Imaging high-enthalpy geothermal reservoirs using seismic noise interferometry

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SM3.1 Ambient Seismic Noise & Seismic Interferometry

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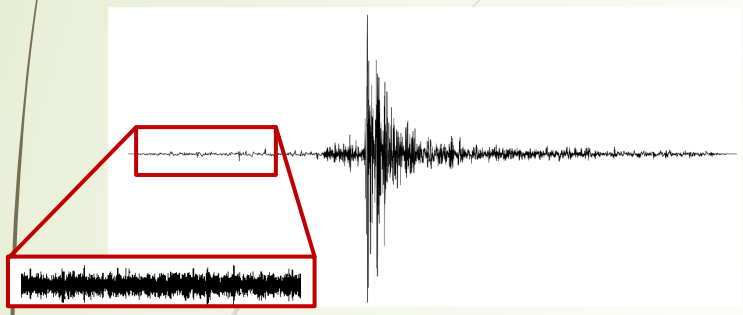
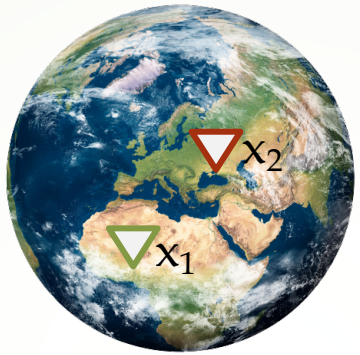
Ambient seismic noise

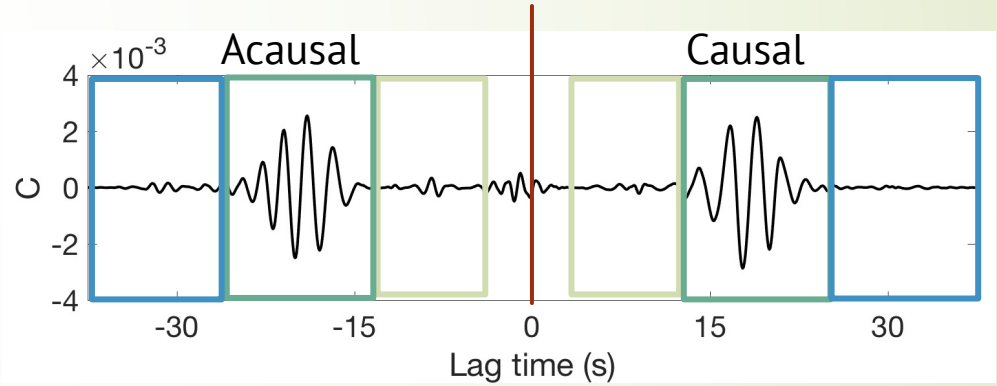
How can we study the subsurface with noise?

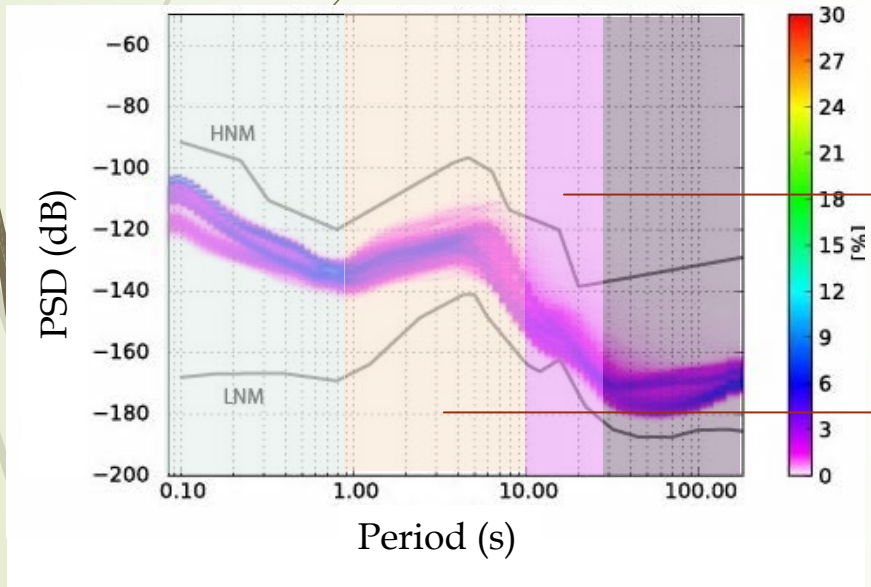


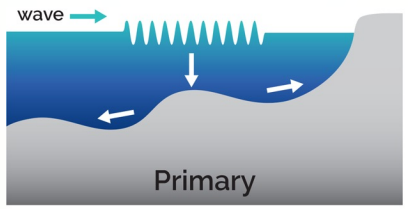


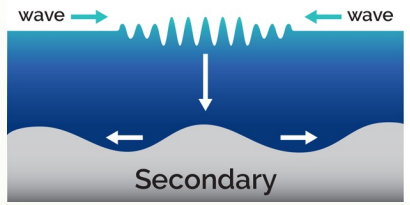
$$\text{corr}\left(u(x_1,t),\ u(x_2,t)\right) \approx G(x_1,x_2,t) + G(x_1,x_2,-t)$$

Seismic response of the medium









Ocean-wave interactions

Seismic noise interferometry

Body waves | Surface waves | Coda waves

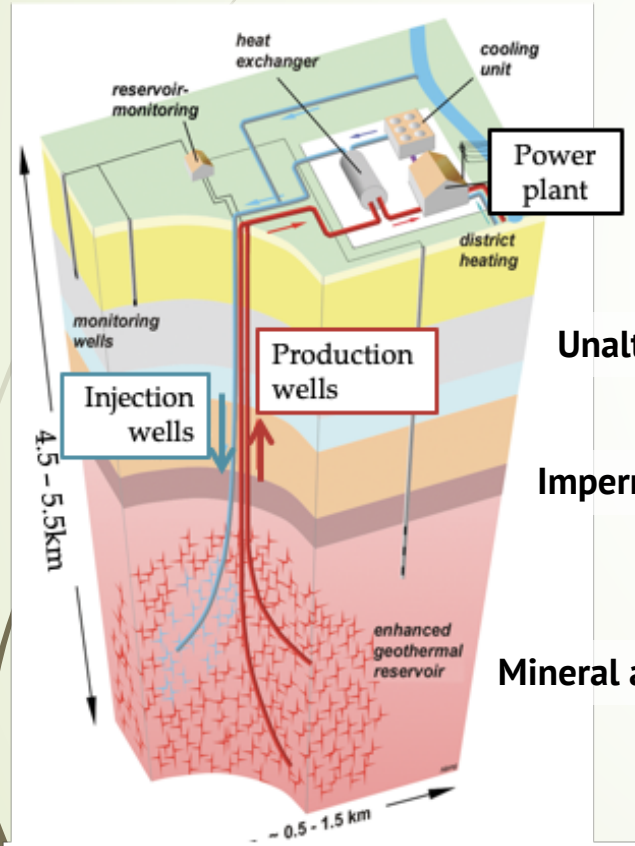
Imaging | Monitoring

Widely used
but barely in geothermal settings (?)

Motivation

Geothermal reservoirs

High temperatures
Presence of fluids
High permeability



(Modified from Geothermal Explorers Ltd, 2005)

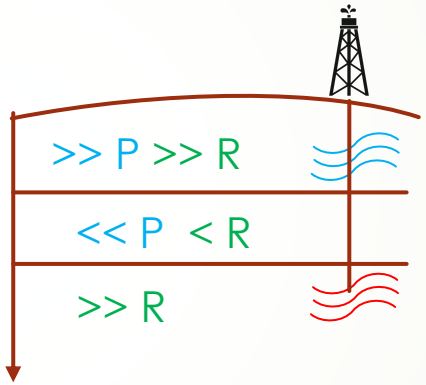
Unaltered rocks

Impermeable

Mineral alteration

Geoelectrical methods

$T_{alteration}$



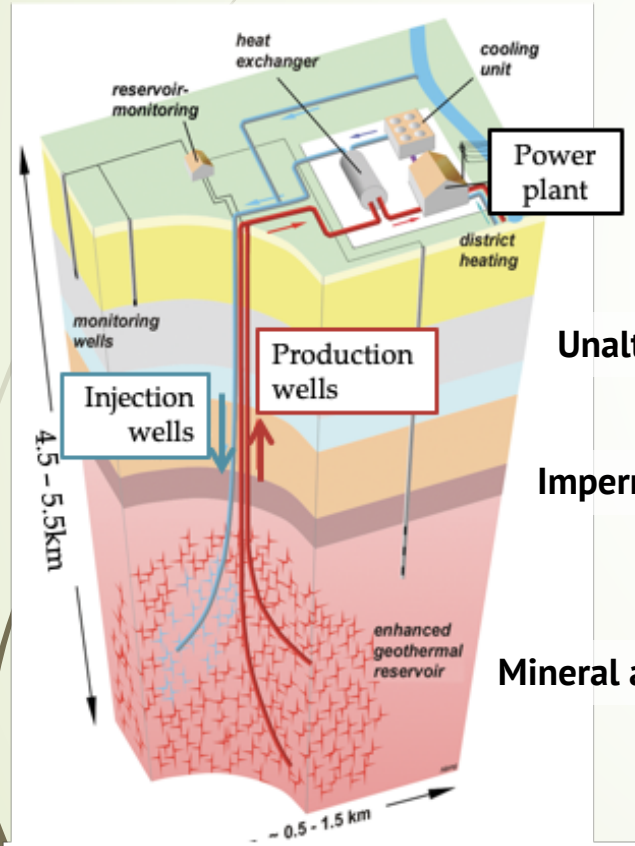
What if...?

No thermal equilibrium

$T_a \neq T_f$ **Limitation!**

Geothermal reservoirs

High temperatures
Presence of fluids
High permeability



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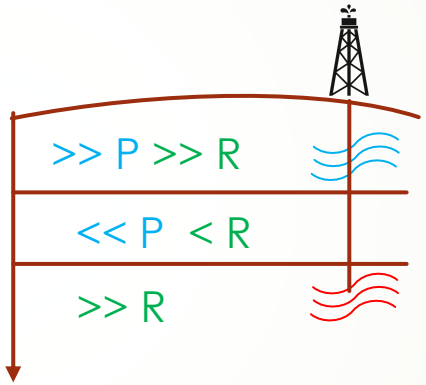


What if...?

No thermal equilibrium

$T_a \neq T_f$ **Limitation!**

Seismic methods

$T_{formation}$

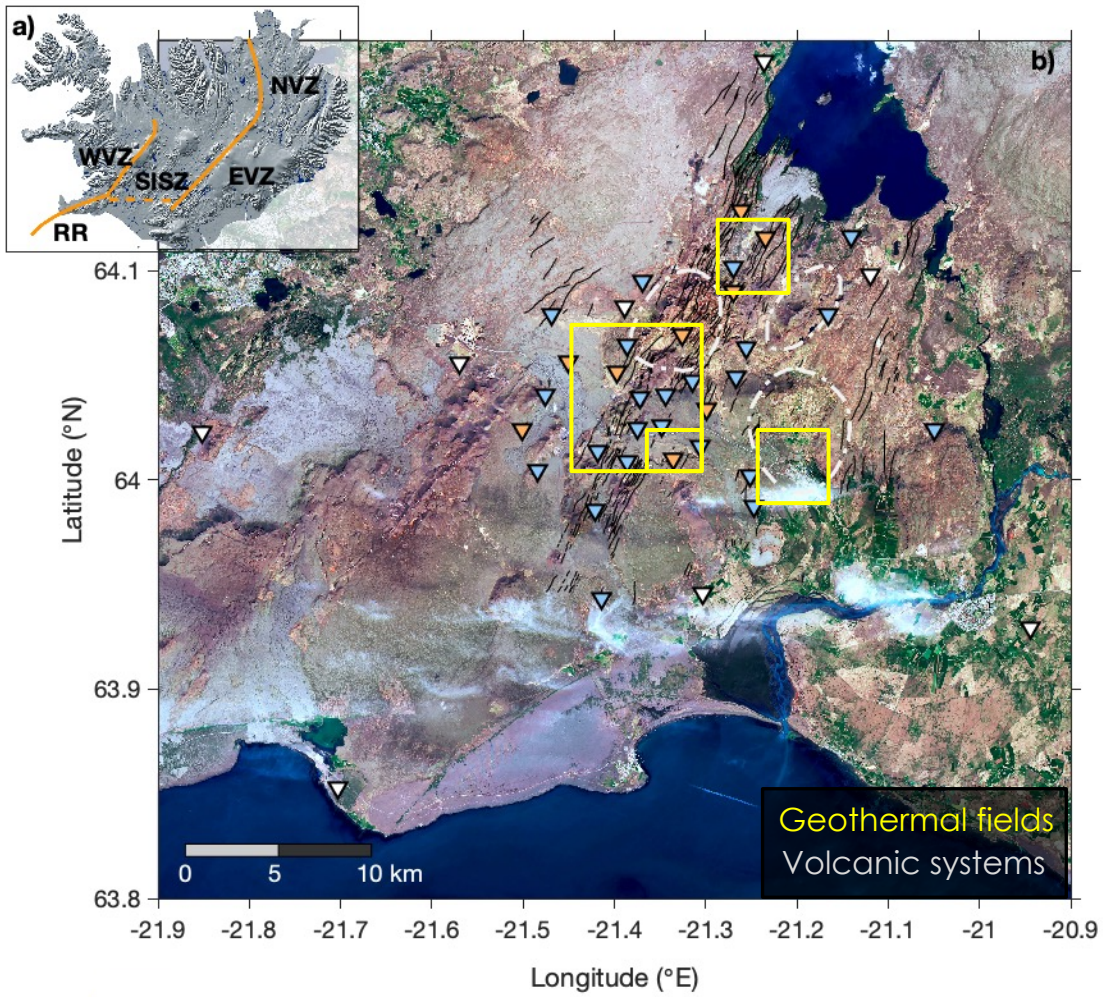
Earthquake tomography

Active sources

Seismic noise

Geo setting

The Hengill area



Hengill

Triple juction between the RR, WVZ, SISZ

Seismic and volcanic activity – Geothermal resources

IDDP (Iceland Deep Drilling Project)

Super-critical fluids

Coseismiq project

Monitoring microseismicity and imaging of the Hengill geothermal area

3D seismic noise tomography

Ambient seismic noise – 2018 – mid-2019

ORKA NÁTTÚRUNNAR

ÍSOR ICELAND GEOSURVEY

▽ Coseismiq ▽ ON Power / ISOR ▽ IMO

Methodology

Seismic noise tomography

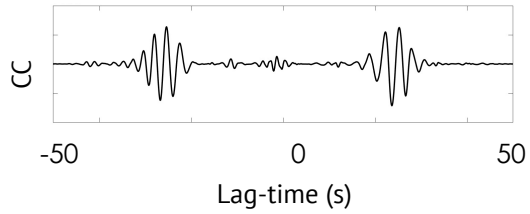
Seismic network deployment

Pre-processing

- PSD plots
- Spectra
- Instrument response
- Gaps
- Filter (0.1 – 3) Hz
- (…)

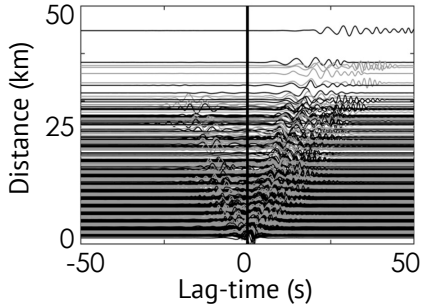
Correlation

Phase-Cross Correlation (PCC; Schimmel, 1999)



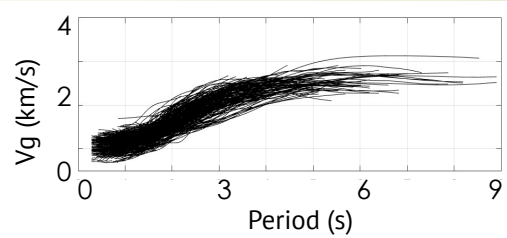
Stack

Time-frequency domain phase-weighted stack (Schimmel et al., 2011)

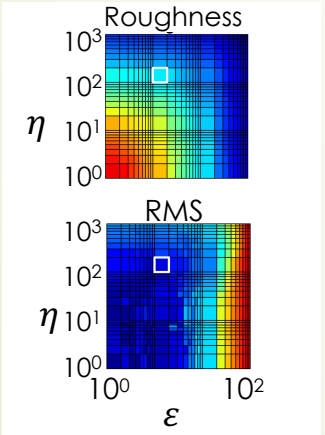


Dispersion curves

Fundamental mode Rayleigh waves
Group velocities
Automatic approach + Manual selection
(Schimmel et al., 2017)

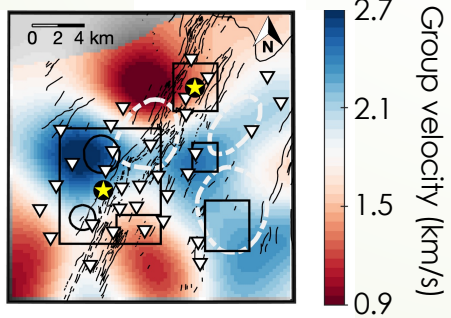


2D Rayleigh-wave tomography



Fast-Marching Surface Tomography (FMST; Rawlinson, 2005)

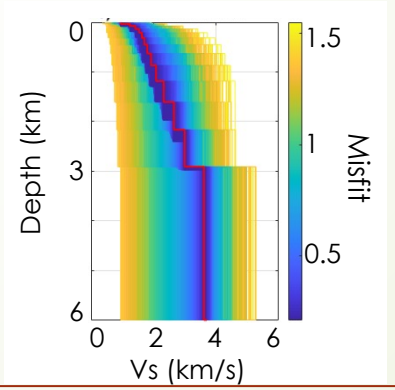
Period: 2 s

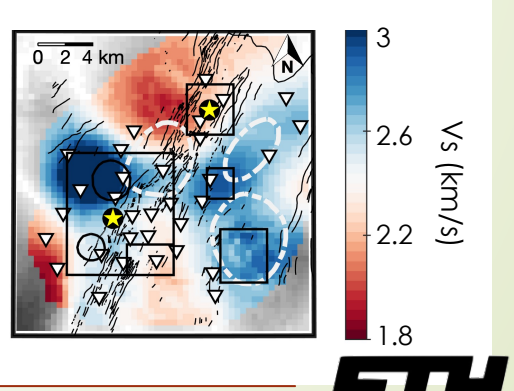


3D Shear-wave tomography

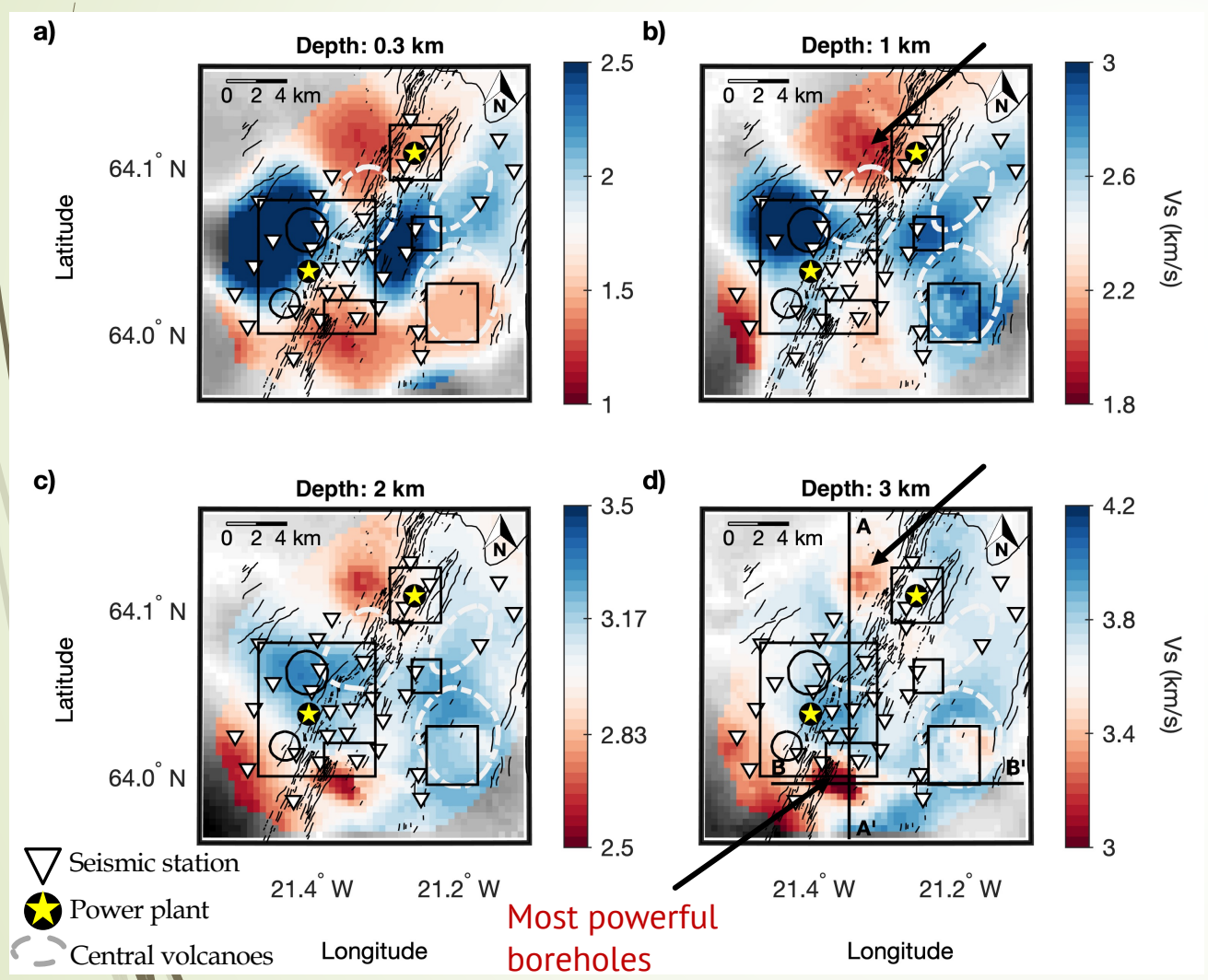
Neighbourhood Algorithm (Sambridge, 1999)

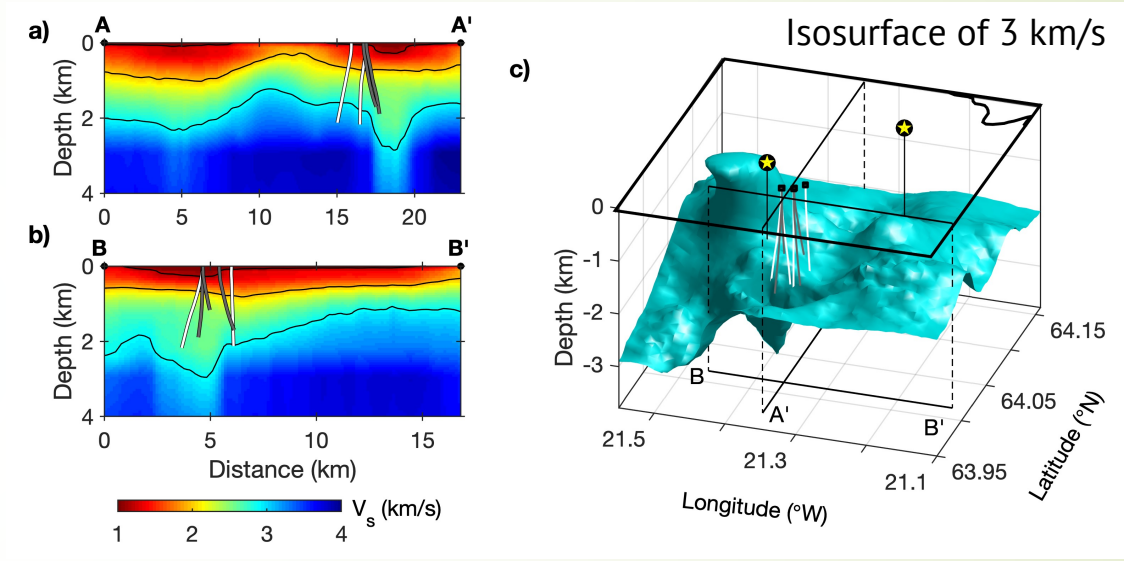
Power-law + Cubic B-splines (Mordret et al. 2014)

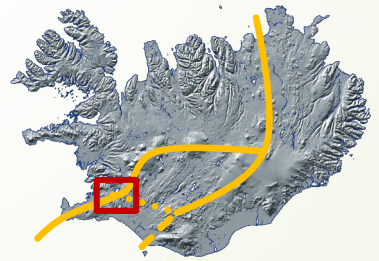




3D shear-wave tomography

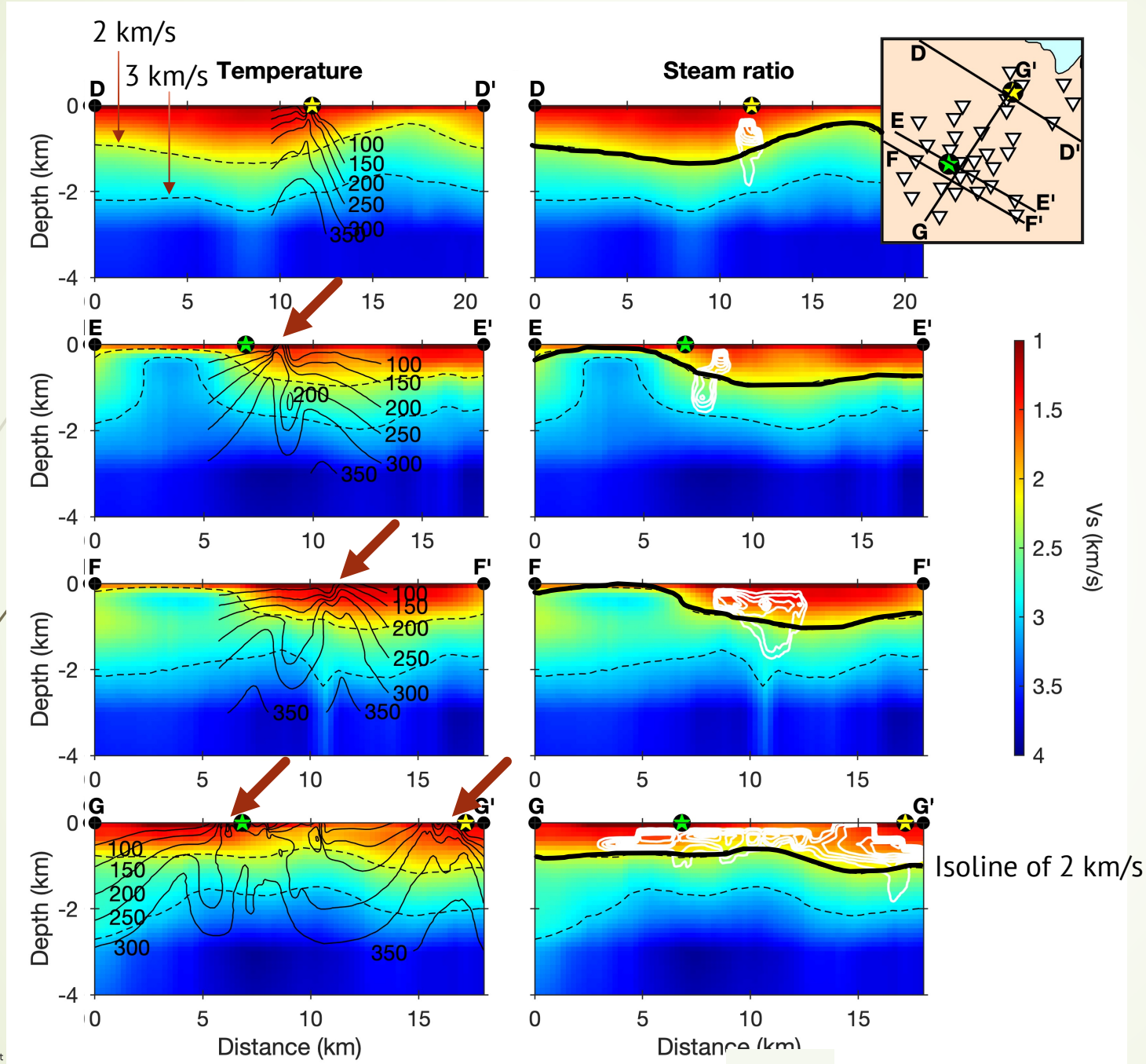






- Density of faults
- Permeability

Attractive target for future drilling projects



Steam cap

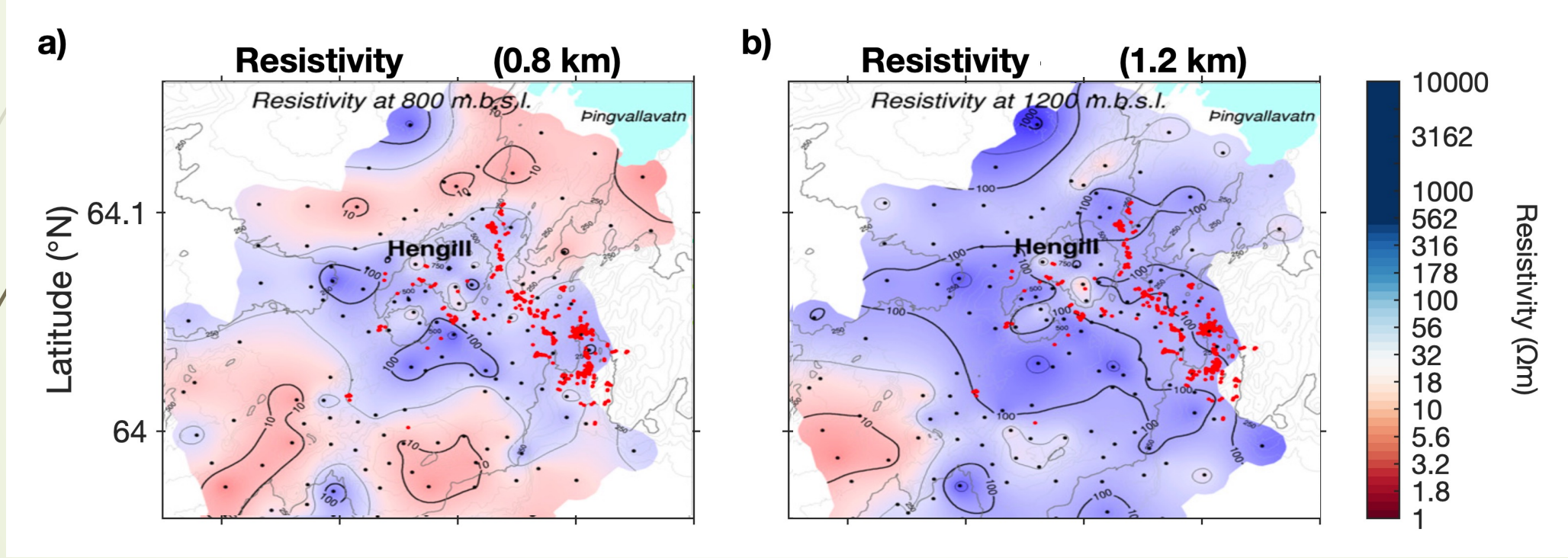
Decompression boiling

Seismic noise tomography

- Formation temperature
- Content of fluids

Resistivity

1D Joint inversion of TEM and MT data



(Modified from Árnason et al., 2010)

Results

Resistivity vs seismic velocity

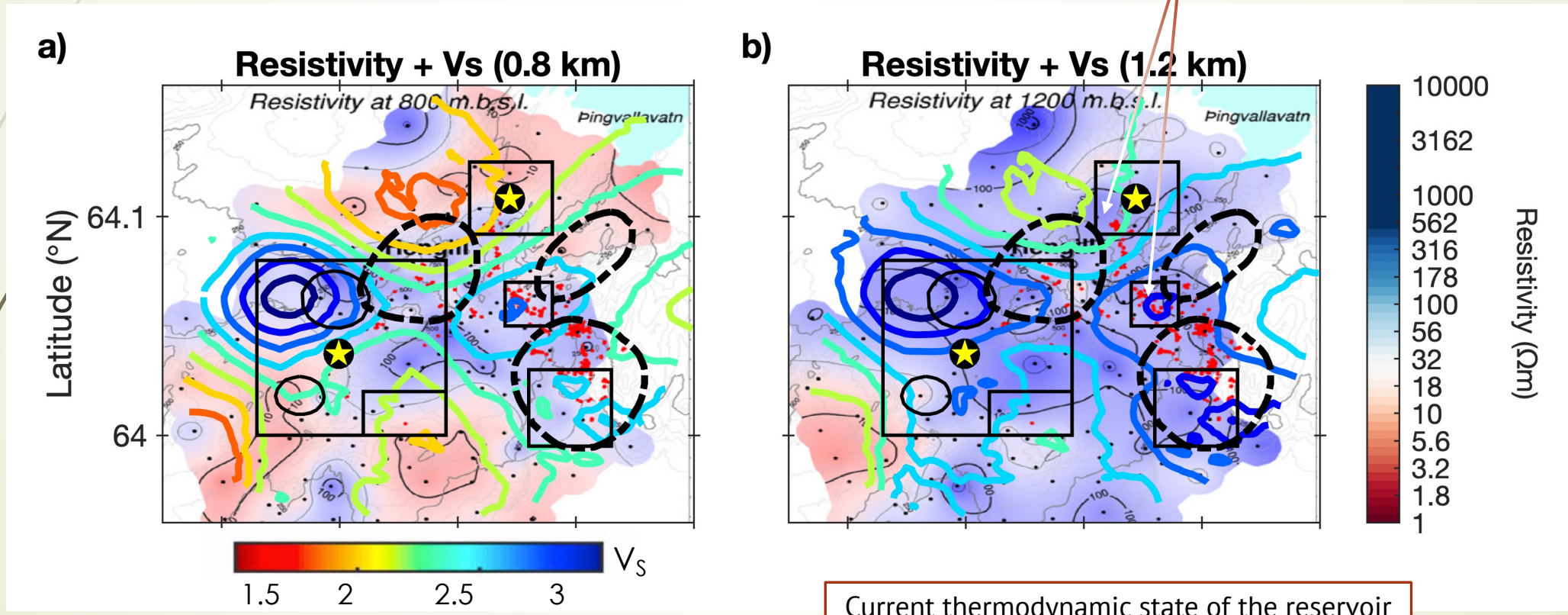
EM – Alteration temperature

Seismics – Formation temperature

1D Joint inversion of TEM and MT data

Excellent correlation

Small discrepancies → No thermal equilibrium

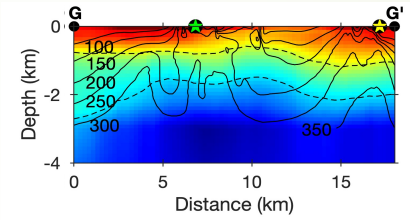


Current thermodynamic state of the reservoir

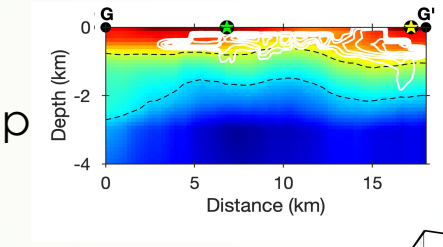
Conclusions

- 3D shear-wave velocity model in Hengill (Iceland)
  with only 1.5 years of data

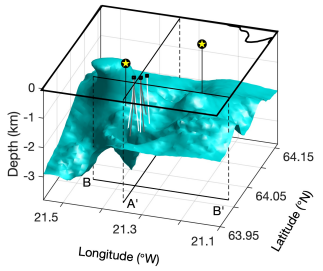
- Shallow velocity anomalies related to high thermal gradient



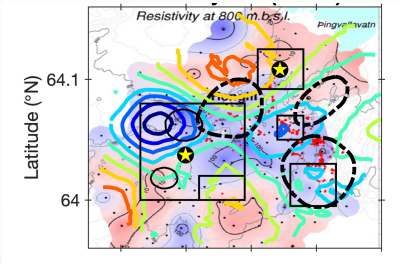
- Bottom of the steam cap



- Potential site for future drilling projects



- Formation temperature of the system
  Geoelectrical methods – Alteration temperature



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