Integrated geophysical characterization of geothermal reservoirs

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GEOTHERMAL ENERGY: Status and Future in the Peri-Adriatic Area

XIV International Conference on Science, Arts and Culture

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Outline

Characterization of geothermal reservoirs by integrated geophysical methods, OGS experiences and contributions:

- Grado district heating project, low-enthalpy reservoir
- Seismic while drilling (SWD) method and application in medium-enthalpy geothermal reservoir
- Perspectives in high-enthalpy geothermal reservoir
- Seismic wave propagation in hot and melting rocks

Grado integrated survey

Integrated geophysical approach

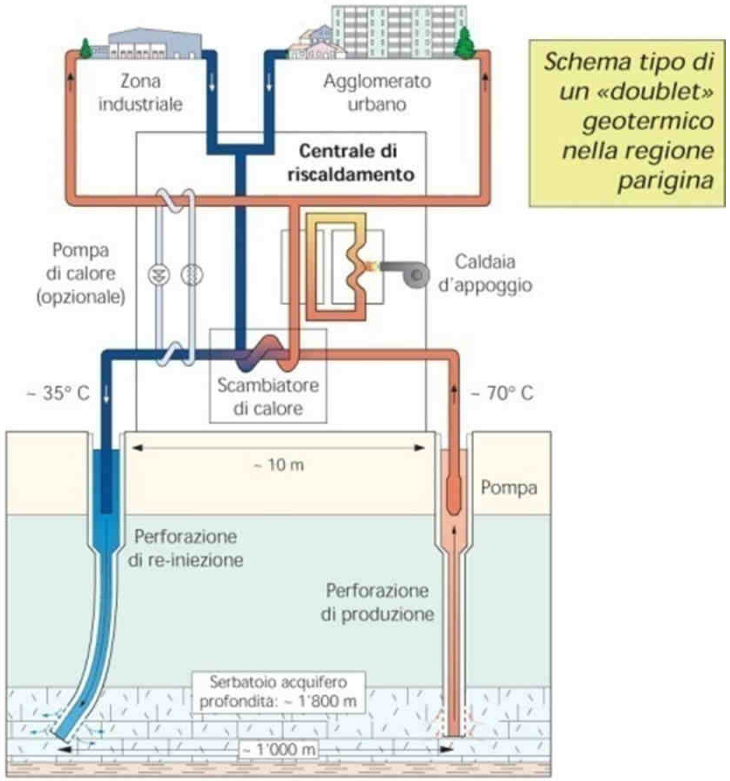
- Geothermal district heating Project, Grado island (NE Italy)

- New geophysical investigations (phase 2):
  - Reflection seismic
  - Borehole seismic (VSP)
  - Gravity data

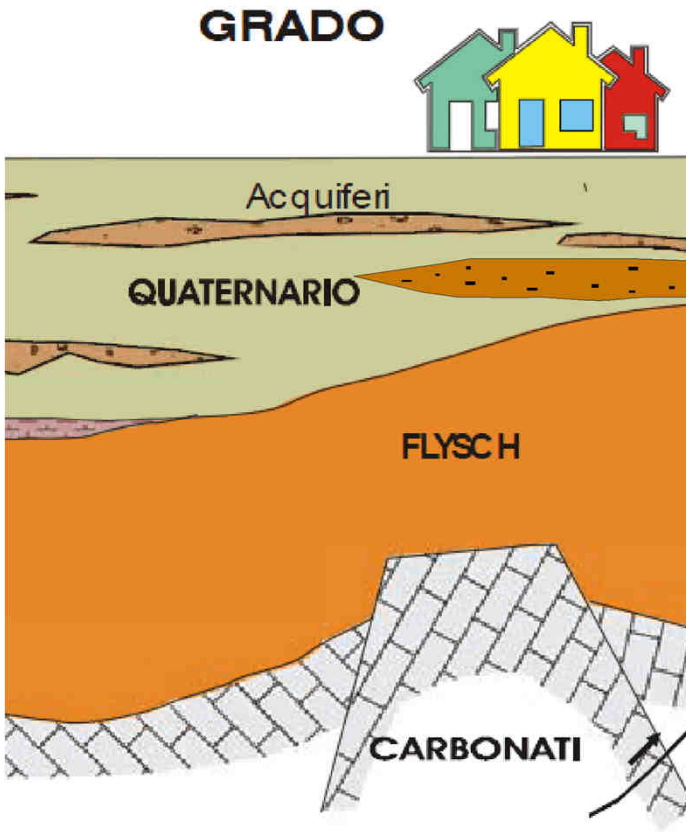
- Provide info for Well 2 location after Grado 1 well results

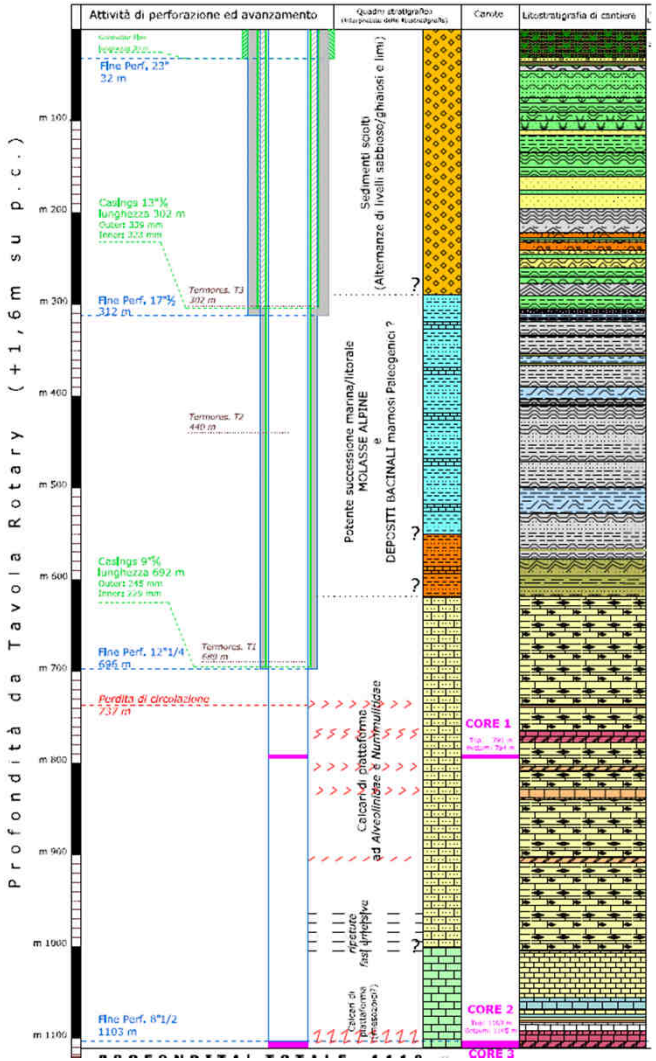
(after L. Petronio, F. Poletto, F. Palmieri and B. Della Vedova, 2012)

Geothermal district heating doublet

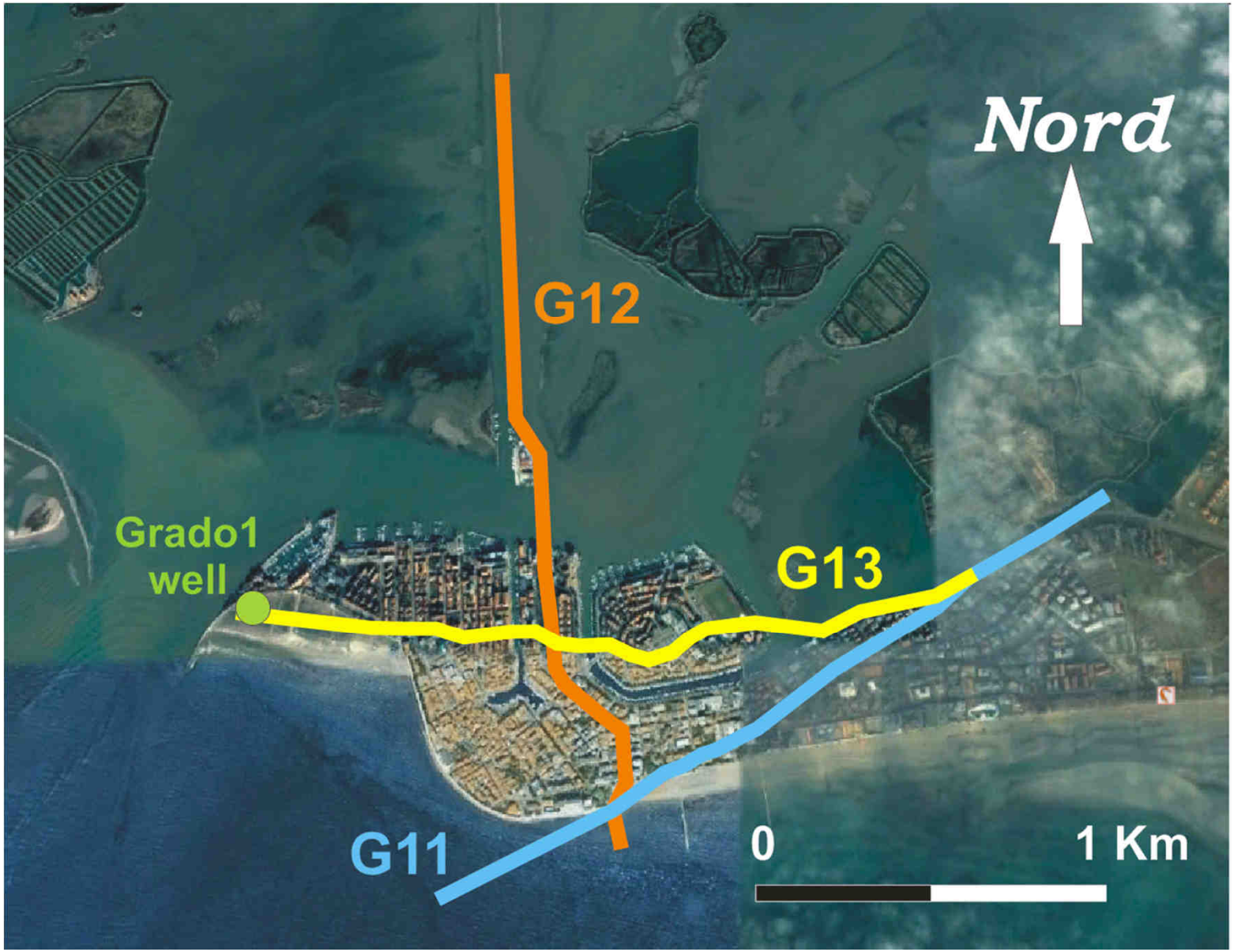


Schema tipo di un «doublet» geotermico nella regione parigina





Surface reflection seismic layout

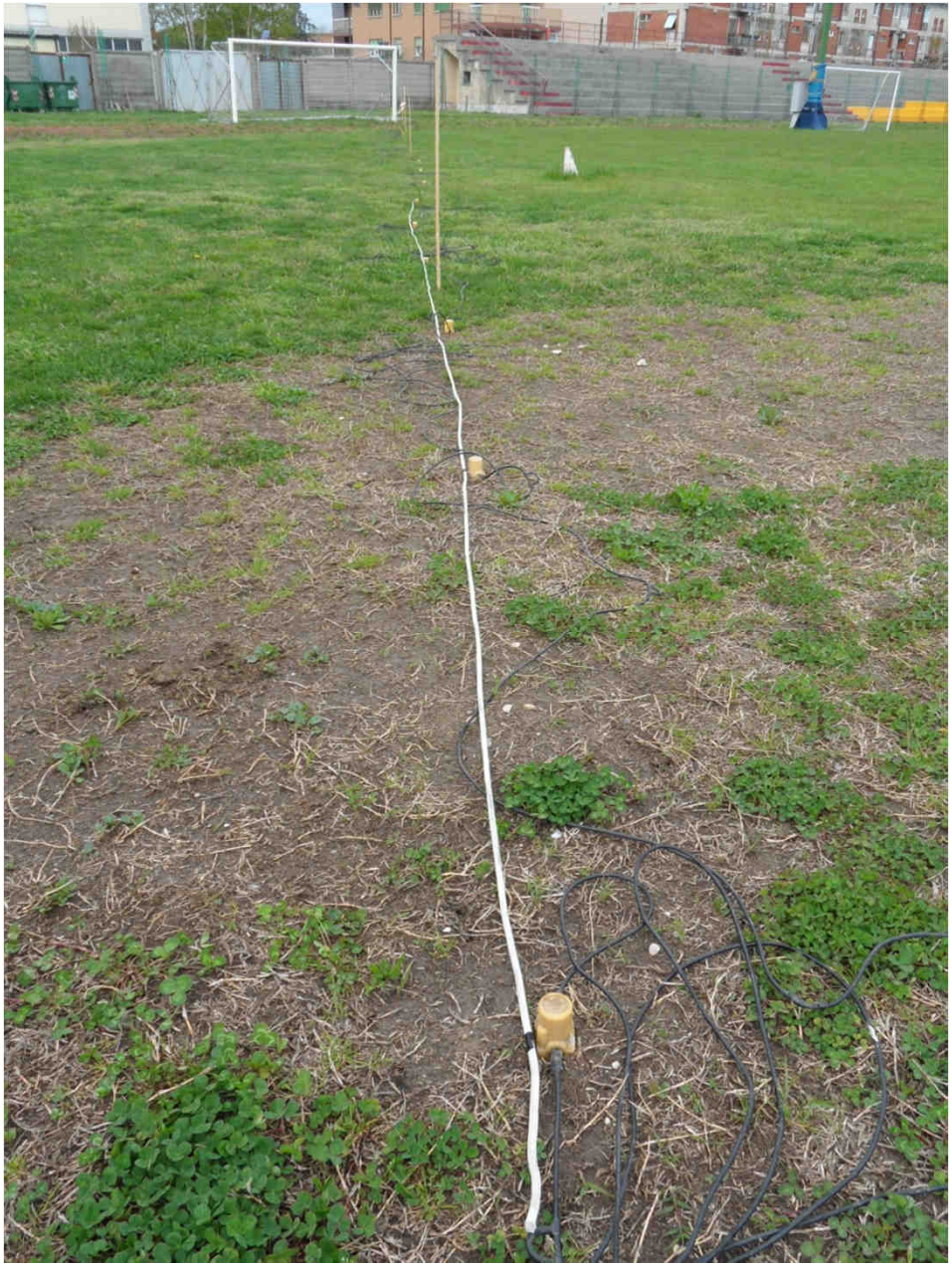


Surface seismic acquisition parameters

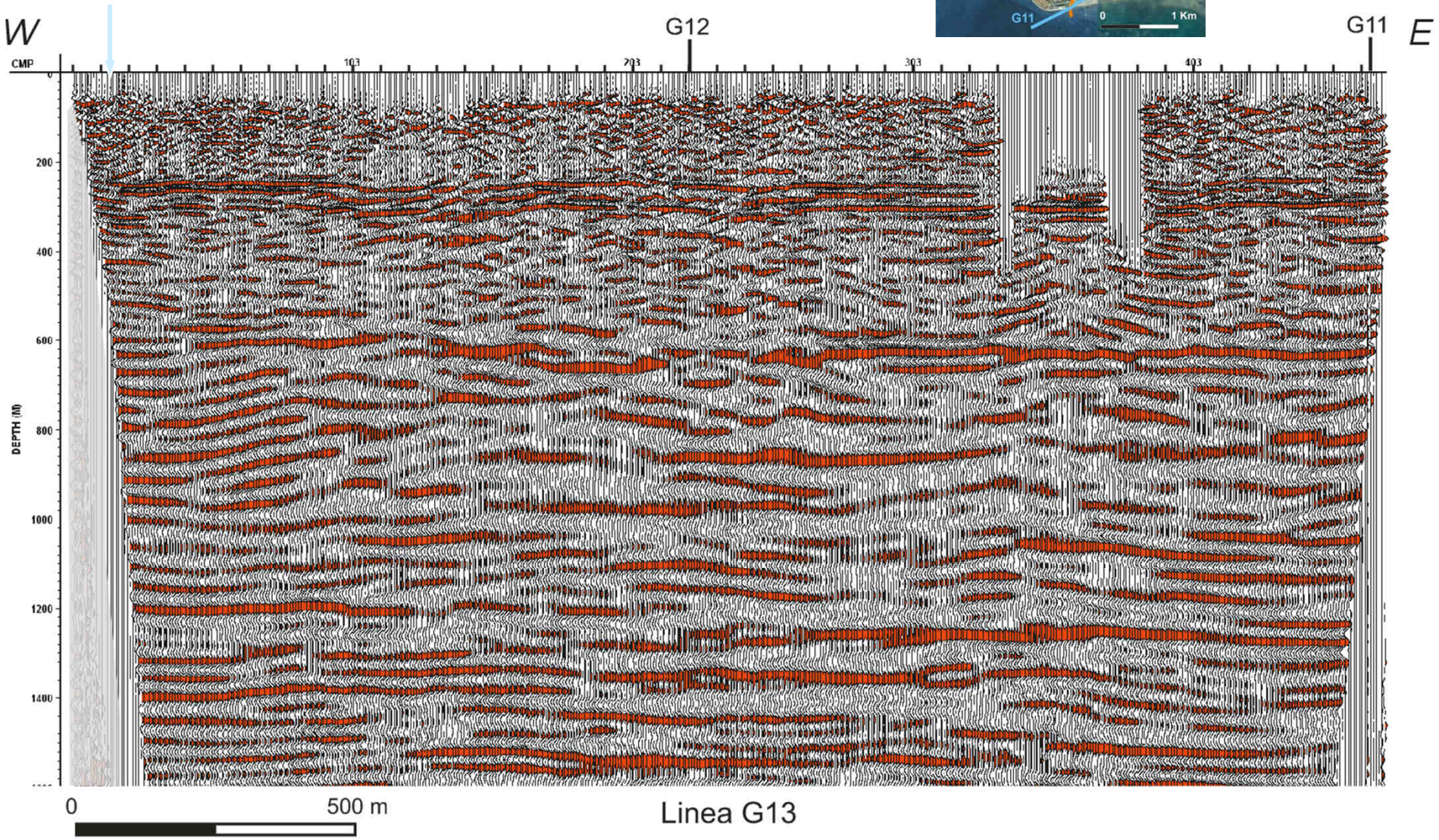
	G11	G12	G13
Seismic source:	Hydrapulse	Hydrapulse	Minivib (18 s, 8 – 200 Hz)
Sensors:	geophone (6x10 Hz) and hydrophone		
Intertrace:		10 m	
Shot interval:		20 m	
Layout:		fixed spread	
Channels:	236	256	174
Length:	2350 m	2550 m	1730 m
Sampling rate:		1 ms	
Data length:	4 s	4 s	22 s

Surface seismic sources

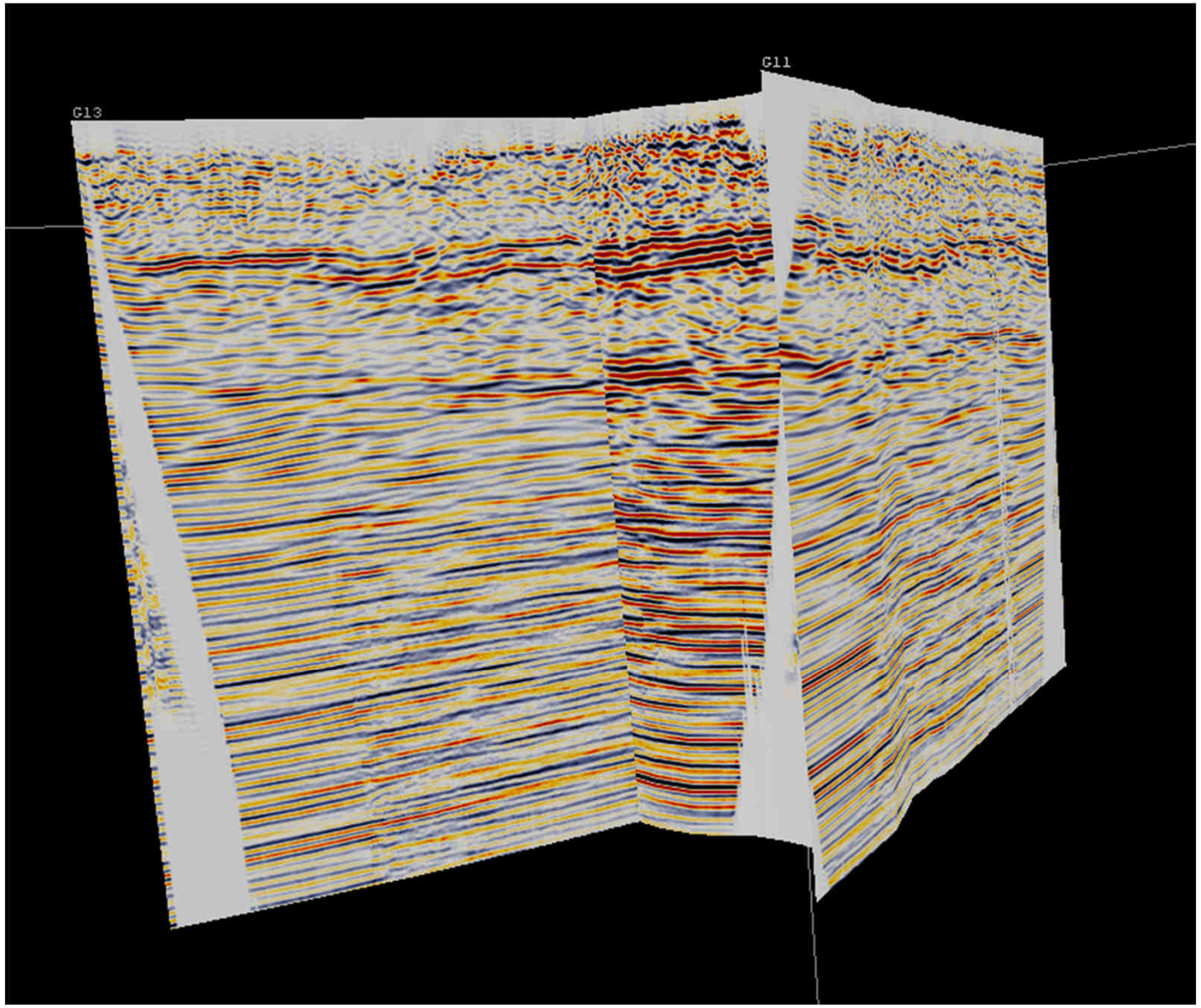
Surface seismic receivers



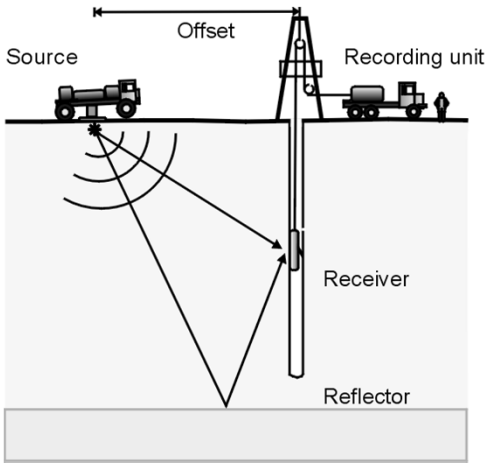
Example of reflection signal processing



Cross-line interpretation



Borehole seismic in Grado 1 well



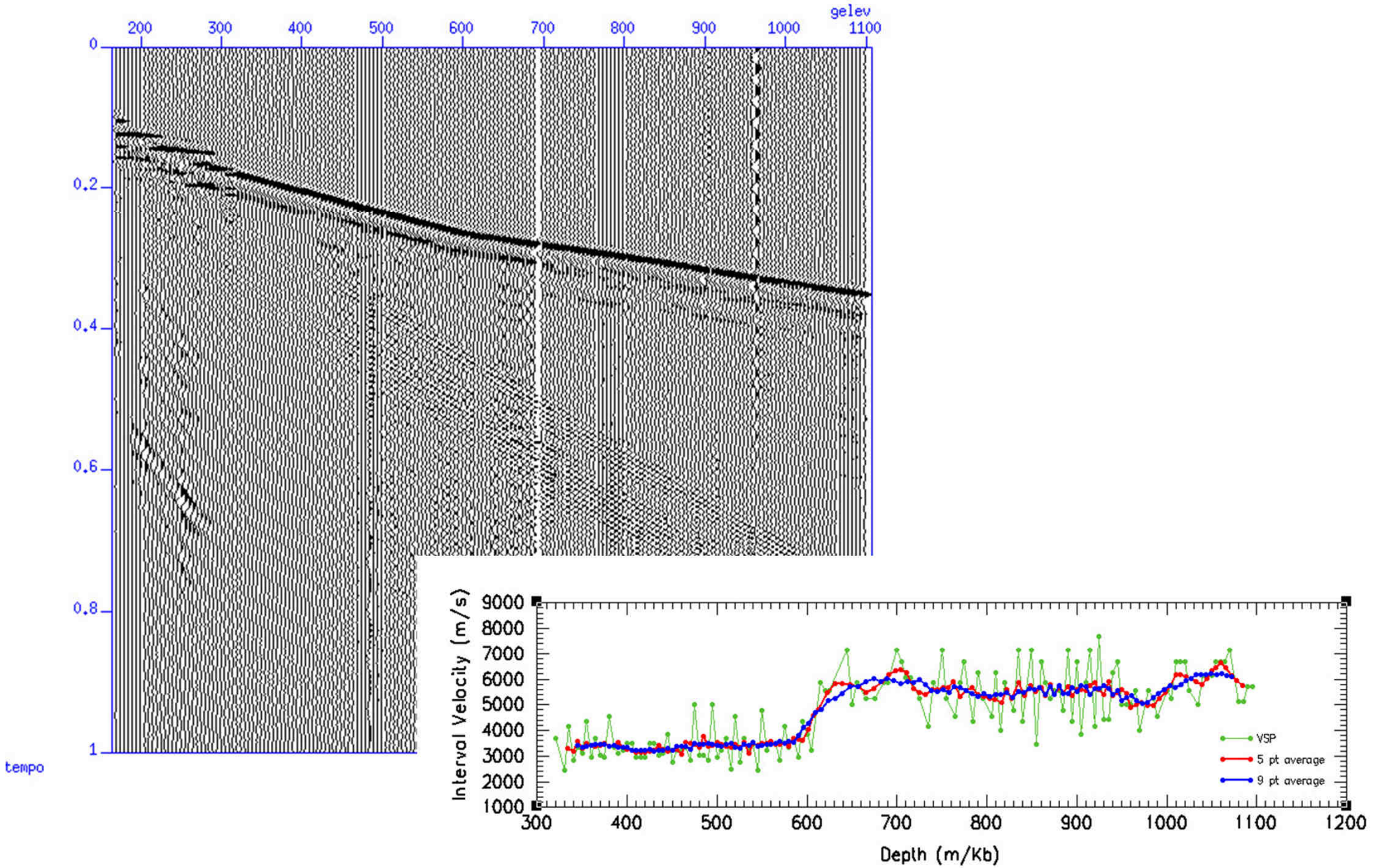
Concept of vertical seismic profile (VSP)

Four VSPs: 1 near offset VSP + 3 offset VSP

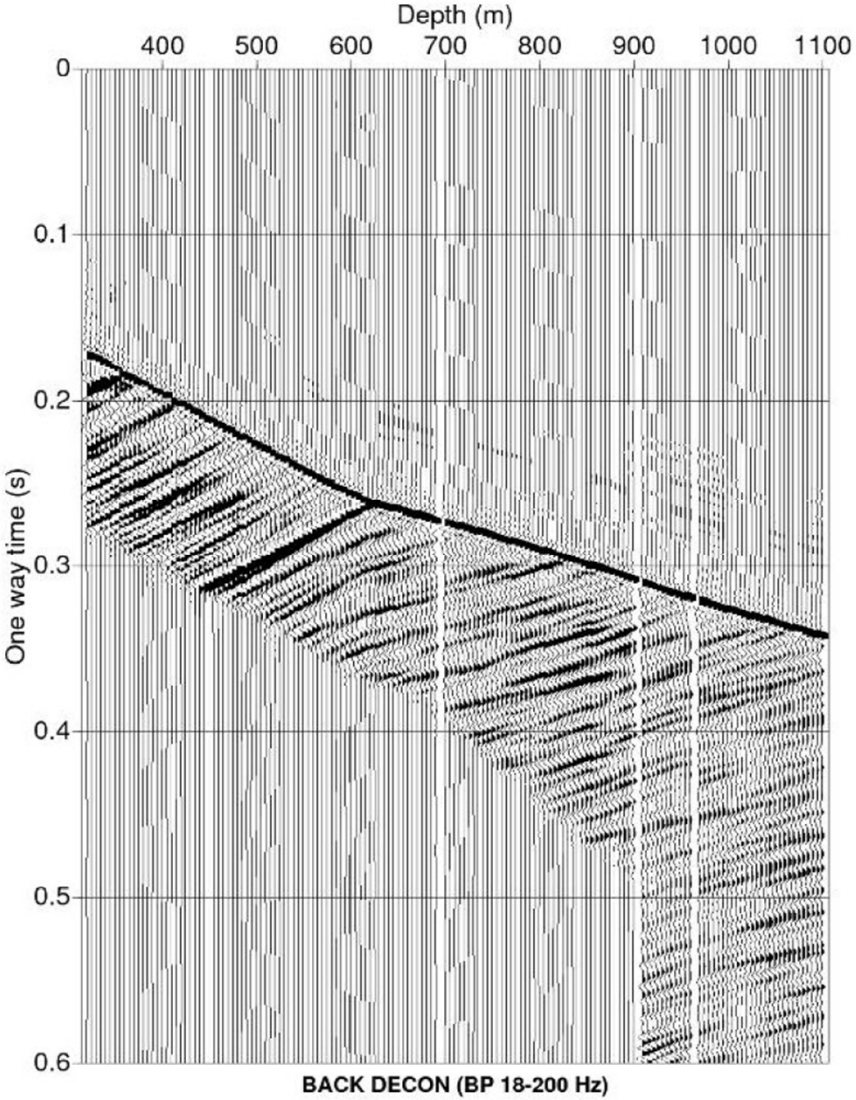
Well depth	1.1 km
Seismic source:	Hydrapulse
Borehole sensors:	3 C geophone (Avalon)
Surface reference sensors:	geophone (10 Hz)
Offset:	44 m, 266 m, 449 m, 939 m
Depth intervals:	5 m (near offset), 10 – 20 m (medium - far offsets)
Depth levels no.:	186, 91, 90, 51
Sampling rate:	0.5 ms
Data length:	4 s

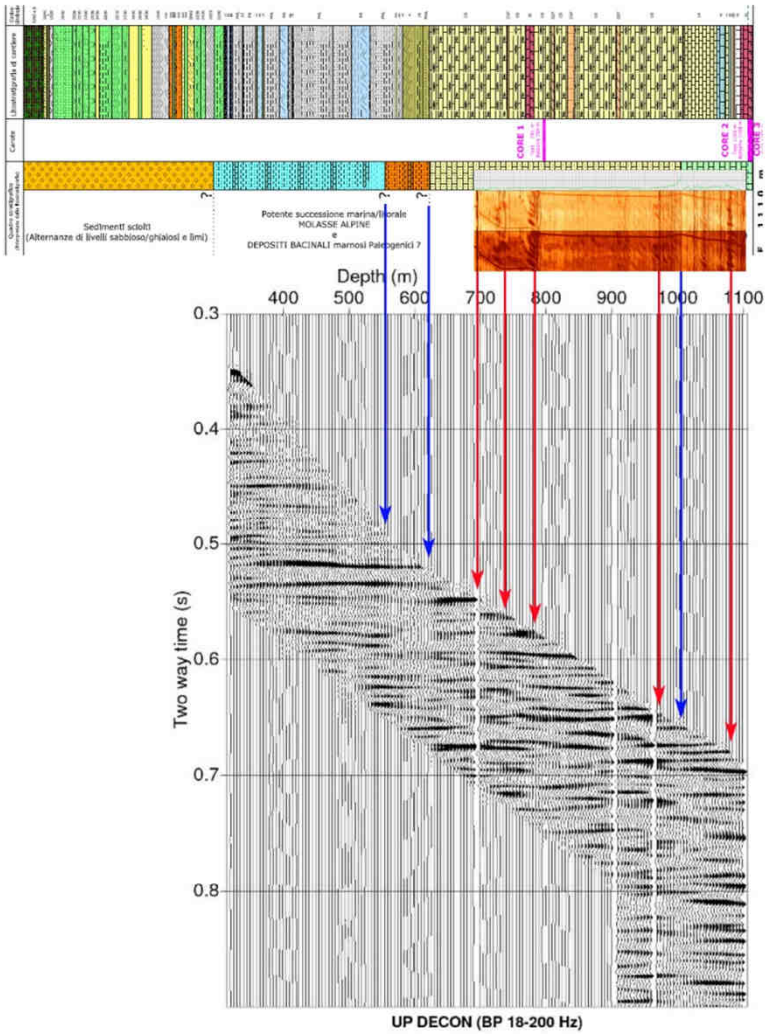
Borehole seismic acquisition map

Near Offset VSP interval velocities



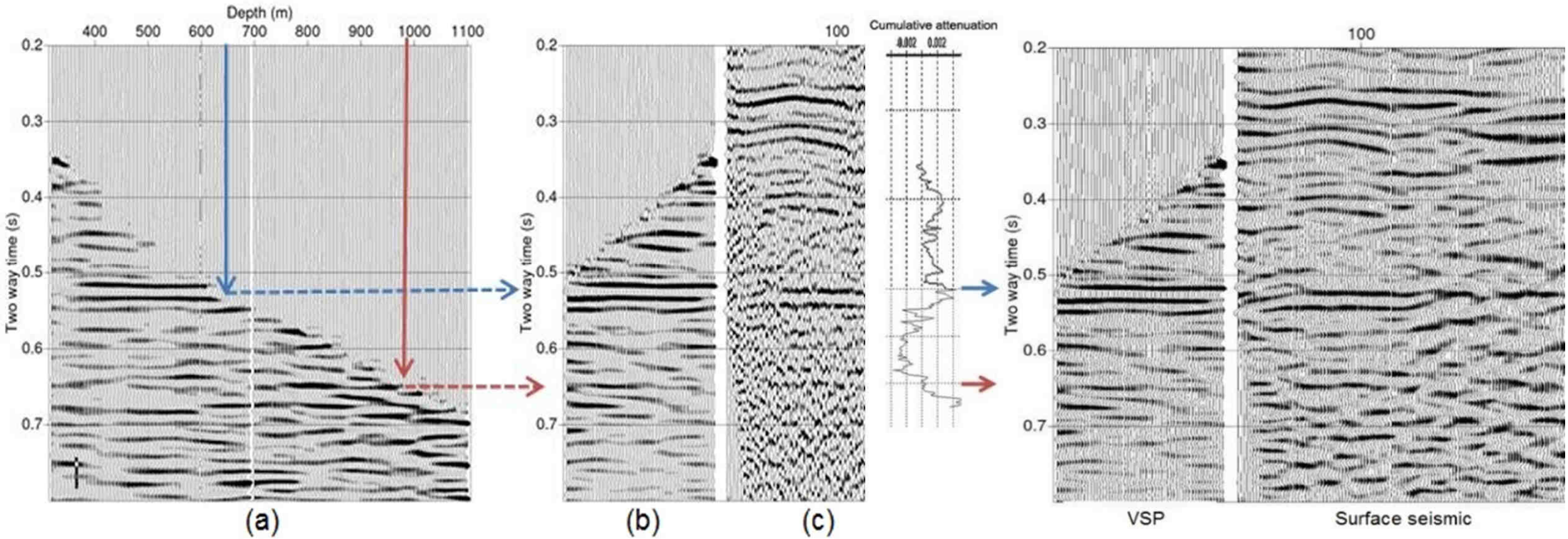
VSP reflectivity and well results



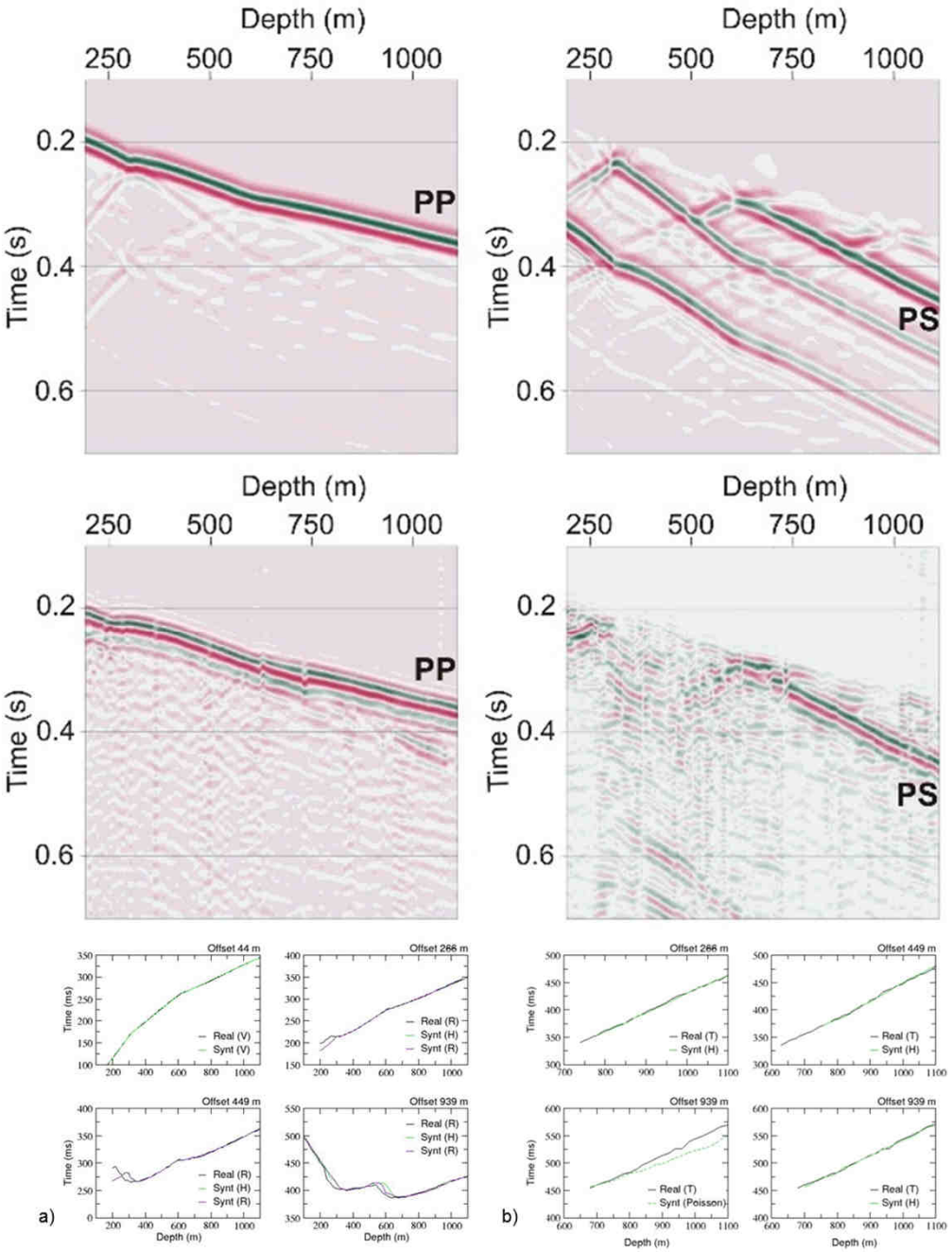


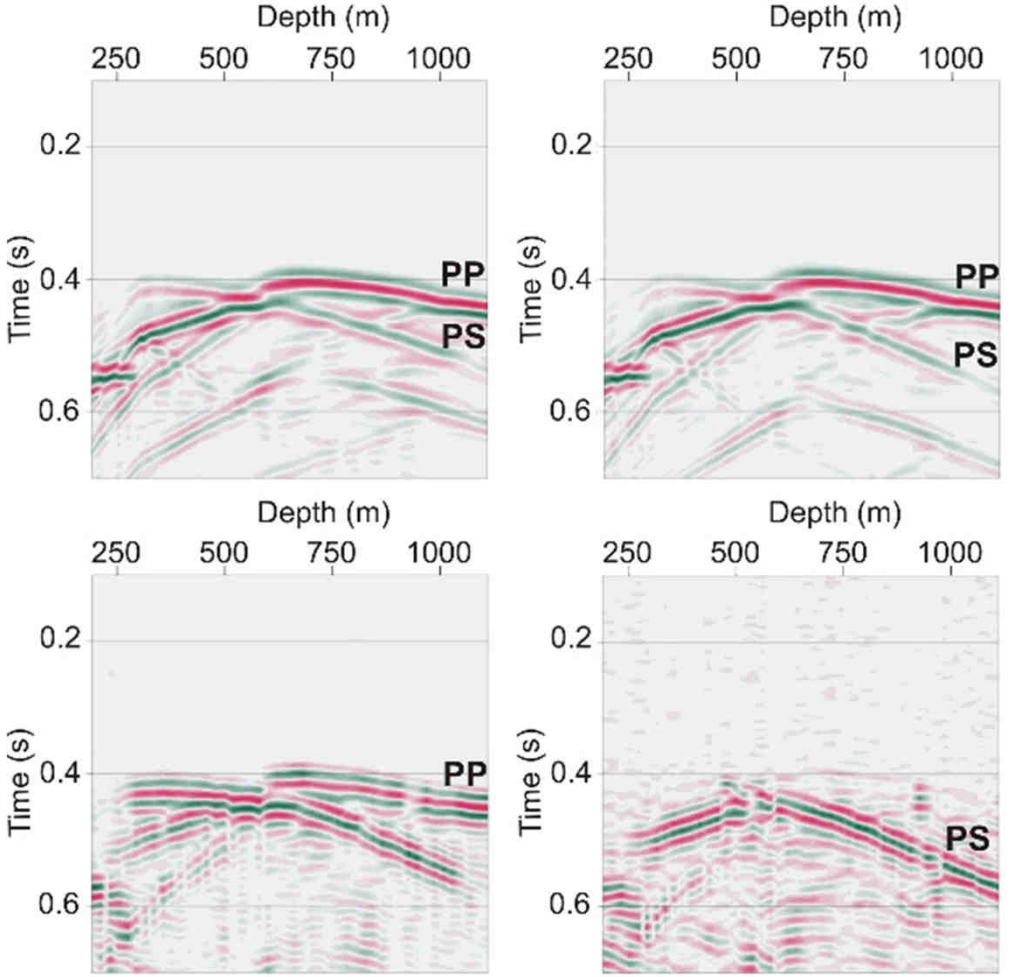
Reflection interpretation and rock Quality

c)

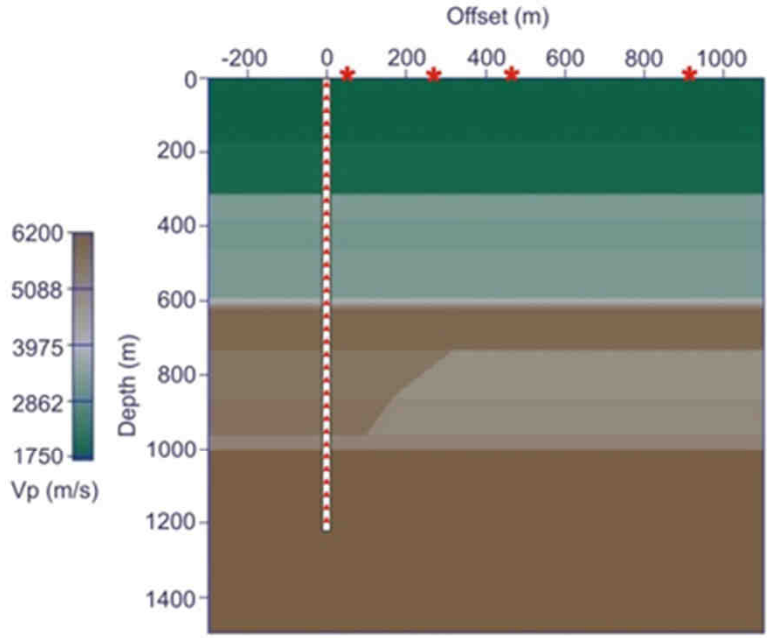


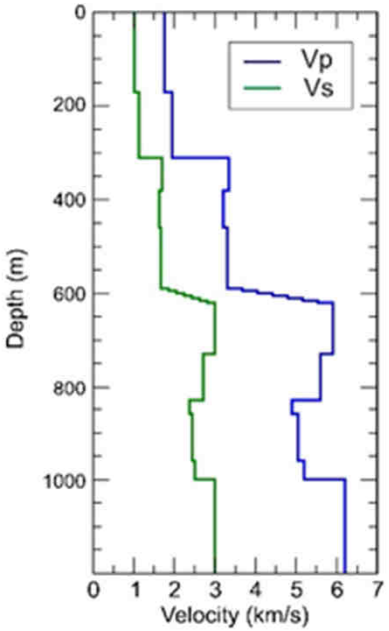
Direct and converted signals in offset VSPs

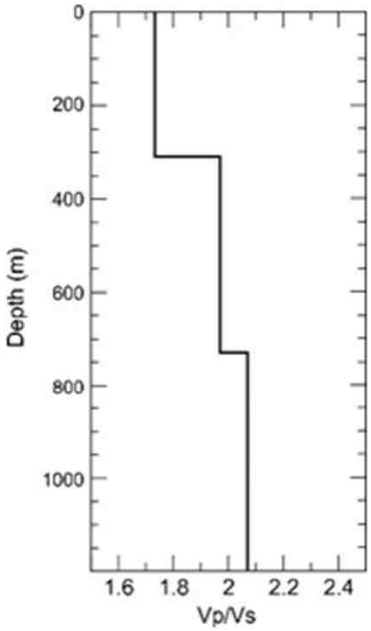


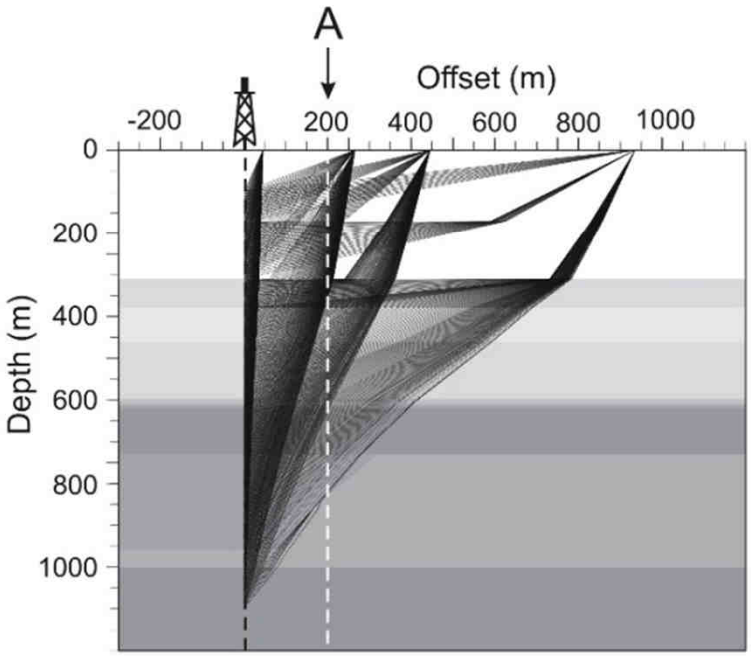


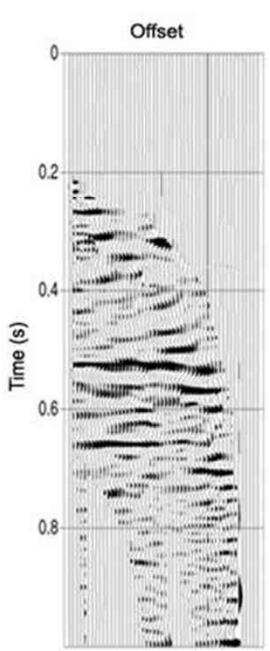
VSP lateral variation and Vp/Vs analysis

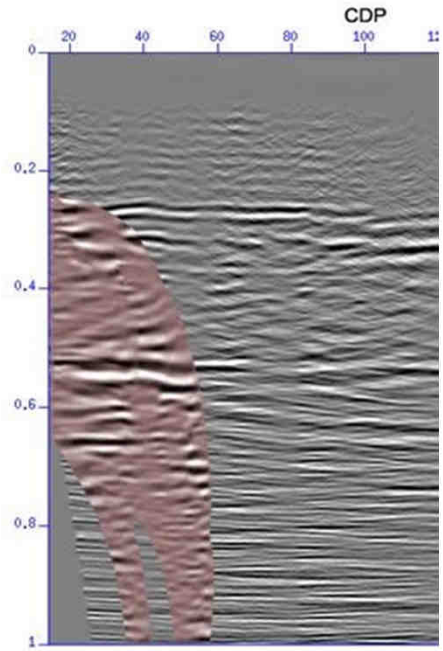










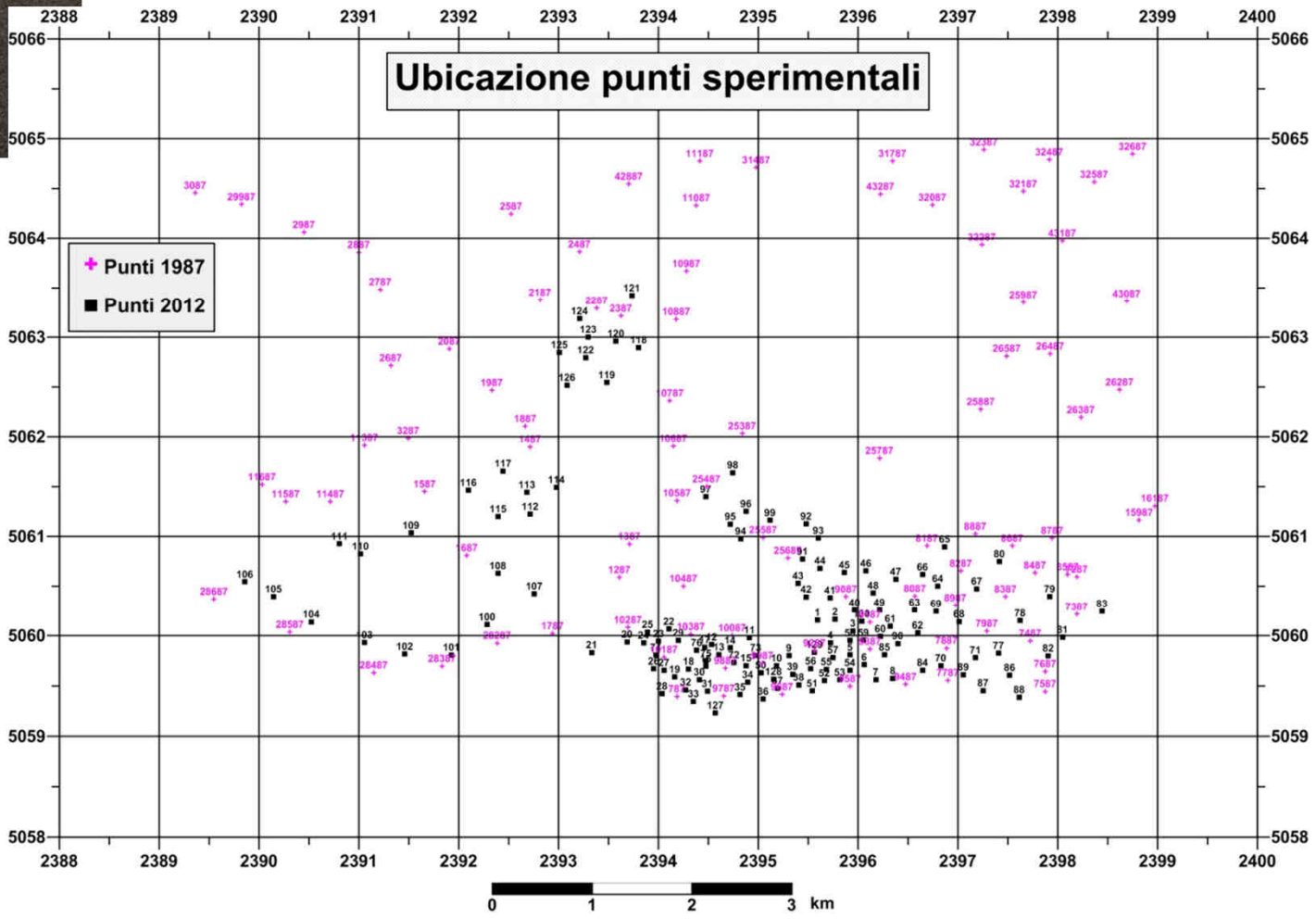


Gravity data acquisition

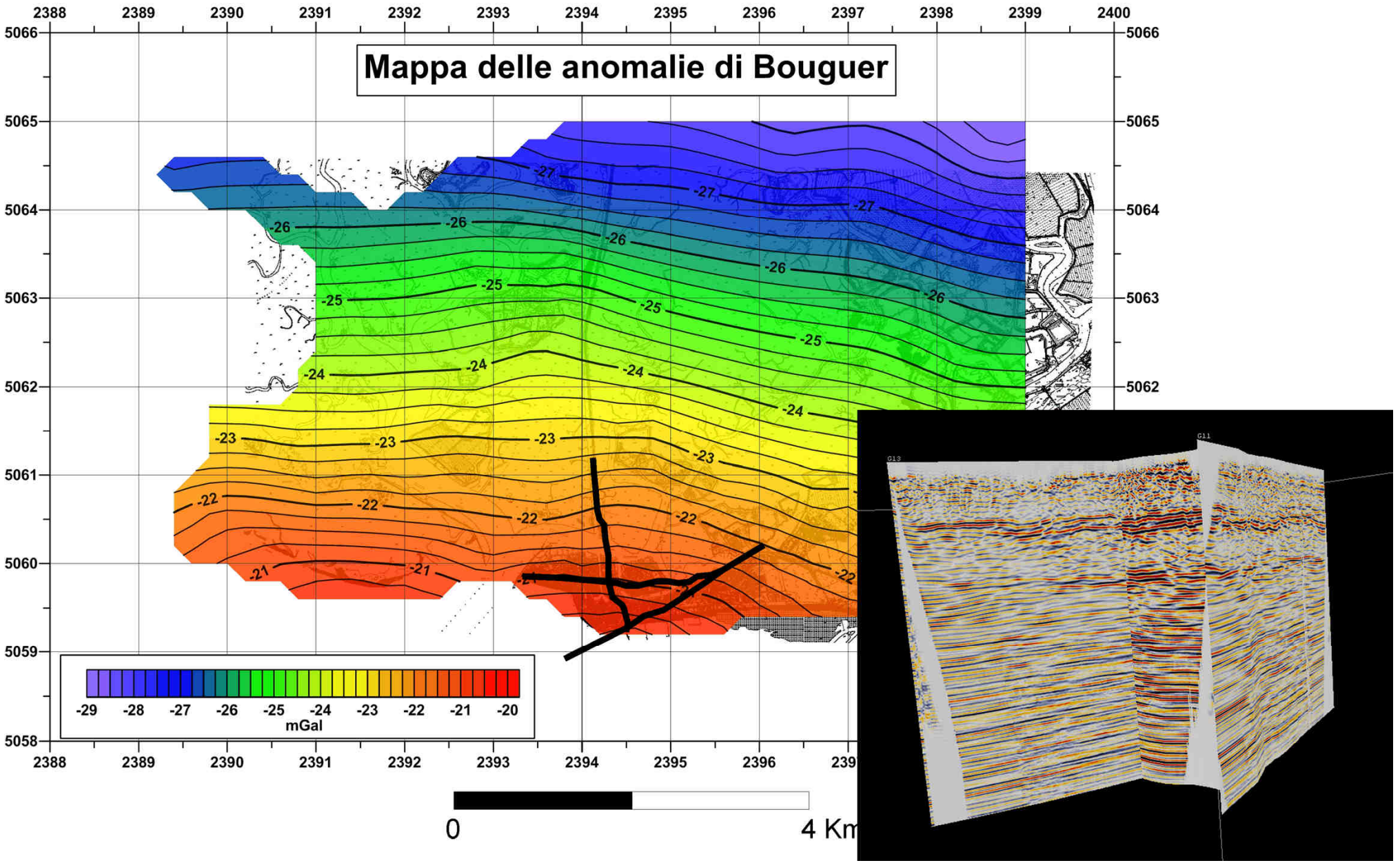
LaCoste & Romberg model D

229 new measurements

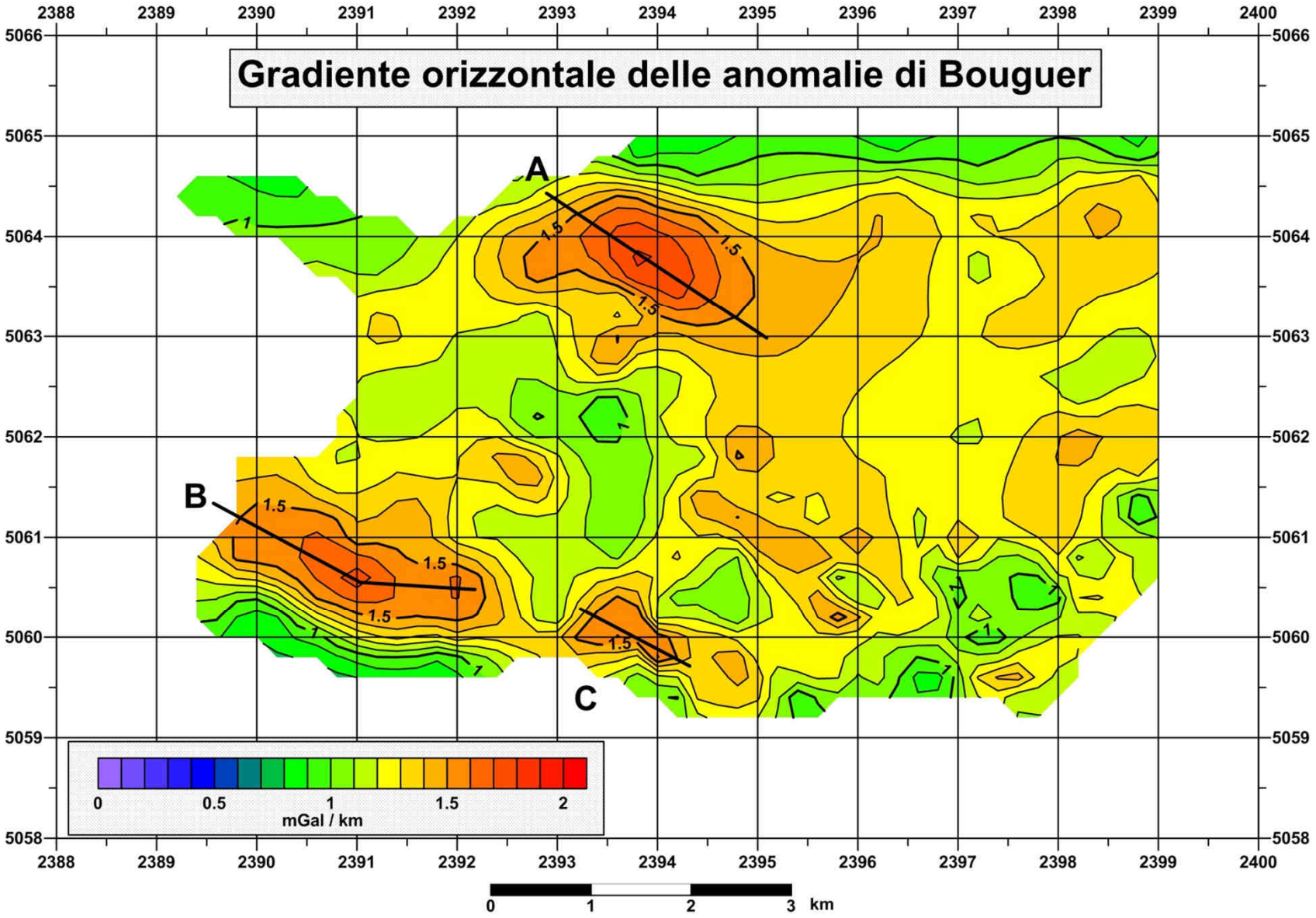
Integration with previous measurements (1987)



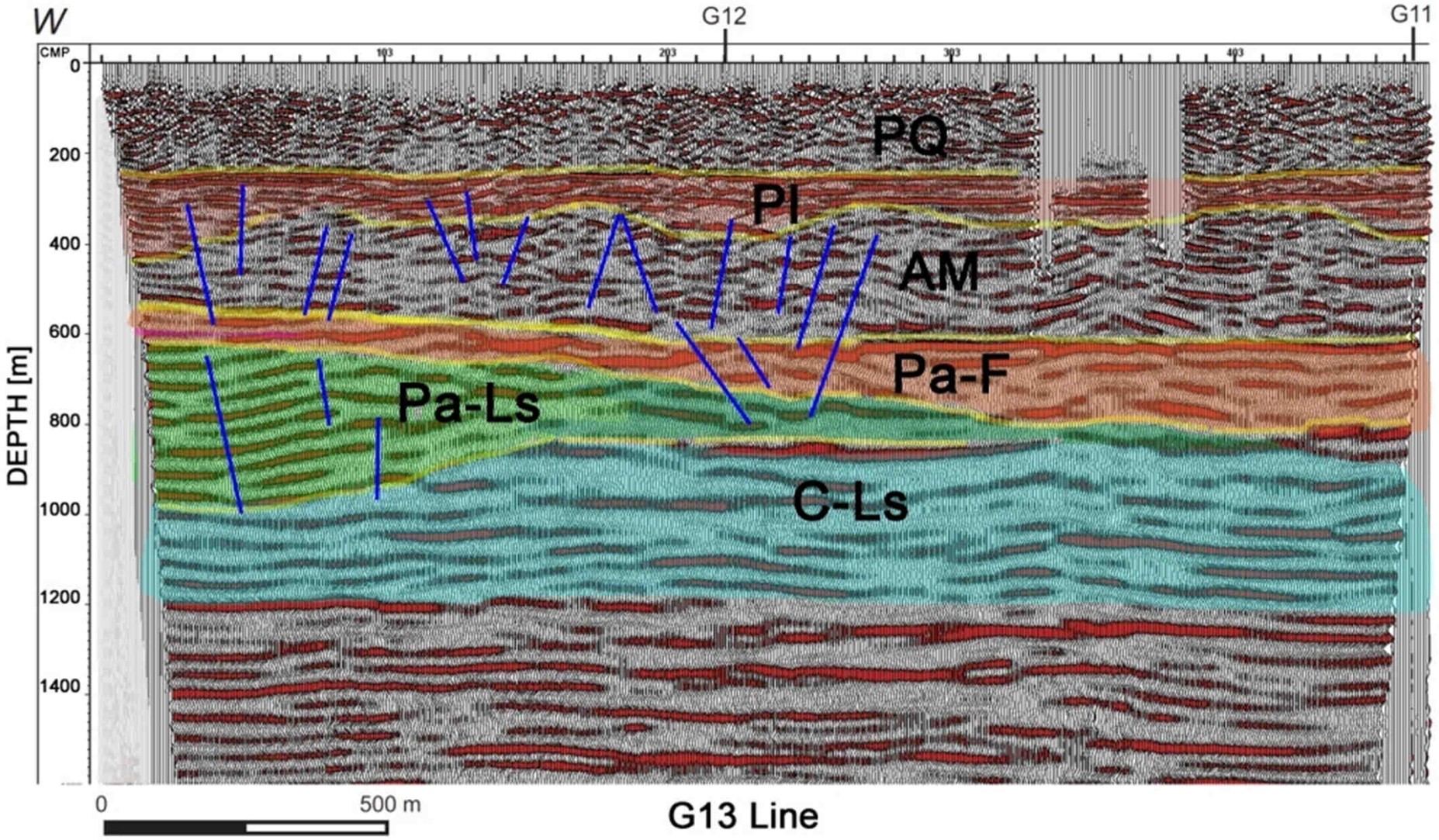
Gravity data map



Joint data interpretation



Joint data interpretation (before Grado 2)

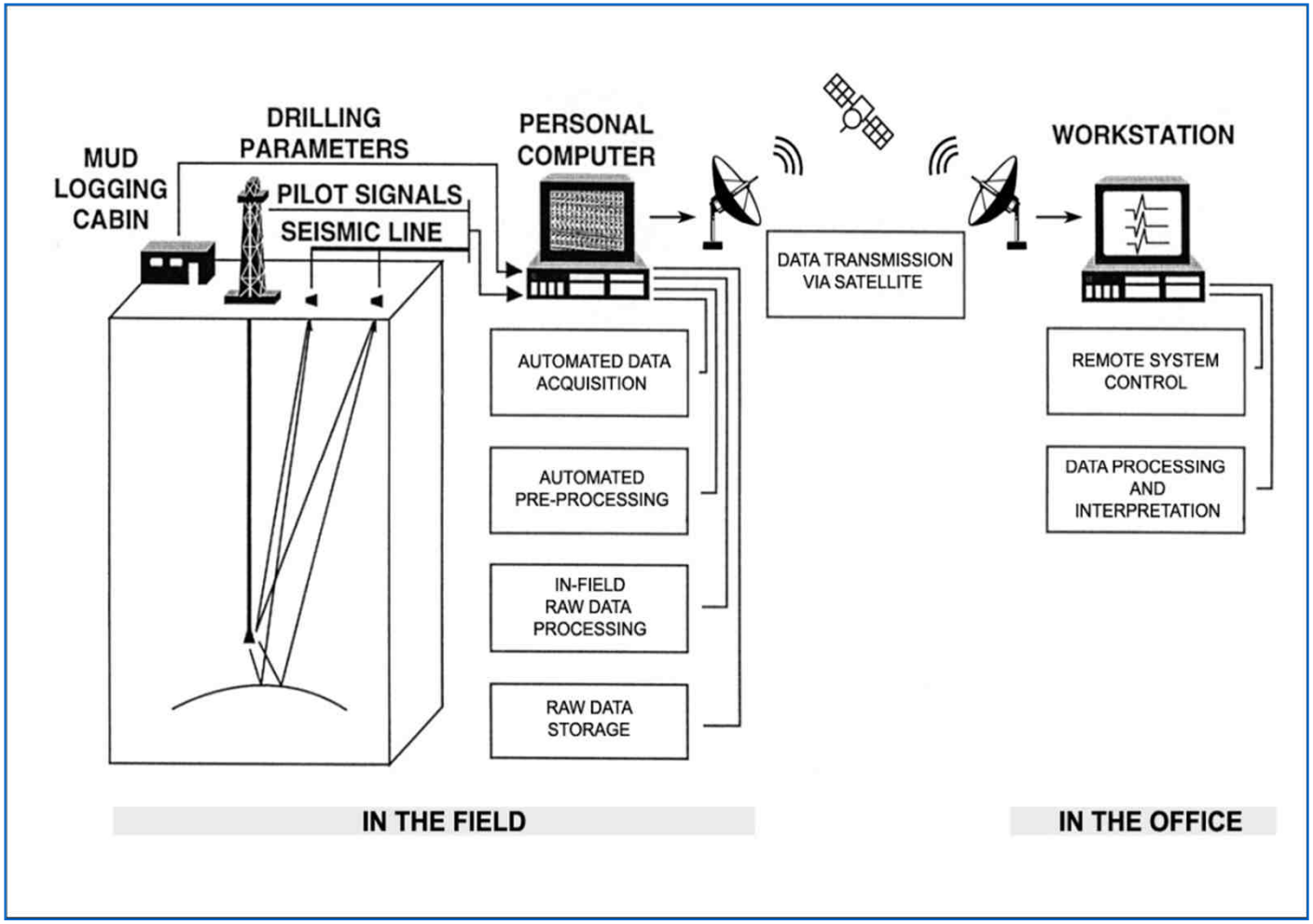


SWD geothermal applications

SWD for geothermal applications

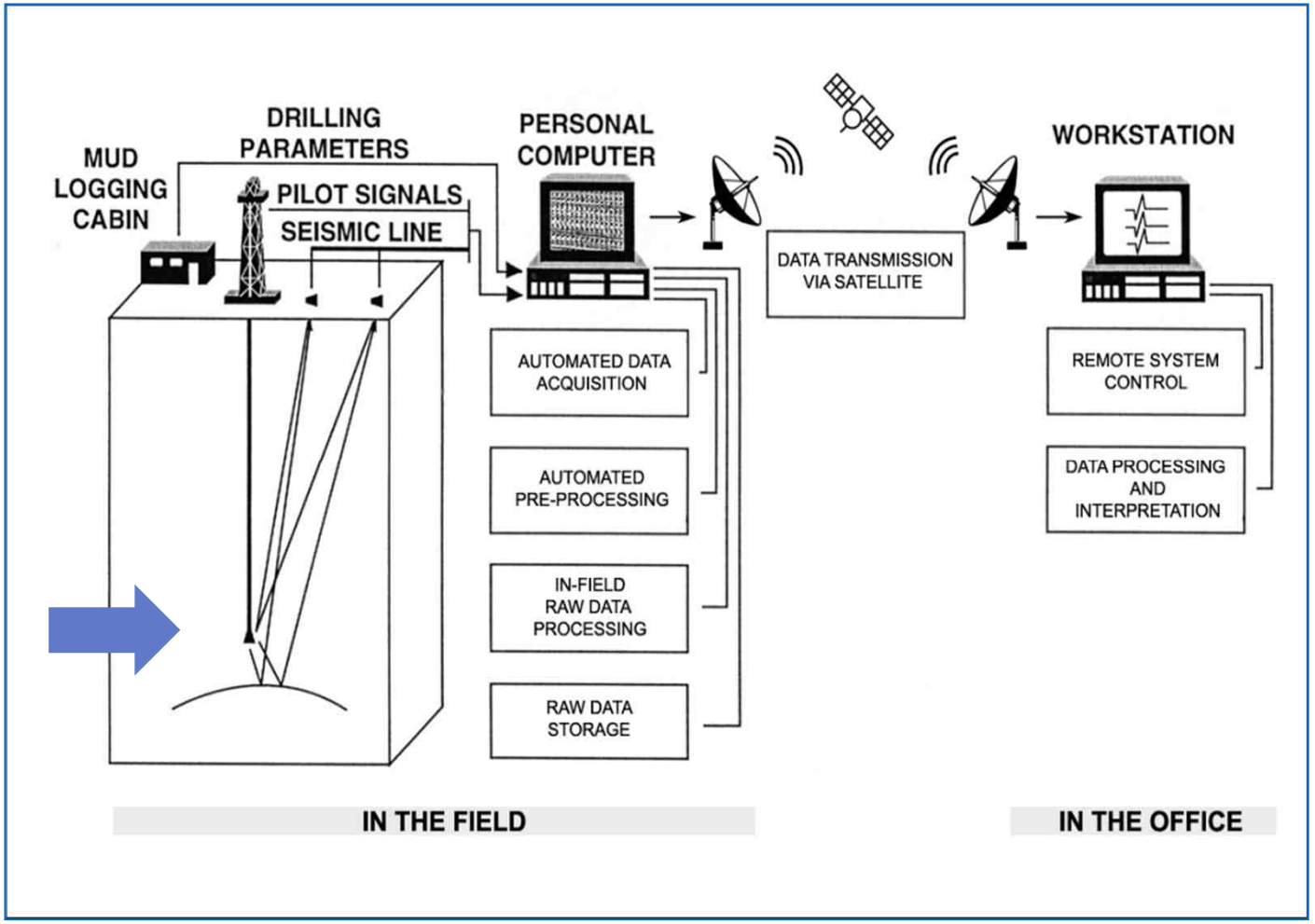
- Use of the working drill-bit as a seismic source
- Roller cone bits, vertical wells, hard rock drilling
- While drilling and additional seismic information
- Advantages in HT – HP wells (no tools in well)
- Integrated geophysical interpretation

SWD for geothermal applications



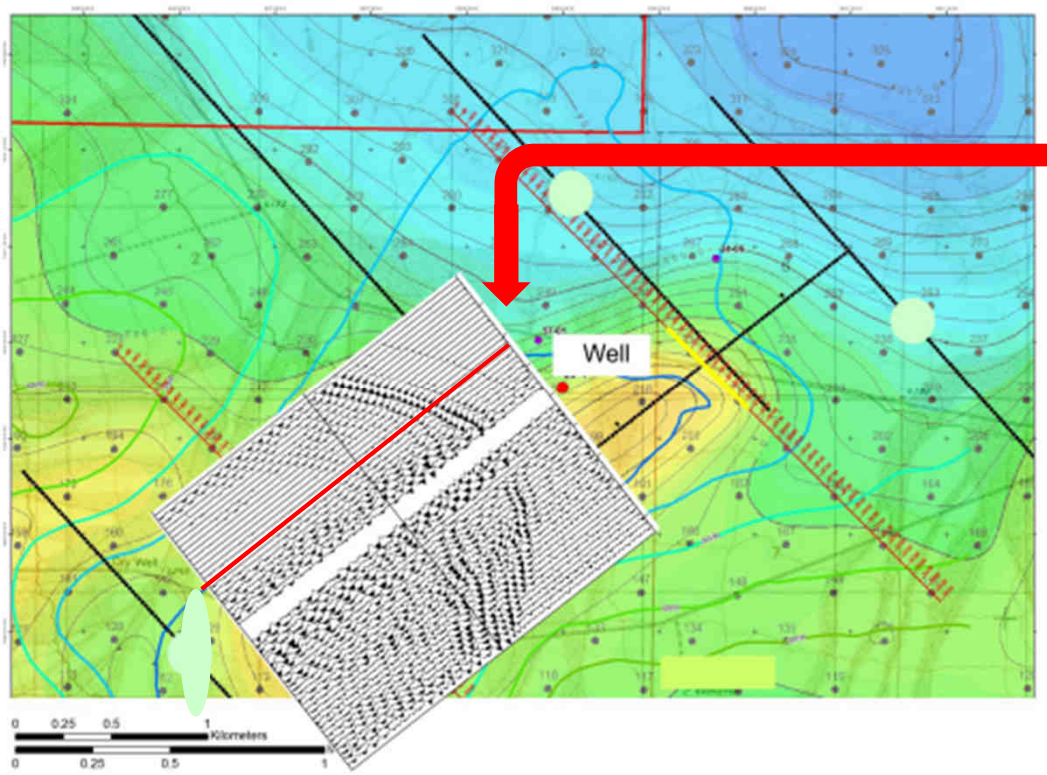
Use of the working drill bit as a seismic source

SWD for geothermal applications



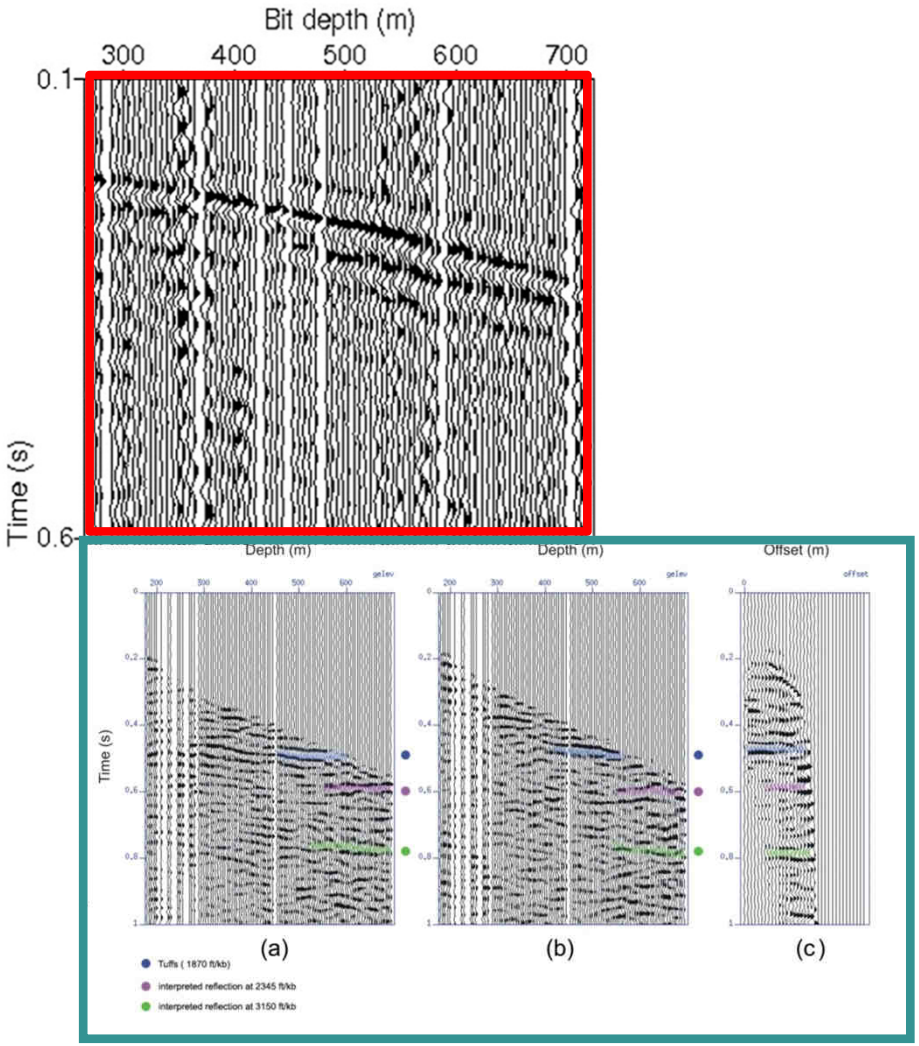
Use of the working drill bit as a seismic source

Medium enthalpy (Nevada US)



Common shot gather

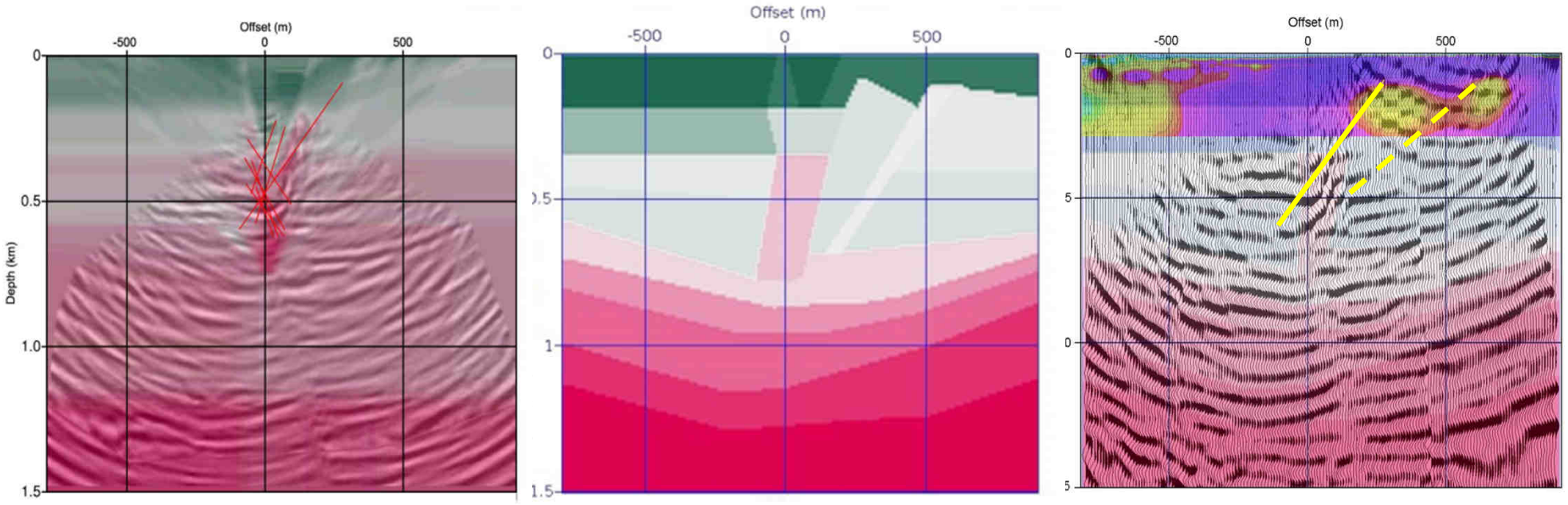
Common receiver gather



Prediction ahead of the bit: (a) and (b) single-offset VSP, and (c) multi-offset VSP

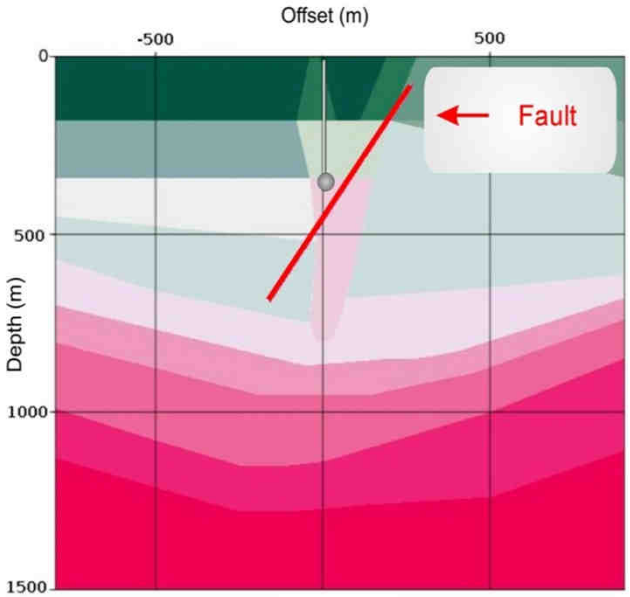
Seismic while drilling survey and gravity map

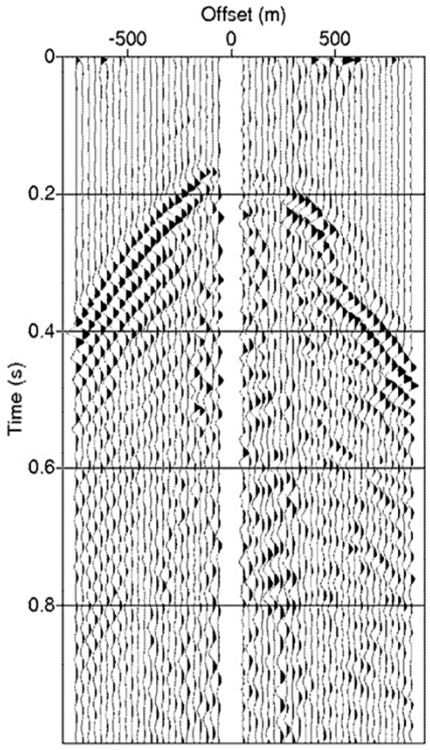
SWD imaging and well results



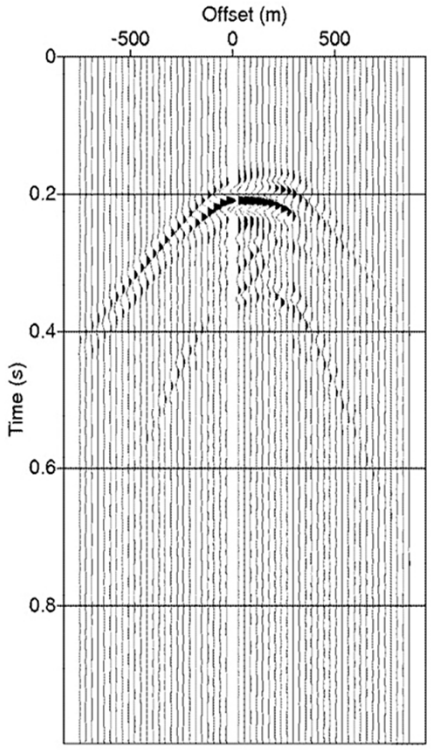
Imaging by seismic tomography and SWD data migration including seismic interferometry.
Comparison of seismic results, drilling CSAMT and fault system interpretation

Fault and SWD full waveform (FW) analysis





Real SWD seismic shot

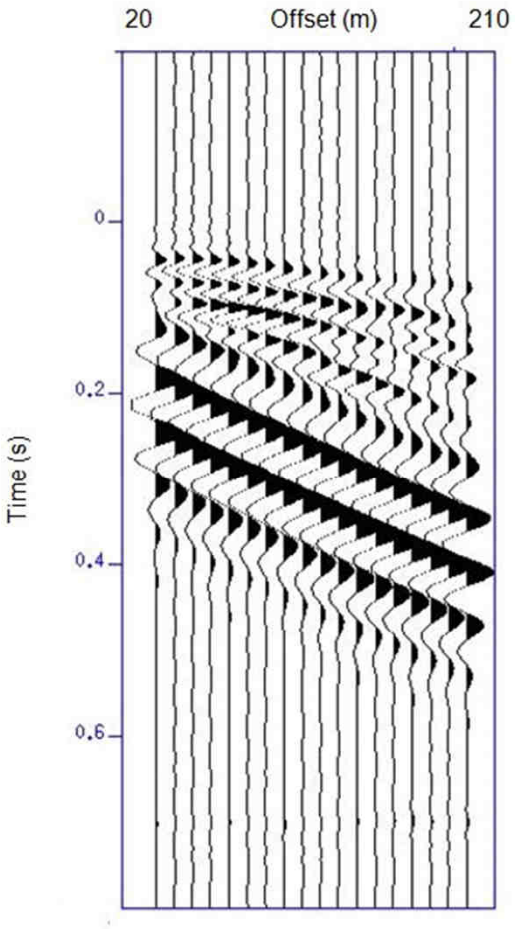


Fault response
(synthetic signal)

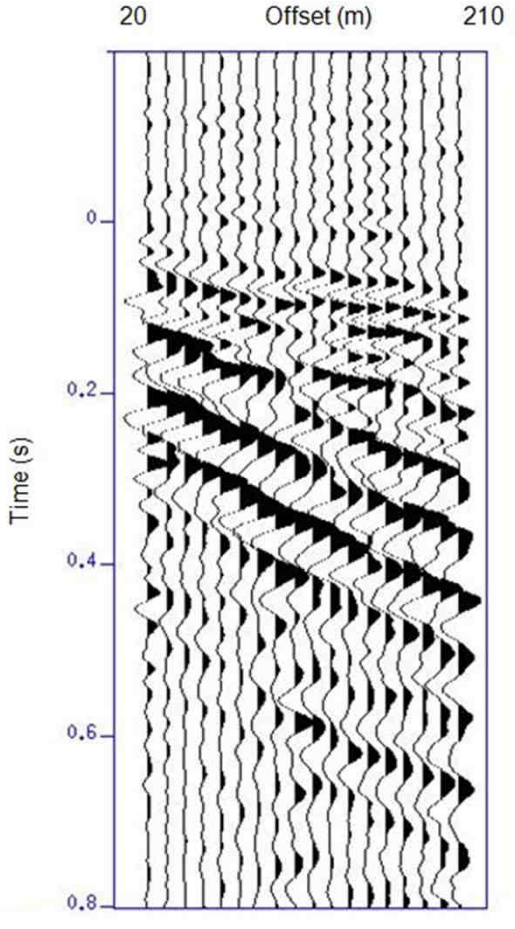
Recent SWD geothermal applications

DTH fluid hammer drilling as a SWD source at Bochum (GZB) drill test site

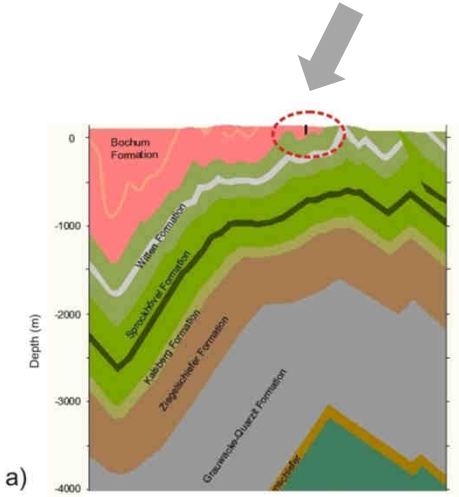
Recent SWD applications

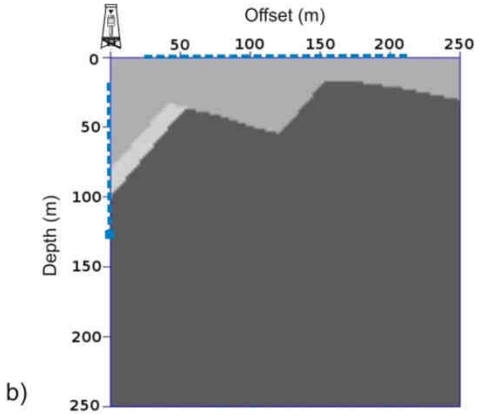


Synthetic SWD

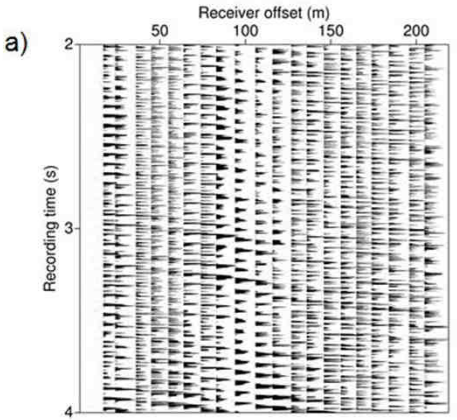


Real SWD

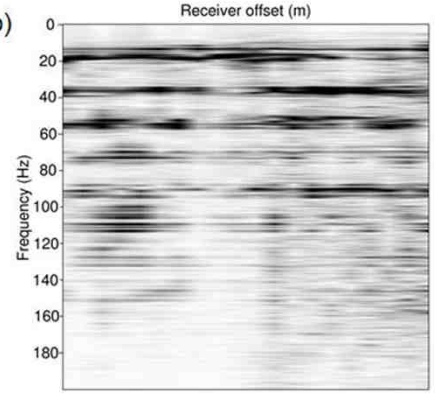




Shallow model



Raw SWD (time)



Raw SWD (freq)

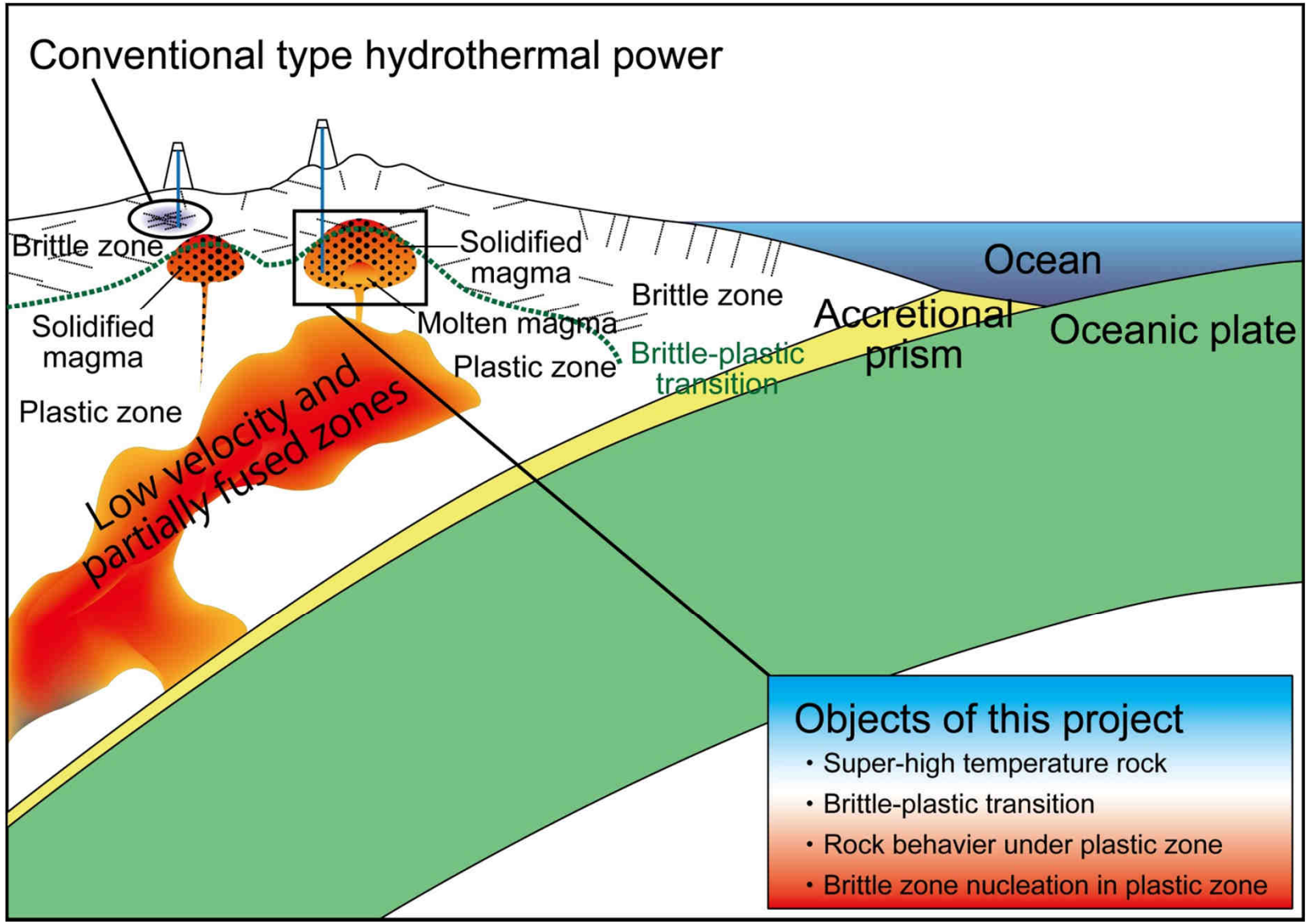
DTH fluid hammer drilling as a SWD source at Bochum (GZB) drill test site

SWD for high-enthalpy purposes

High enthalpy (Iceland)

- Borehole measurements at very high Temperatures (EGS, BDT, magmatic zones)
- "While drilling" characterization of HE geothermal reservoirs

Application in geothermal models



Thanks for your attention

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