Temperature and heat-flow techniques in the exploration of Enhanced Geothermal Systems (EGS): an overview from the shallow surface to deep into the lithosphere

Förster, A., Lenkey, L., Schellschmidt, R., VanWees, J.-D., Cloetingh, S.A.P.L.

GFZ Potsdam

Helmholtz Gemeinschaft

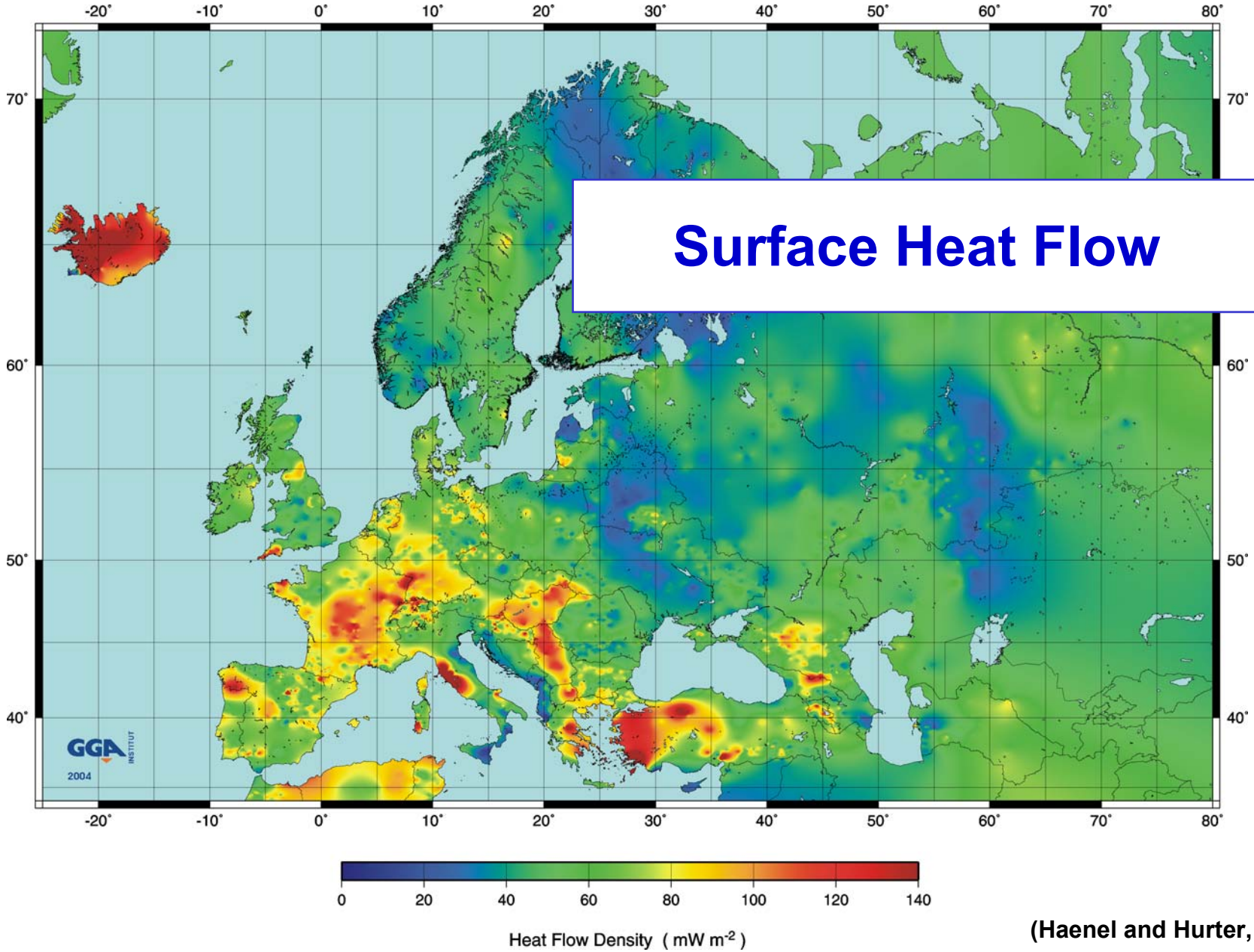
Univ. Budapestinensis de Eötvös Nom. Facultas Sci. Nat.

GGA Institut

TNO

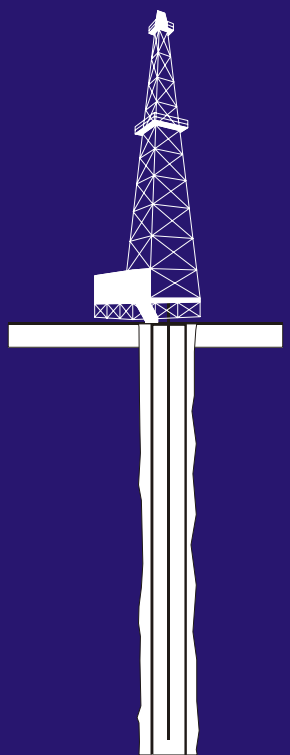
- **Evaluation of the thermal state of subsurface formations at drillable depth**

- **Deciphering of processes responsible for temperatures appropriate for EGS development**



(Haenel and Hurter, 2002)

Heat-Flow Determination

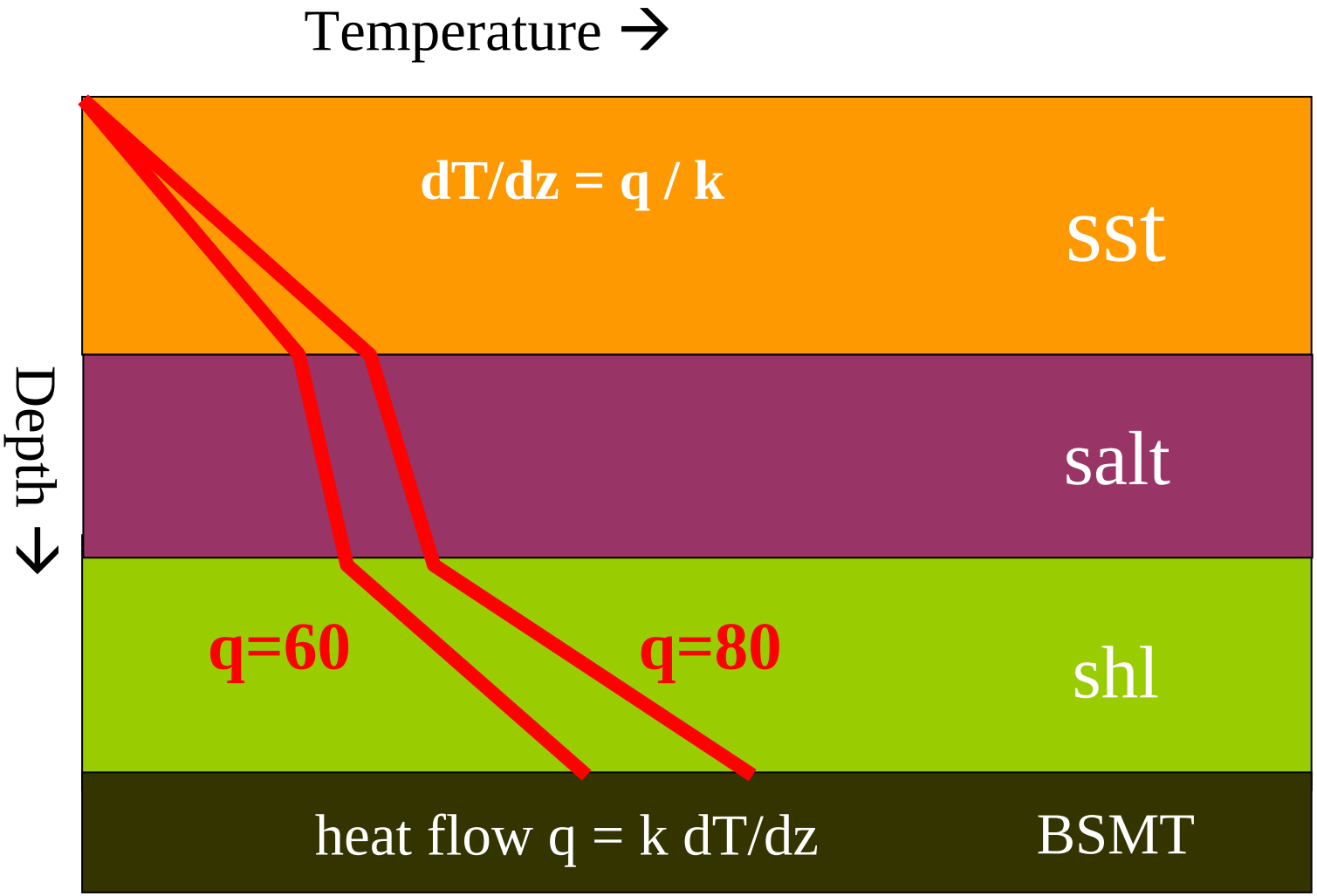


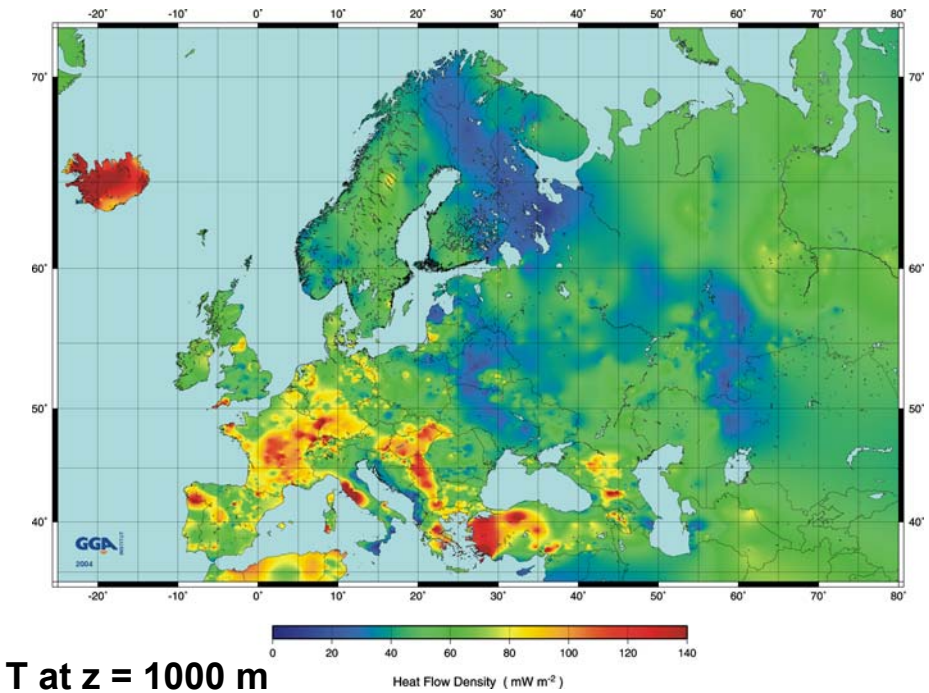
Basic Data

- temperature values/profiles
- temperature gradient
- thermal conductivity (core/cuttings)

Corrections of Temperature and T gradients

- terrain effects incl. topography, paleoclimate etc.

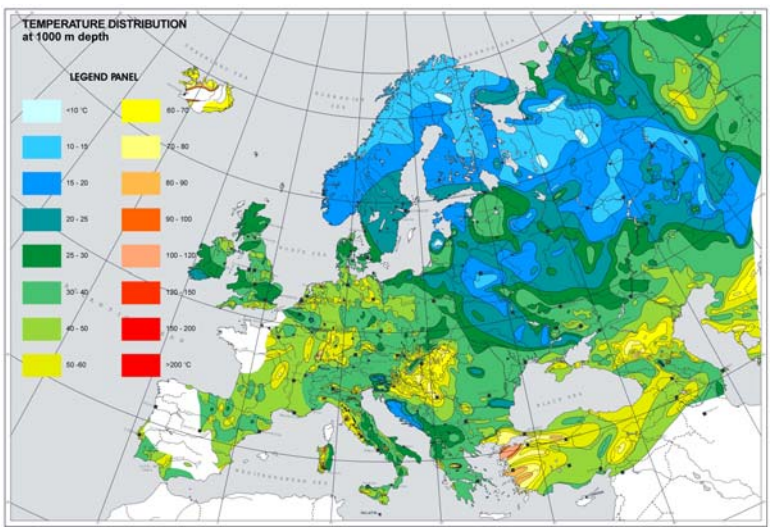

Temperature →
← Depth
dT/dz = q / k
sst
salt
shl
q=60
q=80
heat flow q = k dT/dz
BSMT



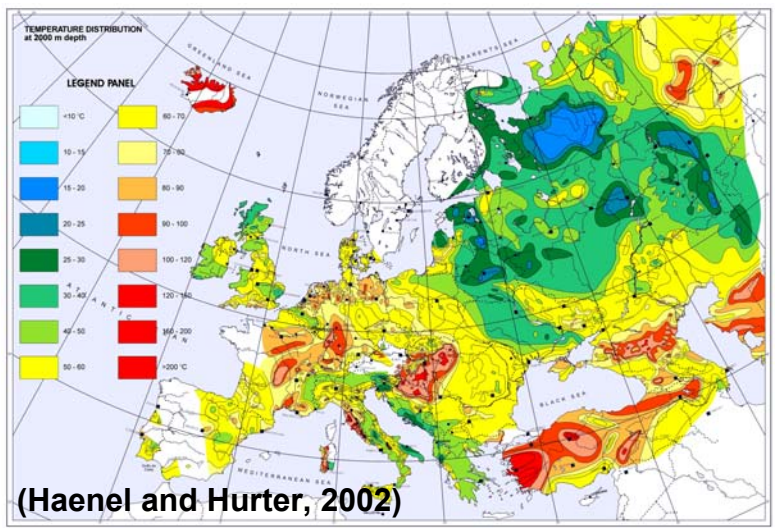
Surface heat flow is an important thermal parameter to characterize thermal potentials

Strong resemblance between surface heat flow and subsurface temperature

T at z = 1000 m



T at z = 2000 m



(Haenel and Hurter, 2002)

Effects on Thermal Field Pattern

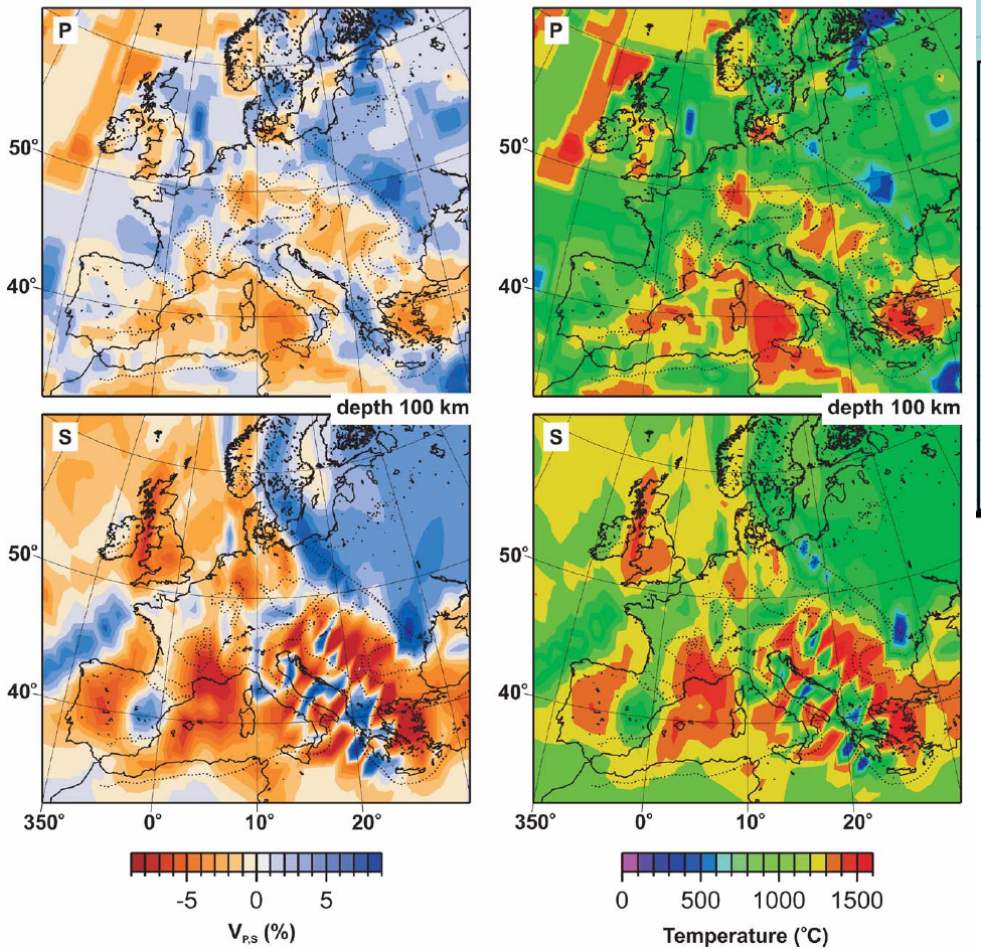
Geodynamic processes in lithosphere and asthenosphere

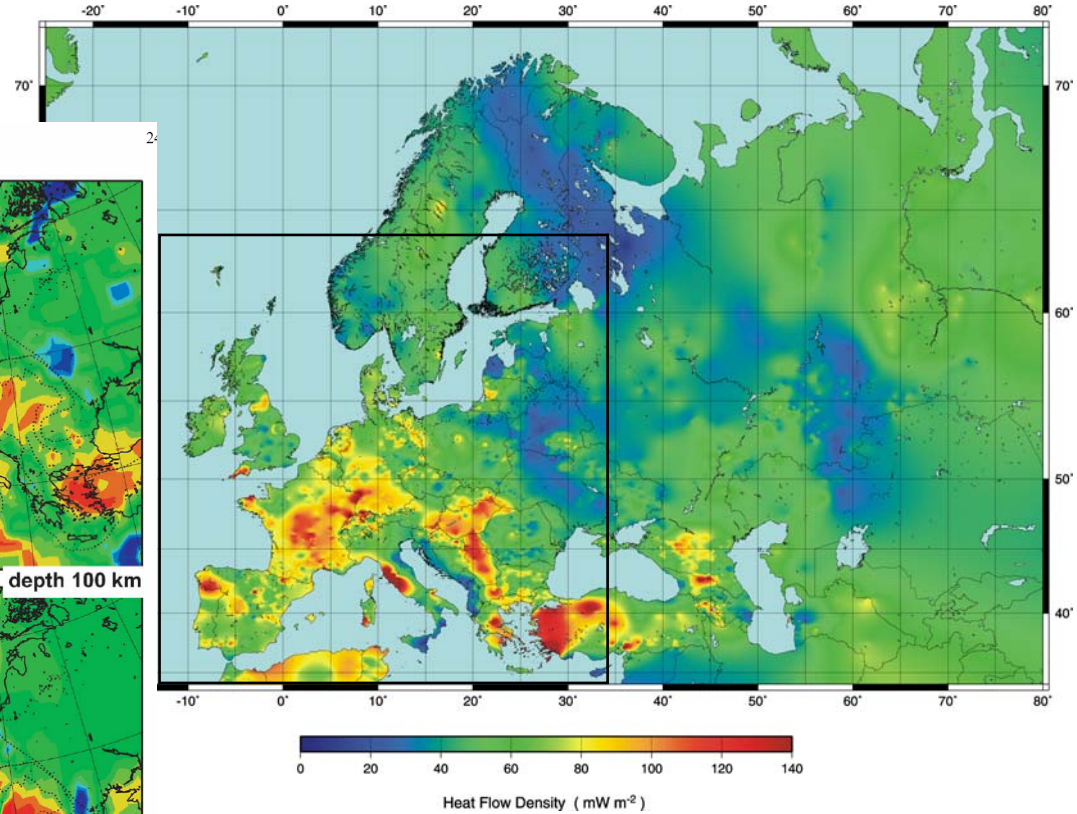
Heat generation and thermal conductivity of crust

Heat distribution by fluids

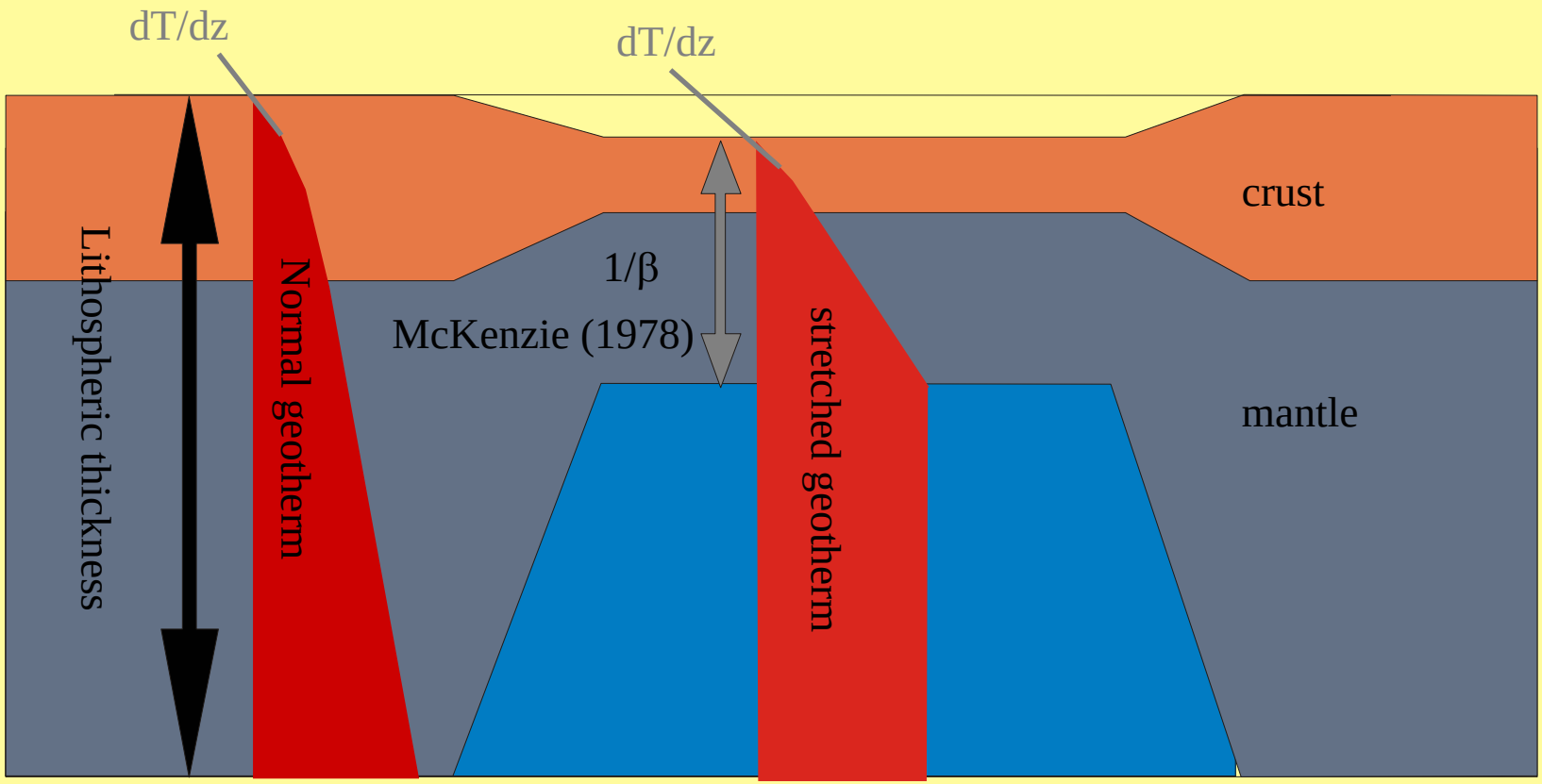
High amplitude / small wavelength anomalies, where and why ?

(Cloetingh et al., 2005)

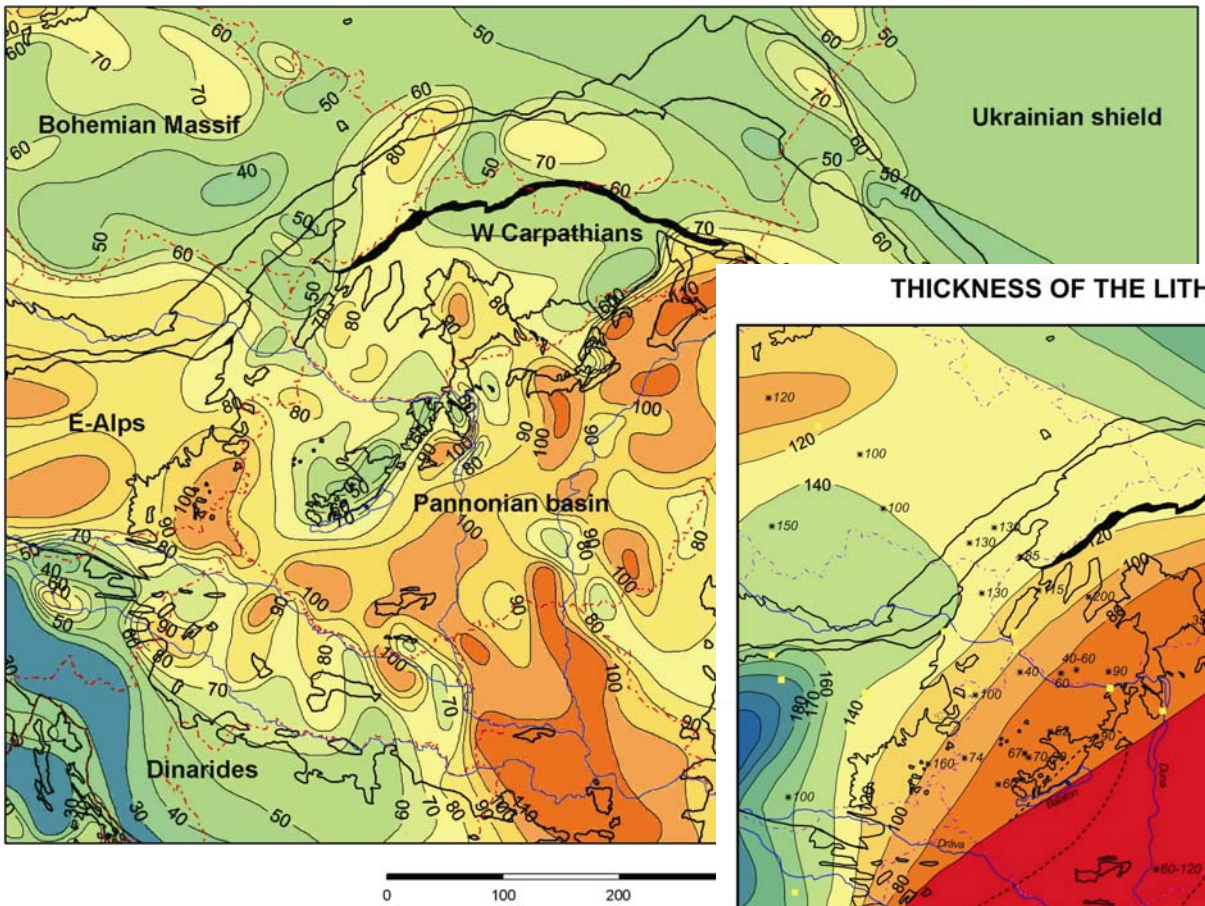




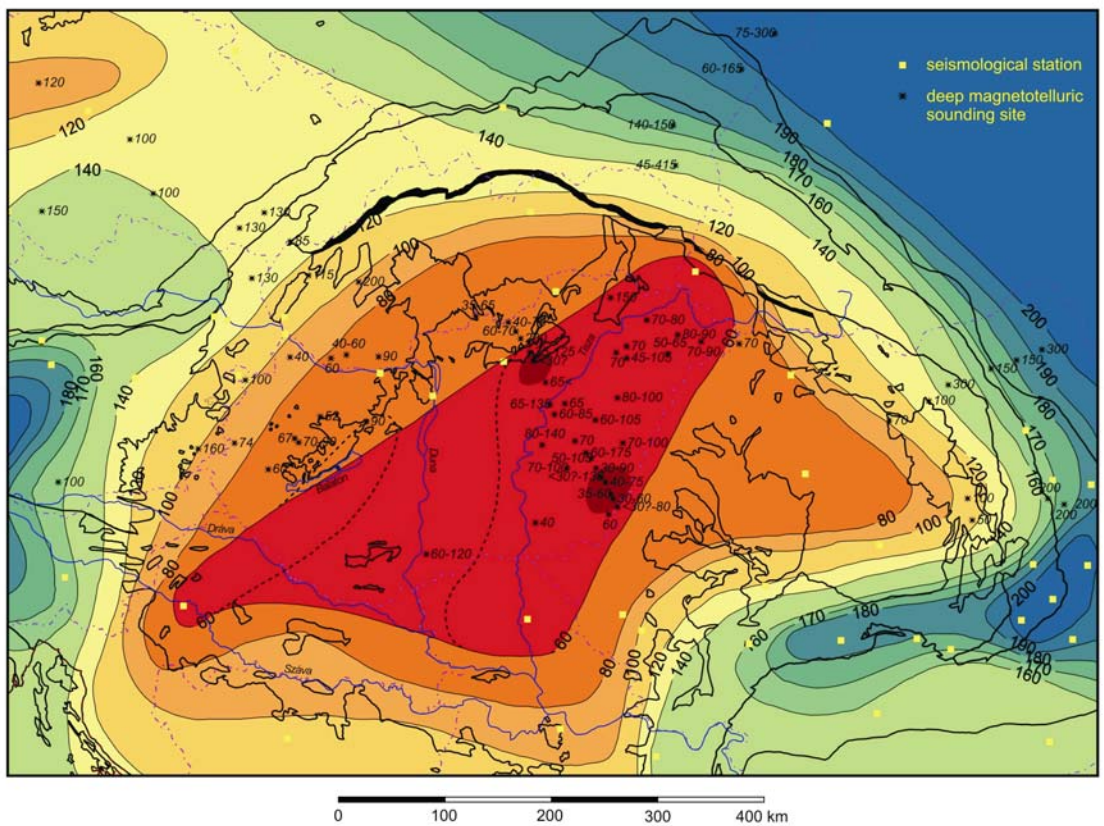
Transient heat flow

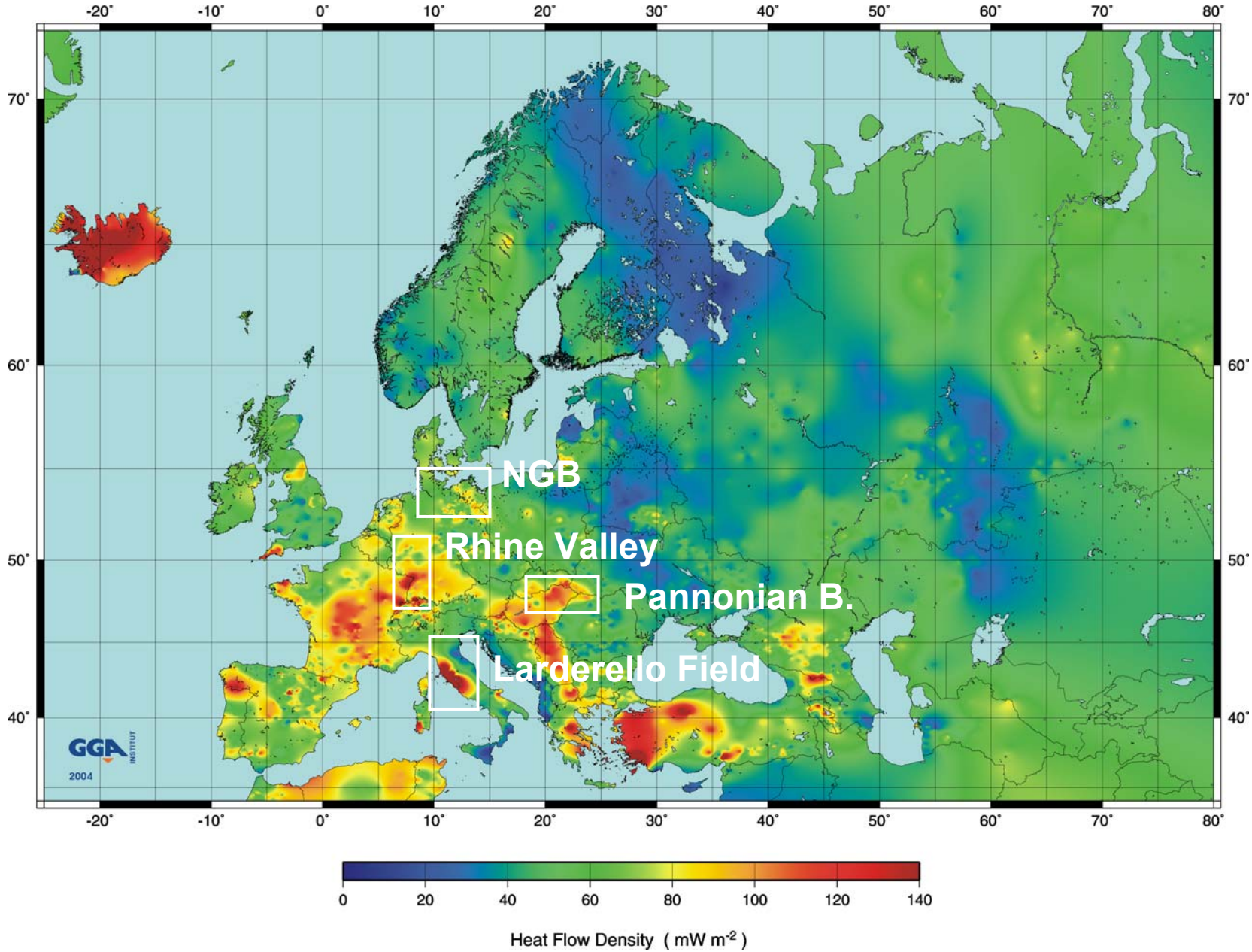


HEAT FLOW IN THE PANNONIAN REGION



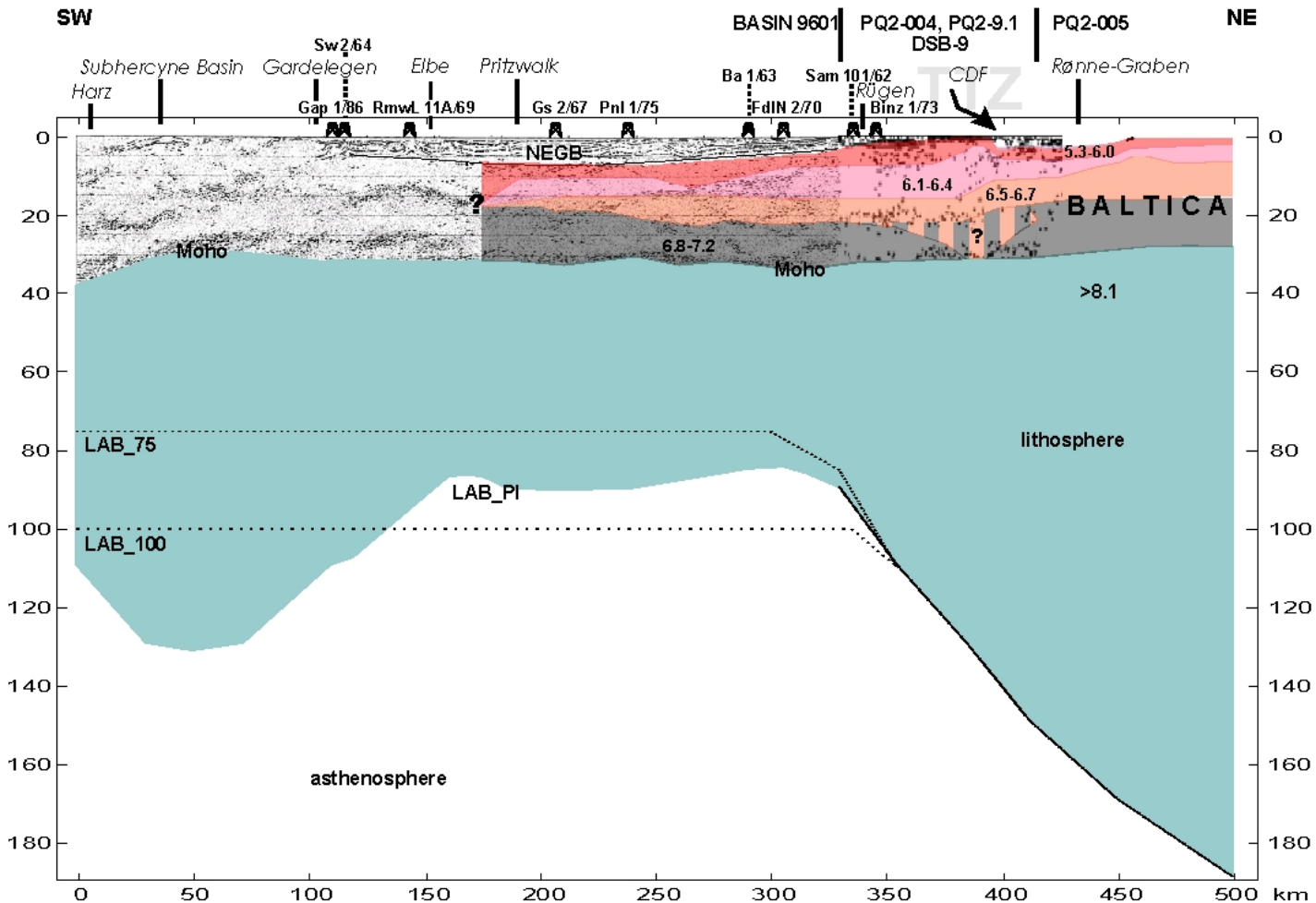
THICKNESS OF THE LITHOSPHERE IN THE PANNONIAN REGION



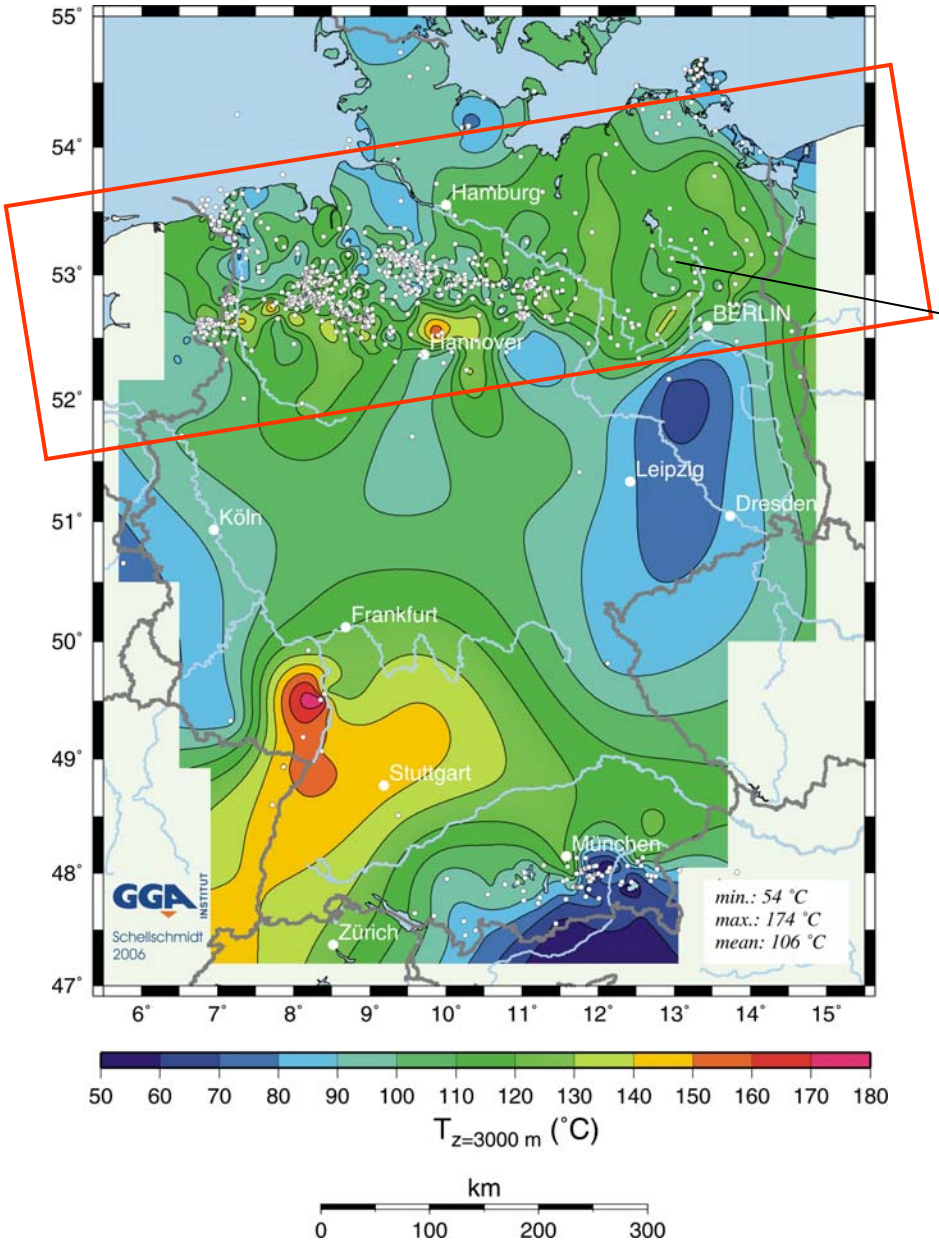

-20°
-10°
0°
10°
20°
30°
40°
50°
60°
70°
80°
70°
60°
50°
40°
NGB
Rhine Valley
Pannonian B.
Larderello Field
GGA INSTITUT
2004
0
20
40
60
80
100
120
140
Heat Flow Density (mW m-2)

North German Basin

- Heat flow by conduction
- High heat flow (70-90 mW/m²) as a result of lithosphere thickness and crustal composition



(Norden and Förster, submitted)



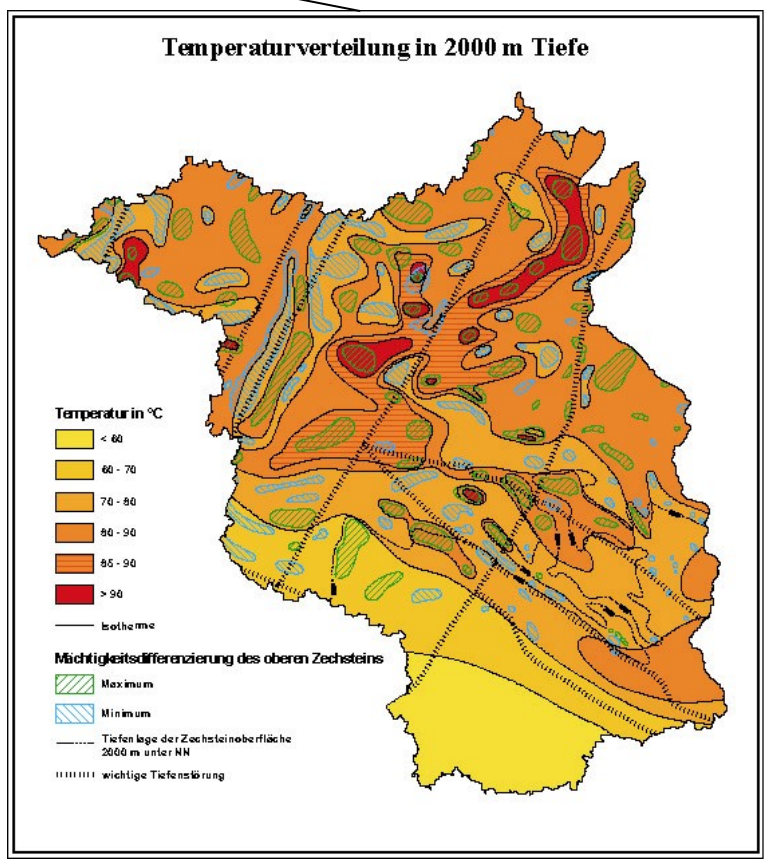
Different temperature qualities

BHTs (DSTs)

T-Logs

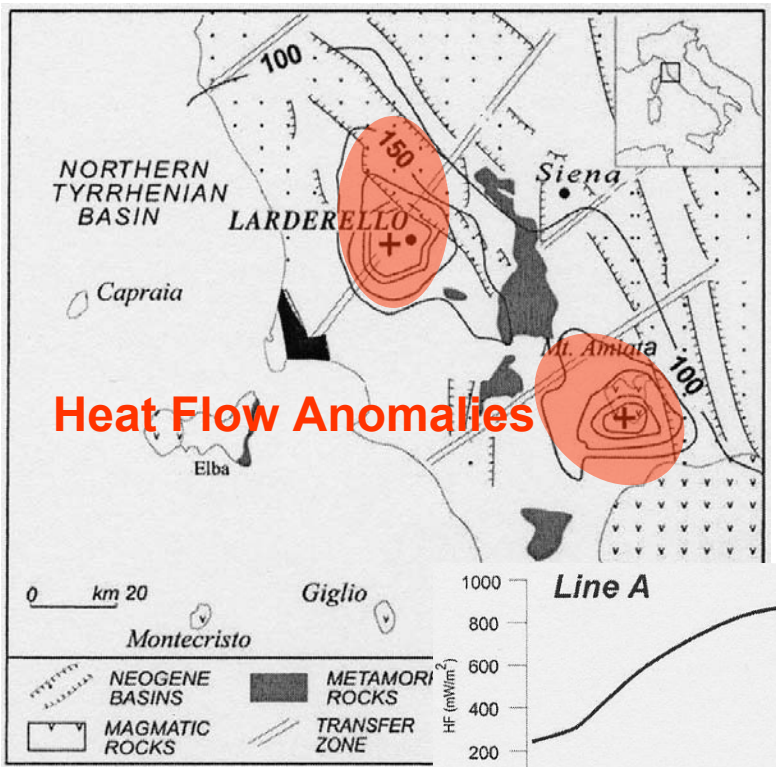
Different mapping scale/detail

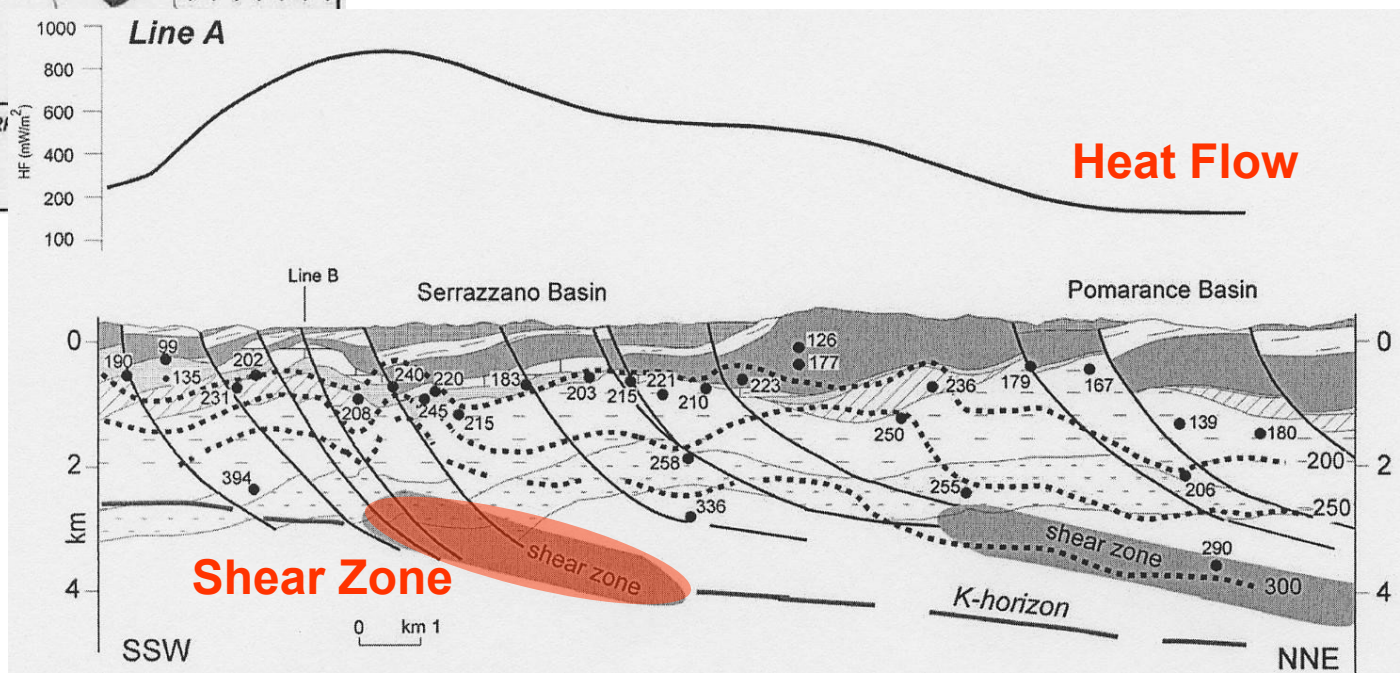
Heat refraction at salt structures



Tuscan Geothermal Fields

- Mass and heat flux from the mantle in an extensional setting
- Emplacement of granite magmas (3.8-1.3 Ma)
- Extensional shear zone as main pathways for flow of hot fluids towards superficial reservoir



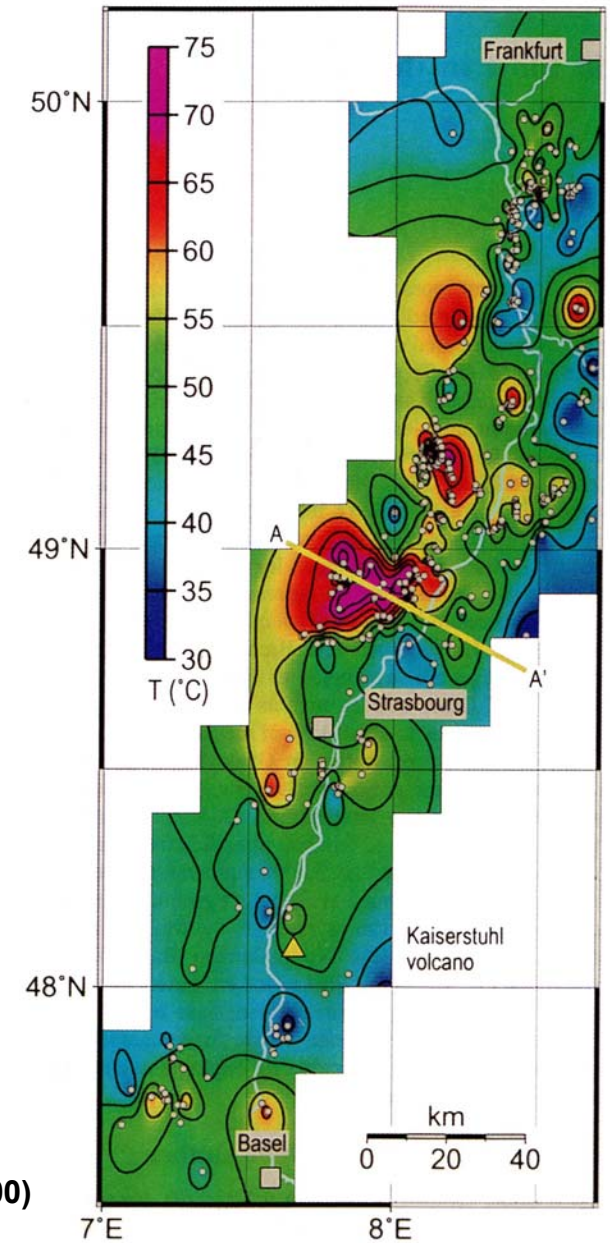


(Bellani et al., 2004)

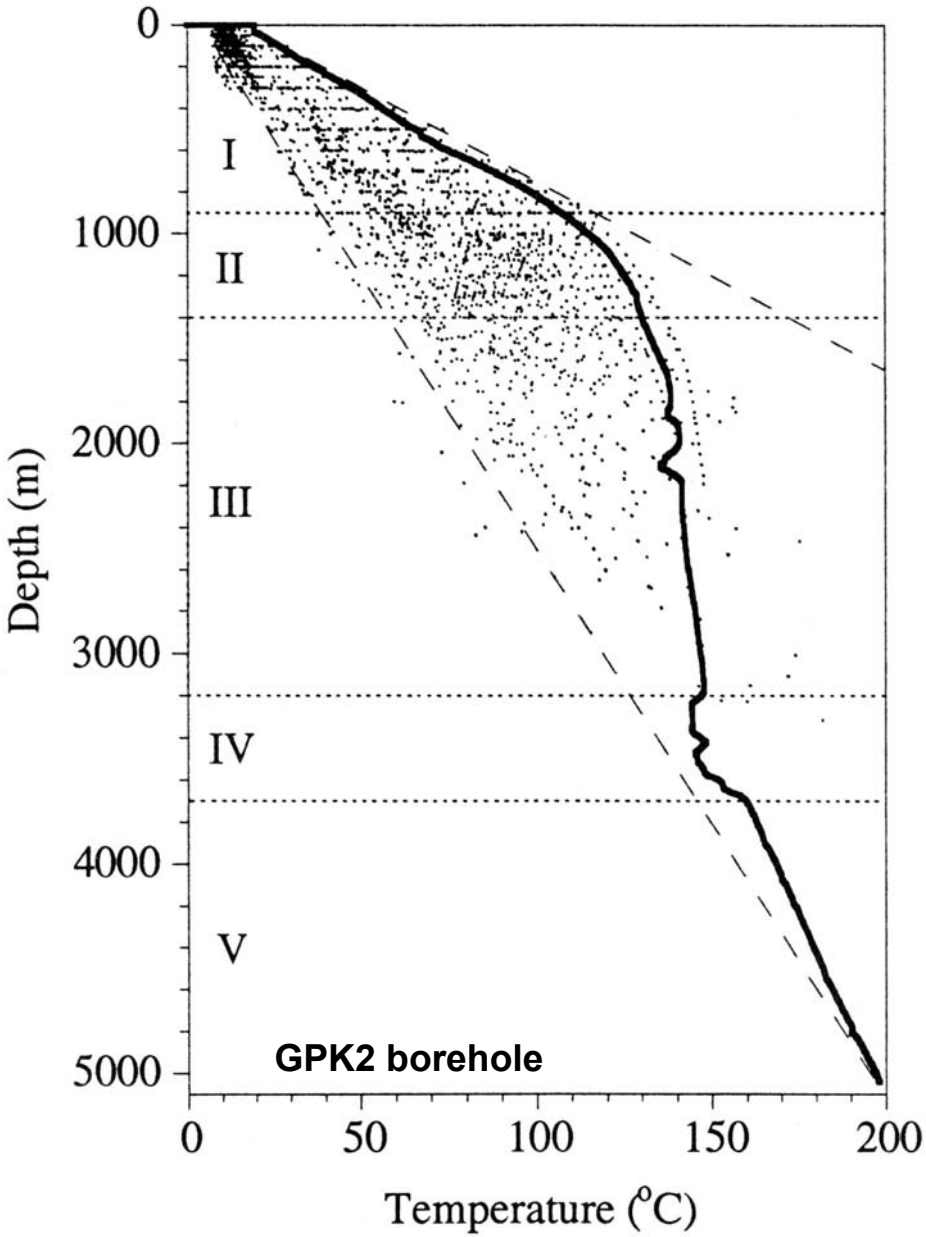
The Rhine Graben
Temperature at 800 m

- Thermal anomalies are not correlated to crustal thickness

- Heat transfer is as combination of conduction and convection



(Pribnow and Schellschmidt, 2000)



conduction

convection

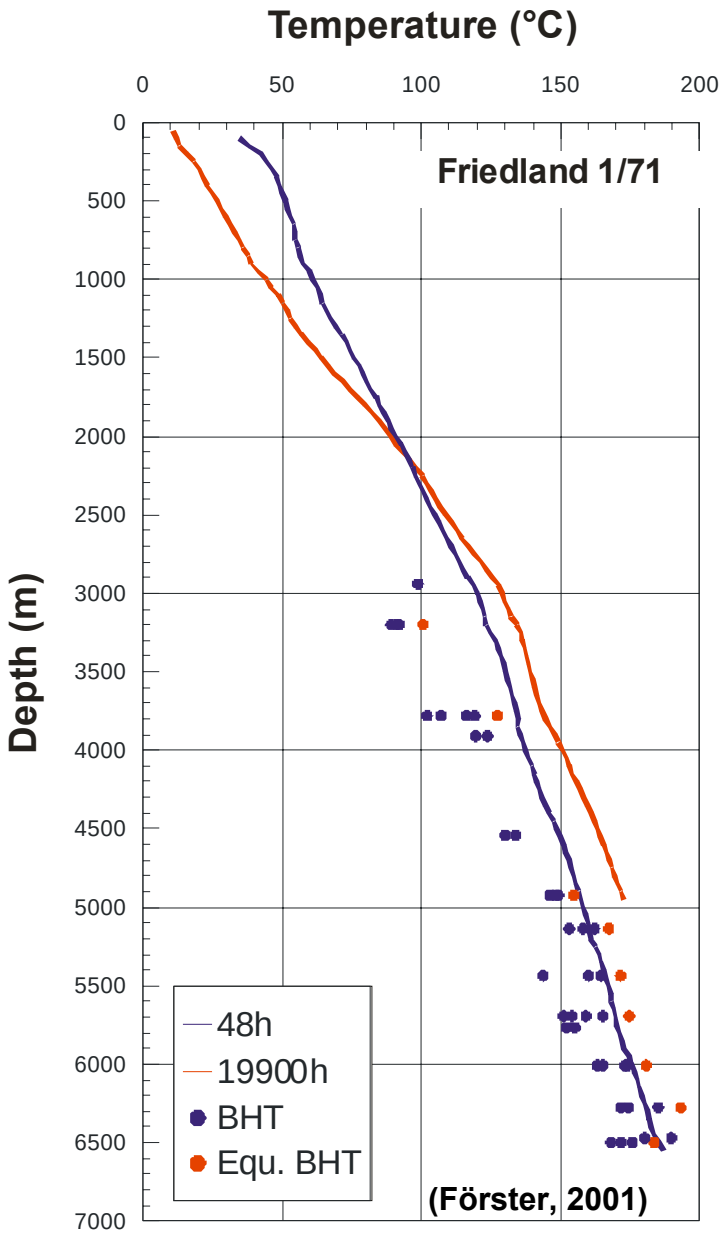
convection

convection

conduction

BHTs versus Temperature Logs

(Pribnow and Schellschmidt, 2000)



BASIC TEMPERATURE DATA:

Temperature log (steady-state conditions)

Temperature log plus multiple BHTs
Temperature log
Temperature log plus single BHT
Multiple BHTs at different depths - no log
Single BHT - no log

CORRECTION

Empirical **Numerical**

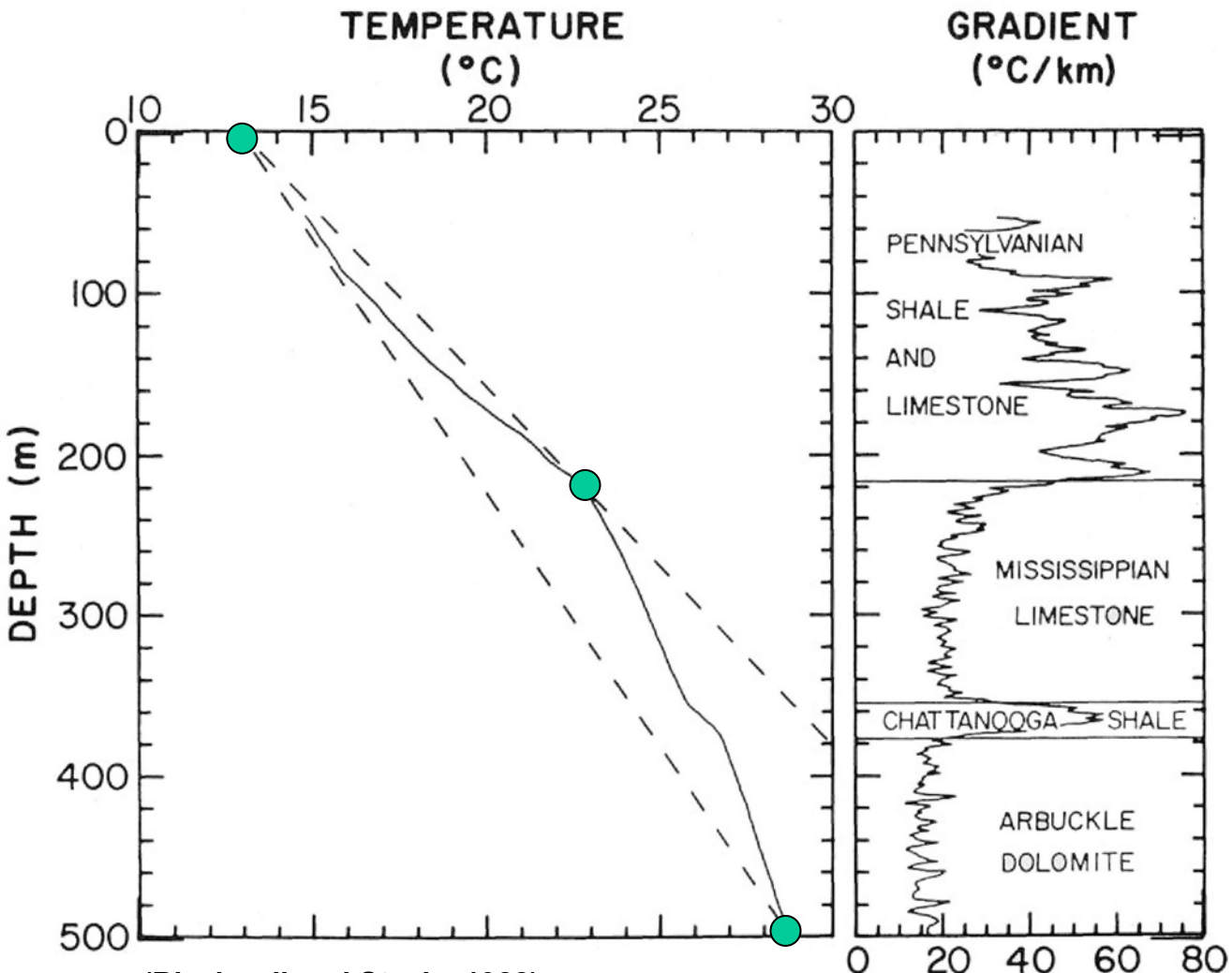
VALID TEMPERATURE-DEPTH DISTRIBUTION

- **Raw temperatures deviate by as much as 22 ± 10°C (1δ) from the true formation temperature**

- **Corrected temperatures underestimate formation temperatures by as much as 8 – 9°C.**

- **Large standard deviations indicate that corrected BHTs (with 2δ confidence) reflect formation temperatures not better than ± 16°C.**

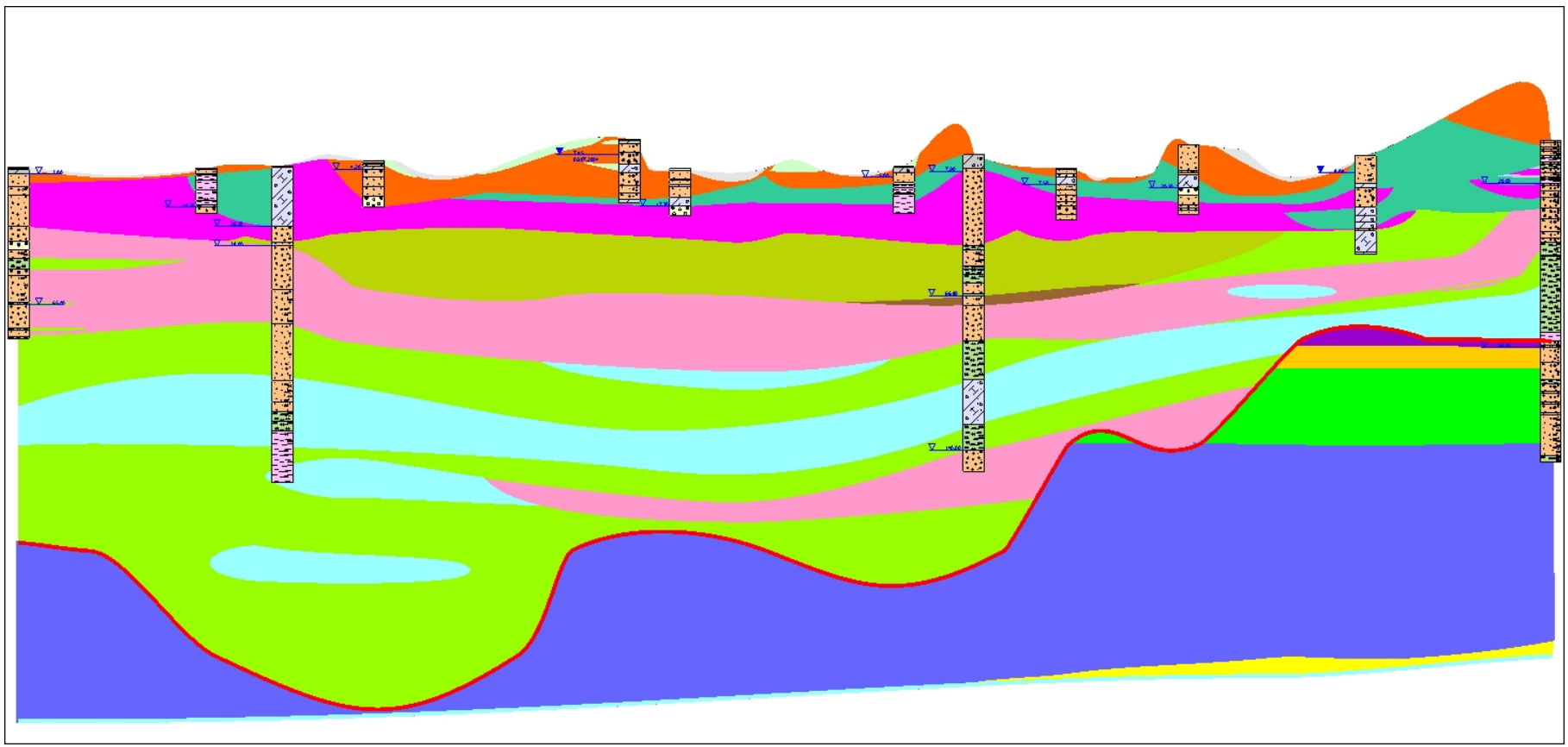
BHTs vs. Temperature Log



(Blackwell and Steele, 1988)

Internal thermal properties of sedimentary basins

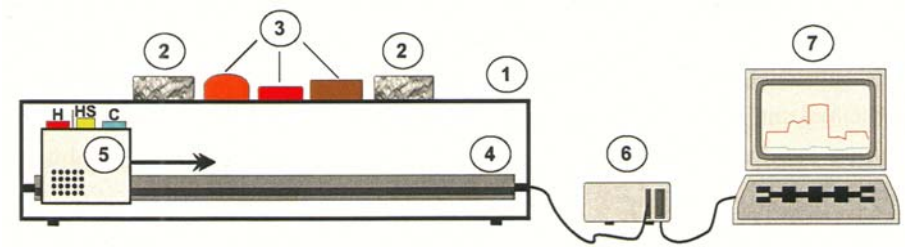
often unknown locally and regionally



Thermal Conductivity

More data are needed
Data banking is rudimentary yet

Laboratory Measurements



Well-Log Approaches

PETROPHYSICAL WIRELINE LOGS:

Gamma-ray (API units)
Density (g/cm^3)
Sonic (msec/ft)
Neutron porosity (limestone-equiv. units)

"PETROPHYSICAL DESCRIPTORS":

Vsh : proportional volume of shale
RHOmaa : apparent matrix density
Dtmaa : apparent matrix transit time

PHIe: "effective" porosity

Estimated Accuracy of Heat-Flow Determination

(based on methodology)

Temperature Data	Thermal Conductivity	Accuracy
High-precision contin. log	Core samples	± 5-10%
High-precision contin. log	Drill chip samples	± 10-15%
Several corr. BHTs	Core samples	± 10-20%
1 or 2 corr. BHTs	Core or chips	± 15-25%
High-precision contin. log or corr. BHTs	Estimated	± 30-40%
Single BHT	Estimated	± 40-50%

Deming et al. (1990)

Signatures of Temperature Field

EGS Concept Phase

EGS Exploration Phase

EGS Development Phase