



**Grand societal challenges:  
energy and sustainability**

## **Integrated Solid Earth Science and Geothermal resources**

Sierd Cloetingh, Jeannot Trampert,  
Wim Spakman, Manfred van Bergen,  
Chris Spiers, Martin Drury

Et al.

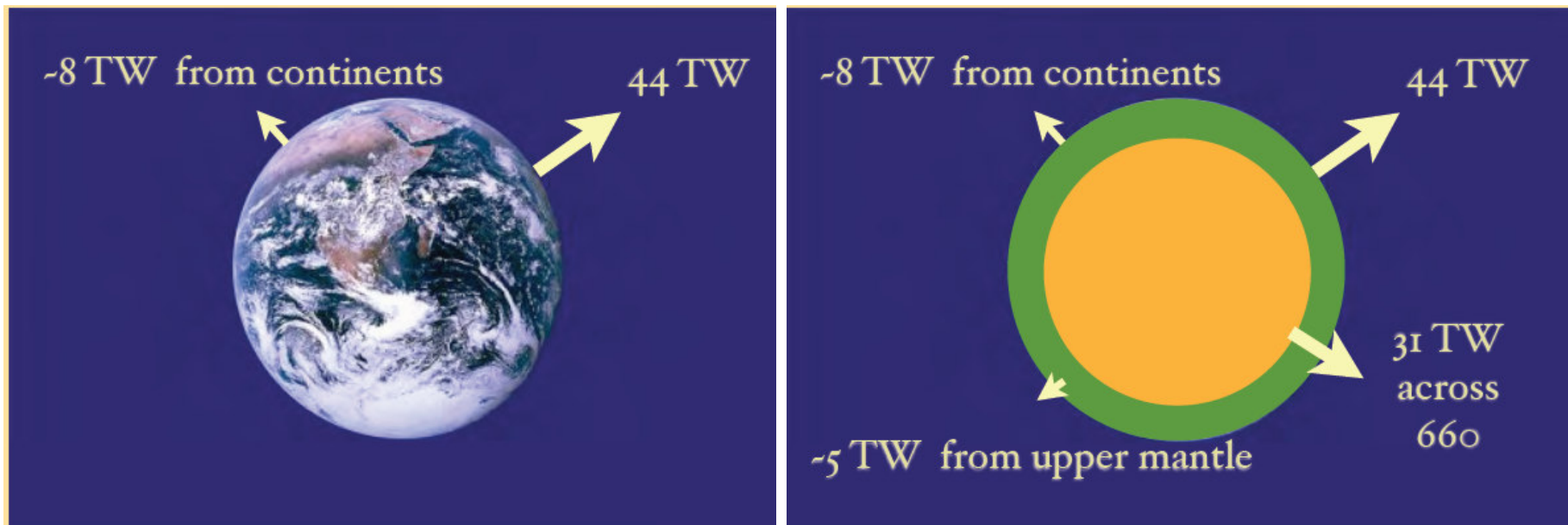


Netherlands Research Centre for  
Integrated Solid Earth Sciences

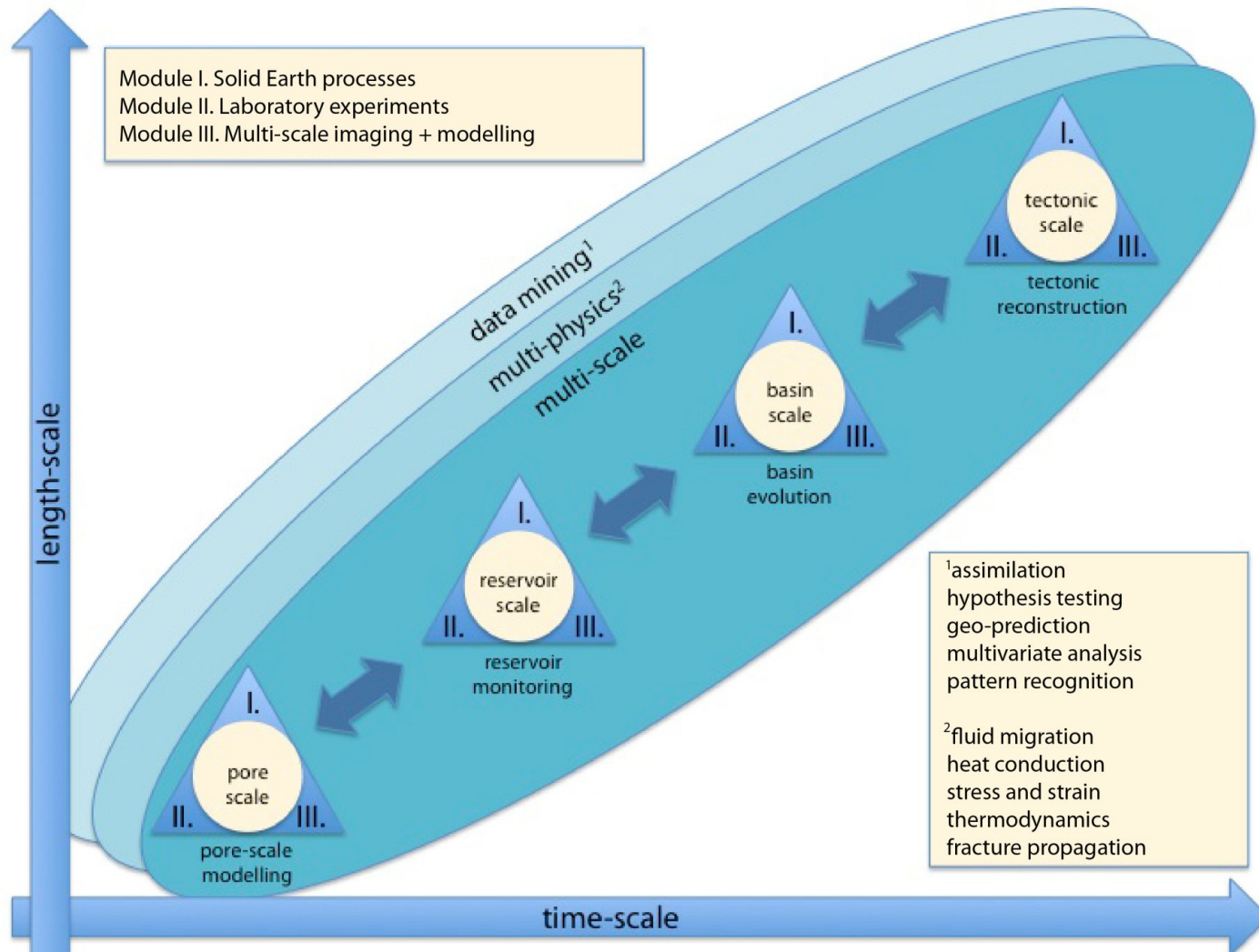


**Universiteit Utrecht**

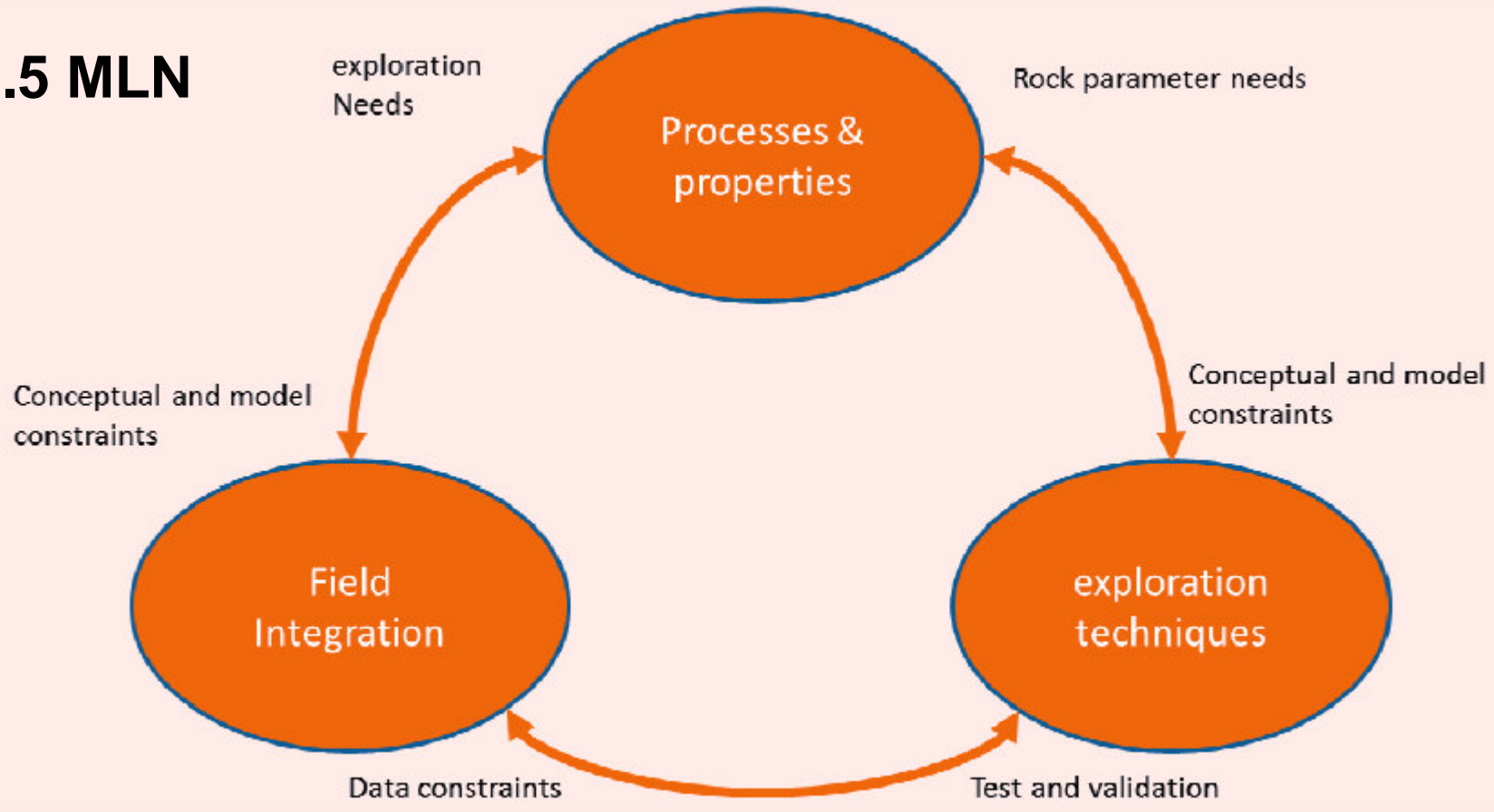
# The Earth as a heat engine



# Linking small to large scales

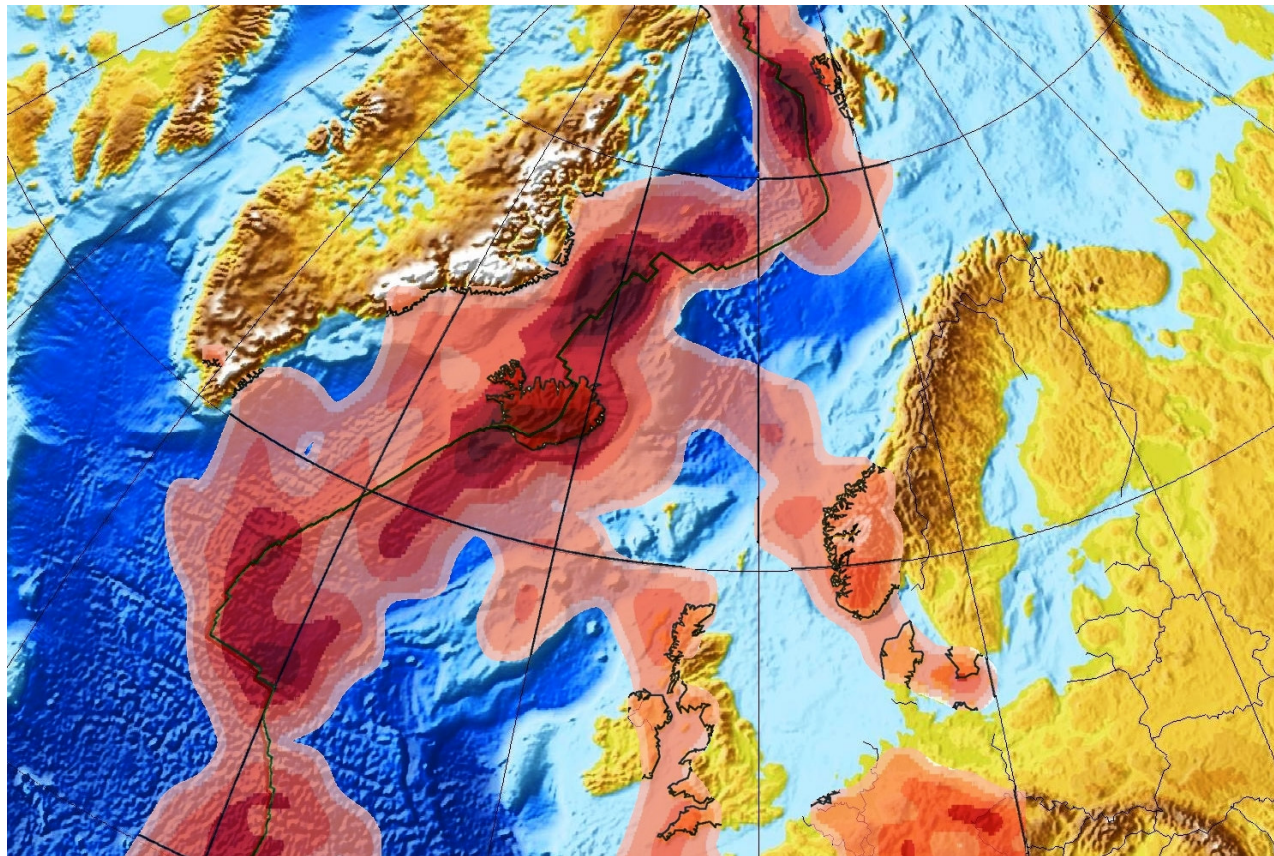


**13.5 MLN**



# Plumes in the upper mantle resolved from seismic tomography – Groups of Spakman and Trampert

(in the Northern Atlantic, depth slice between 100 – 200 km)

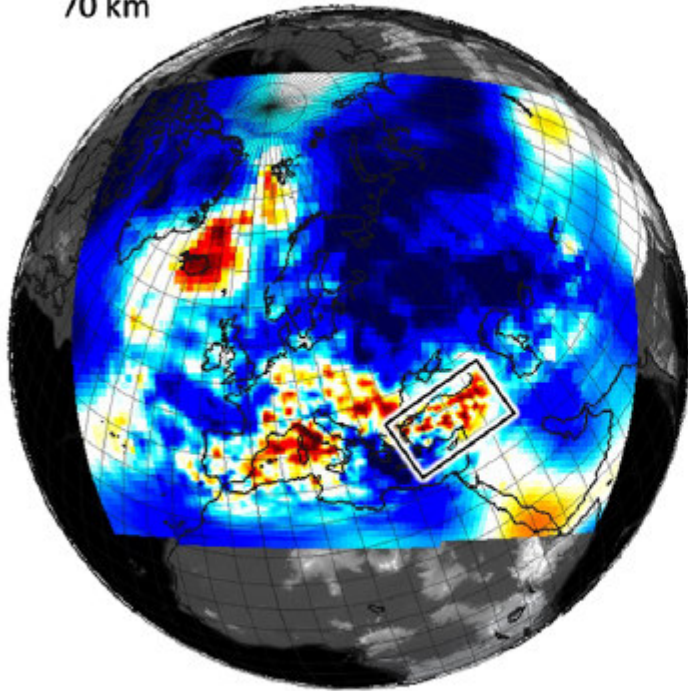


*Rickers et al., 2013.*

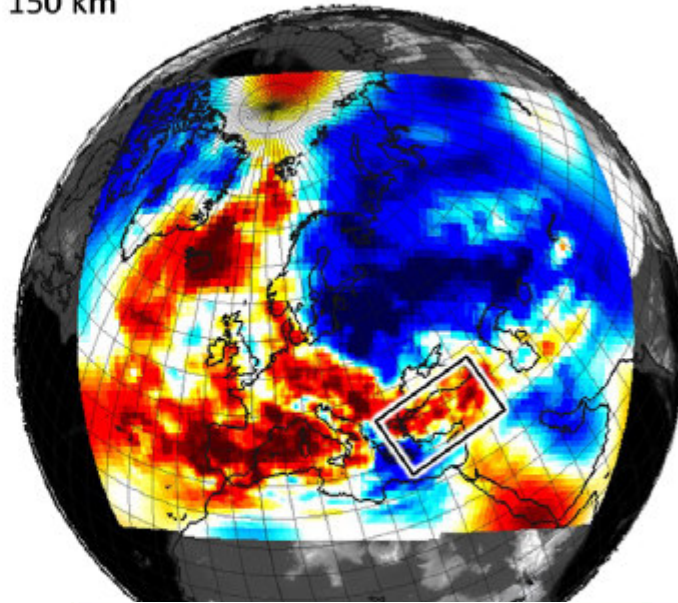
*EPSL.*


# Tomography

70 km



150 km

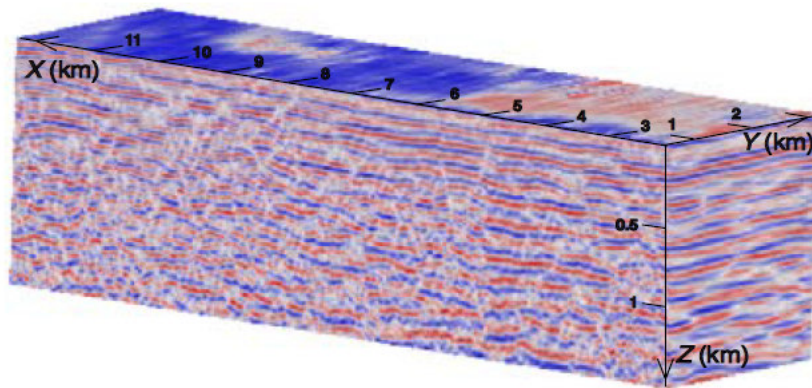


4.05  4.65  
 $v_s$  [km/s]

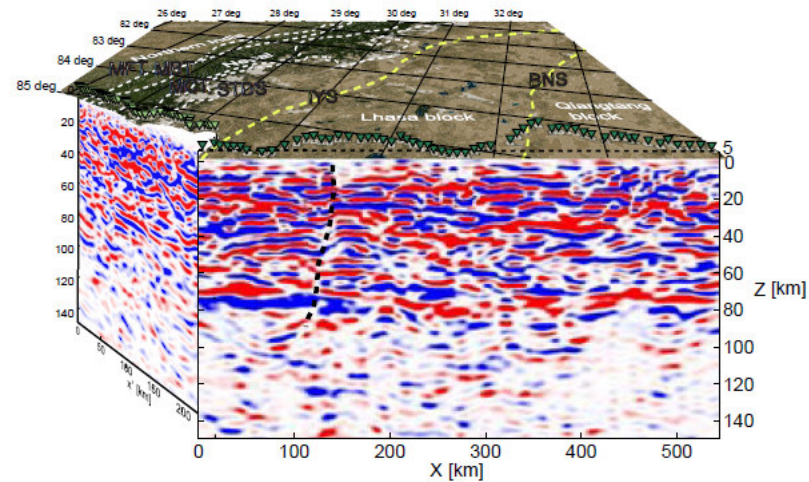


# Imaging, Characterization and Monitoring

## Seismic interferometry applications

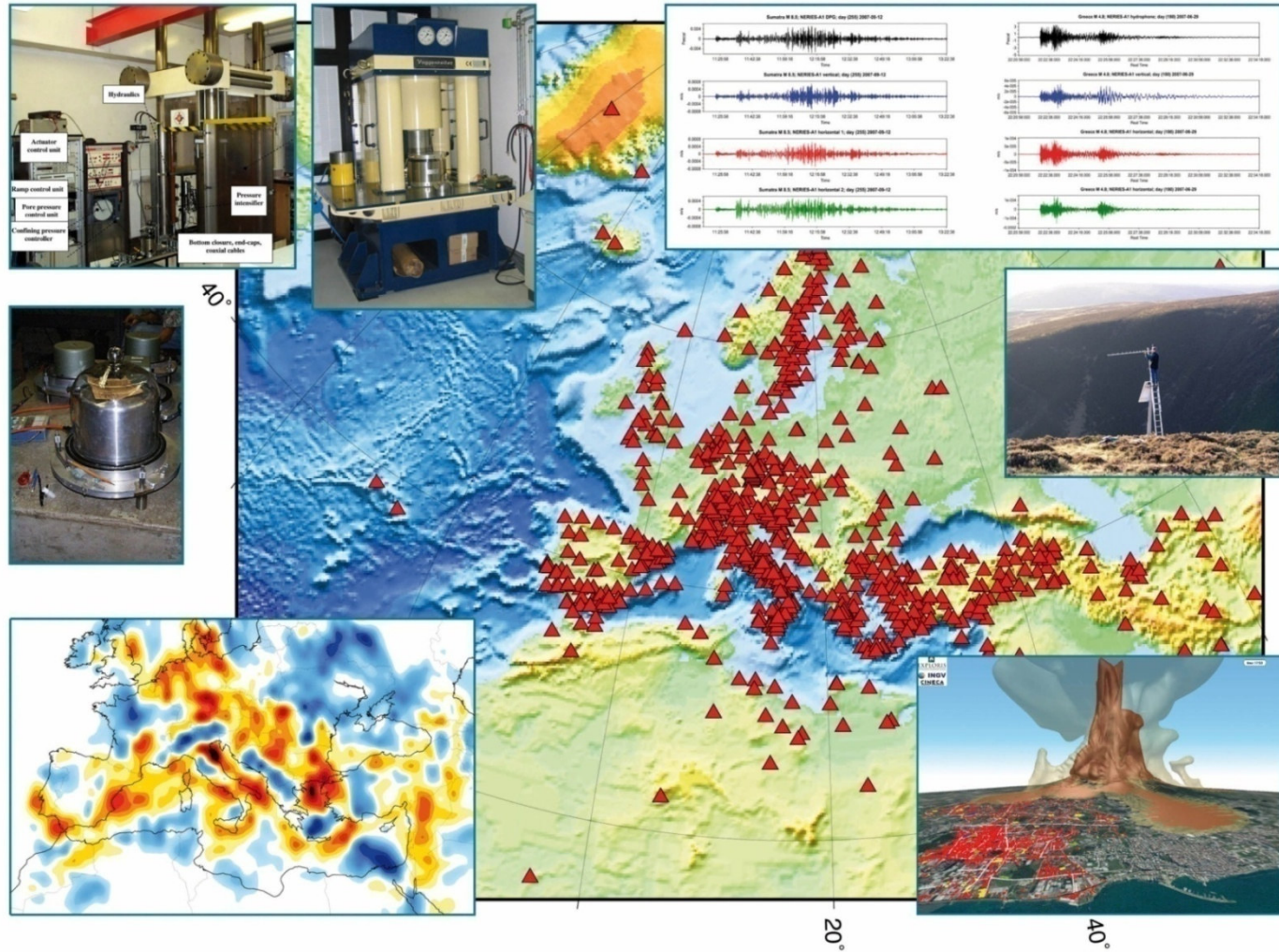


*3D reflection image of the geology beneath the Libyan desert, obtained from ambient seismic noise*



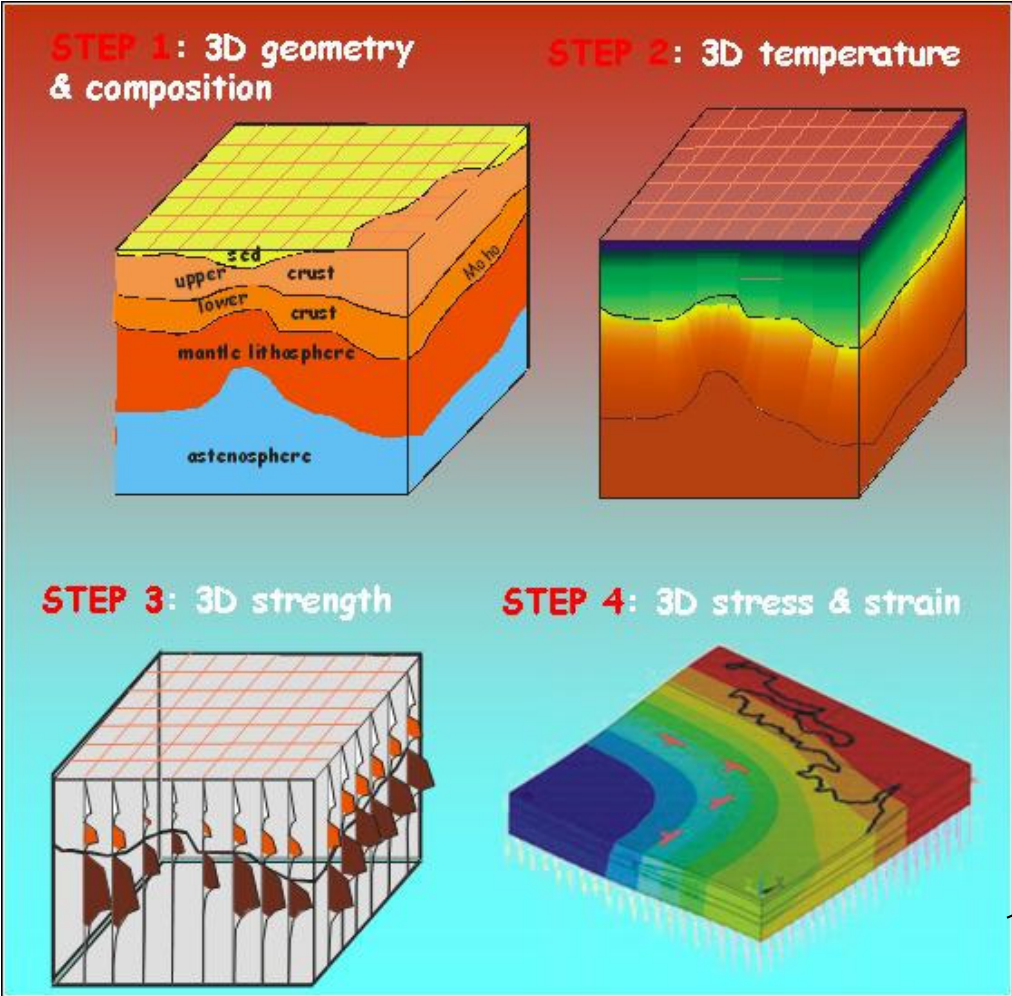
*reflection image of the tectonic blocks below the Tibetan Plateau, obtained from tele-seismic data*



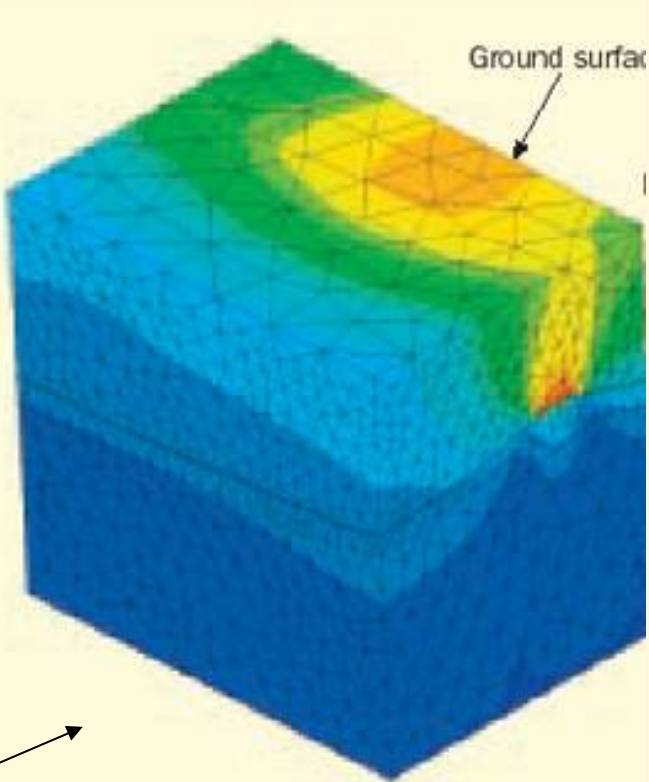




# Lithosphere thermo-mechanics



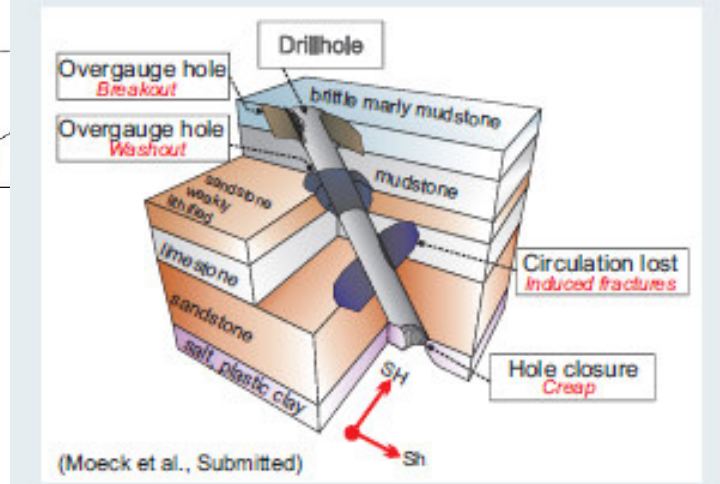
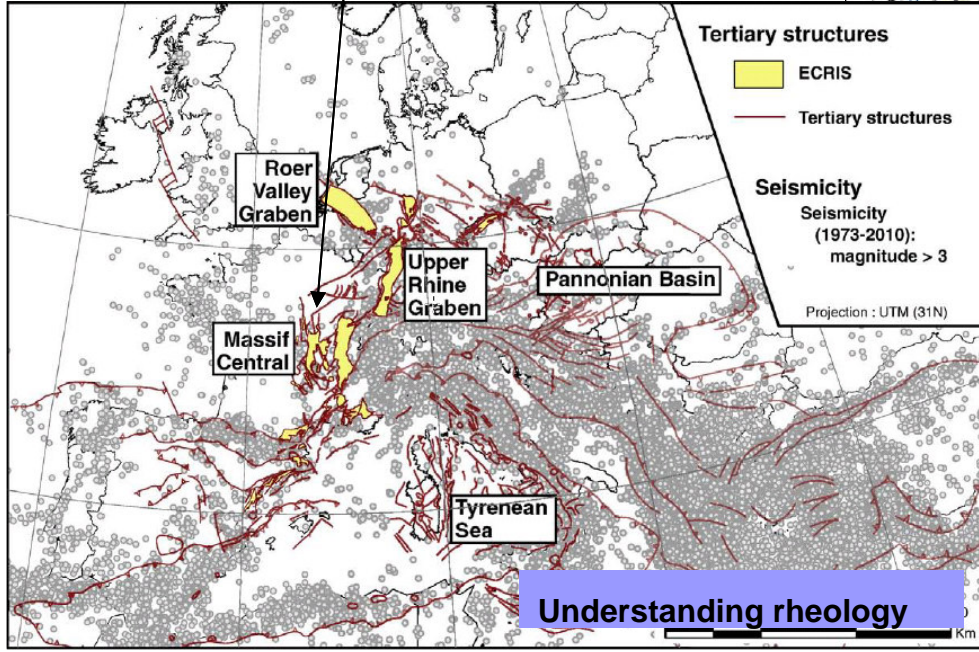
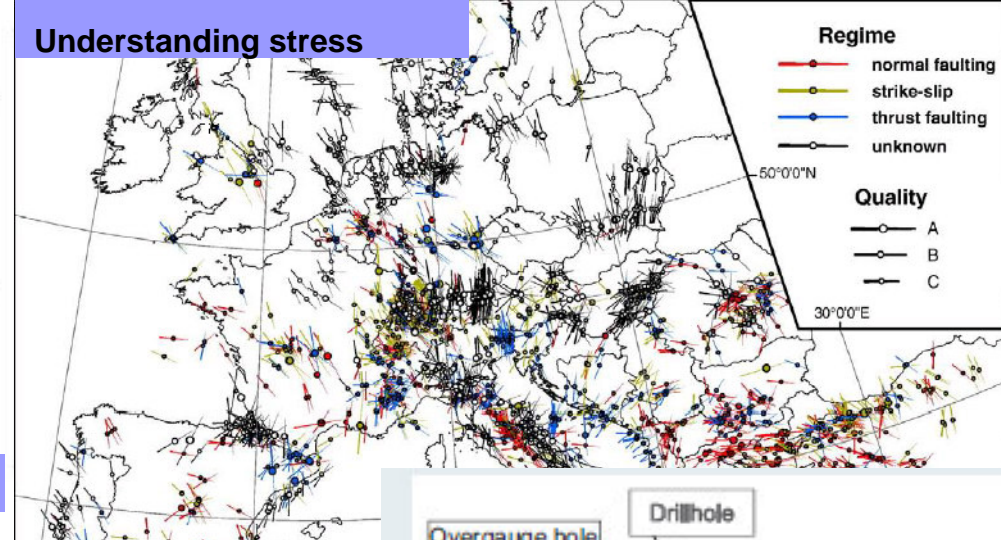
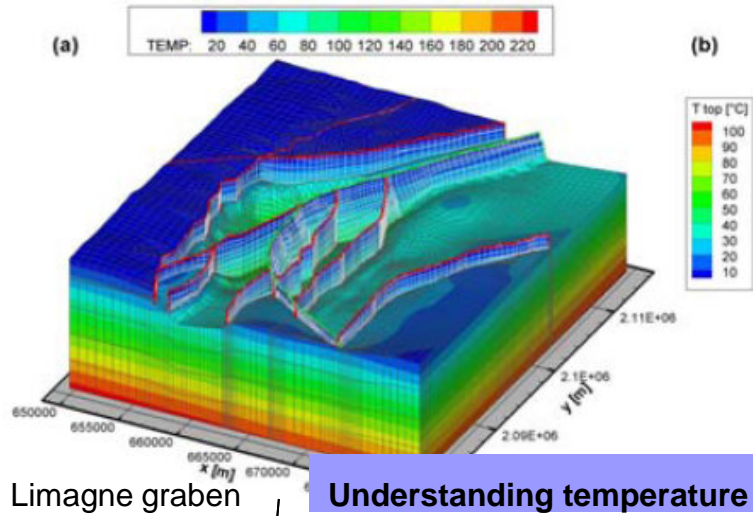
Cloetingh et al., 2010



Boundary conditions  
natural  
fractures/production



# Enhancing reservoir performance → Temperature, rheology and stress are critical



**Enhancing reservoir performance**

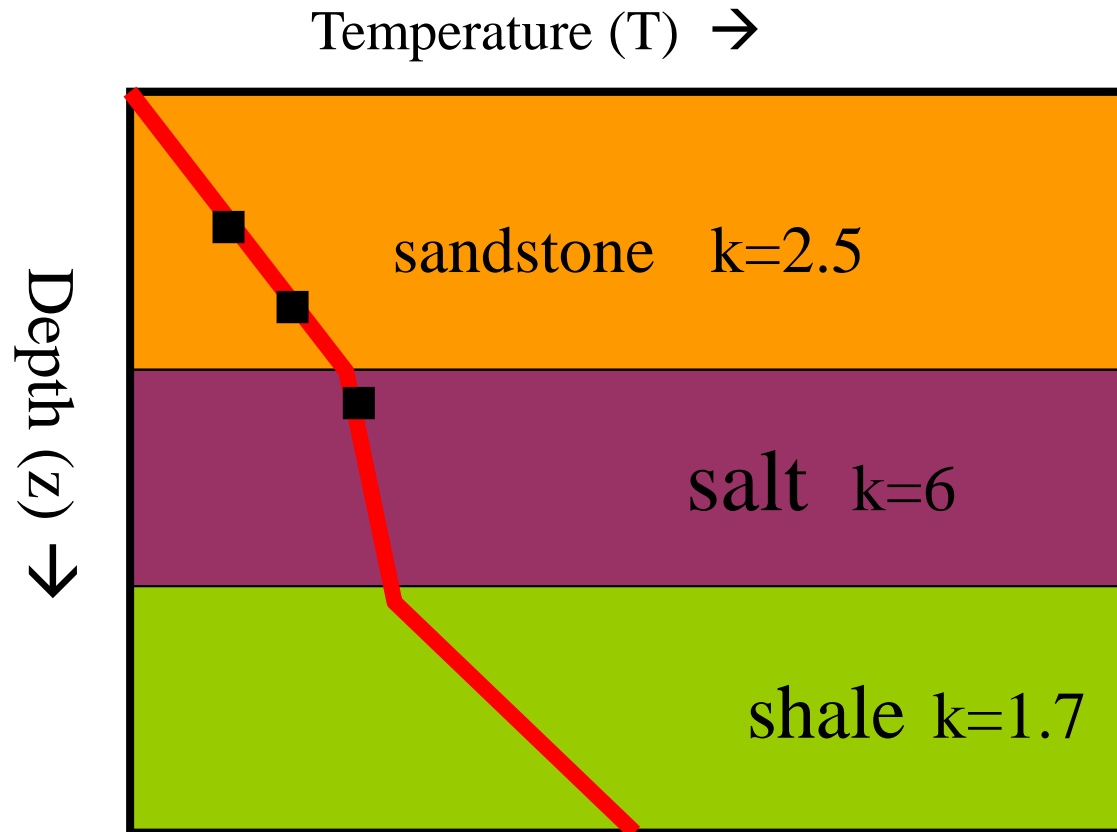
## Conductive-advective models sediments-crust

- **Heat flow  $q$**  [ $\text{mW}/\text{m}^2$ ] determines the temperature gradient in sediments in conjunction with **rock conductivity  $k$**  [ $\text{W m}^{-1} \text{C}^{-1}$ ]. Present day (PD) heat flow is calibrated by Temperature data (■) in wells.

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

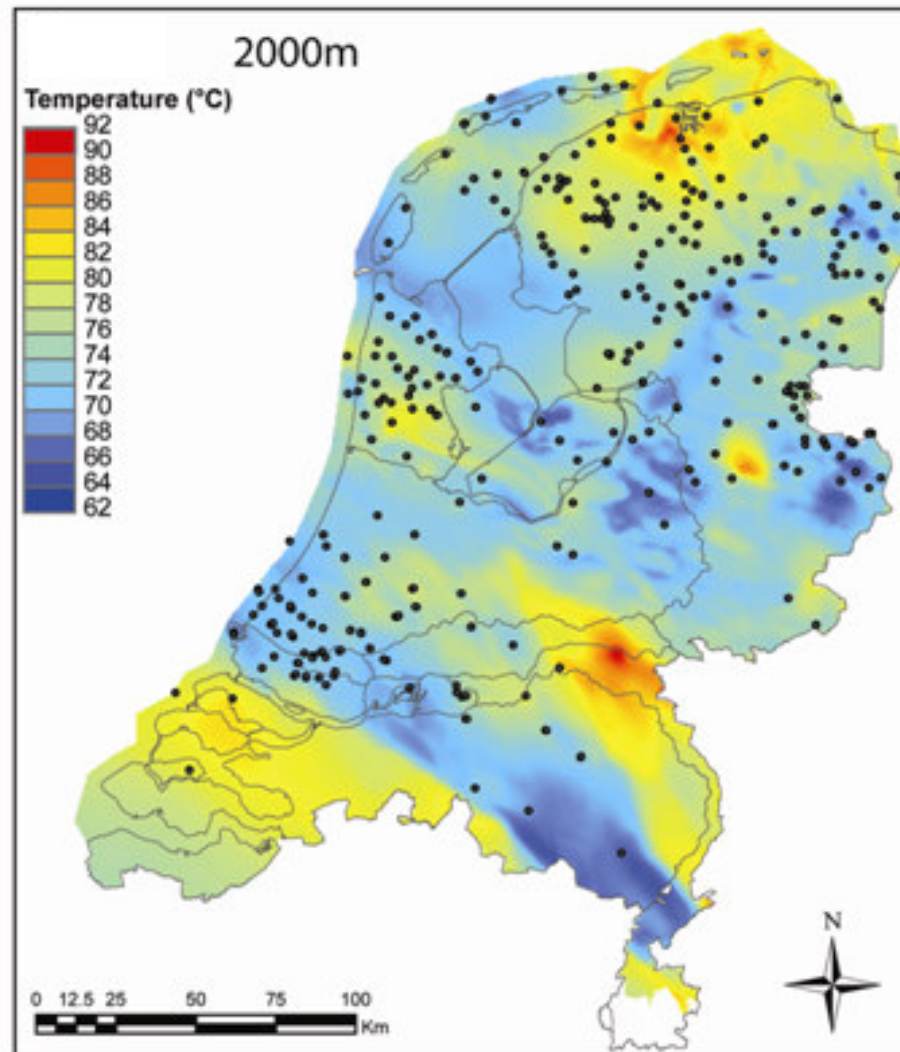
Geotherm

—  $q=60$

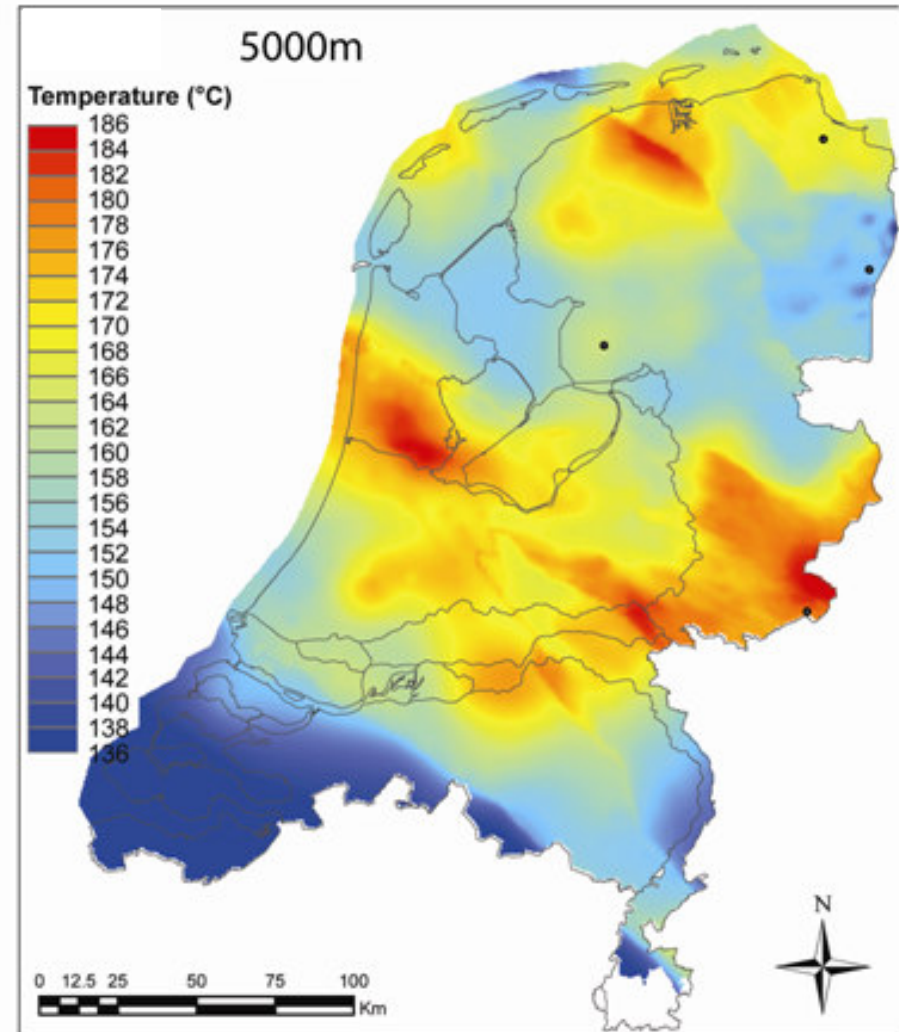


# Results - temperature

(shallow)



(deep)

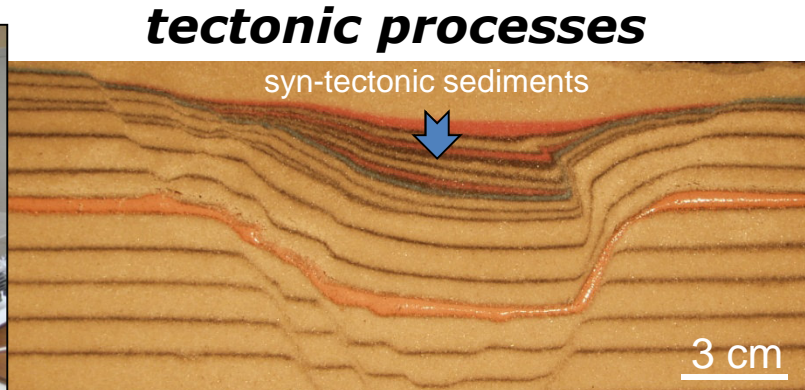


Bonte et al., 2012

# Integrated multiscale experimental facilities EPOS-NL (NSEO) – Cloetingh – Sokoutis- Willingshofer



**TecLab**



**tectonic processes**

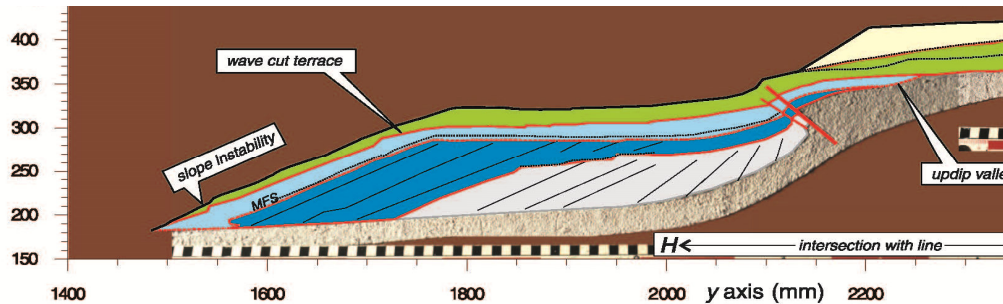
**vertical motions**

**surface mass transfer**

**EuroTank**

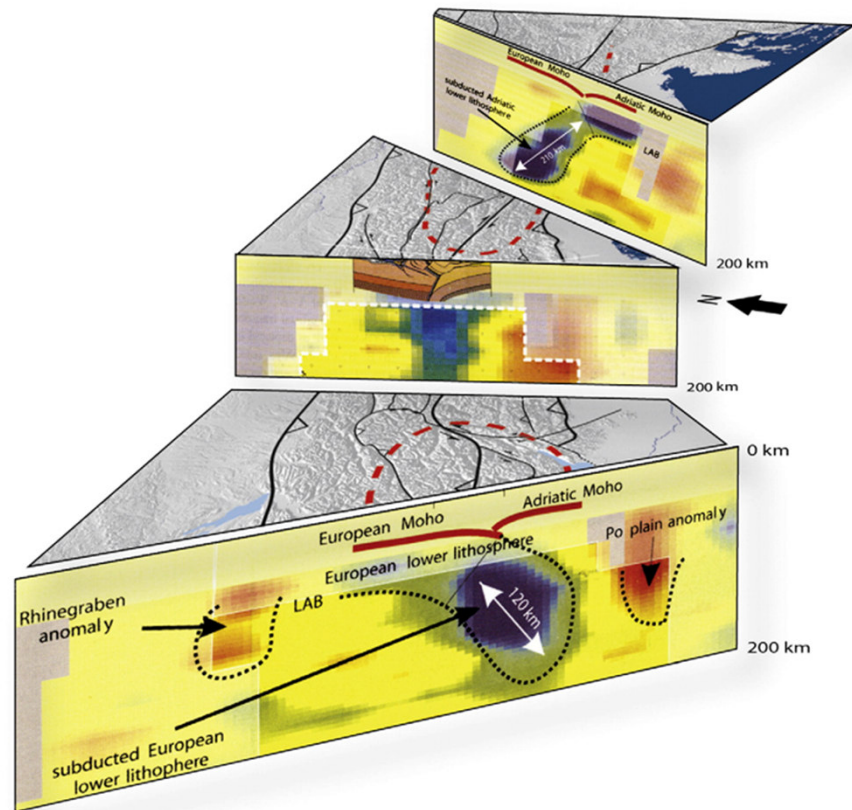


**depositional processes**

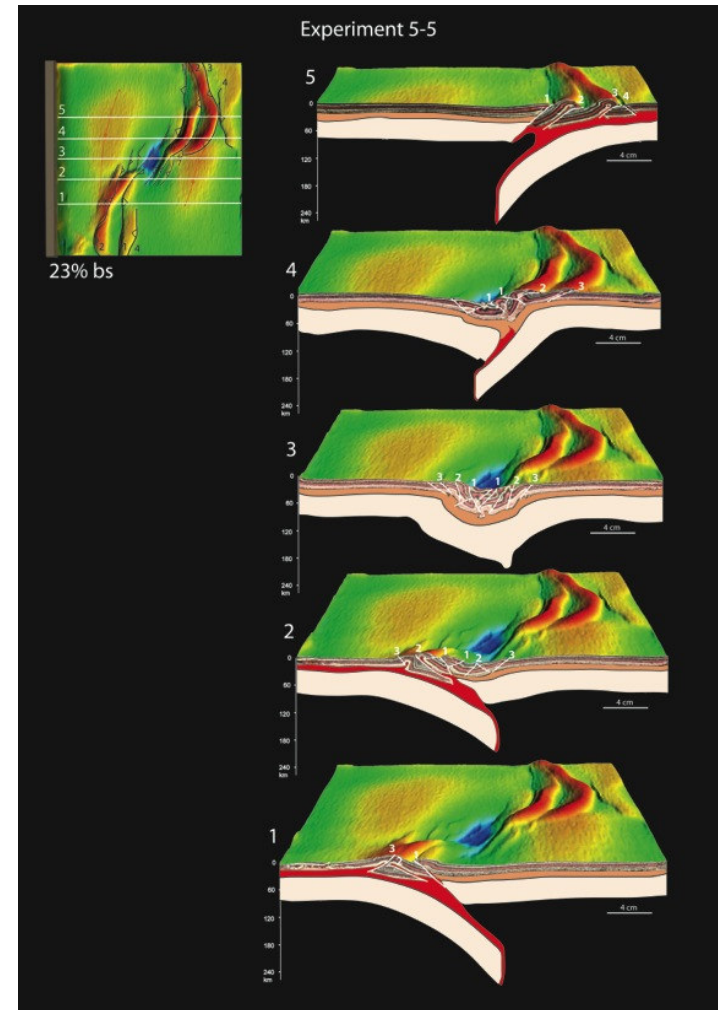


# Alps – Carpathians – Dinarides – Pannonian Basin

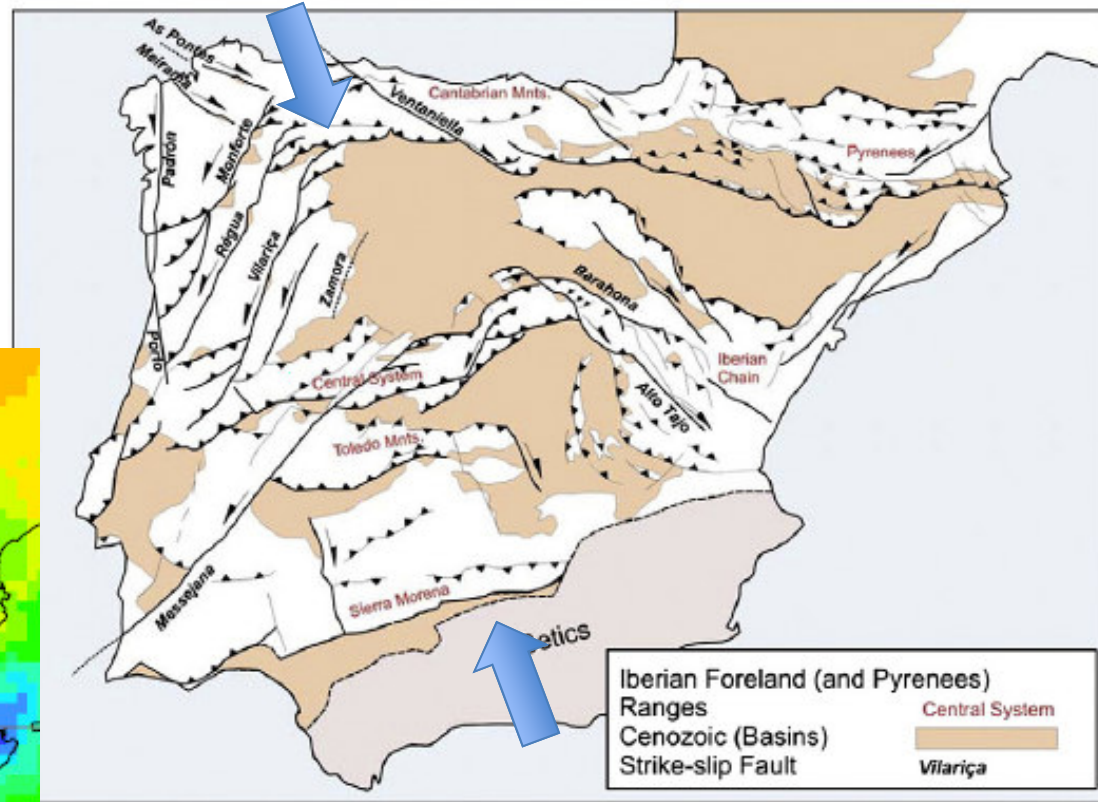
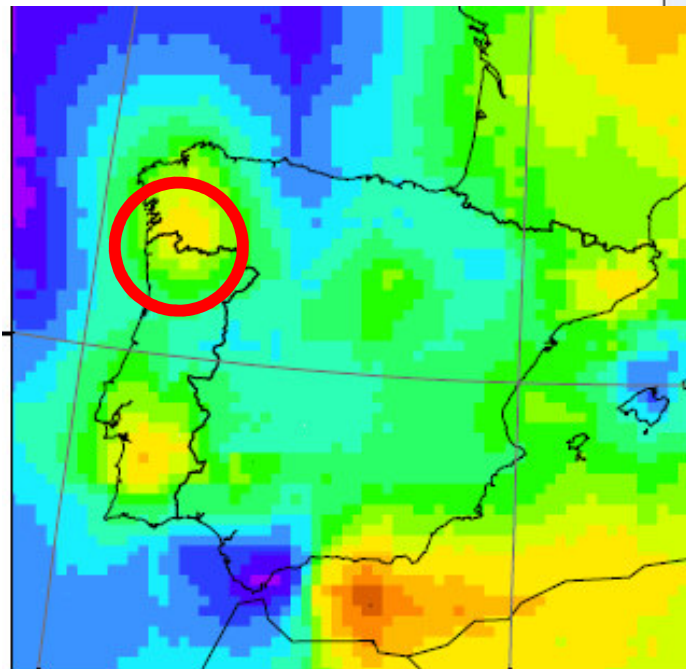
*On the surface expression of laterally changing subduction polarity*



Luth et al. 2013. *Tectonophysics*, 582.  
 Tomography from Lippitsch et al.; (2003)

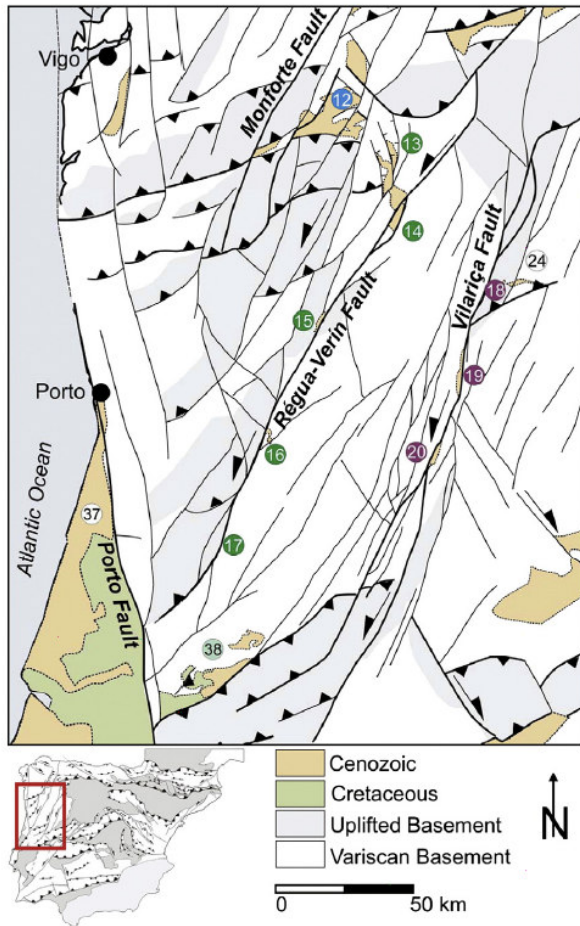


# IBERIA: intraplate tectonic setting

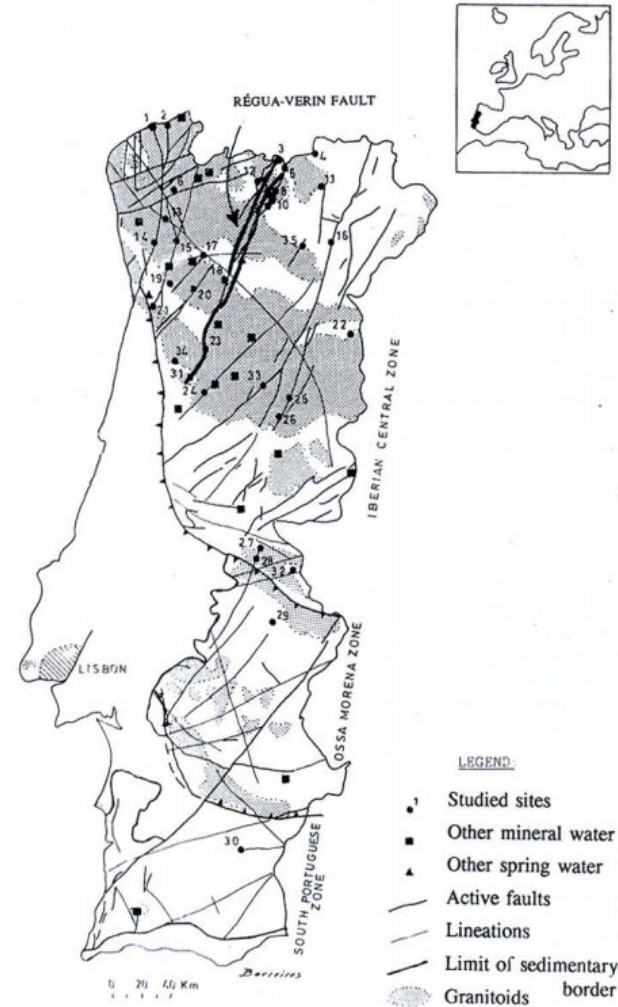


deVicente et al. 2011  
(Tectonophysics)

# Iberia Case study: architecture very dominant in fluid-path ways



deVicente et al. 2011  
(Tectonophysics)



Carvalho 1993



# Petrology group (UU)

Leader: Dr. M.J. van Bergen

## *Expertise in*

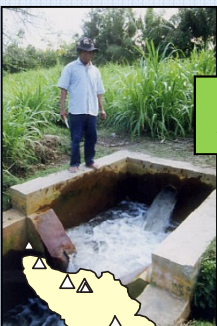
- Magma-fluid-rock interaction
- Petrology-geochemistry-isotope geology
- Field-based studies and lab analysis
- Research and education in Indonesia

Joint field-based research projects with Indonesian partners since 1984

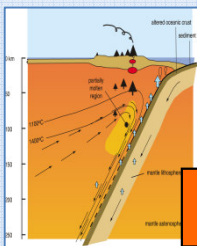
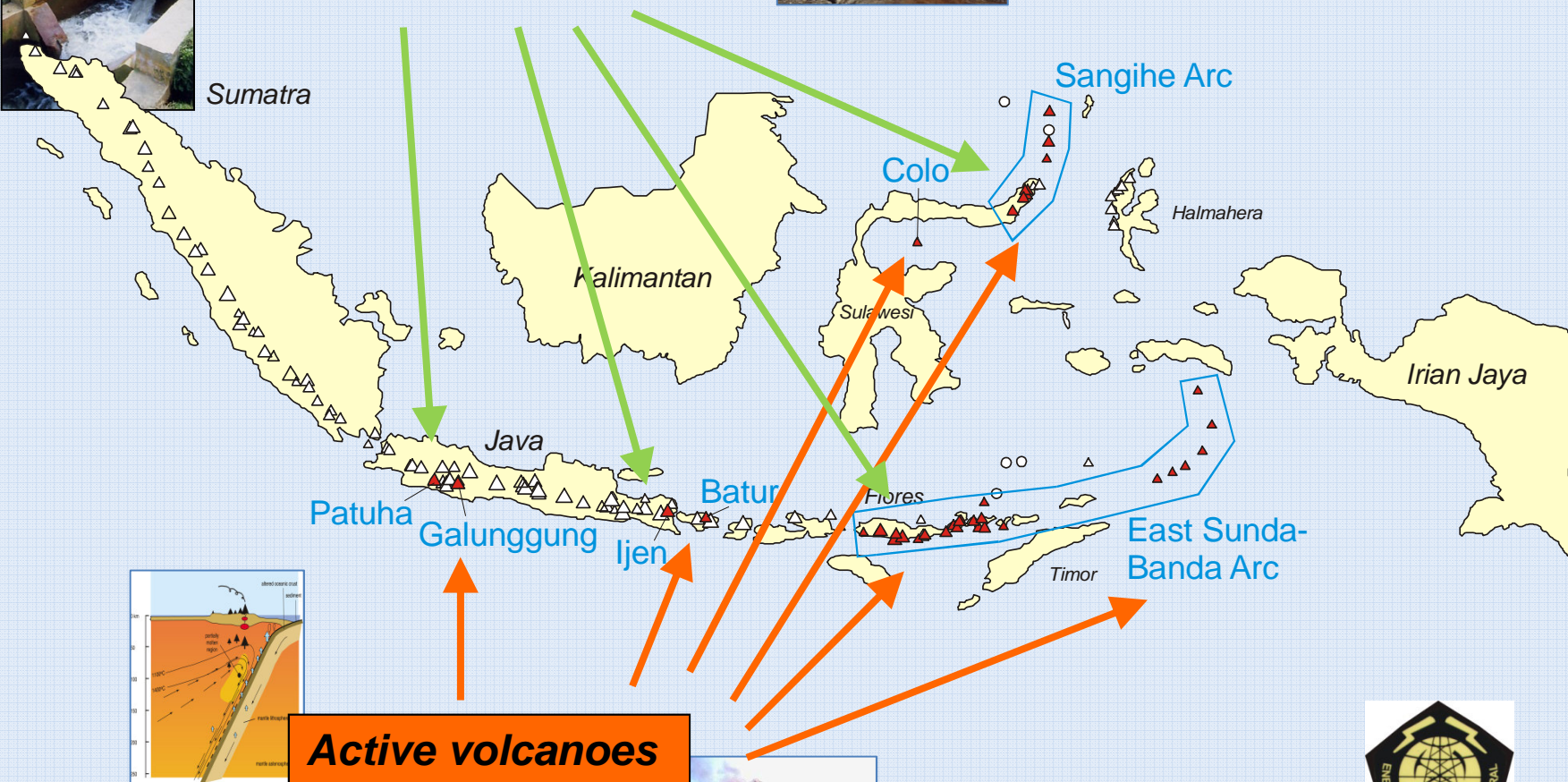
- Host of Indonesian PhD and MSc students
- Supervision of 6 PhD projects in Indonesia
- Ca. 30 scientific publications on projects in Indonesia



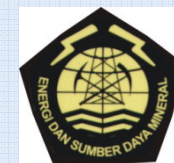
# Joint UU projects with Indonesian partners in volcanic-hydrothermal areas since 1984



**Hydrothermal environments**

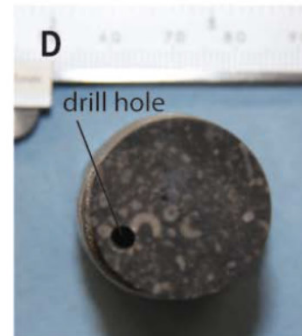


**Active volcanoes**



Direktorat Vulkanologi dan Mitigasi Bencana Geologi

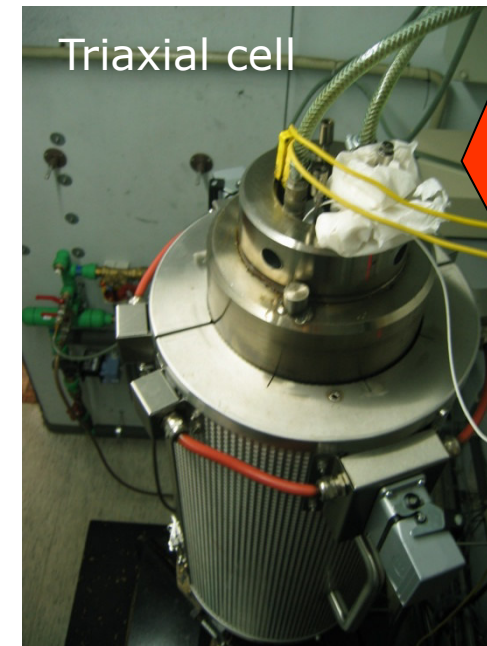
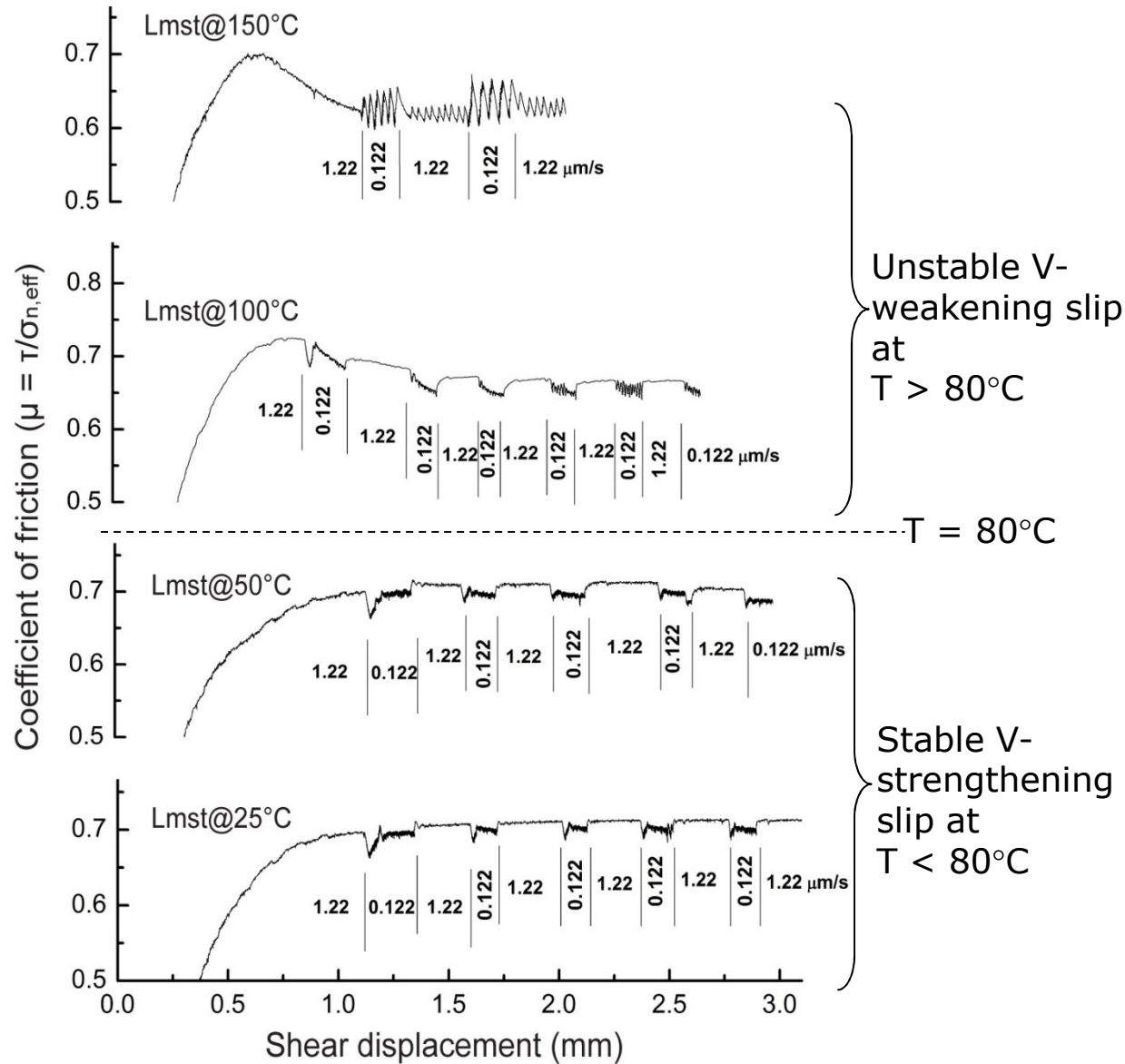
# Geothermal energy research (HPT Lab, UU Spiers)



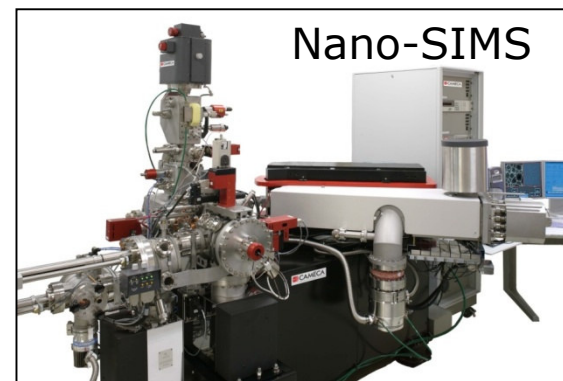
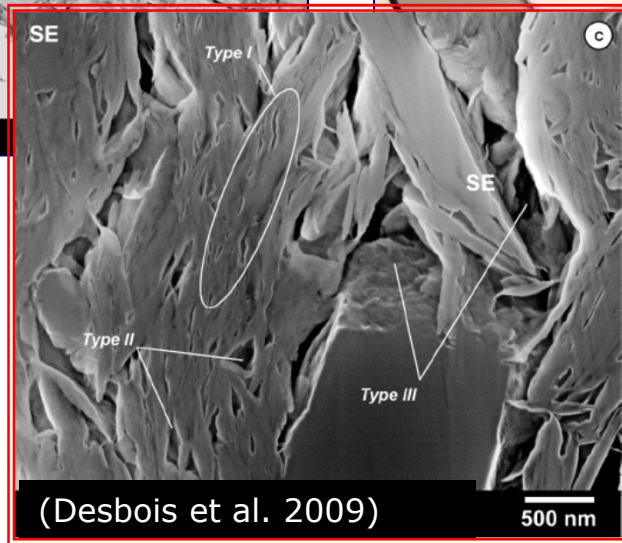
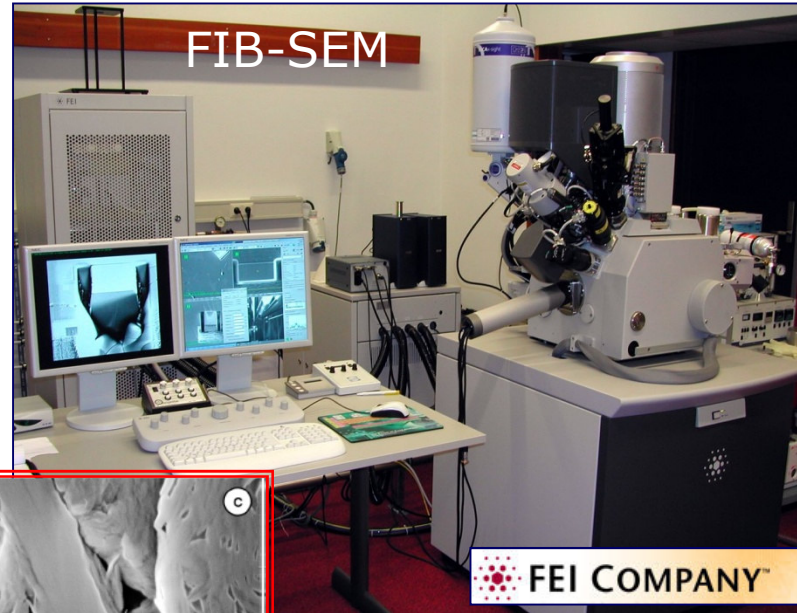
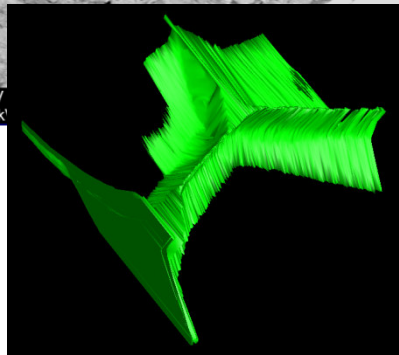
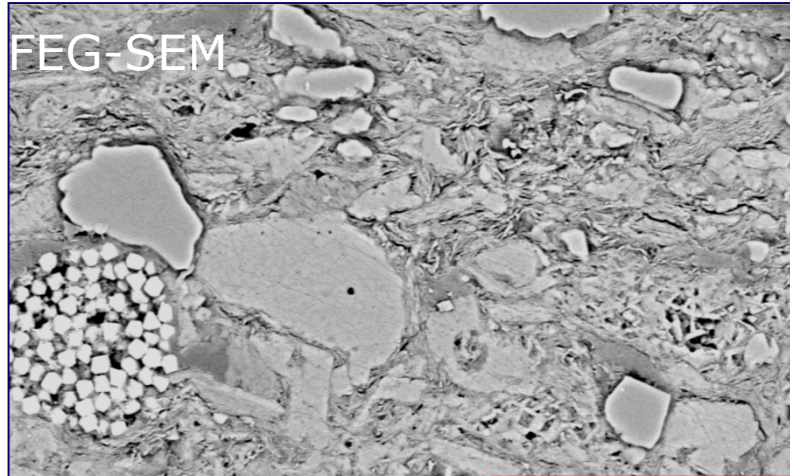
## Feasibility of deep electricity generation from Lr. Carboniferous Limestones

- Fracturing behaviour
- Transport properties
- In-situ P-T conditions
- Sponsor: IF Technology

# Fault motion in carbonates: Induced seismicity above 80°C



# Rock microstructure research at UU (Drury)



Collaboration:

TNO, RWTH Aachen

UU = National Centre for Nano-Analysis (QEM-Scan proposal in NSEO)