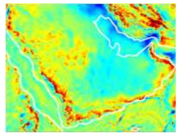


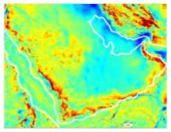
The application of GOCE gravity data for basin and petroleum system analysis

A case-study from the Arabian Peninsula

Rader Abdul Fattah, S. Meekes, S. Colella *(TNO)*
J. Bouman, M. Schmidt *(DGFI)*
J. Ebbing *(NGU)*
R. Haagmans *(ESA)*

TNO innovation for life

DGFI NGU esa



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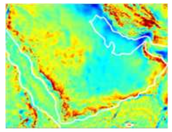
The use of GOCE gravity data for hydrocarbon exploration

GOCE+ GeoExplore

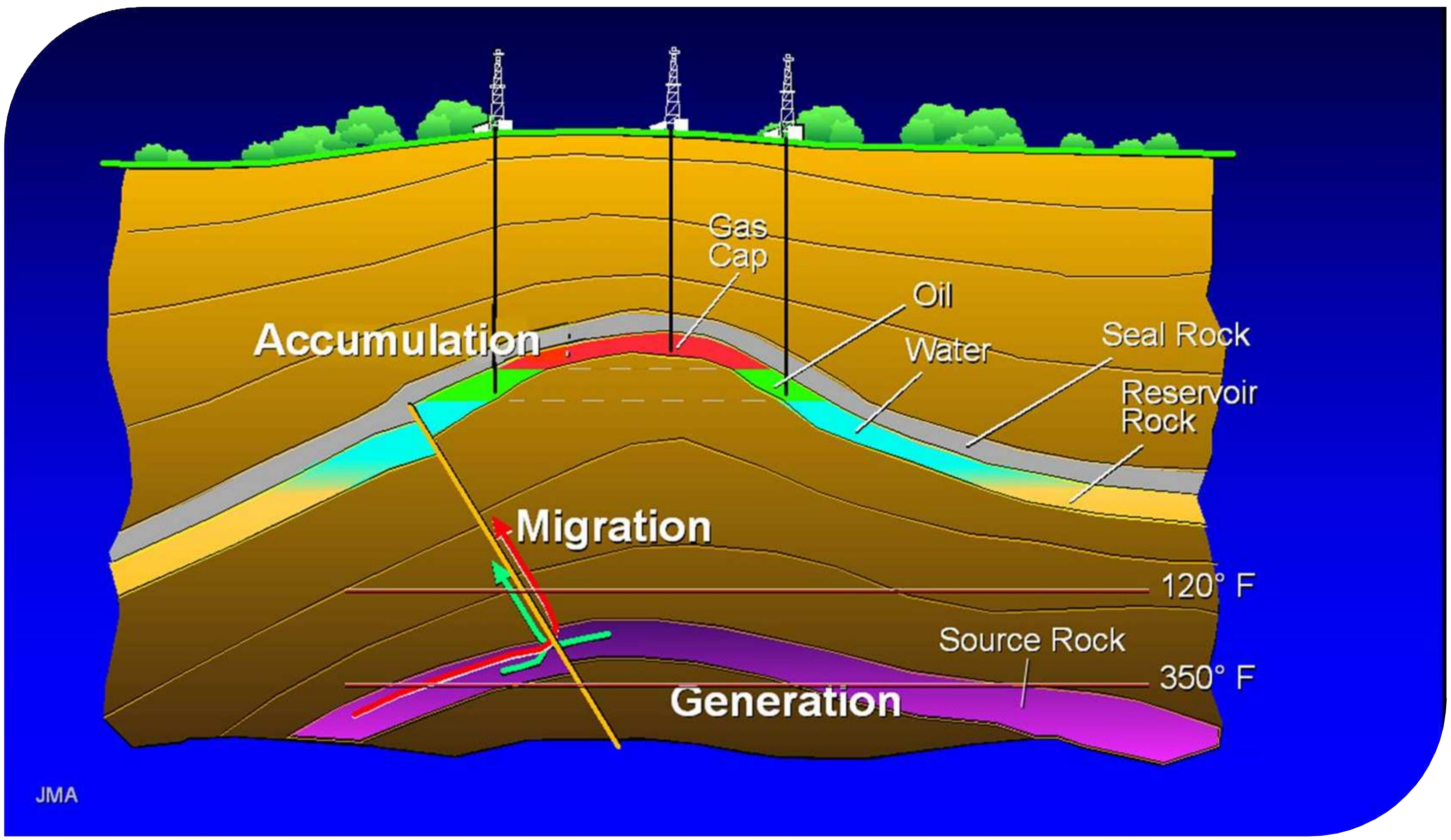
GOCE gravity data may provide improved models of the crust and lithosphere

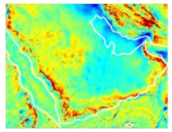
Better understanding of the evolution of the thermal system in the basin

Prospectivity of the basin: areas where hydrocarbons are likely to be generated

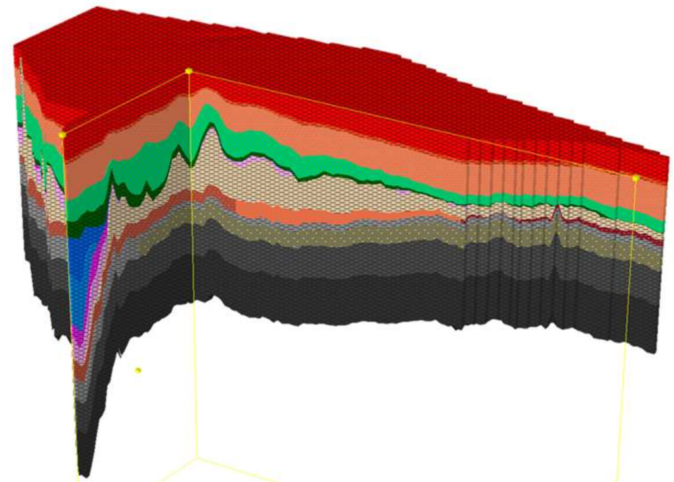


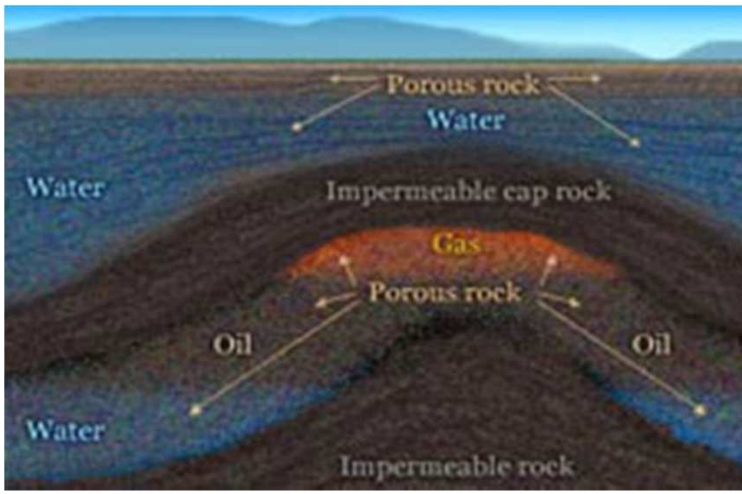
- Generation of hydrocarbons

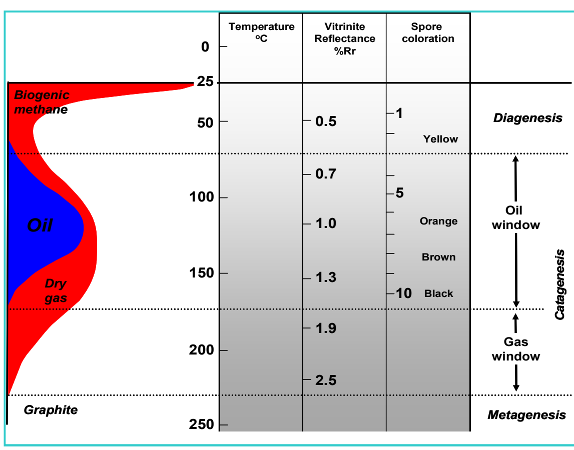


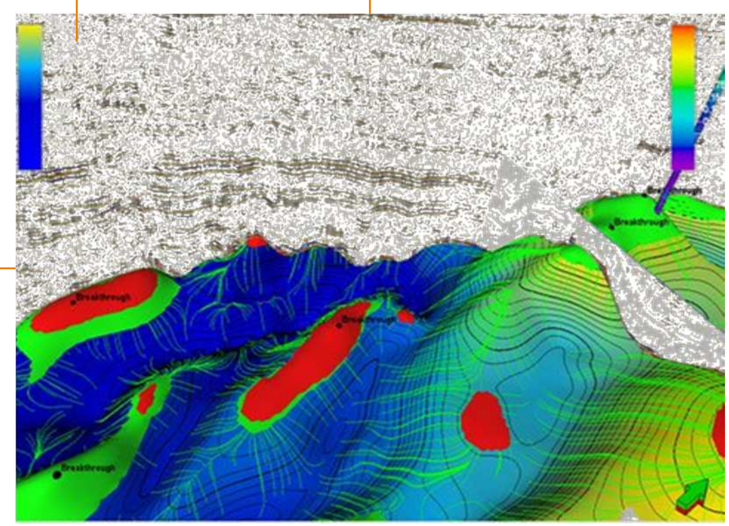


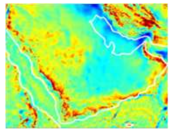
- Generation of hydrocarbons









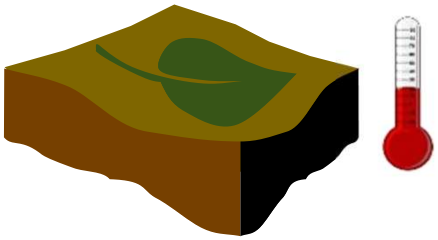


▪ Generation of hydrocarbons

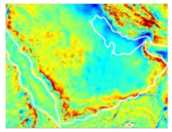
• Organic-rich source rocks in the basin need heat to get mature “cooked” and produce hydrocarbon (oil and gas)

• The heat needed for cooking the source rock:

- *Energy from the mantel*
- *Energy from radiogenic elements in the basement*
- *Energy from radiogenic elements in the sediments*



The amount of heat within the basin is controlled (defined) by the **heat flow** [mW/m^{-2}]



Heat flow: Important parameter in hydrocarbon exploration

Heat flow is usually considered a “user input”

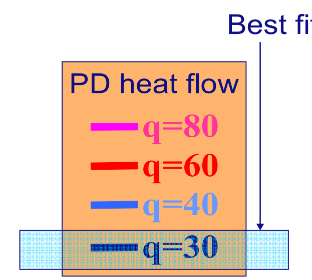
- **Present-day heat flow (measured in wells or assumed for the basin) is applied:**
  - Temporal extrapolation

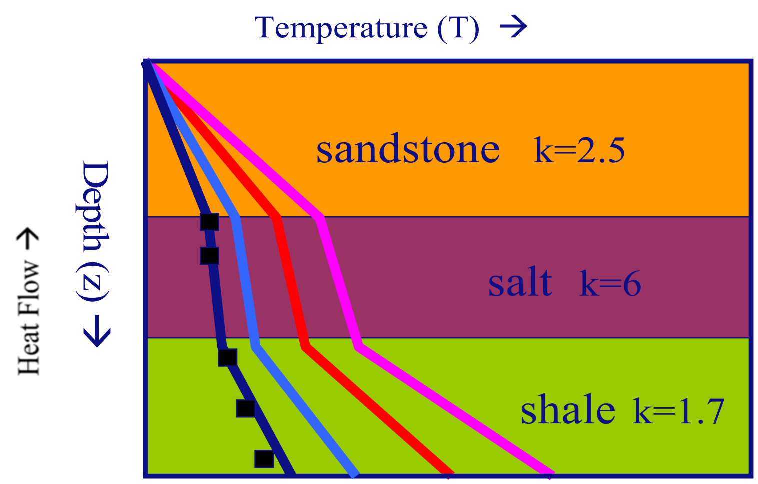
    Apply present-day heat flow as “flat heat flow ” for the whole basin history
  - Spatial extrapolation

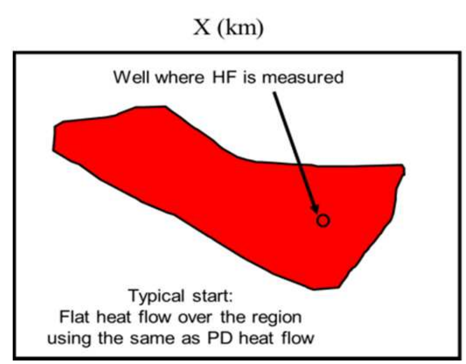
    Apply present-day heat flow as “flat heat flow” for whole basin

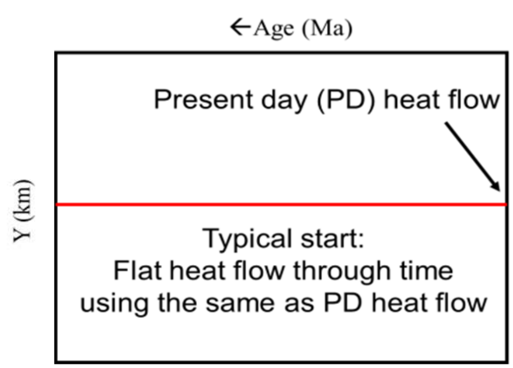
Heat flow determination: Conventional approach

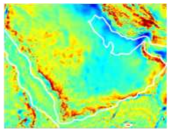
$$\frac{dT}{dz} = q / k$$











Heat flow: Important parameter in hydrocarbon exploration

Tectonic modelling of heat flow

- Based on basin subsidence history (sedimentation, erosion, PWD, .. etc)

  (heat flow variations though time and space)

- Effect of sedimentation infill and heat production in the crust

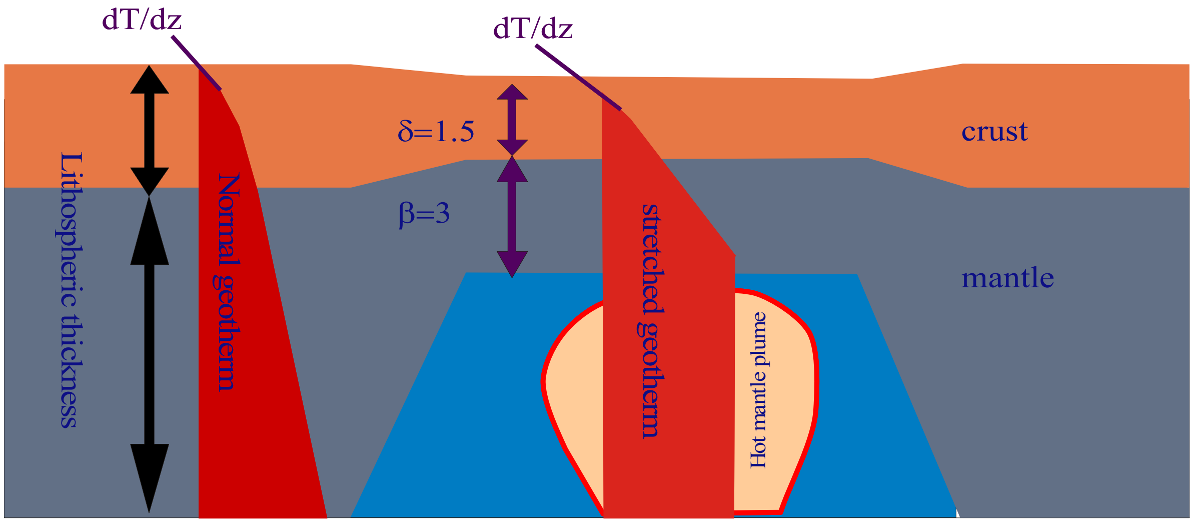
  (Improved McKenzie model)

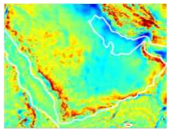
- Conducts calibration with measured

  (Model calibration and verification)

Main inputs:

Lithosphere and Crust thickness

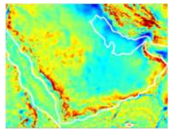




Gravity data and heat flow modelling

- Heat flow can be determined from crustal and lithospheric models

- Gravity data can help constrain the crust the lithosphere underlying the basin



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GOCE data and heat flow modelling

- Suitable for crust and lithosphere studies (can help “mapping” the Moho transition; essential for heat flow modeling).

- GOCE gradient data: higher horizontal resolution for crustal structure discrimination

- Suitable resolution for regional studies

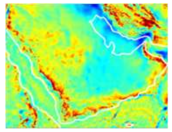
Test case:

The Rub al’ Khali basin

(Arabian Peninsula)

Application	**Accuracy, Geoid** [cm]	**Accuracy, Gravity** [mGal]	**Spatial Resolution** (half wavelength) [km]
Solid Earth			
Lithosphere and upper-mantle density structure		1-2	100
Continental lithosphere:			
• sedimentary basins		1-2	50-100
• rifts		1-2	20-100
• tectonic motions		1-2	100-500
• Seismic hazards		1	100
Ocean lithosphere and interaction with asthenosphere		0.5-1	100-200

Science Goals of the GOCE Mission (ESA, 1999)



GOCE + GeoExplore: Geophysical exploration and basin modeling

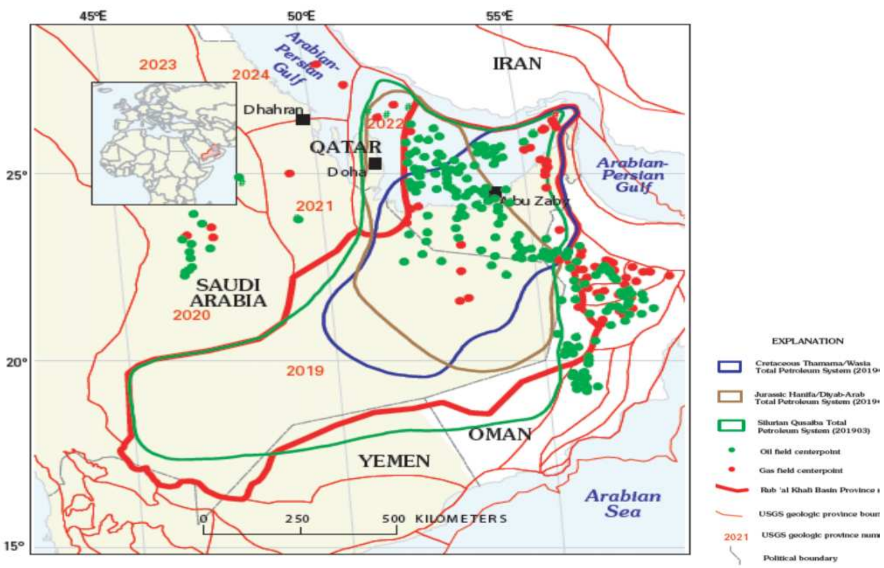
Arabian Peninsula (*The Rub al’ Khali area)*

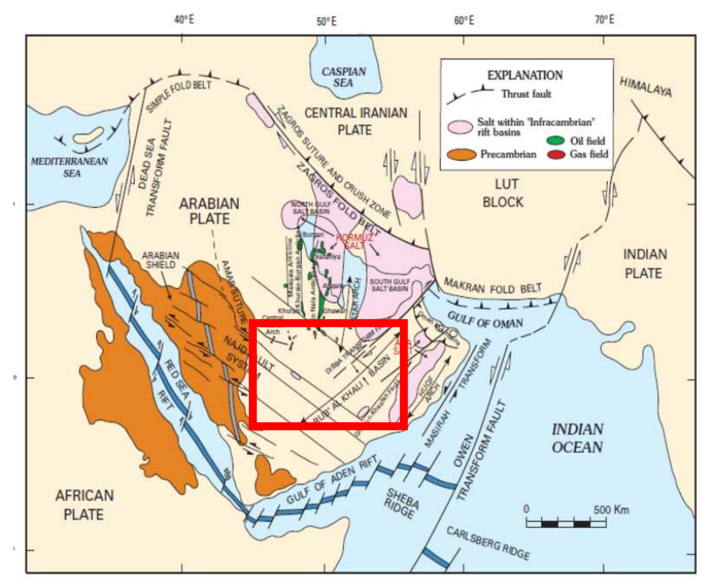
• Large, remote area

• Under-explored with high potential (frontier basin)

• Heterogeneous basement (Arabian shield), possible Impact

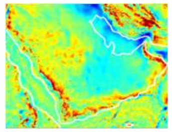
on heat flow in the basin.



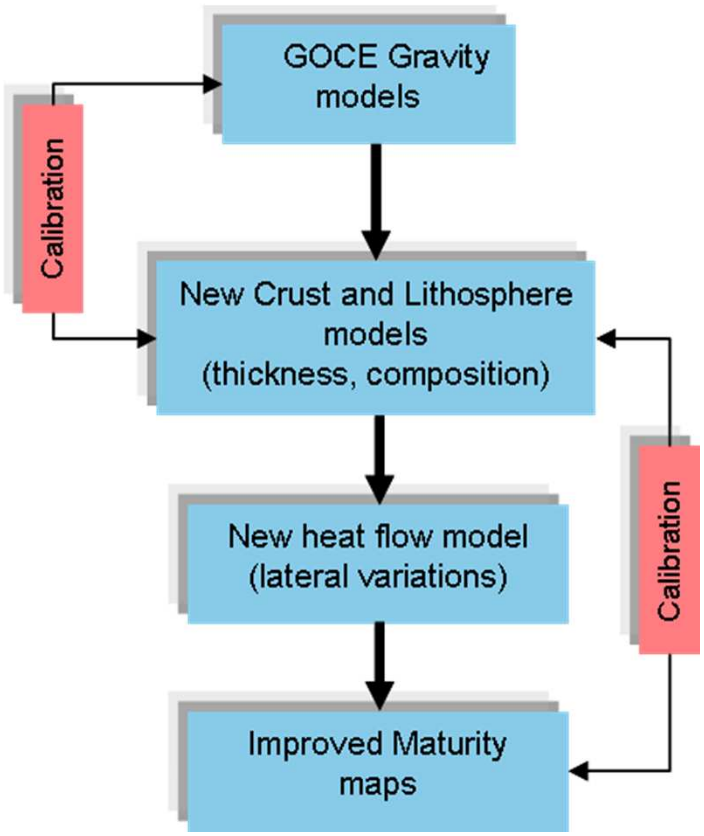


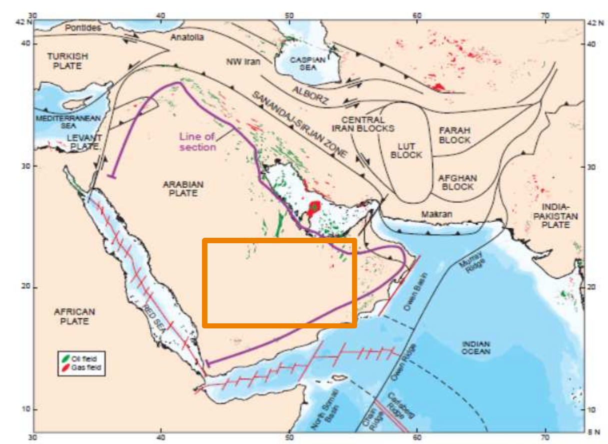
(Pollastro, 2003)

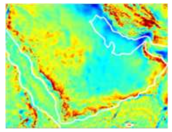
Geophysical exploration and basin modeling Arabian Peninsula (*The Rub al' Khali area)*



Approach



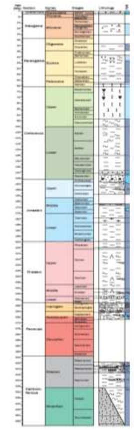


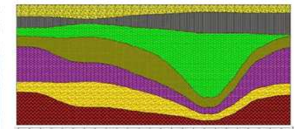


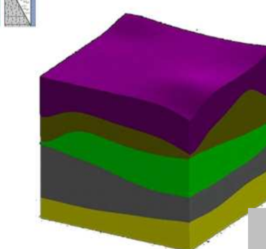
Workflow

- Building a geologic model of the area.
    - *Layer thicknesses, litho-stratigraphy, paleo water depth, tectonic evolution.*
- GOCE gravity model (gravity gradients, gravity anomaly)
    - *Required correction and processing*
    - *Integration of different data (land, satellite ..etc)*
- Inversion and forward modeling of gravity data
    - *Crust model (thickness variations)*
- Geologic model and crust model used for heat flow calculation
    - *Stretching factor (β) for initial crust thickness*
    - *Het flow maps through time*
- Maturity of source rock units

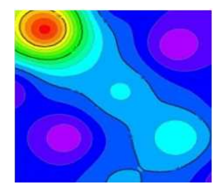
Calibration and verification



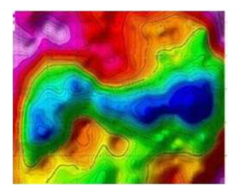




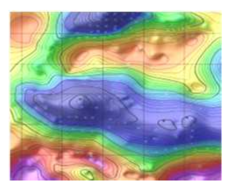
Geologic model



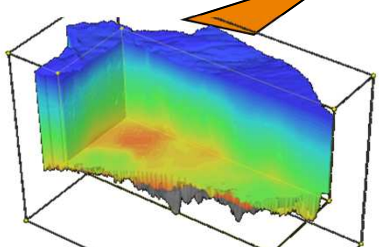
Gravity data "Fwd. models"



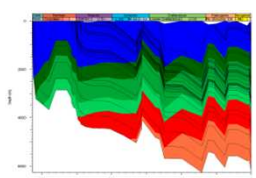
Integrated GOCE data



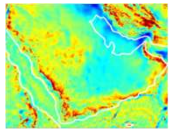
Lithosphere Crust model



Heat flow model

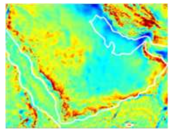


Maturity model



Work progress

- Geological model
- Gravity models preparation and analysis
- Preliminary heat flow analysis



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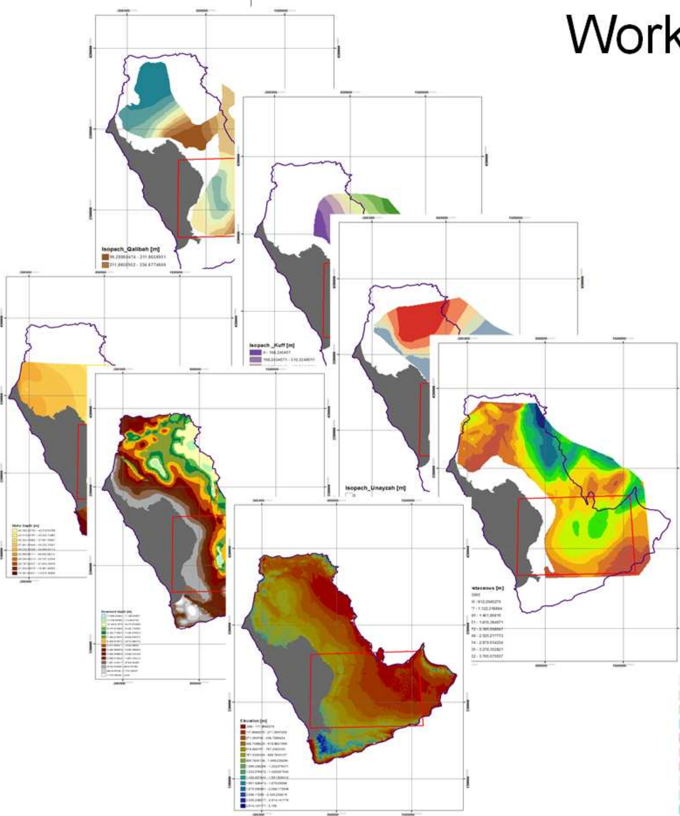
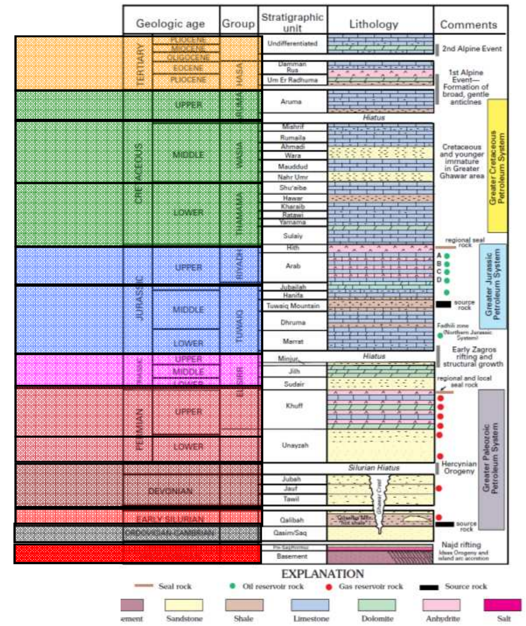
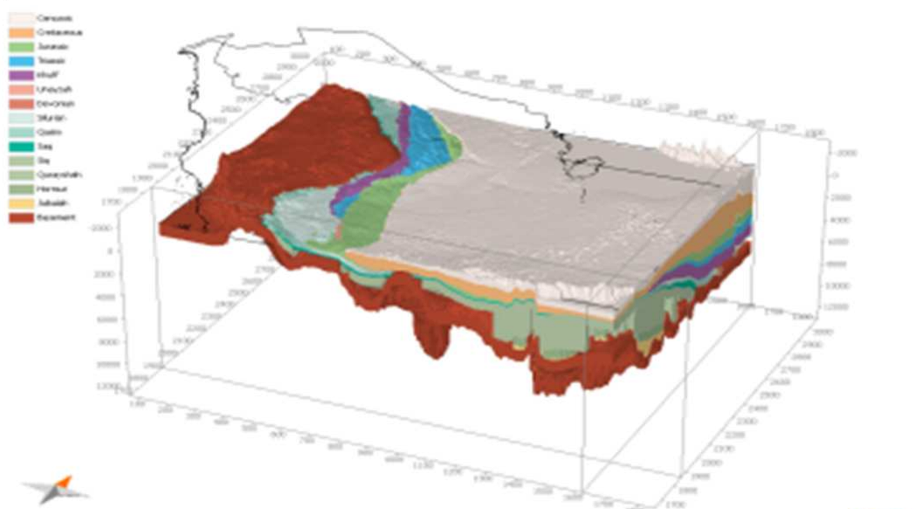
Work progress: Geologic model

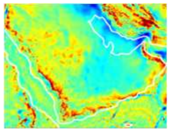


Used for:

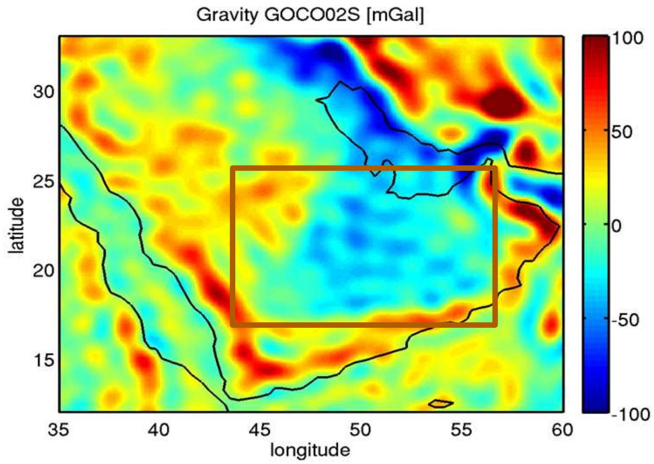
- *Gravity modeling*
- *Heat flow modeling*
- *Maturity modeling*







Work progress: GOCE gravity models / data



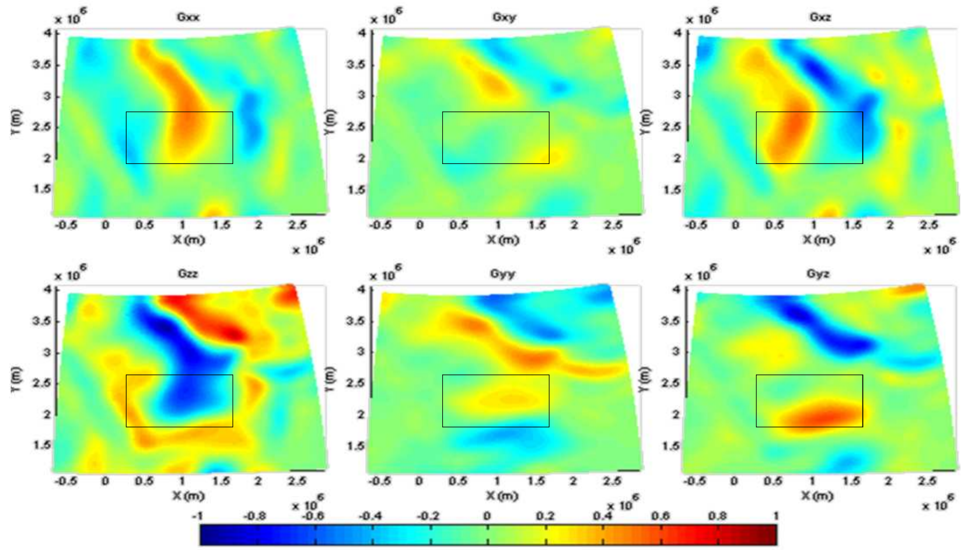
- Gravity anomaly data
- GOCE gradient data
- Combined gravity models

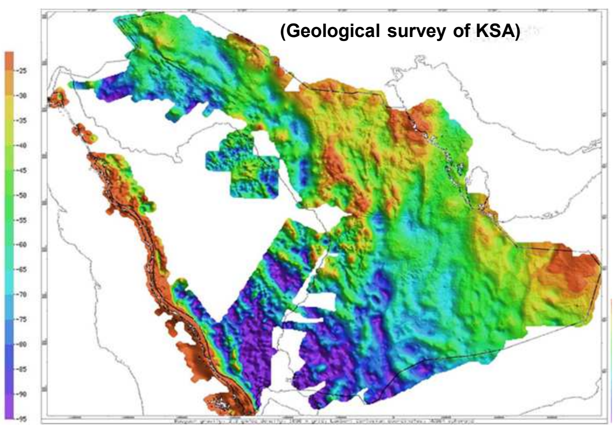
Used for:

•Crust model

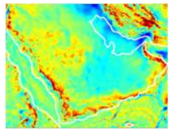
•Lithospheric thickness

GOCE gravity gradient components derived from gravity models over the region



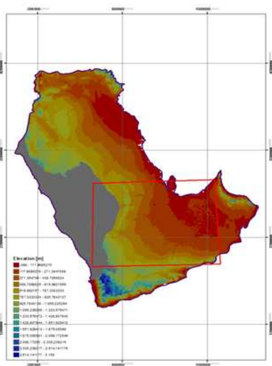


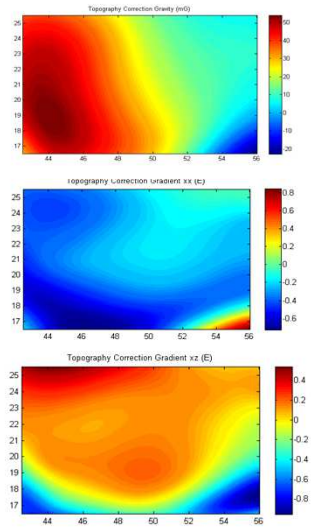
Bouguer anomaly map of KSA



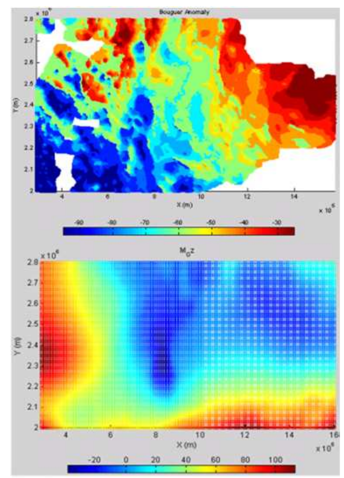
Work progress: Gravity data analysis

Topography reduction

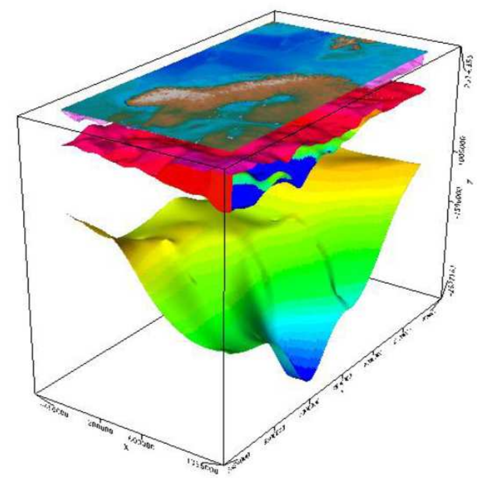




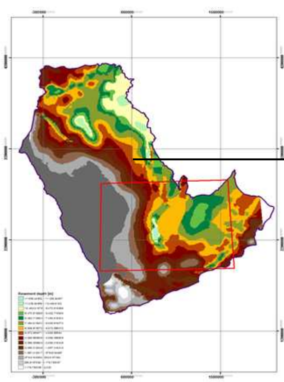
- **Preliminary analyses**
  - Gravity anomaly forward modelling
  - Topographic reduction
- **Sensitivity analysis**
  - North-East Atlantic margins

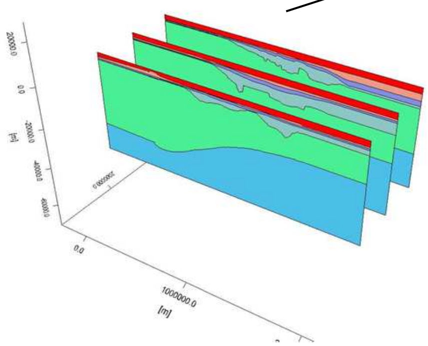


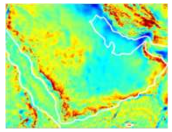
Comparison between preliminary GOCE gravity gradients (Vij) and gravity gradients from lithospheric density model (Uij).



Forward modeling



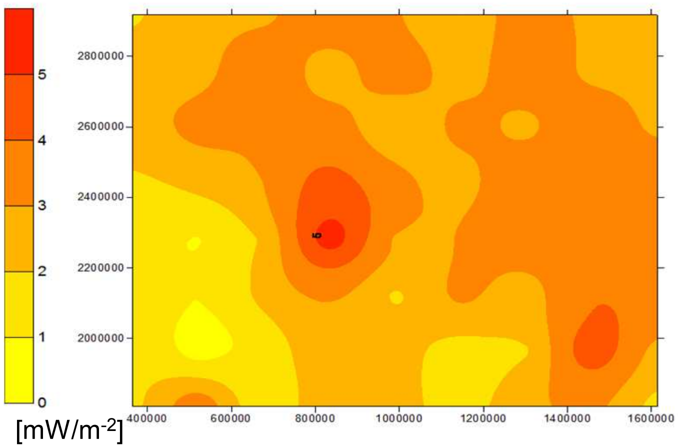




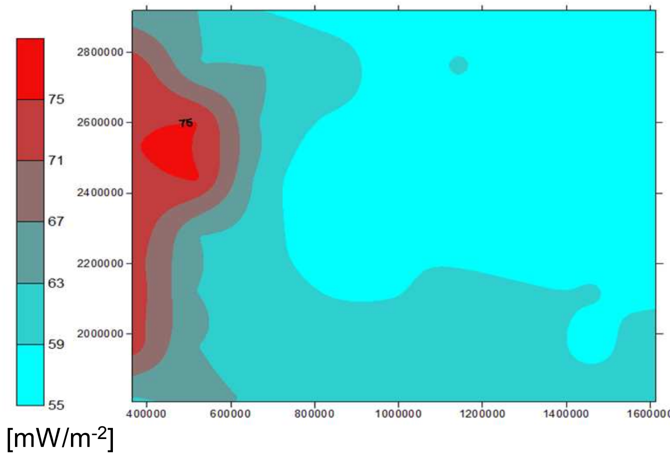
Work progress: Preliminary heat flow analysis

Effect of crust and lithosphere thickness on heat flow

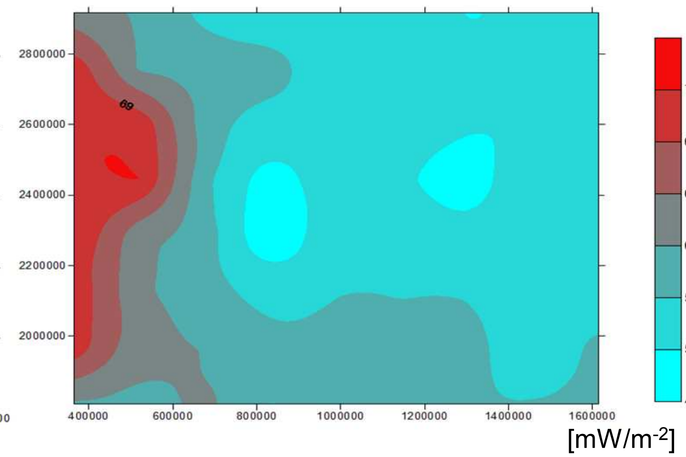
Difference: HF (45) – HF(30)

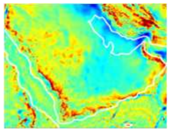


Heat flow: *crust 45 Km*



Heat flow: *crust 30 Km*

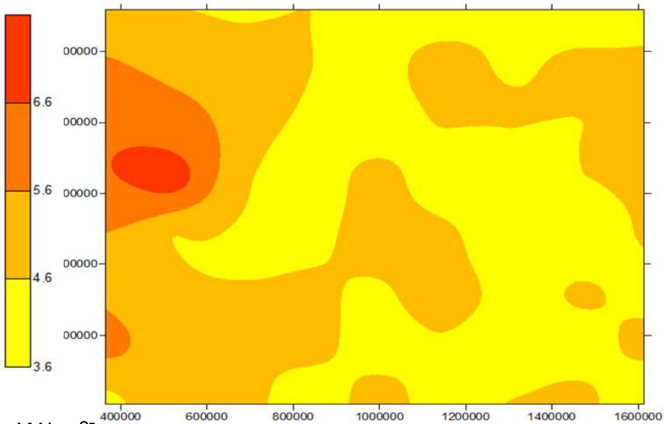




Work progress: Preliminary heat flow analysis

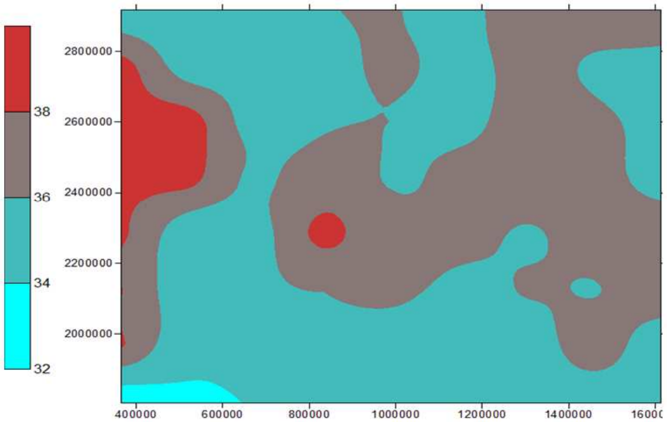
Effect of crust and lithosphere thickness on heat flow

Difference: HF(110) –HF(125)



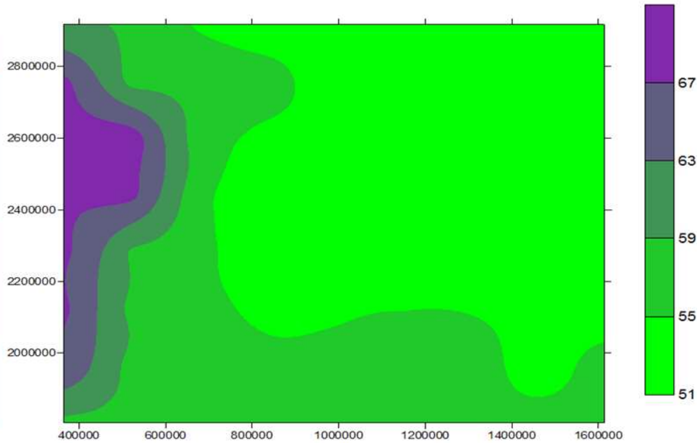
[mW/m^{-2}]

Heat flow: *Litho 110 Km*

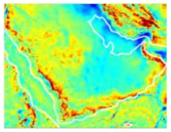


[mW/m^{-2}]

Heat flow: *Litho 125 Km*



[mW/m^{-2}]



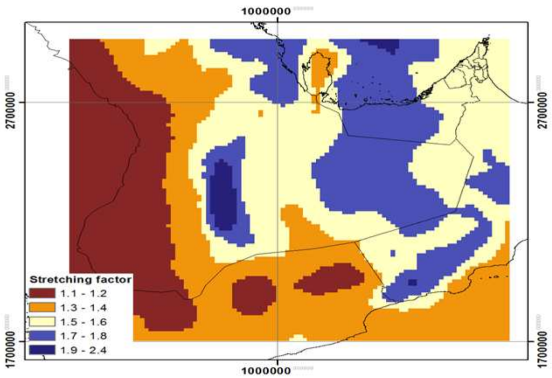
Work progress: Preliminary heat flow analysis

Reconstructing crustal thickness in geologic time. Based on:

1. Present day crust thickness (obtained from GOCE for example)
2. Crustal stretching (obtained from basin subsidence analysis)

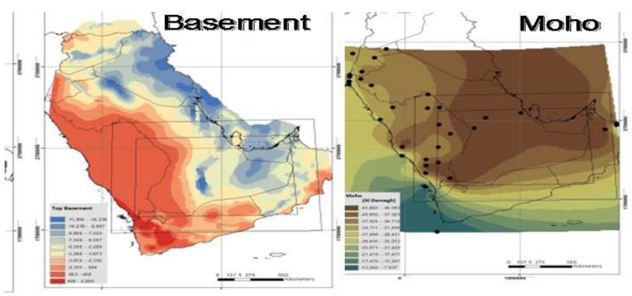
Important for heat flow variations through geologic times and therefore maturity and hydrocarbon generation though time.

Stretching factor

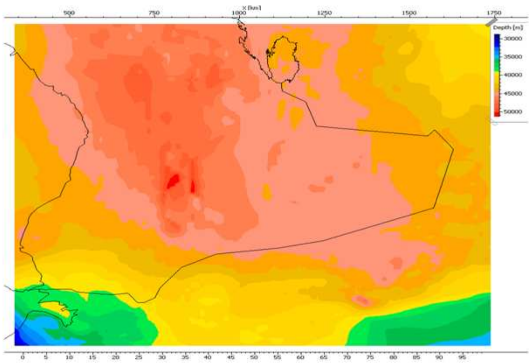


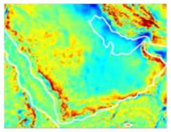
Present day crust

(from literature)



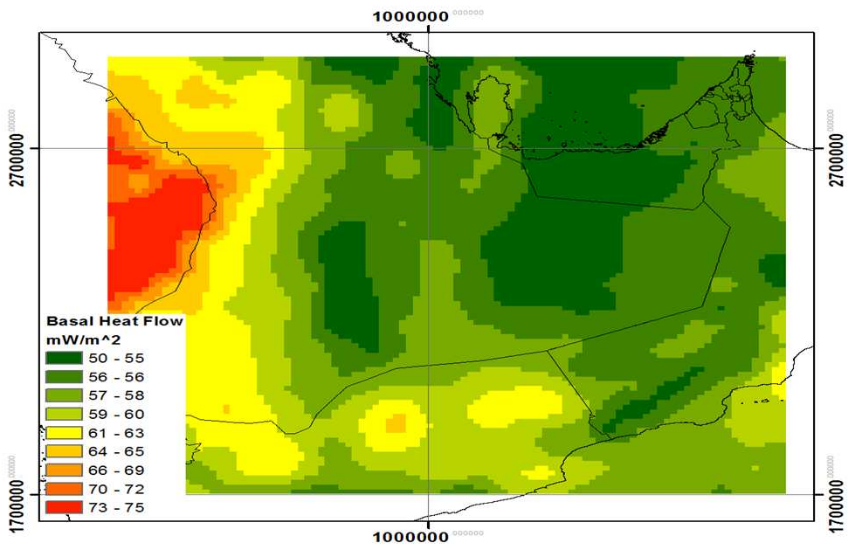
Paleo-crust thickness



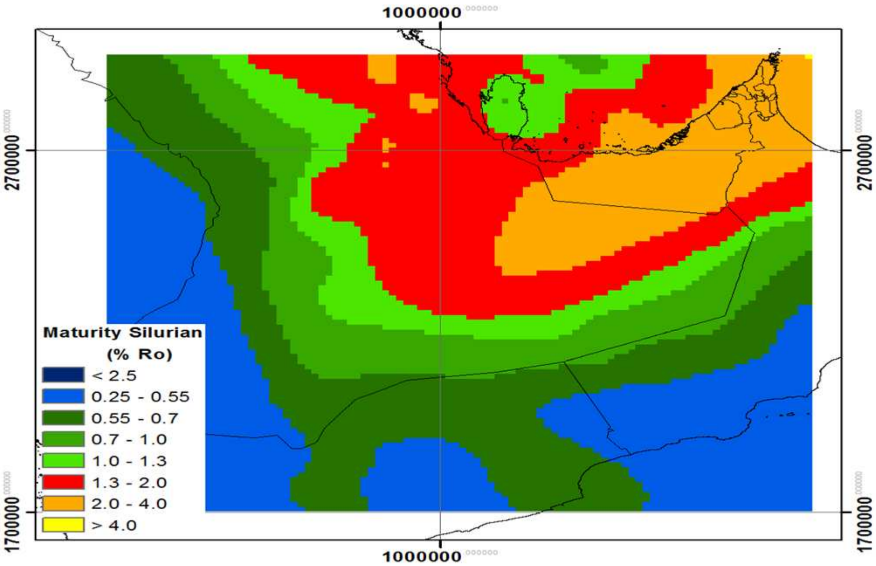


Work progress: Preliminary heat flow analysis

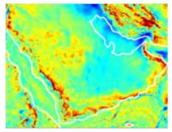
Heat flow and maturity based on varying crustal thickness



Basal heat flow derived from a crustal model based on literature

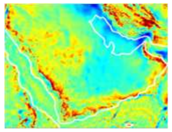


Modelled present day maturity of Paleozoic source rock



Initial modelling of heat flow: preliminary conclusions

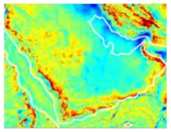
- Heat flow is sensitive to crustal thickness (radiogenic heat generation) and lithospheric thickness.
- Possible to link present day crustal thickness to paleo crustal thickness (important for tectonic heat flow modeling).
- Variations in crust thickness (provided by GOCE ?) will result in variations in heat flow and therefore hydrocarbon generation.

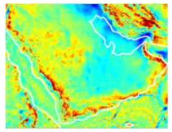


Future plans

- GOCE gravity data will be interpreted to update the crust and lithosphere models.
  - Hopefully a better resolution is provided by the gradient data (different crustal structures might be detected).
  - Sensitivity of GOCE to deep structures?
- New crust and lithosphere thickness model which can fit GOCE data, will be used to model the heat flow.
- The results will be calibrated to seismic stations, temperature, vitrinite reflectance and surface heat flow measurements.

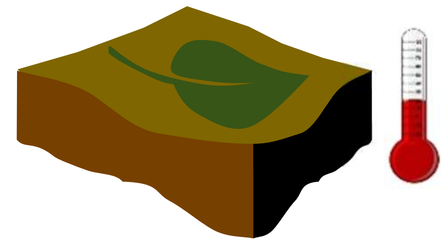

Thank you for your attention



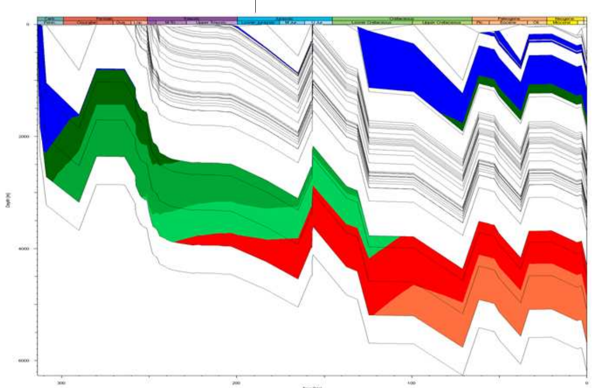


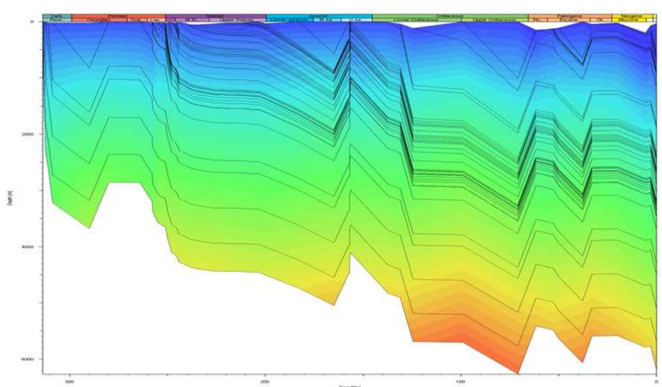
▪ Generation of hydrocarbons

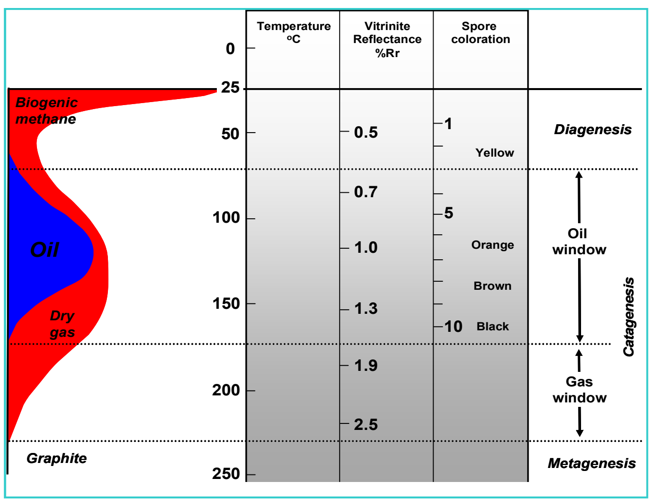
- Organic-rich source rocks in the basin need heat to get mature "cooked" and produce hydrocarbon (oil and gas)
- The heat needed for cooking the source rock comes from the crust
    - *Energy from the mantel*
    - *Energy from radiogenic elements in the basement*
    - *Energy from radiogenic elements in the sediments*

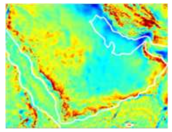


- The amount of heat within the basin is controlled (defined) by the heat flow [mW/m^{-2}] within the basin



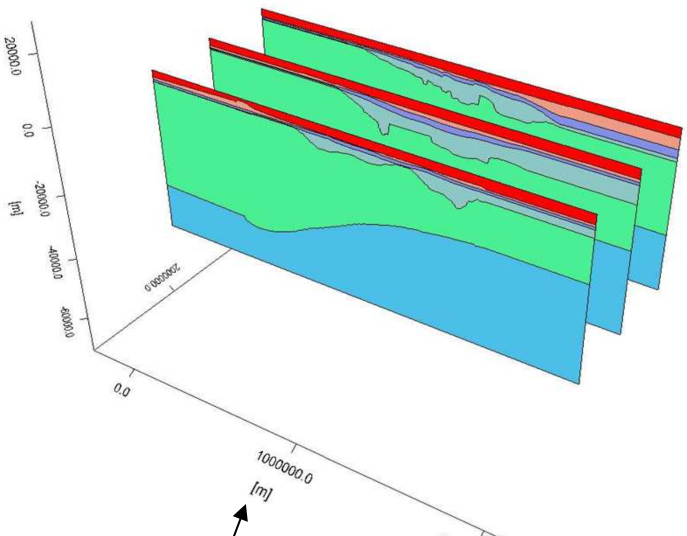




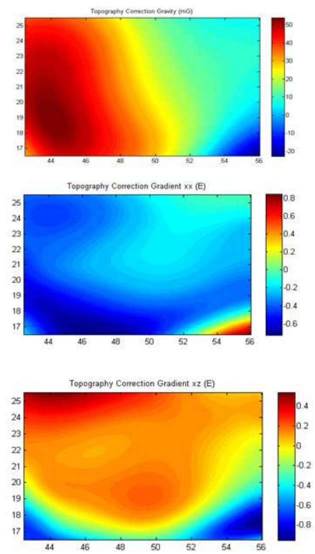


Work progress: Gravity data analysis

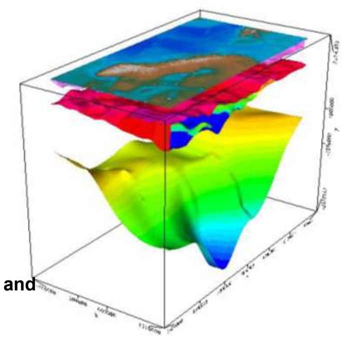
Forward modeling



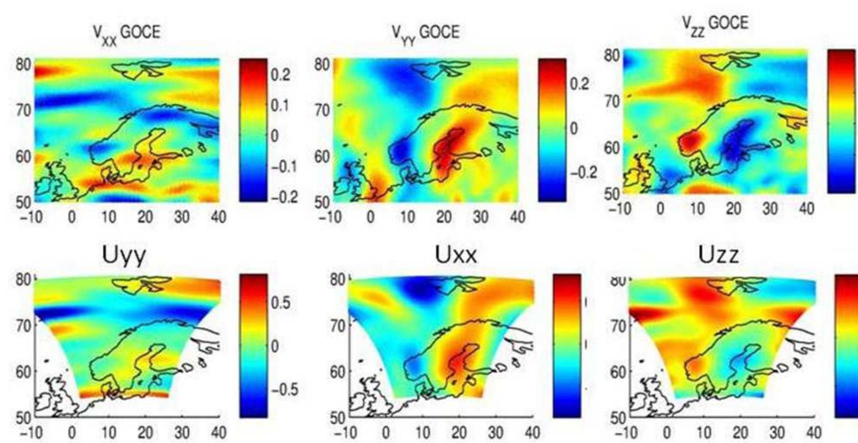
Topography reduction

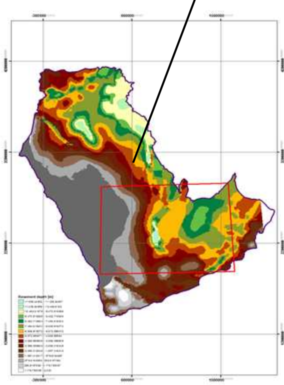


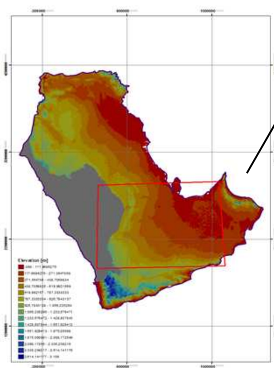
- **Preliminary analyses**
  - Gravity anomaly forward modelling
  - Topographic reduction
- **Sensitivity analysis**
  - North-East Atlantic margins



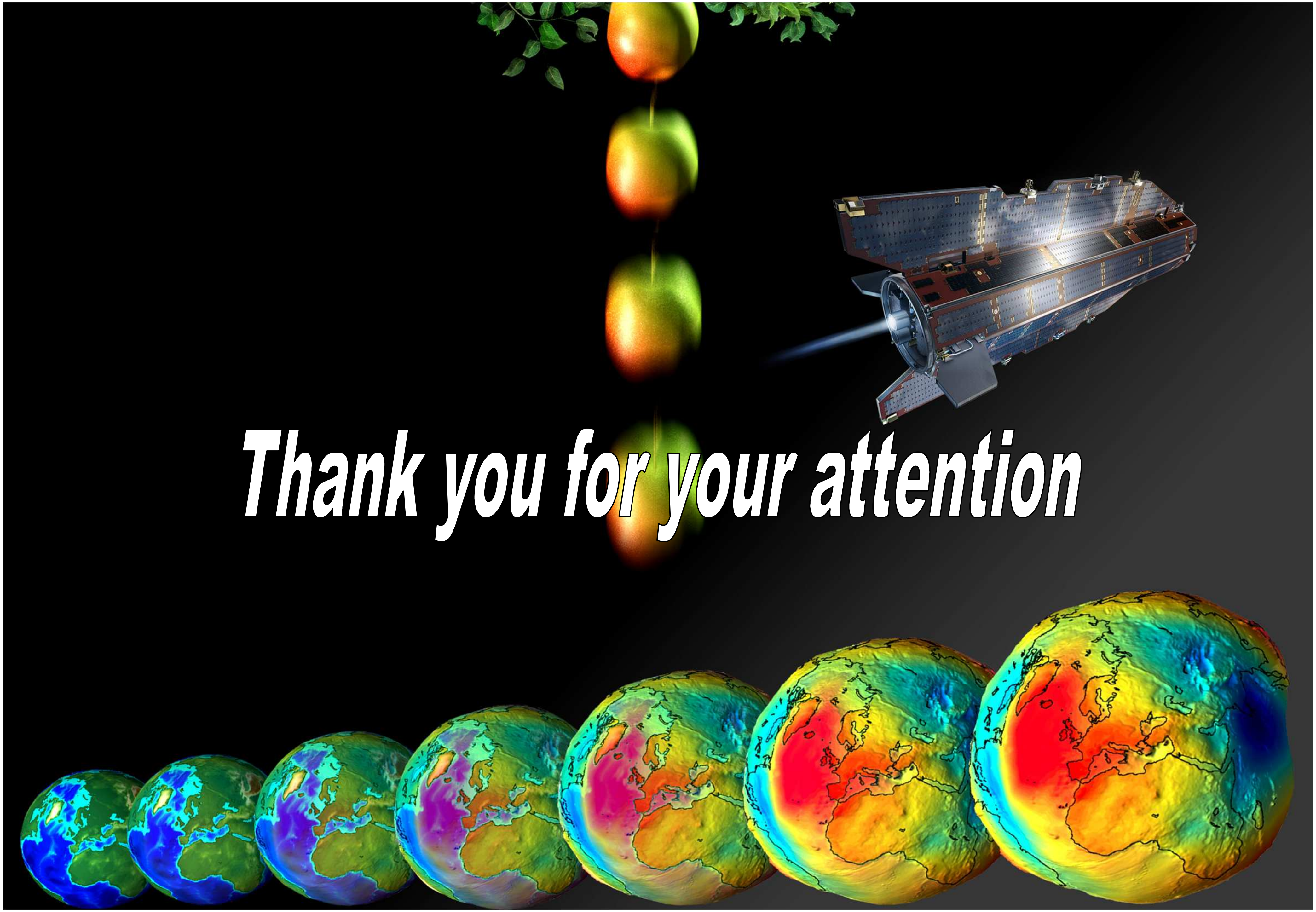
Comparison between preliminary GOCE gravity gradients (Vij) and gravity gradients from lithospheric density model (Uij).

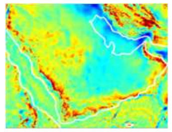




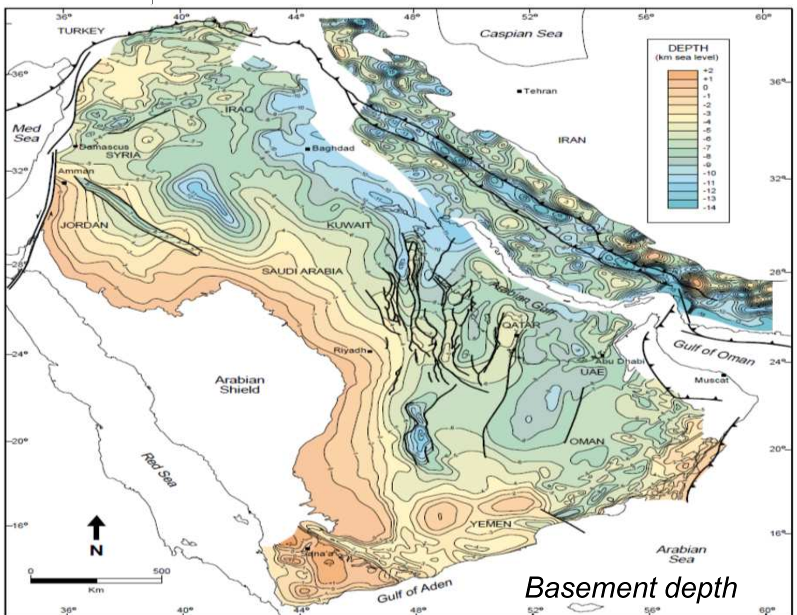


Ebbing et al (2011)


Thank you for your attention

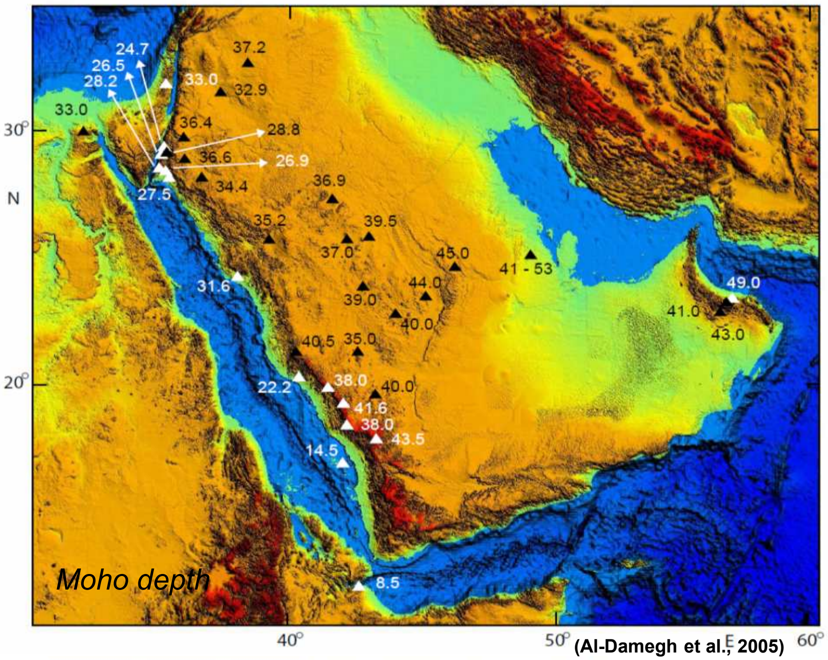


Data: Basement model, Calibration data (Maturity modeling)



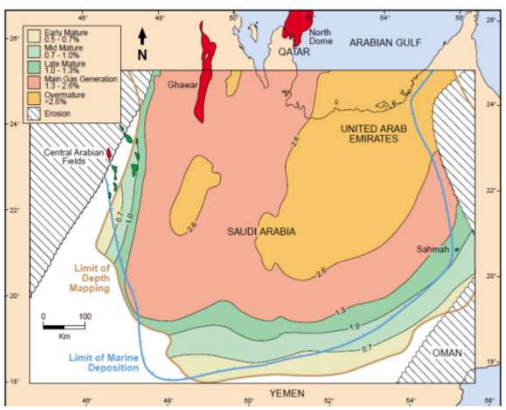
Basement depth

(Stern and Johnson, 2010)

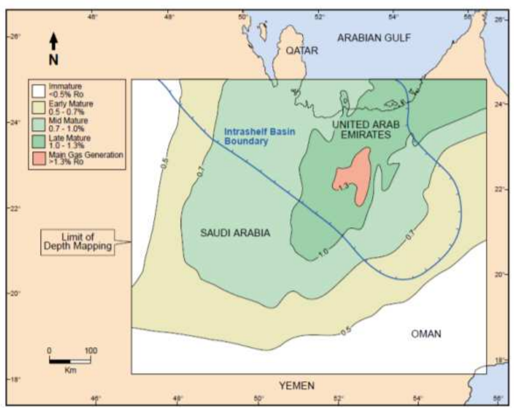


Moho depth

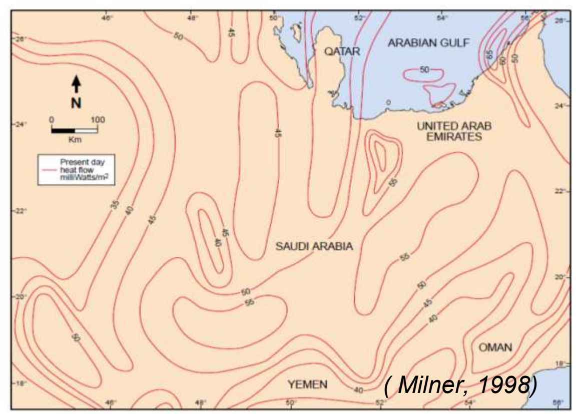
(Al-Damegh et al., 2005)



Jurassic maturity (Vr %)

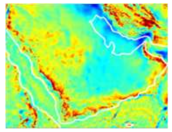


Permian maturity (Vr %)

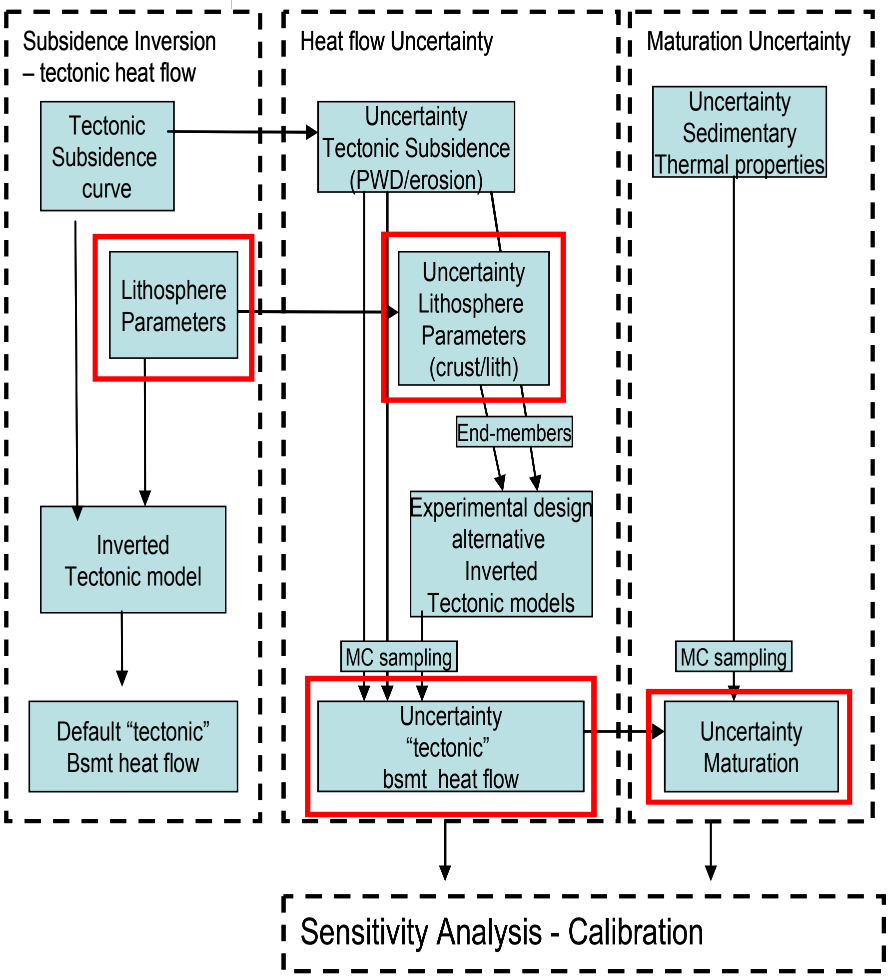


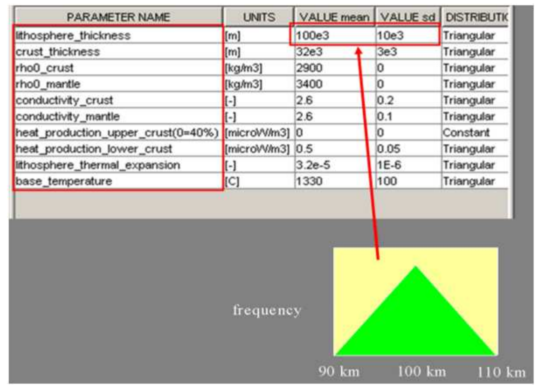
(Milner, 1998)

Surface heat flow (mW/m2)

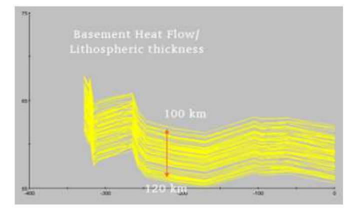


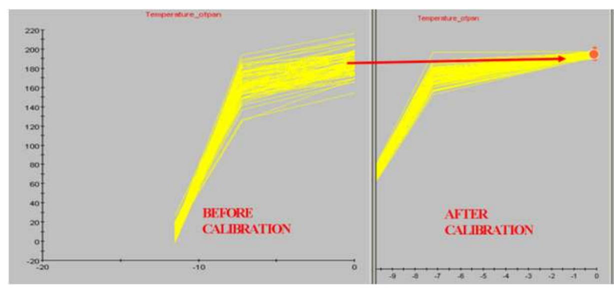
Heat flow and Maturity (PetroProb):

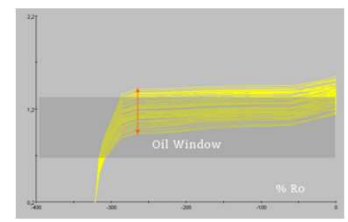


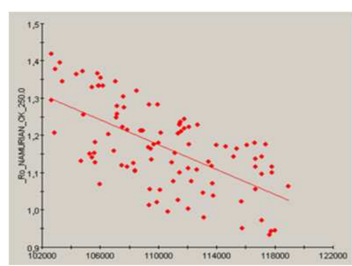


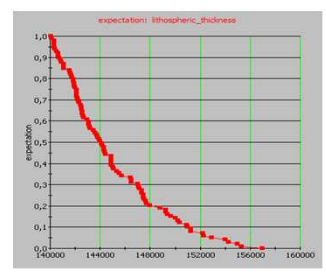
PARAMETER NAME	UNITS	VALUE mean	VALUE sd	DISTRIBUTI(
lithosphere_thickness	[m]	100e3	10e3	Triangular
crust_thickness	[m]	32e3	3e3	Triangular
rho0_crust	[kg/m3]	2900	0	Triangular
rho0_mantle	[kg/m3]	3400	0	Triangular
conductivity_crust	[-]	2.6	0.2	Triangular
conductivity_mantle	[-]	2.6	0.1	Triangular
heat_production_upper_crust(0=40%)	[microW/m3]	0	0	Constant
heat_production_lower_crust	[microW/m3]	0.5	0.05	Triangular
lithosphere_thermal_expansion	[-]	3.2e-5	1E-6	Triangular
base_temperature	[C]	1330	100	Triangular

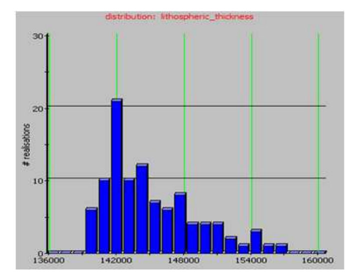


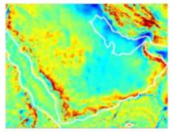








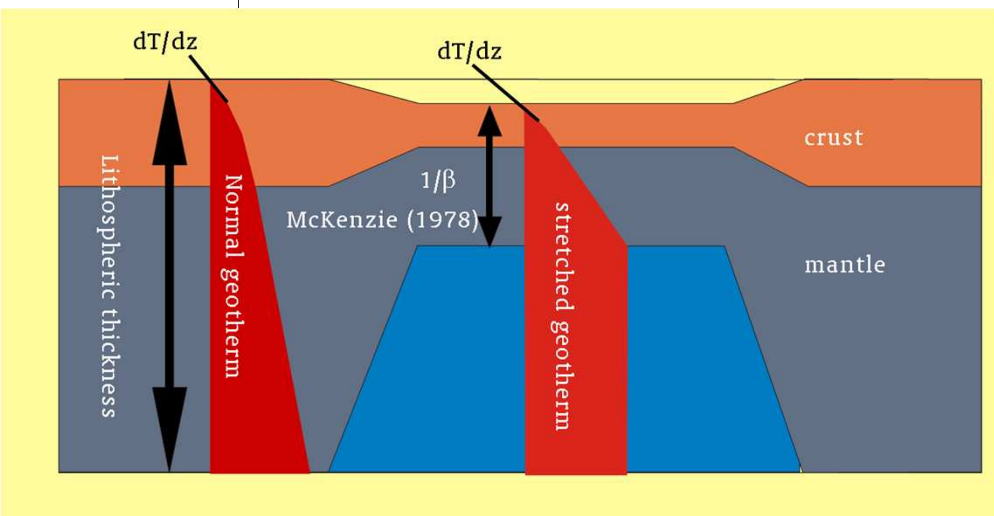


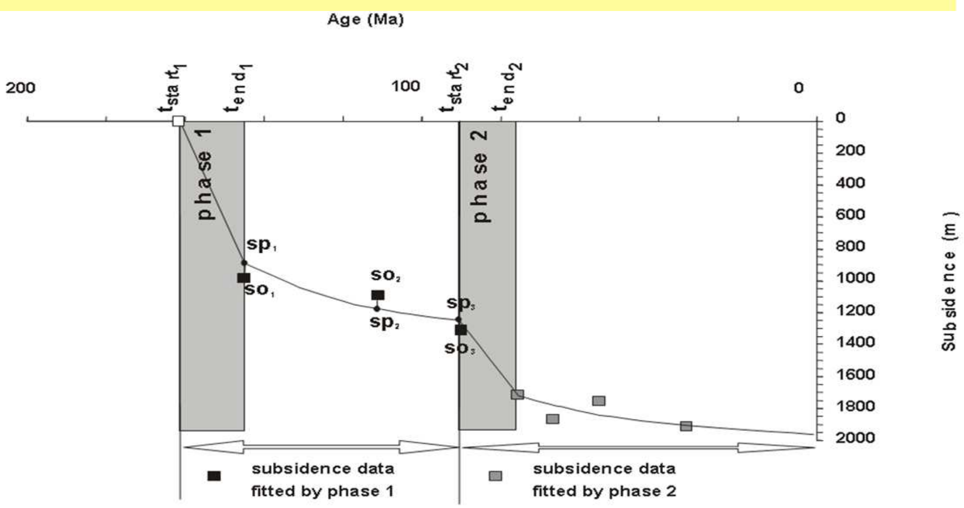


innovation for life

Heat flow modeling:

Probabilistic tectonic heat flow modeling (PetroProb)





- A multi- 1D tectonic heat flow modelling approach

  (Temporal and spatial variations)

- Based on inversion of basin subsidence data (sedimentation, erosion, PWD, .. etc)

  (Modelled tectonic heat flow)

- Incorporates the effect of sedimentation infill and heat production in the crust

  (Improved McKenzie model)

- Includes uncertainty in the input parameters

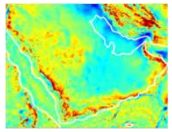
  (Probabilistic approach)

- Conducts calibration with measured data and sensitivity analysis

  (Model calibration and verification)

Main inputs:

Lithosphere and Crust thicknesses and properties

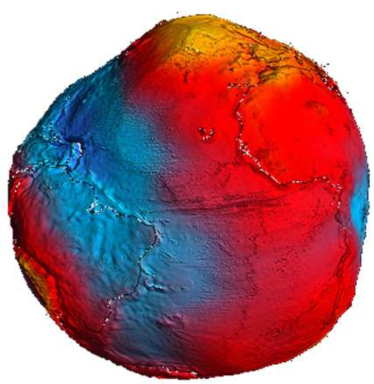



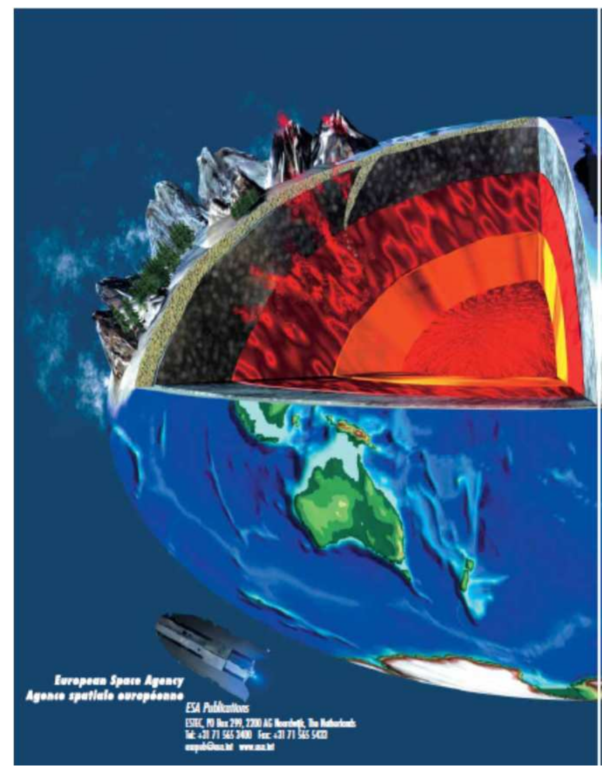
The GOCE satellite mission

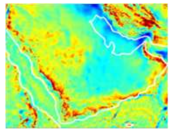
- Gravity Field and Steady-State Ocean Circulation Explorer **(GOCE)**
- ESA satellite launched in 2009
- Measures gravity gradient (gradiometer)
- Objectives:
    - *Gravity field with high accuracy*
    - *Spatial resolution of ~ 75 km*
    - *Model of the Geoid (1-2 cm)*

Solid Earth

Sea-level Change
Geodesy
Ocean Circulation







Basal heat flow and maturity in the basin

- Heat flow influences the maturity of the source rock
- Basement heat flow is influenced by the crust properties

composition

within the crust

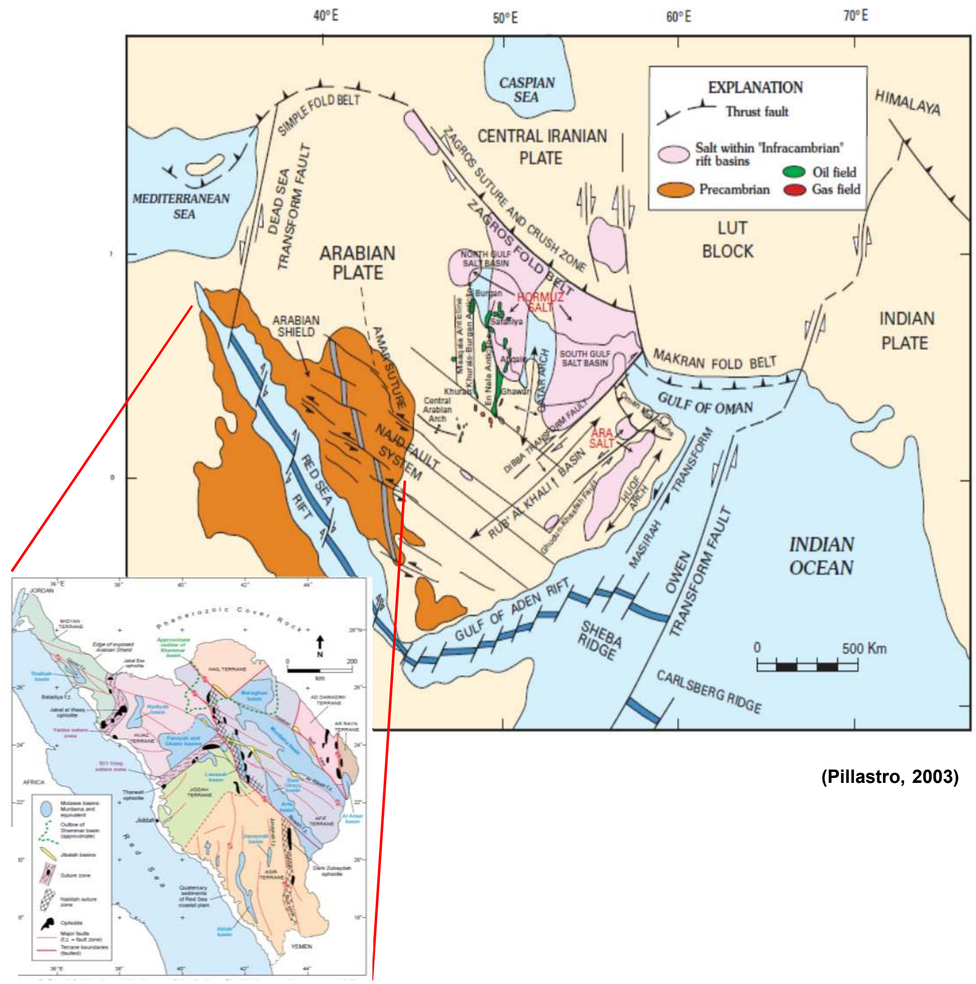
heat flow

nin the basin

ub al'khali ?

abian shield) shows

s in the Arabian Platform



(Pillastro, 2003)