# Drilling 2.5 km in the Swedish Caledonides: The COSC project

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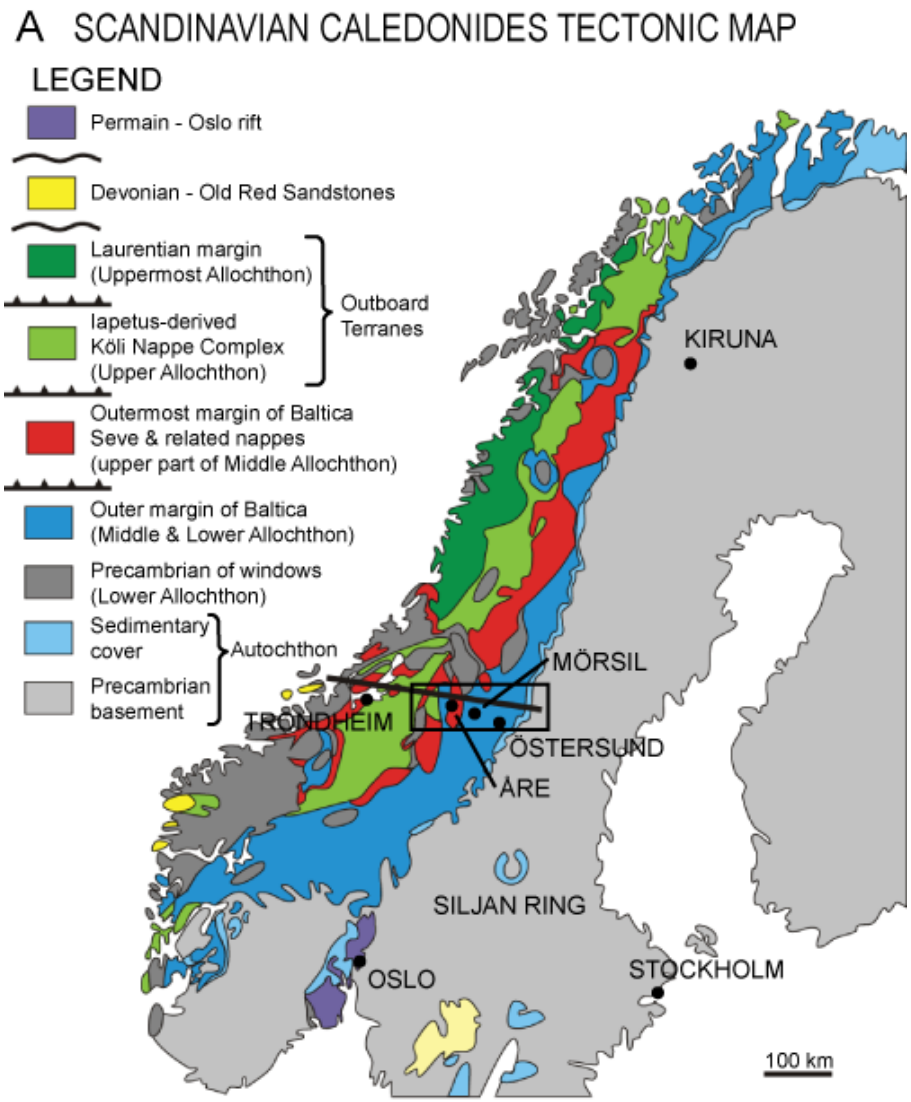
# Where are we and what are we looking for?

- Allochthon
  - Upper
  - Middle (hot)
  - Lower
- Sole thrust
- Autochthon



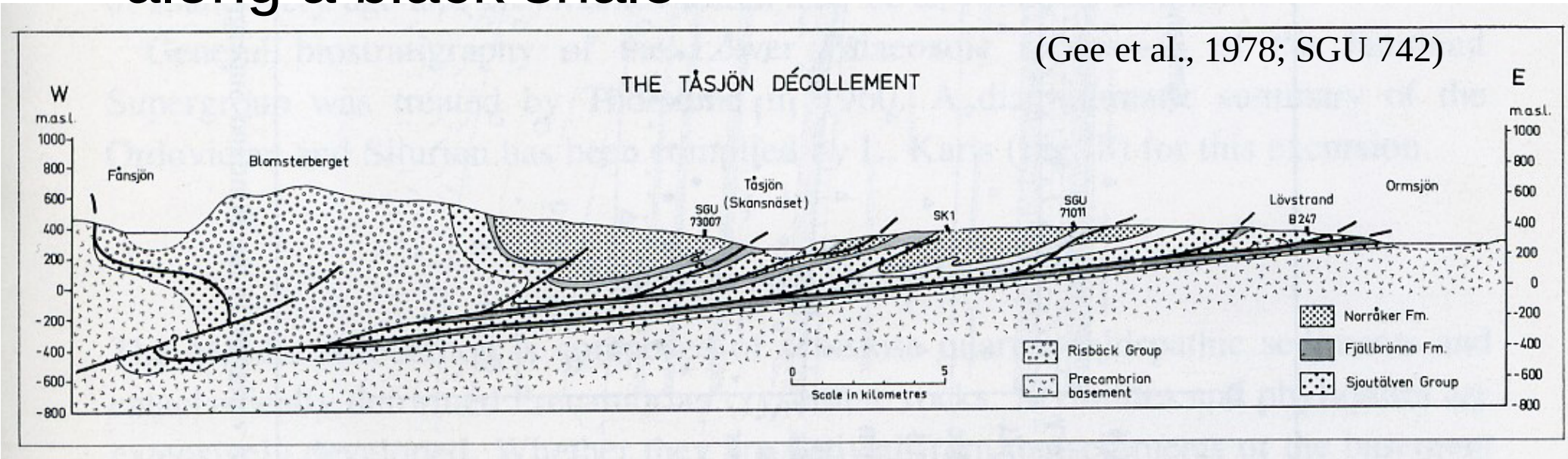

Collisional Orogeny in the Scandinavian Caledonides (COSC)

# The Caledonian front north of the COSC area

Clear detachment close to basement

Duplication and triplication of units above

Transport of allochthons of at least 70 km along a black shale

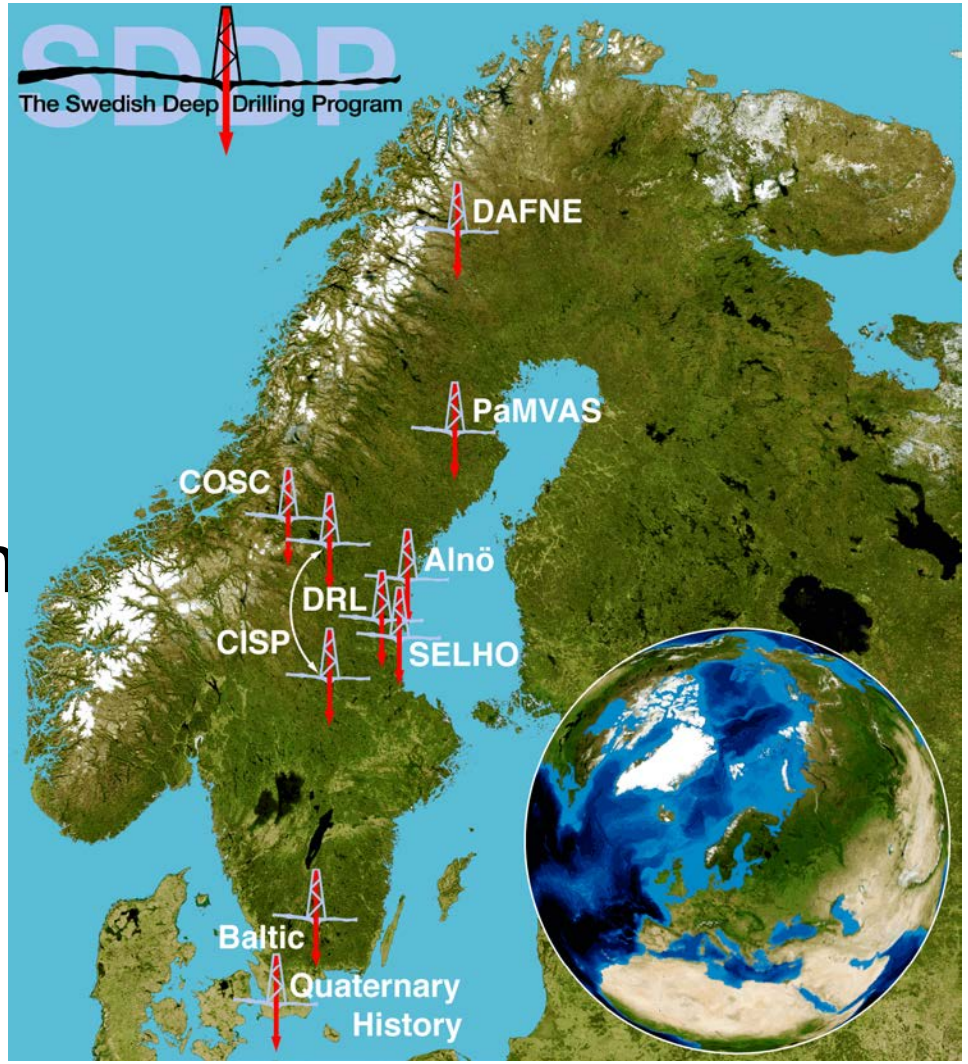


# Why drill in the Caledonides?

- Tectonic evolution
  - Channel flow
  - Basement involved thrusting
- Comparison with the Himalayas
- Present day and past deep fluid circulation patterns
- Current heat flow and climate modeling
- Deep biosphere
- Calibration of high quality surface geophysics

# Swedish Deep Drilling Program (www.sddp.se)

- 8 potential drill sites in Sweden
- Swedish Research Council (VR) funded drill rig for depths of 2.5 km
- Will become the Swedish Scientific Drilling Program (www.ssdp.se)



# 8 drilling proposals

- Collisional Orogeny in the Scandinavian Caledonides (COSC)
- Postglacial Fault Drilling Project (PFDP or DAFNE).
- Concentric Impact Structures in the Palaeozoic – the Lockne and Siljan craters (CISP)
- Palaeoproterozoic mineralized volcanic arc systems: the Skellefte district (PaMVAS)
- The Alnö complex: A messenger from the Earth's mantle
- Baltic Glacial History (spin-off of IODP expedition#347)
- The Dellen Impact Crater: Integrated physical, hydrological, chemical, biological and mechanical characterization of deep crystalline rocks – A geoscientifc deep rock laboratory (DRL)
- Svecofennian accretion, an example of the early Structural Evolution in a Large Hot Orogen (SELHO)

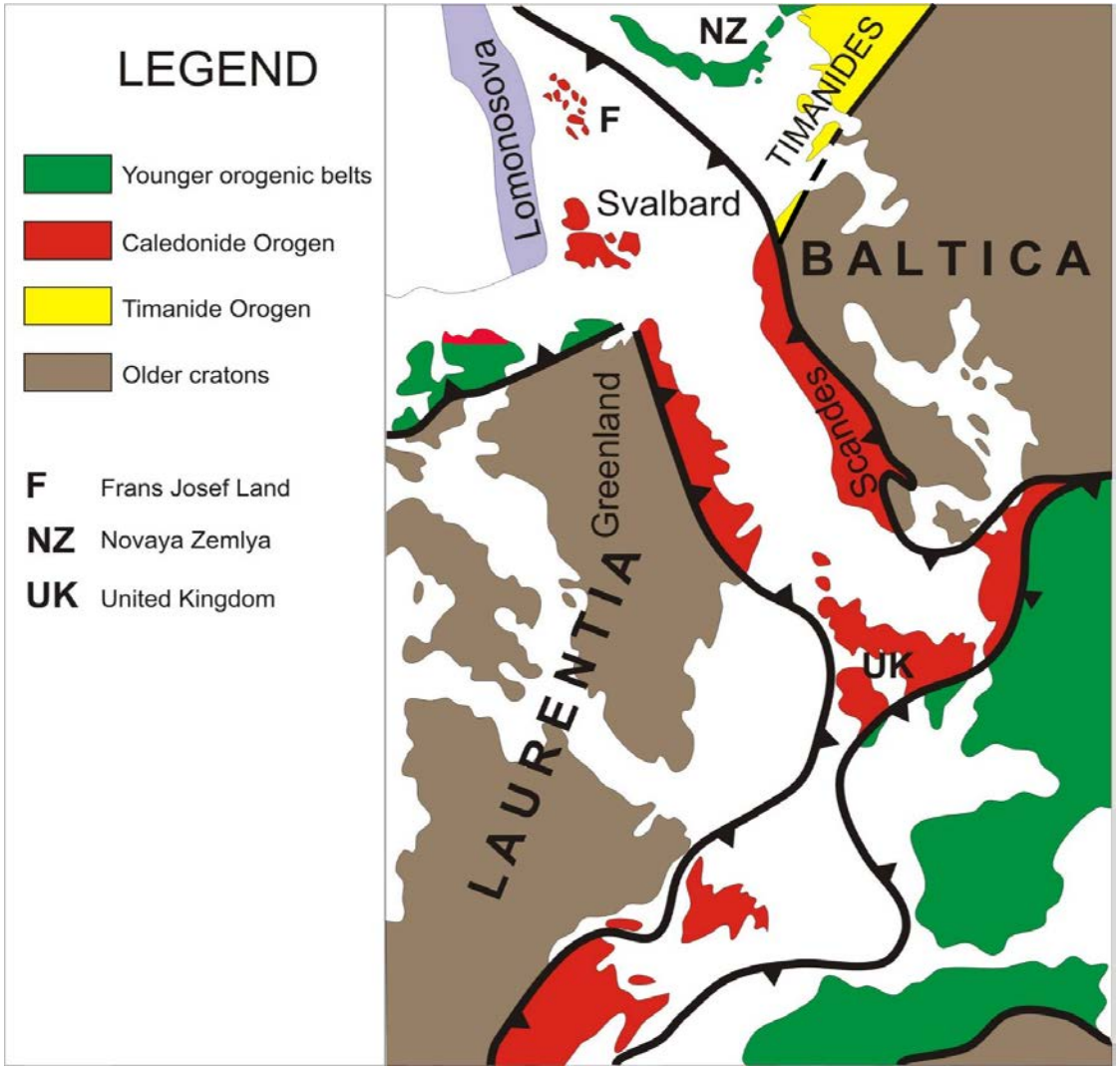

CRAMO
FRAKT


Atlas Copco
CT 20

# COSC funding

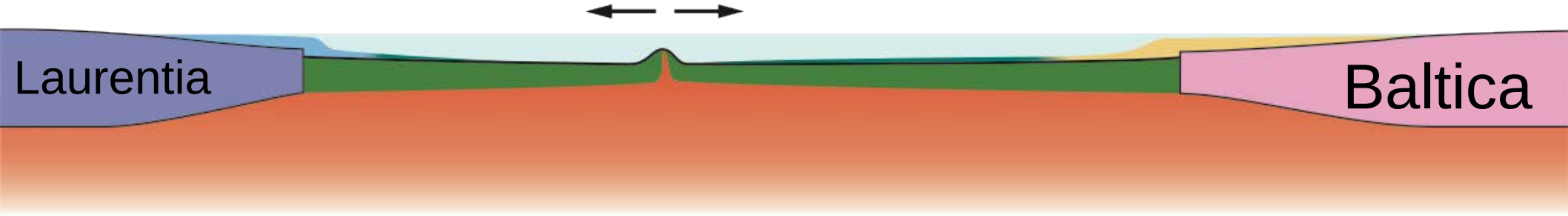
- Drilling costs
  - 1 MUSD from ICDP (International Continental Scientific Drilling Program)
  - 4.3 MSEK from the Swedish Research Council
- Scientific studies
  - Various national funding agencies

# COSC Project focus: better understanding of orogenic processes, both in the past and in today's active mountain belts

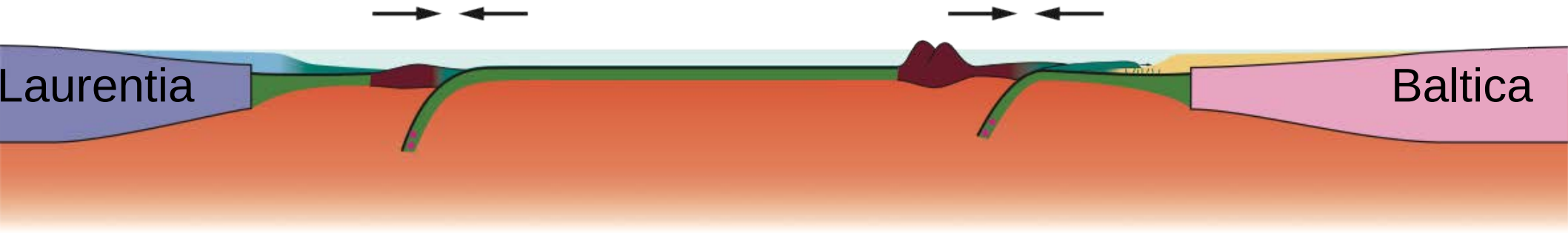



(Gee et al., 2010: GFF)

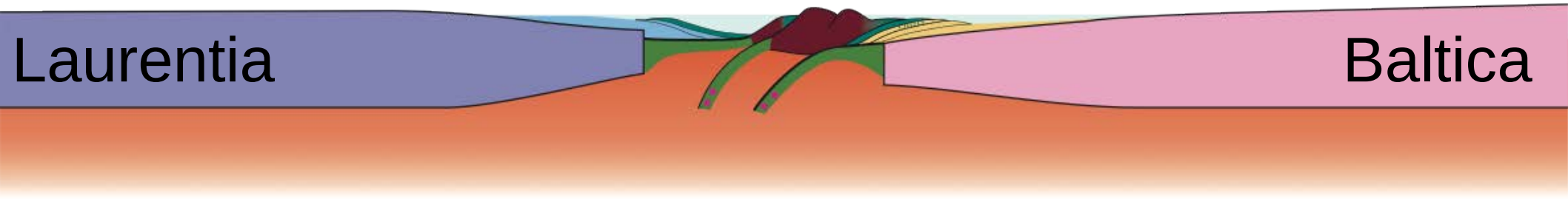
c. 600 - 500 Ma



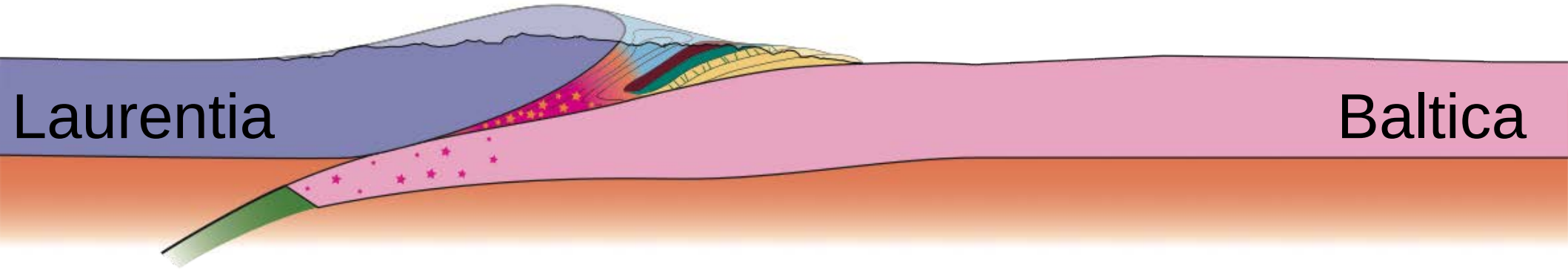
c. 480 Ma

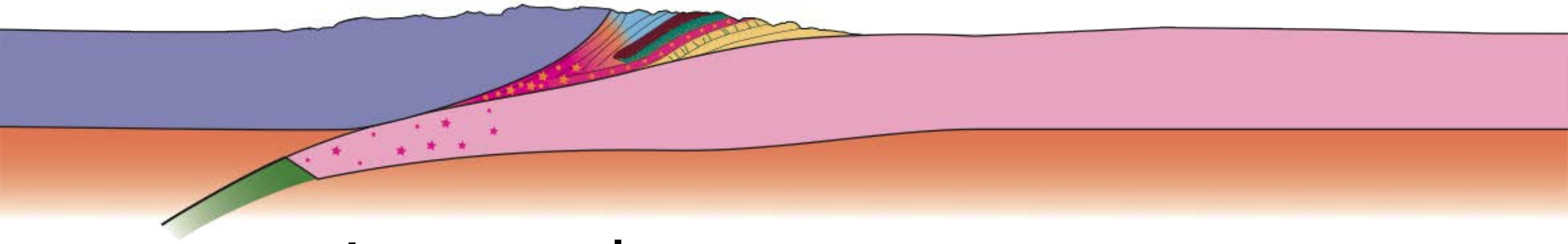


c. 450 Ma



c. 440 Ma

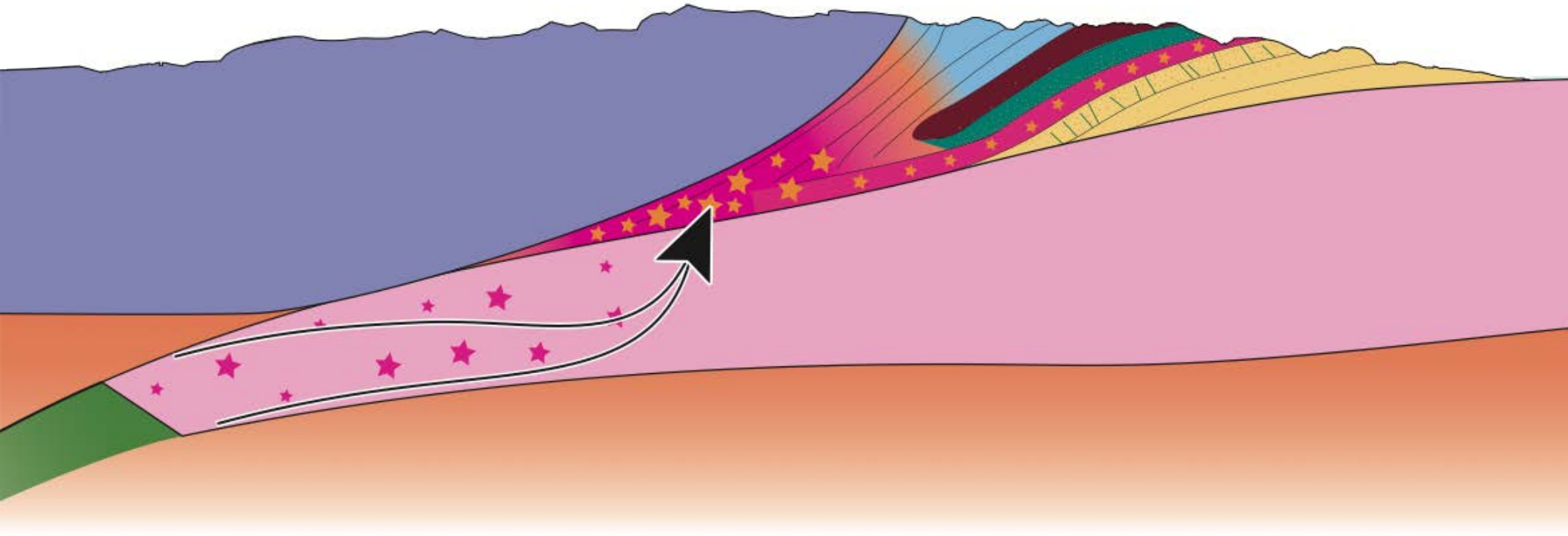




Laurussia

# The Swedish Deep Drilling Program

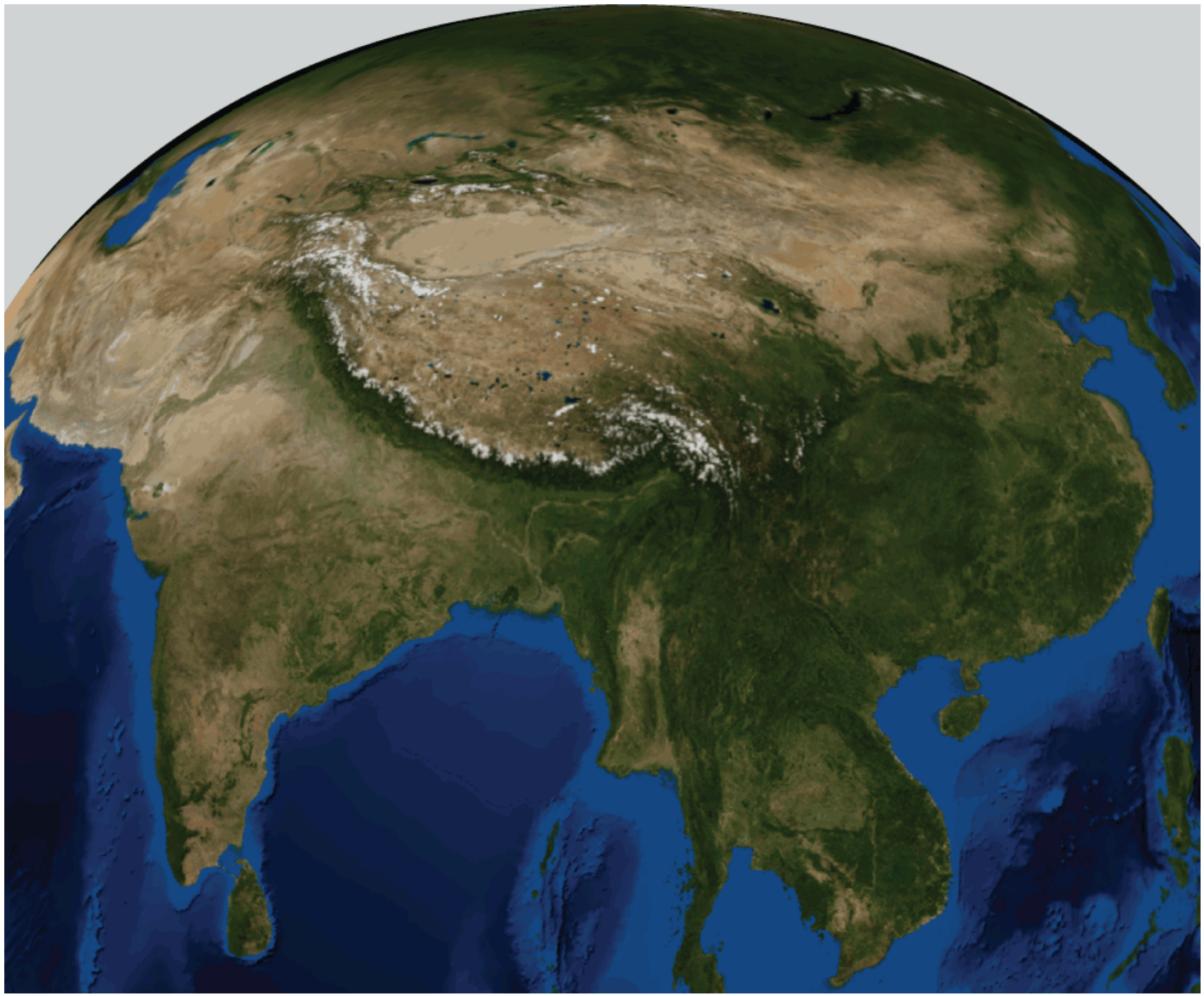
for science and society ...



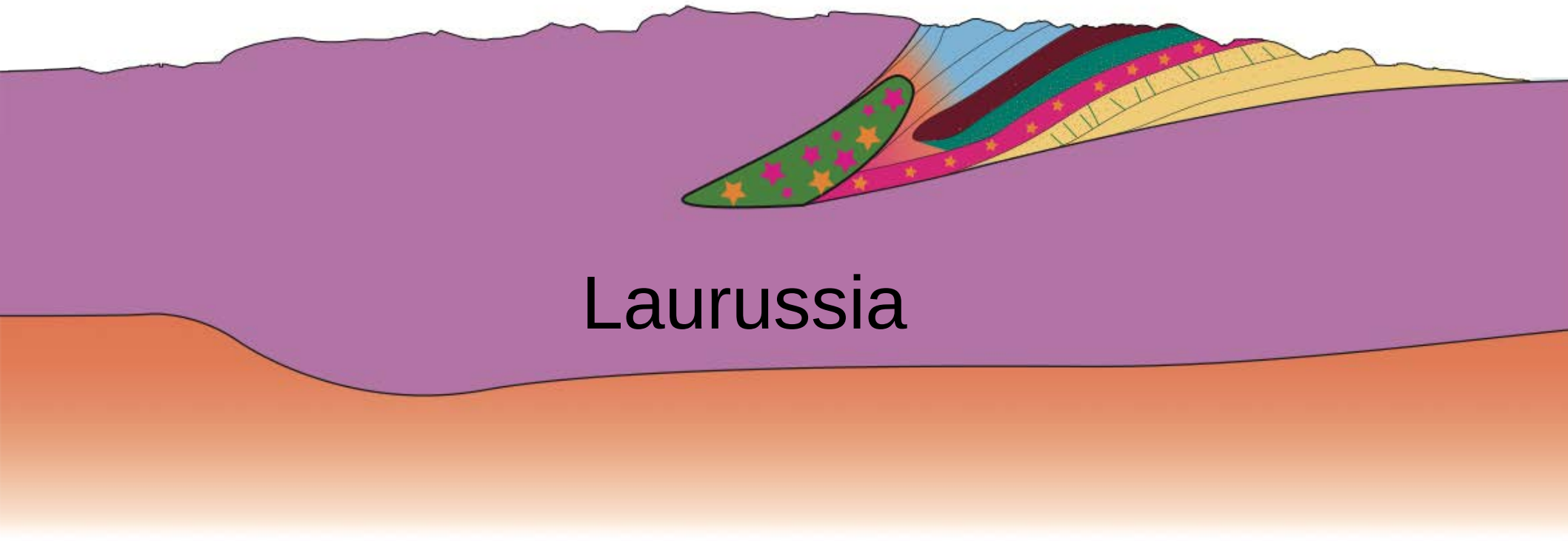
# Comparison to the Himalayas

*India-Asia collision zone - high spatial image from NASA Earth-observing satellites*

*http://earthobservatory.nasa.gov/Features/BlueMarble*

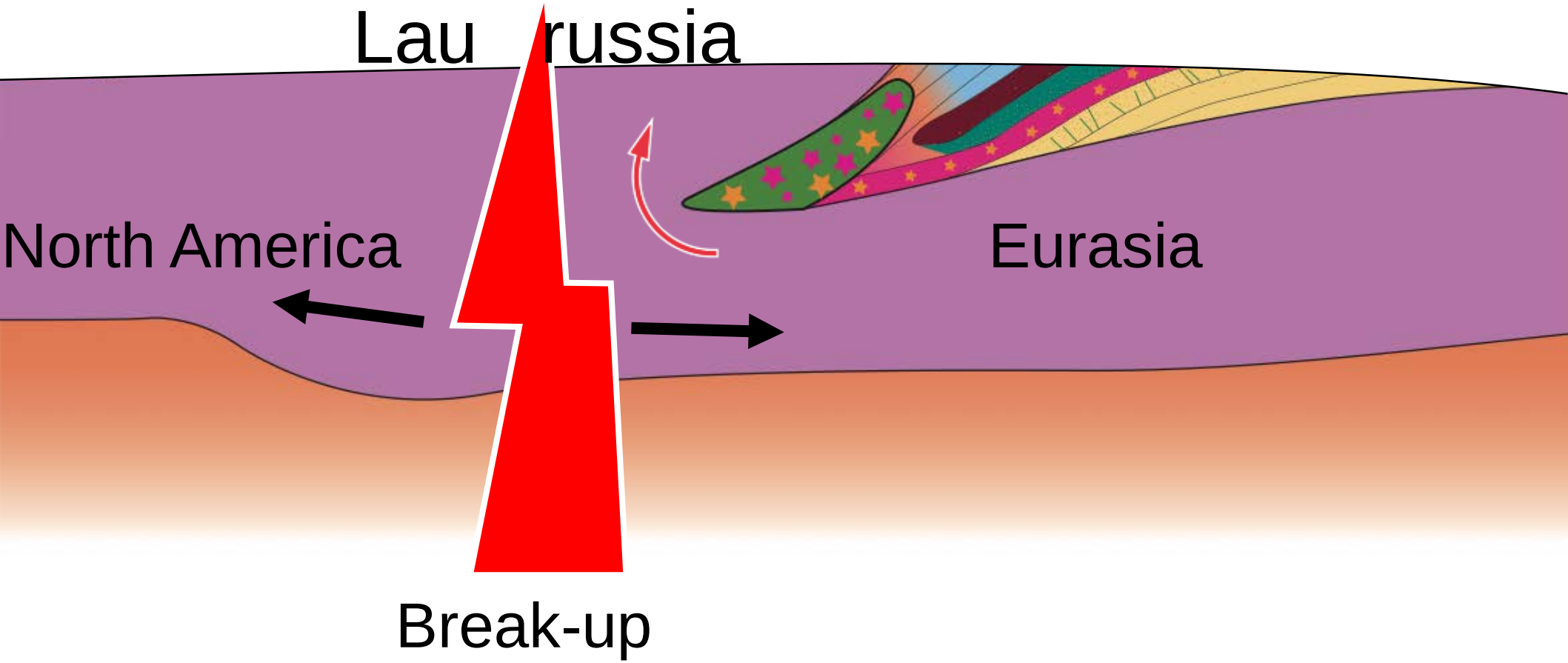


c. 400 Ma



Erosion

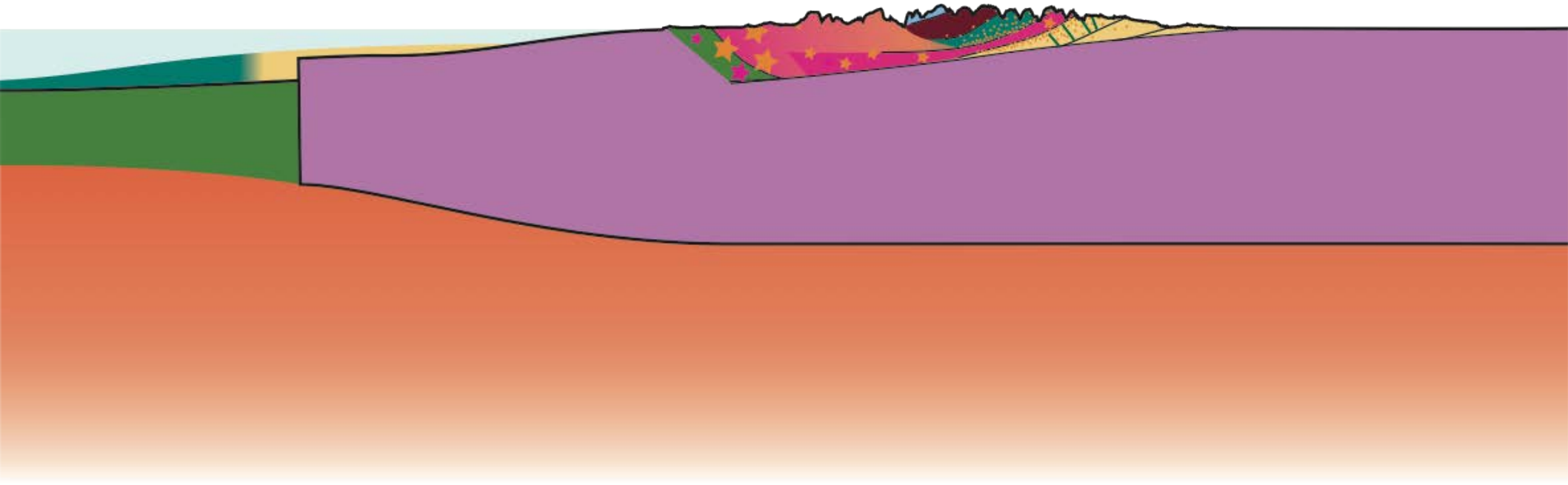
c. 60 Ma



# The Swedish Deep Drilling Program

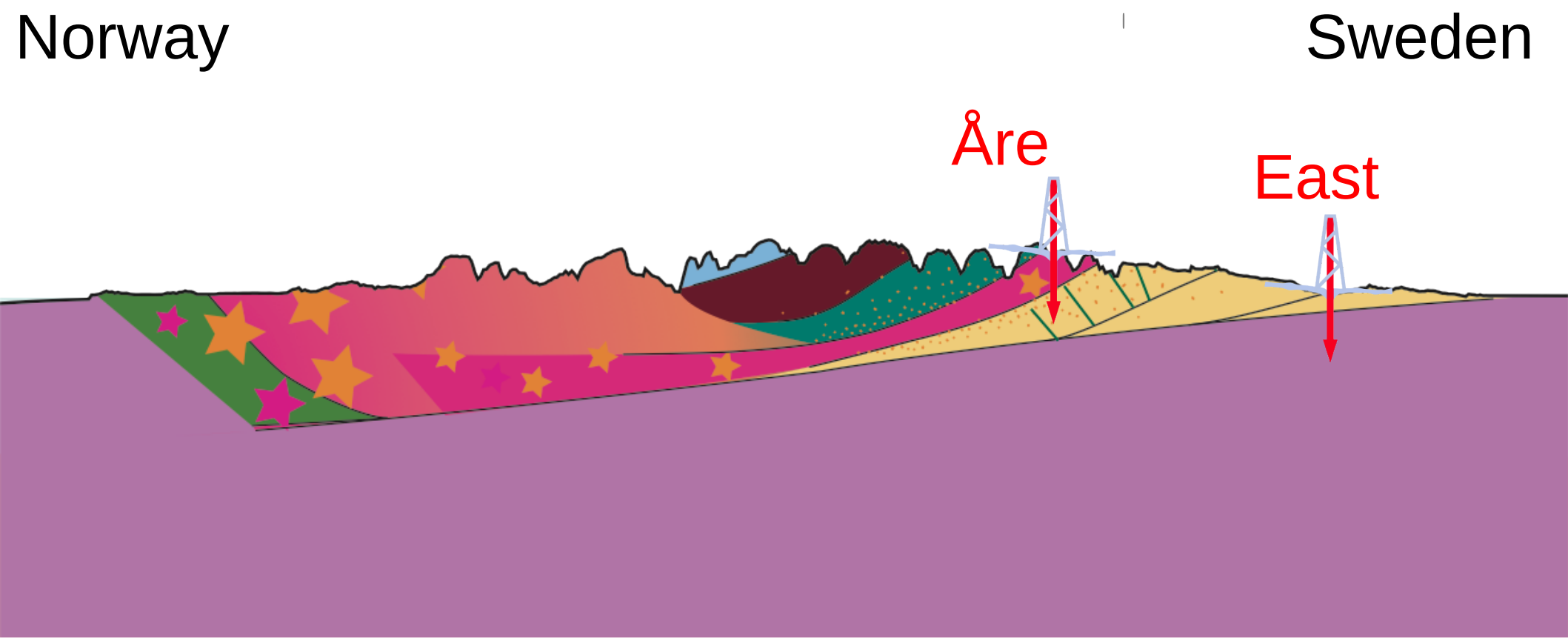
for science and society ...

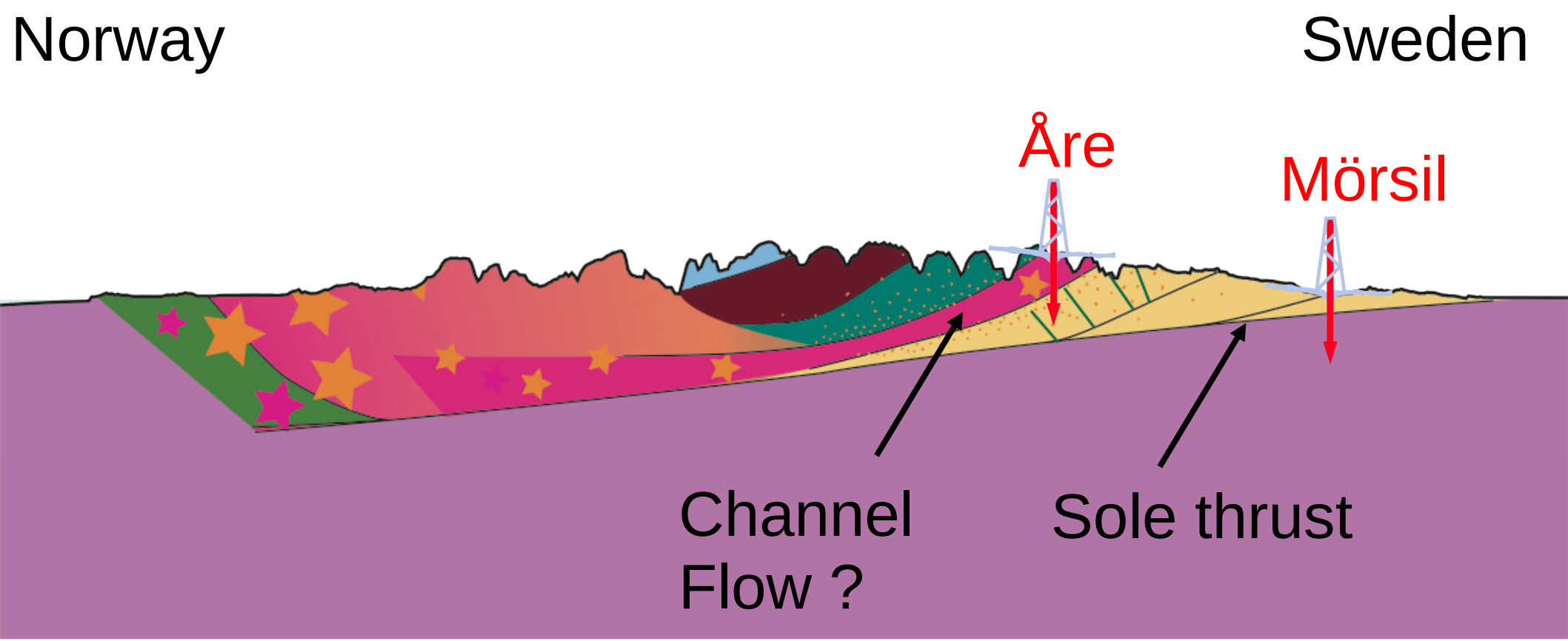
Today



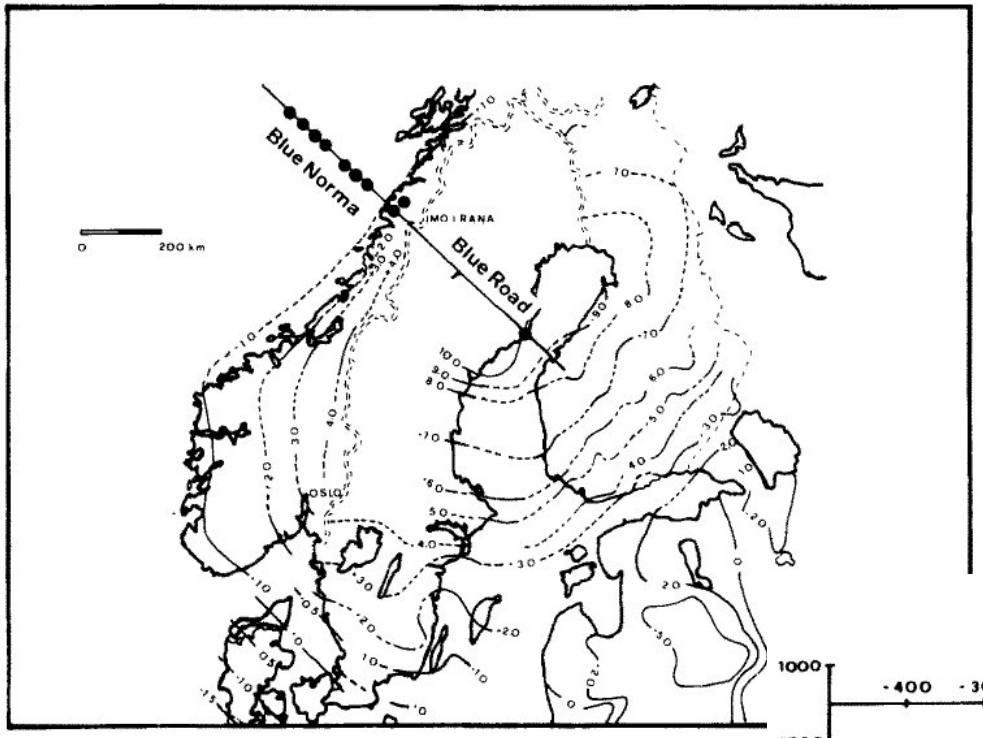
# The Swedish Deep Drilling Program

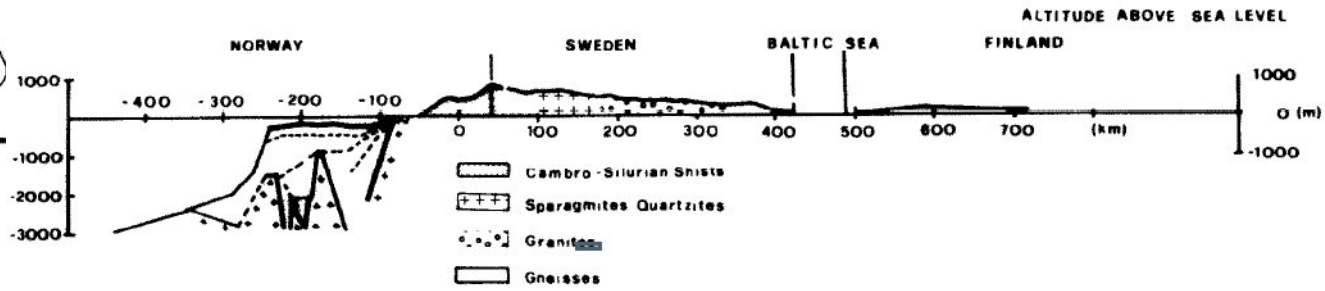
for science and society ...




Norway
Sweden
Åre
Mörsil
Channel
Flow ?
Sole thrust

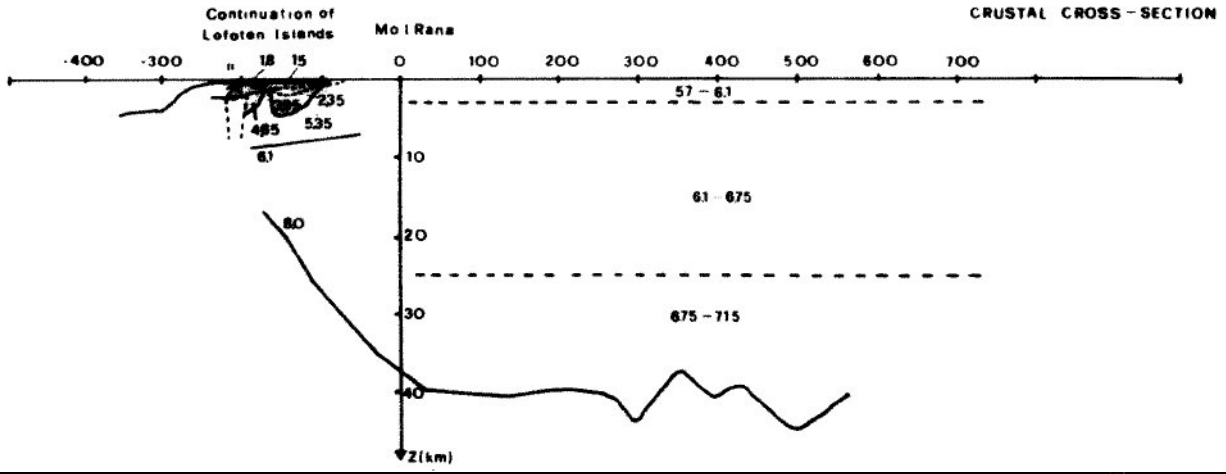
# Deep refraction survey from the 1970s



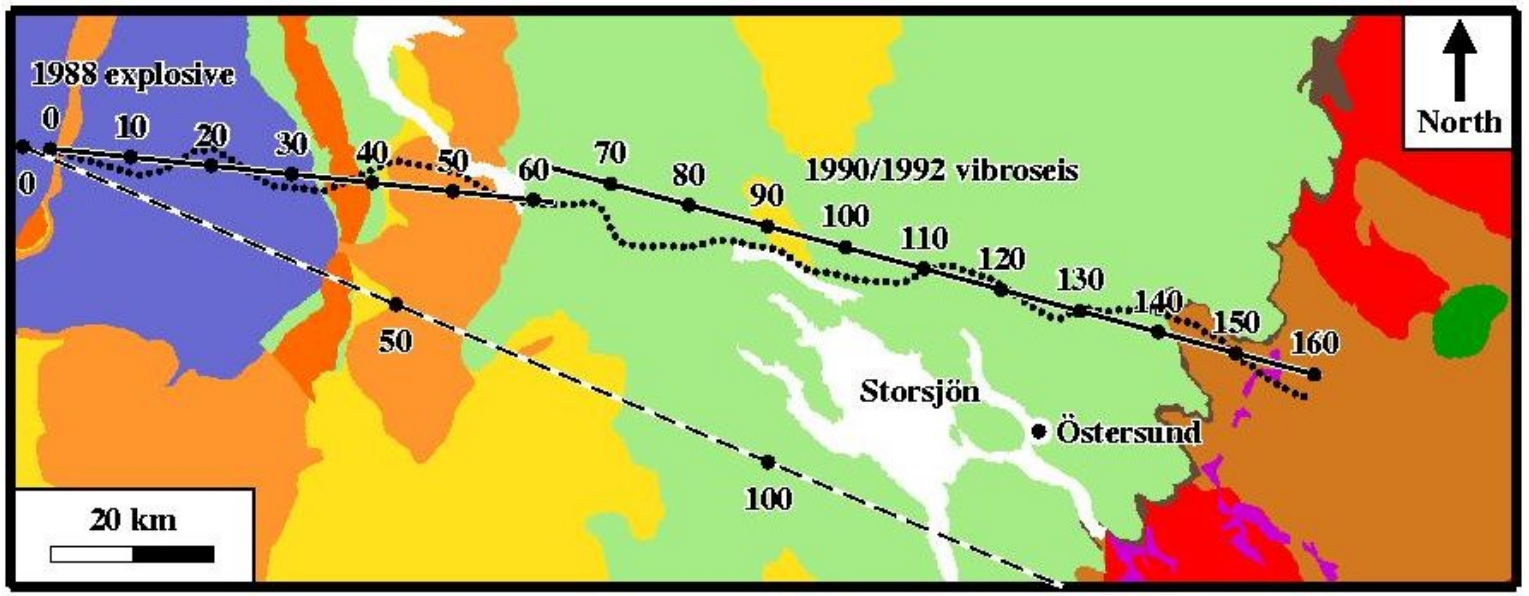



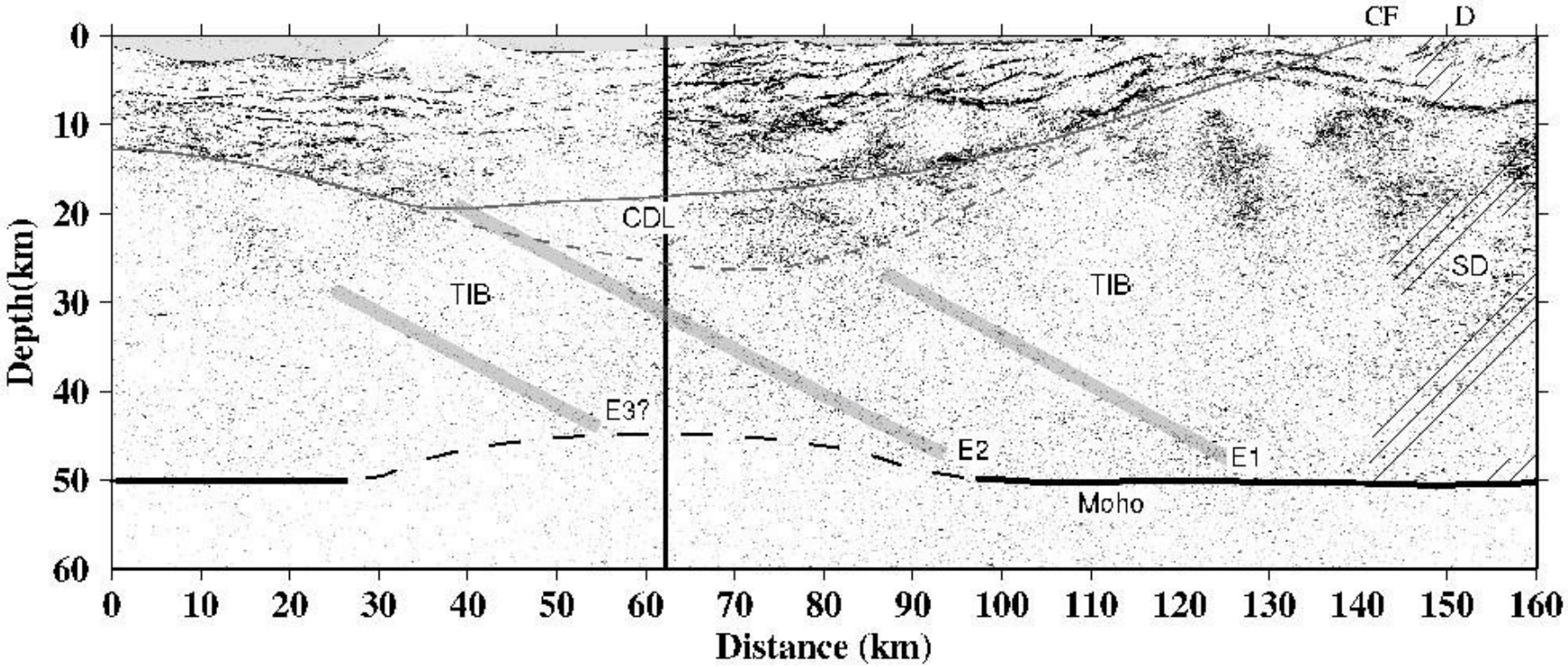

Moho depth c. 40 km

No root

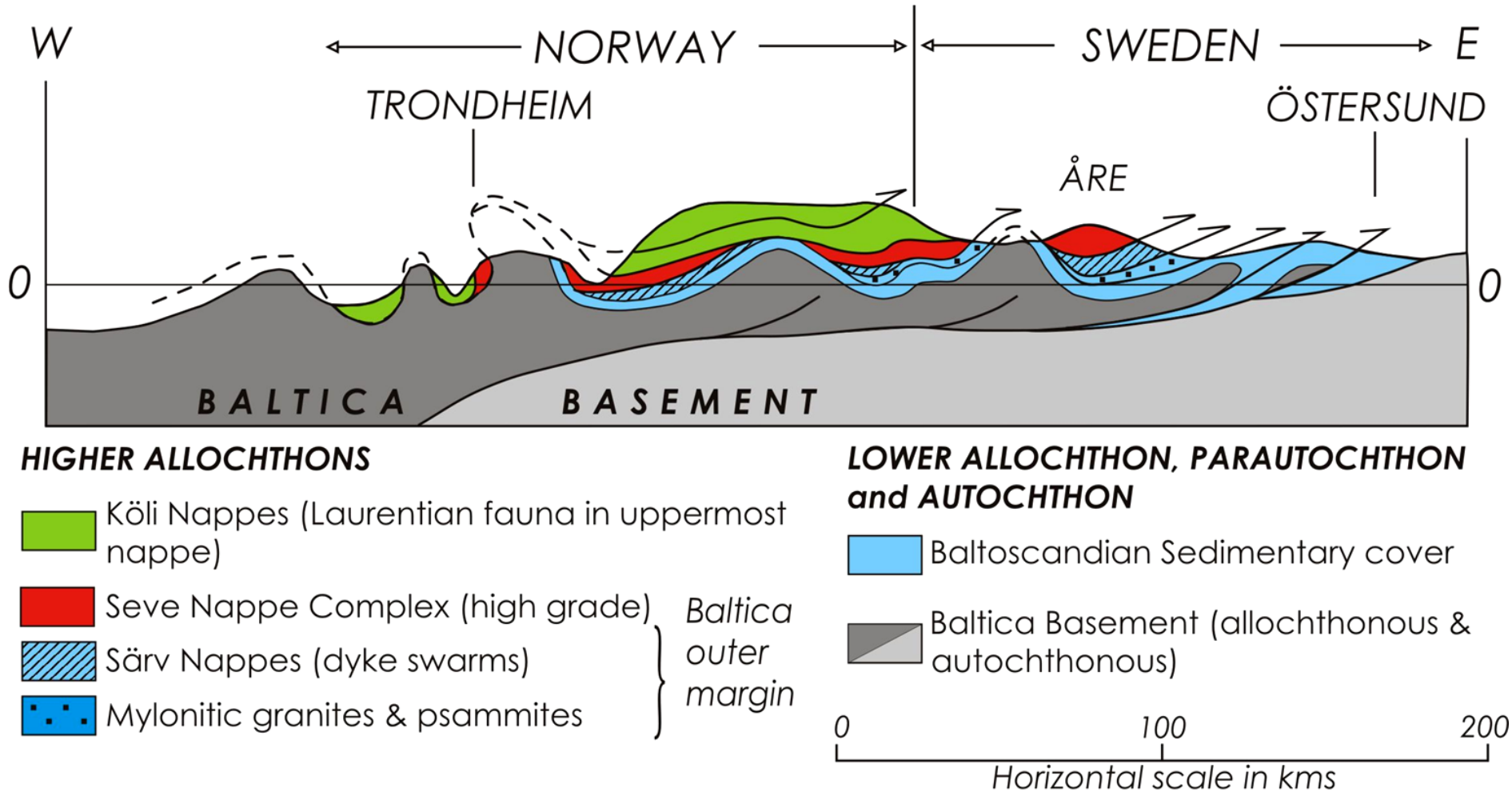


# Deep reflection survey, late 80s, early 90s



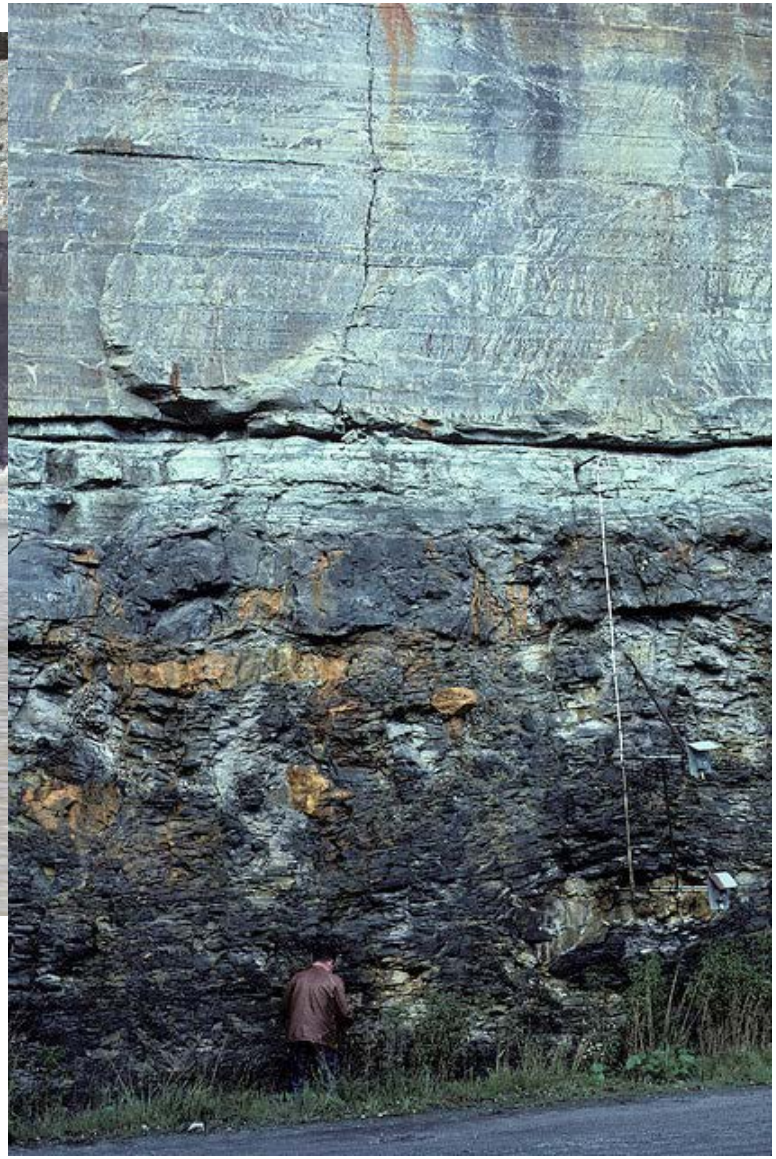



# Lateral transport: 100s of km



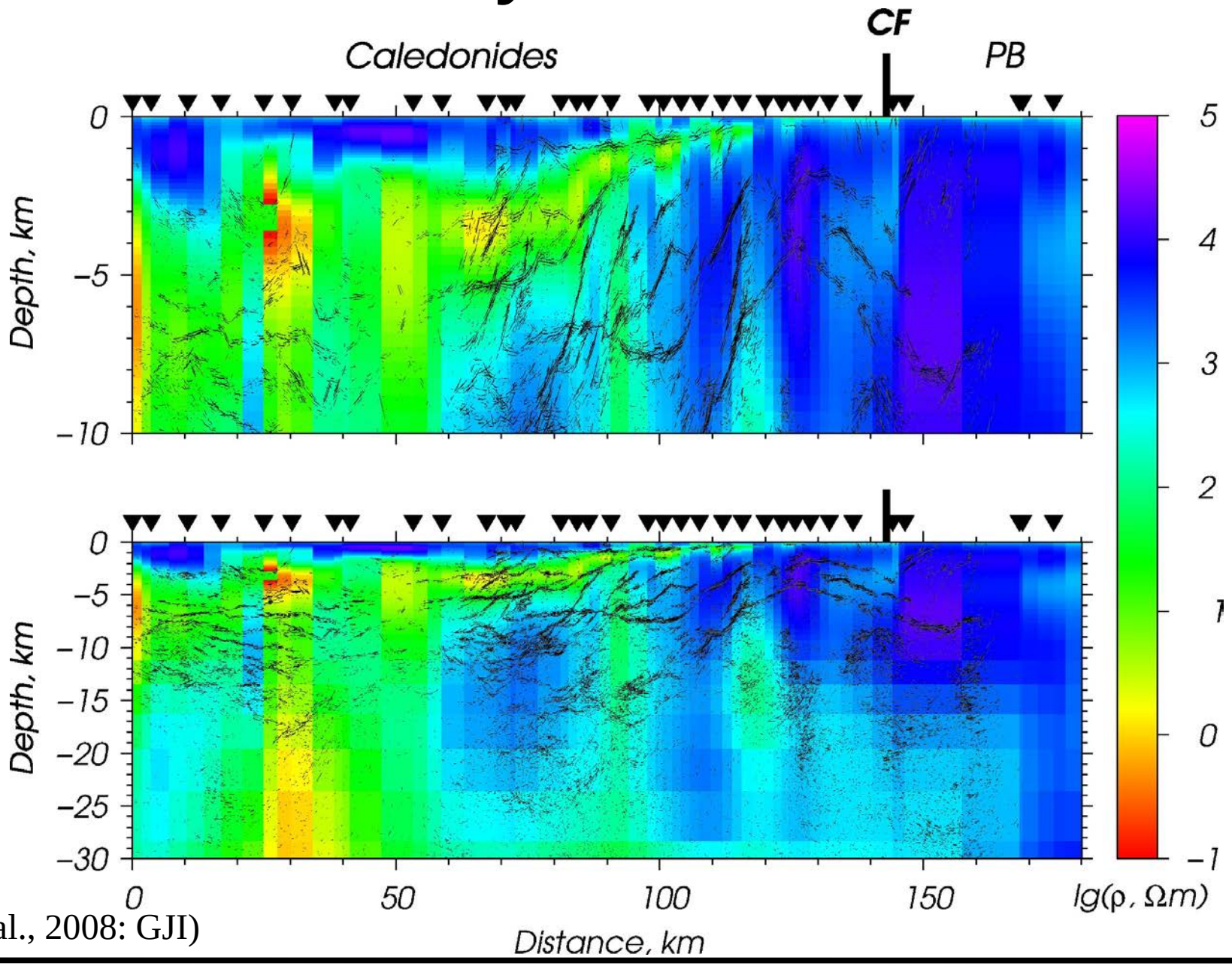

***Schematic profile of Central Scandes***

# Transport along the Alum shale



Ranstad mine, Sweden

# Resistivity on seismic

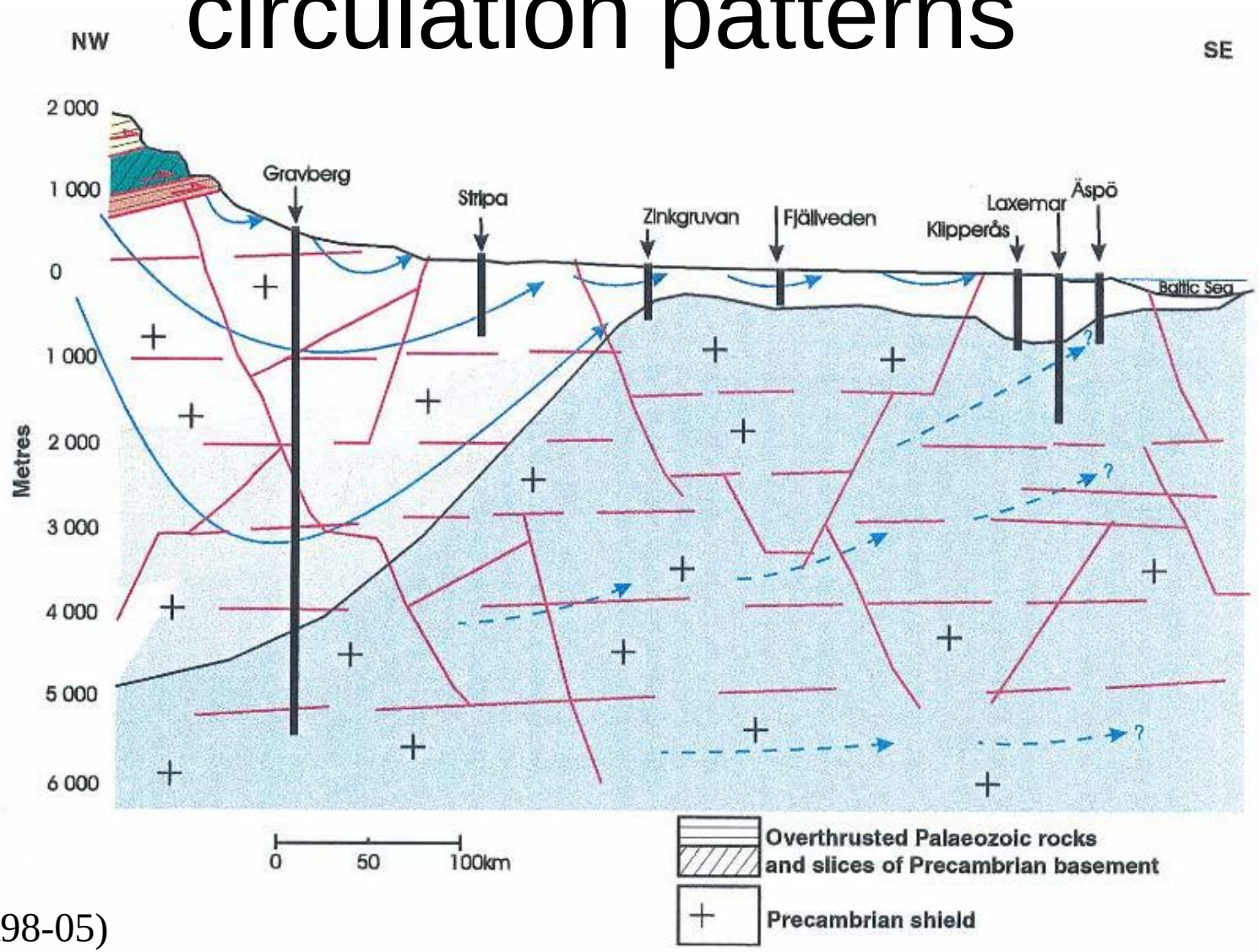



(Korja et al., 2008: GJI)

# Drilling goals

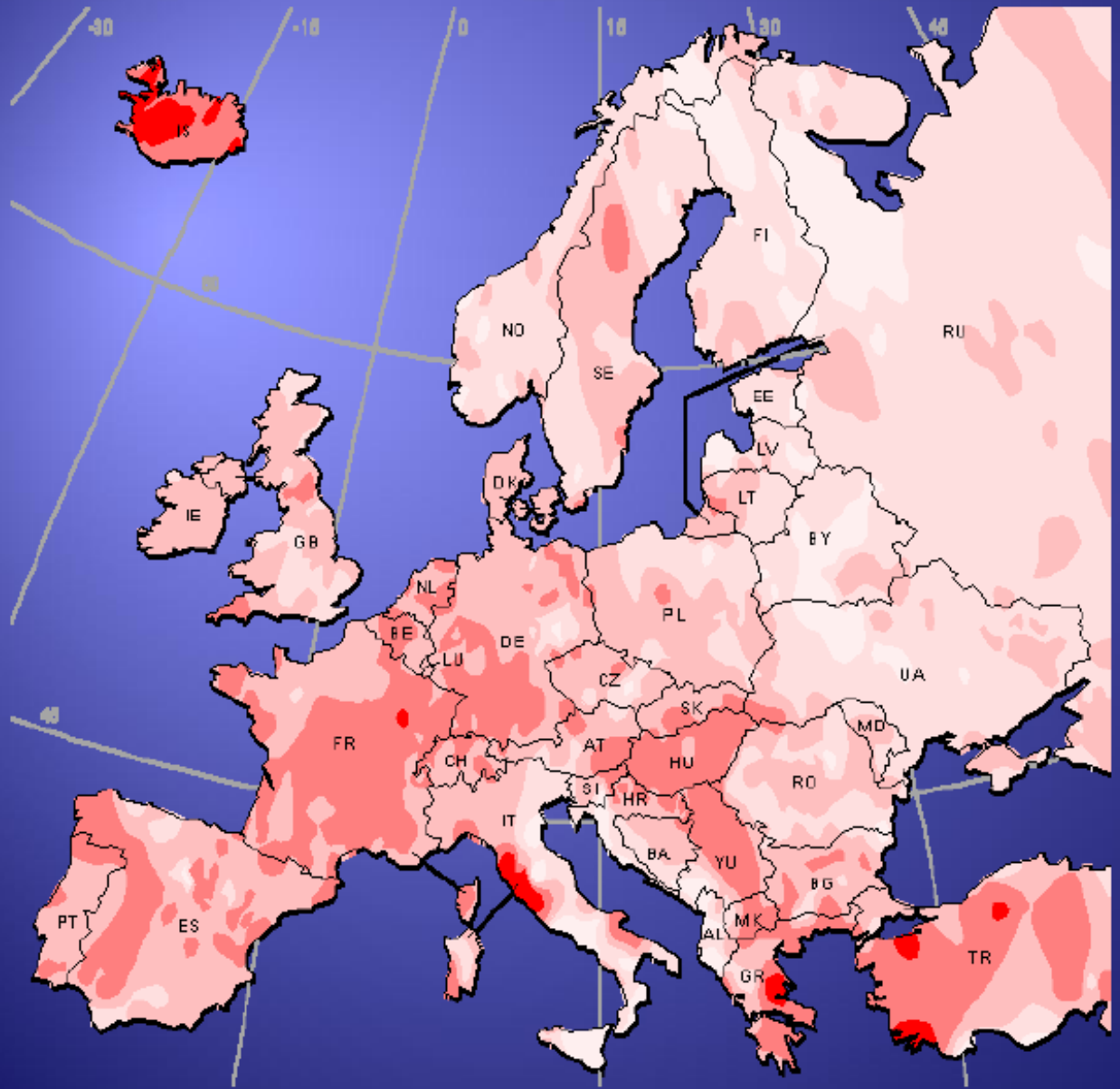
- Geological objectives
  - Drill through a long portion of the hot middle allochthon to study channel flow
  - Penetrate the sole thrust (Alum shale) and one or more basement reflectors
- Complementary studies
  - Heat flow and climate
  - Large and small scale water circulation patterns, present and past
  - Deep biosphere
  - Calibration of geophysical surveys

# Large scale groundwater circulation patterns




(SKB TR98-05)

# Heat flow density in Europe



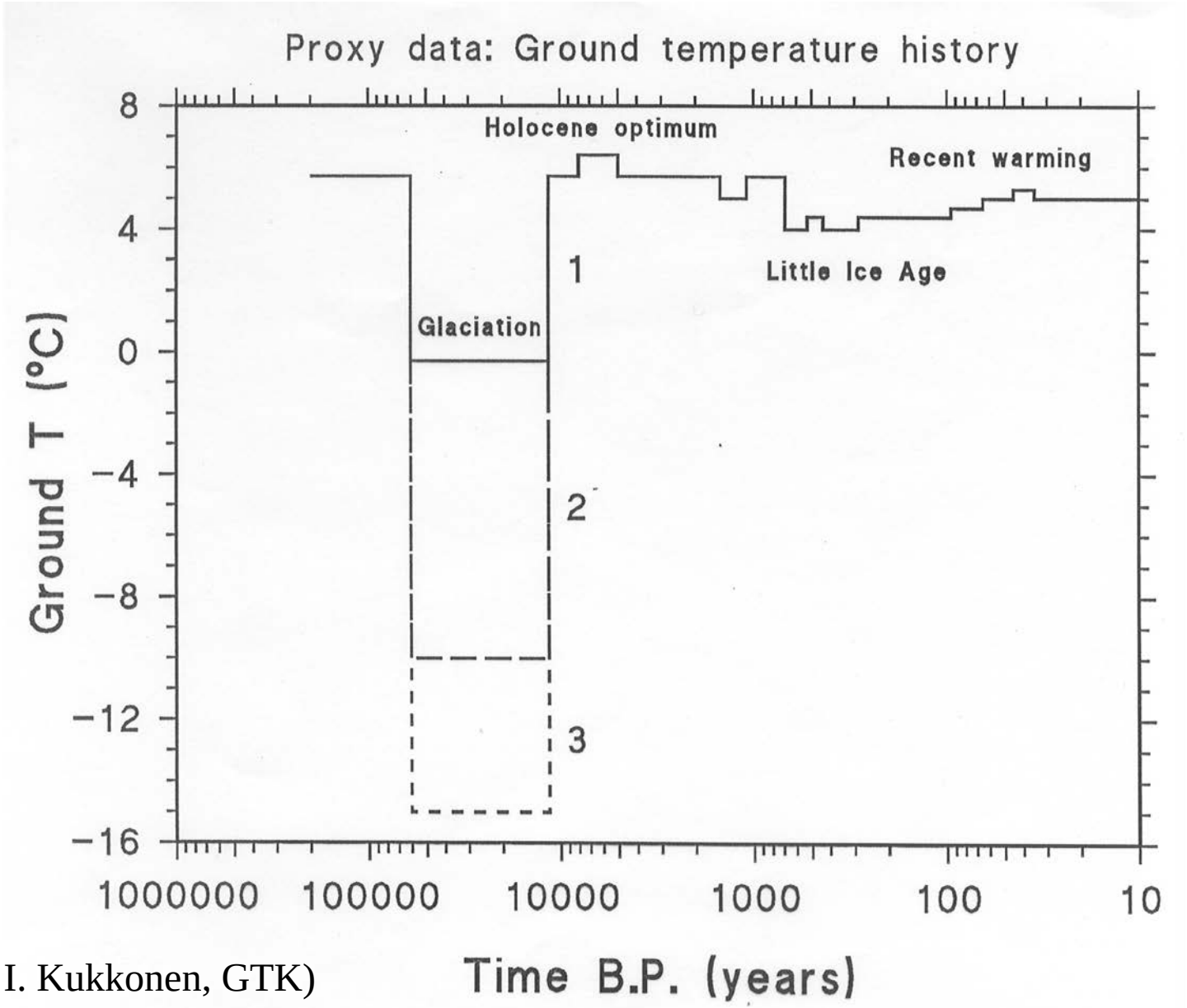

**Geothermal heat-flow density**

- > 150 mW/m²
- 80 - 150 mW/m²
- 50 - 80 mW/m²
- 30 - 50 mW/m²
- < 30 mW/m²

Original map:
Atlas of Geothermal Resources in Europe
Plate 1
Heat-flow density
© 2002
European Communities
Publ. Nr. EUR 17811

Redesign and generalisation:
© 2005
Energie-Atlas GmbH
CH-4142 Münchenstein

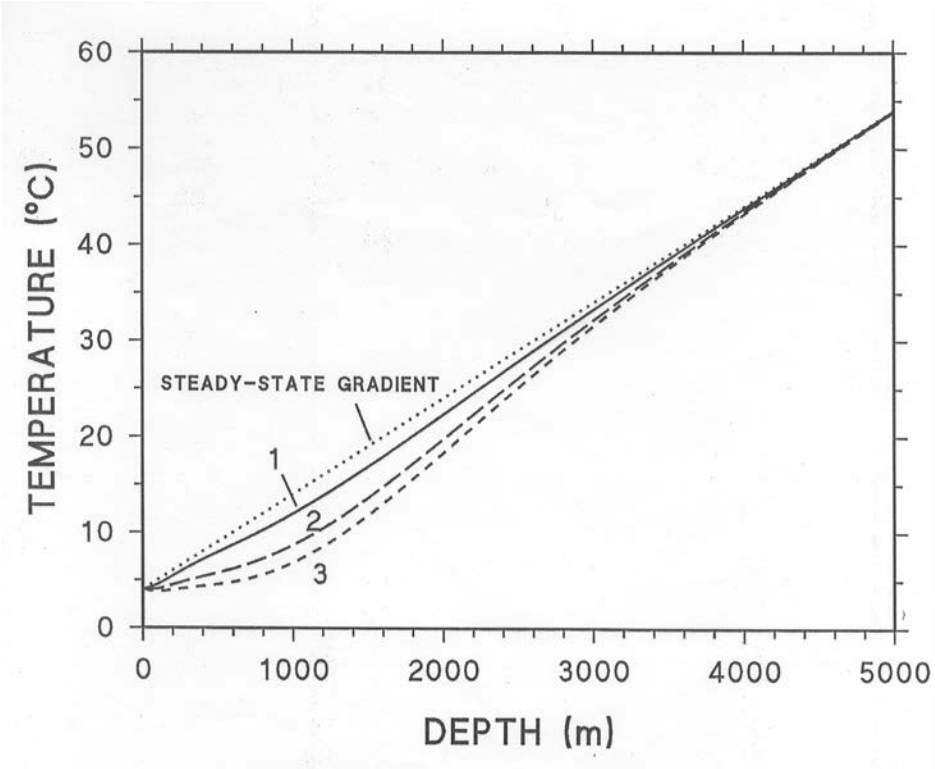
# Effect of paleoclimatic ground surface temperature (GST) variations

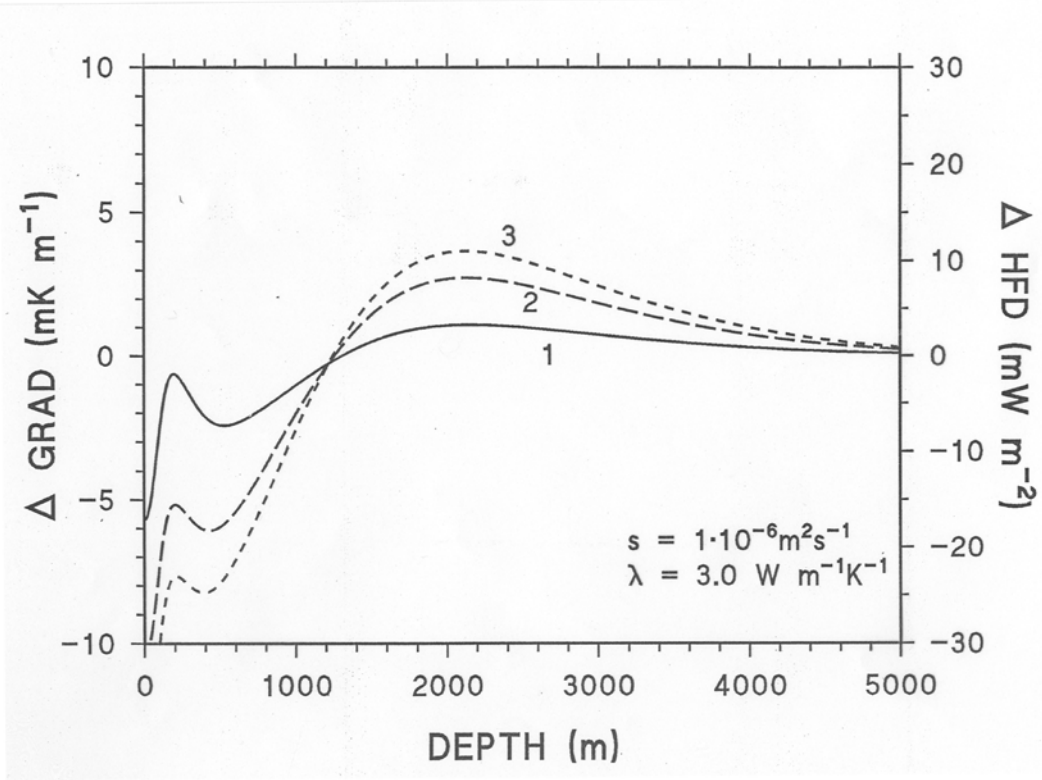



(Courtesy of I. Kukkonen, GTK)

# Theoretical disturbances on borehole temperature, heat flow and gradient calculated from proxy GST model

- ***Significant vertical variation expected at 0 – 2.5 km depth***
- ***Strong signal from the Weichselian GST expected***

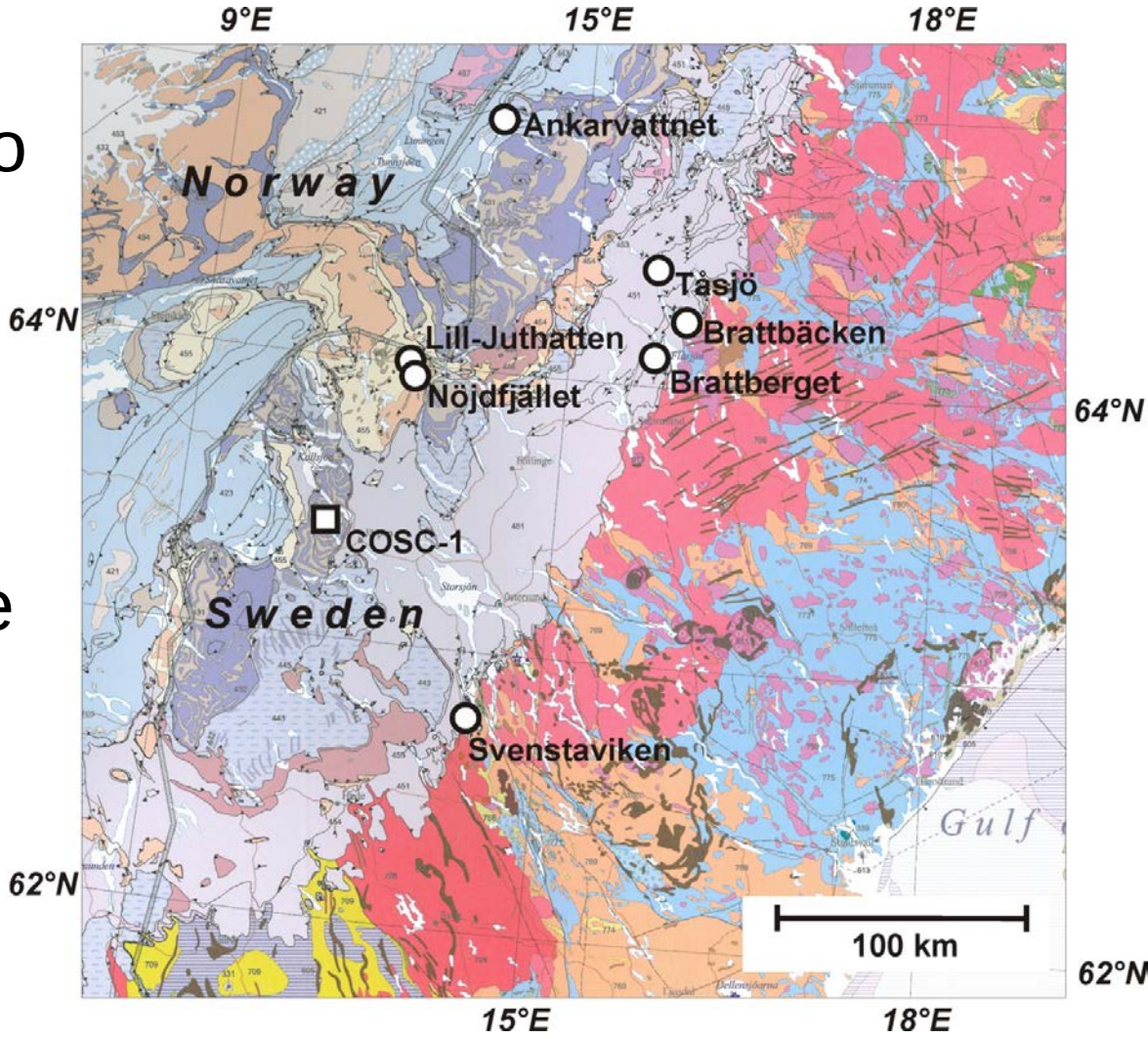



(Courtesy of I. Kukkonen, GTK)

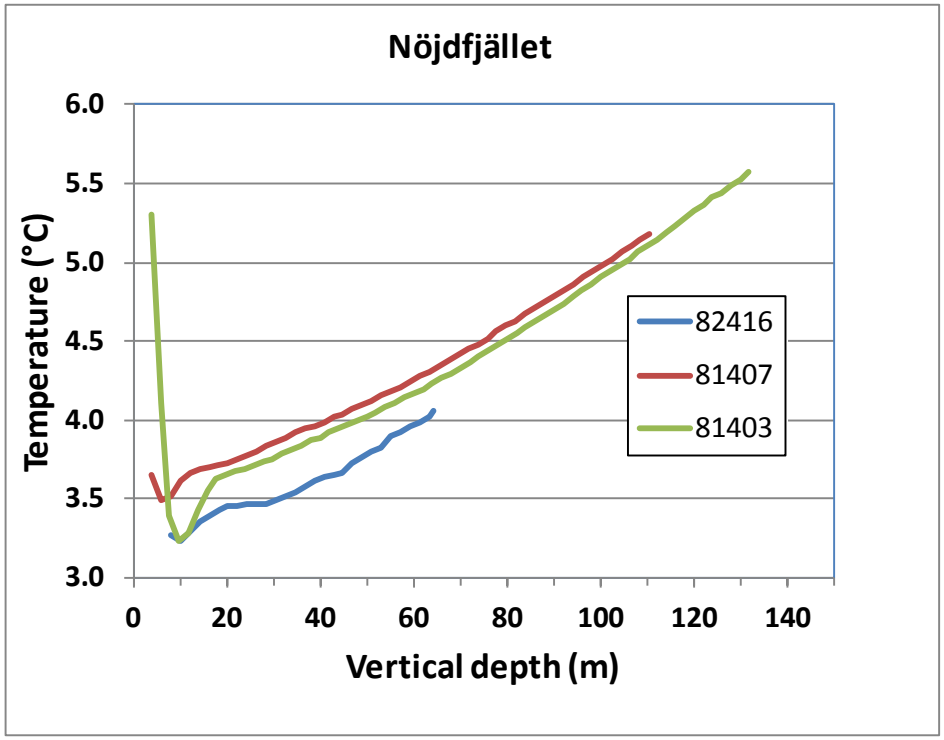
# Temperature measurements in shallow boreholes

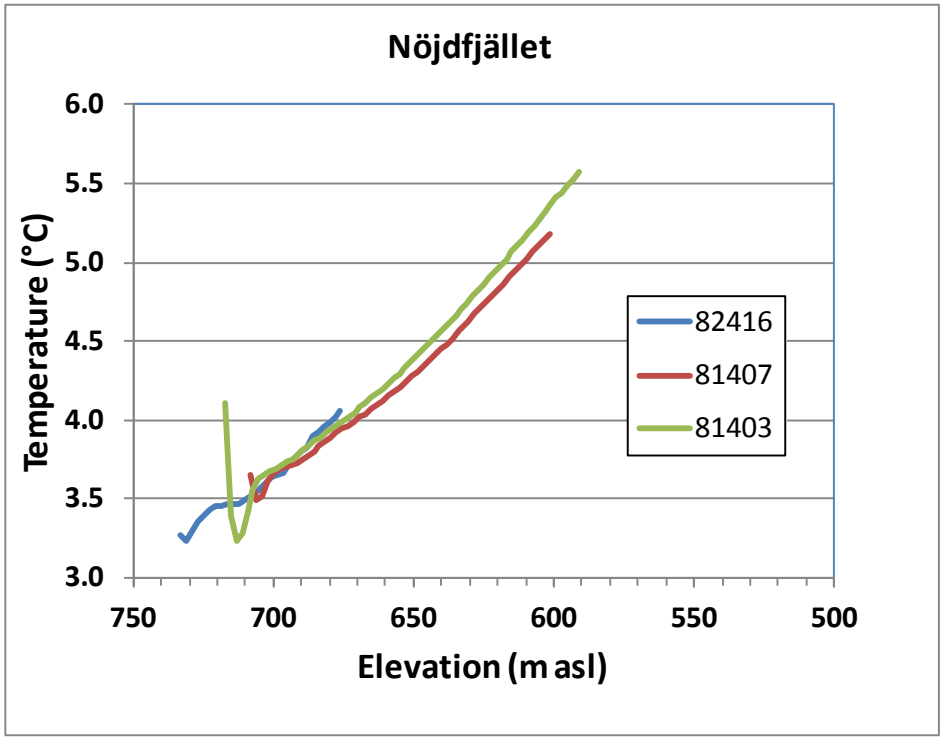
- Data acquired in 2012
- Mining boreholes down to a maximum of about 300 m
- Thermal conductivity measurements on core
- Some boreholes from the 1960s still open and accessible




(Kukkonen, Juhlin and Schwarz)

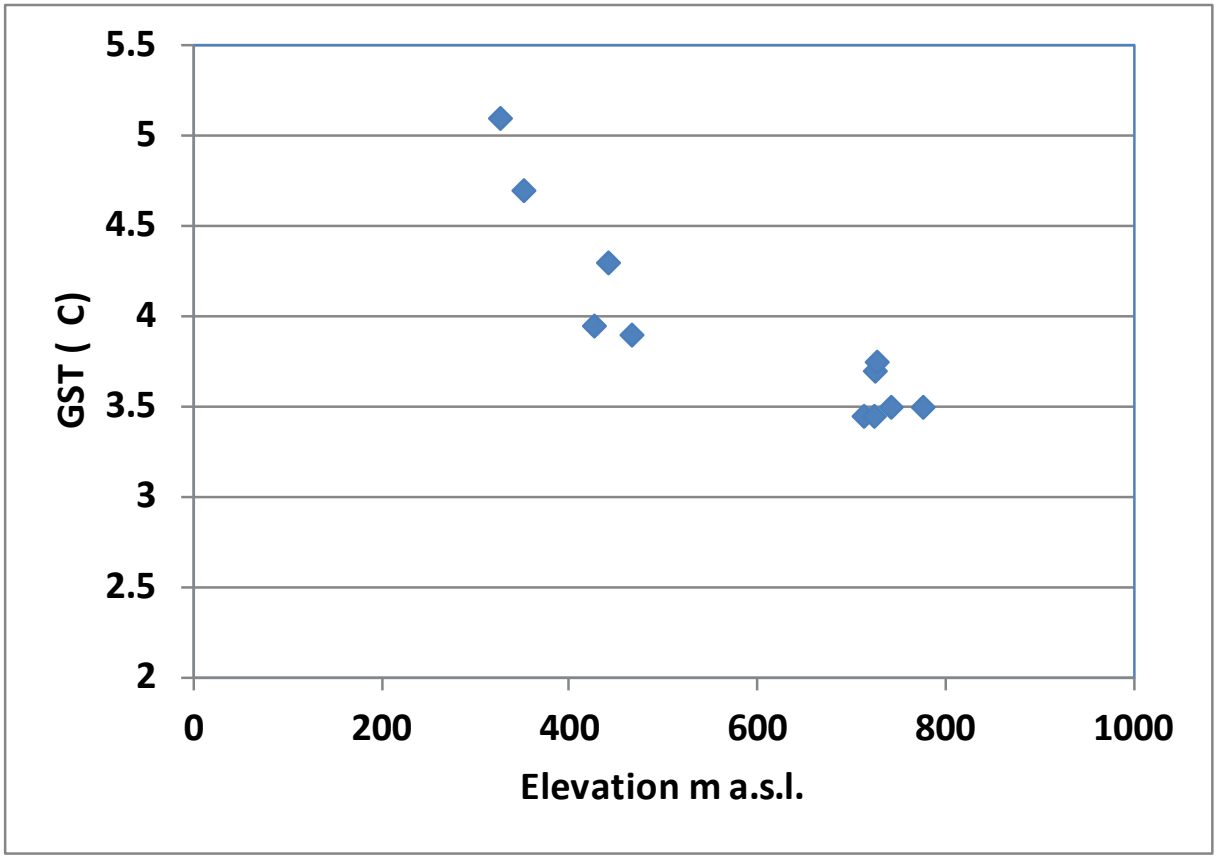
# Example of measured data




(Kukkonen, Juhlin and Schwarz)

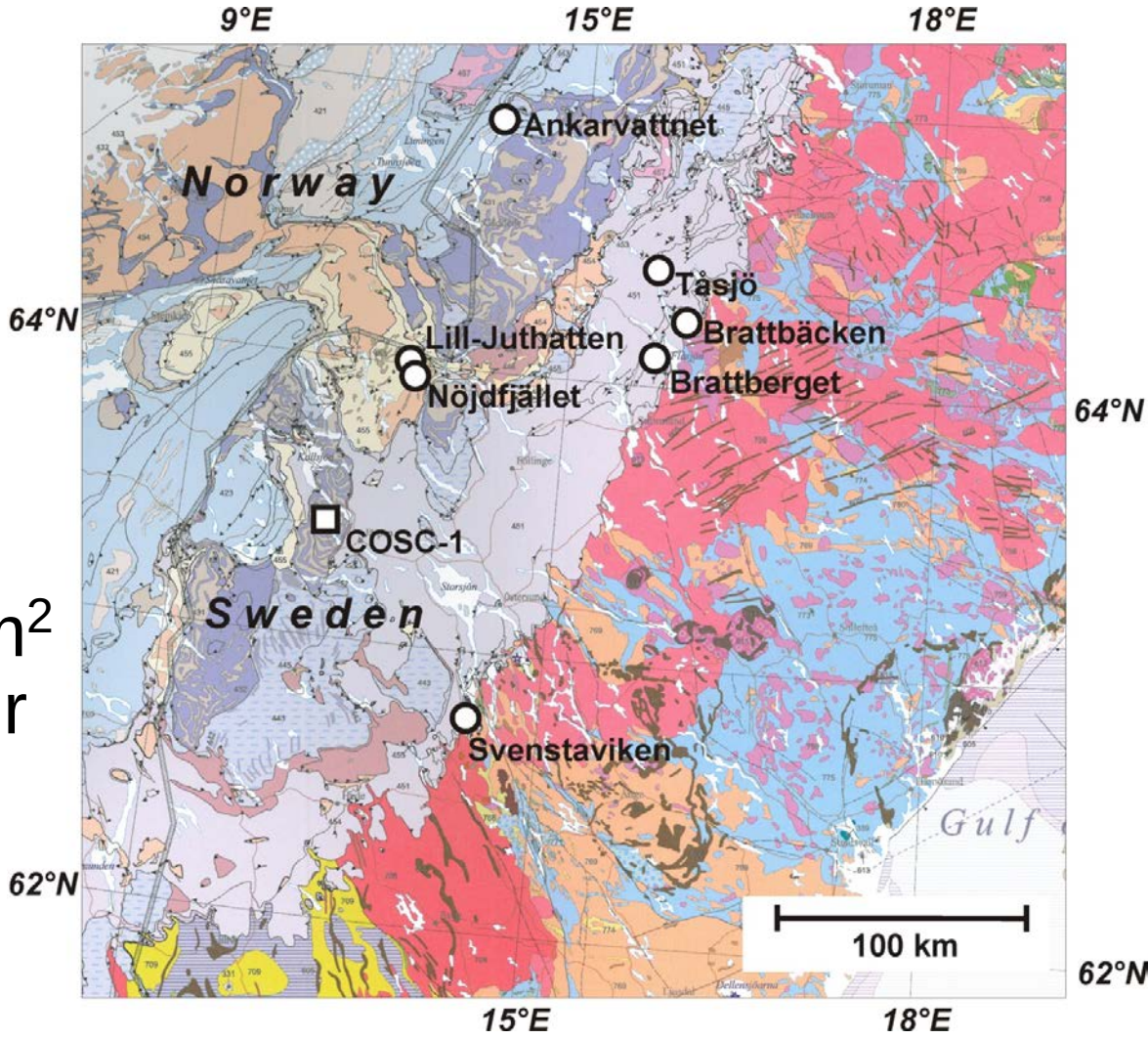
# Average ground surface temperature values extrapolated upwards




(Kukkonen, Juhlin and Schwarz)

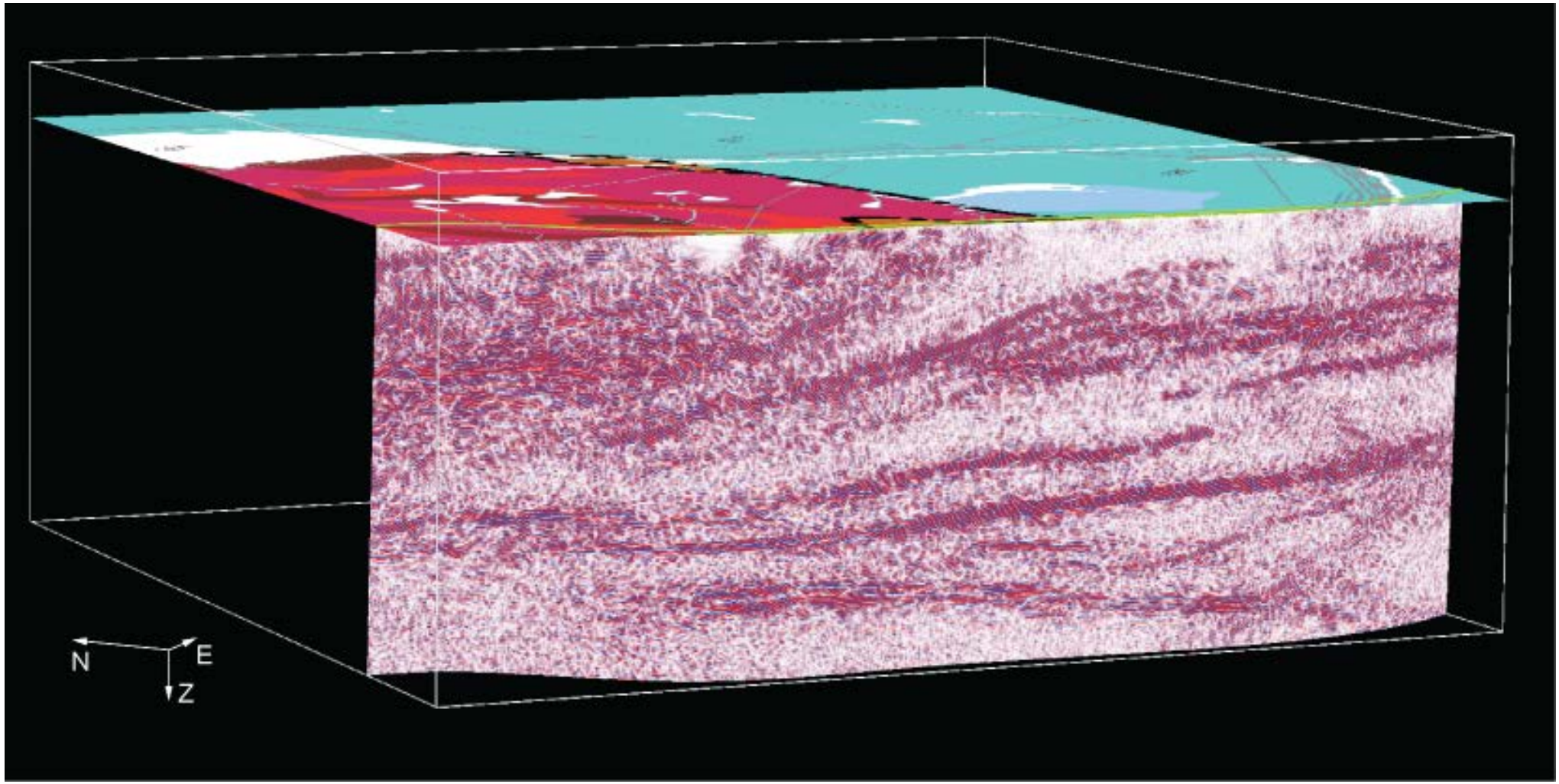
# Heat flow estimates (minimum)

- Ankarvattnet
  - 7-10°/km
  - 28 mW/m$^2$
- Nöjdfjället
  - 19-20°/km
  - 47 mW/m$^2$
  - Still less than 80 mW/m$^2$ that is estimated further north

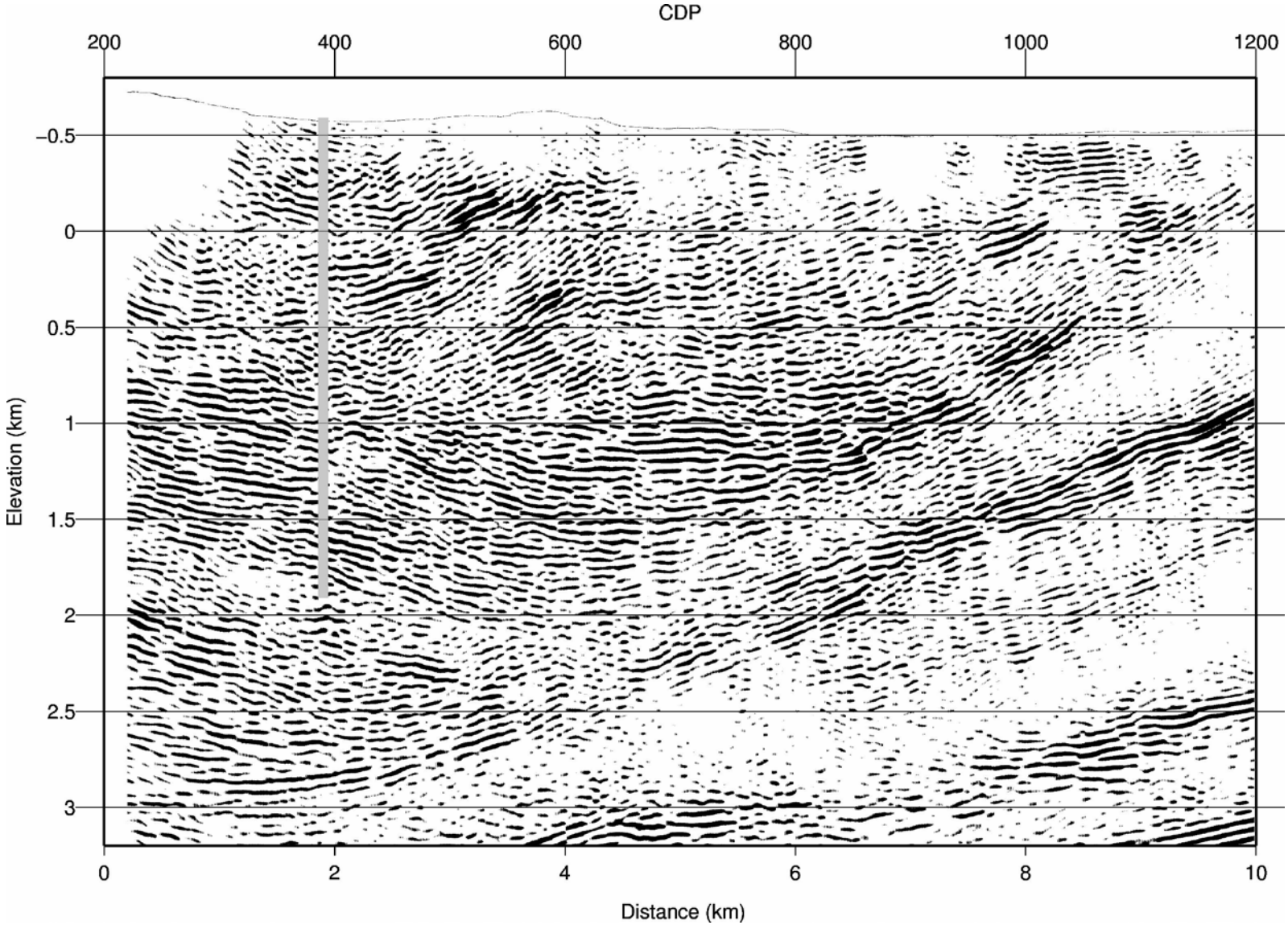



(Kukkonen, Juhlin and Schwarz)

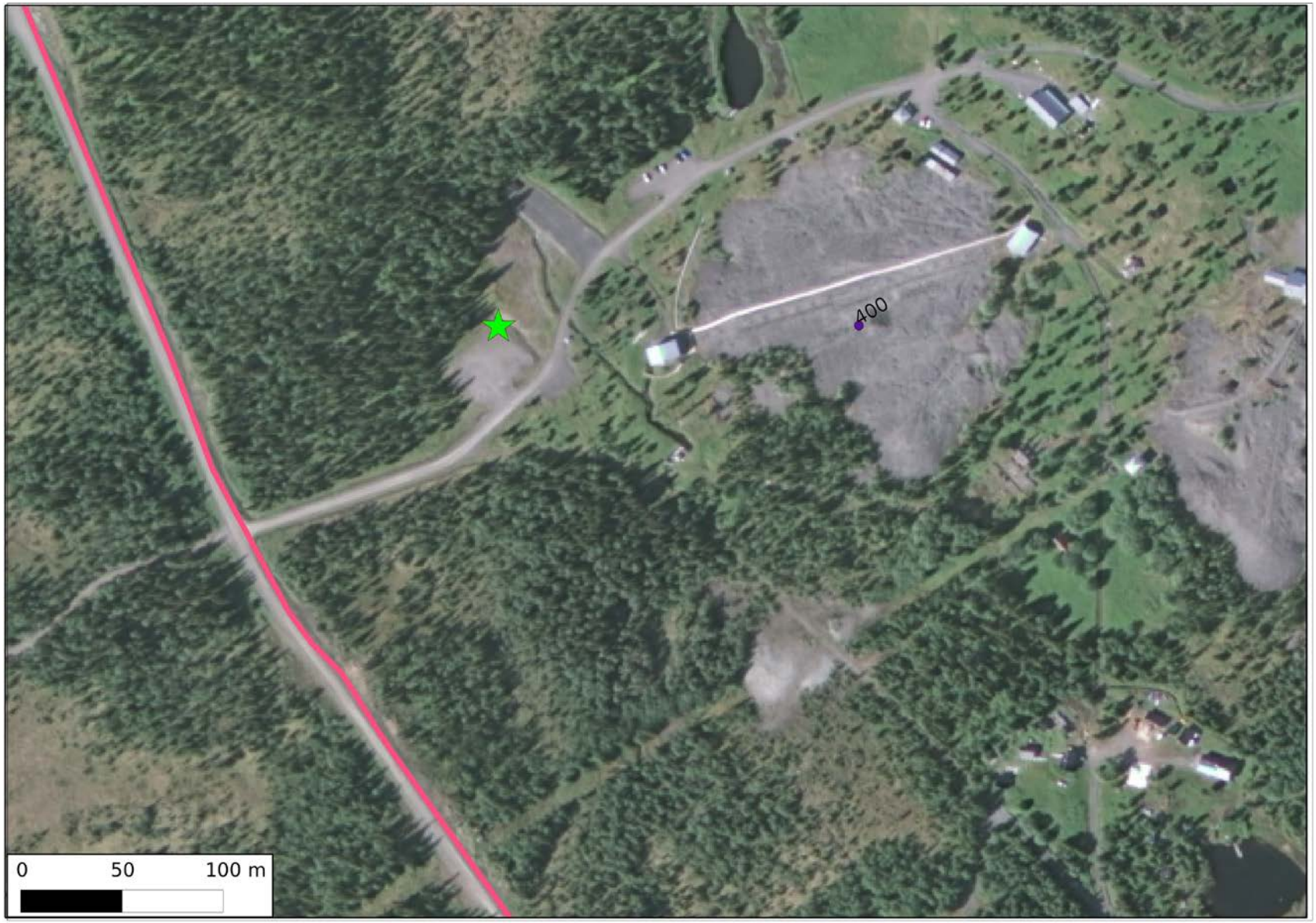
# High grade Seve Nappe is highly reflective

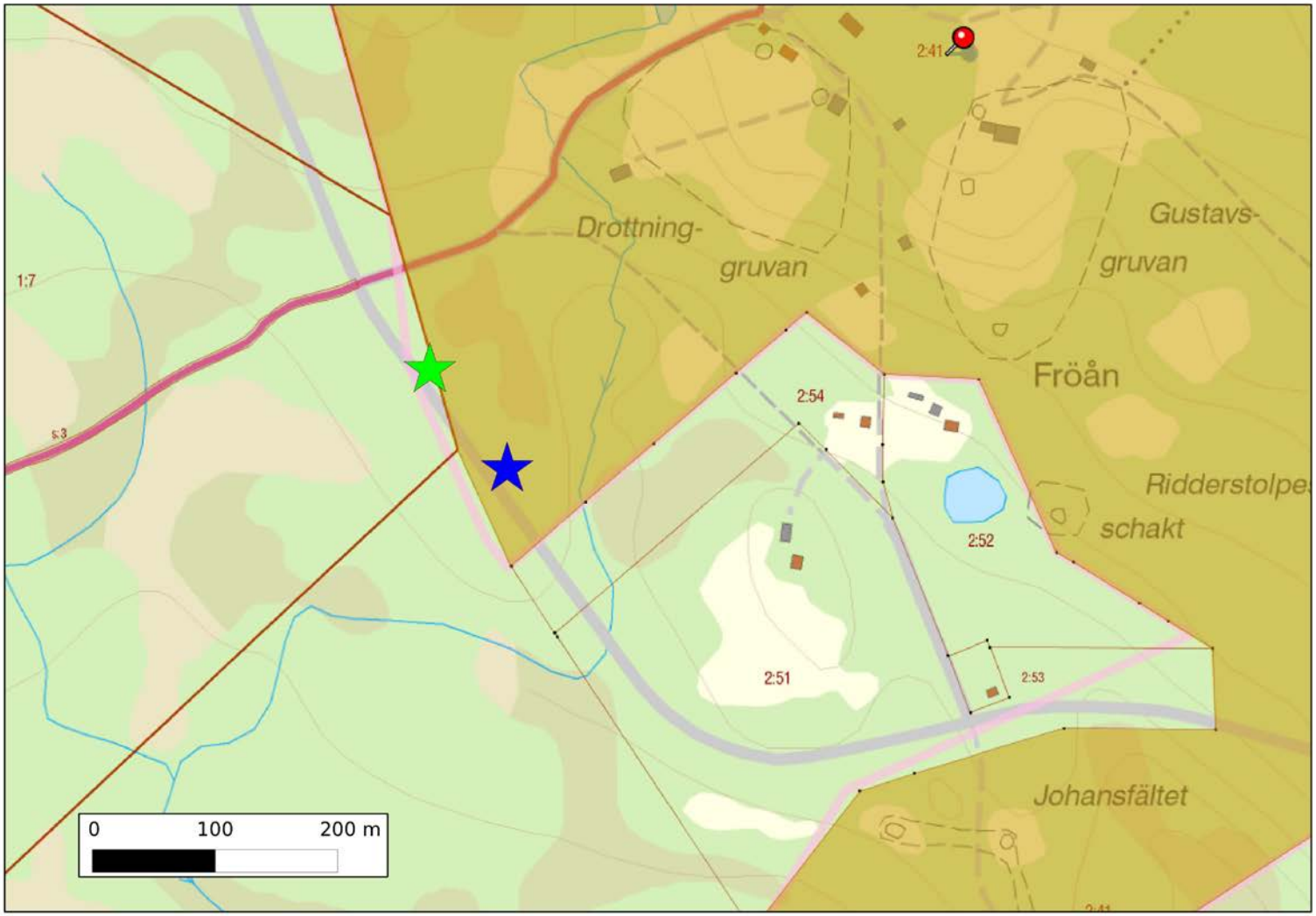


# COSC 1

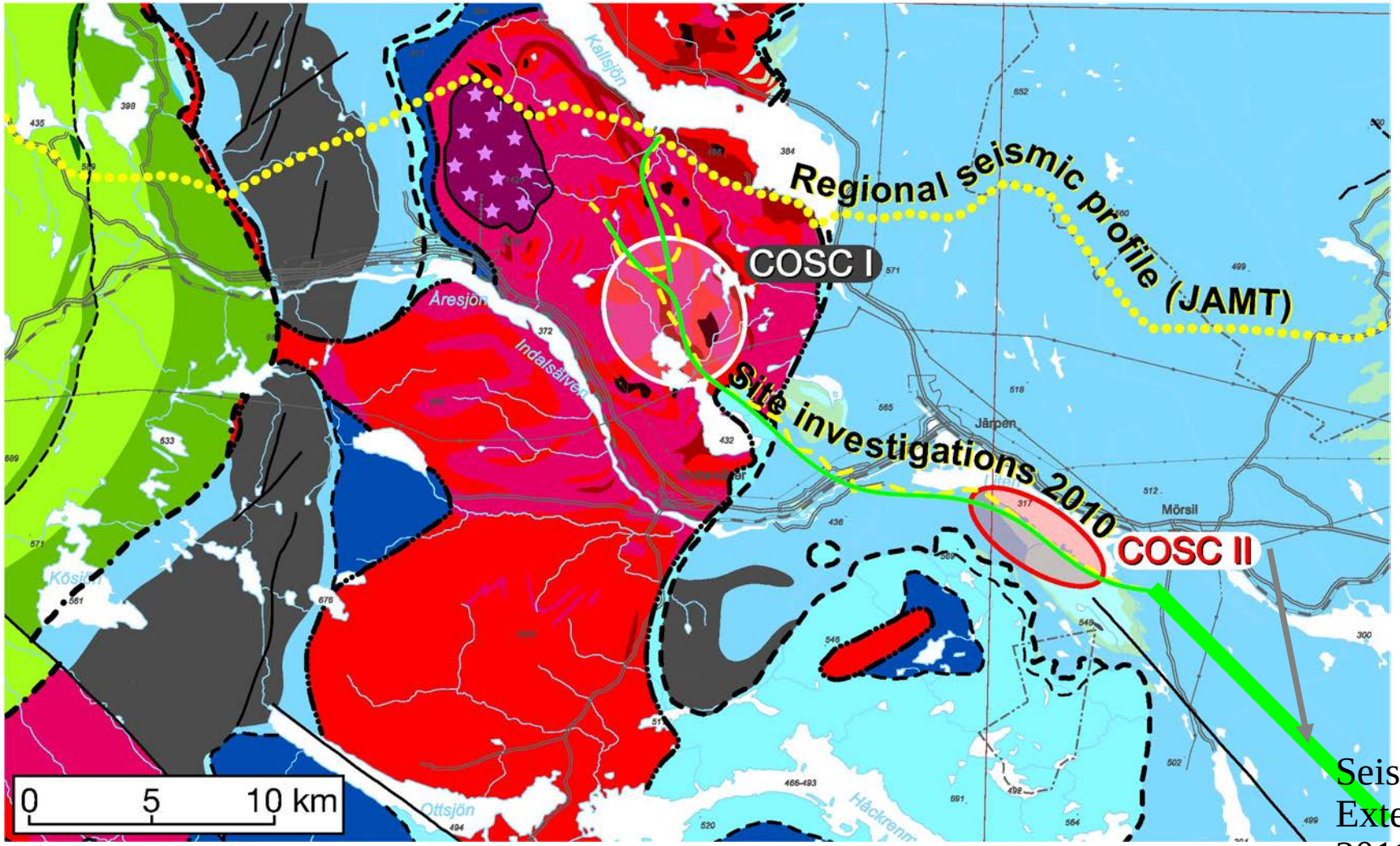

CDP
200
400
600
800
1000
1200
−0.5
0
0.5
1
1.5
2
2.5
3
Elevation (km)
0
2
4
6
8
10
Distance (km)

# Detailed view of initial COSC-1 location

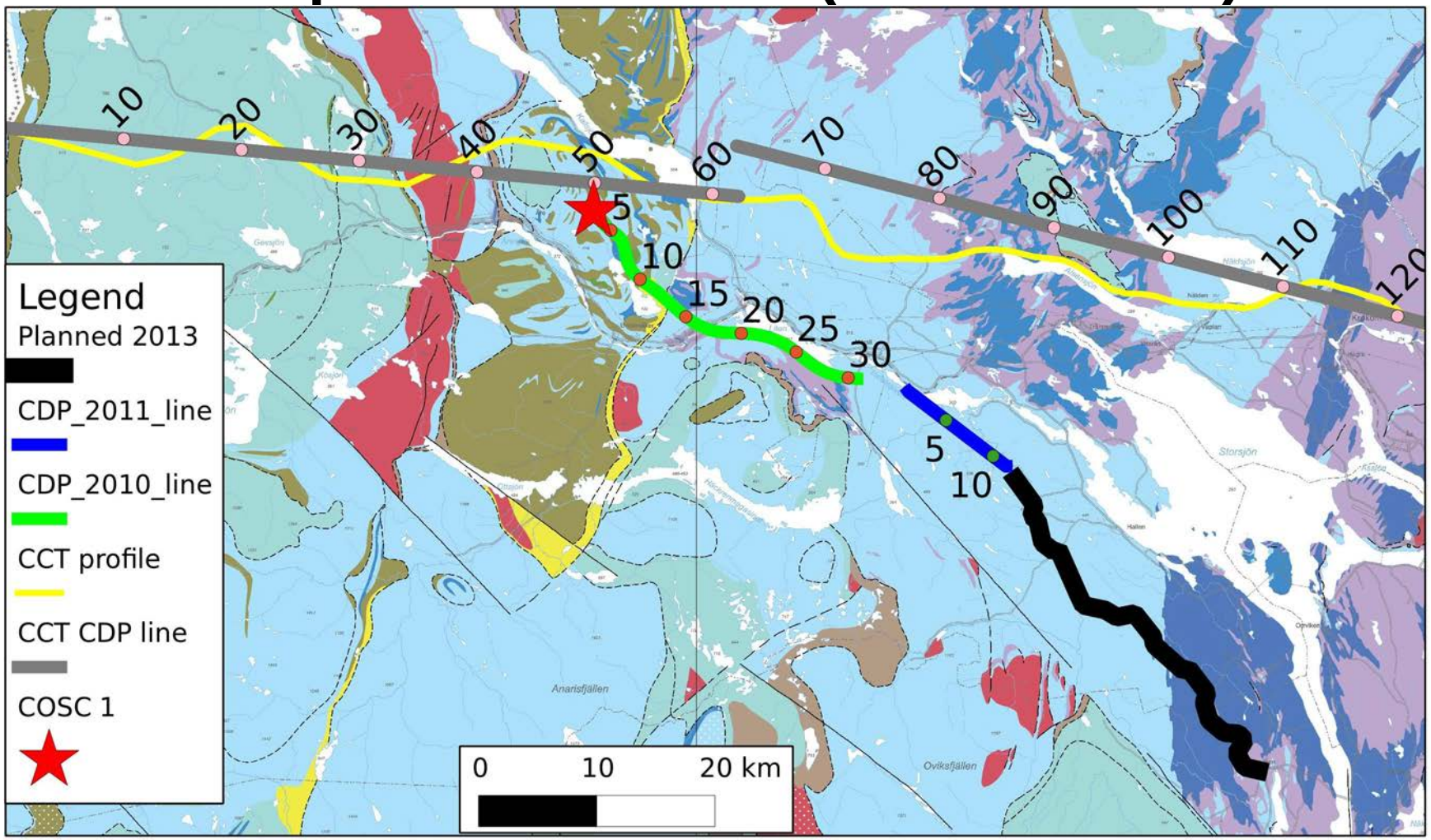



2:41
Drottning-
gruvan
Gustavs-
gruvan
Fröån
1:7
2:54
Ridderstolpe
schakt
2:52
2:51
2:53
Johansfältet
0
100
200 m

# COSC 2 location not decided



# Reflection seismic extension to be acquired 2014 (if funded)



# COSC: Planned borehole experiments

Fully cored boreholes to 2.5 km

Borehole geophysical logging

Integrated borehole and surface seismic surveys

Downhole hydraulic measurements

Downhole fluid sampling

Long-term (years) temperature monitoring

# Timing

Aug/Sep 2013: Site preparation

Oct 2013: Installation of a borehole seismic geophone array to 100 m

Apr/May 2014: Core drilling starts

Aug 2014:Downhole hydraulic measurements

Sep 2014: Borehole seismics

Oct 2014: Stress measurements (if funded)

2015: Long-term (years) temperature monitoring (if funded)

COSC 1 site, May 2013

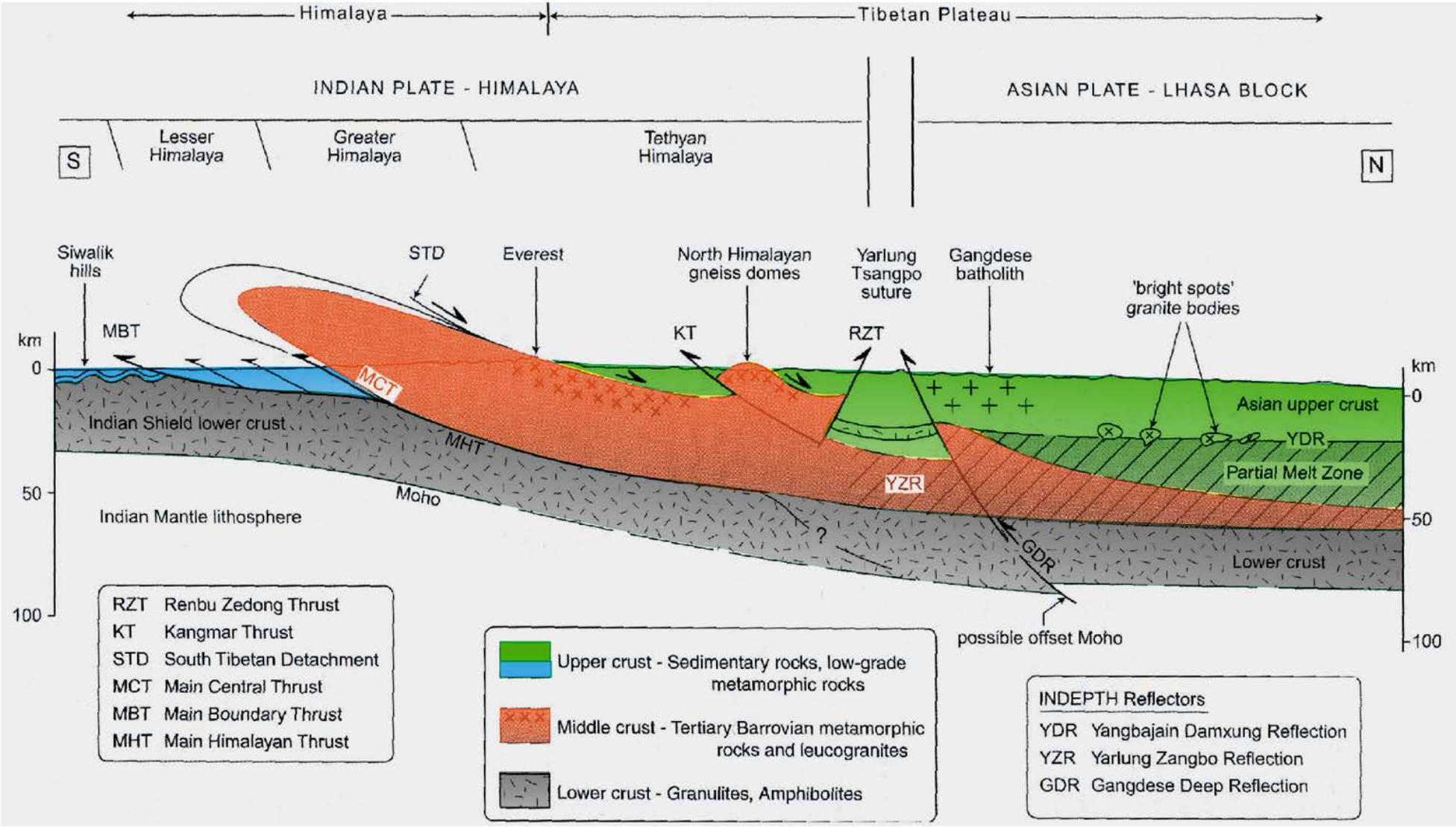
COSC 1 site, August 2013

# Summary

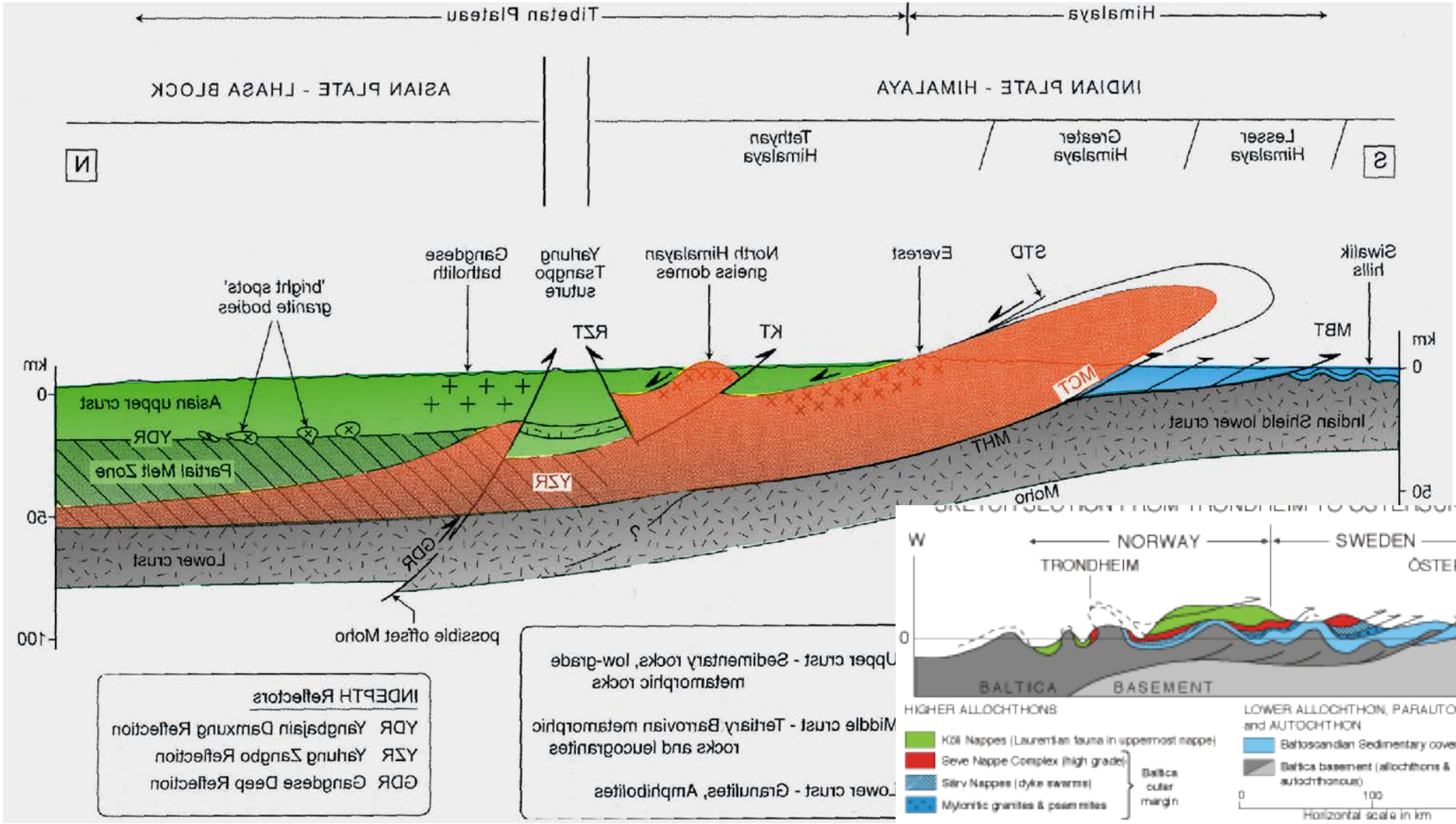
- COSC 1 borehole located: Will penetrate primarily the high grade Seve Nappe
- Further reflection seismic profiling is required before the COSC 2 borehole can be located: Goals are to penetrate the sole thrust (Alum shale) and at least one basement reflector
- Boreholes will be fully cored using the Swedish National Drilling Infrastructure
- Several post drilling experiments planned, including extensive borehole seismic surveys and long term (years) monitoring of temperature
- Funding is in place for drilling of COSC 1 and drilling will start in April/May 2014
- New AMT/MT, geological mapping, petrophysics and potential field data have been acquired in summer 2013

# Thank you!

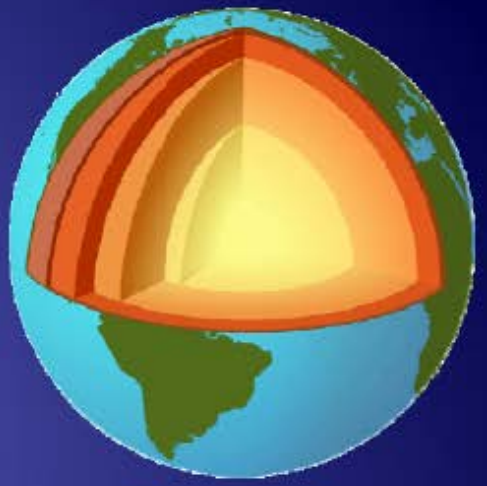
# Schematic cross section through the Himalayas



# Schematic cross section through the “Caledonides”



# Earth´s heat stores



The total heat release of Earth
~ 40 TW, does not seem like a lot.

Our geothermal energy extraction capacity is already 1/1000 of that.

However, the time scale of Earth is $10^5$ times the time scale of human kind.

The heat stored in the top few km of the Earth´s crust is $10^{27}$W = $2 \cdot 10^6 \times$ the total annual energy consumption.