Neue Möglichkeiten für geophysikalische Exploration und Monitoring mit ortsverteilten akustischen Messungen

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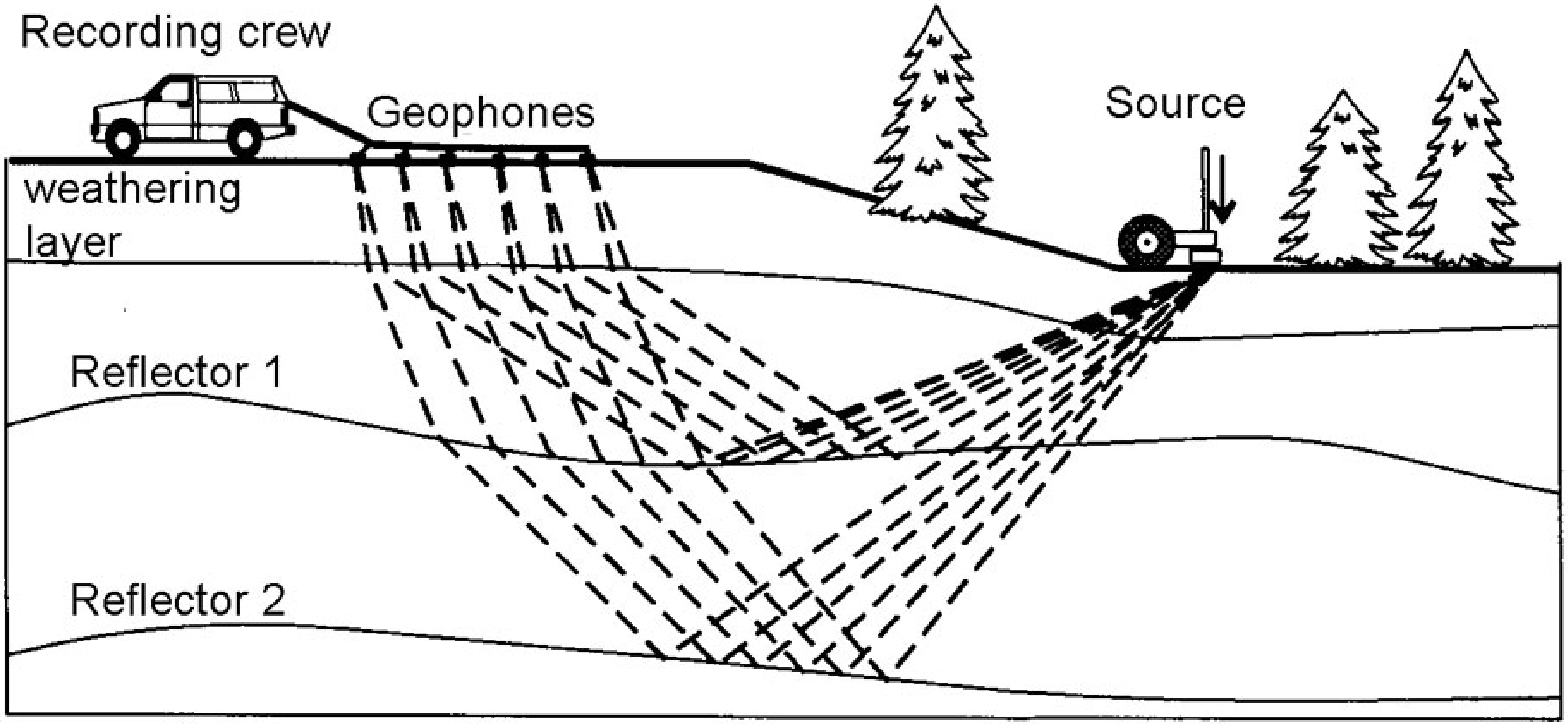
Motivation

- Subsurface technologies to reduce CO_2 emissions during energy production:
  - Geothermal energy (heat, chill, storage)
  - Geological storage of CO_2
- Requirements: exploration of the geological subsurface, monitoring of changes and processes during utilization
- Frequently used: acoustic methods (e.g. reflection seismology, passive seismic monitoring)
- Aims for data acquisition:
  - Improve capabilities
  - Reduce cost

Outline

- Introduction
  - Motivation, acoustic methods in geophyiscs, conventional sensors
  - Distributed Acoustic Sensing (DAS) method
- Case studies
  - Vertical seismic profiling in boreholes
    - Ketzin: permanent sensor cables
    - Groß Schönebeck: wireline deployment
  - Passive recording using suface cables
    - Seismological investigations in Reykjanes (Iceland)

Exploration: reflection seismology

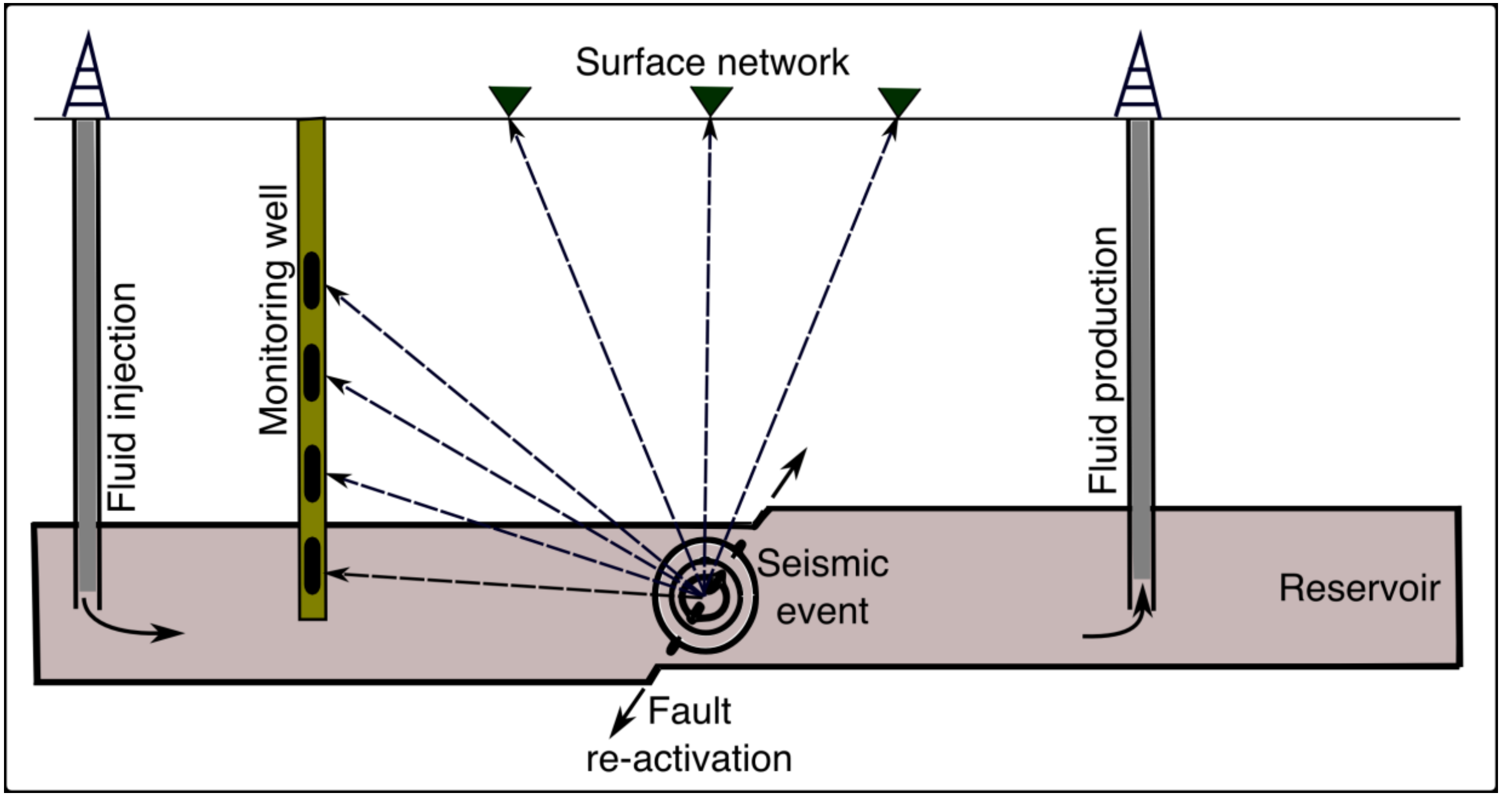


Knödel et al. (1997)

Recorded seismic signals: image of subsurface structures

Receivers in borehole: vertical seismic profiling (VSP)

Monitoring of (induced) seismicity



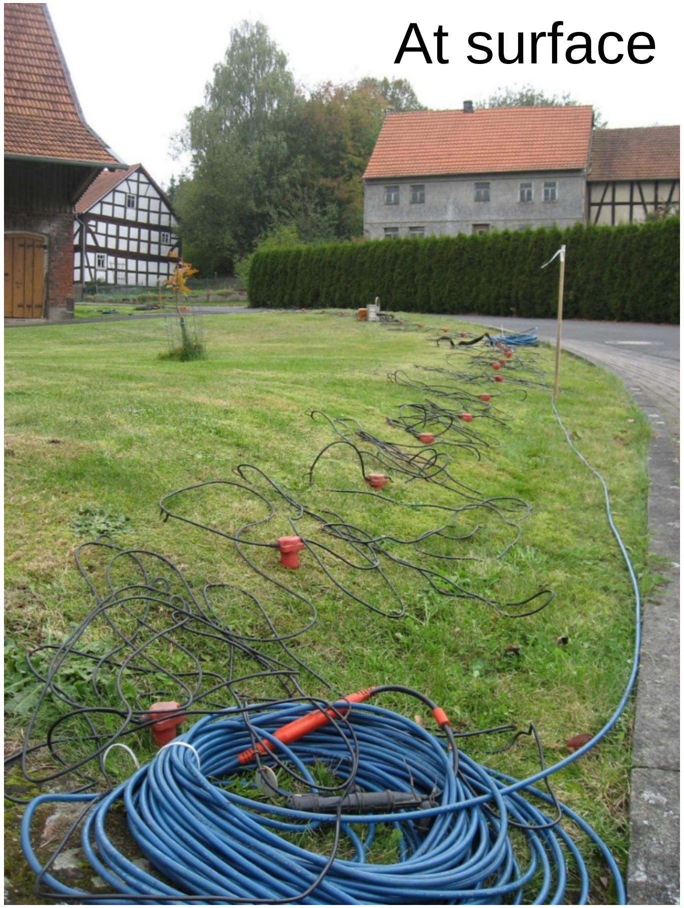
M. Kendall et al., University of Bristol

(passive) recording of acoustic emissions: localization

Events: natural earthquakes, or induced (fluid movement)

Acoustic sensors for geophysics

Geophones: record particle motion (velocity, acceleration)



© Foto: A. Schuck, GGL GmbH

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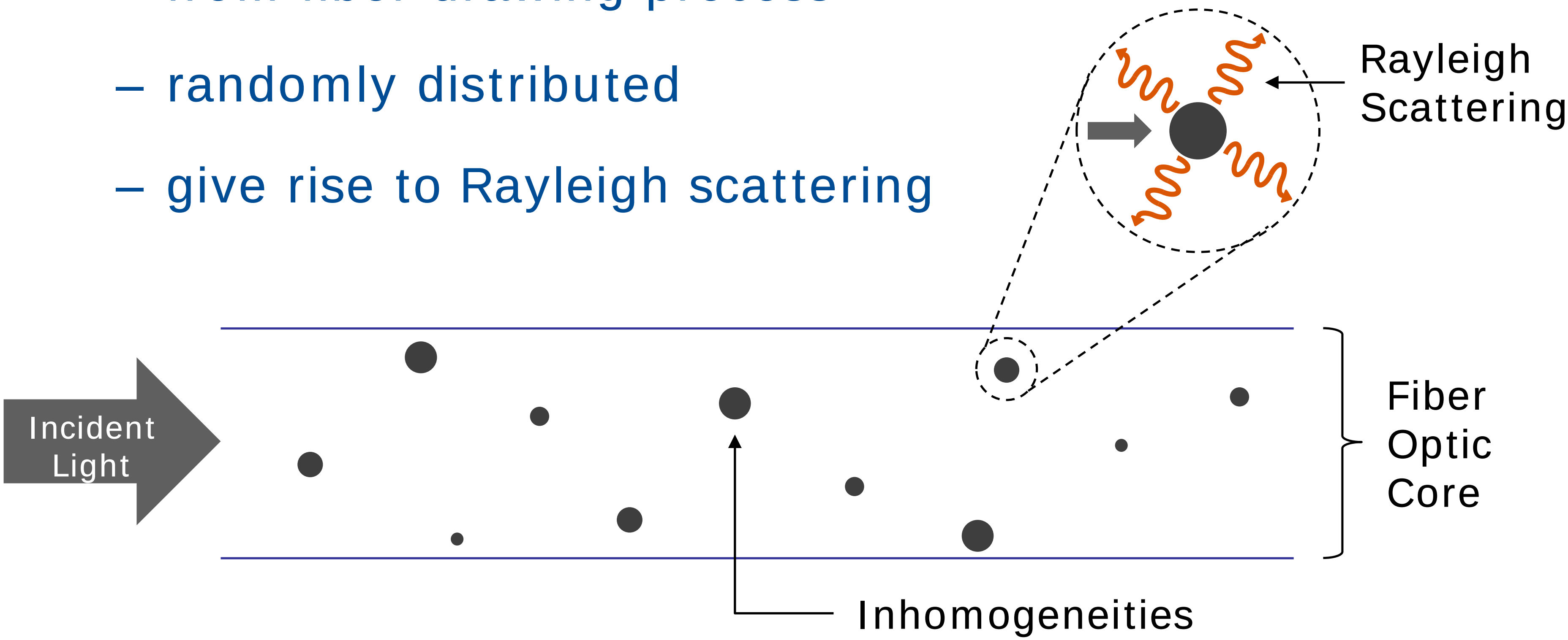
DAS: Method and applications

- Measurement technique, characteristics:
  - acquisition of acoustic signal along sensor cable
  - main advantages: easier to deploy, many measurement points
  - length: up to 10s of km, spatial resolution: ~ 10 m, sampling frequency: 1 m, 1 kHz
  - sensor: optical fiber
  - opto-electronic surface readout unit
- History, Applications:
  - technical concept: early 1990s
  - intrusion detection (~2005)
  - gephysics (>2011), borehole seismic (VSP), flow monitoring (production and injection profiling), microseismic monitoring, surface seismic
- Current R&D subjects:
  - sensitivity (e.g. s/n, directivity), signal processing, hardware

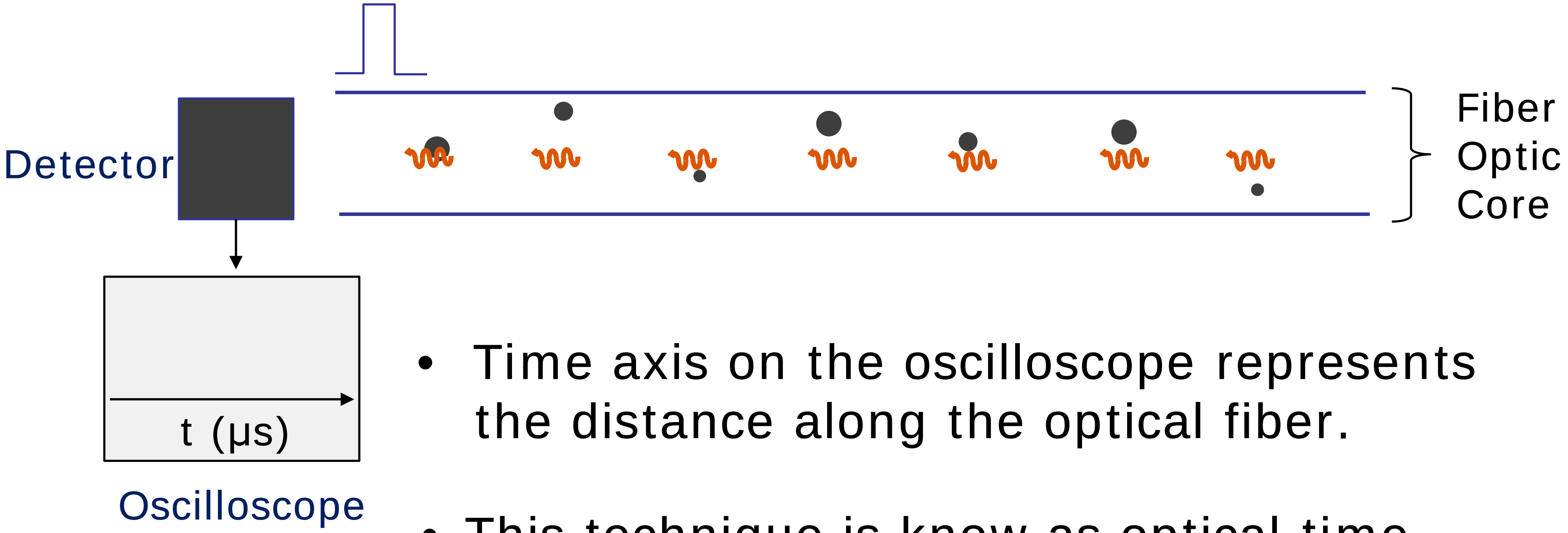
Method: Rayleigh Scattering

- Inhomogeneities within glass of optical fiber core
  - from fiber drawing process
  - randomly distributed
  - give rise to Rayleigh scattering



Method: OTDR

- As a pulse of light propagates through an optical fiber, a small portion of the scattered light propagates backward.

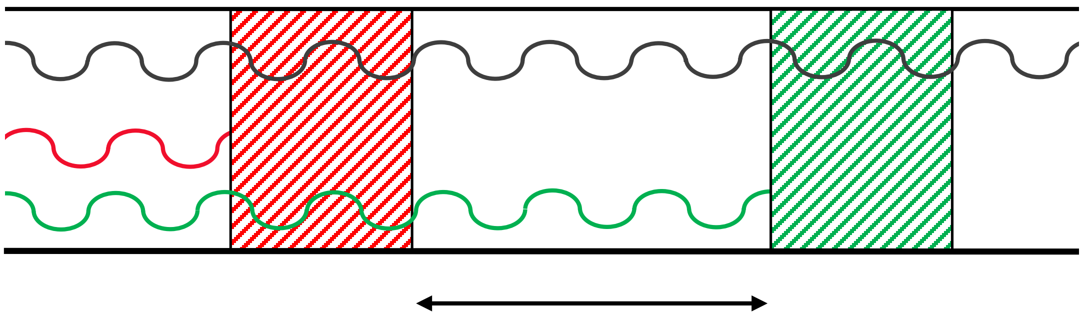


- Time axis on the oscilloscope represents the distance along the optical fiber.

- This technique is know as optical time-domain reflectometry (OTDR).

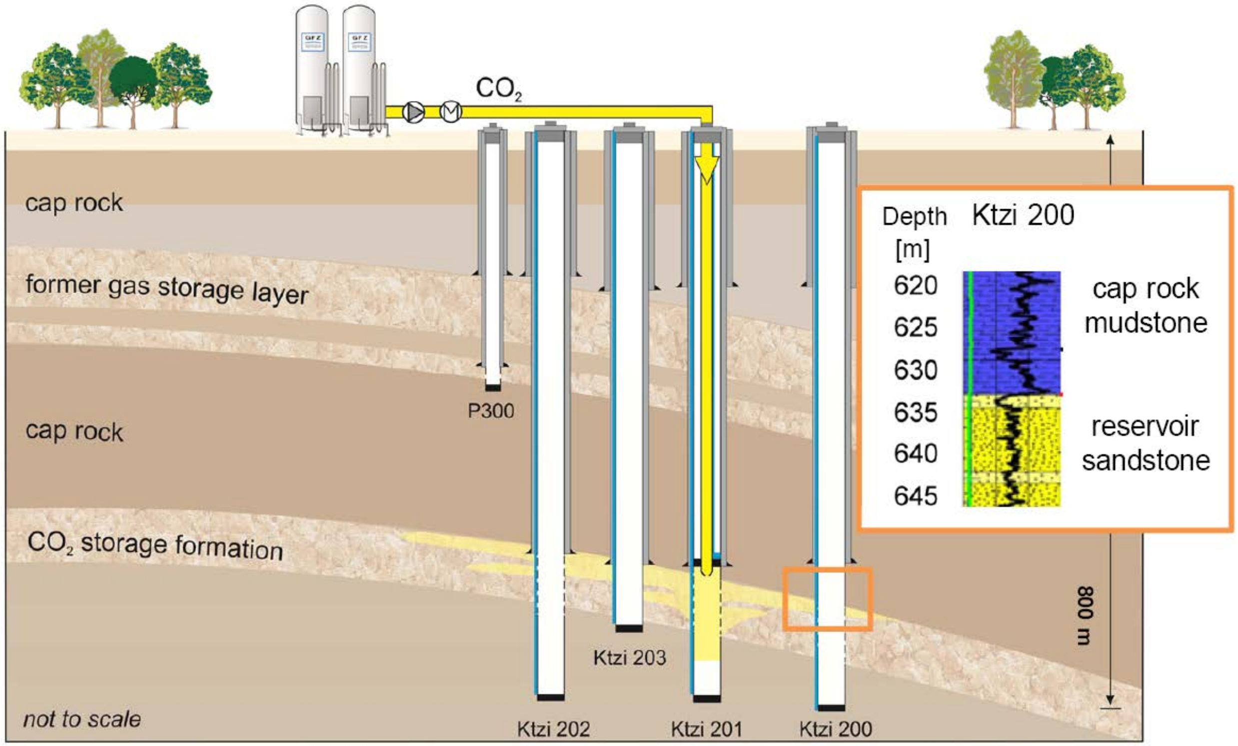
Method: Phase-OTDR

- Phase-OTDR is an OTDR technique which relies on the phase of the backscattered light.



- The phase of the backscattered light changes as the fiber is stretched.
- The strain rate can be measured by comparing the phase difference between the backscattered light from two regions (e.g. Masoudi et al., 2013).

Ketzin pilot site, schematic cross section



Modified after Martens et al. (2015)

In-situ laboratory for geological storage of CO_2 in a saline aquifer

25 km West of Berlin, Germany

Target reservoir: Sediments of Upper Triassic Stuttgart formation

Depth 630-650 m

5 wells: 1 injection, 3 deep and 1 shallow observation well.

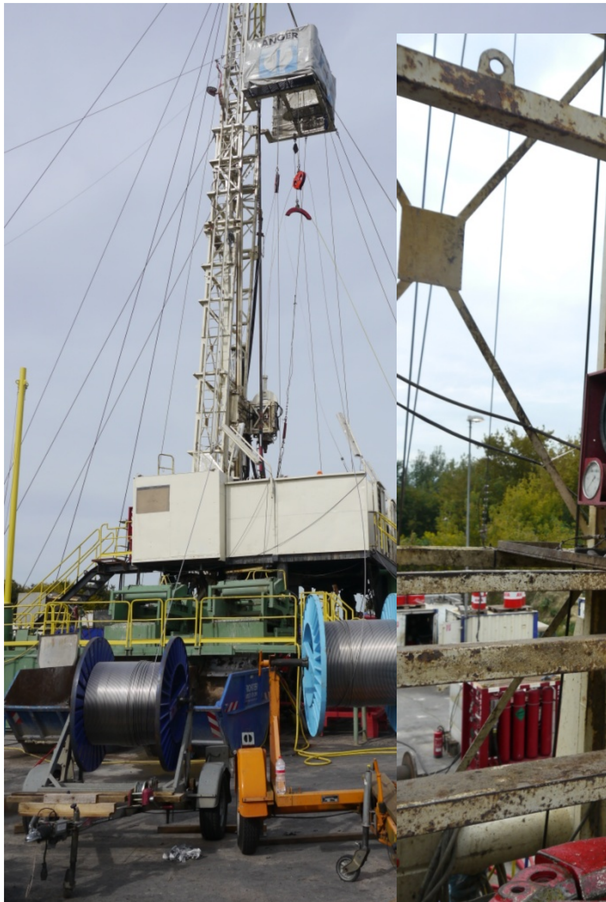
Deployment/equipment: Installation of permanent downhole sensor cable

- Permanent installation
  - Tubing-deployed, or behind casing.
  - Sensor cable: Protect fiber from mechanical and chemical influences. steel tube, with additional jacketing (plastic, steel). May contain several fibers for different sensing techniques.
  - Cable clamps: Attach cable to tubing/casing, protection (centralization).
  - Mechanical coupling determined by annular fill (gas, liquid, cement), and well completion (number of casing strings, cementing).

AFL Telecommunications

150 ° C, 20.000 psi
Tube: 316SS,Incoloy
OD 6.35 mm (1/4“)

Permanent sensor cables behind casing: Ktzi 203



cable drums

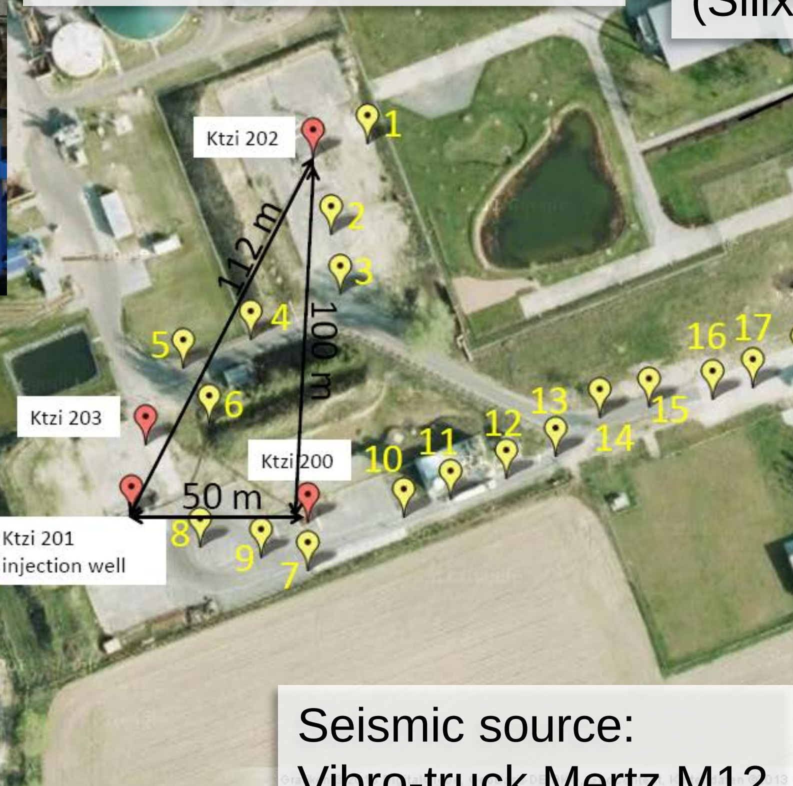
fastening
with steel bands

feed-through
casing spider

DAS-VSP survey Ketzin

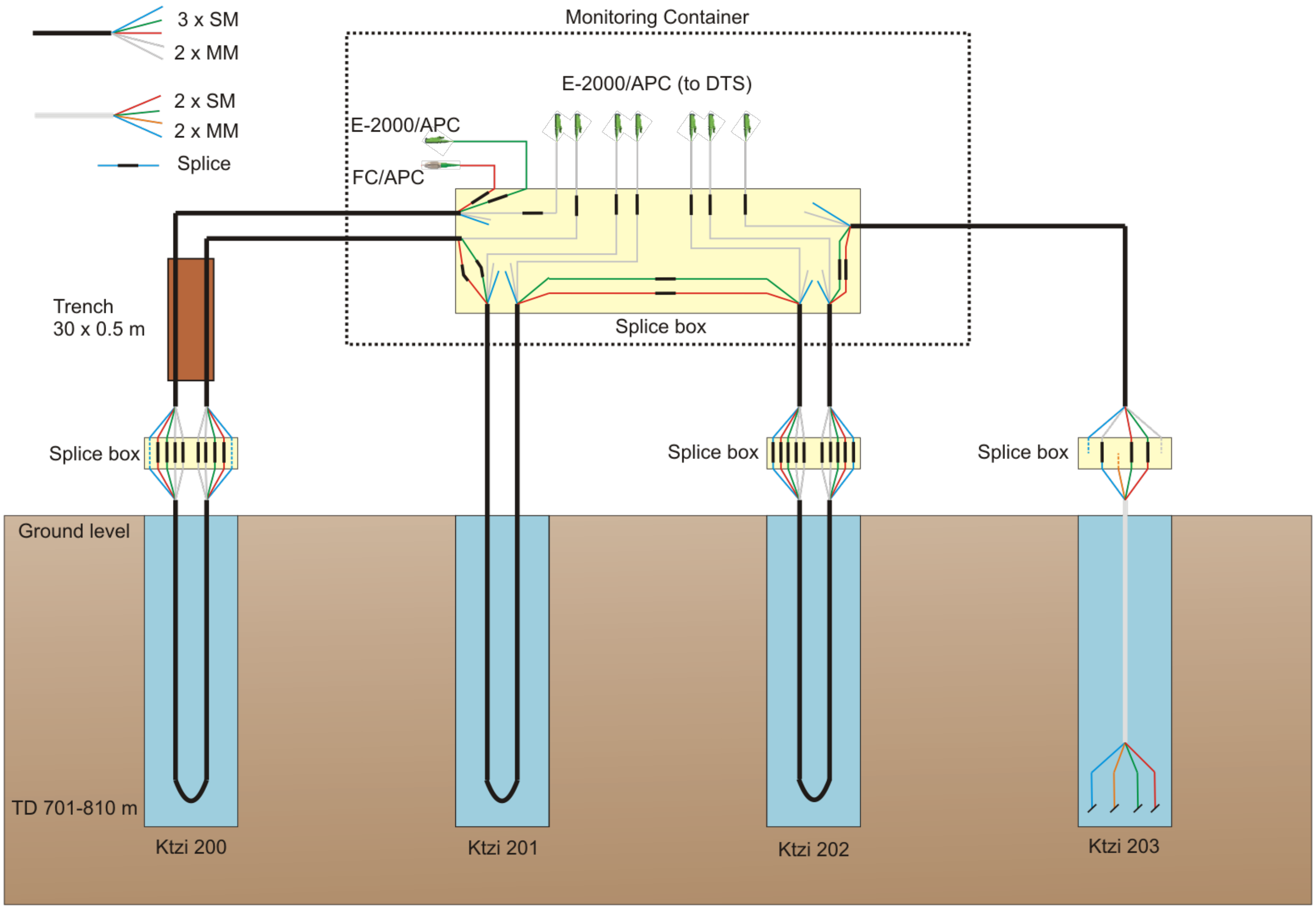
4 wells with
sensor cables
installed behind casing

DAS recording
in all wells
simultaneously
(Silixa)

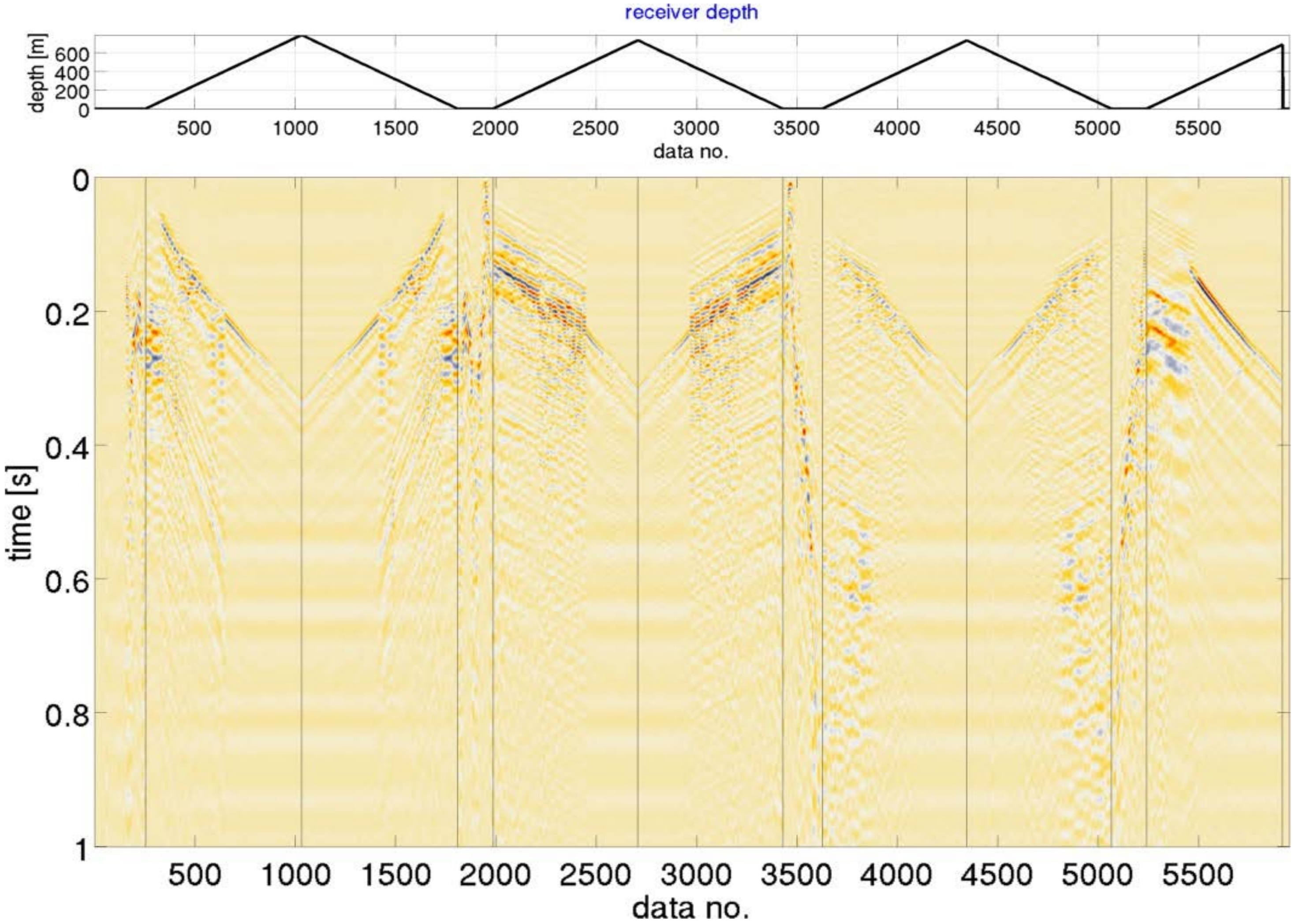


Seismic source:
Vibro-truck Mertz M12

Ketzin GFZ fiber-optic cable layout



Example DAS profile along senor cable



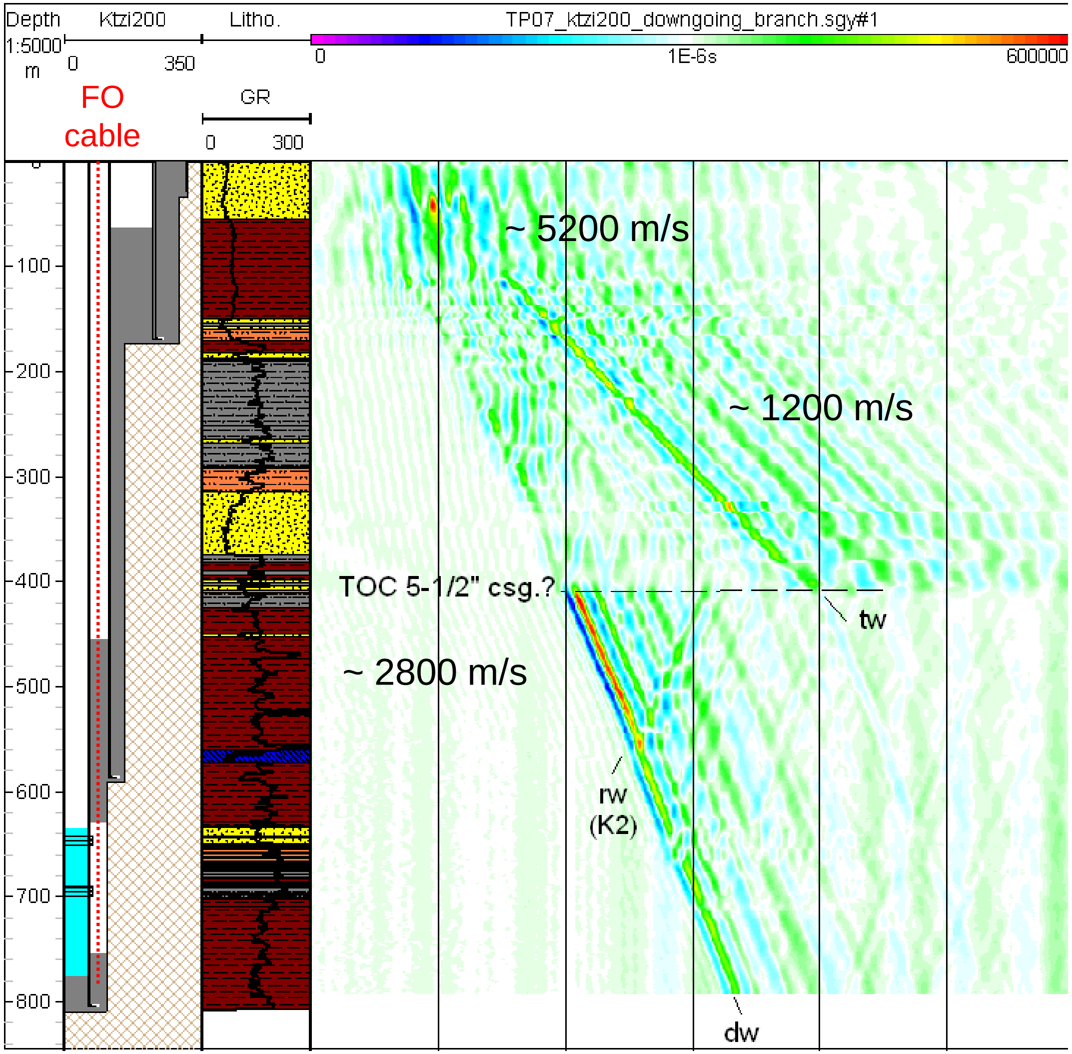
Source point TP08

29 sweeps, 50s duration, 7-120 Hz

DAS acquisition: 1m, 1 kHz

Processing: stacking, correlation (J. Götz, S. Lueth, GFZ)

Zero-offset Ktzi 200: influence of completion

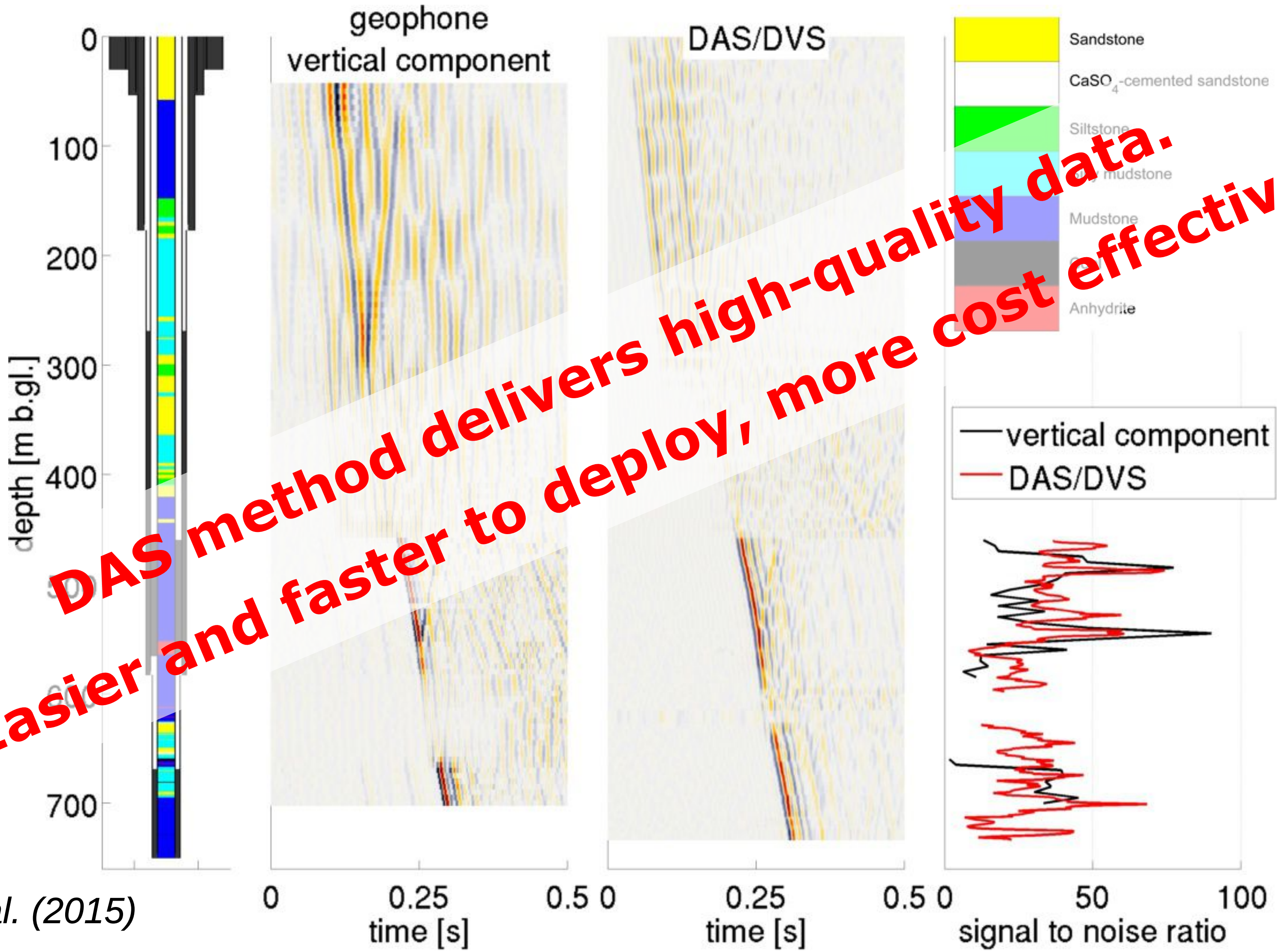


Upper part: casing waves, tube waves

Lower part: direct wave, reflected wave (K2 horizon)

Signal quality depends on well completion and coupling of sensor cable.

Comparison of DAS and conventional sensors

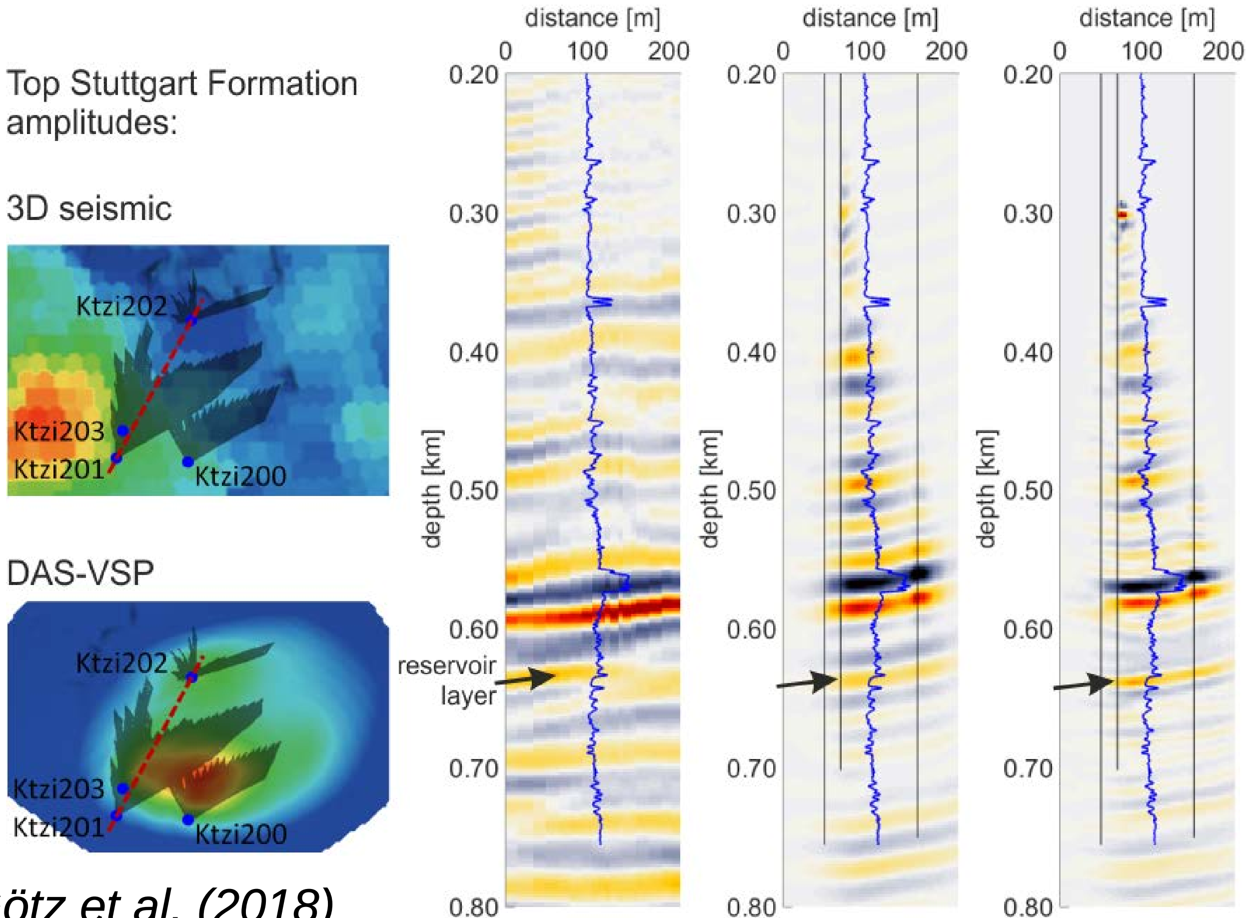


DAS method delivers high-quality data.

Easier and faster to deploy, more cost effective.

Götz et al. (2015)

DAS-VSP Ketzin: 3D depth migration



Götz et al. (2018)

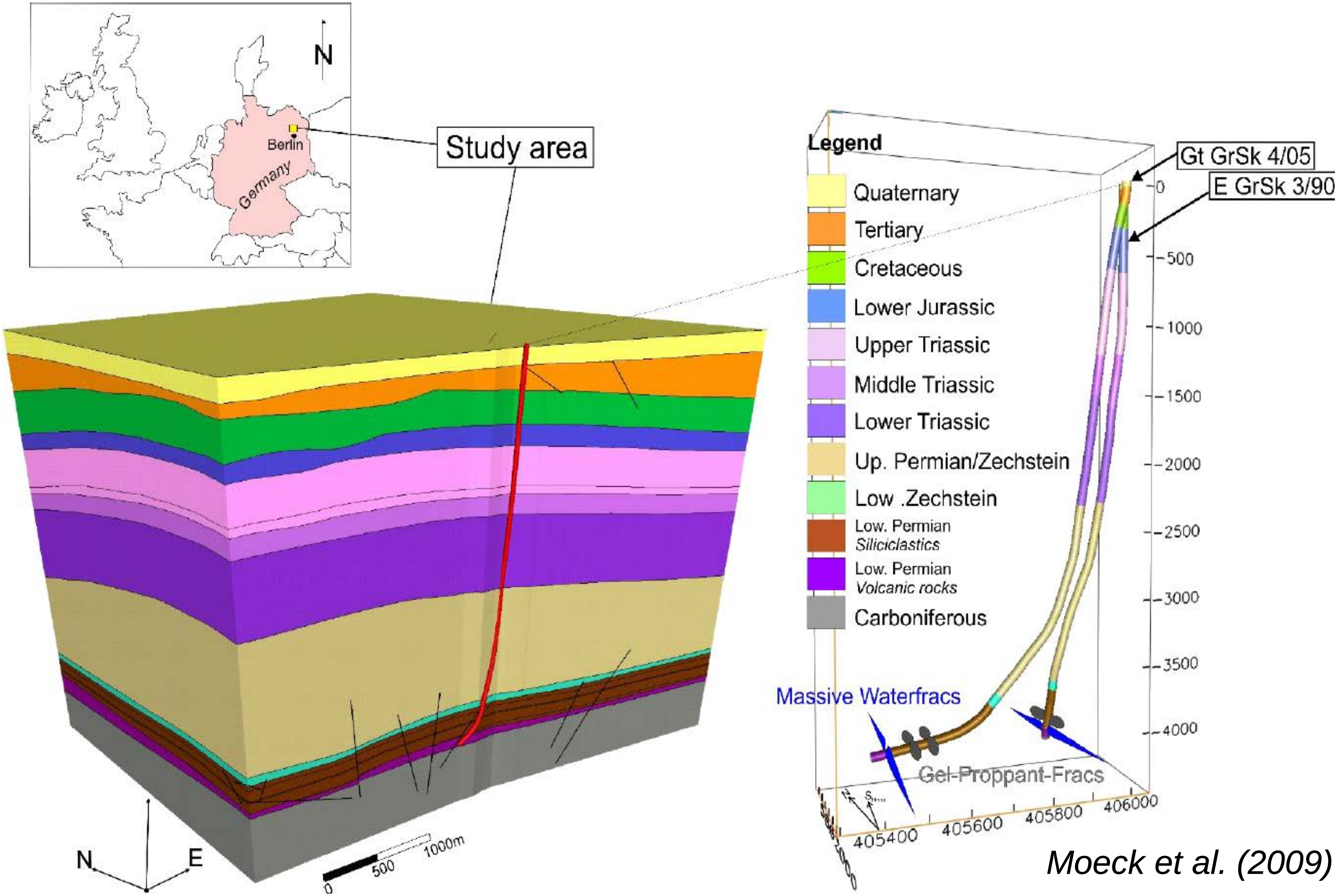
Left: amplitude maps Top Stuttgart (630 m, see arrow in profiles.

Right: cross sections 3D surface seismic and DAS-VSP (band-pass filtered, raw).

Blue curve: acoustic impedance from log data, Ktzi201 well.

Better/more detailed imaging of target layer with DAS-VSP data.
Coverage could be improved by optimizing source locations.

In-situ geothermal lab Groß Schönebeck



Moeck et al. (2009)

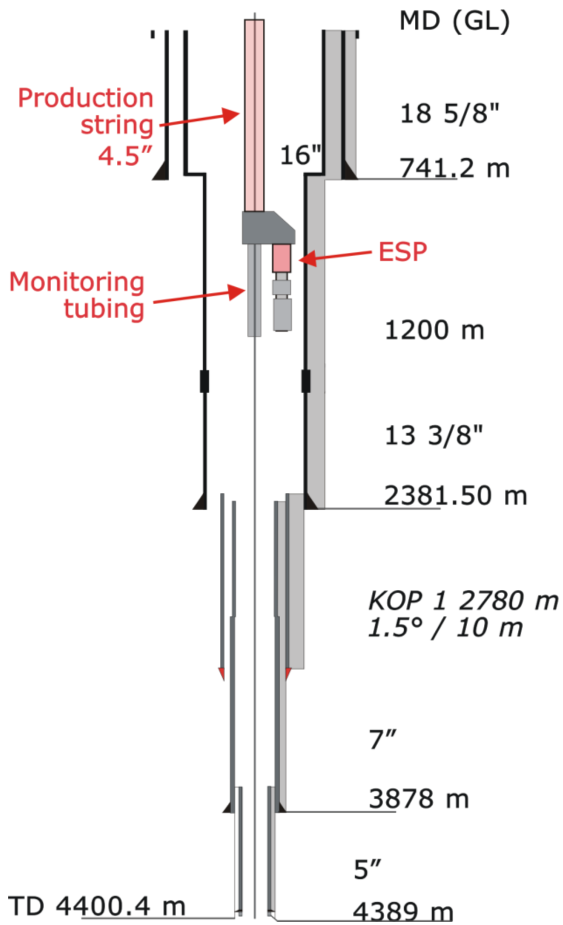
Completion and production string Gt GrSk 4/05

Total depth 4400 m

Deviated > 2780 m

Perforation intervals
4118 – 4389 m

Production string with
pump at 1200 m
Y-Tool:
Access with logging
tools during
production



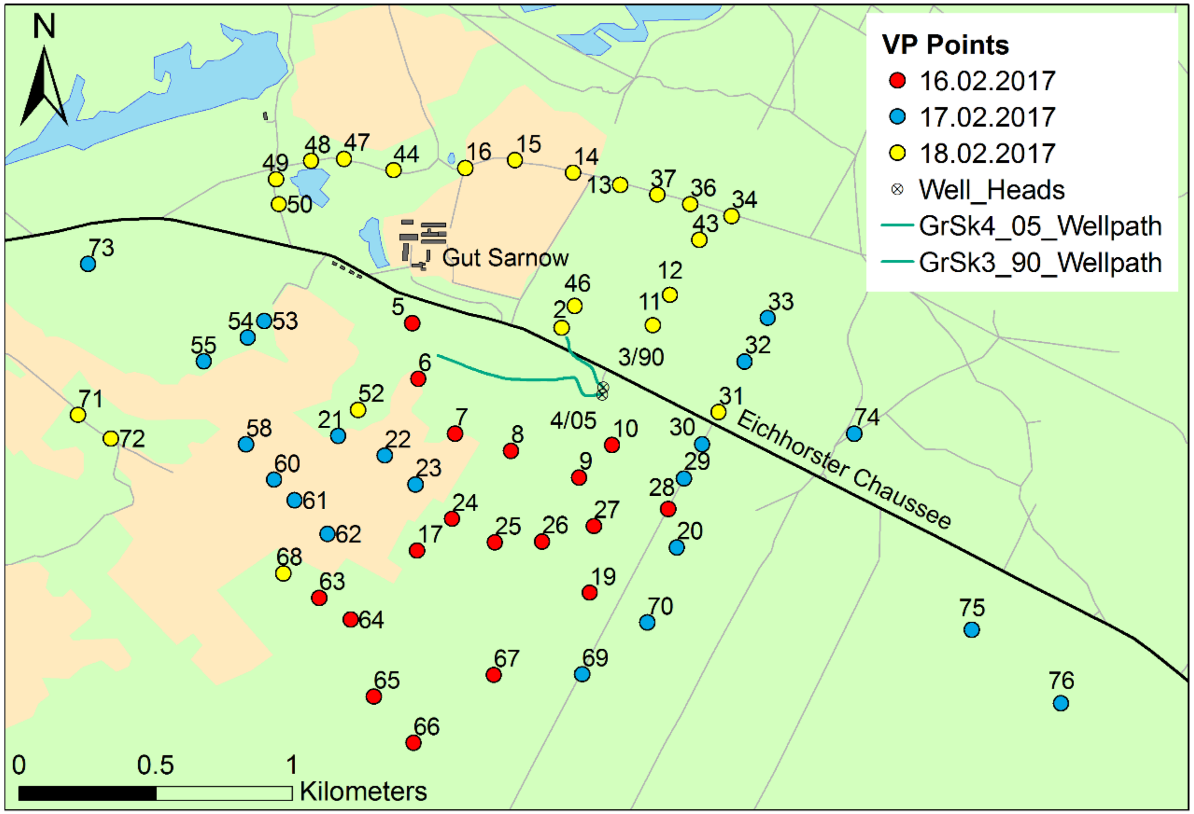
GFZ hybrid wireline logging system

Henninges et al. (2011), 73rd EAGE Conference & Exhibition

3,5 t tractive force
2 x 5,500 m logging **cable**: standard 4-conductor and **hybrid with optical fibers**

Production logging tools: pressure, temperature, spinner flow meter
Depth correlation: gamma ray, casing collar locator
Operations: Motion

DAS-VSP survey: geometry, schedule



Survey design:
61 VPs, spiral pattern around target zone, some far offset positions. 2 receiver wells, 4300 m deep.

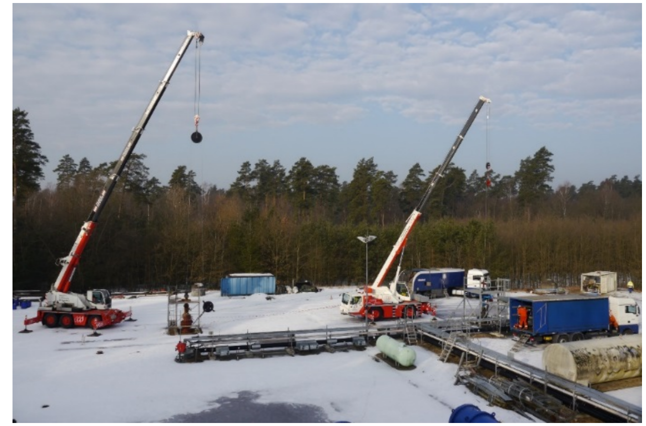
Schedule:
Day 0: Start-up test (sweep parameters, slack test).
Day 1-3: 3 x 20 VPs.

Study area: North-East German Basin, 40 km N of Berlin.

DAS-VSP field work Feb 15-18, 2017

Seismic sources: 4 vibro trucks (DMT)

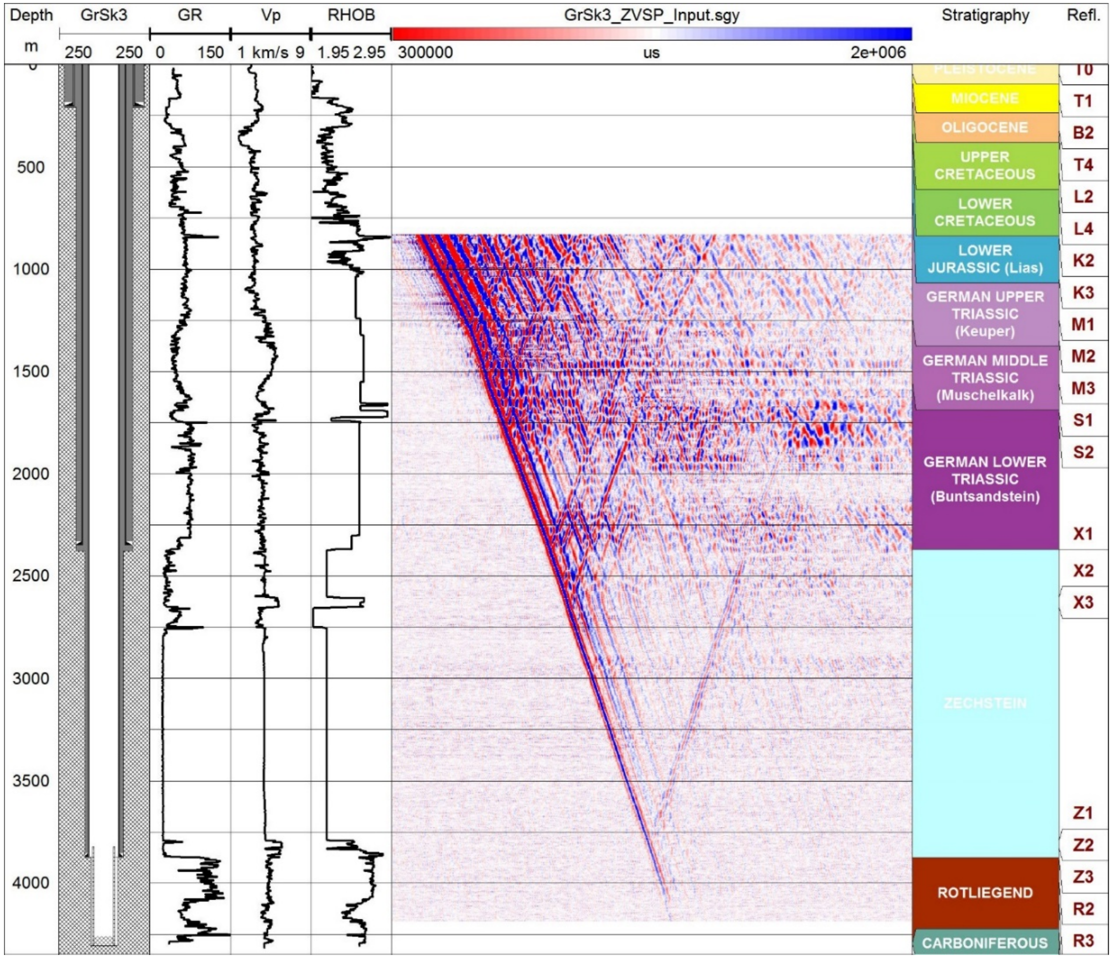
Wireline operations (SLB, GFZ)



VSI tool: 3C accelerometer (SLB)

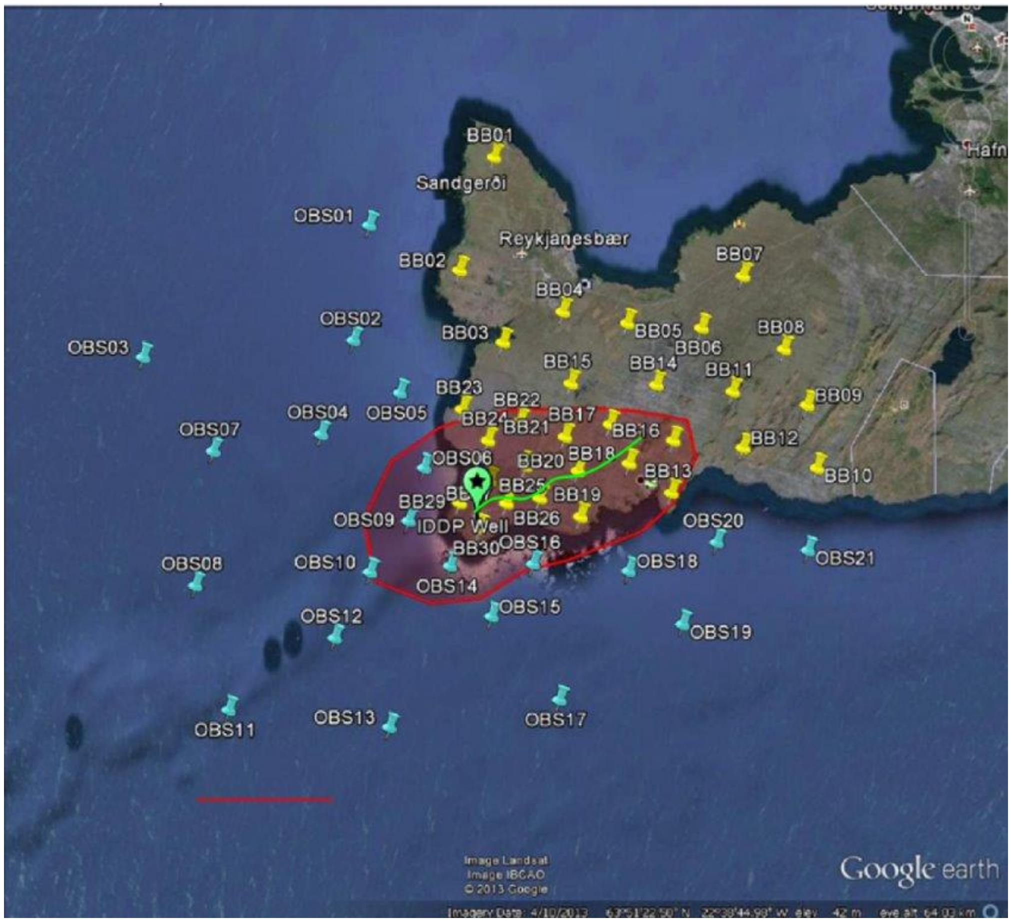
2 hDVS acquisition units (SLB)

ZOVSP, well logs & geology GrSk3



Stiller et al. (2018)

IMAGE seismic network



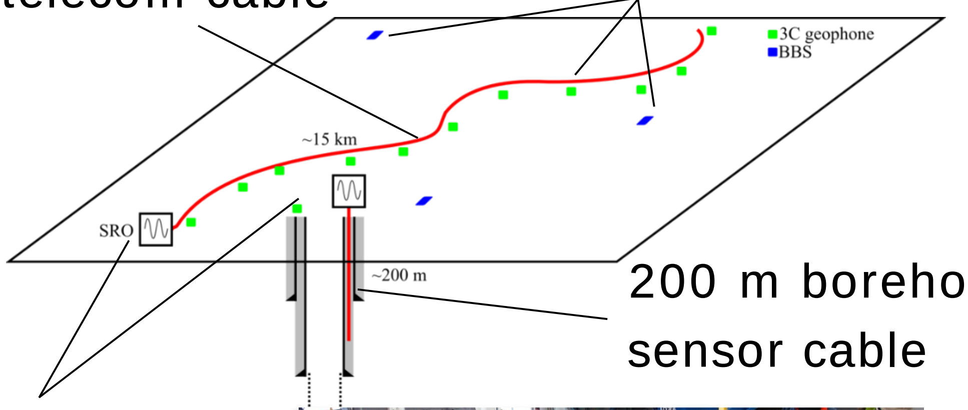
Reykjanes peninsula, SW Iceland

- deployed in 2014 (GFZ + ÍSOR):
  - 20 broadband stations, 10 short-period sensors
  - 24 ocean bottom seismometers
  - recording for > 1 year
- DAS survey: borehole installation, surface cable (connect to existing 15 km data cable)
- 150 additional short-period sensors in vicinity of DAS cables

DAS monitoring at Reykjanes/Iceland (IMAGE)

15 km surface telecom cable

3C geophones and bbs

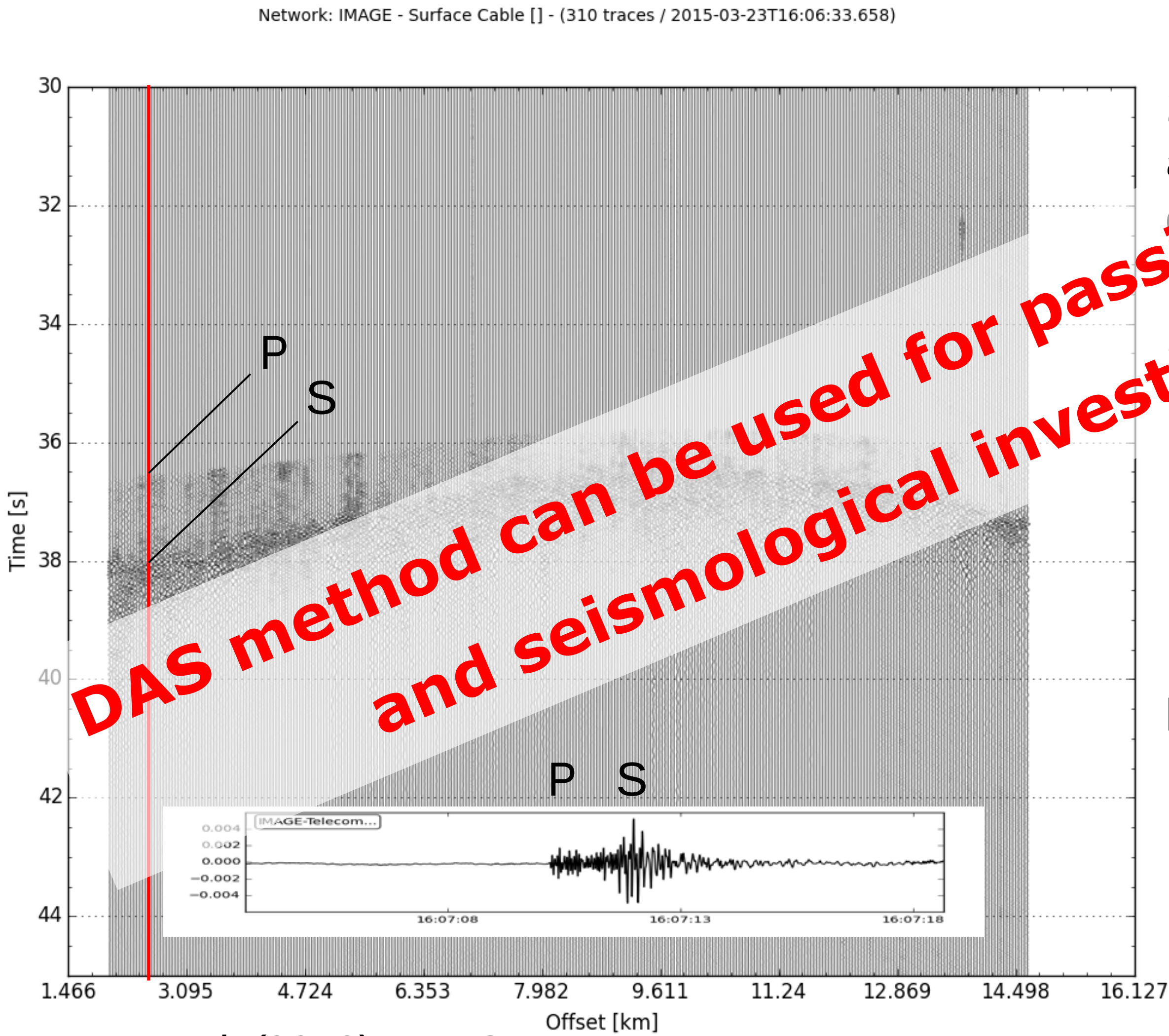


200 m borehole sensor cable

DAS recording (Silixa):

9 days, 1000 Hz, 4m/1m sampling interval

Example from surface cable DAS field data



DAS method can be used for passive monitoring and seismological investigations

2D-plot: Dynamic strain amplitude along length of cable (15 km) versus time (15 s).

Inset: individual trace at position marked in red (2.4 km).

M 1.02 earthquake, location 3.6 km underneath cable (IMO).

Jousset et al. (2018) Nat. Comm.

GFZ Helmholtz Centre Potsdam

HELMHOLTZ ASSOCIATION

Summary

Distributed acoustic sensing opens up **new possibilities for geophysical exploration and monitoring**.

- **Advantages**: ruggedized, high temperature tolerance, easy to deploy. Distributed methods: high spatial and temporal resolution over long distances. Time and cost effective!
- **Challenges**: lower signal-to-noise ratio, directional sensitivity, very large data volumes. Deployment: coupling of sensor cable. Development of custom processing methods, improved understanding of signal characteristics required.
- Need for **research**: ongoing and future projects.

Thank you for your attention!

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Groß Schönebeck: E. Martuganova (GFZ 6.2), M. Stiller, K. Bauer (GFZ Section 2.7 Near-surface Geophysics), service companies: Schlumberger, DMT, GGL, GGD.

Iceland: T. Reinsch, P. Jousset (GFZ 6.2)

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