Thermal regime of the Arabian plate, Red Sea and Gulf of Aden

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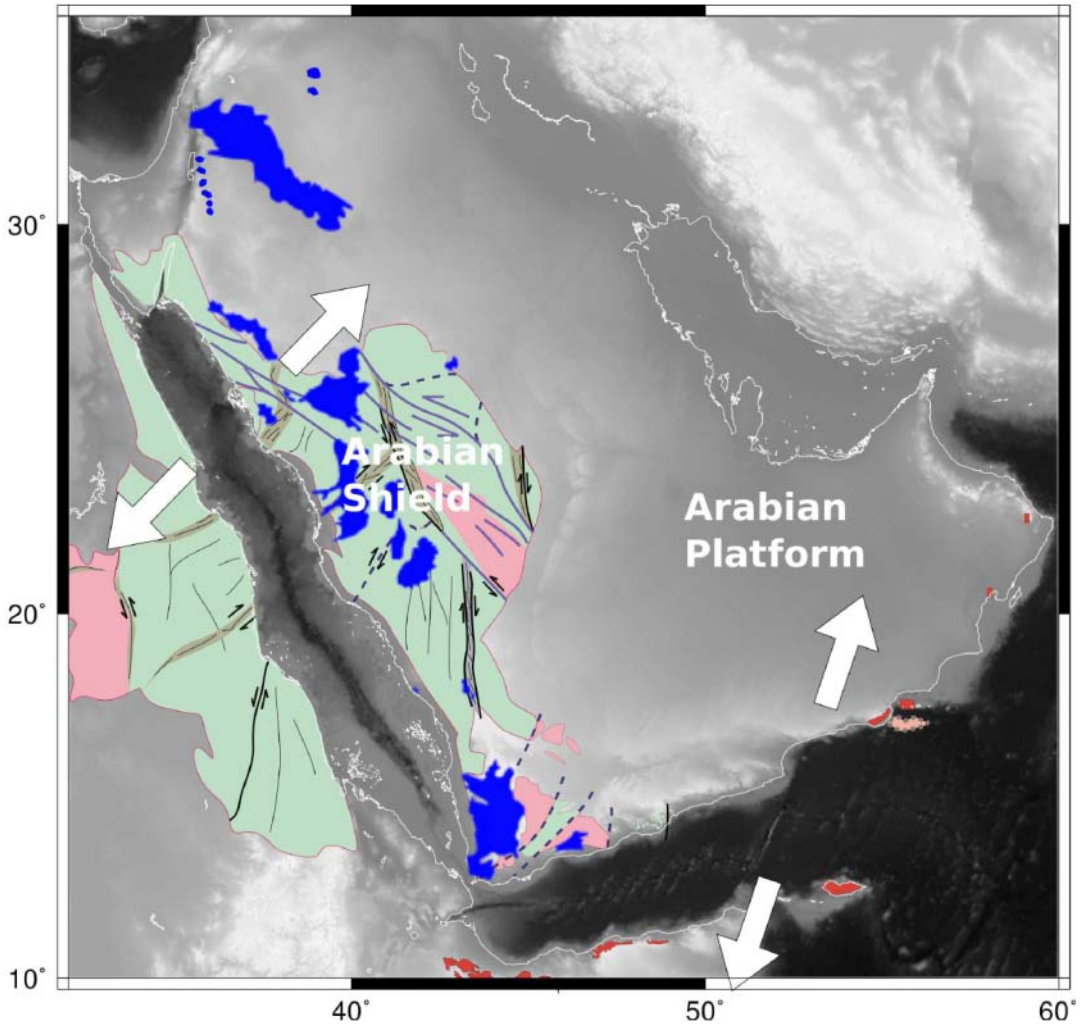
Proterozoic Shield and Paleozoic Platform
Rifting and Volcanism since Oligocene

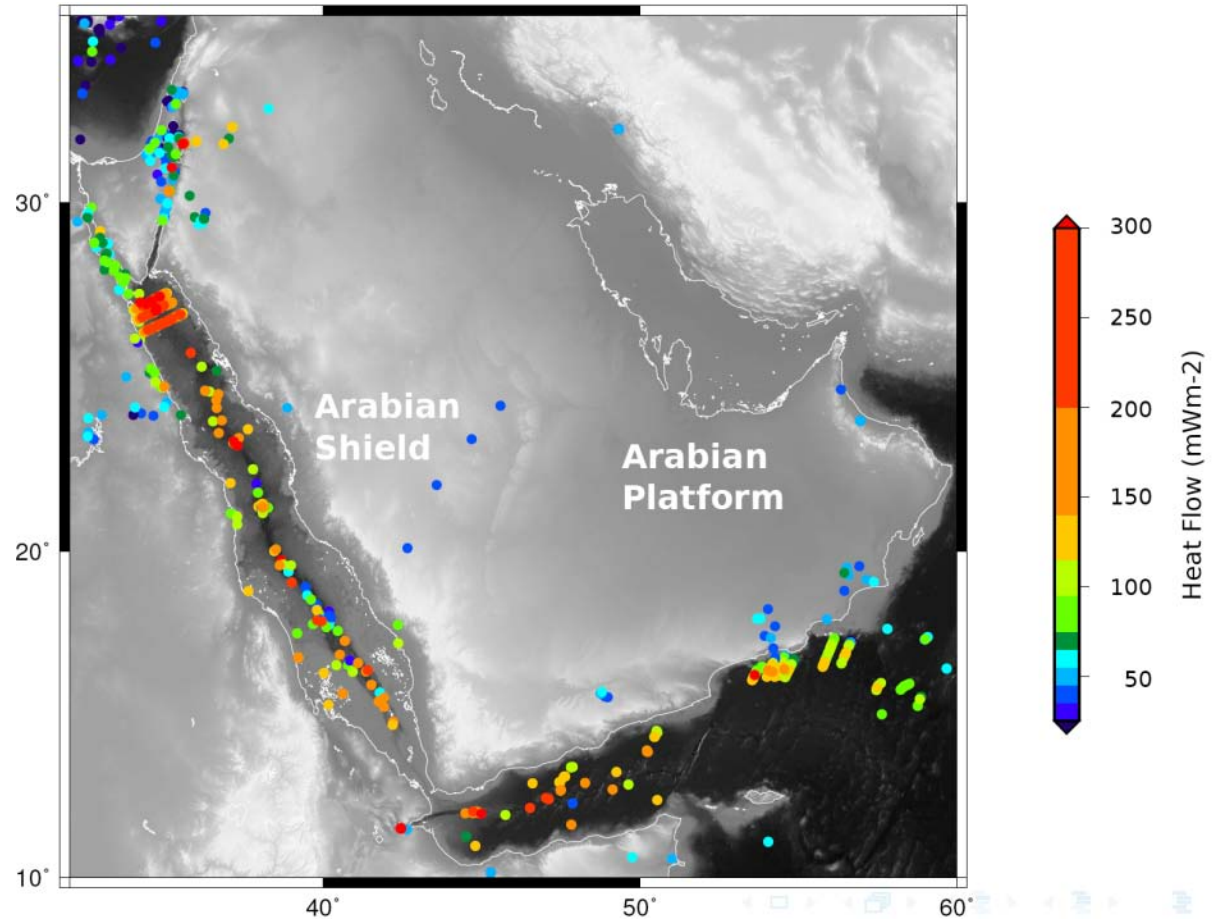


- Proterozoic shields are generally regions of thick lithosphere and low heat-flow.
- In the specific context of Arabia, rifting and plume impingement have affected strongly the mantle.

. How does that affect the thermal regime of the Arabian plate?

- How far into the plate?

Compilation of existing Heat Flow data

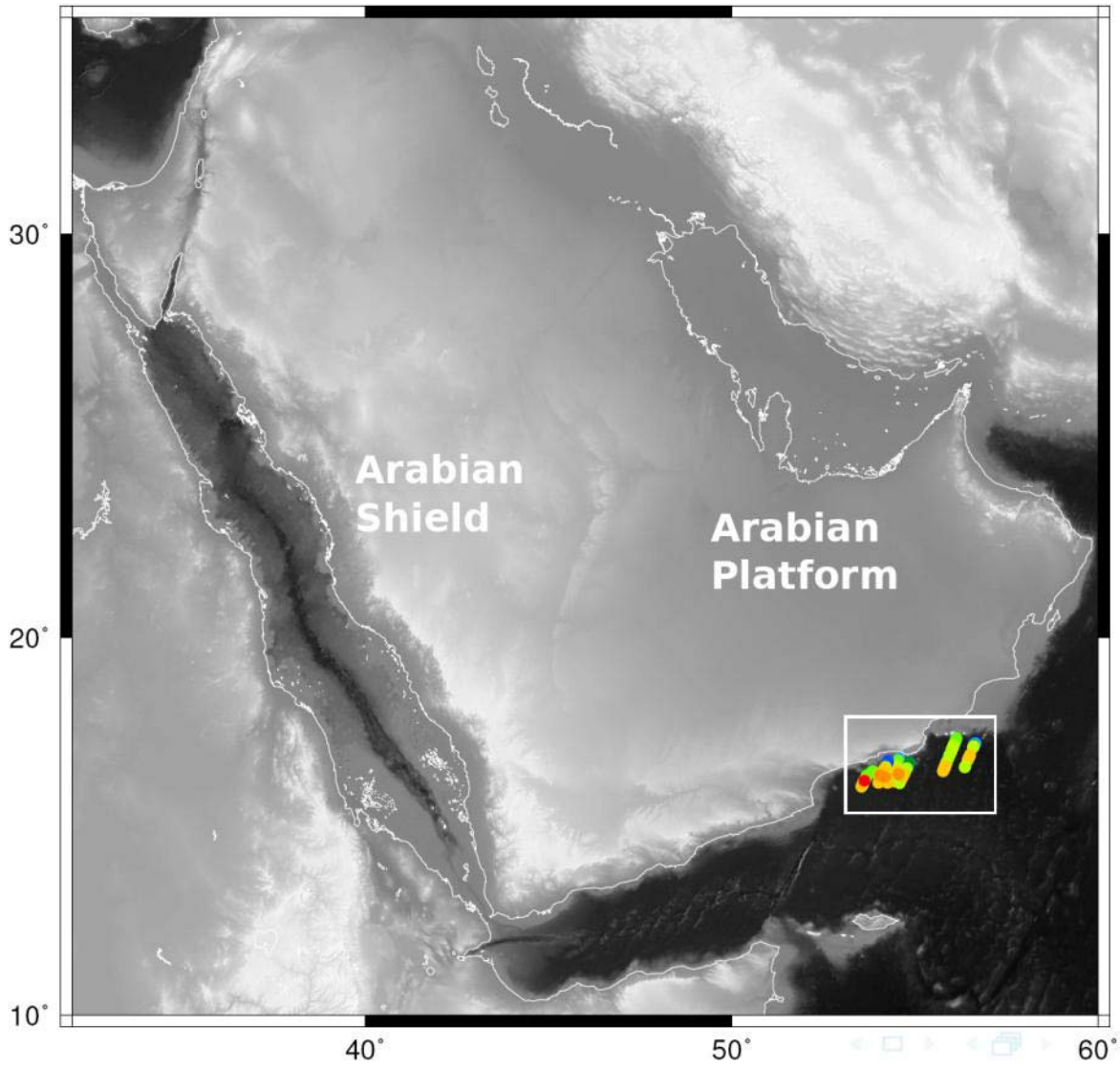


- Heat-Flow can provide some answers in addition to other geophysical studies.

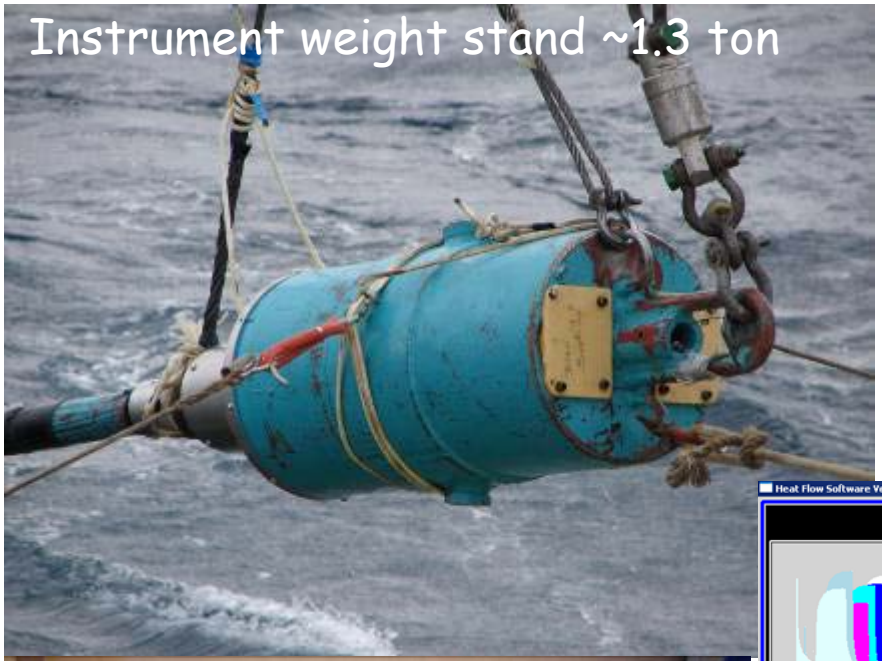
- New HF measurements:
  - in the Eastern Gulf of Aden
  - in Yemen and Oman

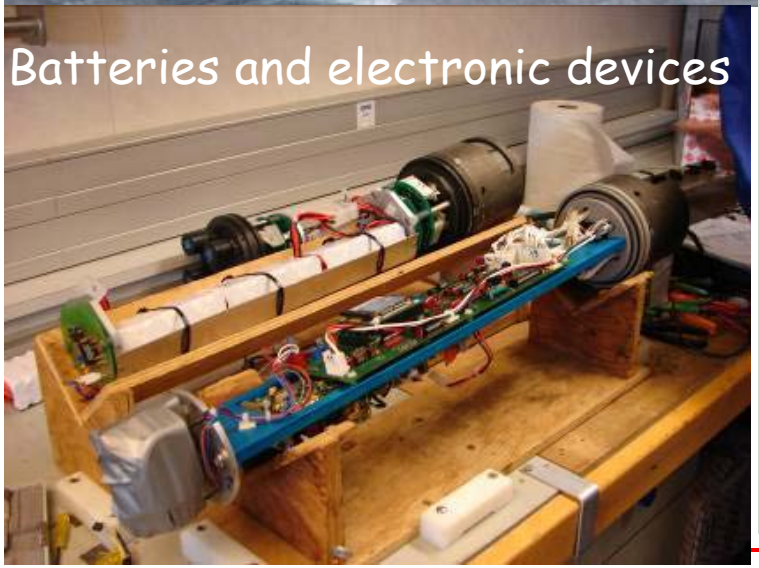
- and discuss previous data in the Northern Red Sea, Saudi Arabia and Jordan.

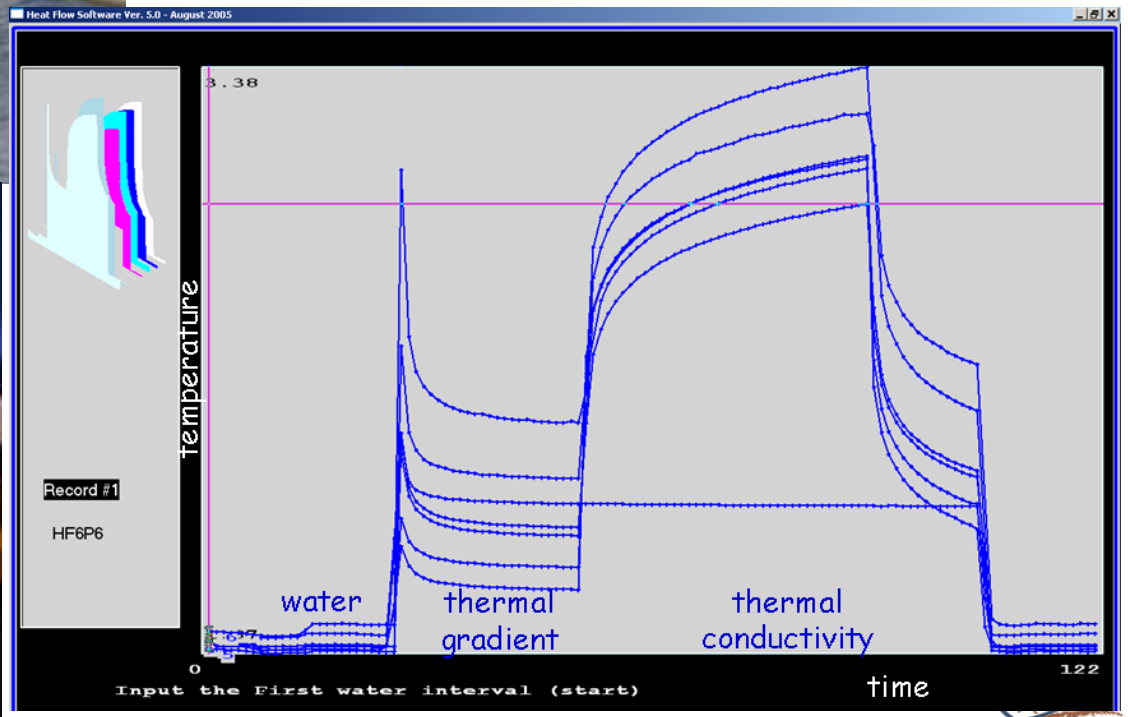
ENCENS-flux survey (Lucazeau et al., 2010)



Marine heat-flow from measurements

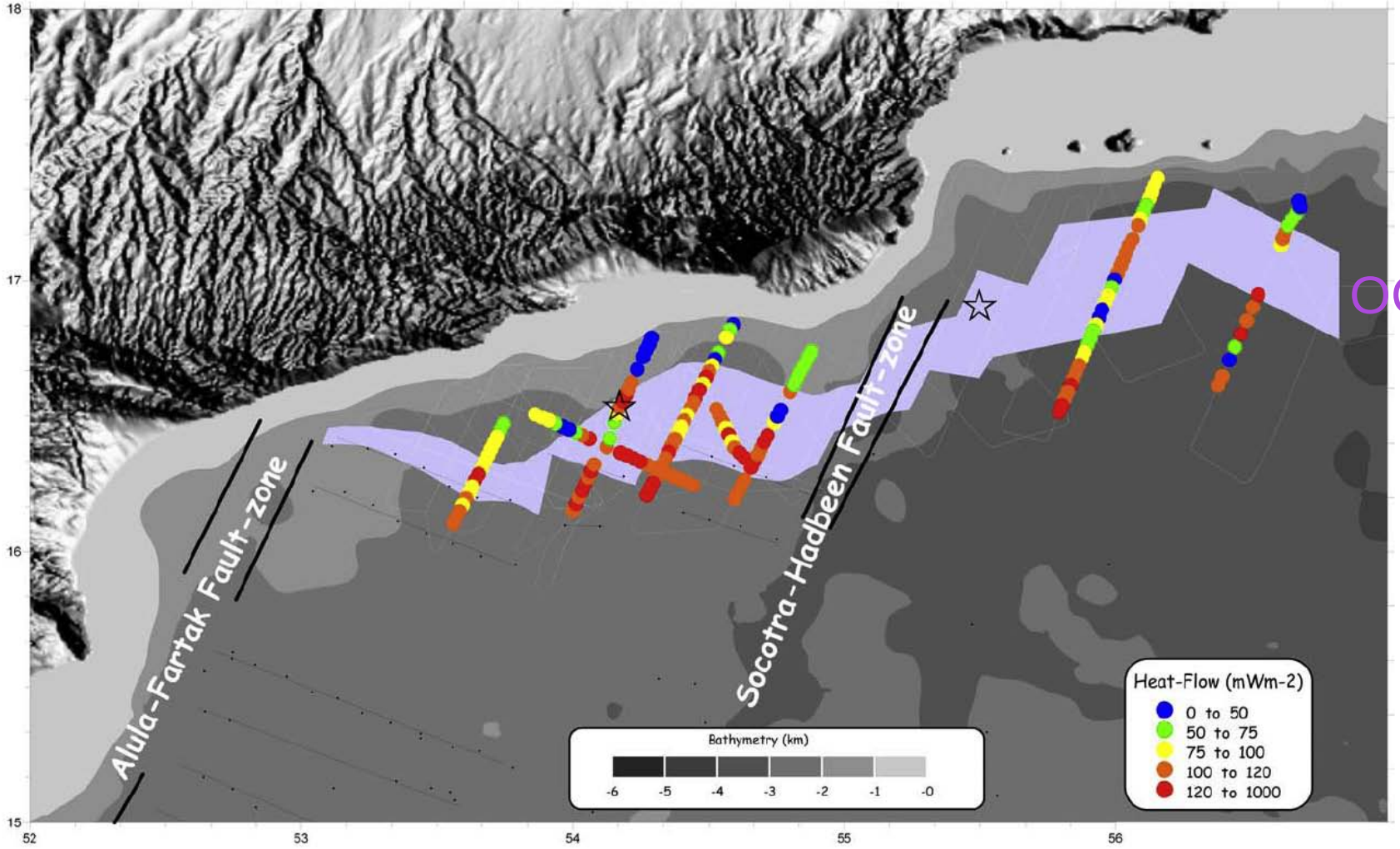






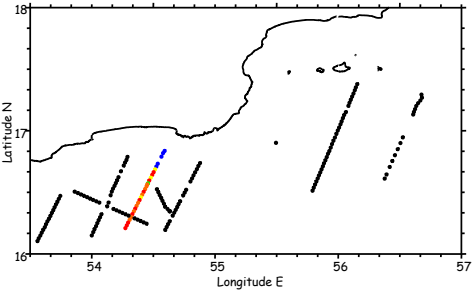
Encens-Flux Survey

162 new heat-flow measurements in the Eastern Gulf of Aden along multichannel seismic profiles.

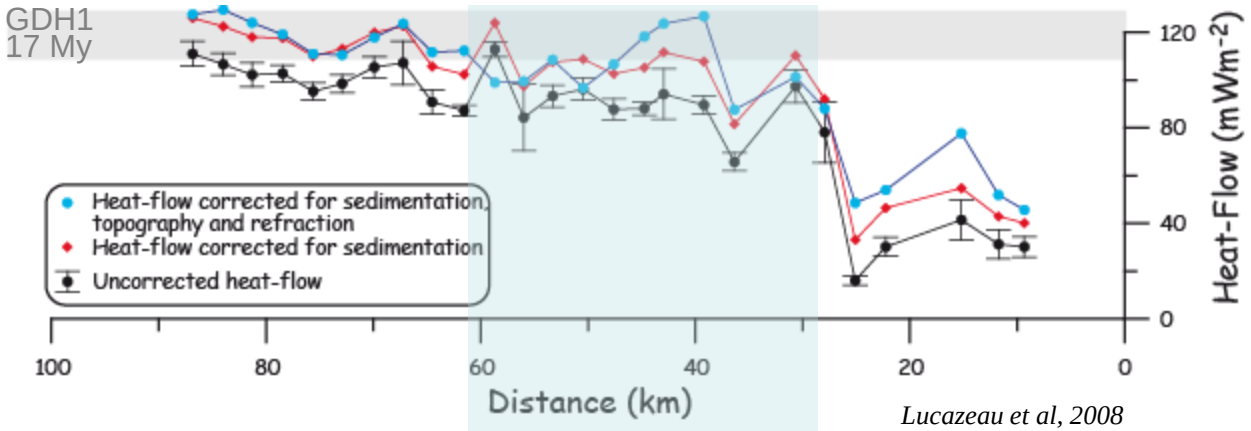


Large scale and small scale variations of heat flow?

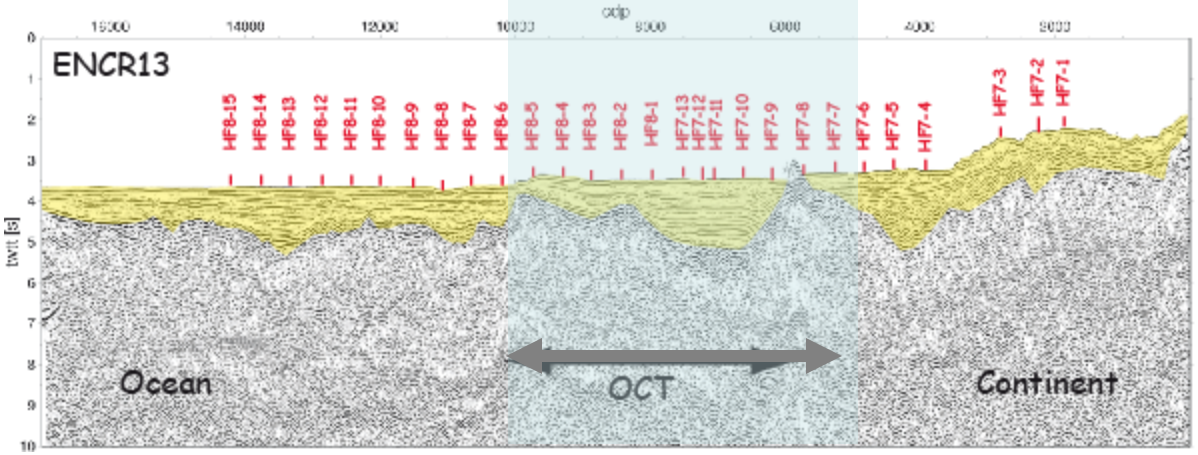
Large scale thermal state



Profile ENCR13



Lucazeau et al, 2008

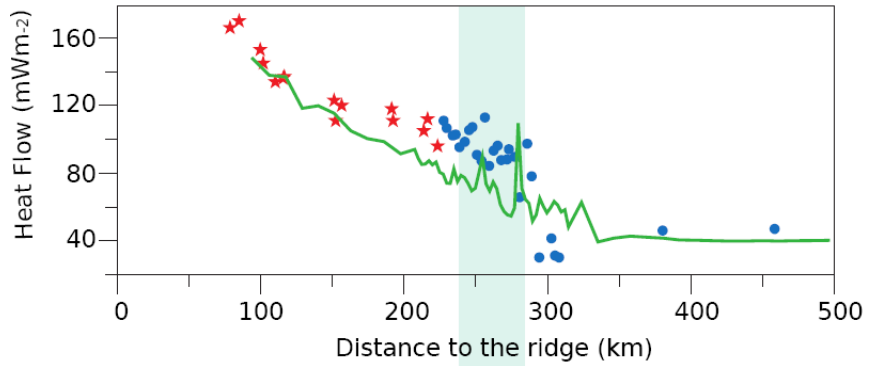


=> At the margin scale, heat-flow is high (100-120 mWm^{-2}) in the ocean and in the OCT, and low (45-65 mWm^{-2}) near the continental slope with an abrupt transition.

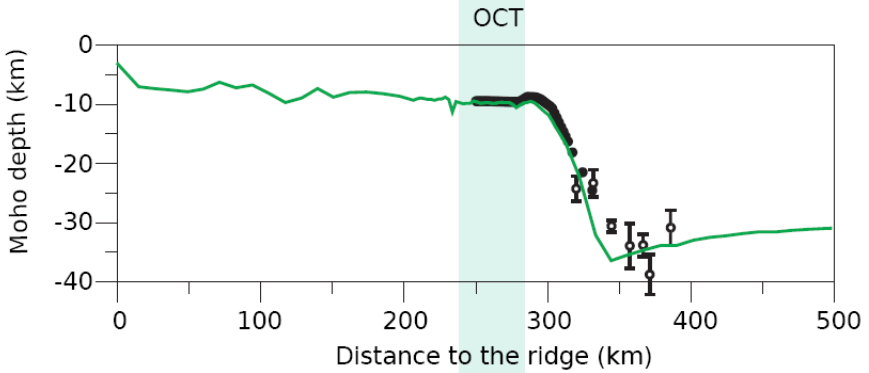
=> How this is related to the margin dynamic?

Large scale thermal state : modeling results

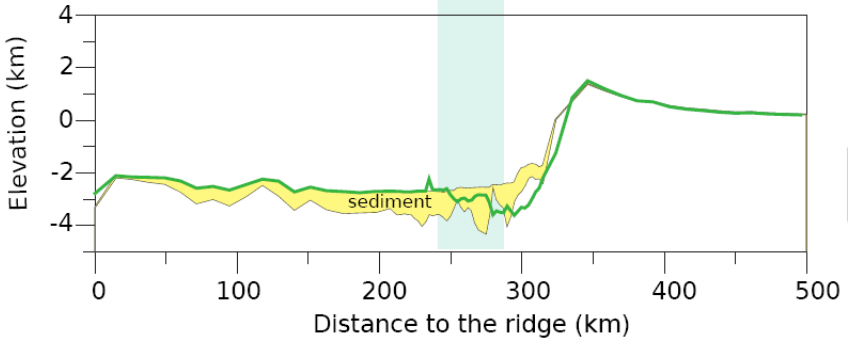
2D thermo-kinematic to model the thermal evolution of a passive margin.



Uncorrected Heat-Flow
ENCENS-FLUX
Cochran, 1981

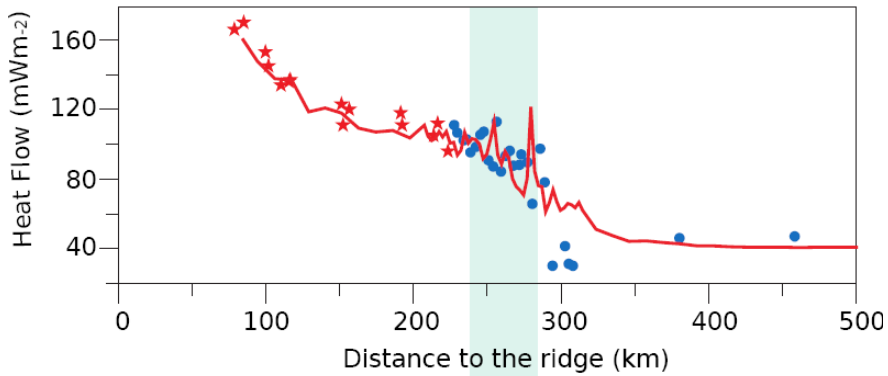


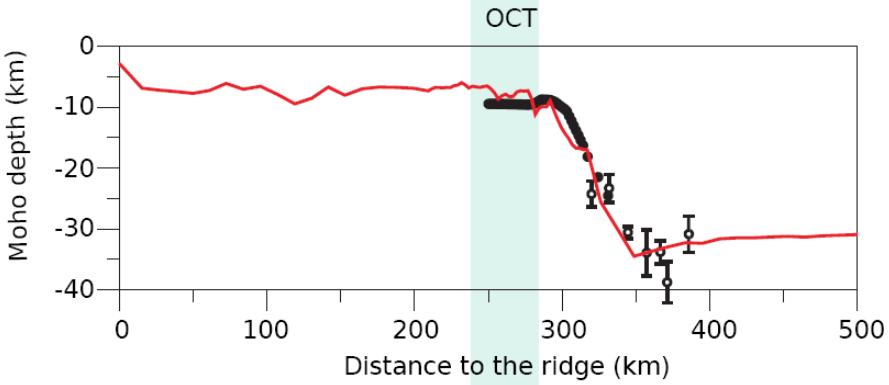
Refraction sismology
Receiver functions

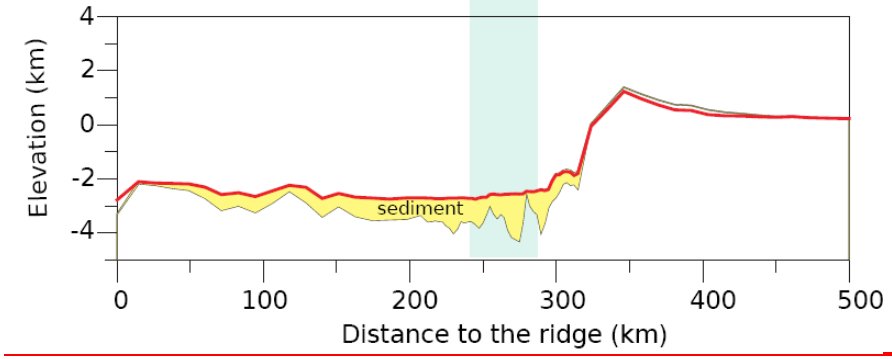


Homogeneous thinning + thermal relaxation

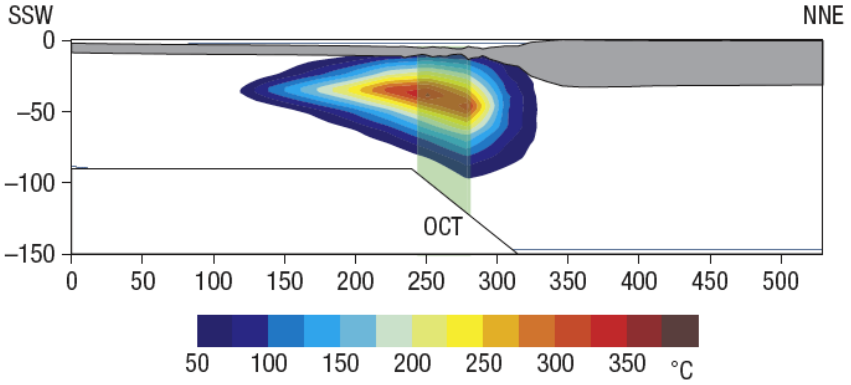
Large scale thermal state : modeling results







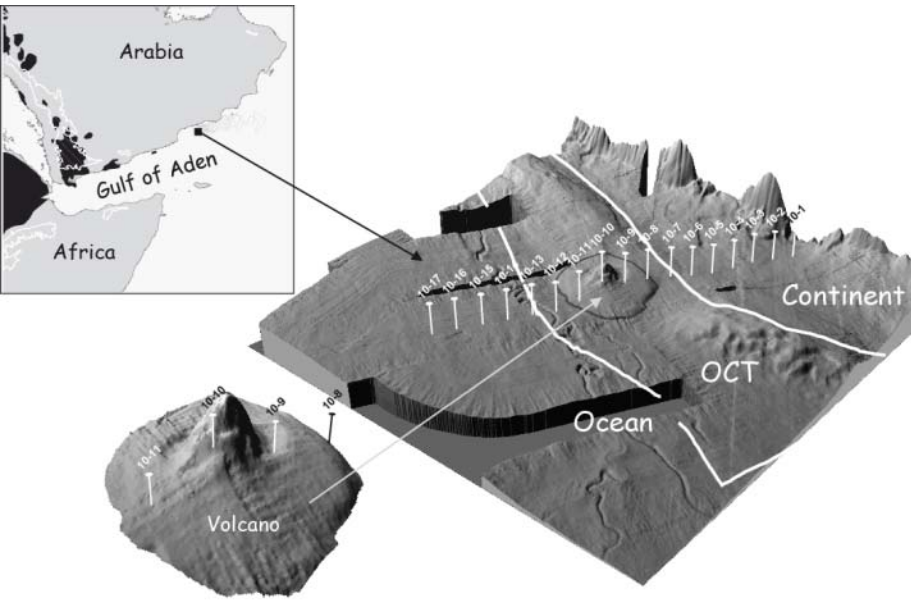
Best model with a thermal anomaly in the mantle which is maintained during the post-rift

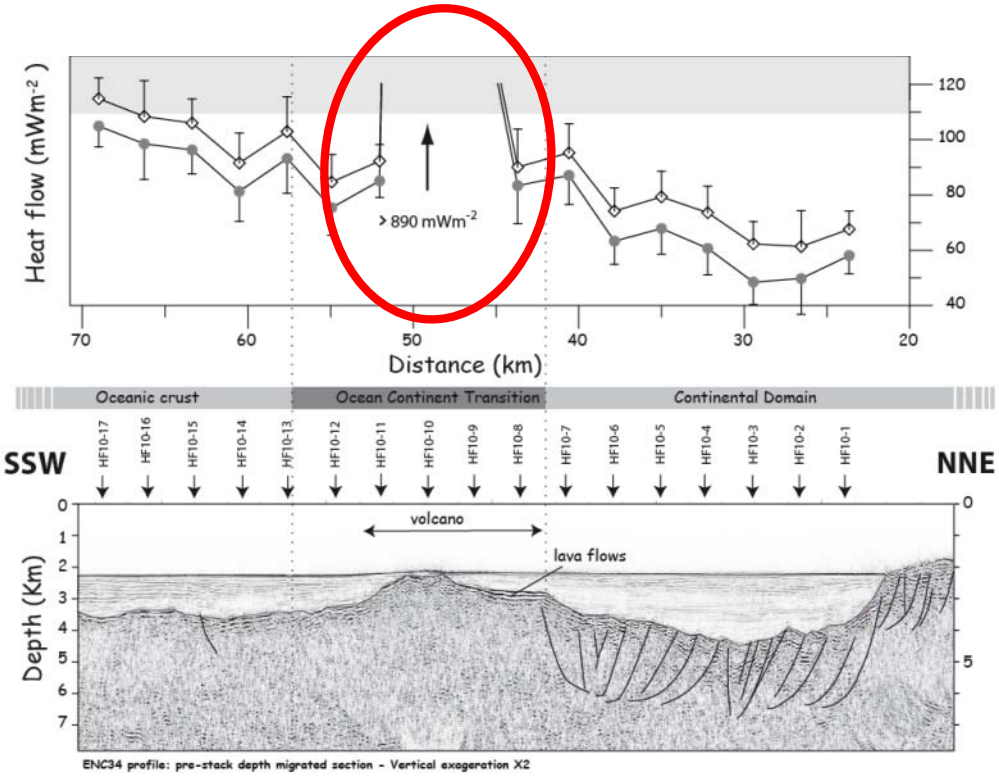


=> Small-scale convection that occurred during and after rifting.

Small scale thermal variations

Small scale anomaly at the OCT: evidence of magmatism?





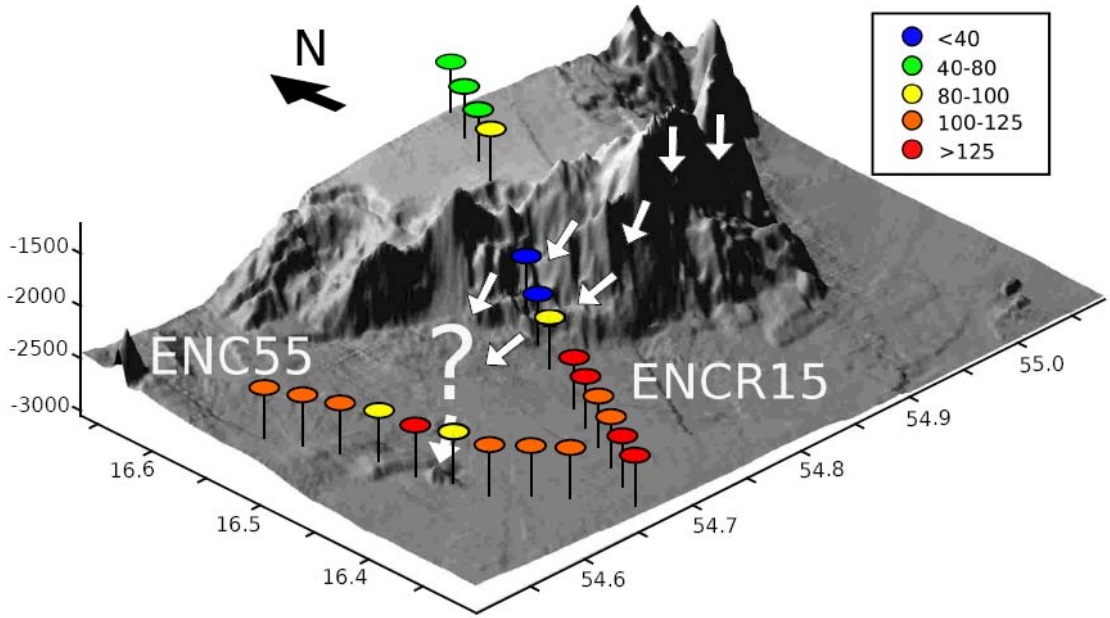
Lucazeau et al, 2009

=> High heat-flow (~900 mWm^{-2}) at the OCT implies that the latest activity of the volcano was about 100,000 years old and therefore continued at least ~18 Ma after the break-up of Africa and Arabia.

=> Related to channeling of the Afar plume (Leroy et al., 2010).

Small scale thermal variations

Small scale anomaly at the OCT: evidence of fluid circulations?



Fluid circulations affect only area around the basement exposures.

=> Circulations of fluids are limited.
Where sediments seal the structure, there is no effect.

A post-rift activity in the distal margin

At large scale, heat flow is characterized by:

- An abrupt change at the transition between the continent and the OCT
- The anomalous heat-flow in the OCT cannot be explained by thermal relaxation

=> small-scale convection at depth.

At small scale, heat flow anomalies are explained by:

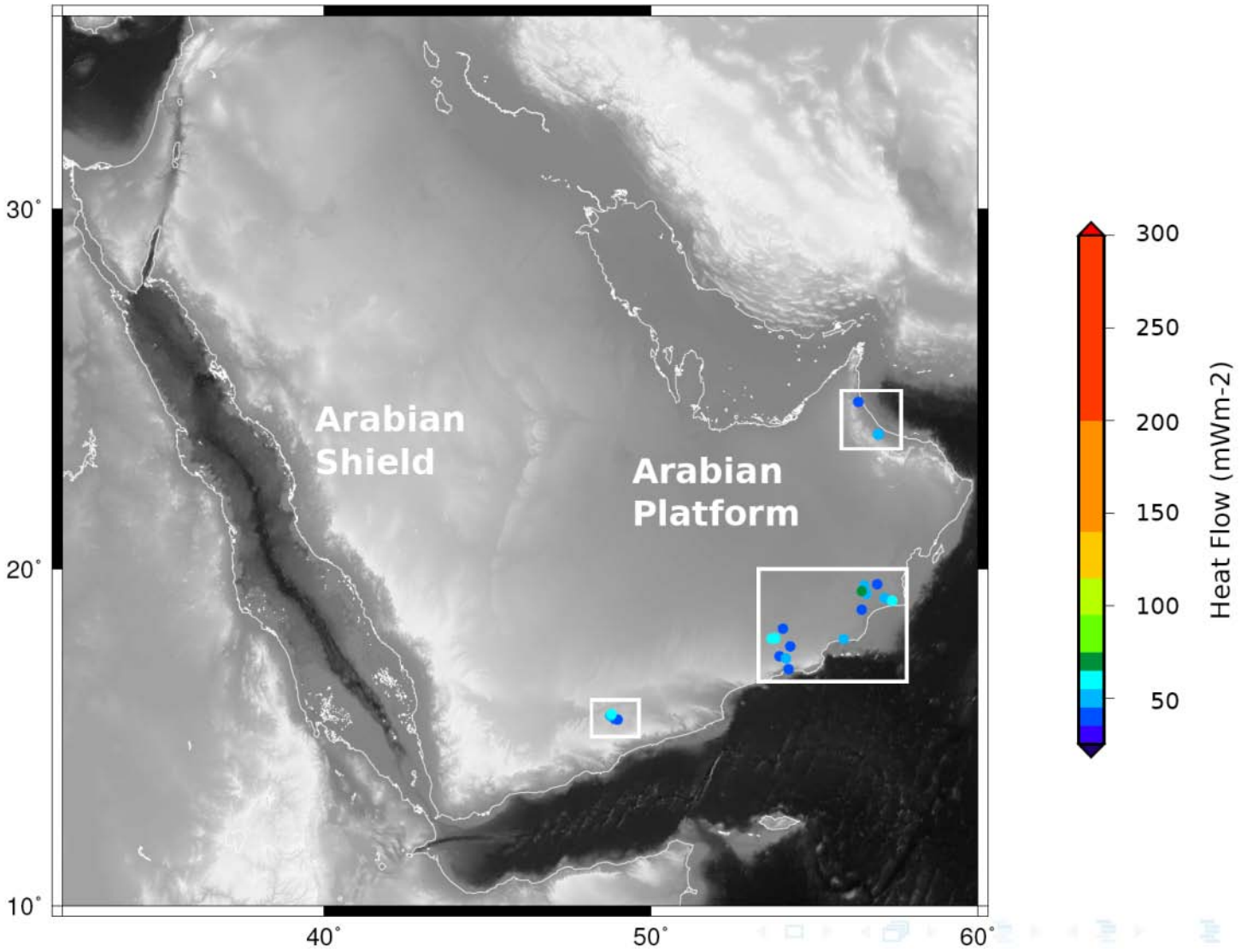
- A recent magmatic activity
- Limited fluid circulations.

Main consequence:

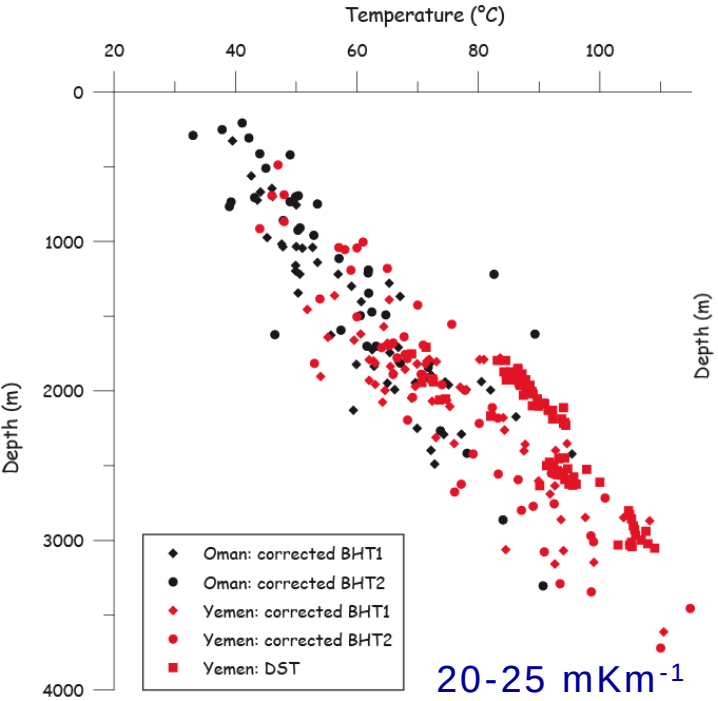
- Persistent thermal anomaly and magmatic activity during Post-rift.

=> Is the continental domain of the Arabian plate affected by rifting?

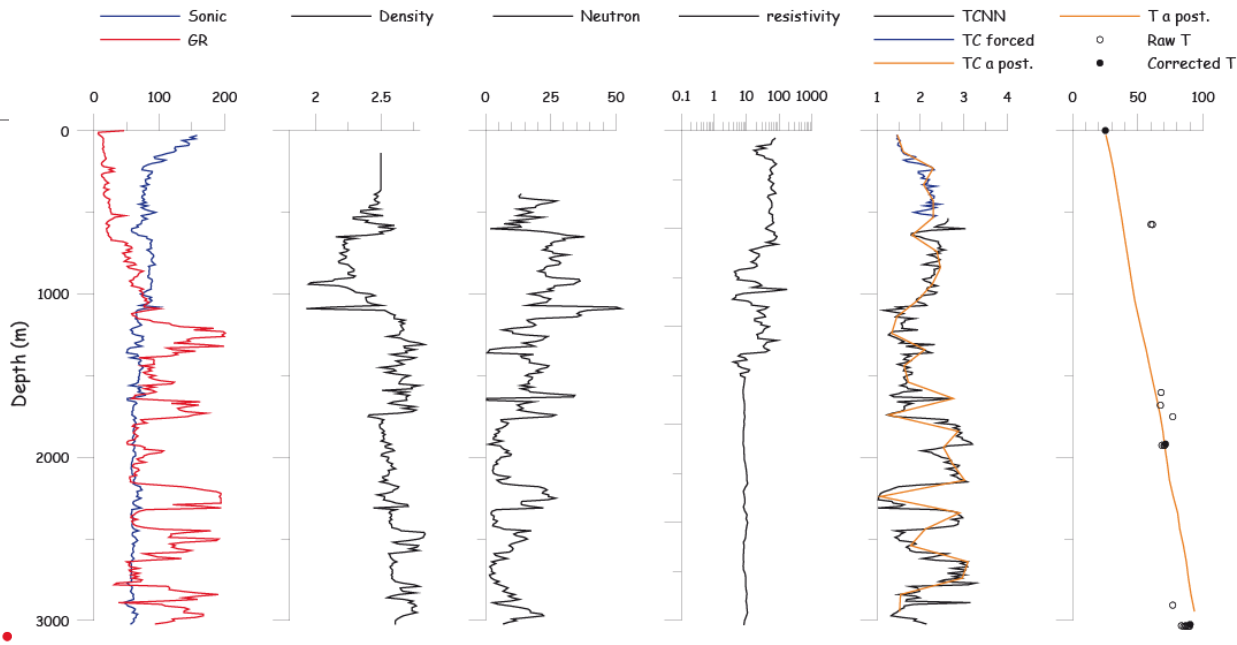
Continental Heat flow survey



Heat flow from oil exploration



20-25 mKm^{-1}



1.8-2.2 $Wm^{-1}K^{-1}$

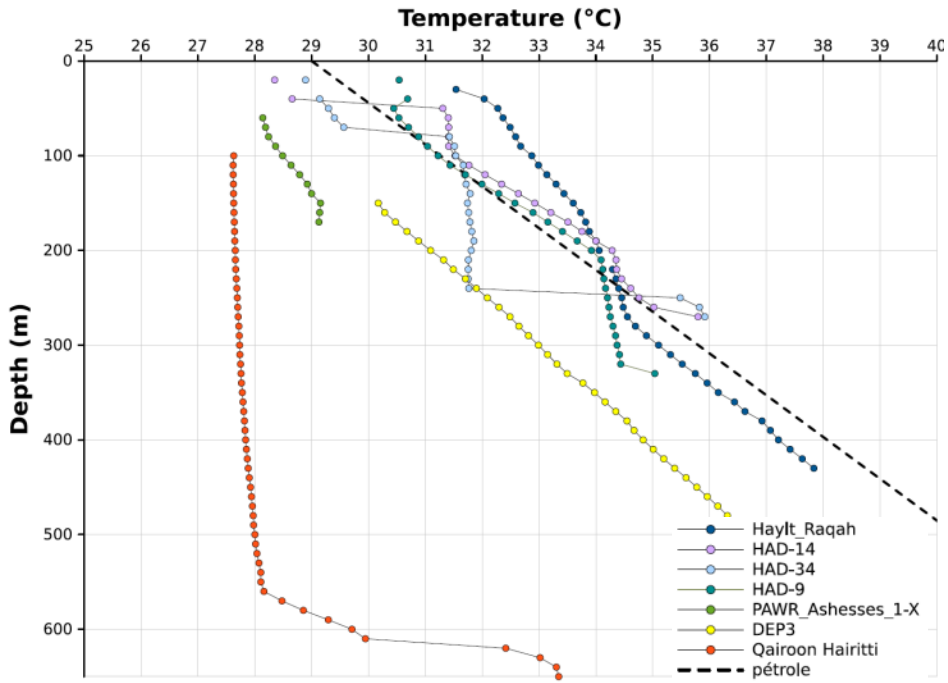
Oil Wells

11 wells in Yemen: 45 ± 6 mWm^{-2}

9 wells in Dhofar: 46 ± 4 mWm^{-2}

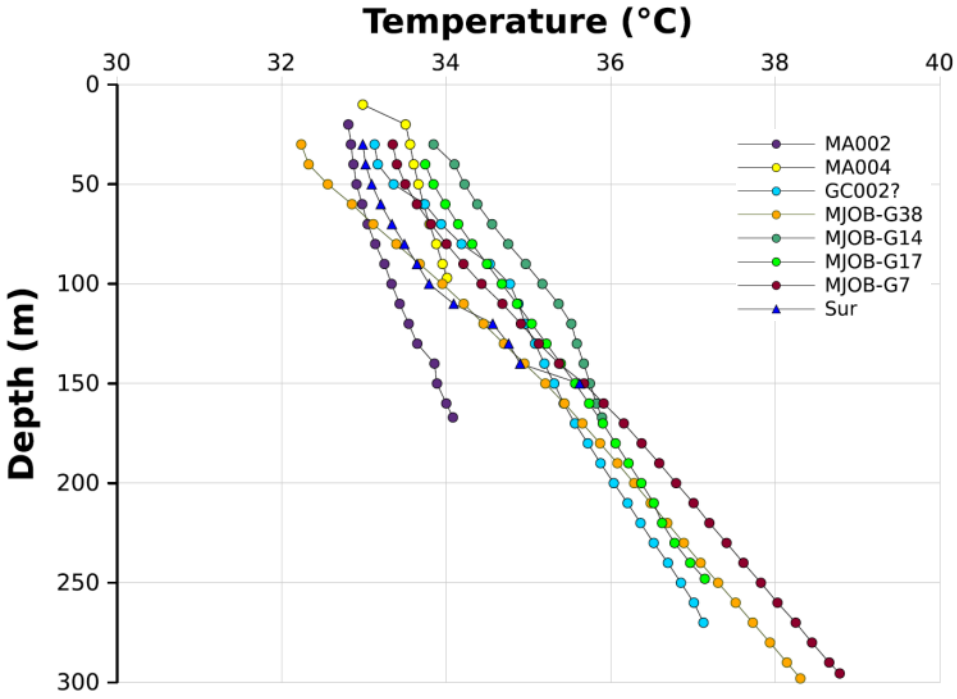
Heat flow measurements

Water wells in Dhofar



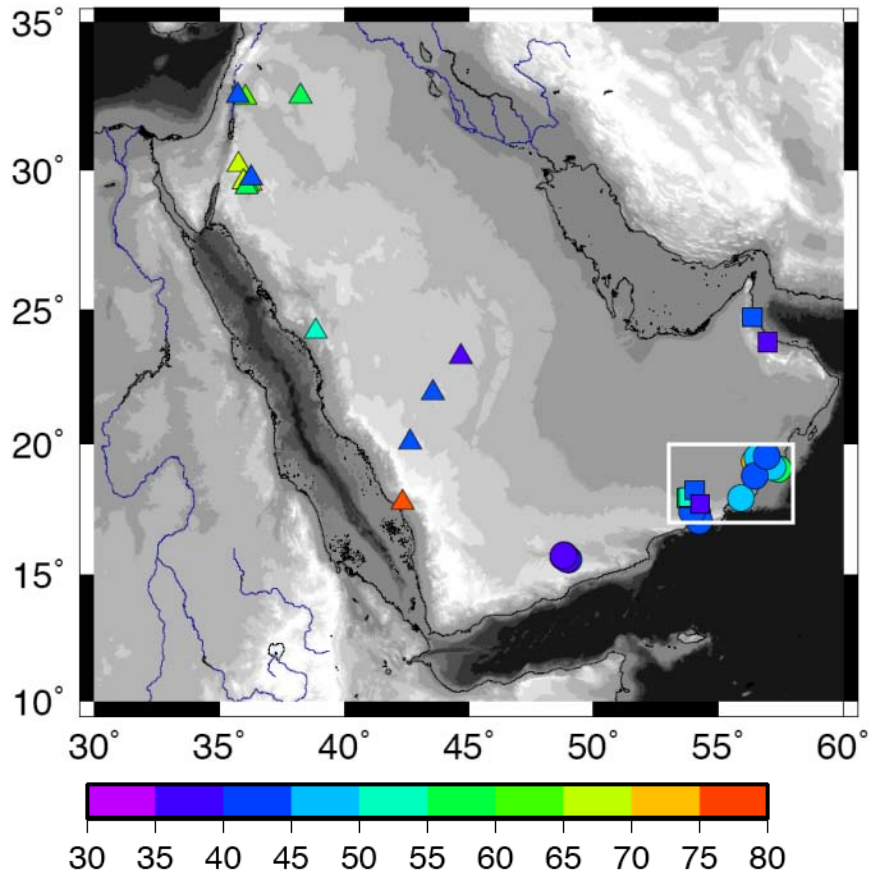
Water Wells (Dhofar)
sometimes perturbed by pumping tests
otherwise 45 ± 6 mWm^{-2}

Mining wells in northen Oman



Mining wells (Ophiolite)
44 ± 4 mWm^{-2}

Heat Flow in Arabia



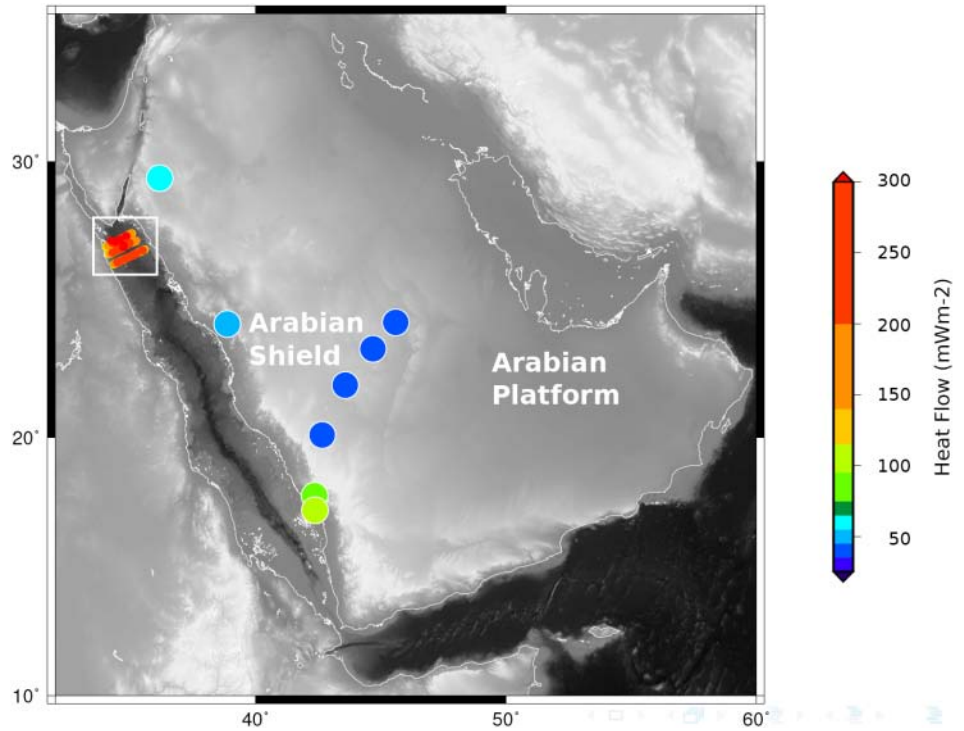
Very homogeneous low HF in the AP: 45 mWm^{-2}

The continental domain is not affected by rifting in the Gulf of Aden and oceanic accretion

Heat-flow data from Saudi Arabia (Gettings, 1981) are similar to HF in the AP.

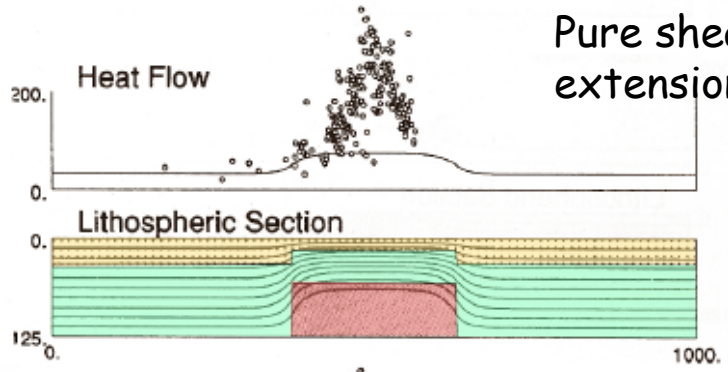
Forster et al. (2007, 2009) find higher values in Jordan: 60 mWm^{-2}.

Heat flow in the Northern Red Sea

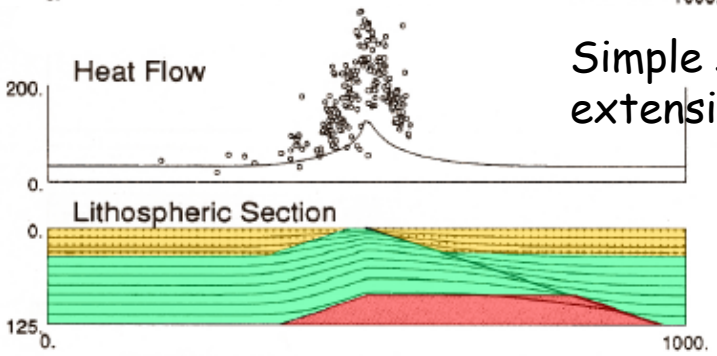


(Martinez & Cochran, 1989)

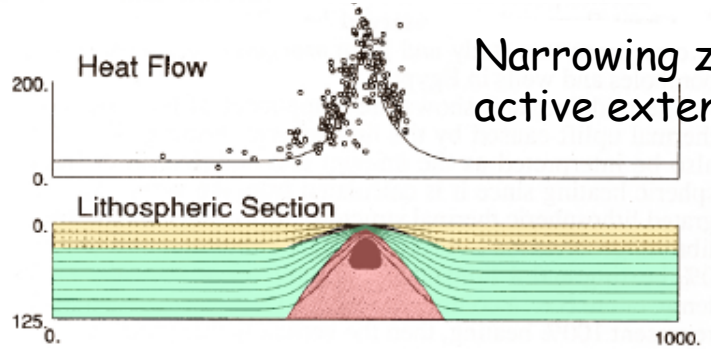
⇒Active mantle involved.
⇒ Continental domain is affected.



Pure shear extension.



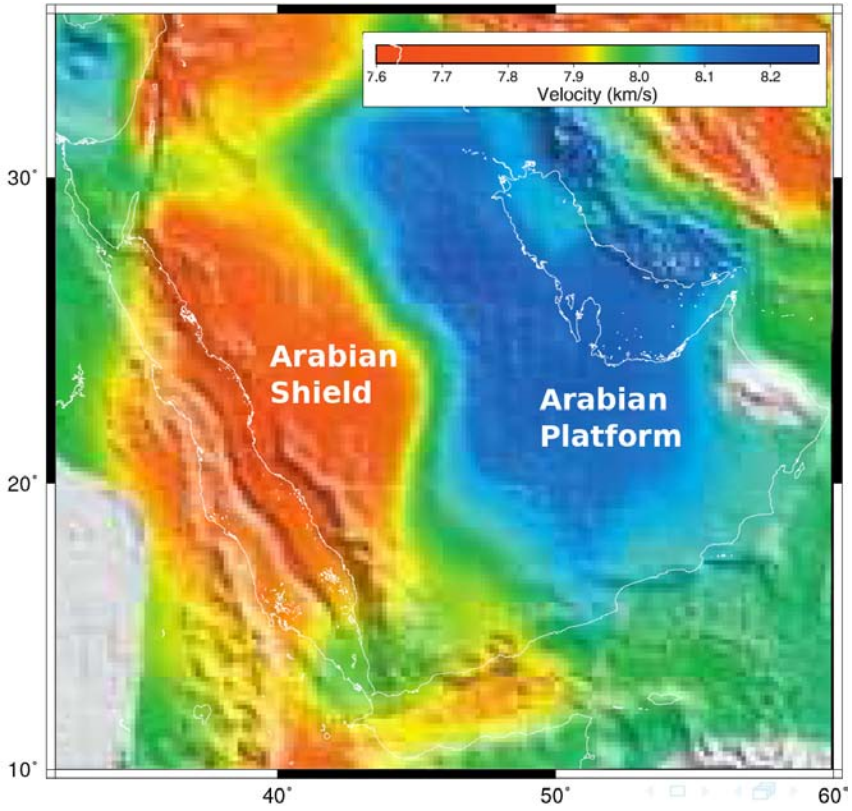
Simple shear extension.



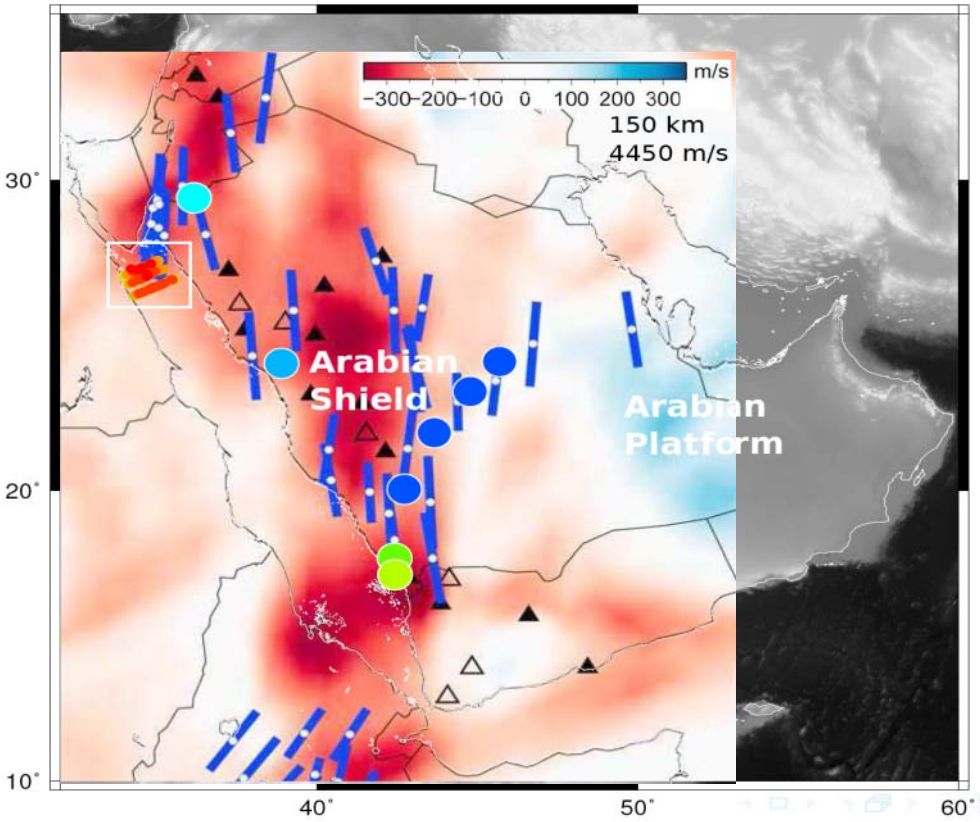
Narrowing zone of active extension.

Relations between surface HF and deep structures imaged by seismology

(P waves tomography; Phillips et al., 2007)



(S waves tomography; Chang et al., 2011)

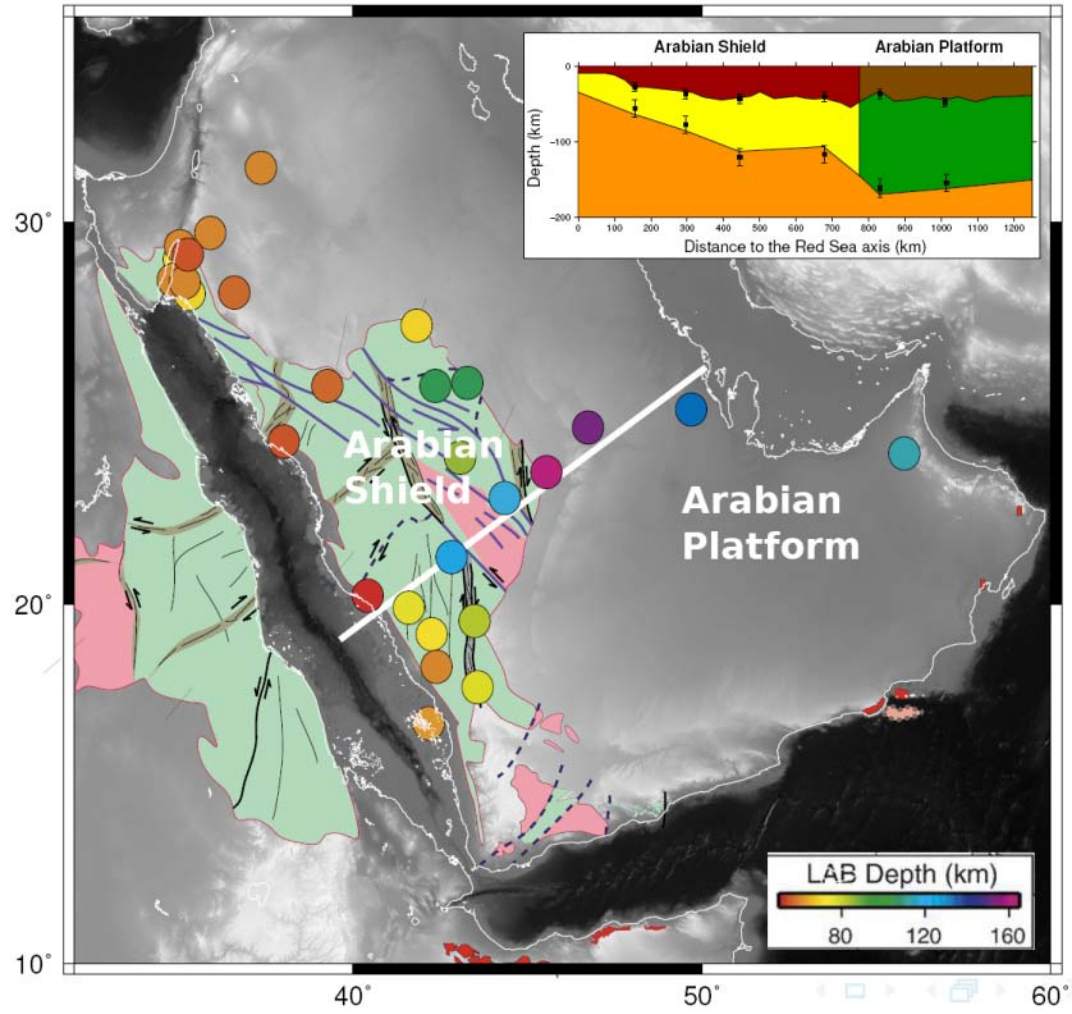


- Strong contrast between AS and AP
- Lateral influence of the thermal anomaly around the Red Sea.

- Mantle flow from Afar channeled beneath the Gulf of Aden and Arabia
- Low-velocity beneath Jordan.

=> Good correlation with HF

LAB depth from receiver functions

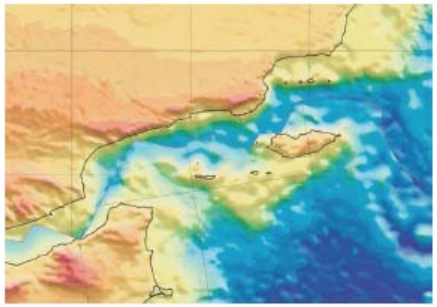


(Hansen et al., 2007)

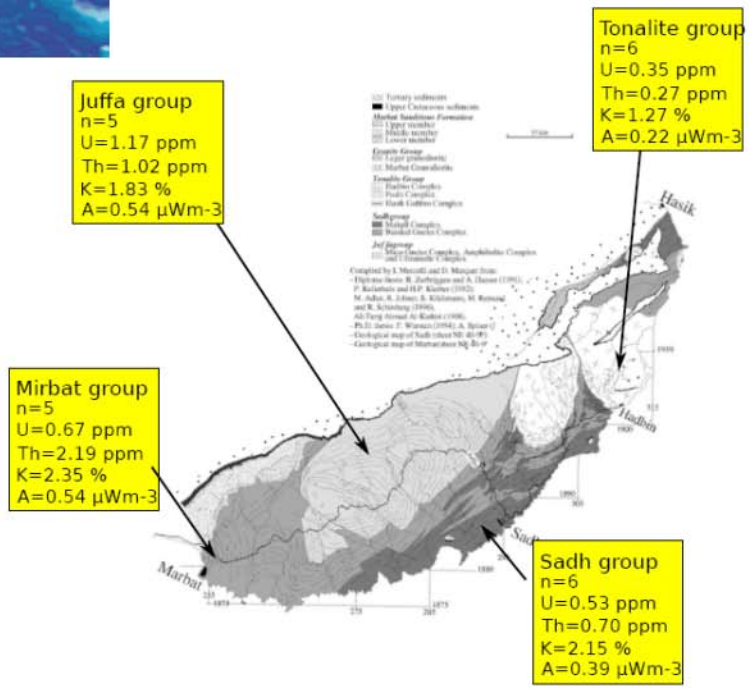
•LAB near the coast at 50 km and deepens to reach 120 km beneath the AS and 160 km beneath the AP

=> To derive the lithospheric thickness from our HF values, we need to constrain the crustal heat production.

Heat-Production within the Arabian Platform

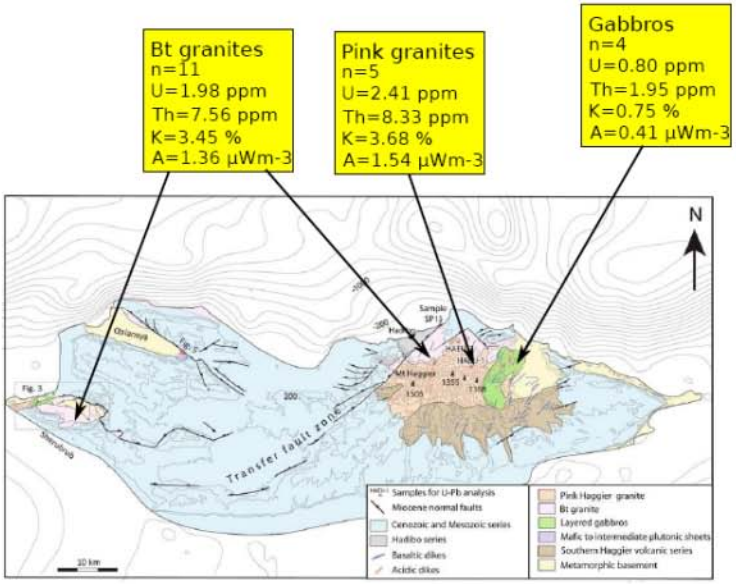


Mirbat



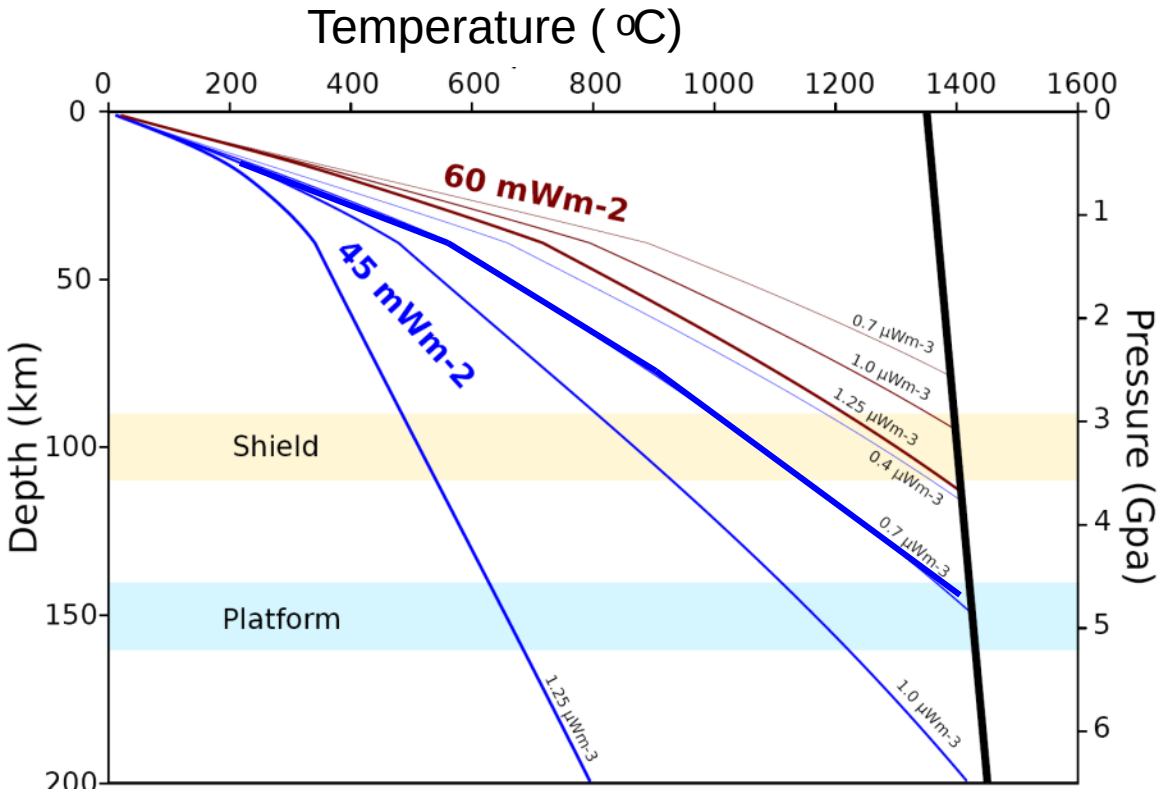
Socotra

(Denèle et al., 2011)



Upper crustal heat production in the AP:
60-70% Mirbat + 30-40% Socotra = 0.6-0.8 μWm^{-3}.

Calculated geotherms



Arabian Platform: low Heat-Flow (45 mWm^{-2}) and low heat production (0.7 μWm^{-3}) leads to a LAB depth of 150 km.
Arabian Shield: higher Heat-Flow (60 mWm^{-2}) but higher heat production (1.25 μWm^{-3}) leads to a LAB depth of 110 km.

Conclusions

•Heat-Flow in the Arabian Platform (45 mWm^{-2}) lower than in the Arabian Shield (60 mWm^{-2}).

•Heat-production in the Arabian Platform (0.7 μWm^{-3}) lower than in the Arabian Shield (1.25 μWm^{-3}).

•These differences may explain the thicker lithosphere in the Arabian Platform.

•In the Gulf of Aden, the transition from high to low Heat-Flow occurs at the limit between the OCT and the continental margin. The continental domain is not affected by rifting.

•In the Red Sea, this transition occurs below the Arabian plate and is probably related to the channeling of the Afar plume to the North.

• Perspectives: heat flow measurements in Ethiopia.