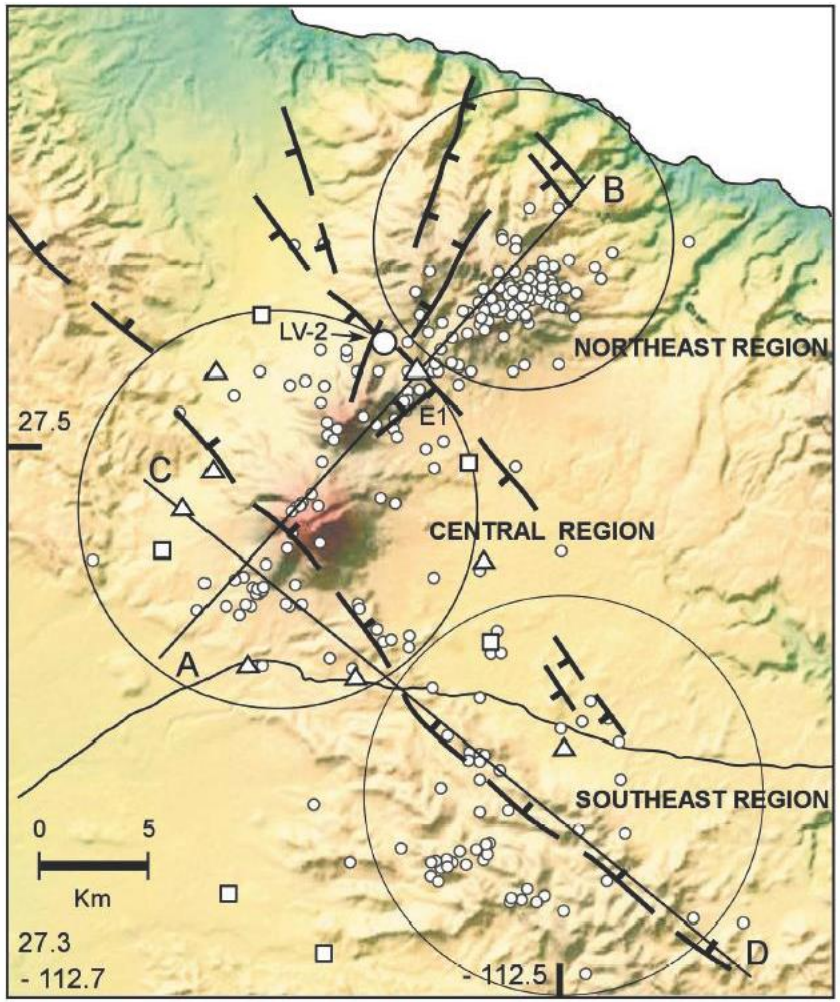
- Recent eruptions
- Near city of Medina
  - Population ~ 1.3 million
  - Recent lava flows into city.
- Northward progression of eruptions.
- Earliest about 500,000 years ago to historic



Harrat	Recent eruptions	Sub-surface water	Proximity to cities
Lunayyir	2009* AD	?	50-100 km
Khaybar	Holocene	Yes	50-100 km
Hutaymah	Holocene	Yes	50-100 km
Ithnayn	Holocene	?	100-150 km
Rahat	641, 1256 AD	?	Close

Medina and surrounding area

A motivating example



- Las Tres Virgines Geothermal Field, MX
- Volcanics on transforms faults
- Related to Gulf of California spreading
- Permeability associated with faults
- Reservoir about 275° C
- 10 MW

Wong and Munguia, 2006

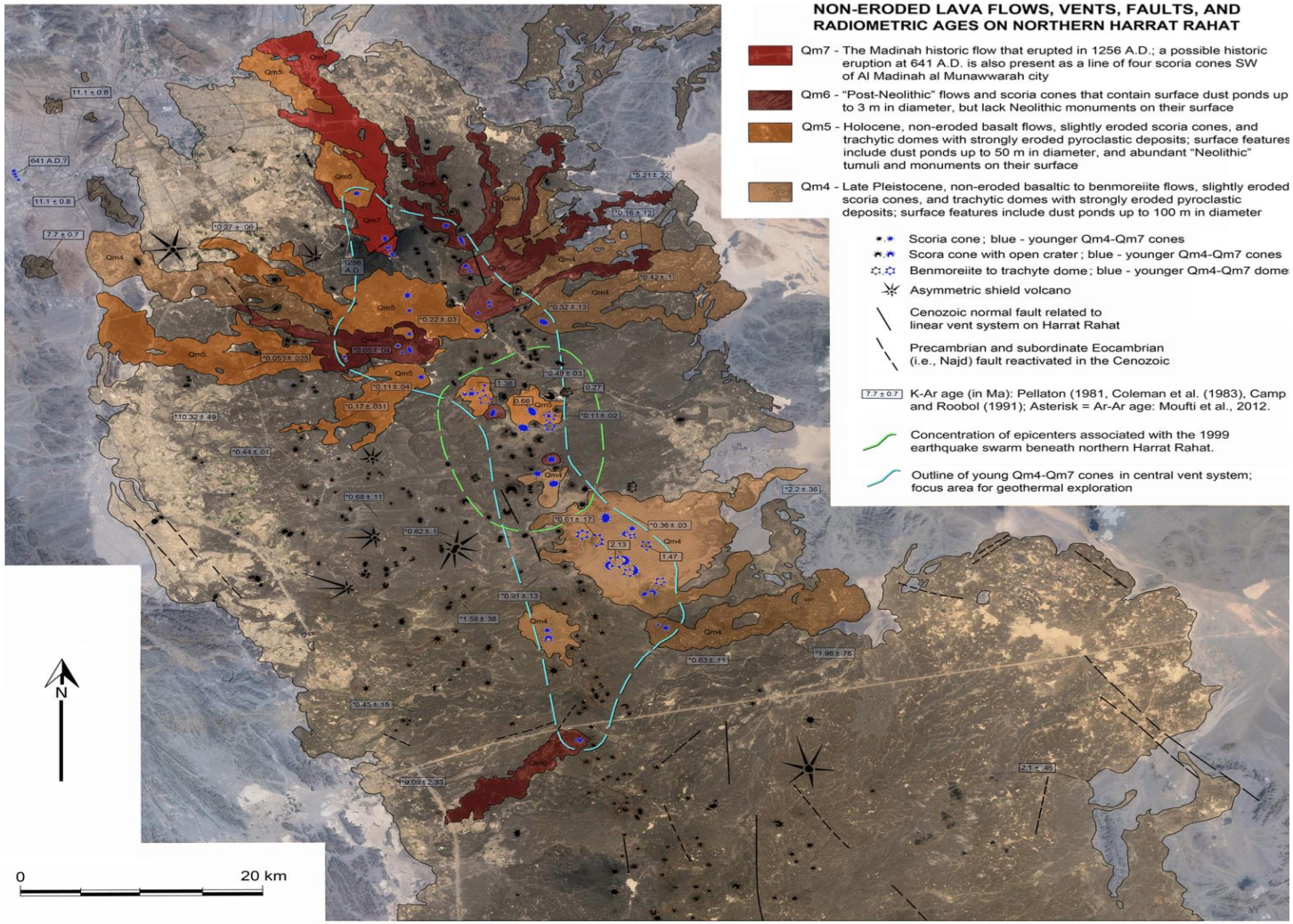
Data and strategy

- Limited data; limited budget
  - Passive seismic data
  - Geological mapping
  - May be useful for volcanic hazard as well
  - Test new tools: automated seismic interferometry and detection algorithms (fast and cheap)
  - passive seismic data is widely available in many regions

- Objective
  - Use continuous seismic data to image low velocities and possibly relate to geothermal gradient
    - *is all of Harrat Rahat potentially productive or only part?*
  - Look for small earthquakes and basement faults
    - *can we define areas with possible high permeability?*

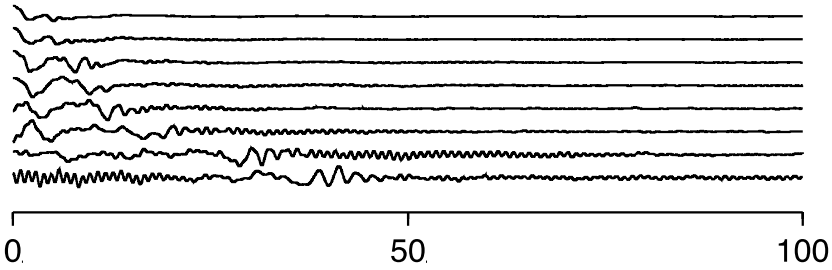
- Combination of geologic mapping and seismic analysis

Geologic mapping



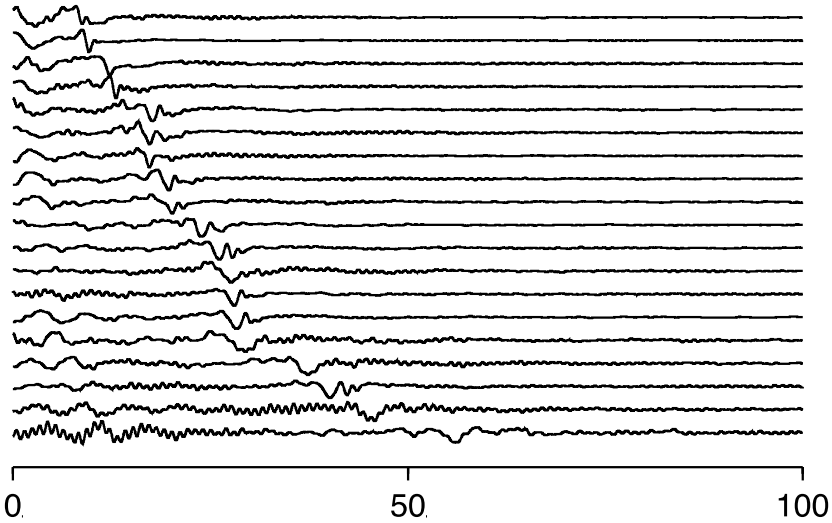
Seismic interferometry

Volcanic paths

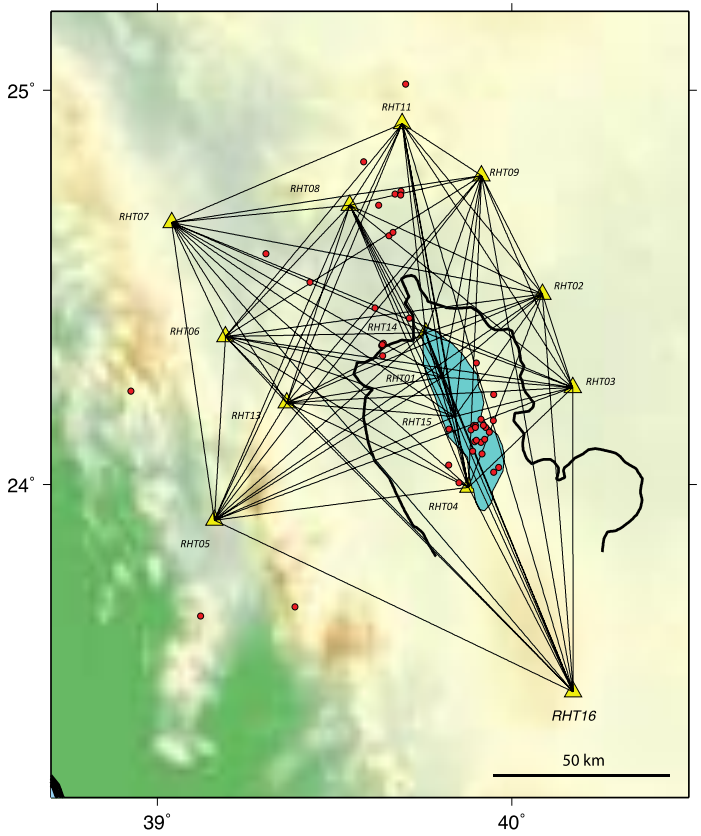


11.6 RHT01_RHT15
13.3 RHT01_RHT14
20.3 RHT04_RHT15
25.0 RHT14_RHT15
31.9 RHT01_RHT04
45.2 RHT04_RHT14
84.9 RHT15_RHT16
109.8 RHT14_RHT16

Shield paths



25.6 RHT06_RHT13
27.3 RHT08_RHT11
35.5 RHT06_RHT07
39.0 RHT05_RHT13
51.1 RHT07_RHT08
51.2 RHT06_RHT08
51.8 RHT05_RHT06
58.4 RHT08_RHT13
60.4 RHT07_RHT13
71.3 RHT07_RHT11
78.2 RHT06_RHT11
81.7 RHT03_RHT08
84.7 RHT05_RHT07
85.0 RHT11_RHT13
88.6 RHT03_RHT11
115.9 RHT13_RHT16
123.8 RHT05_RHT11
141.5 RHT06_RHT16
175.5 RHT07_RHT16

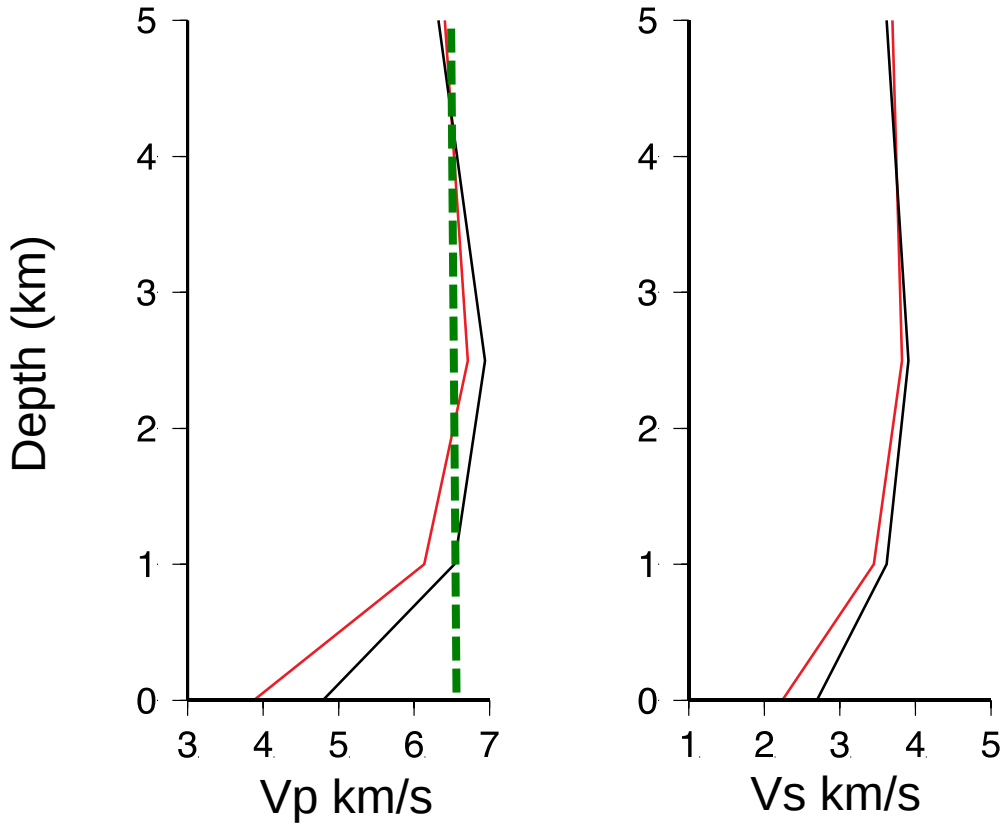


Green's functions estimated from noise

Inversion

- Volcanic areas consistently lower velocities at shallow (1 km depth)
- Values consistent with previous refraction work on the shield [*Mooney et al., 1985*]
- Technique appears to be effective [e.g. *Tibuleac et al., 2015*]
- Depth resolution limited by frequency response
- May be guide to geothermal gradient

Red – average volcanic
Black – average shield
Green – refraction line on shield

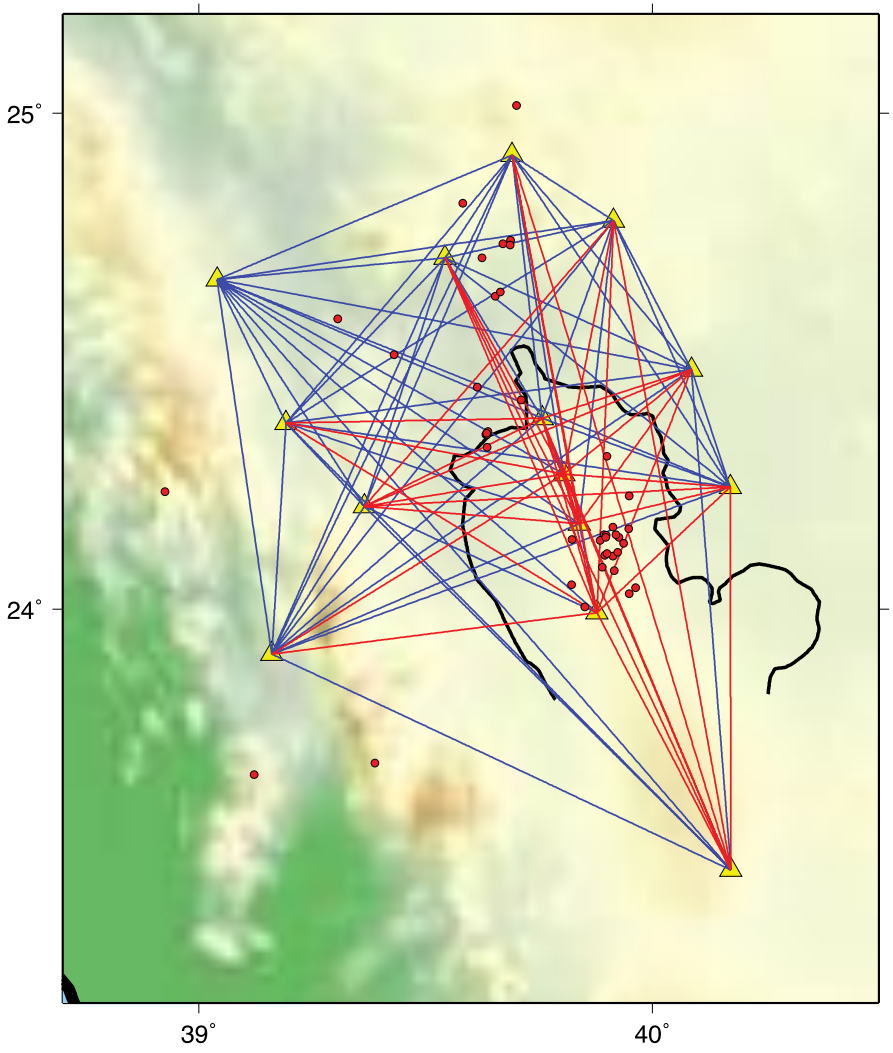


Velocities and volcanic region

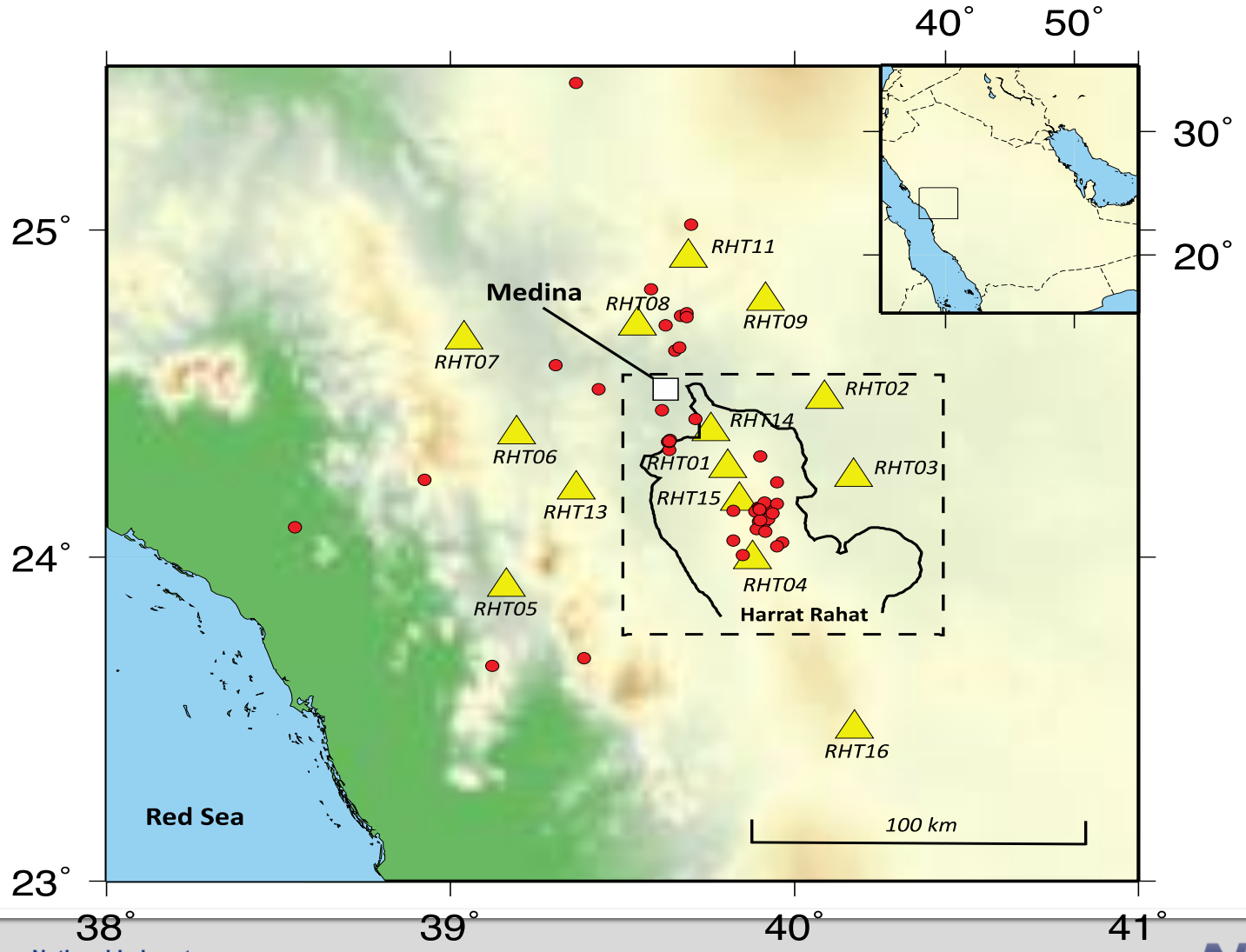
Red – average velocity slower (below median)
Black – average velocity faster (above median)

Average of upper 3 km

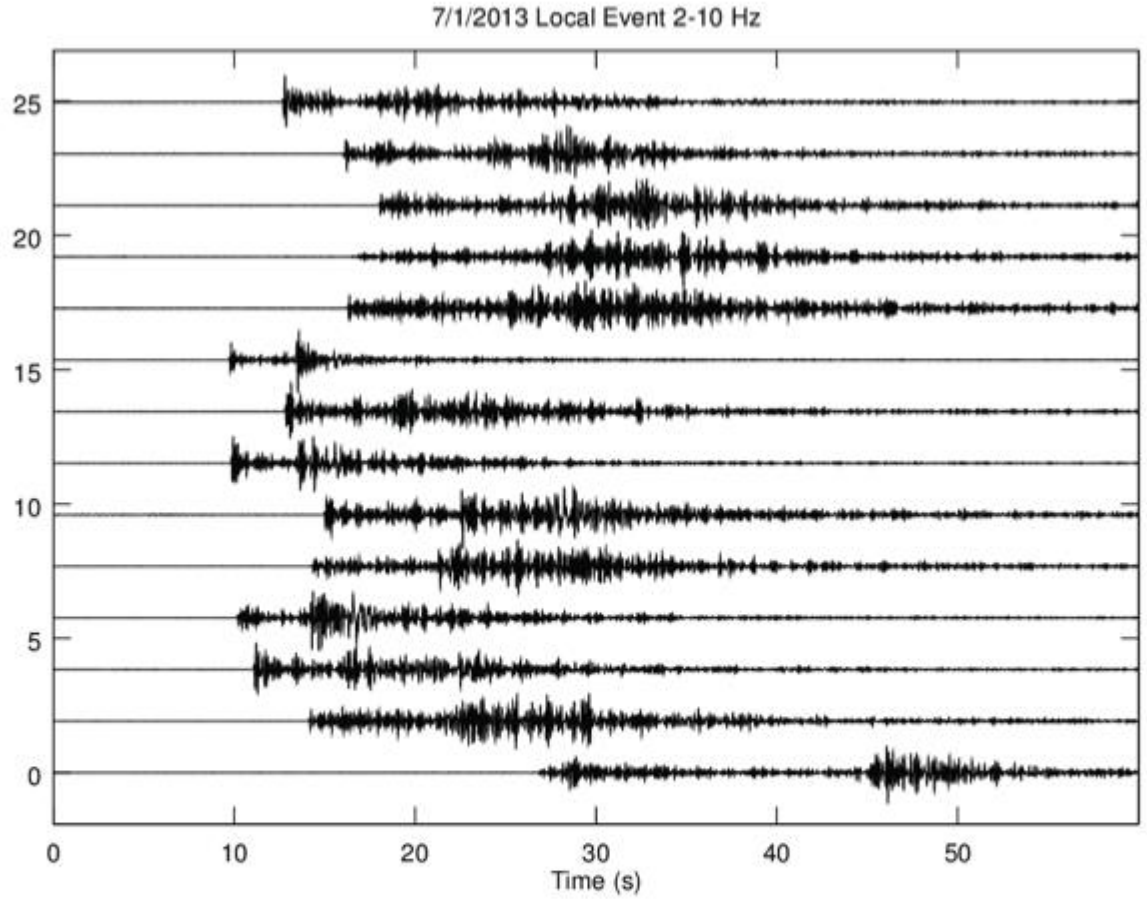
- Raypaths with more than 50% in harrat are slower.
- Shield paths are faster
- Ambient noise tomography capable of mapping areas of anomalous velocity



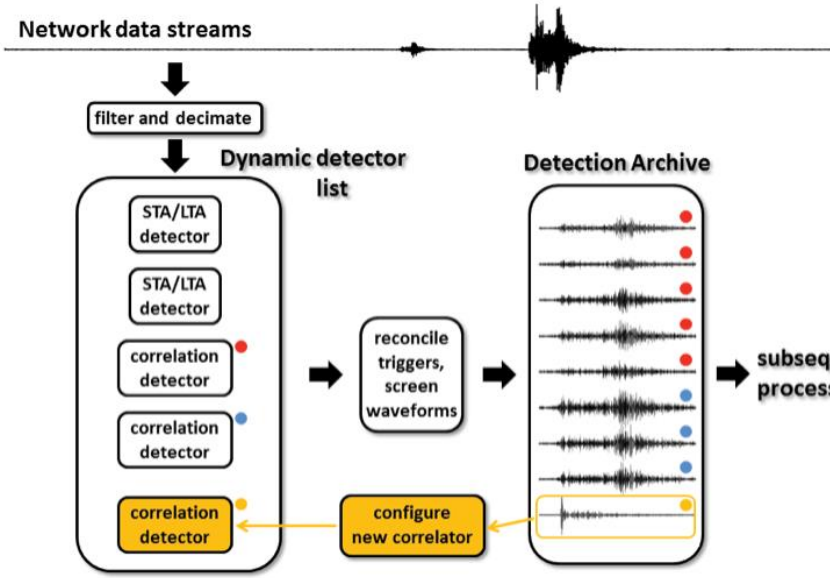
Seismic network and earthquakes

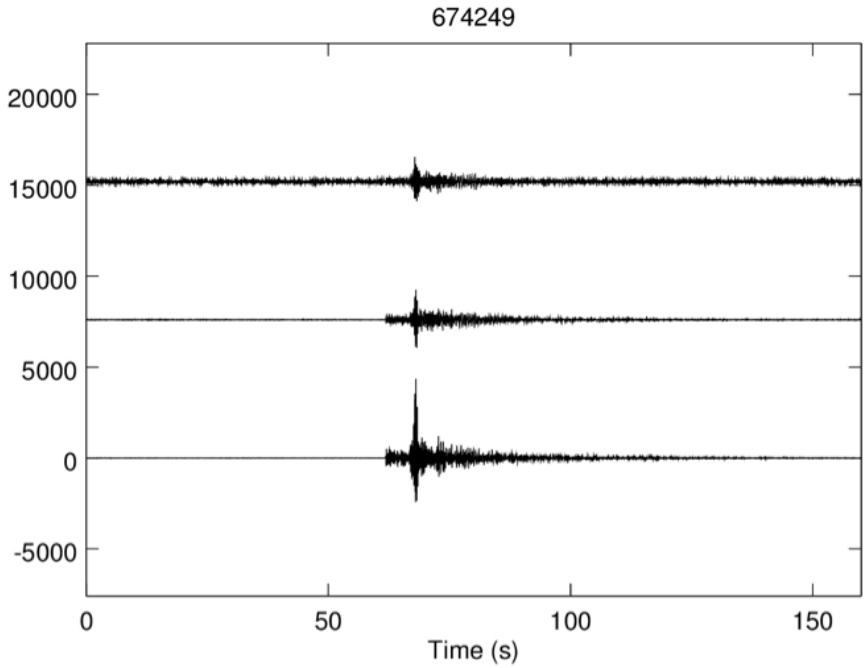


Local earthquake



Signal processing

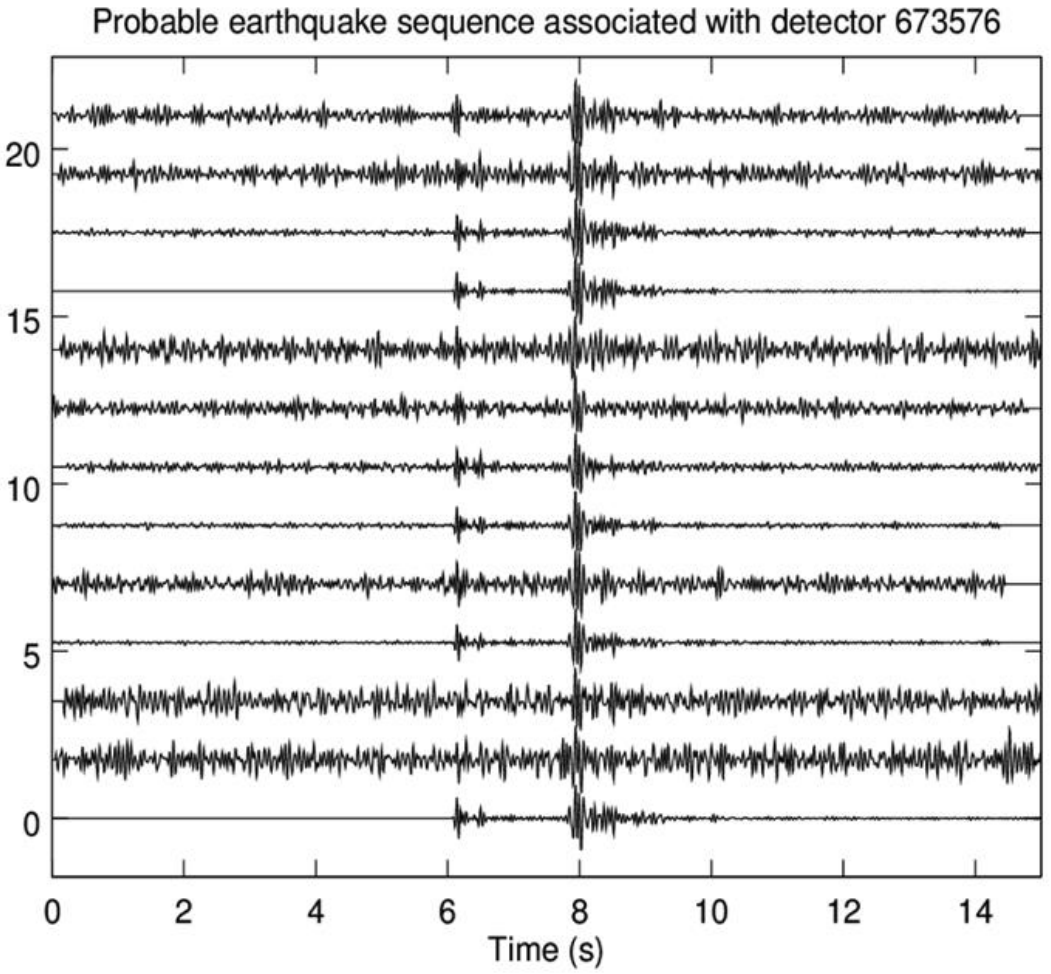




- Correlation based on existing events
- Applies ‘subspace’ detectors

Results of detection

- One year of data (7/13 – 7/14)
- 16 catalog events
- Detection added additional 36 events
- Some events associated with quarries
- Three new events near Harrat Rahat



Faulting

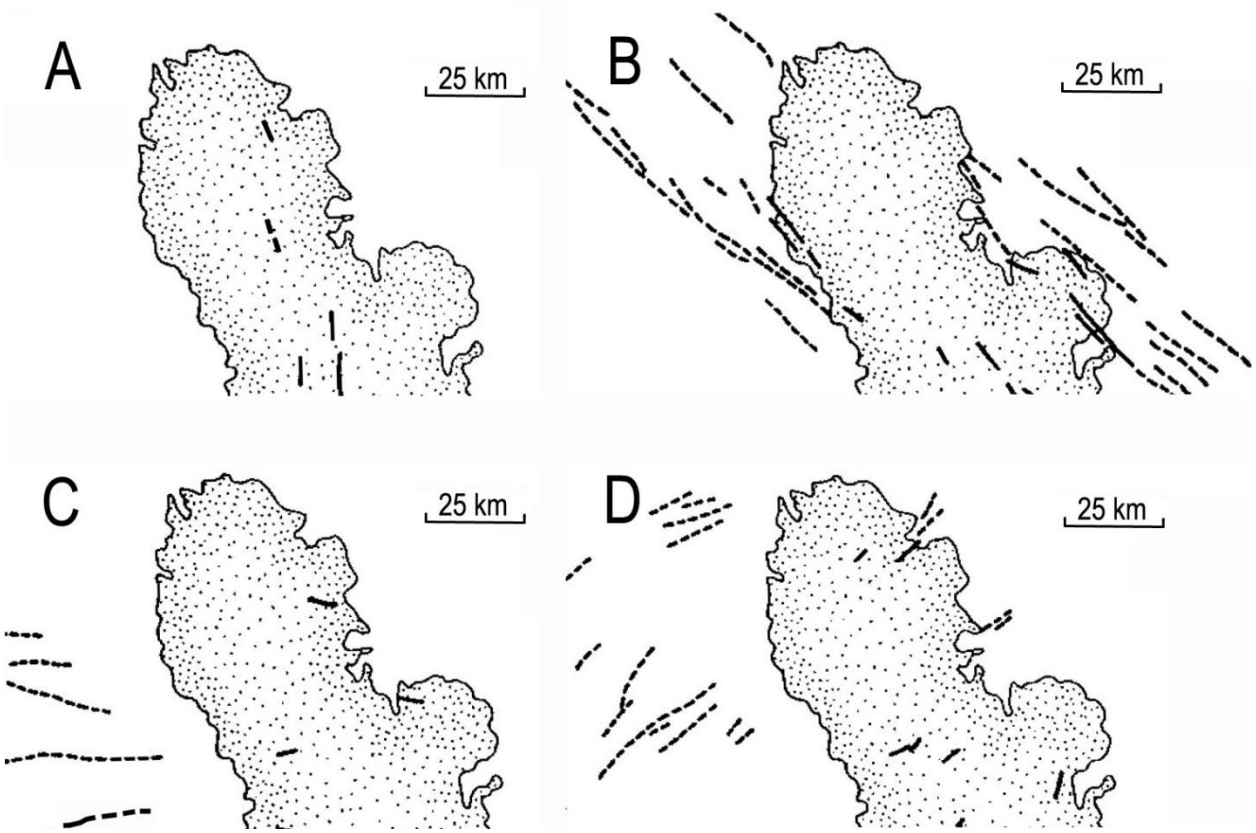
Faulting

A) NW to NE fault in central Harrat

A) NE related basement faults, possibly re-activated

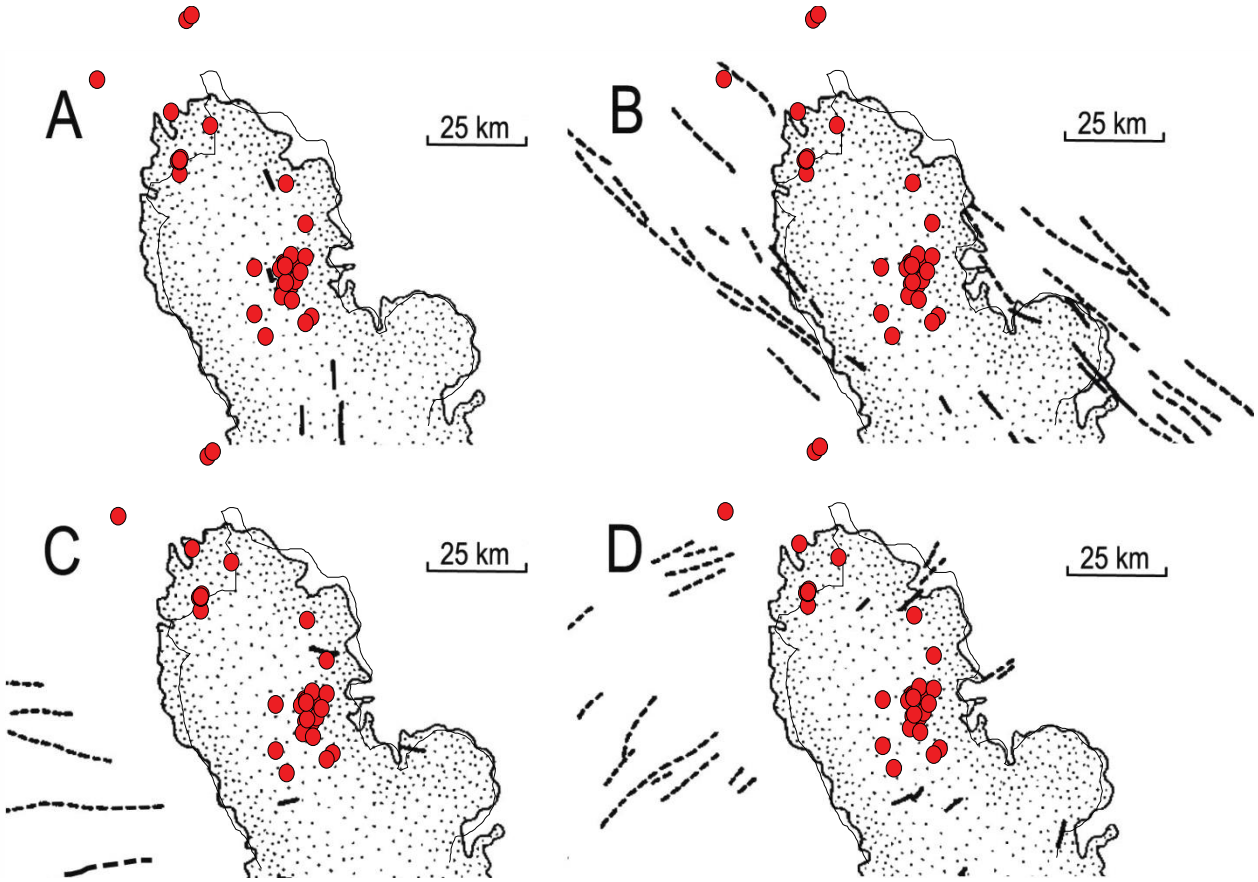
A) East-west faults of unknown origin

A) NE basement faults, also possibly re-activated



Faulting and earthquakes

- Seismicity roughly aligned with set B (as do recent cones)
- Area near intersection of B and D may show higher permeability.

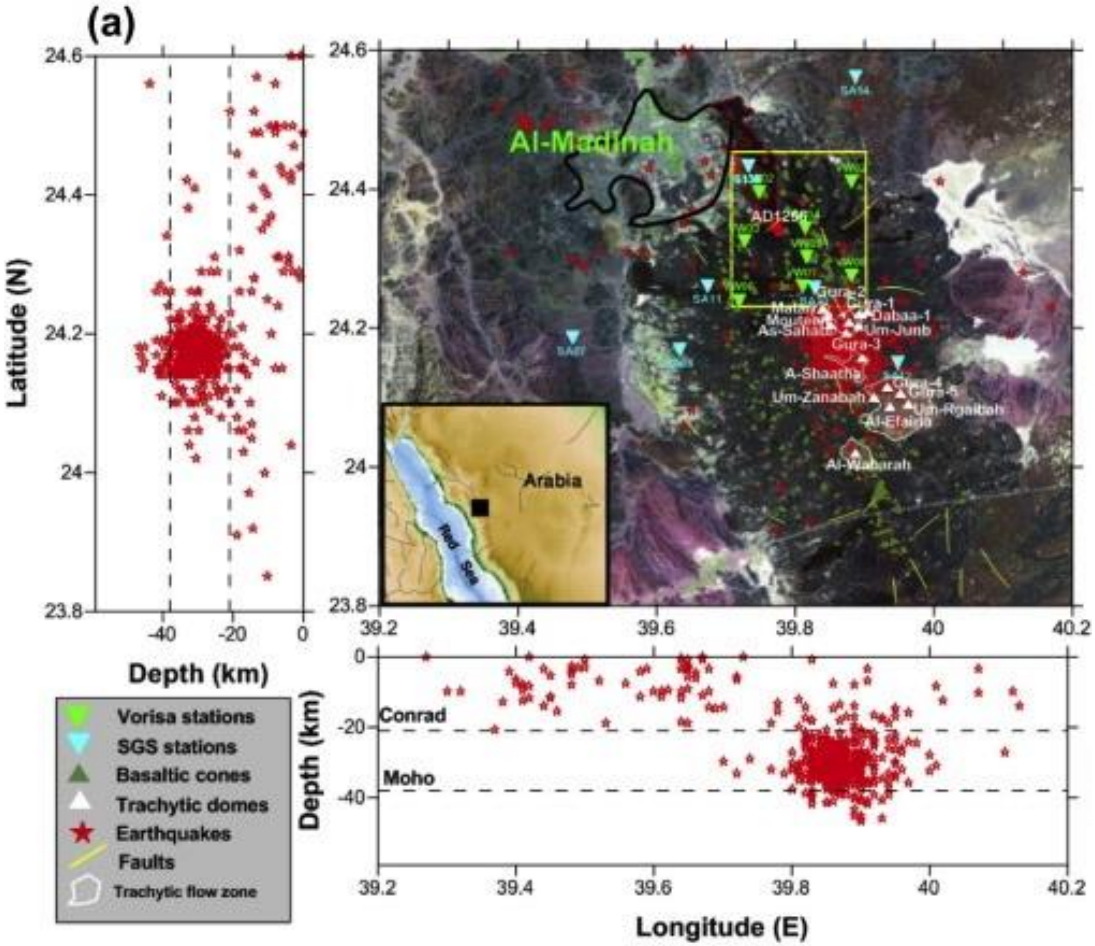


Results and conclusions

- Harrat Rahat is a potential geothermal resource
  - High heat flow
  - Near to populated area
  - Permeability is unclear
- Seismological tools
  - Signal processing yielded more events but insufficient for improved maps
  - Interferometry capable of mapping low velocities associated with volcanism
- Basement faults
  - Appear to influence volcanism and seismicity
  - Current mapping indicates correlation with NE trending faults
- Permeability?
  - Based on analogous field, look for intersection of fault trends
  - Basement fault trends B and D may be the best place for future investigation

Backup slide: 1999 swarm

- Significant swarm
- Poor control on depth
- Tomography indicates low velocities under volcanic area



From Abdelwahed et al., 2016