Past and Future of Thermal Conductivity Testing

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Relevance of thermal conductivity in BTES installations

- The thermal conductivity determines the amount of drilling needed in the design of a BTES given the energy storage and power requirements.
- In case of future performance discussions a thorough conductivity measurement may form a sound basis for improvements or extensions.

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Transient probe method

Carslaw & Jaeger
Ingersoll & Plass

The infinte line source equation

$$\Delta T(r,t) = \frac{\dot{Q}}{2\pi\lambda} \int_{\frac{r}{2\sqrt{at}}}^{\infty} \frac{e^{-\beta^2}}{\beta} d\beta$$

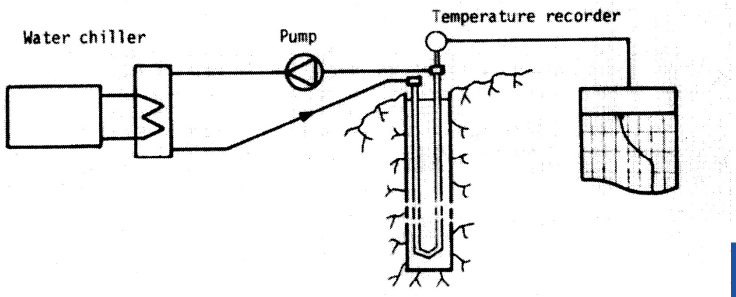
T …	Undisturbed ground temperature
Q …	Specific injected heat (W/m)
λ …	Ground thermal conductivity
a …	Ground thermal diffusivity
t …	time
r …	Borehole radius

Mogensen, 1983

First reported TRT test in a borehole.

Measures borehole resistance as well.

2,7 kW cooling power



Notable features of the TRT equipment

Cooling instead of heating – close to water density maximum – less buoyancy flows

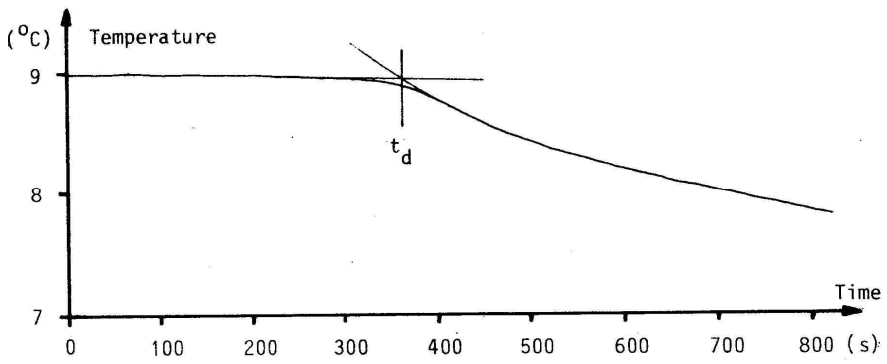
Compressor cycle, inherently as stable as the line frequency, however, thermostats etc. required

Single phase operation

Transportable in a medium sized van

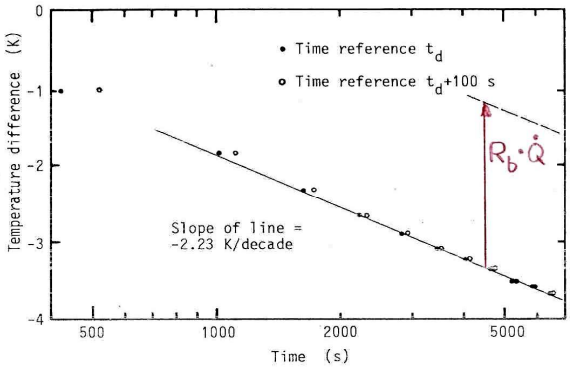
Temperature registration at the first TRT

The time required by the circulation through the borehole is noticeable



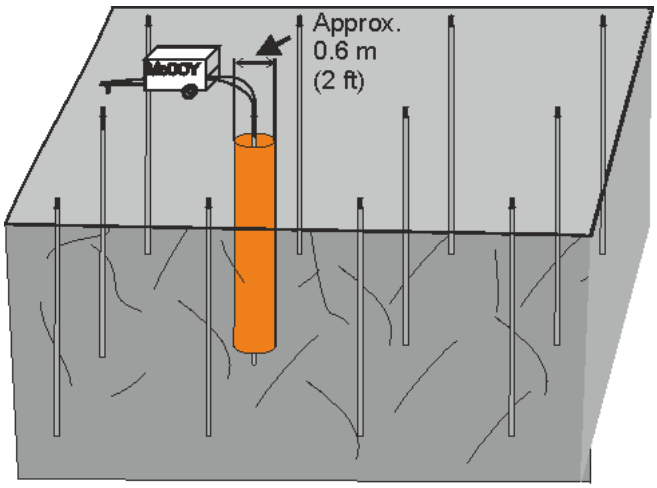
Evaluation of temperature registration

The temperature is plotted with a logarithmic time scale. The result is a straight line, the slope of which is a measure of the thermal conductivity

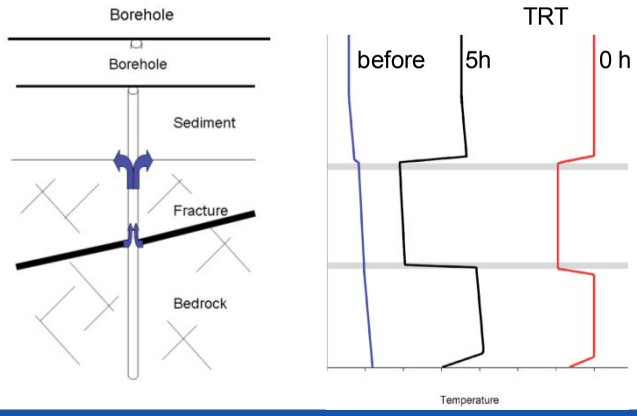


What does a TRT represent?

Influence radius after 100 hours of heat injection



Example of simulated ground water flow with impact on TRT (Liebel, 2012)



Milestones

- **1983**, Mogensen, P. Fluid to Duct Wall Heat Transfer in Duct System Heat Storages. *Int. Conf. on Subsurface Heat Storage in Theory and Practice.*, (ss. 652-657). Stockholm, Sweden.
- **1996**, Eklöf and Gehlin. TED – A Mobile Equipment for Thermal Response Test. MSc thesis 1996:198E. LTU.
- 2000, Austin, W., Yavuzturk, C., & Spitler, J. (2000). Development of an in-situ system for measuring ground thermal properties. *ASHRAE Transactions, 106(1)*, ss. 365-379.
- **2001**, ASHRAE – RP1118, and **2011**, ASHRAE Handbook-HVAC Applications Ch 34.
- **2002**, Gehlin, S. *Thermal Response Test. Method Development and Evaluation.* PhD thesis. LTU, Sweden.
- **2006, Fujii, H, Okubo, H, Itoi, R. TRT Using Optical Fiber Thermometers. *GRC Transactions, 30*.**
- **2012, Liebel H. Influence of groundwater on measurements of thermal properties in fractured aquifers. PhD thesis, NTNU.**
- **2013**, IEA ECES ANNEX 21. Final report, Thermal Response Test.
- **2013**, Acuña J. Distributed thermal response tests. *New insights on U-pipe and Coaxial heat exchangers in groundwater filled borehole*. PhD thesis. KTH.
- **2015**, Svenskt Geoenergicentrum. Riktlinjer för TRT.

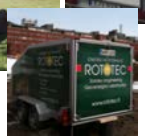
Equipment around the world

Asplan and Båsum (Norge)

Accio, Bengt Dahlgren, HP borrningar&SWECO, Neoenergy, Rototec (Sweden)

Ewbank OSU, GTRI (USA)

UK



Canada

Groenholland (Netherlands)

Geoenergikonzept, UBeG (Germany)

The future:
Better Documenation and Measurements during TRTs

- Drilling logs
- Groundwater Level and flow
- Notes on soil/rock
- Temperature
- Exact location

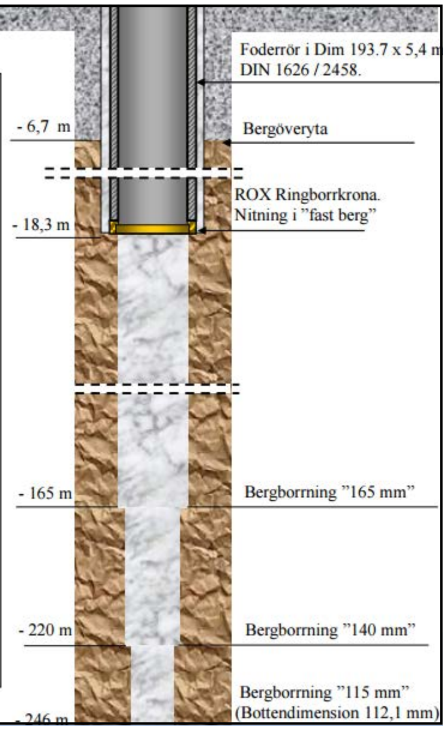
Geologisk Kartering:

0 – 2 m	Lerig siltig morän
2 – 4 m	Sand
4 – 6,7 m	Siltig lerig morän
6,7 m	Bergöveryta
6,7 – 18 m	Växlande grå och röd gnejs V2 lokalt vittrade partier V3
18 – 20 m	Kaolinvittrad gnejs V3
20 – 28 m	Växlande grå och röd gnejs V2 lokalt små inslag av vittrad amfibolit V5
28 – 40 m	Växlande grå – röd gnejs
40 – 46 m	Grå gnejs
46 – 58 m	Röd gnejs med lokal epidotläkning och lerfyllda sprickor
58 – 64 m	Grå gnejs (finkornig 61-64 m)
64 – 71 m	Röd gnejs
71 – 82 m	Grå finkornig gnejs
82 – 97 m	Växlande grå-röd gnejs
97 – 100 m	Mörkt brunröd finkornig metamorf gång lokalt vittrad V5
100 – 175 m	Röd gnejs Qz rik
175 – 224 m	Röd gnejs med små inslag av grå glimmerrika horisonter, lokalt V2 vittring
224 – 229 m	Mörkt grå gnejs med små inslag av vittrade V5 partier (amfibolitgångar)
229 – 246 m	Röd gnejs

Sprickor och vatten

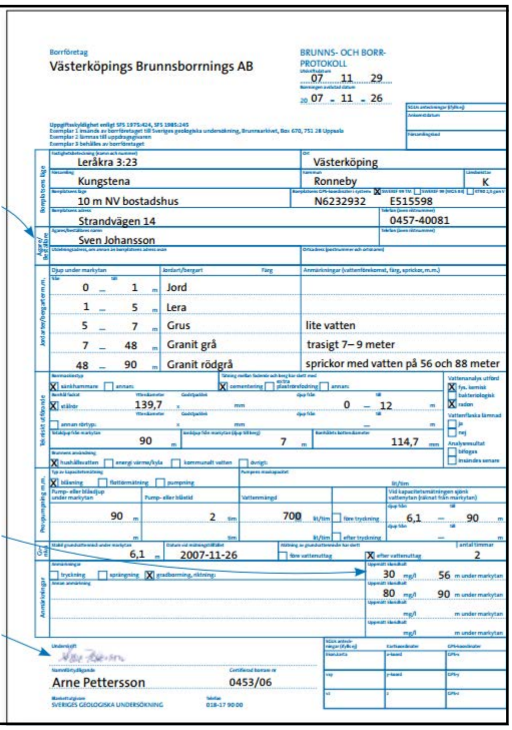
31 m	Sprickor	10 l/min
55 m	Sprickor	30 l/min
62-64 m	Sprickzon	170 l/min
80-82 m	Sprickzon	250 l/min
107-115m	Sprickzon	400 l/min
134-135m	Sprickor	>500 l/min
141-142m	Sprickor	>500 l/min
154 m	Lerfyllda sprickor	>500 l/min
234 m	Sprickor	>500 l/min

Om vittring i bergmassan förekommer anges detta med skalan V1-V5 där V1 står för ovittrat och V5 helt leromvandlat.

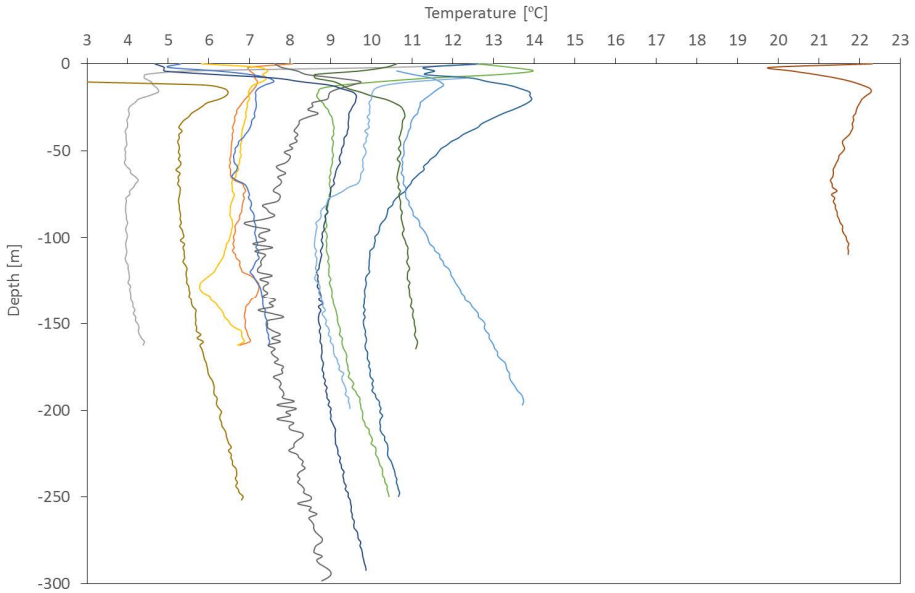


Drilling log

- Current template suggested by SGU in Sweden
- Drilling logs writen by contractors today, can often be more detailed
- Proper documentation of drilling activities complement the evaluation of measured data during TRTs

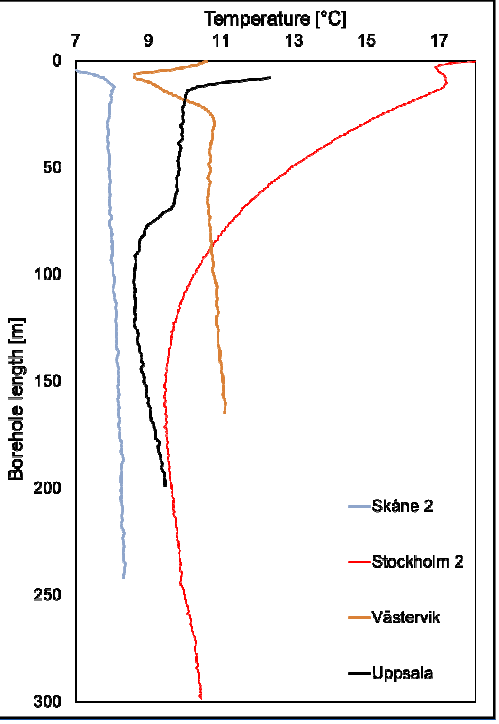


Examples of undisturbed temperature profiles



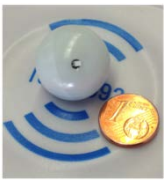
Undisturbed ground temperature

- Local conditions at different depths
- Influence from neighbour installations
- First indication about ground properties
- Information about stability of the borehole before performing a TRT



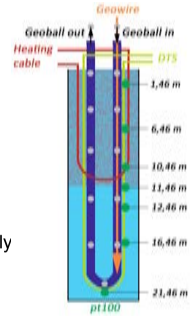
Some options to measure along the depth (1)

GeoWIRE: Automated temperature acquisition at pre-established sequences.
- Wired waterproof temperature sensor
- Sensor position through depth adjusted by a servomotor and an encoder

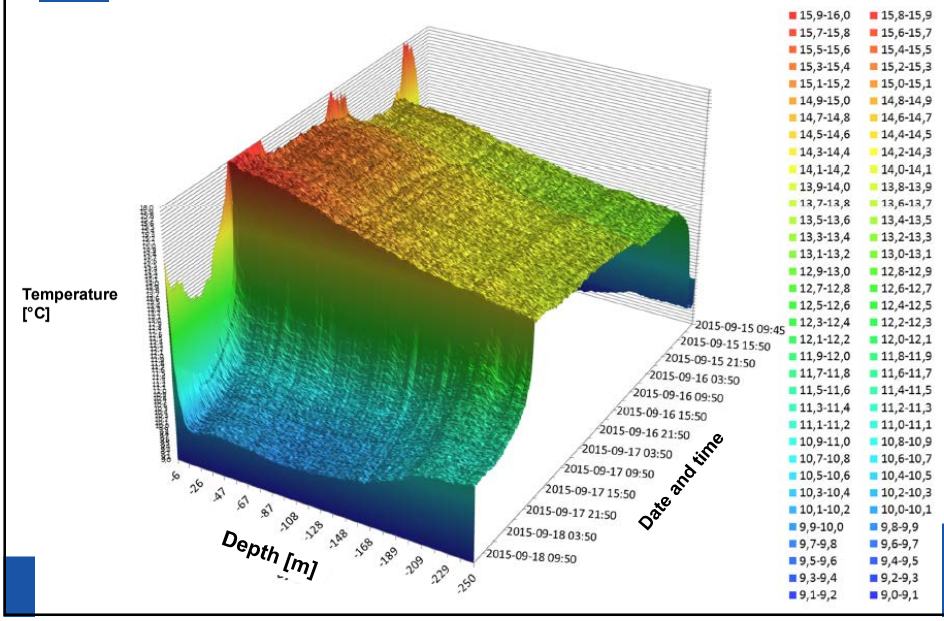


GeoBall:
-Autonomous temperature sensor
- Circulates inside the pipes
- Data downloaded wirelessly and battery charged at the same time

Distributed Temperature Sensing with laser light through optical fiber. Part of backscattered signal is temperature dependent

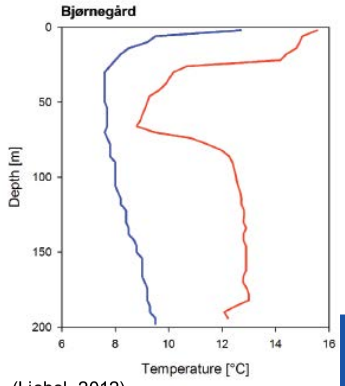


Temperature logs along the borehole during a TRT

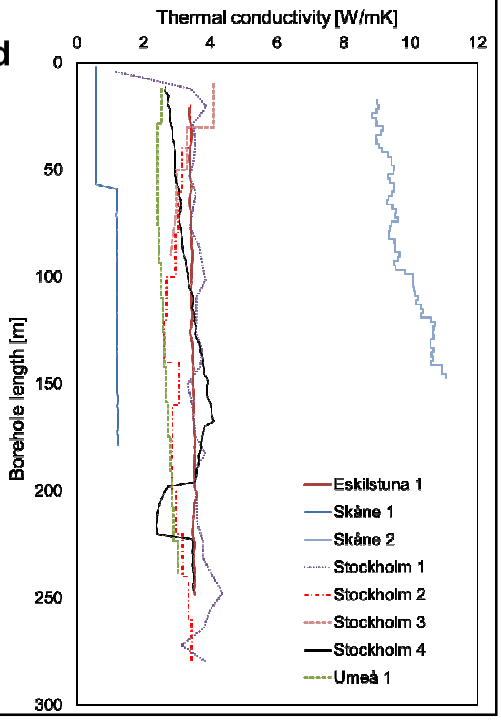


Example of observed anomalies

- Groundwater flow
- Low and high thermal conductivity layers



(Liebel, 2012)



Conclusions

- Performing thermal conductivity tests dates from the early 80s
- Often, the data evaluation is based on the transient probe method (line source)
- The radius of thermal influence of a TRT is approximately 0.6 m
- TRTs in presence of groundwater flow can influence test results
- Better documentation of test boreholes during drilling and testing is recommended
- Temperature measurements at different instances along test boreholes help identifying anomalies with better resolution


2016
GSHP Convention
TACK FÖR UPPMÄRKSAMHETEN!