ASIR
Advanced Seismic Instrumentation & Research LLC

SMU Power Plays Conf.
26 April 2016

Drilling 5 km to Boiling:

The St1 Helsinki District-Heating Gamble

PE Malin

GFZ – Seismomechanics

Advanced Seismic Instrumentation and Research

Summary of geothermal from Kukkonen - Proceedings World Geothermal Congress 2000

"Finland has …

…Precambrian granitics covered with < 5 m of Quaternary sediments

…subdued topography so little advective groundwater circulation

…low rock porosity and water content

…heat flow in top 1 km ranges from < 15 to 69 mW m^{-2}

…geothermal gradient is typically 8-15 C km^{-1}

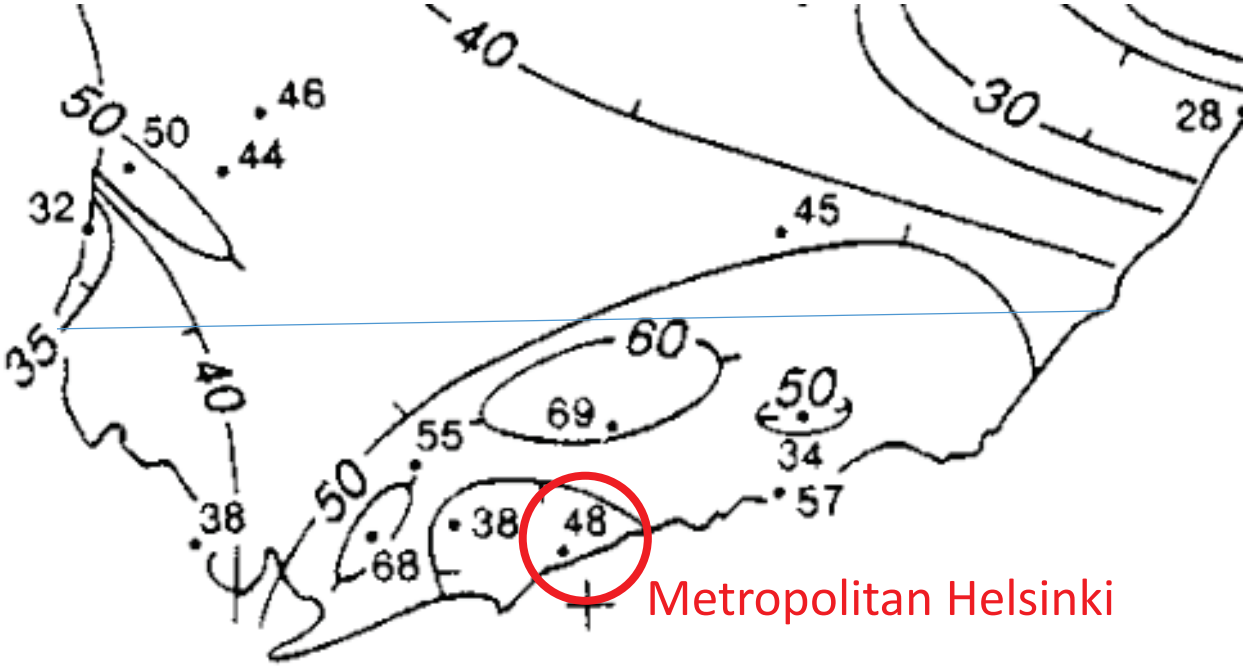
…at 1 km depth temperature ranges from 14 to 22ºC

…drilling to ~6 km is required to reach 100ºC.

…suggesting it is not a good candidate for wet or dry geothermal use".

Heat flow in southern Finland

mW/m^2

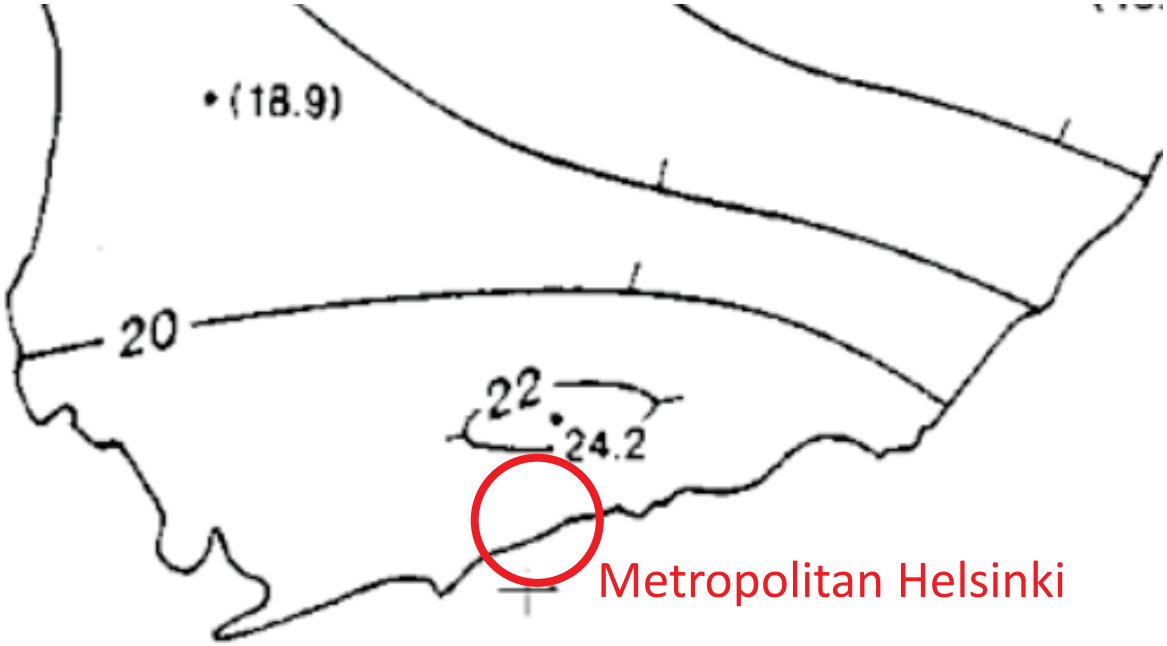


Metropolitan Helsinki

(about 1 m people)

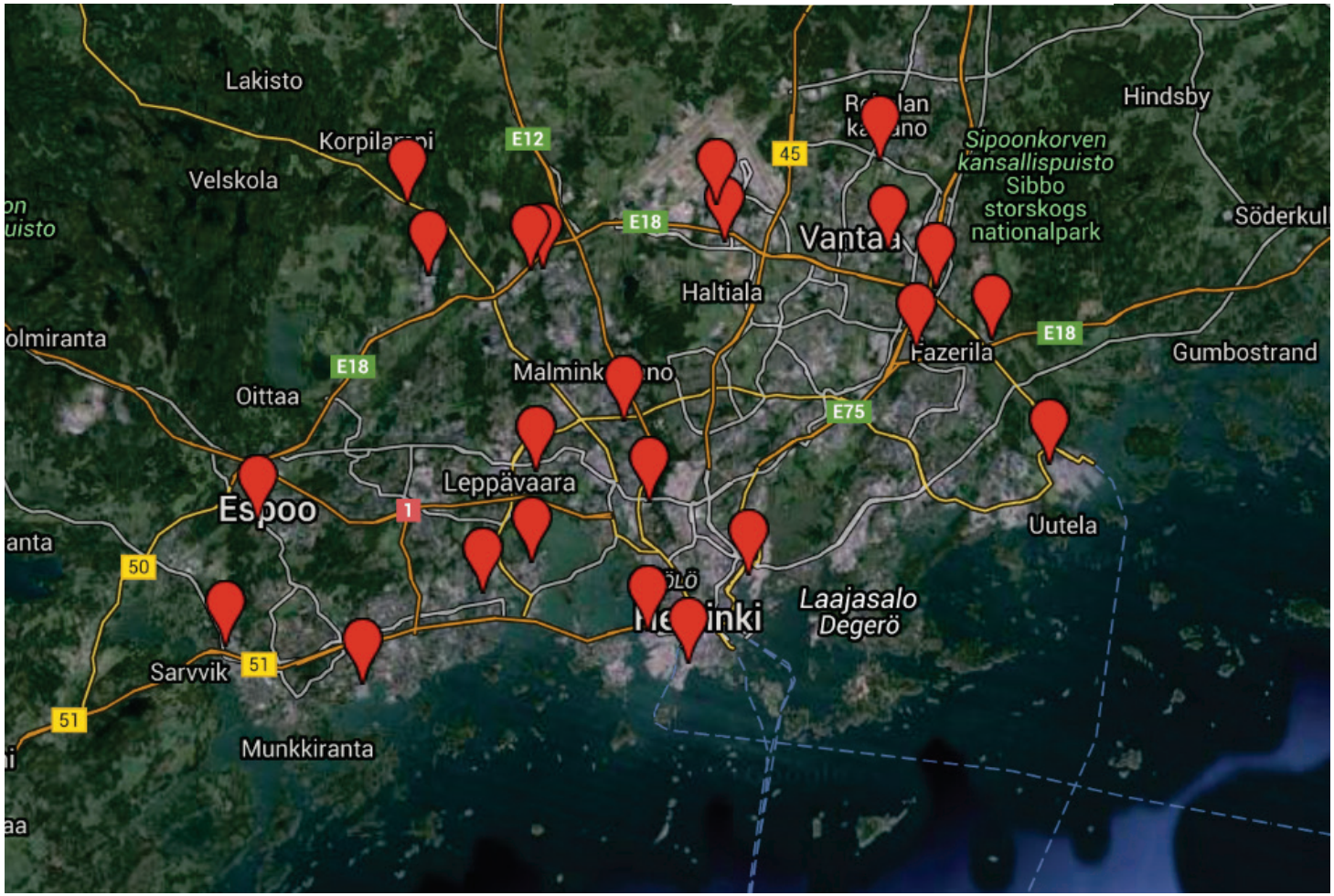
Temperatures at 1 km in southern Finland

^{0}C



However there is the Voimalaitosverkko and next come EU climate change regulations

District Heat Plant Network



More than 20 plants in metropolitan Helsinki

The Otaniemi District Heat Plant – built circa 1949

A business and environmental challenge … (!)

- Finland has over 350 District Heating networks

A business and environmental opportunity … (?)

- The retail price of District Heat is almost double of electricity

…enter 2 players and 1 technology

Rami Niemi

WATER DRIVEN WELL DRILLING FOR HARD ROCK

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A hammer driven by 2 concentric drill pipes

Mika Anttonen

Vision and strategy

- Traditional **oil business** of St1 generates **cash flow**,
  enabling development of new **CO_2-aware energy solutions**

- Employees working in **oil business** are **strategy enablers**

- Employees working in **renewable** energy are **strategy executors**

- St1 **values** are based on **Nordic society model**

Key Figures 2012–2014

St1 Group Oy Consolidated	2012	2013	2014
Turnover, M€	**5 037,3**	**4 136,2**	**4406,8**
- Finland	***17 %***	***0 %***	***0%***
- Sweden	***83 %***	***100 %***	***100%***
Operating profit, M€	**49,1**	**76,7**	**85,1**
Profit before taxes, M€	**27,1**	**58,4**	**74,9**
Net profit M€	**16,7**	**47,0**	**64,1**
Equity, M€	**14,3**	**60,0**	**120,3**
Balance sheet total, M€	**1 038,3**	**901,9**	**609,7**

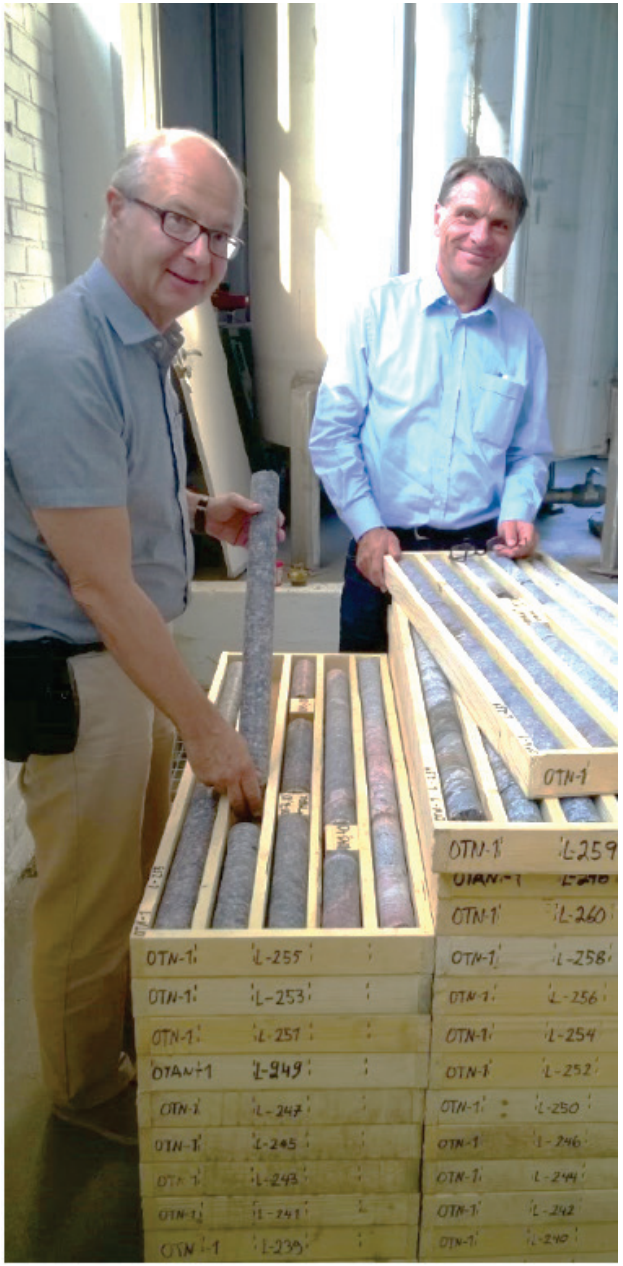
Mika Anttonen controls about 3/4 of this amount

… and he wrote the vision statement

- **In July 2015 a 2015 m well was fully cored**
- **logged in following fall and winter**

  Temp
  Resistivity
  Heat production
  Accoustic velocities
  Two wellbore imaging methods

- **stress tests of rock where made**
- **mini-frack tests used for in-situ stress**



Ilmo Kukkonen **Georg Dresen**

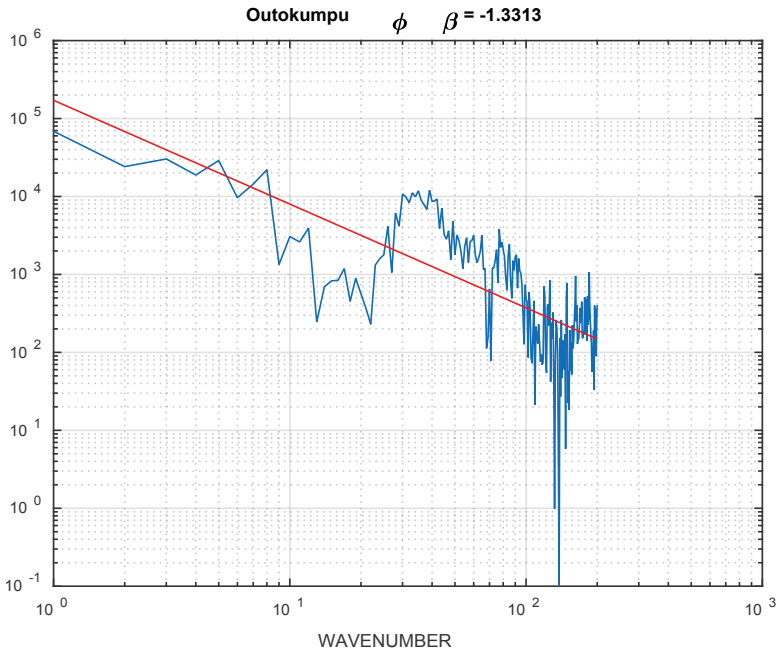
Well-logs are power law scaled

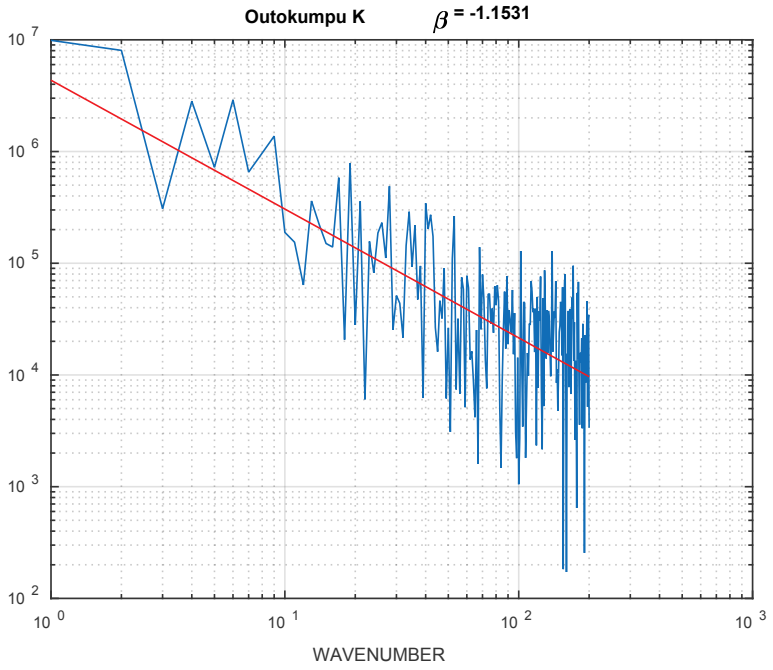
$$S(k) \propto 1/k^{\beta}$$

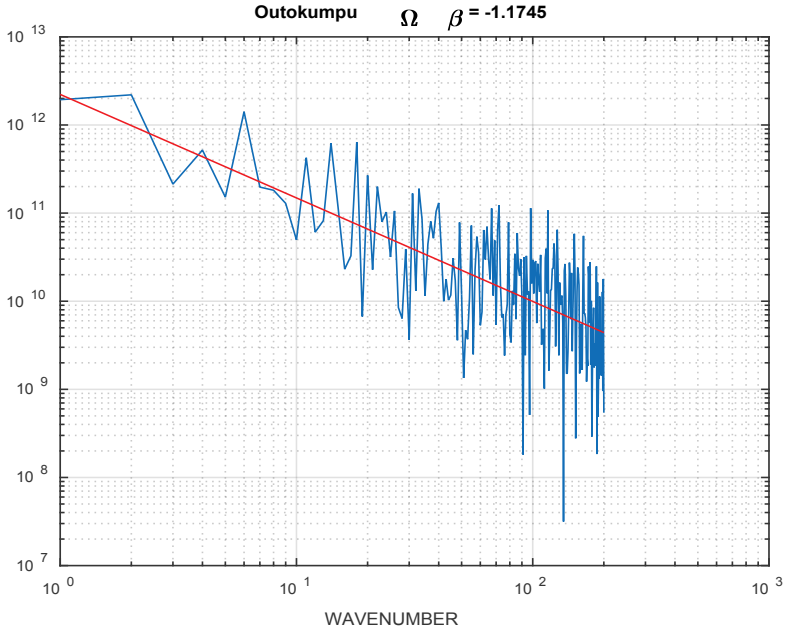
$\beta \sim 1$

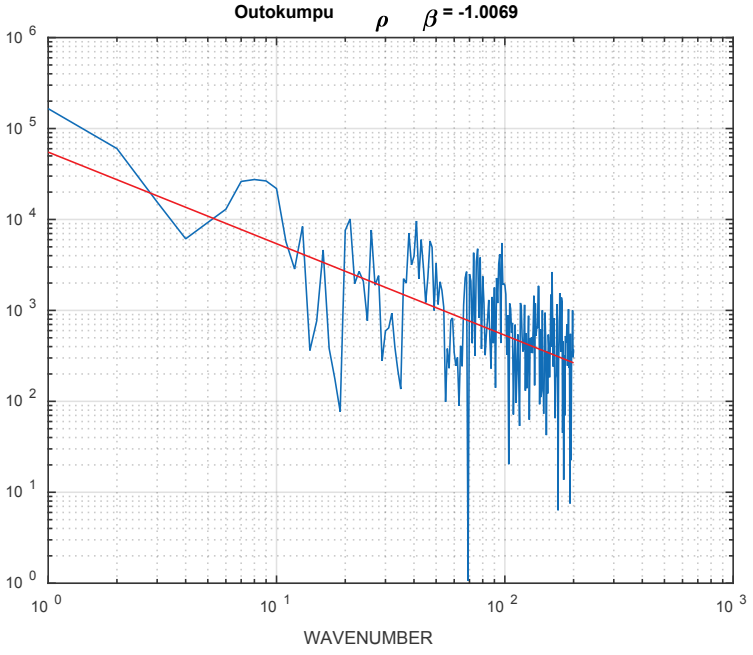
1/km < k < 1/cm scale range

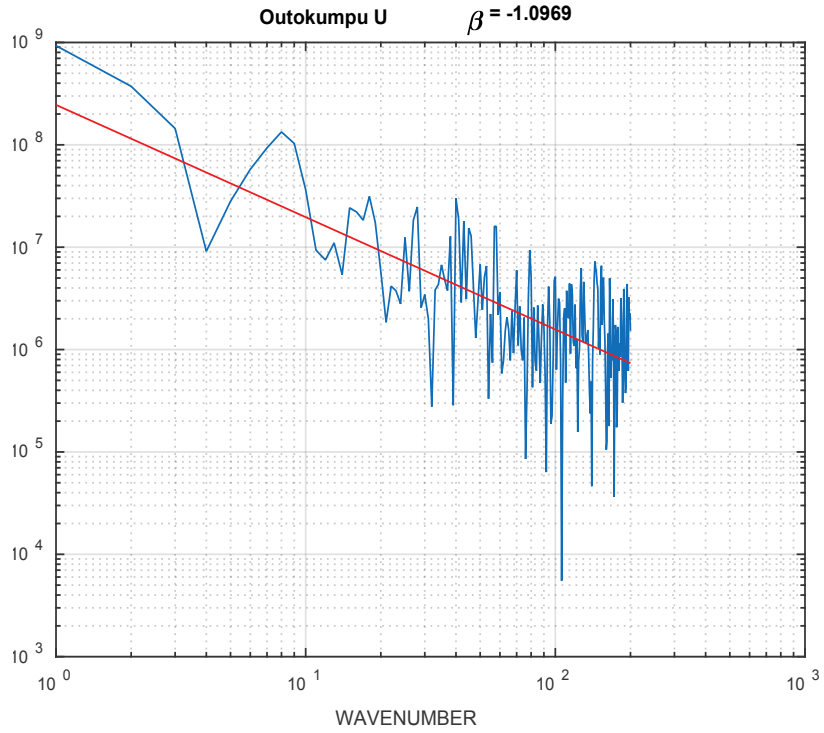
(Eastern Finland)

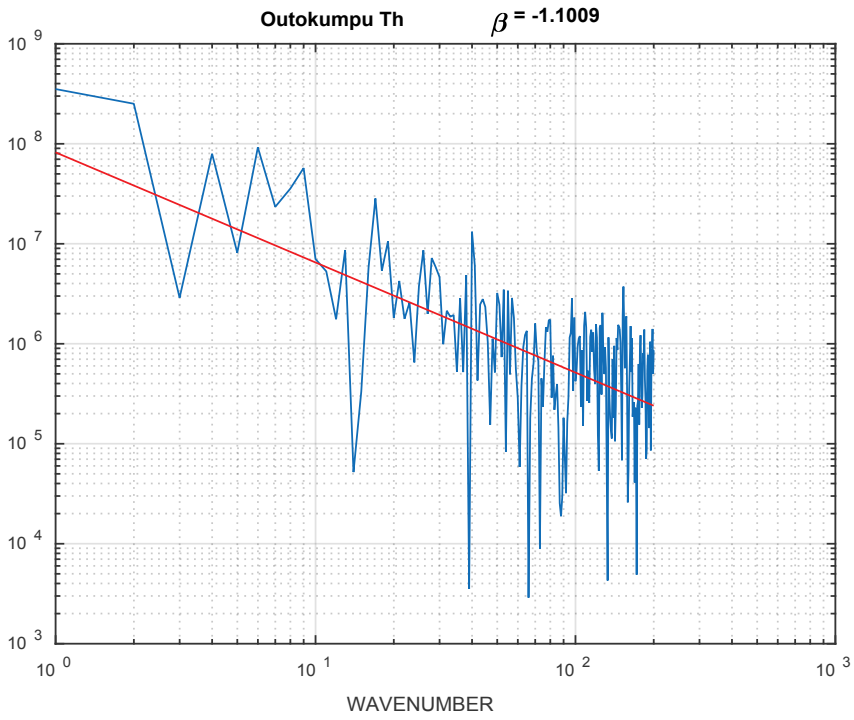

Outokumpu
ϕ
β = -1.3313
WAVENUMBER

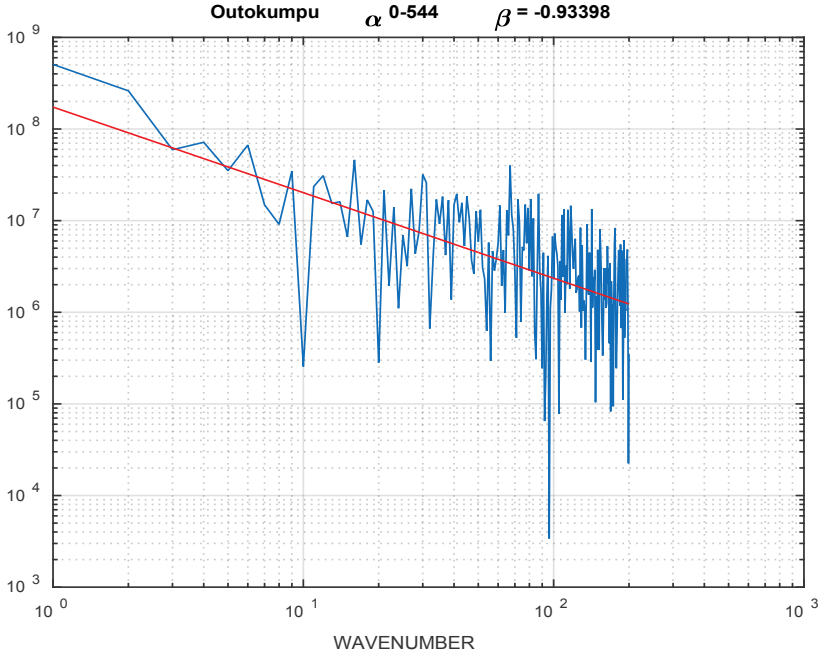

Outokumpu K
β = -1.1531
WAVENUMBER

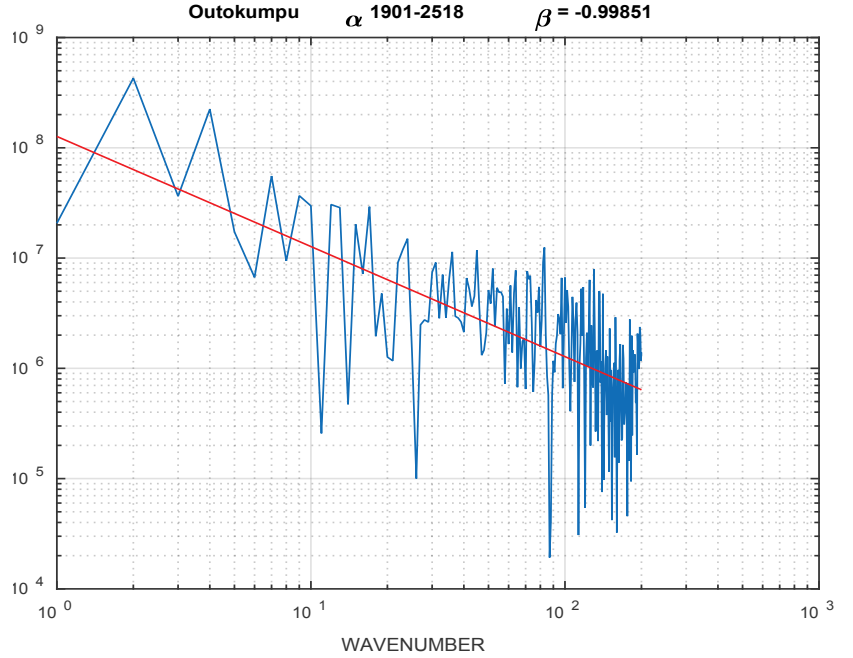

Outokumpu
Ω
β = -1.1745
WAVENUMBER


Outokumpu
ρ
β = -1.0069
WAVENUMBER


Outokumpu U
β = -1.0969
WAVENUMBER


Outokumpu Th
β = -1.1009
WAVENUMBER


Outokumpu
α 0-544
β = -0.93398
WAVENUMBER


Outokumpu
α 1901-2518
β = -0.99851
WAVENUMBER

Well-flow is lognormal distributed

$$\kappa \propto exp(\alpha\varphi)$$

$20 < \alpha < 50$

Reservoir scale

Fennoscandia

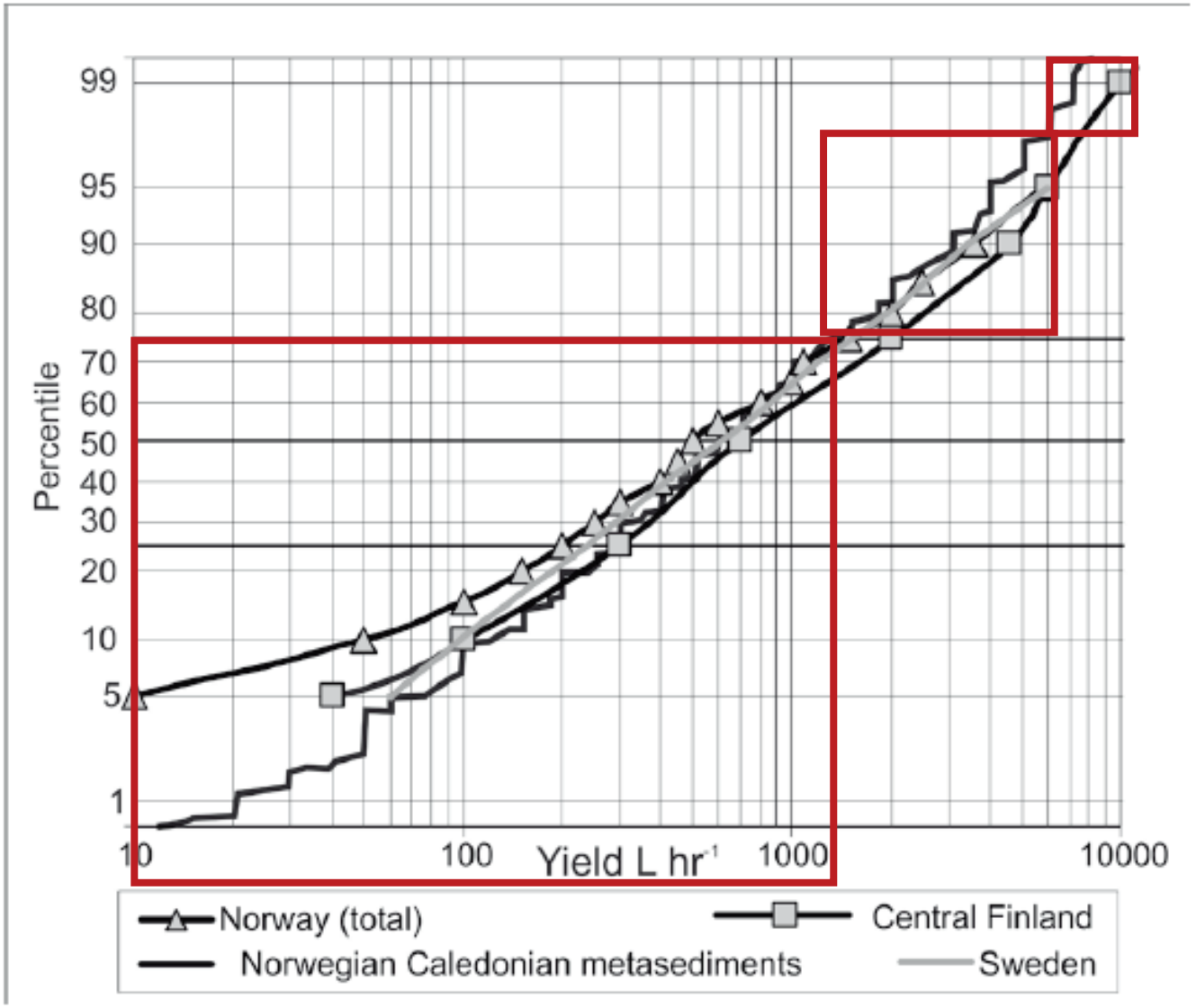
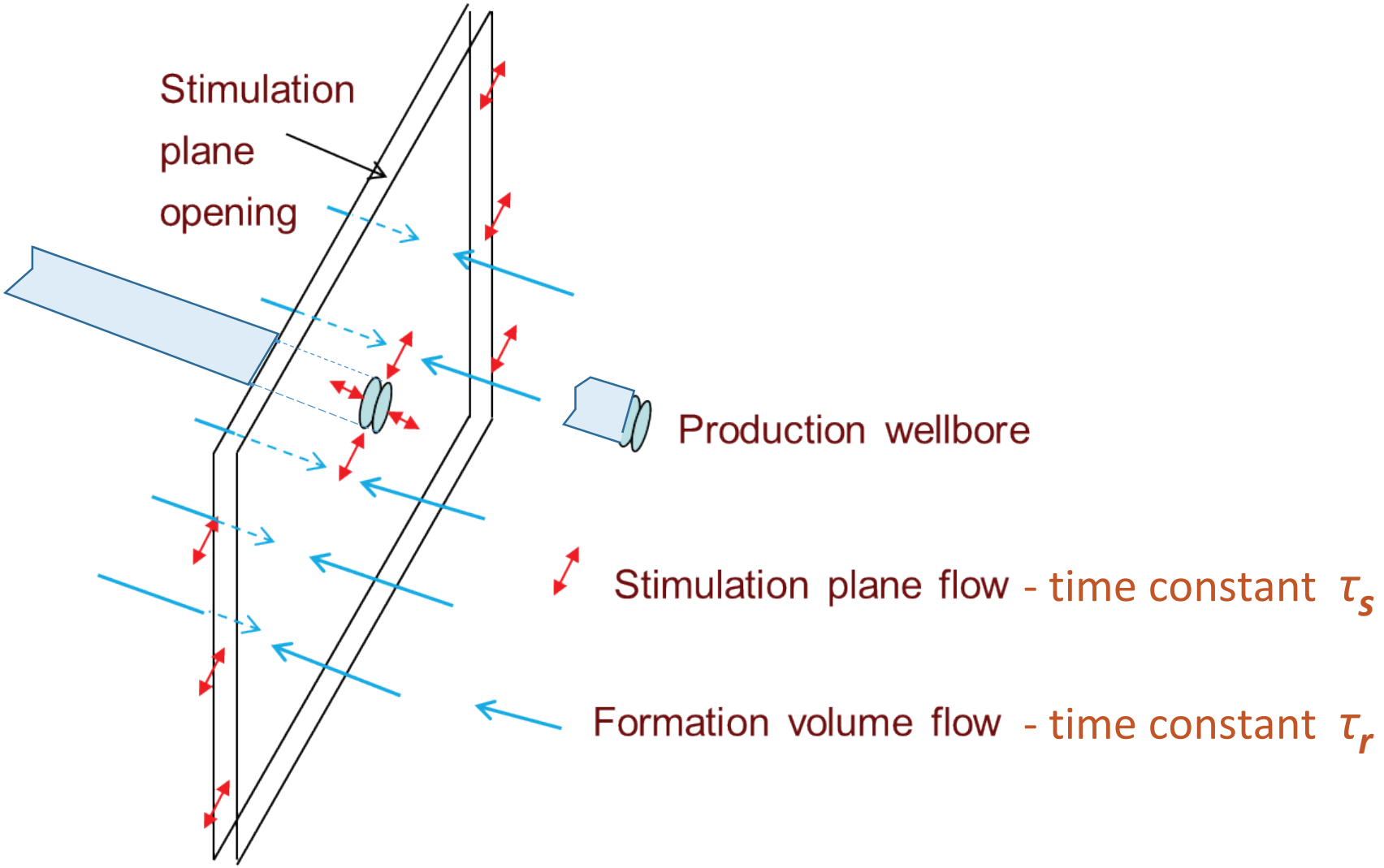


Figure 2. Comparison of distribution of short term well yield in crystalline rocks of the three Fennoscandian nations. Note the probability scale on the y-axis and the log-transformed x-axis. On such log-probability plots, a log-normal distribution yields a straight line.

Frack model geometry – an O&G analog for EGS stimulation*



*Carslaw & Jaeger, *Conduction of Heat in Solids*, Oxford University Press 1959, §1.14, p33.

Summary/Conclusions for hydrofracking of heterogeneous fractured rock

- Heterogeneity of porosperm precludes *normal-statistics* stimulation
- Maximum radius of standard stimulation may be no more than 20m
- Peclet number $\gamma \sim 5$ may be limit of feasible stimulation
- $Q \sim 1$ MW in 1 km-long well gives $\gamma \sim 5$ for fracture poro $\varphi \sim 10\%$.
- Volume V of fluid producing $Q \sim 1$MW heat energy is $V \sim 2$L/s.

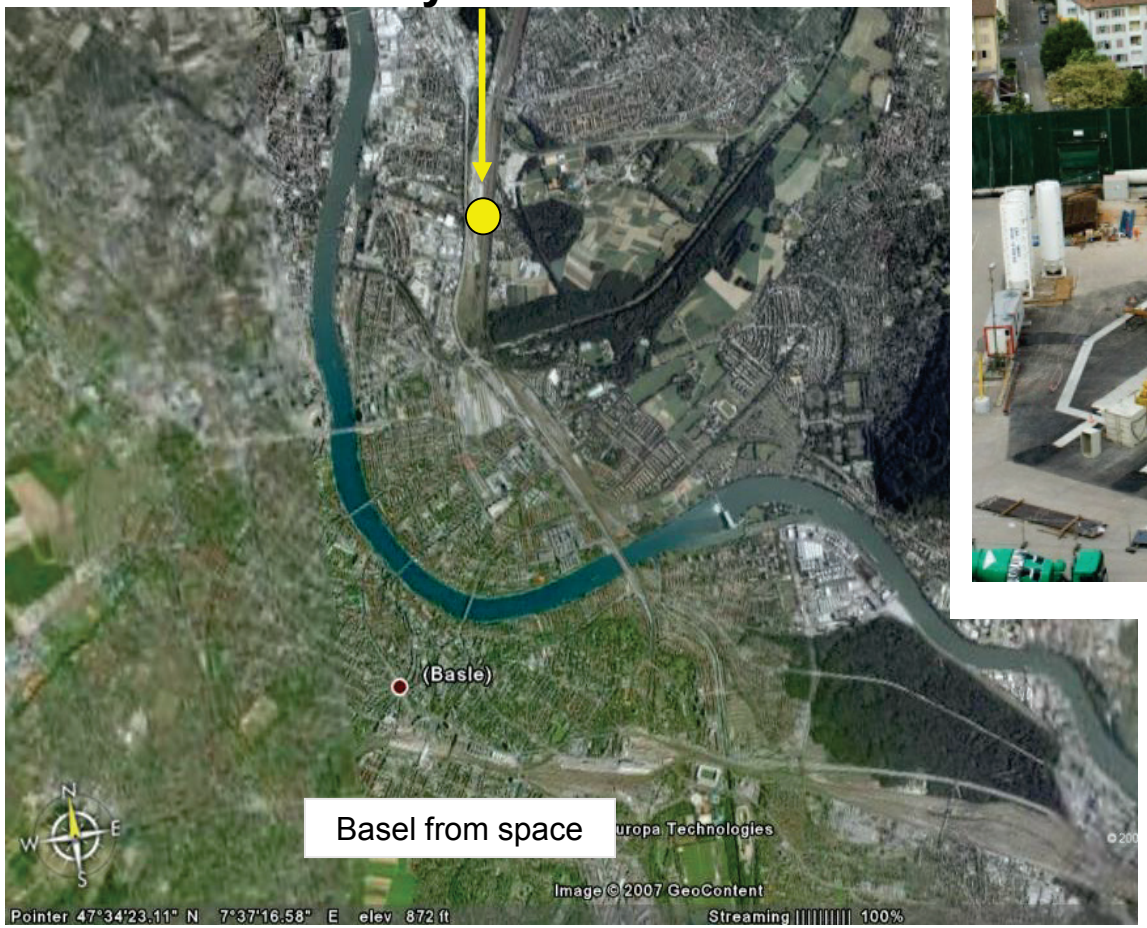
(EGS power provision requires at minimum $\gamma \sim 50$)

A hard lesson in hard-rock EGS

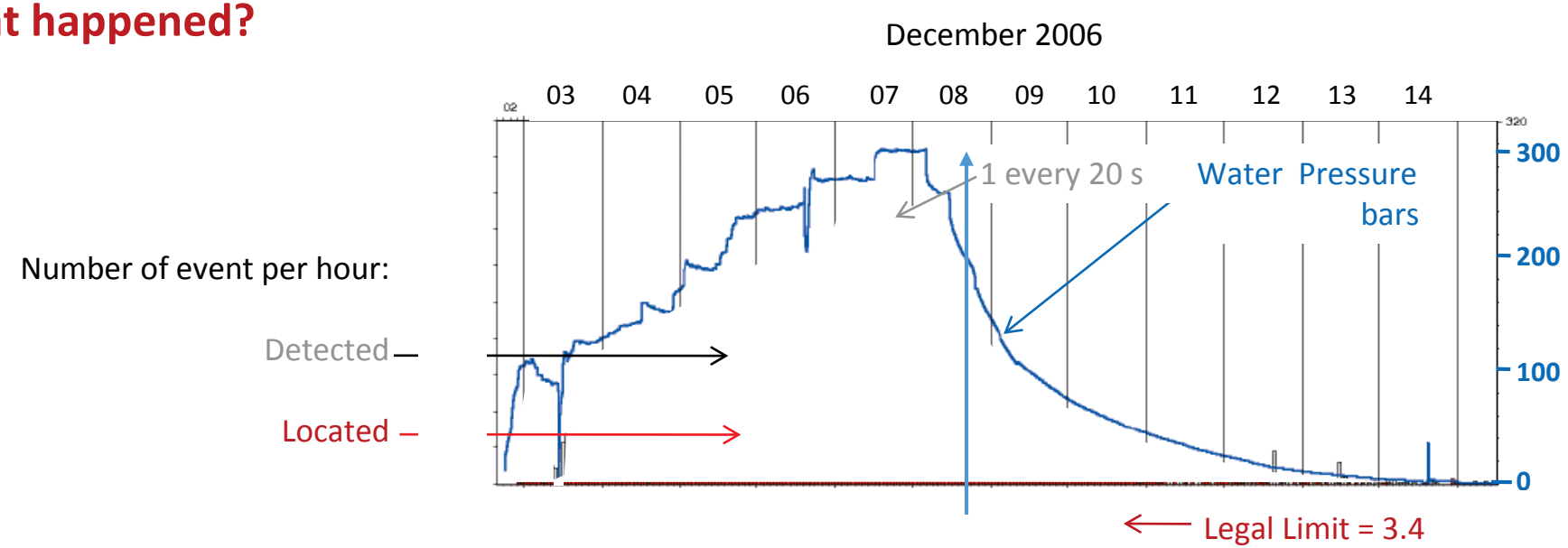
Induced Earthquakes and Geothermal in …

…Downtown Basel, Switzerland

“Hot/Dry Rock” well



What happened?

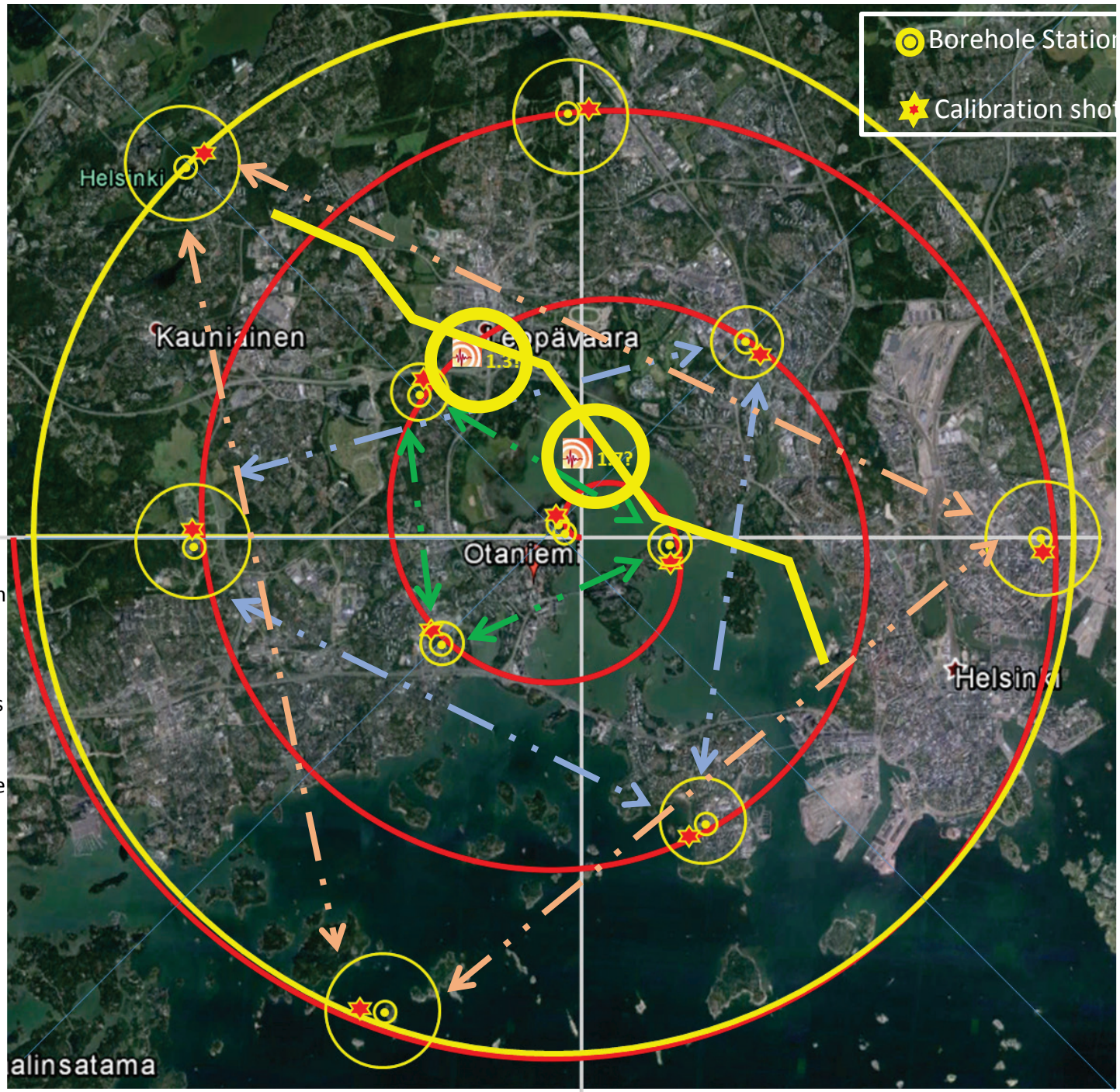


st1 Otaniemi Heat Mine 3-C borehole seismic net

This diagram shows the design principles for the network and calibration shots.

The design criteria are:

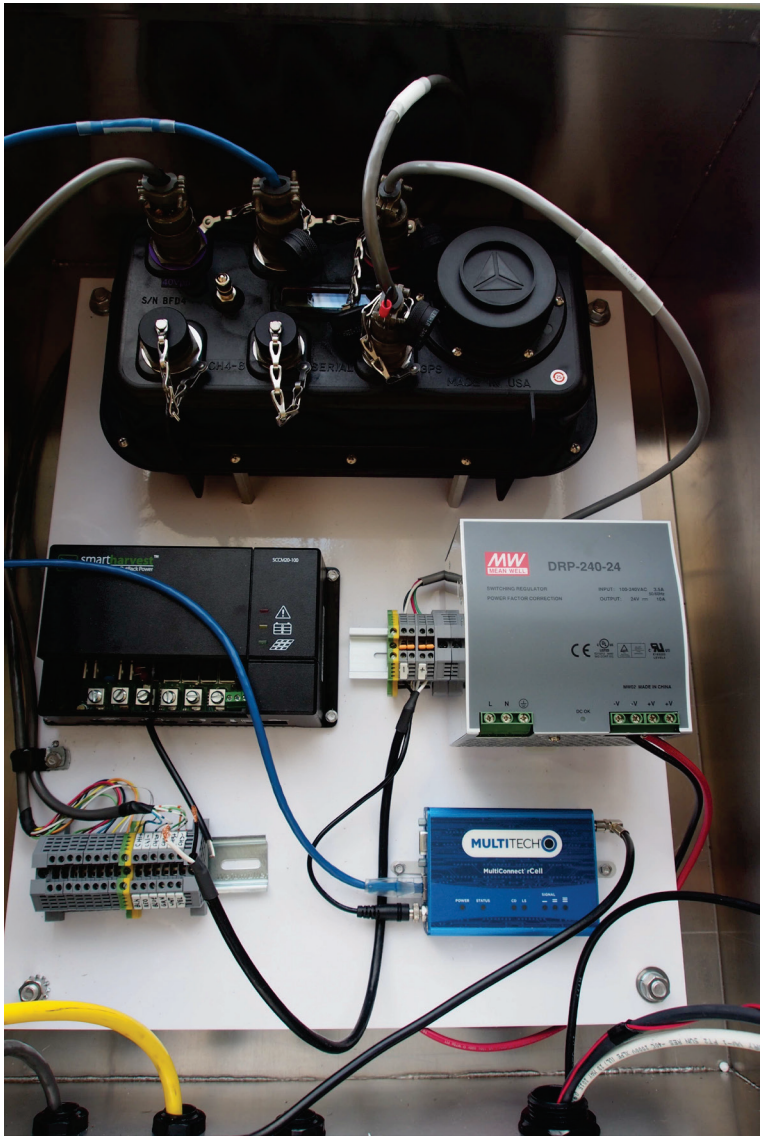
1. 3-C borehole seismometers to record both P & S for epicenter and depth control.
2. Progressive station radial distances to 1.5 times 5 km target depth for epicentral (horizontal) location control.
3. Progressive 0.2 to 0.5 km station location tolerance.
4. Triangular inner, mid, and outer ring station configuration covers azimuthal gaps.
5. Stations st01, st10 & st11 can be eliminated without significantly effecting events in NW epicenter locations.



Downhole 3-C 4.5 Hz seismograph for 350 m borehole

Sivi Kivivirta st1 - Campus of University of Helsinki

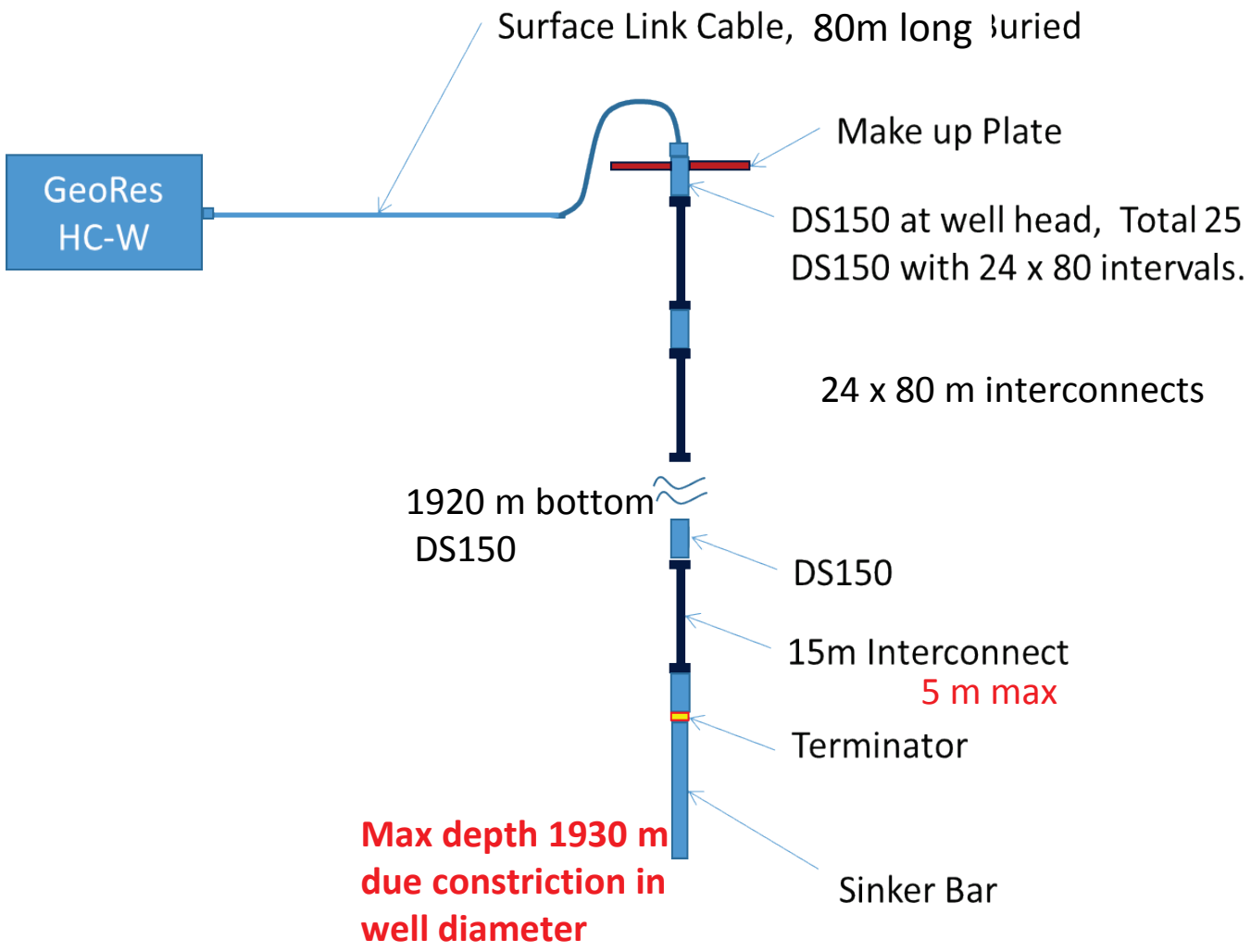
Network station at Lassilla Heat Plant



Sergio Valenzuela ASIR Patrick Vassa st1

25 Level, 1920 m Otaniemi Pilot Hole DS150 Vertical Seismic Array

- Drill Bit Seismic



25 Level array installation

- 60 m crane

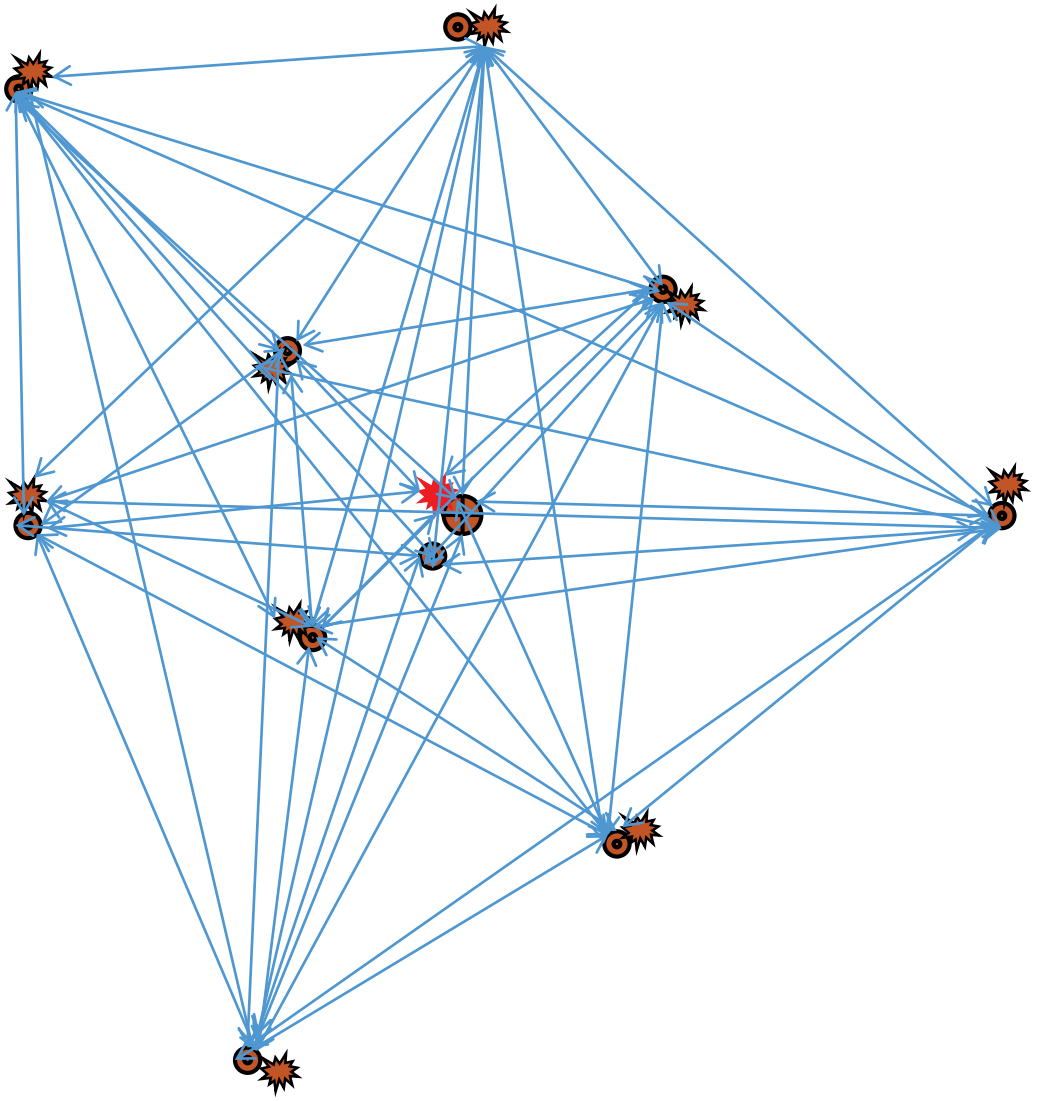
st1 EGS microearthquake monitoring and crust structure imaging system.

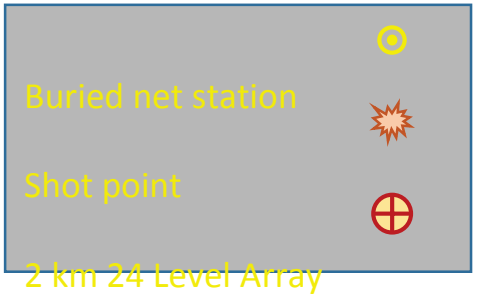
Reciprocal shot points and receivers:

10 shots into 10 stations and 25 level VSP

= 4 ton caisson hammer drill to 40 m
144 mm hammer drill to 5000 m
Alternate explosive source point

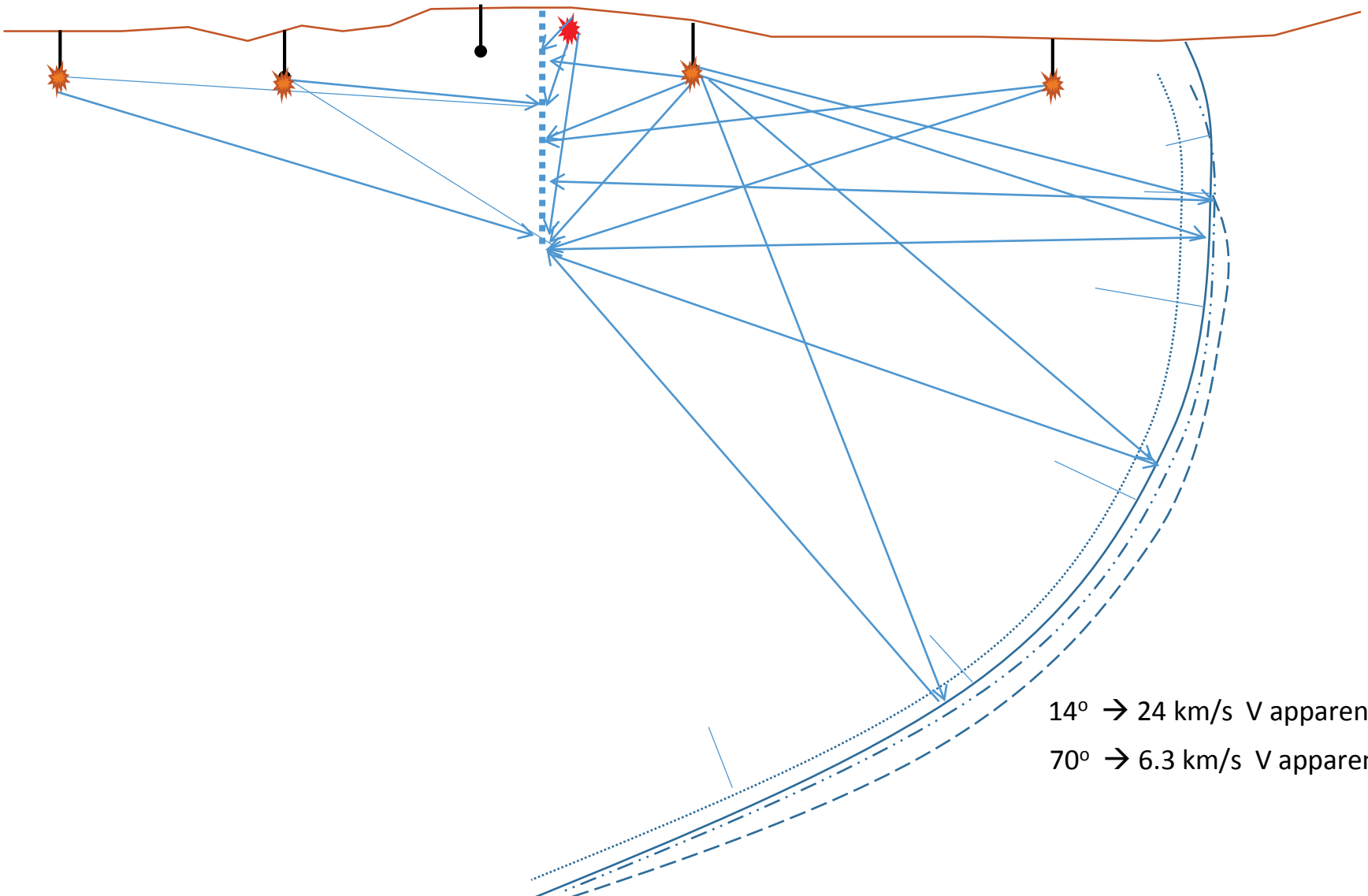
MAP VIEW OF STRAIGHT LINE PATHS



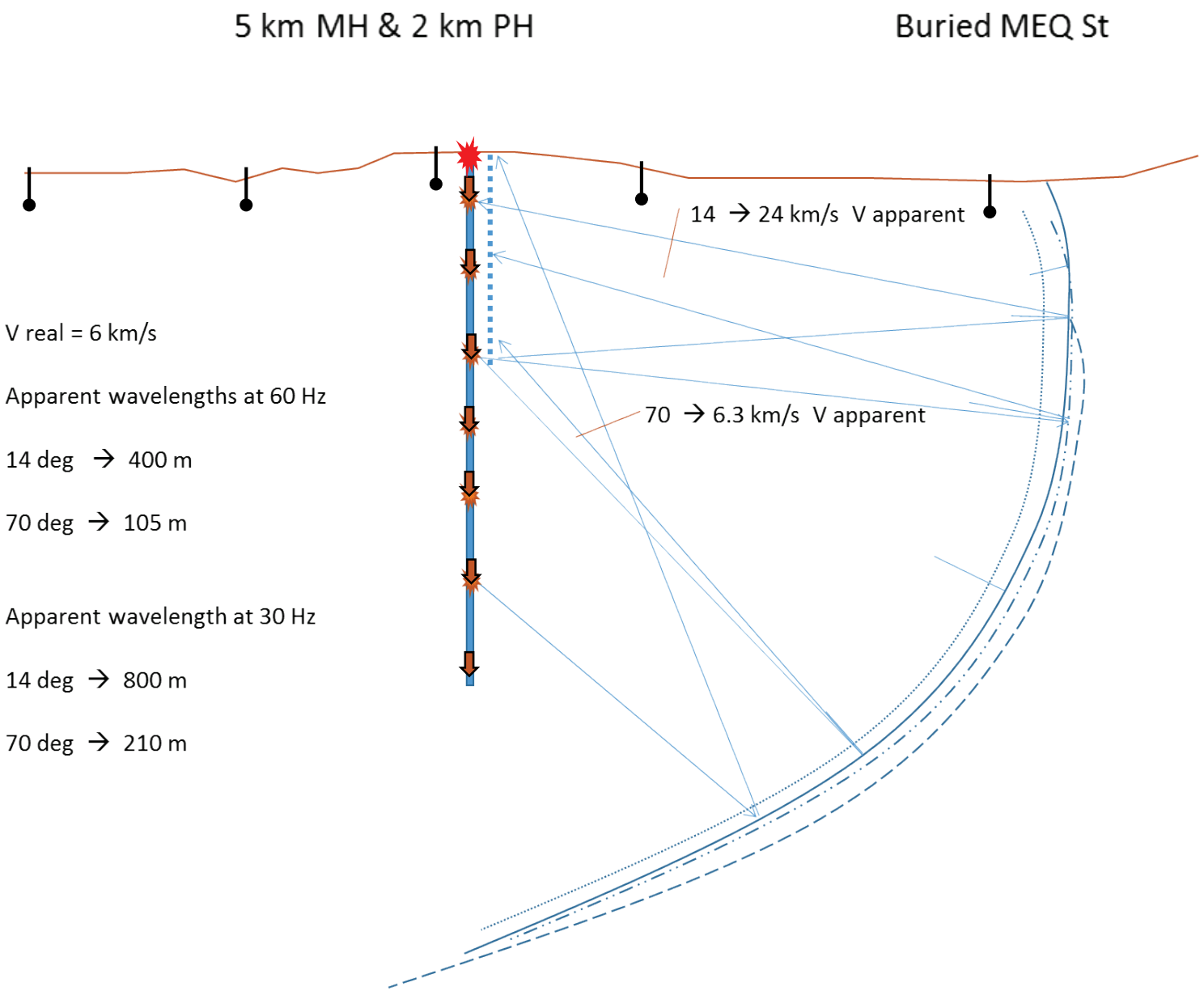


Trying to look ahead

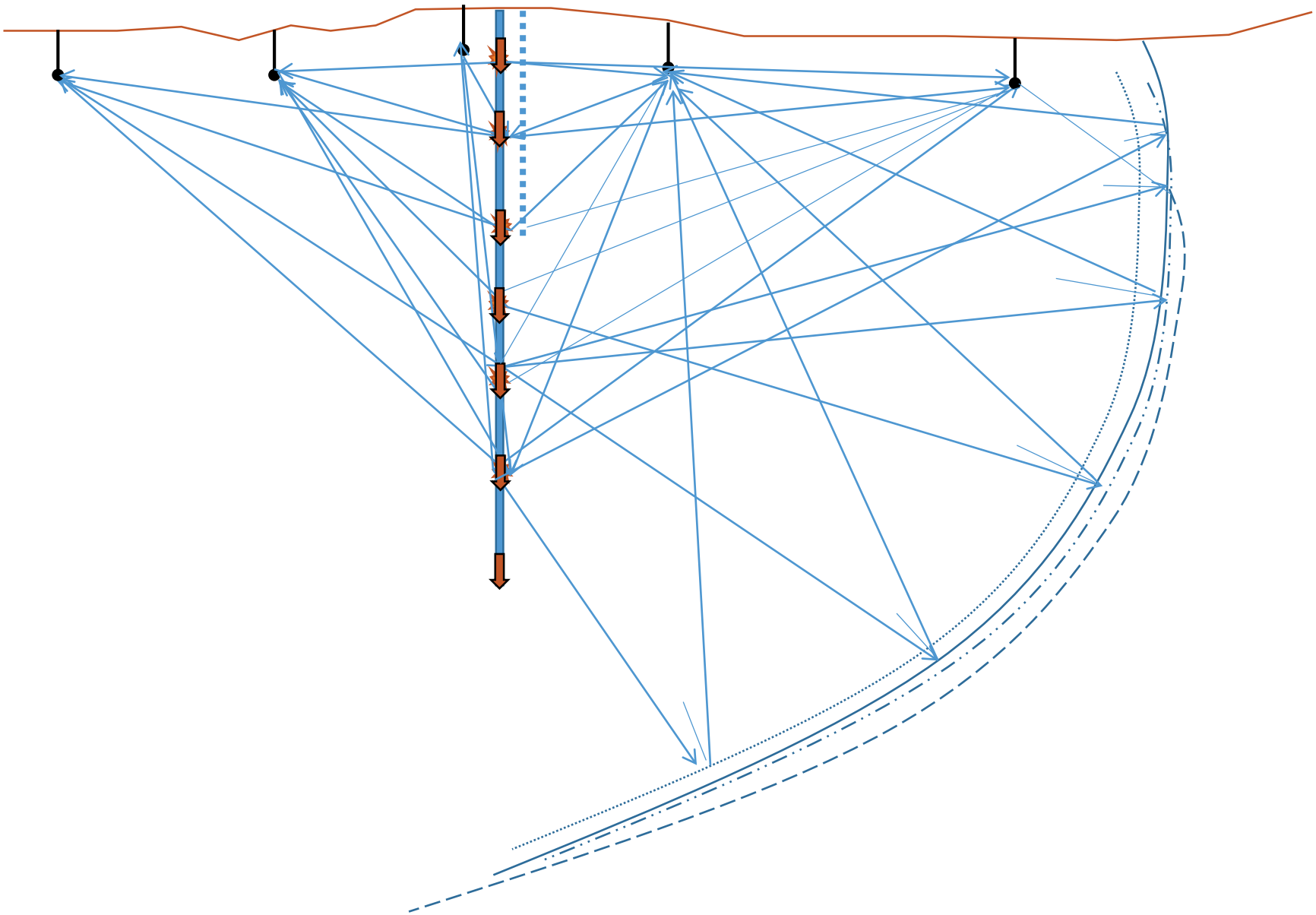
Seismic imaging using 10 shot points from MEQ net work site to PH array



Drill Bit Seismic imaging using MH air hammer drilling ⇩ into PH array



Drill Bit Seismic imaging using MH air hammer drilling ⬇ into MEQ net work



As of Friday, 22 April -