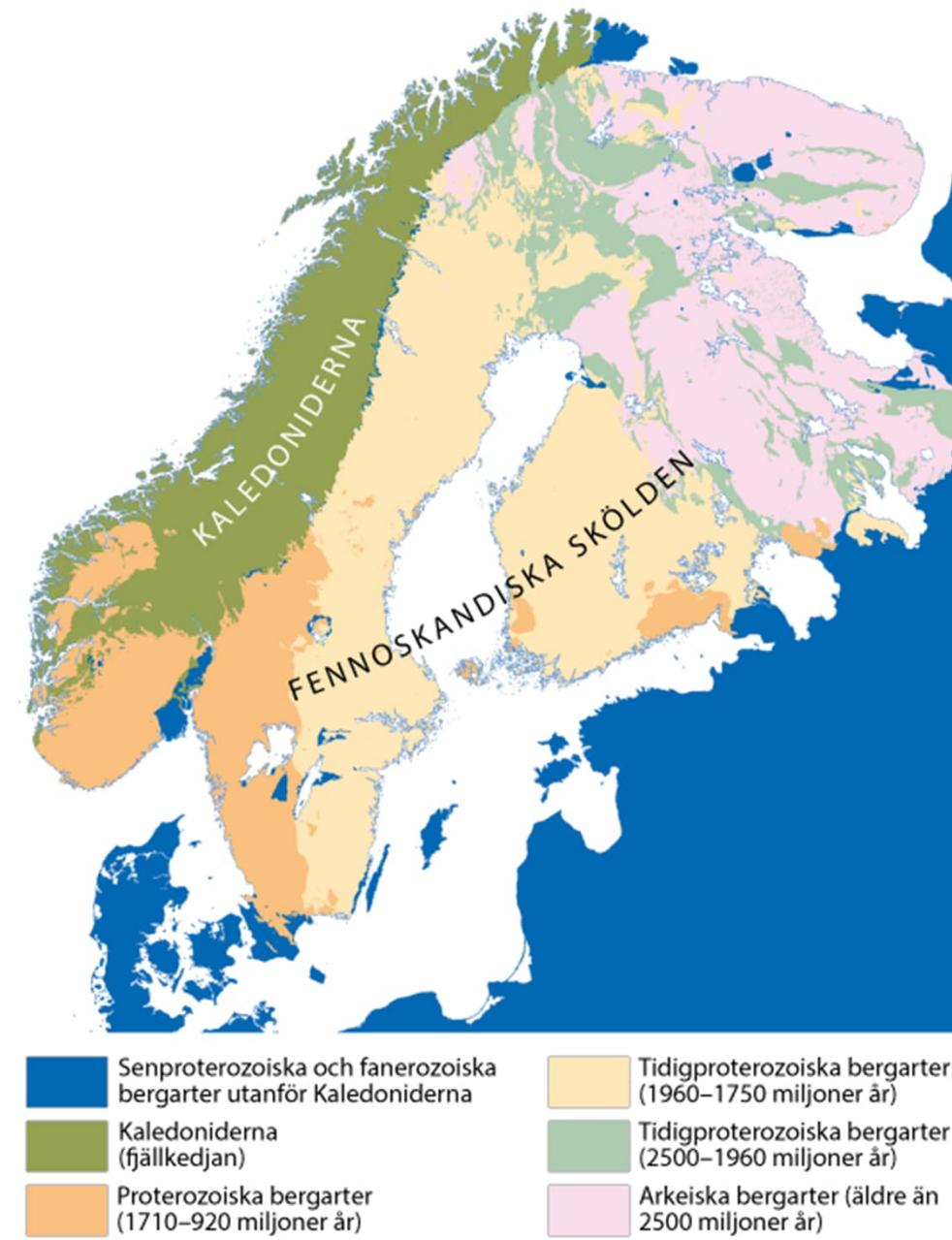


# Djupgeotermi – borrteknik, förutsättningar och erfarenheter

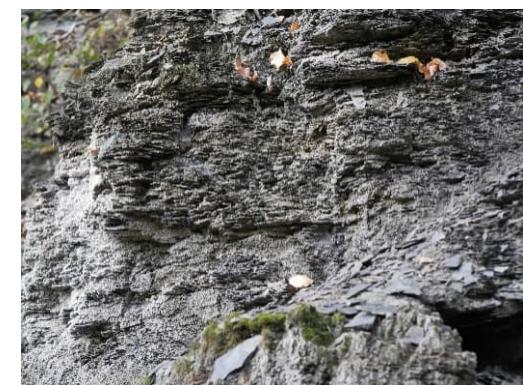


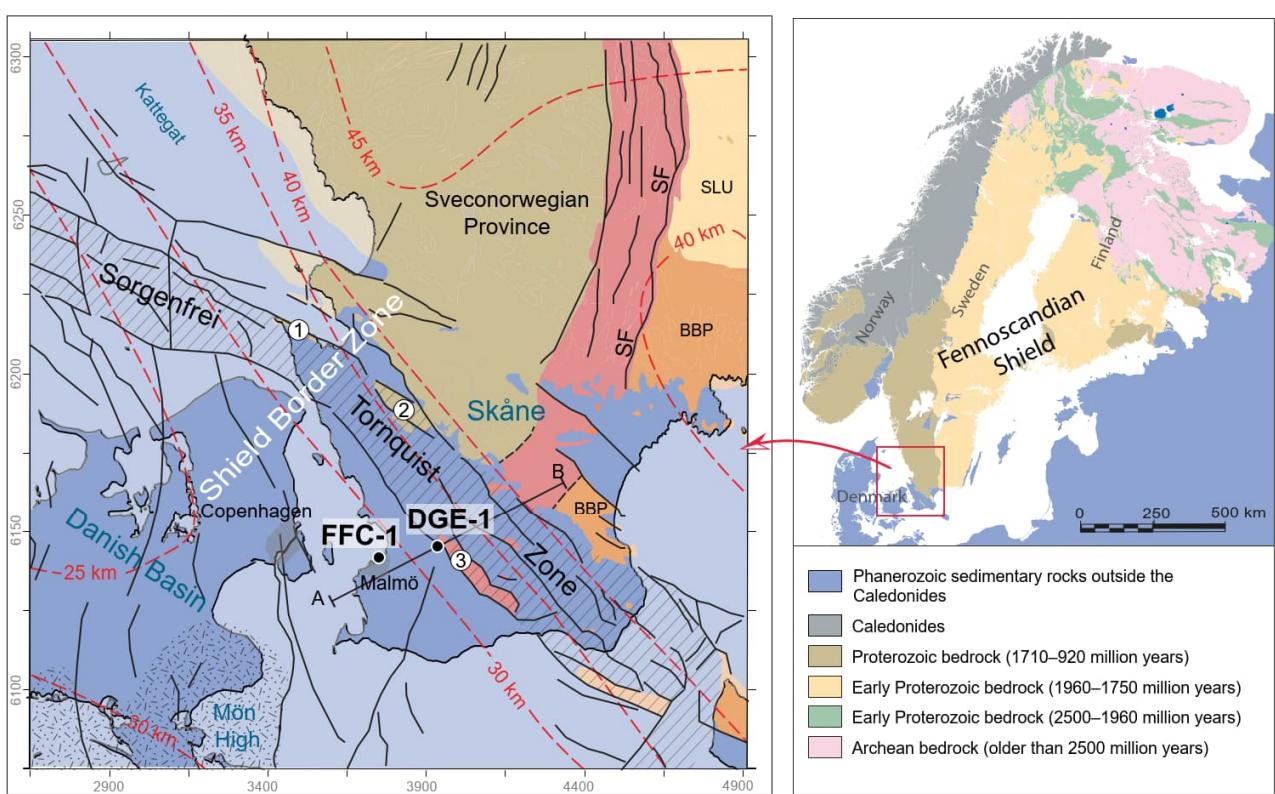
Jan-Erik Rosberg  
Teknisk geologi, LTH, Lunds universitet



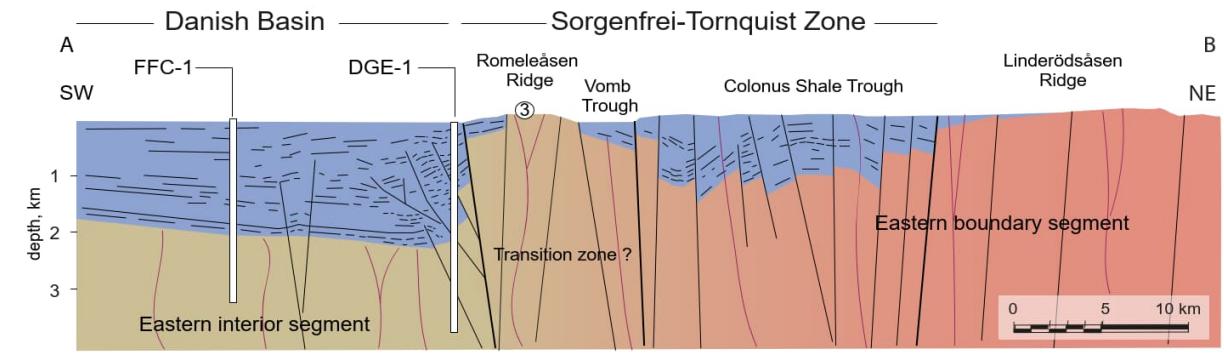


[www.sgu.se](http://www.sgu.se); Foto: Joakim Robygd

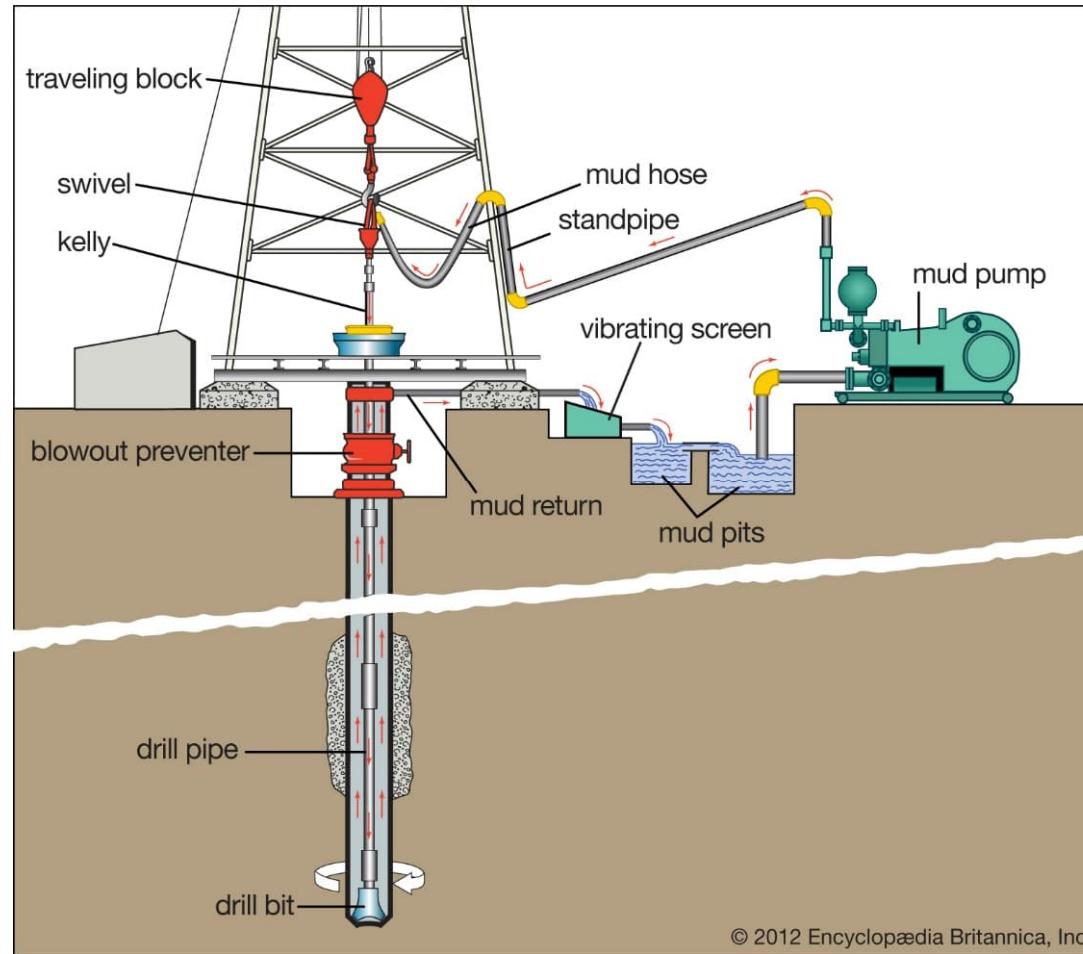




|  |  |                                       |
|--|--|---------------------------------------|
| Sveconorwegian Province (1.1–0.9 Ga)   | Phanerozoic platform cover strata                                    | SF: Sveconorwegian Front              |
| Eastern interior segment   | Limestone, shale, sandstone  | BBP: Bornholm Blekinge Province       |
| Granitoid and syenitoid migmatitic gneisses, granite, and amphibolite (1.7–0.9 Ga)   | Dolerite dyke (Permo-Carboniferous)                                  | SLU: Småland lithotectonic unit       |
| Eastern boundary segment   | // Fault   |                                       |
| Granitic orthogneiss and granite, syenitoid and metamorphic equivalents (1.8–1.2 Ga) | / Estimated thickness of the crystalline crust (Balling et al. 1995) | Outcrop areas referred to in the text |
| Bornholm-Blekinge Province (BBP) (1.5–1.4 Ga)  |  | ① Kullen                              |
| Granitic orthogneiss, granite (1.8–1.7 Ga)   |  | ② Söderåsen                           |
| Småland lithotectonic unit (SLU) (2.0–1.7 Ga)  |  | ③ Dalby quarry                        |
| Granite, granodiorite, gabbro, rhyolite, dacite and metamorphic equivalents (1.8 Ga) |  |                                       |



# Rotationsborrning med mud/Spolborrning



# DGE#2 borrplats



# Borrkronor



Impregnated drill bits



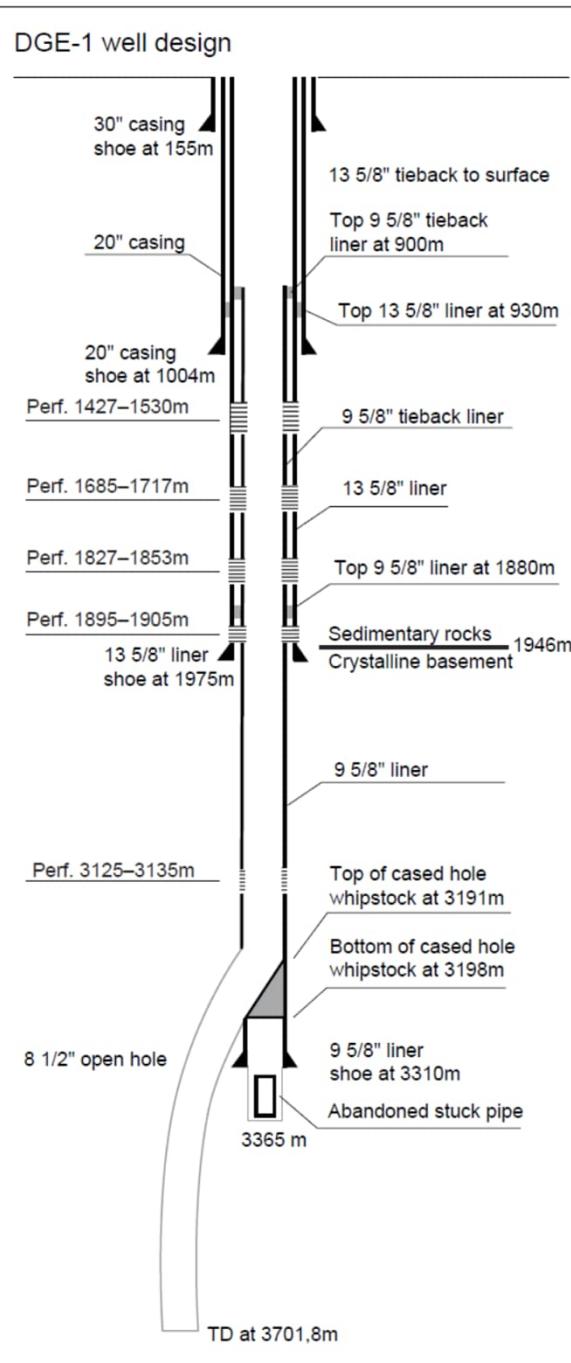
PDC (Polycrystalline  
diamond compact)



# Borrvätska/mud



# Foderrör/Casing



# Några fördelar med Rotationsborrning med mud

- Användbar i de flesta geologiska material.  
(Borrmetoden som används för de djupaste  
borrningarna i världen)
- Kontrollerad borrning, t.ex. Vid höga  
formationstryck eller i okonsoliderade bergarter.
- Möjlighet till styrd borrning

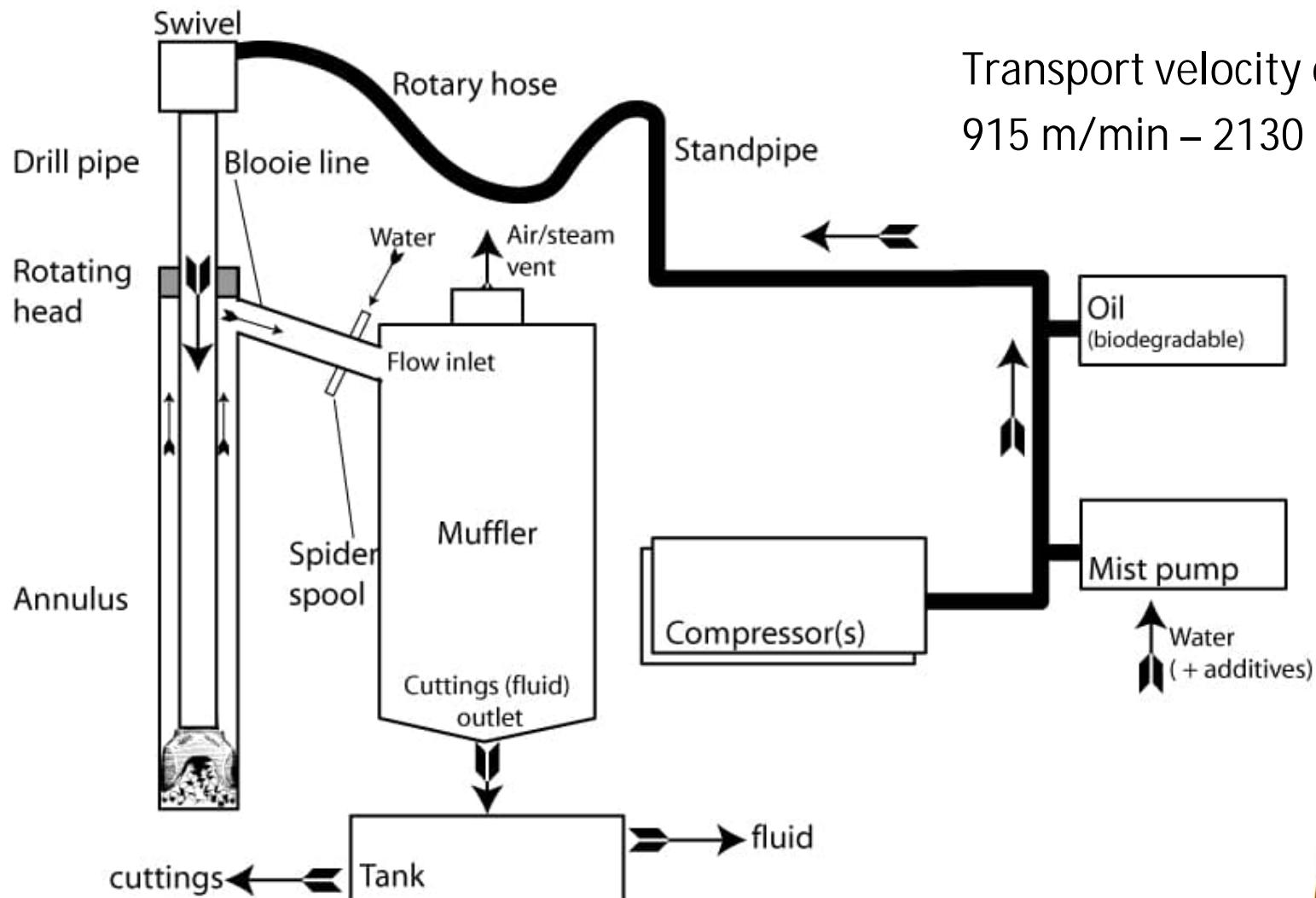


# Några nackdelar med Rotationsborrning med mud

- Borrvätska kan sätta igen permeabla formationer.
- Fördröjd provtagning (lag time)
- Låg sjunkhastighet (Rate of Penetration (ROP) i kristallina bergarter.



# Rotationsborrning med luft

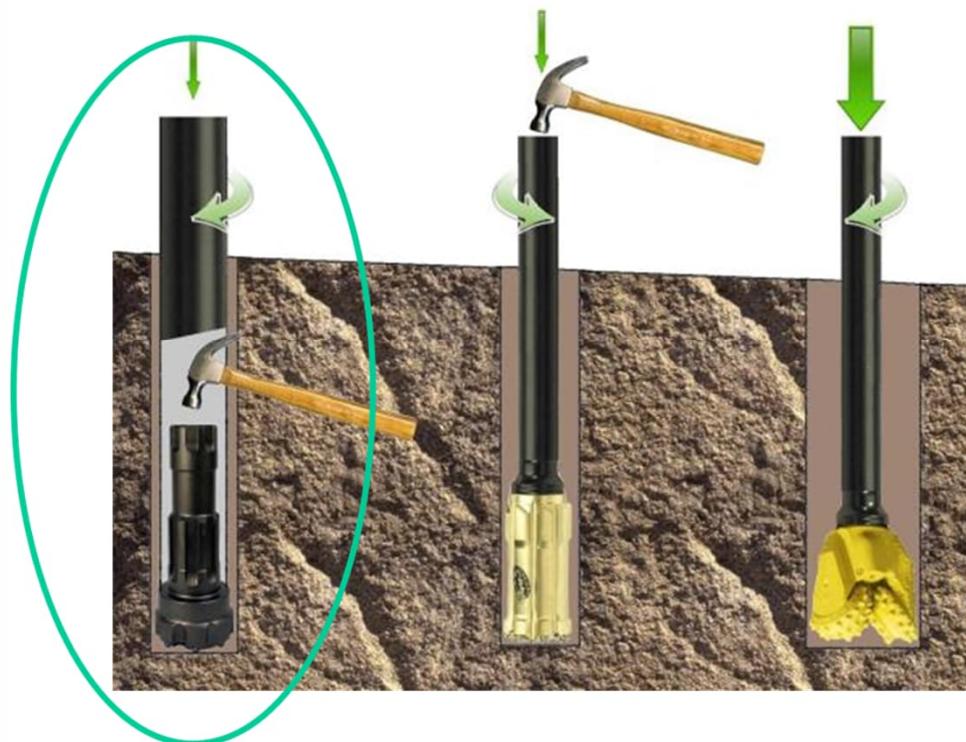


Transport velocity of cuttings:  
915 m/min – 2130 m/min



# Hammborrning (DTH) med luft

DTH (Down The Hole)      Top hammer      Rotary (non-percussive)



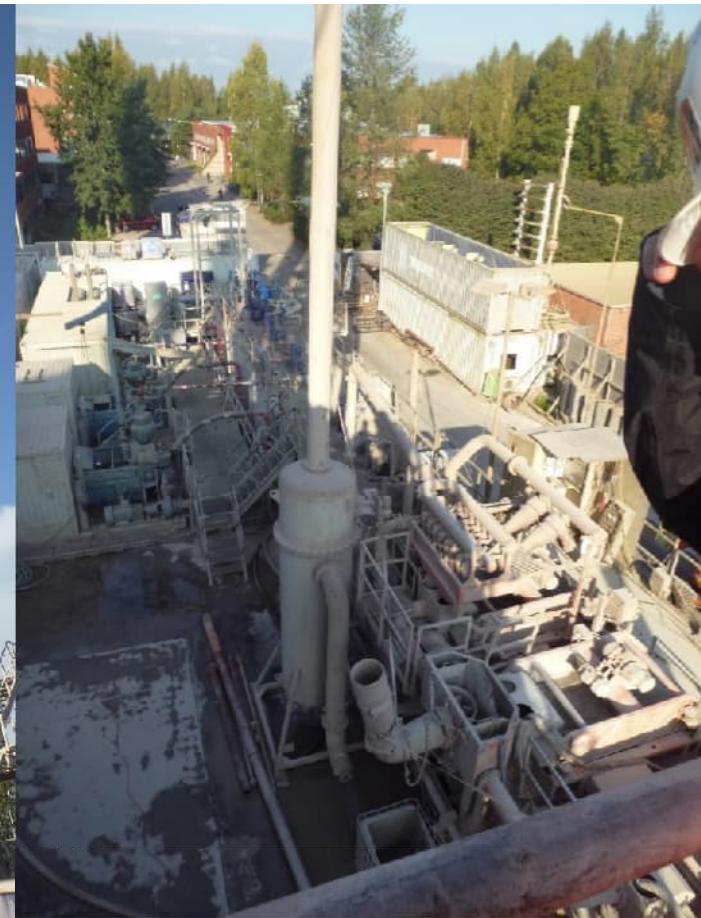
# Hammarborring (DTH) med luft



# Kompressorer



# Djupast hittills -ST1 Espoo (Djup 4500 m, 12 ¼" (311 mm))



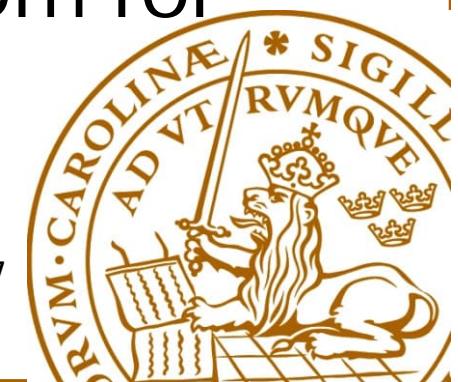
# Några fördelar med Hammarborrning med luft

- Hög sjunkhastighet i urberg (t.ex. gnejs, granit, metabasit/amfibolit).
- Lätt att identifiera vattenförande formationer.
- Mindre risk för igensättnings av permeabla formationer.
- Kan användas som seismisk källa.



# Några nackdelar med Hammarborrning med luft

- Begränsad användning till hårdare bergarter.
- Begränsad användning i vattenförande formationer.
- Hålsinstabilitet och övertryck i formationen begränsar användningen.
- Styrd borrning inte lika utarbetad som för rotationsborrning.



# Vattenhammarborrning/ Mudhammarborrning



Source: D&B Hanjin

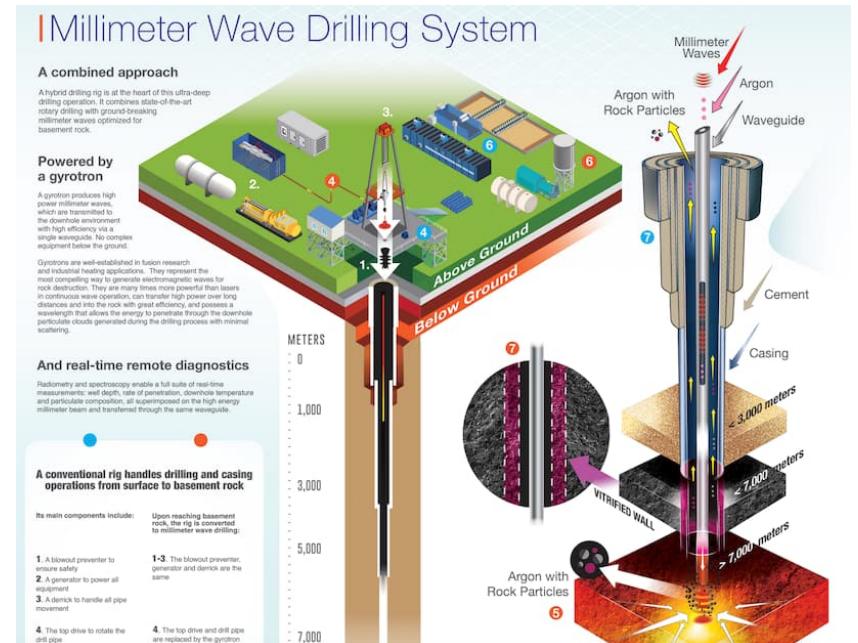
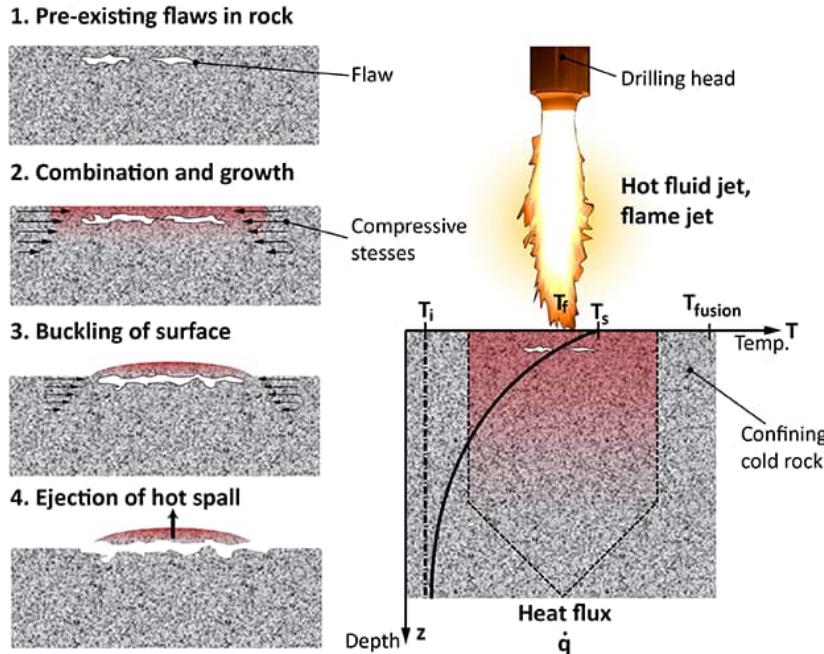


# Kärnborrning (undersökningsborrning)



# Framtida borrmetoder

Laser, Plasma, Spallation drilling, Millimeter drilling etc.



[https://ltr.ethz.ch/en/research/spallation\\_drilling.html](https://ltr.ethz.ch/en/research/spallation_drilling.html)

<https://www.thinkgeoenergy.com/research-partnership-to-explore-ultra-deep-geothermal-drilling/>

# Mechanical Specific Energy (MSE)

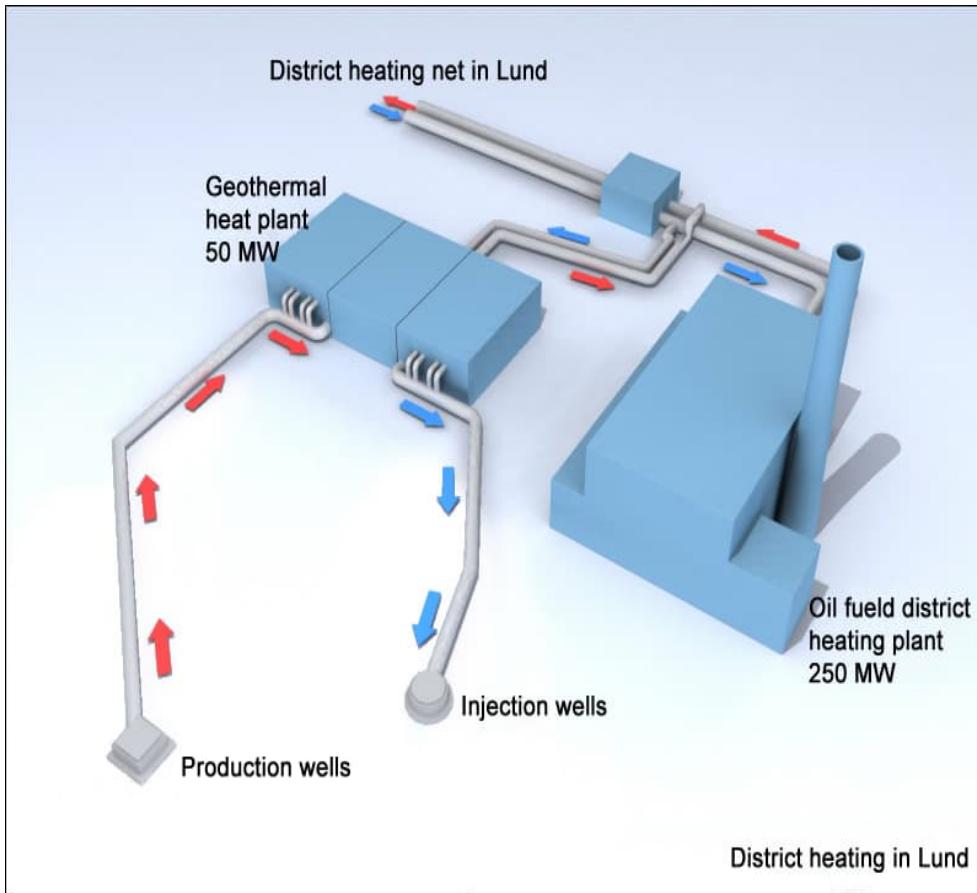
(Teale, 1965)

$$MSE \approx \frac{\text{Input Energy}}{\text{Output ROP}}$$

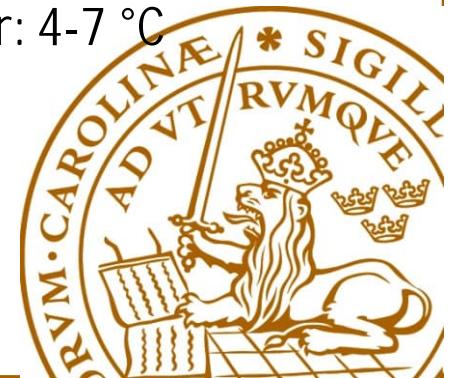
$$MSE = \frac{4WOB}{\pi D^2} + \frac{480rpm \cdot T}{D^2 ROP}$$



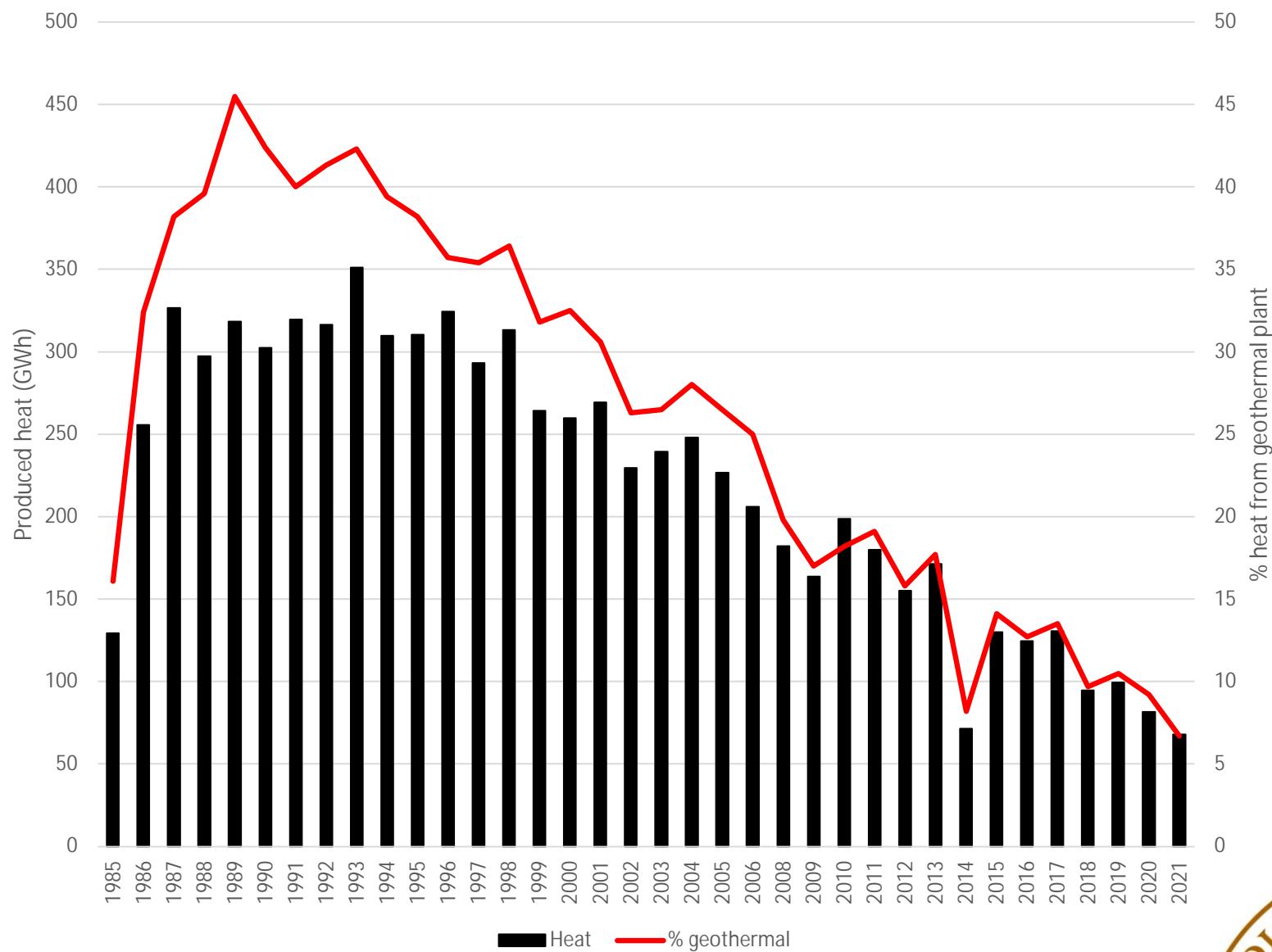
# Geotermianläggningen i Lund



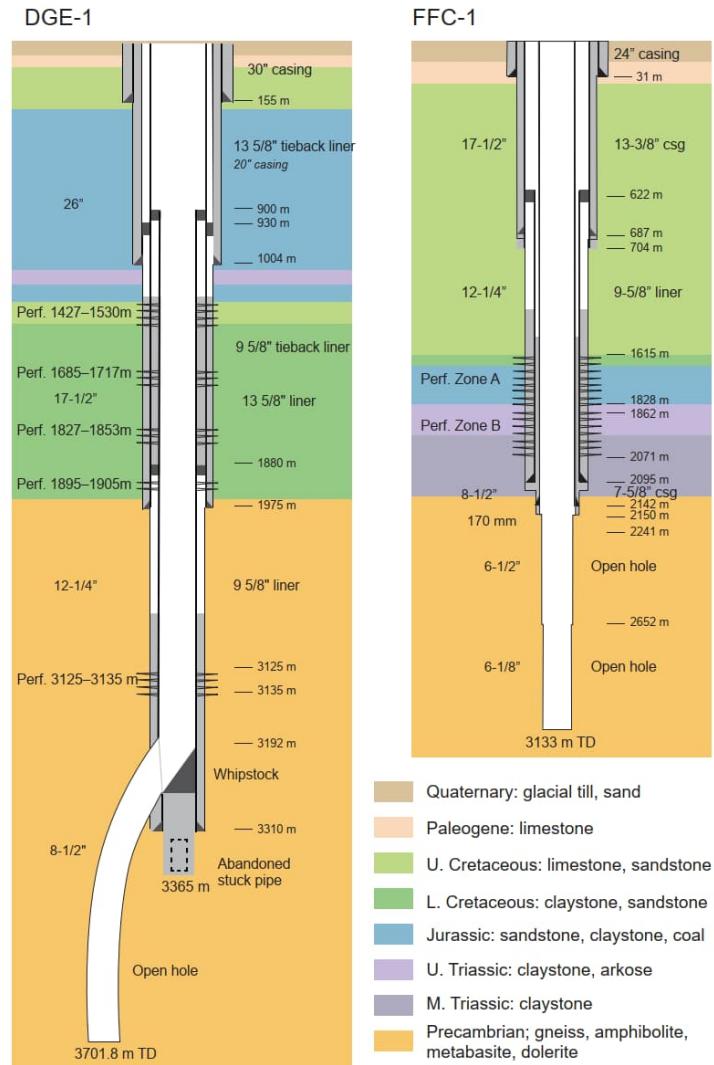
- Akvifer: Campan sandsten
- Produktionsbrunnar : 4
- Injekteringsbrunnar: 4 (Initialt 5)
- Borrmетод: Rotationsborrning med mud
- Borrdjup: 650 - 800 m
- Undersökningsborrningar: 2
- Produktionsflöde: ca 1600 m<sup>3</sup>/h
- Produktionstemperatur:  
initialt: ca 22 °C  
idag: 12 - 20 °C
- Injekteringstemperatur: 4-7 °C



## Geothermal heat pump plant in Lund

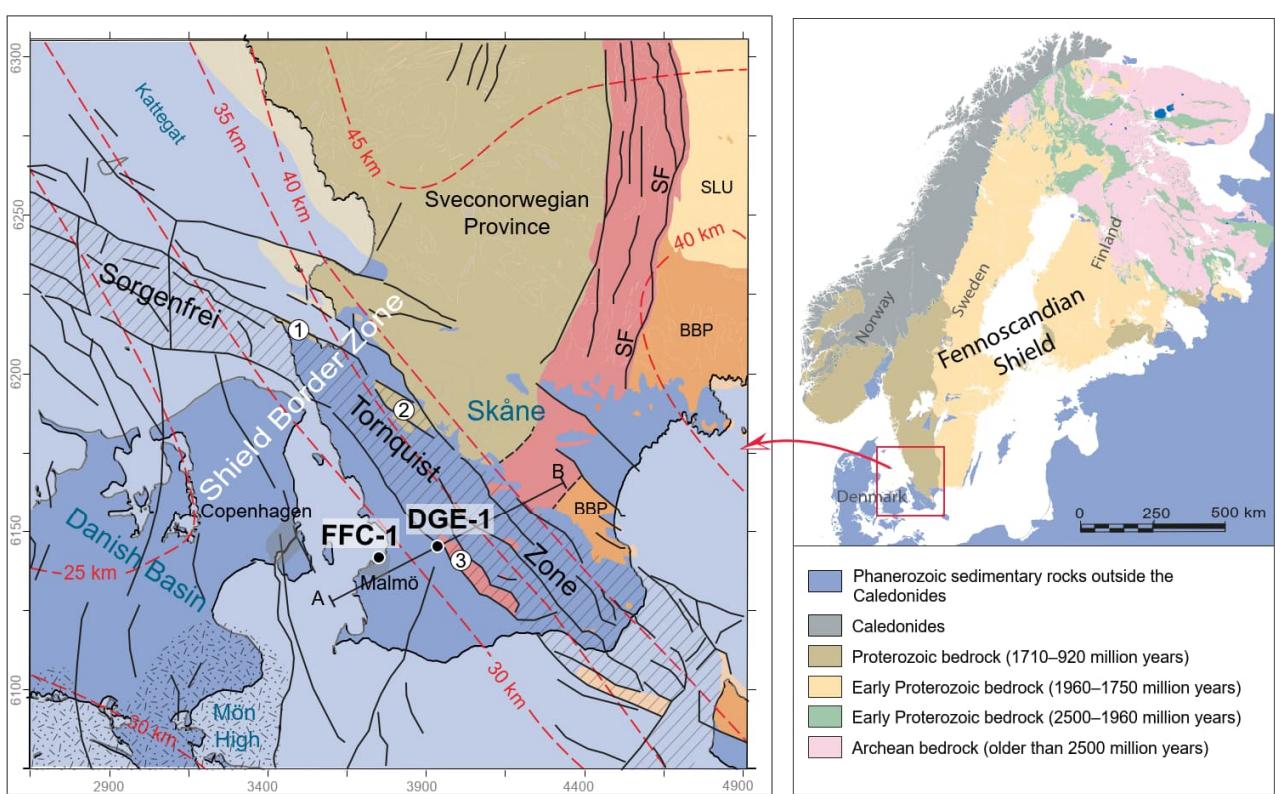


# Erfarenheter från djupgeotermiska undersökningar (>3 km) i Lund och i Malmö

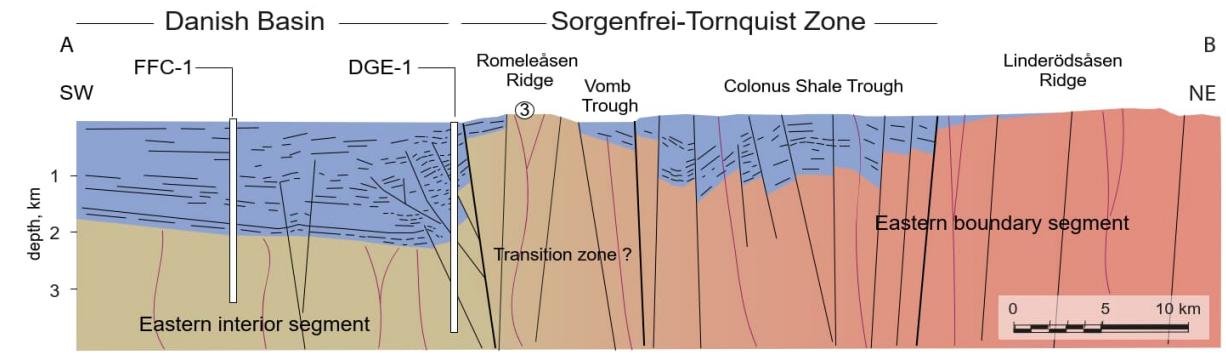


(Rosberg & Erlström, 2021)



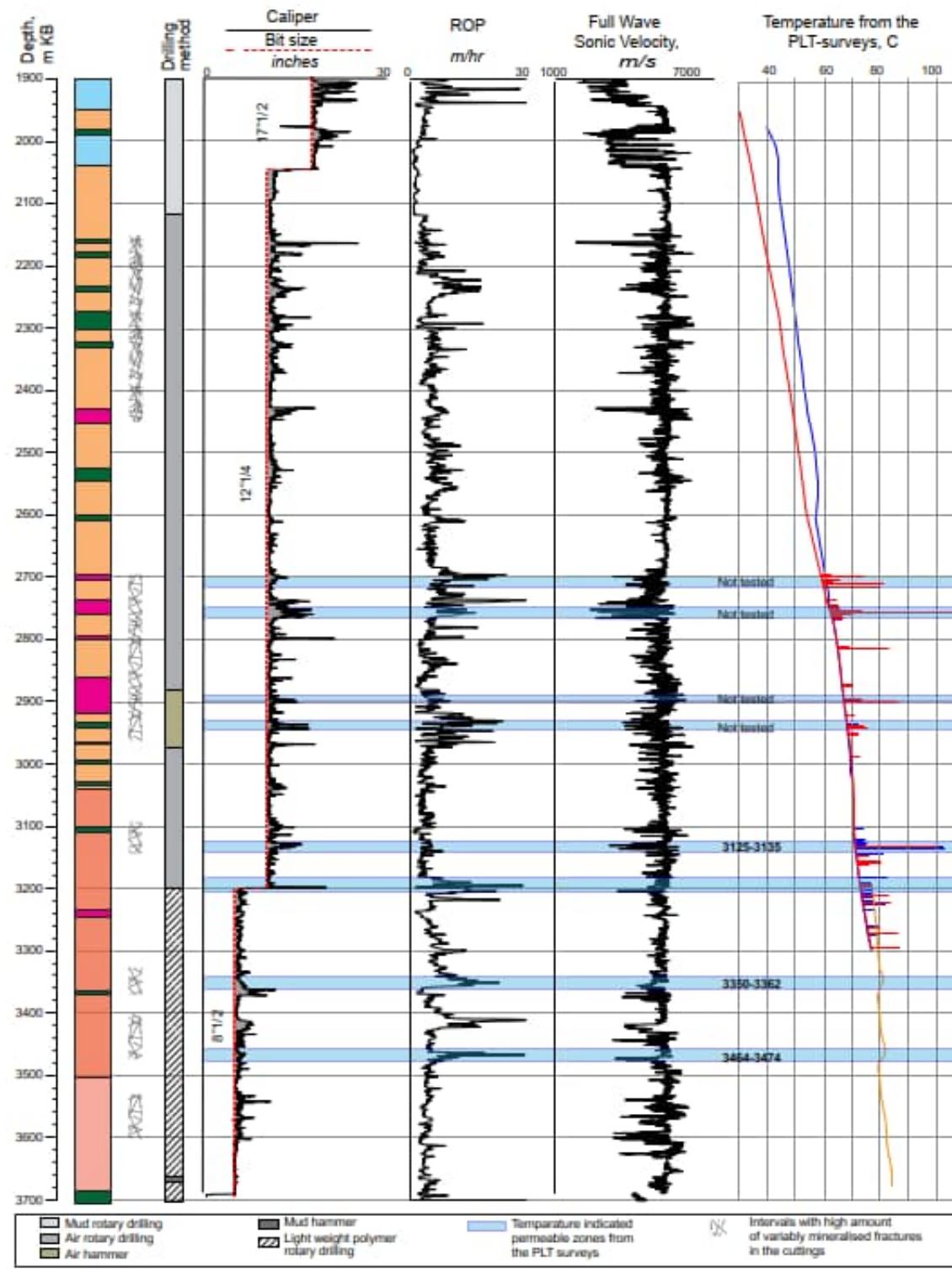


|  |  |                                       |
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| Eastern boundary segment   | Fault  |                                       |
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| Granite, granodiorite, gabbro, rhyolite, dacite and metamorphic equivalents (1.8 Ga) |  | ③ Dalby quarry                        |



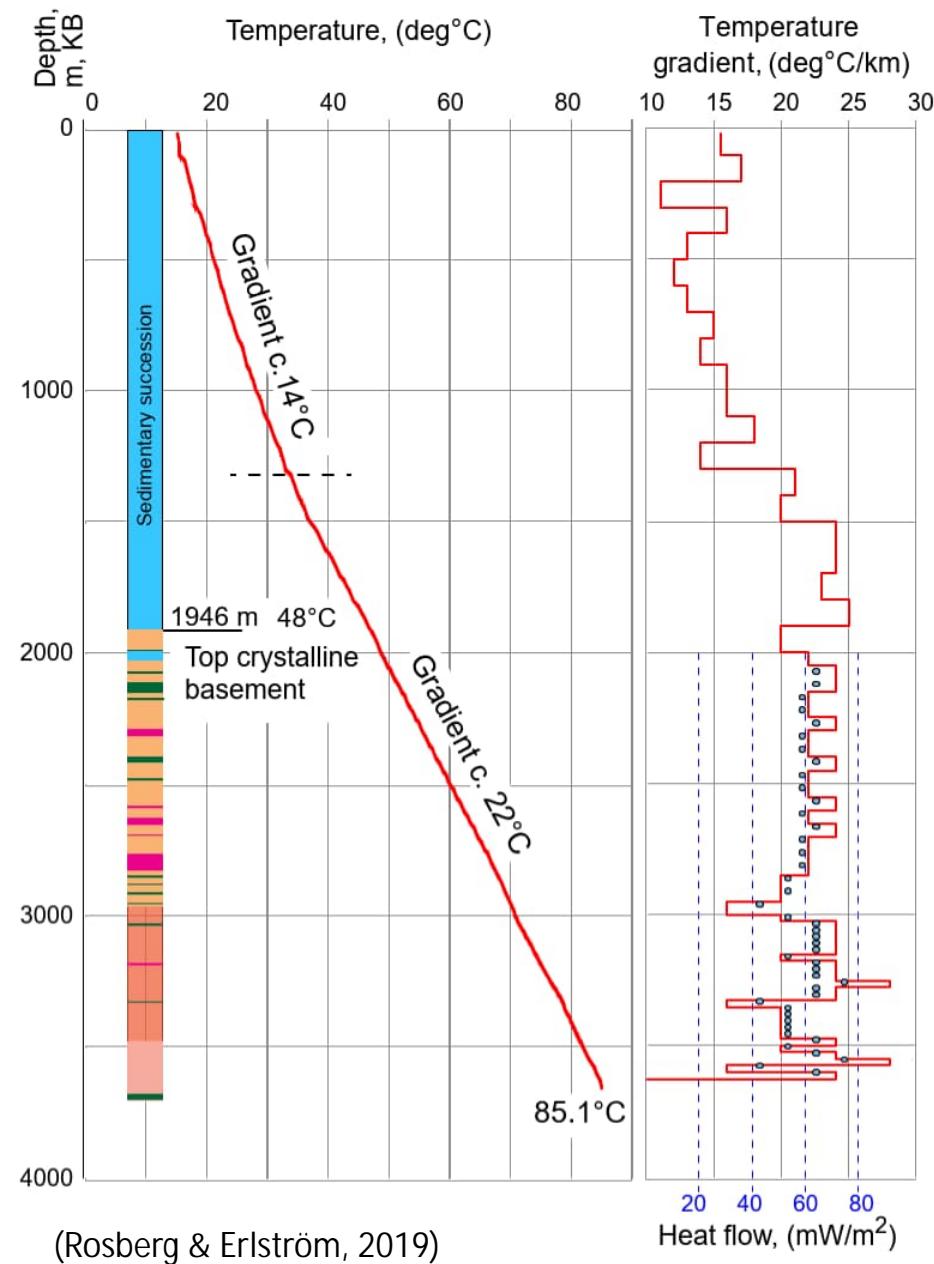
# DGE#1





(Rosberg & Erlström, 2019)



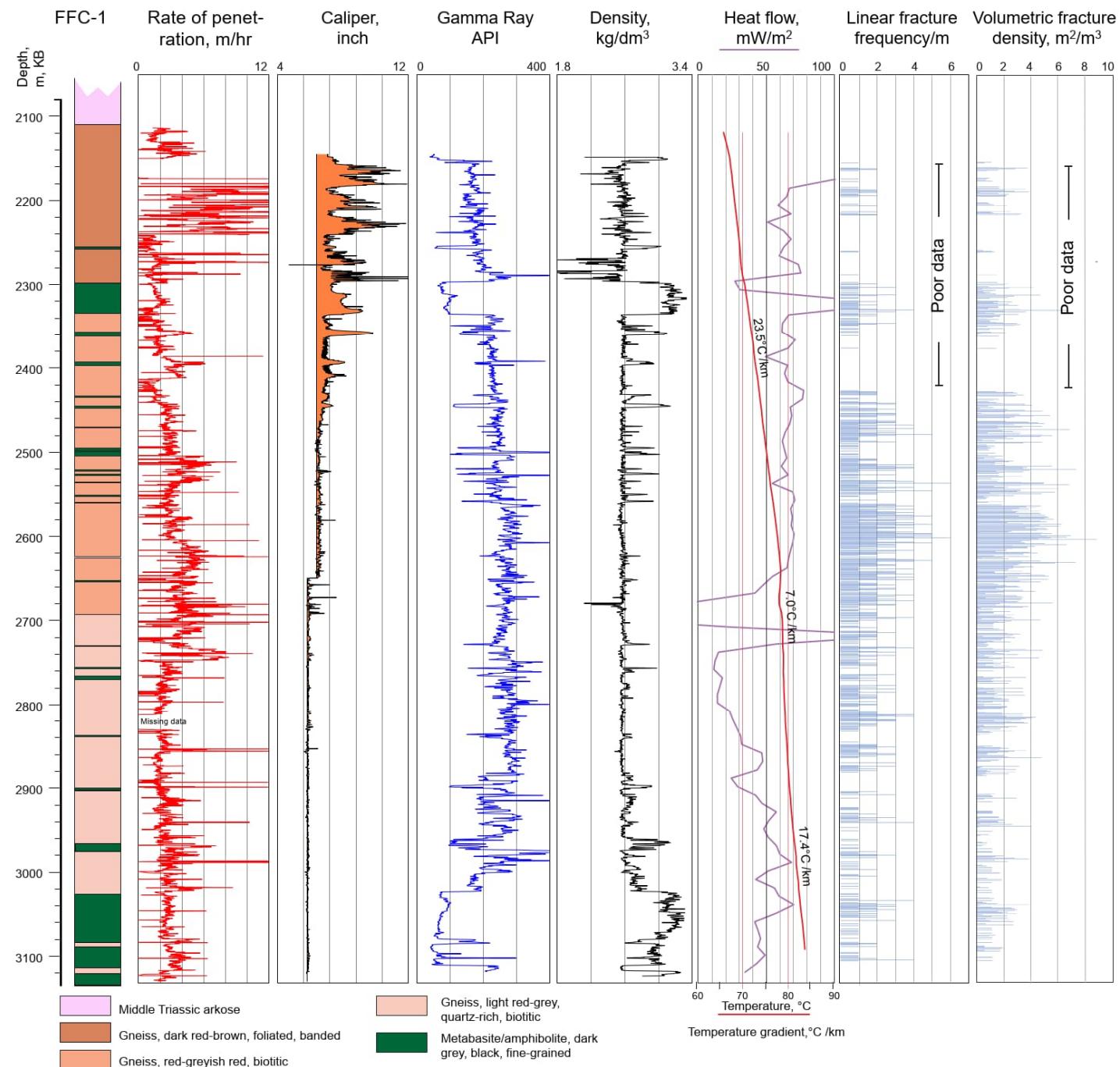


# FFC-1 Malmö



Jan-Erik Rosberg, Teknisk geologi, LTH, Lunds universitet

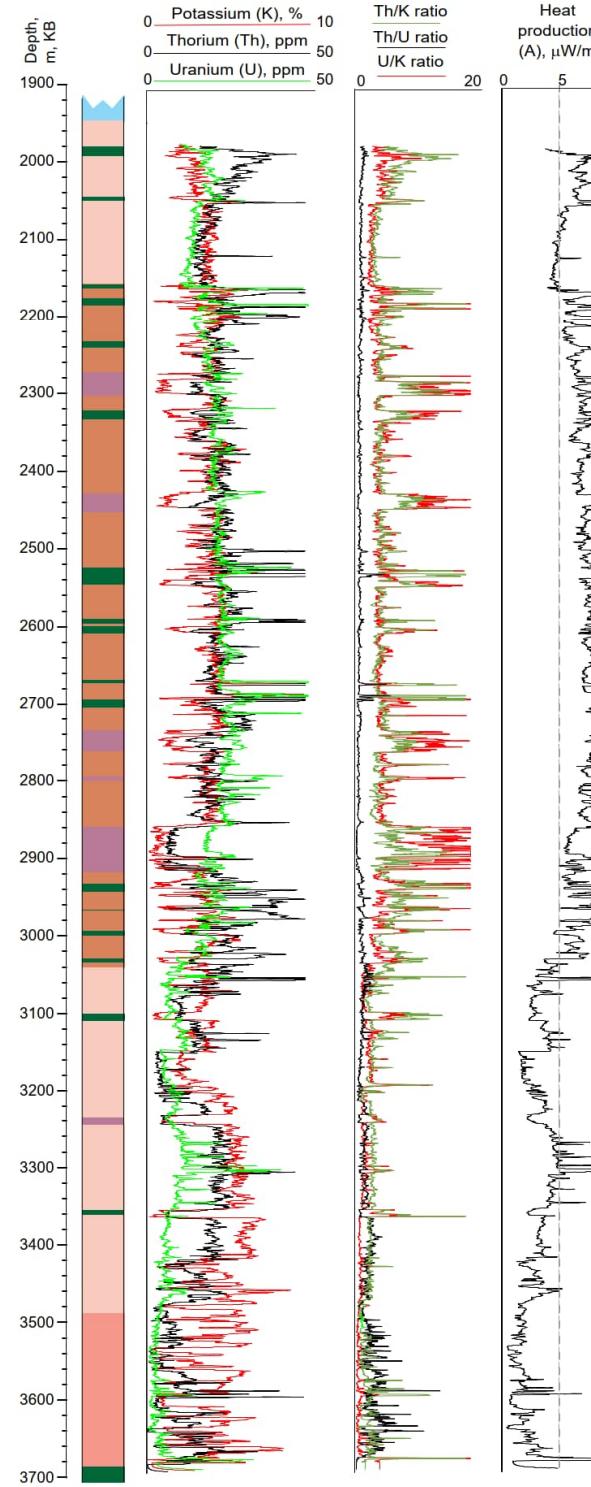




(Rosberg & Erlström, 2021)



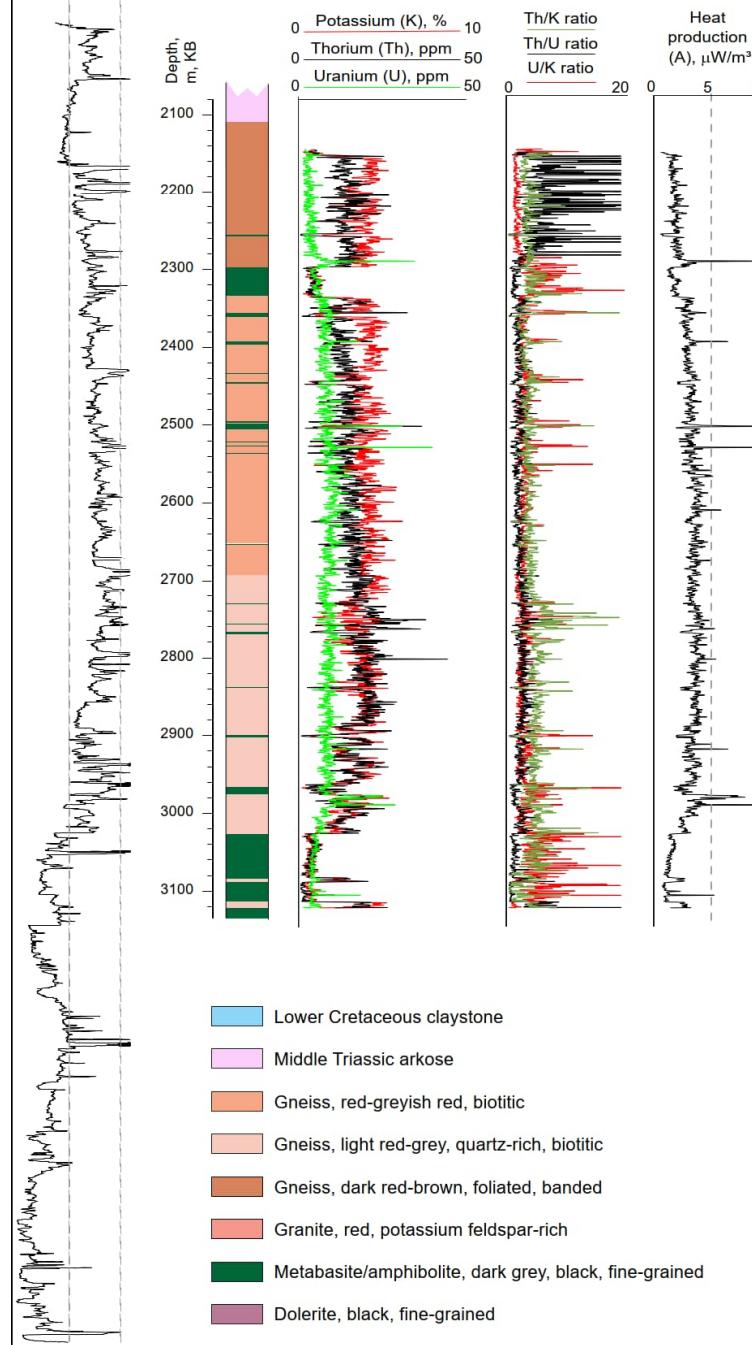
DGE-1



$$A = 10^{-5} \cdot \rho \cdot (9.52 \cdot U_{\text{ppm}} + 2.56 \cdot Th_{\text{ppm}} + 3.48 \cdot K_{\text{percent}})$$

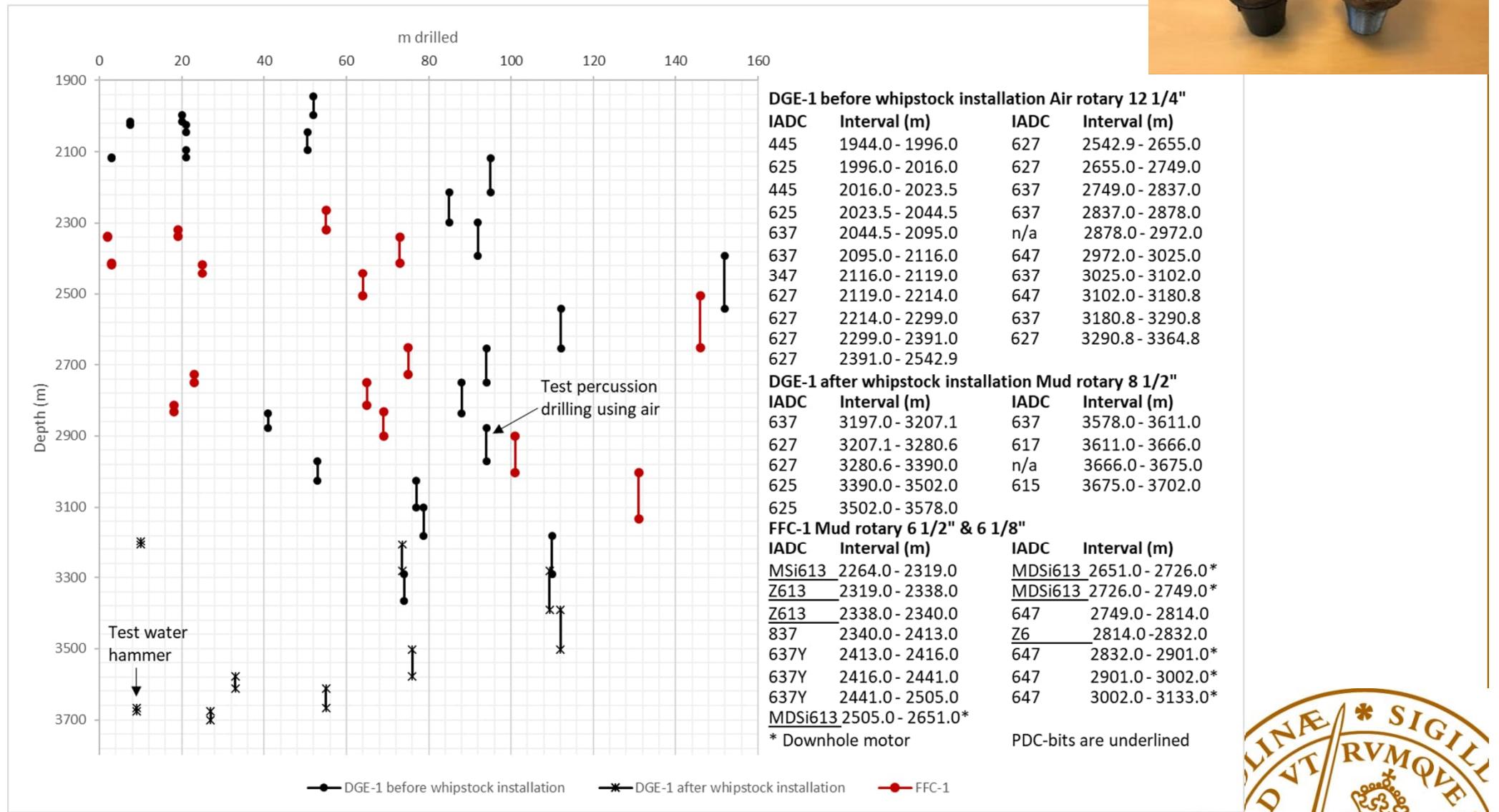
(Bücker and Rybach, 1996)

FFC-1



- Lower Cretaceous claystone
- Middle Triassic arkose
- Gneiss, red-greyish red, biotitic
- Gneiss, light red-grey, quartz-rich, biotitic
- Gneiss, dark red-brown, foliated, banded
- Granite, red, potassium feldspar-rich
- Metabasite/amphibolite, dark grey, black, fine-grained
- Dolerite, black, fine-grained





(Rosberg & Erlström, 2021)

|                                  | <b>FFC-1</b>           | <b>DGE-1<sup>1)</sup></b> | <b>Gravberg-1<sup>2)</sup></b> | <b>Bh32012 in<br/>Lake Vättern<sup>3)</sup></b> | <b>Outokumpu<br/>R-2500<sup>4)</sup></b>                 | <b>Hunt well,<br/>Western<br/>Canada<sup>5)</sup></b> |
|----------------------------------|------------------------|---------------------------|--------------------------------|---|--|---|
| <b>Depth, m</b>                  | 3133                   | 3702                      | 6957                           | 1820  | 2516   | 2363  |
| <b>Temperature, °C</b>           | 84                     | 85                        | 116                            | 37  | 40   | 47  |
| <b>Q, mW/m<sup>2</sup></b>       | 51–66*                 | 58*                       | 50                             | 35–47   | 40–45  | 51  |
| <b>Gradient, °C/km</b>           | 17–24                  | 22–24                     | 14–18                          | 15–20   | 14–17  | 20  |
| <b>K, W/(m K)</b>                | 2.4–3.6                | 2.5–3.6                   | 3.4                            | 1.8–2.8   | 2.5–3.3  | 2.5   |
| <b>A, µW/m<sup>3</sup></b>       | 3.0*                   | 5.8*                      | 2.0–5.0                        | 0.1*  | 1.6–5.4  | 2.9–3.4   |
| <b>Dominating rock<br/>types</b> | Gneiss,<br>amphibolite | Gneiss,<br>amphibolite    | Granite                        | Diorite   | Metasediments<br>Pegmatitic granite,<br>ultramafic rocks | Gneiss,<br>granite,<br>mylonite                       |

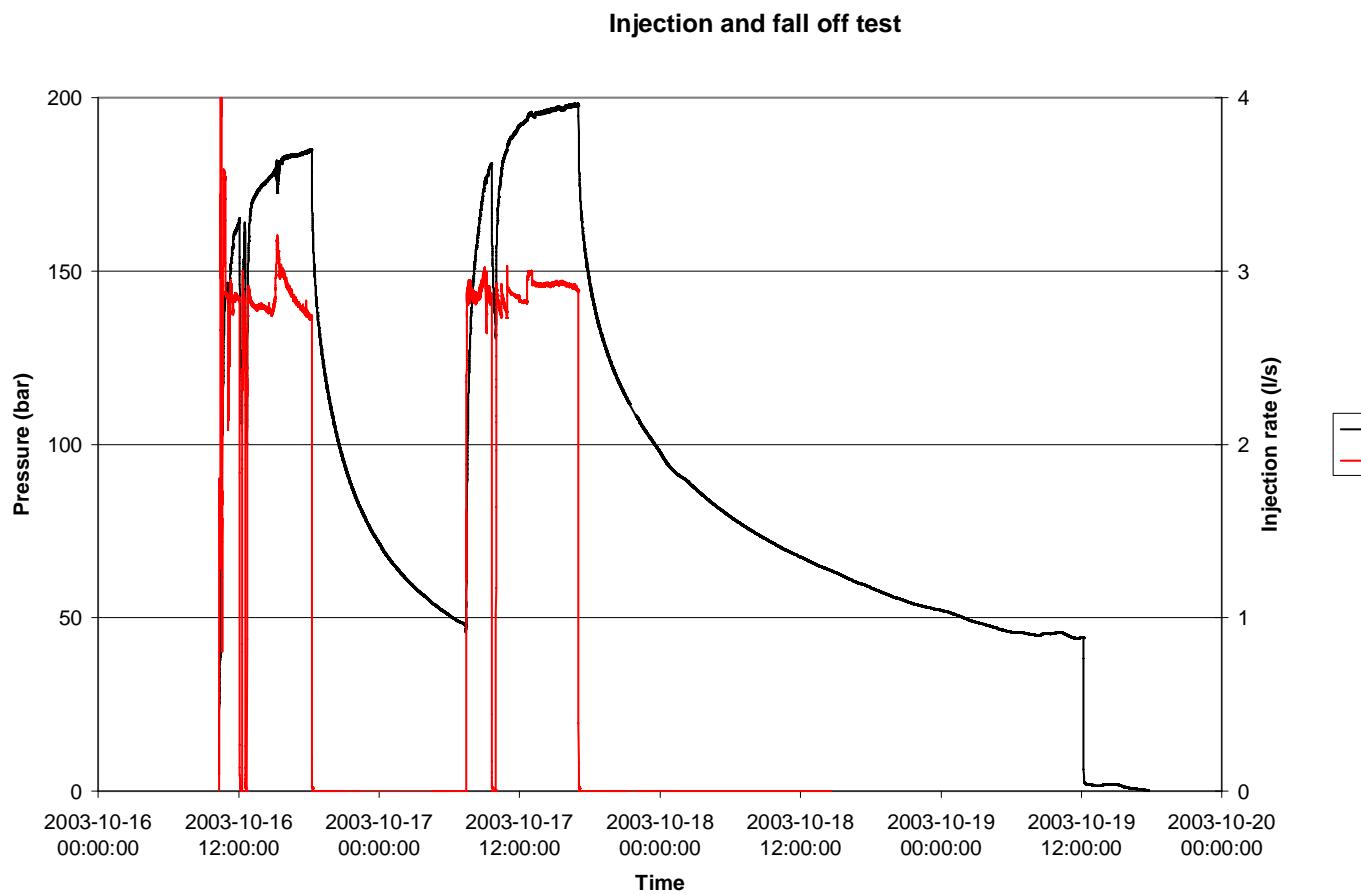
<sup>1)</sup>Rosberg and Erlström (2019), <sup>2)</sup>Aldahan et al. 1991, <sup>3)</sup>Sundberg et al. 2016, <sup>4)</sup>Kukkonen et al. 2011,

<sup>5)</sup>Majorovicz et al. (2014), \*Weighted average

(Rosberg & Erlström, 2021)



# Injection and fall-off test



Transmissivitet  $5.0 \cdot 10^{-7} \text{ m}^2/\text{s}$   
Hydraulisk konduktivitet  $9.9 \cdot 10^{-10} \text{ m/s}$



# Erfarenheter från djupgeotermiska undersökningar (>3 km) i Lund och i Malmö

- Bergarter
- Sprickor & sprickriktning
- Termiska egenskaper och geotermisk gradient
- Hydrauliska egenskaper
- Mekaniska egenskaper t.ex. bergsspänningar
- Borrbarhet
- Vatten- och gaskemi
- Seismiskmätning under borrning



Tack för er uppmärksamhet!



