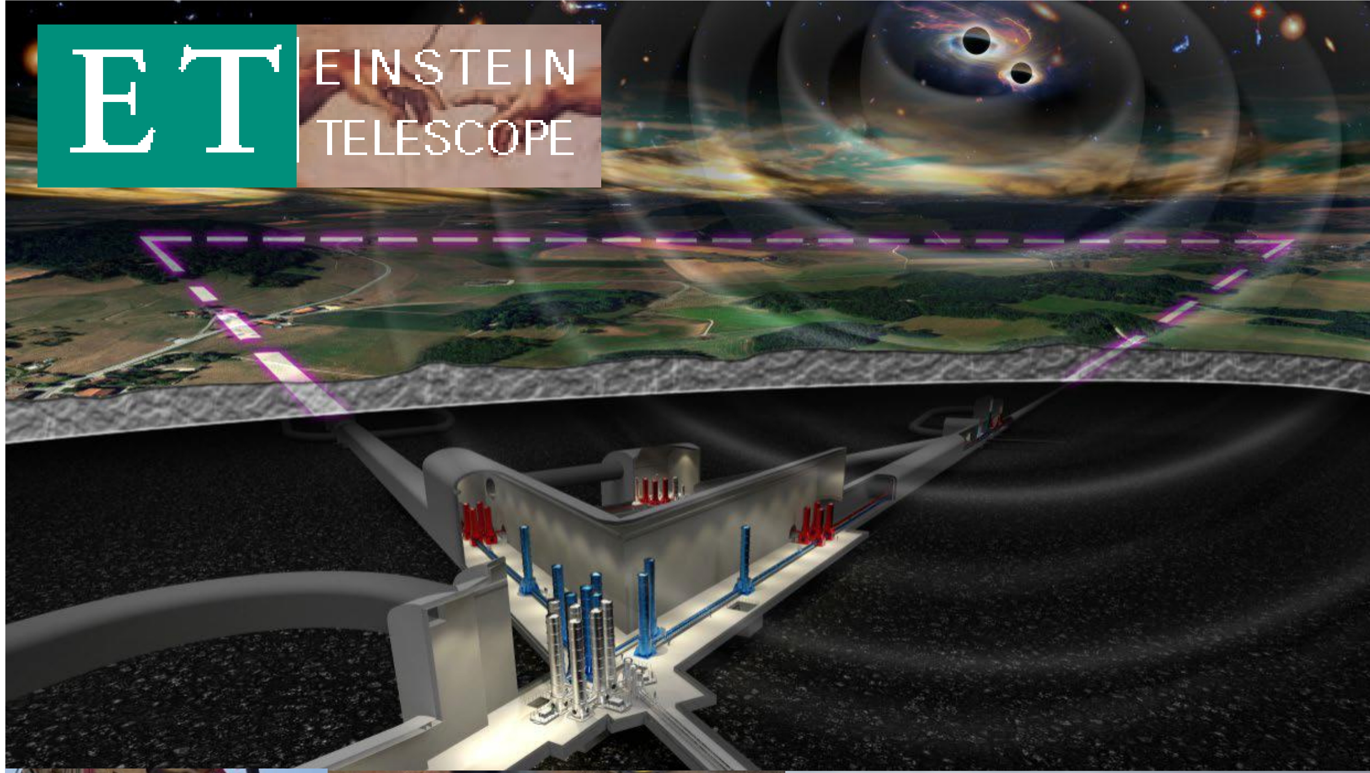
ET – 3rd SPB Workshop – Amsterdam, Dec. 6-7, 2023

Boreholes at the ET corners in Sardinia

Luca Naticchioni (INFN Roma)

On behalf of the Sardinia site characterization team

ET-0493A-23



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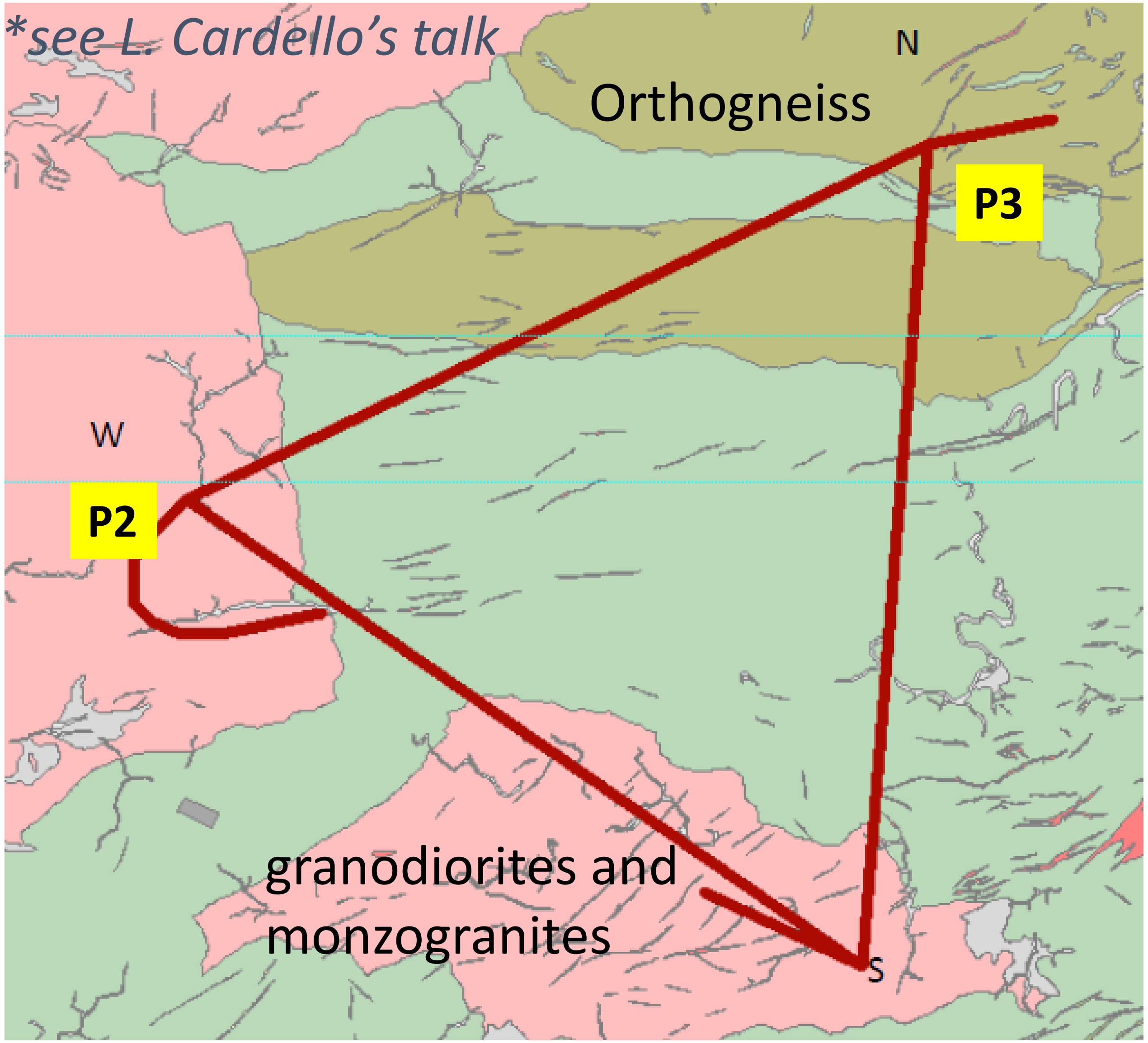
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Outline

Summary:

- ❑ **P2 and P3 sites**
- ❑ Experimental setup
- ❑ Borehole preparation
- ❑ Geophysical logs
- ❑ Seismometers installation
- ❑ Costs & practical aspects

P2 and P3 sites

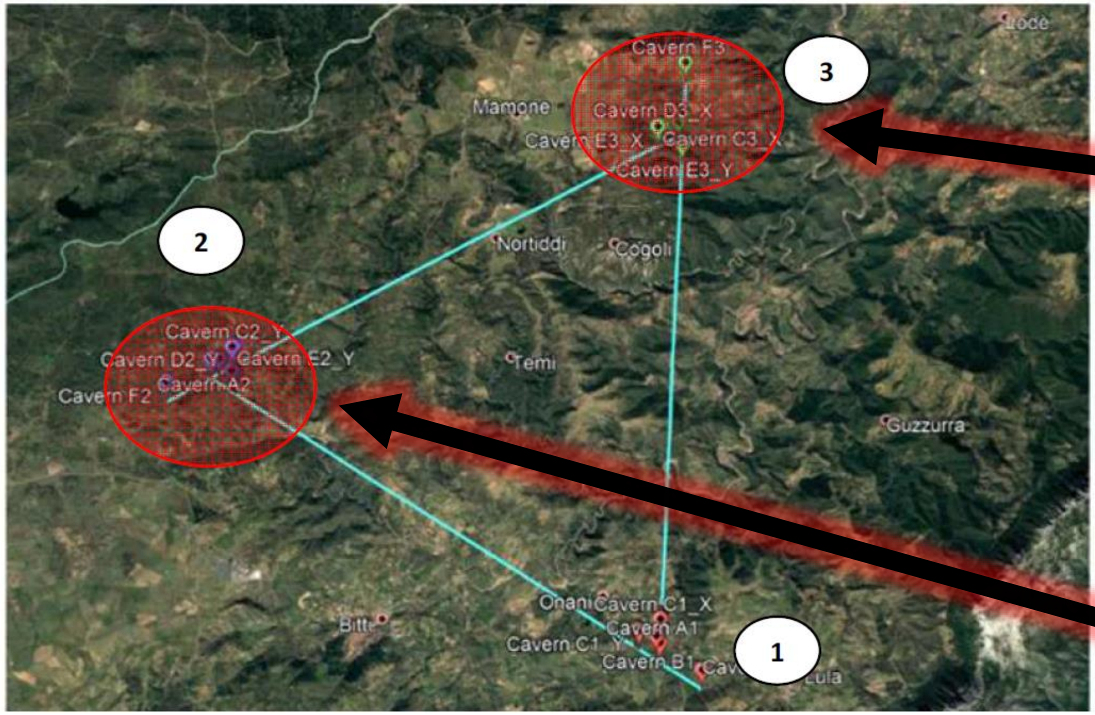


ET Δ layout (10km):

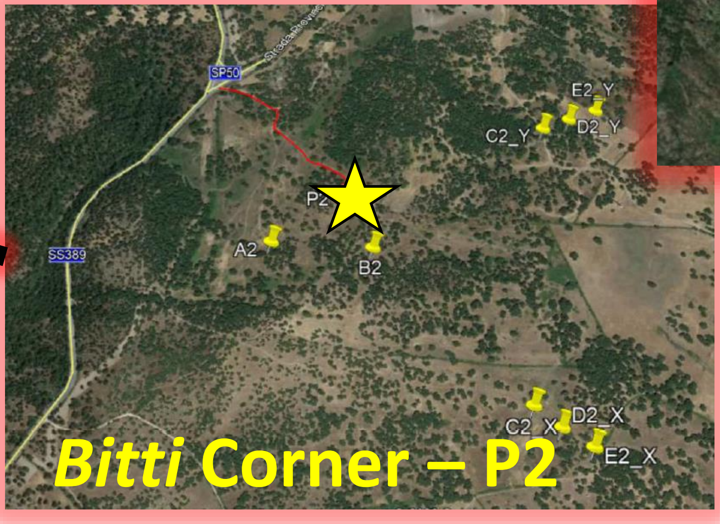
- One corner is close to the Sos Enattos area (Lula)
- The other two corners are located in rocks with good geomechanical properties (granites and orthogneiss)
- Two boreholes have been excavated at these two corners (P2, P3, *see C. Rossini's talk in this session*)

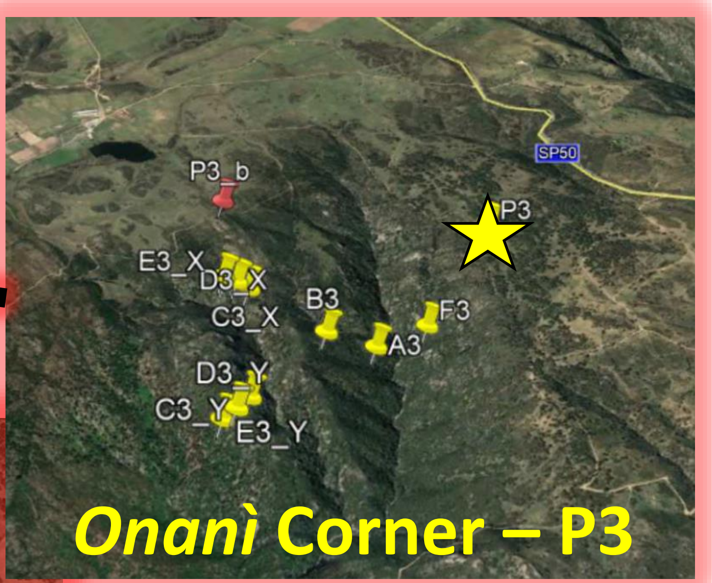
P2 and P3 sites

In July 2021 we started the surface and underground seismic, geophisical and environmental measurements at the other two corners (named after the local municipalities of *Bitti* and *Onanì*).



P1 - *Lula* Corner – *Sos Enattos*



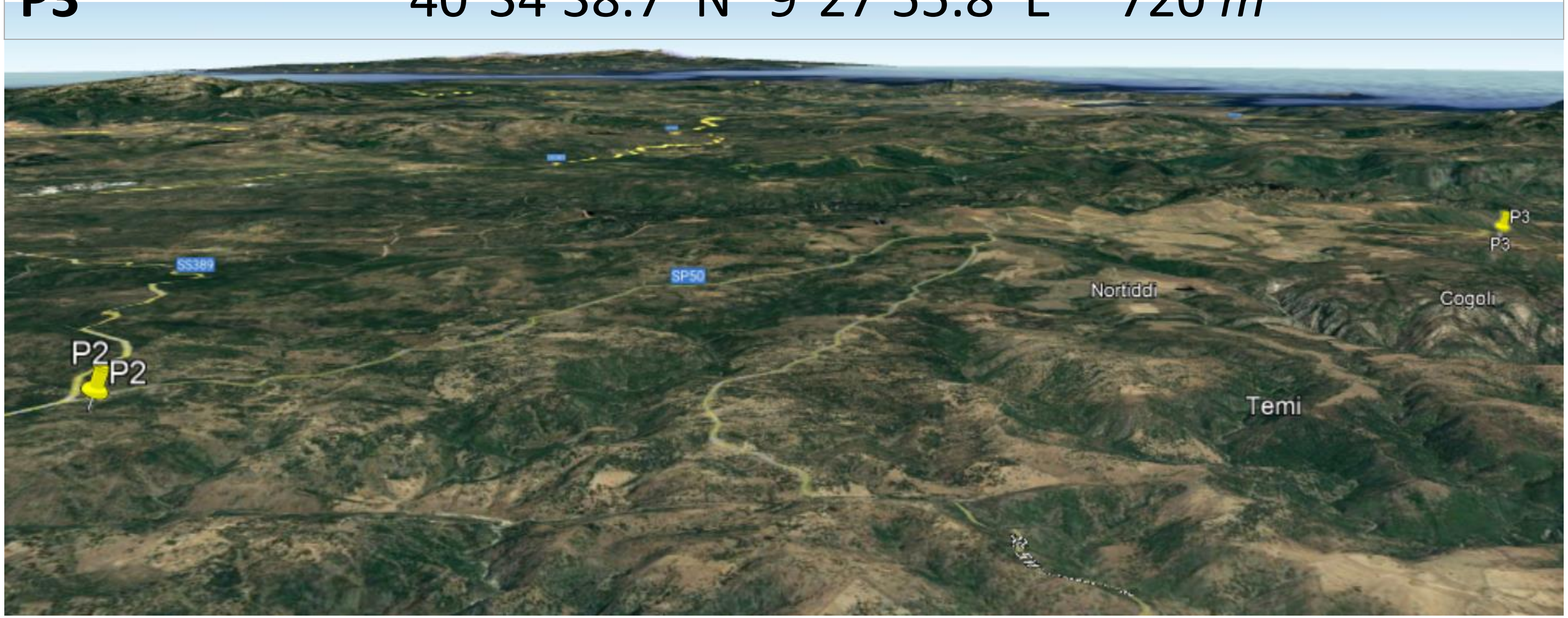


★ : Borehole area

: proposed locations for ET ∆ main caverns

P2 and P3 sites

SITE	COORDINATES		ALTITUDE AMSL
P2	40°31’24’’N	9°20’55.7’’E	767 *m*
P3	40°34’38.7’’N	9°27’55.8’’E	720 *m*



P2 and P3 sites

Bitti corner, borehole area *before excavation*

Onanì corner, borehole area *before excavation*

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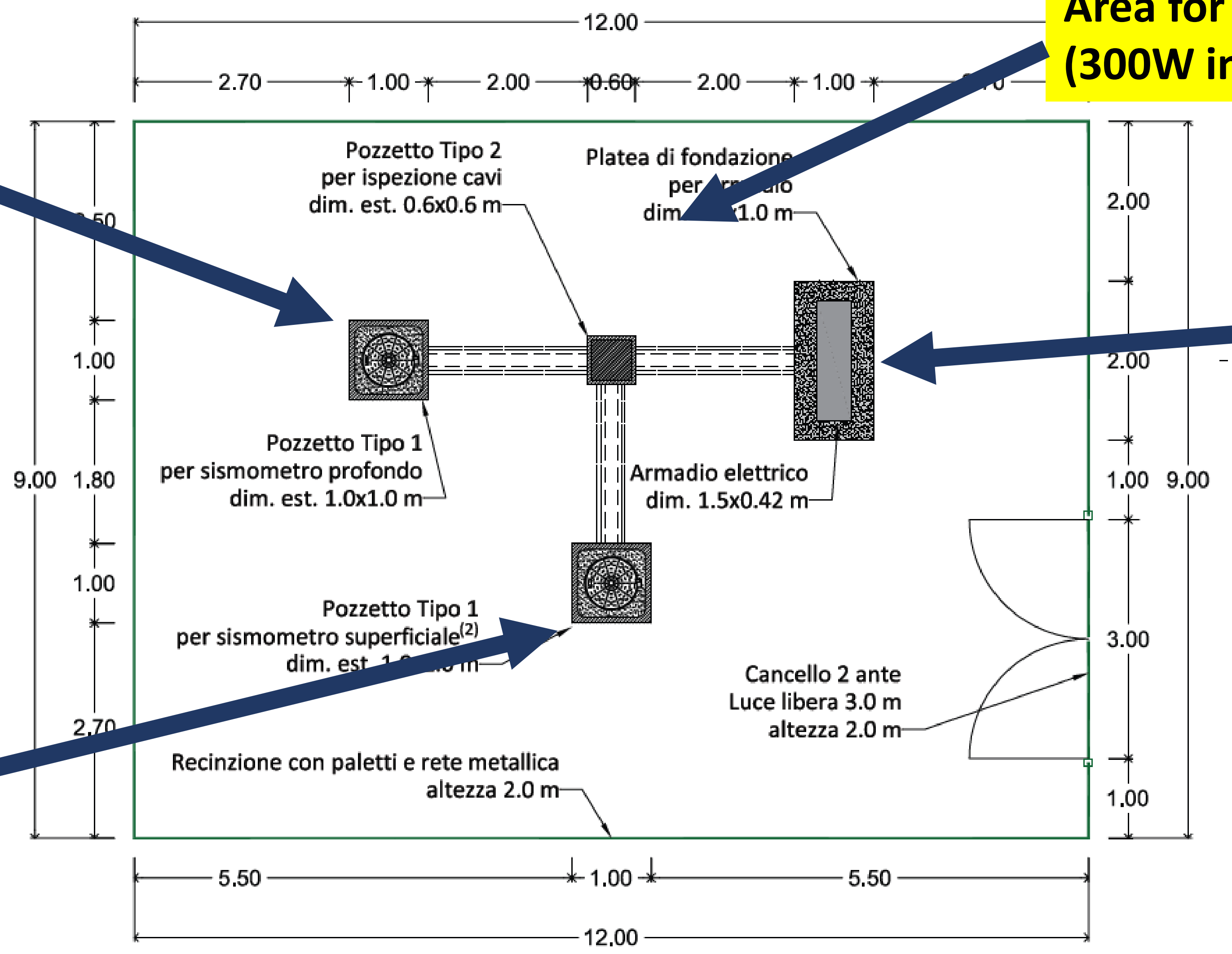
Experimental setup

General plan of the borehole area

Borehole access (inside a manhole):
- Borehole broadband triaxial seismometer (Nanometrics Trillium 120 BH Slim)

Vault access (inside a manhole):
- Broadband triaxial seismometer (Nanometrics Trillium 120 Horizon)



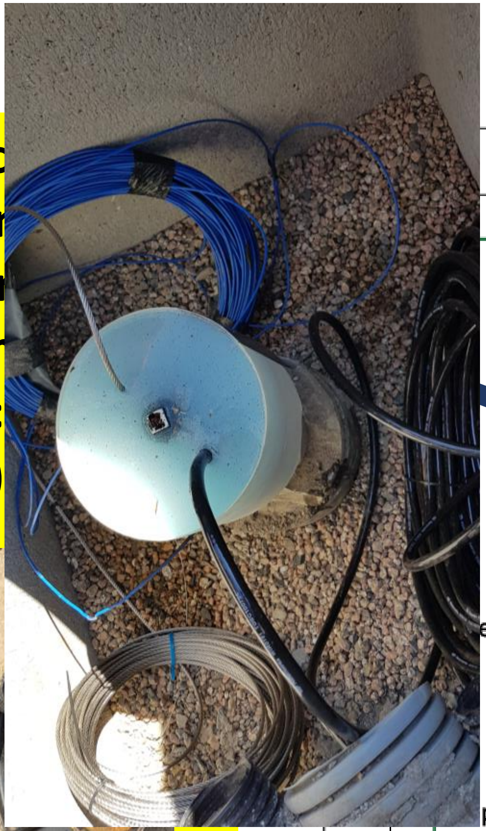
Area for Solar Panels (300W installed)

Electrical Cabinet:
- **DAQ (Nanometrics Centaur 6ch. 24bit)**
- **12V Battery pack**
- **UMTS modem, GPS receiver, solar charge controller**
- **DAQ for magnetometers**
- **Opt. Fiber strainmeter connection**

Experimental setup

General plan of the borehole area

Borehole acc
(inside a ma
- Borehole b
triaxial seism
(Nanometric
120 BH Slim)



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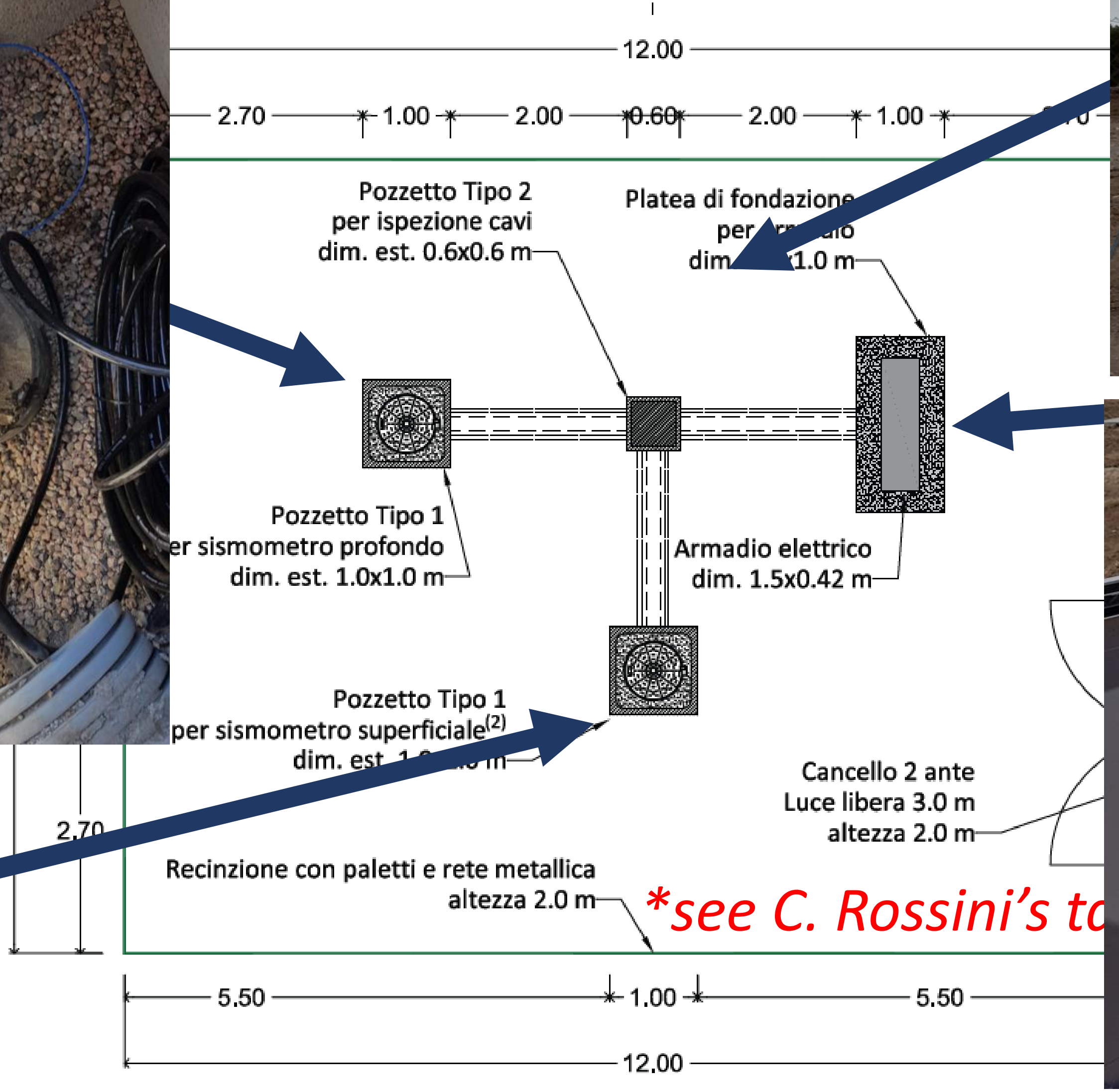

**see C. Rossini's ta*

net:
metrics
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12V Battery pack
s

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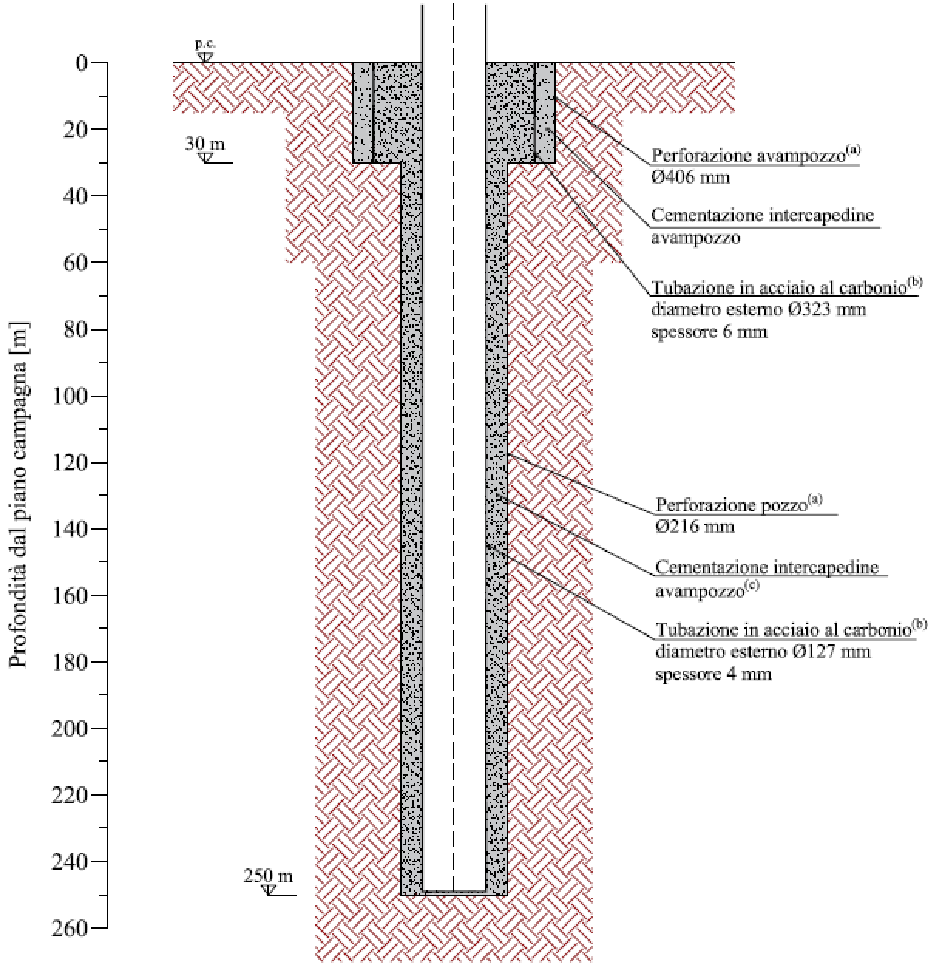
Borehole preparation

- Excavation of two boreholes at the corner points P2 (-270m) and P3 (-260m). The drilling and consolidation of the boreholes has been started in April 2021 and completed in July 2021.

- A steel pipe was inserted into the borehole and cemented to the surrounding rocks. An optical fiber strainmeter was fixed inside the concrete (*see A. Rietbrock's talk*).

- Final inner diameter: 119mm.

- Pressure test passed in both cases.



Borehole preparation

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Geophysical logs

PROS

✓ **continuous logging of geophysical parameters** and comparison with litostratigraphic information;

✓ **reliability and repeatability** because are based on standard probes and automated processes;

✓ **continuous coring is not required** and destructive perforation for less **time consuming and cost-effective** field activities;

CONS

✓ **don't substitute totally continuous coring** that can be necessary in unexplorated areas based on the aim of the field surveys;

✓ **not unique response** and require litostratigraphic characterization of the soil cutting;

✓ **limited volume of rock investigated**;

From GEOexplorer reports RT Bitti and RT Onanì*: S. Bernardinetti, S. Berti, T. Colonna, P. Conti, E. Guastaldi, N. Lopane*

GEOexplorer

Geophysical logs

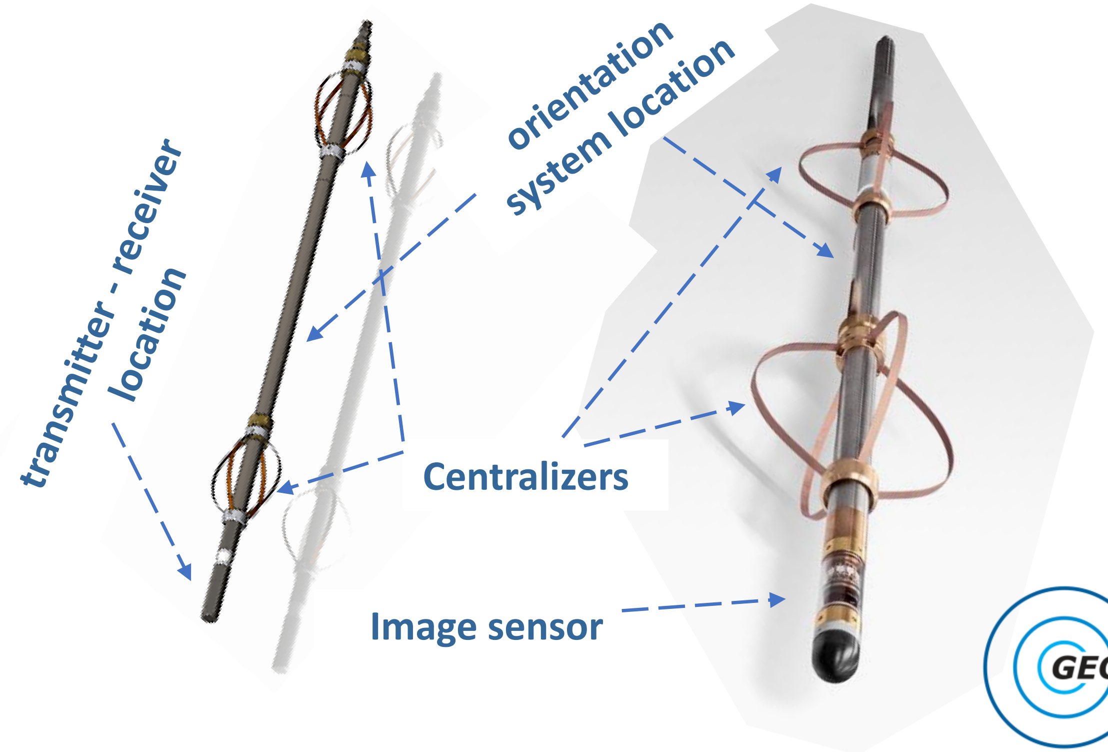
Logs were made right after the drilling and before the consolidation of the borehole with the steel pipes.

Probes:

QL40 Caliper

QL40 Gamma and FTC stacked

QL40 ABI 2G (acoustic) **QL40 OBI 2G (image)**

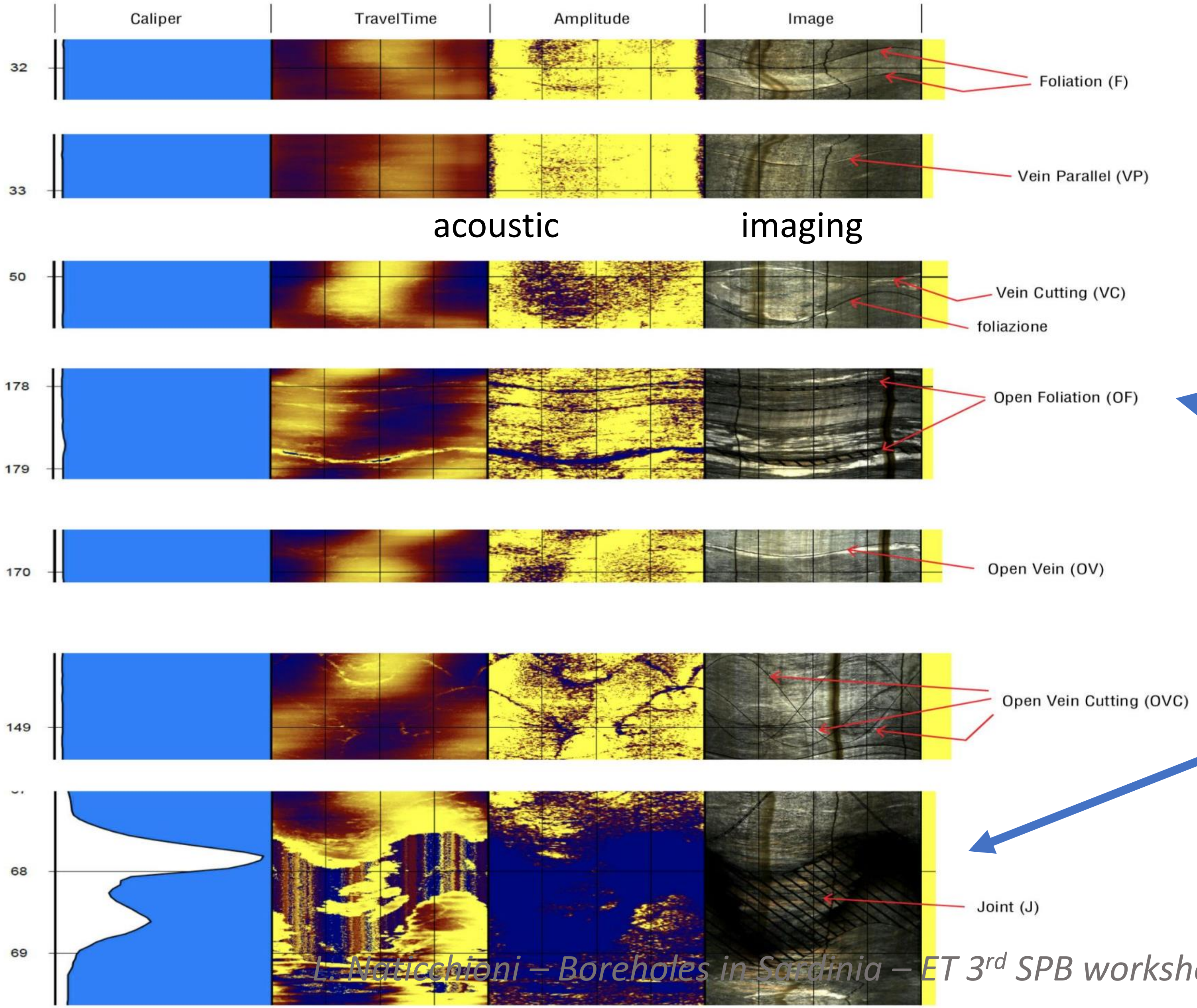


Geophysical logs

Geophysical Logs	
Temperature & Conductivity	Incoming water flow; Geothermal gradient
Self-potential	Lithological local variation; Incoming water flow with different salinity
Natural Gamma Ray	Clay content variation
Normal Resistivity	Lithology and water content variation
Caliper	Well diameter; Discontinuities mapping

Structural Logs	
Acoustic	Discontinuities in water: orientation, spacing, frequency, aperture
Optical	RGB image of the well; Discontinuities in dry or clean water: orientation, spacing, frequency, aperture

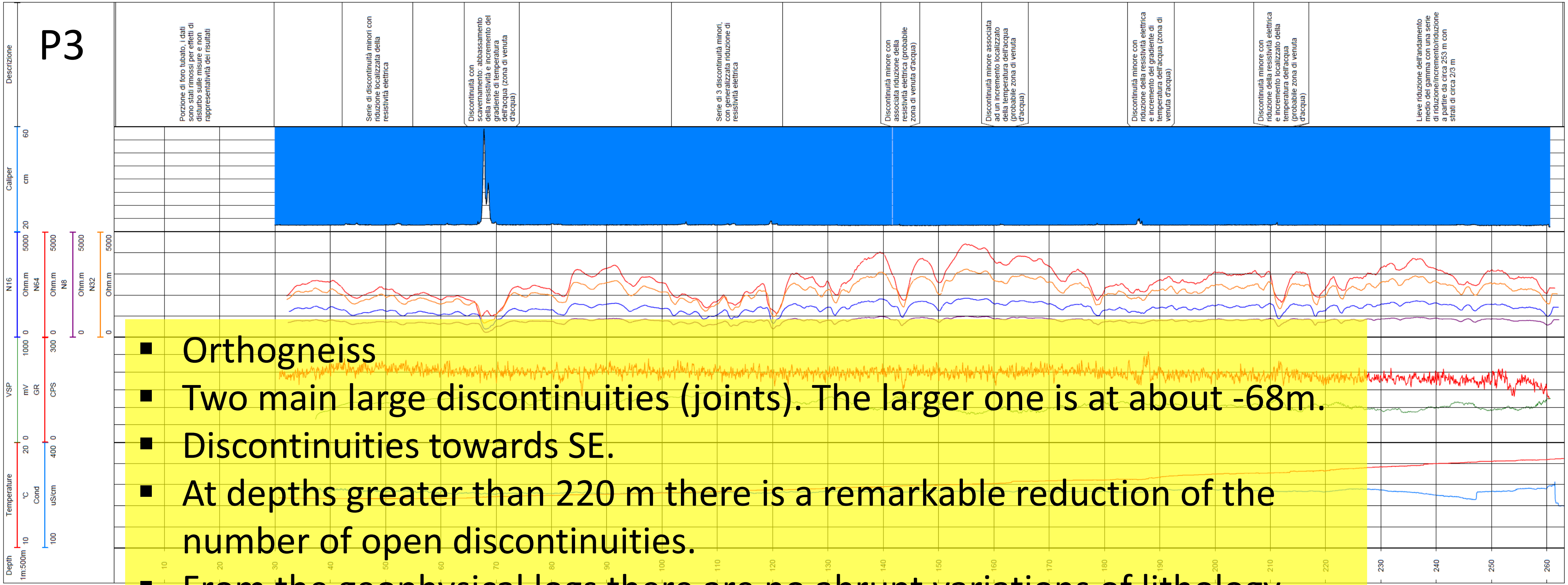
Geophysical logs



Example of discontinuities encountered in the P3 borehole and interpretation:

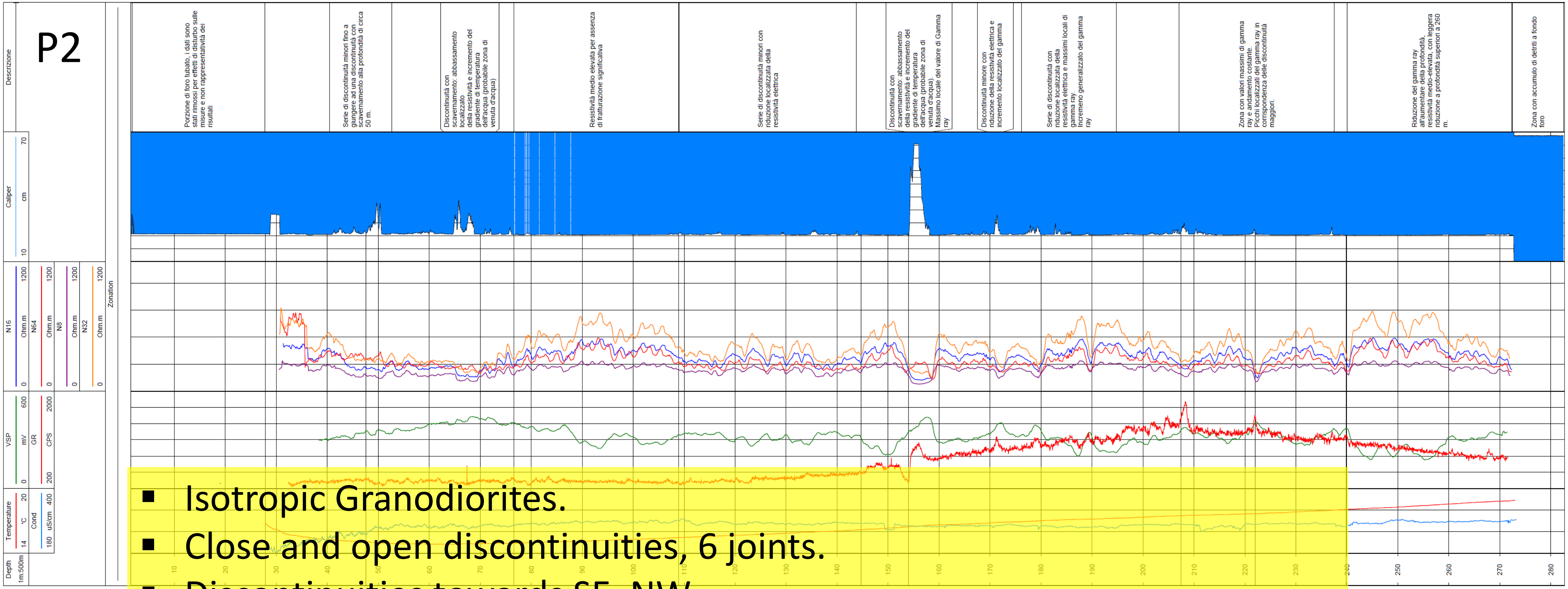
- Small-aperture discontinuities
- Large-aperture discontinuities

Geophysical logs



- Orthogneiss
- Two main large discontinuities (joints). The larger one is at about -68m.
- Discontinuities towards SE.
- At depths greater than 220 m there is a remarkable reduction of the number of open discontinuities.
- From the geophysical logs there are no abrupt variations of lithology, and the borehole looks drilled into the same geological formation.

Geophysical logs



- Isotropic Granodiorites.
- Close and open discontinuities, 6 joints.
- Discontinuities towards SE, NW
- Main discontinuity at -154m

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- ❑ Costs & practical aspects

BH Seismometer installation

Surface and borehole seismometers have been installed @P2 and P3 in the first half of September 2021 with the assistance of Nanometrics and Codevintec technicians.

ET-0426A-21, https://apps.et-gw.eu/tds/?content=3&r=17710

BH Seismometer installation

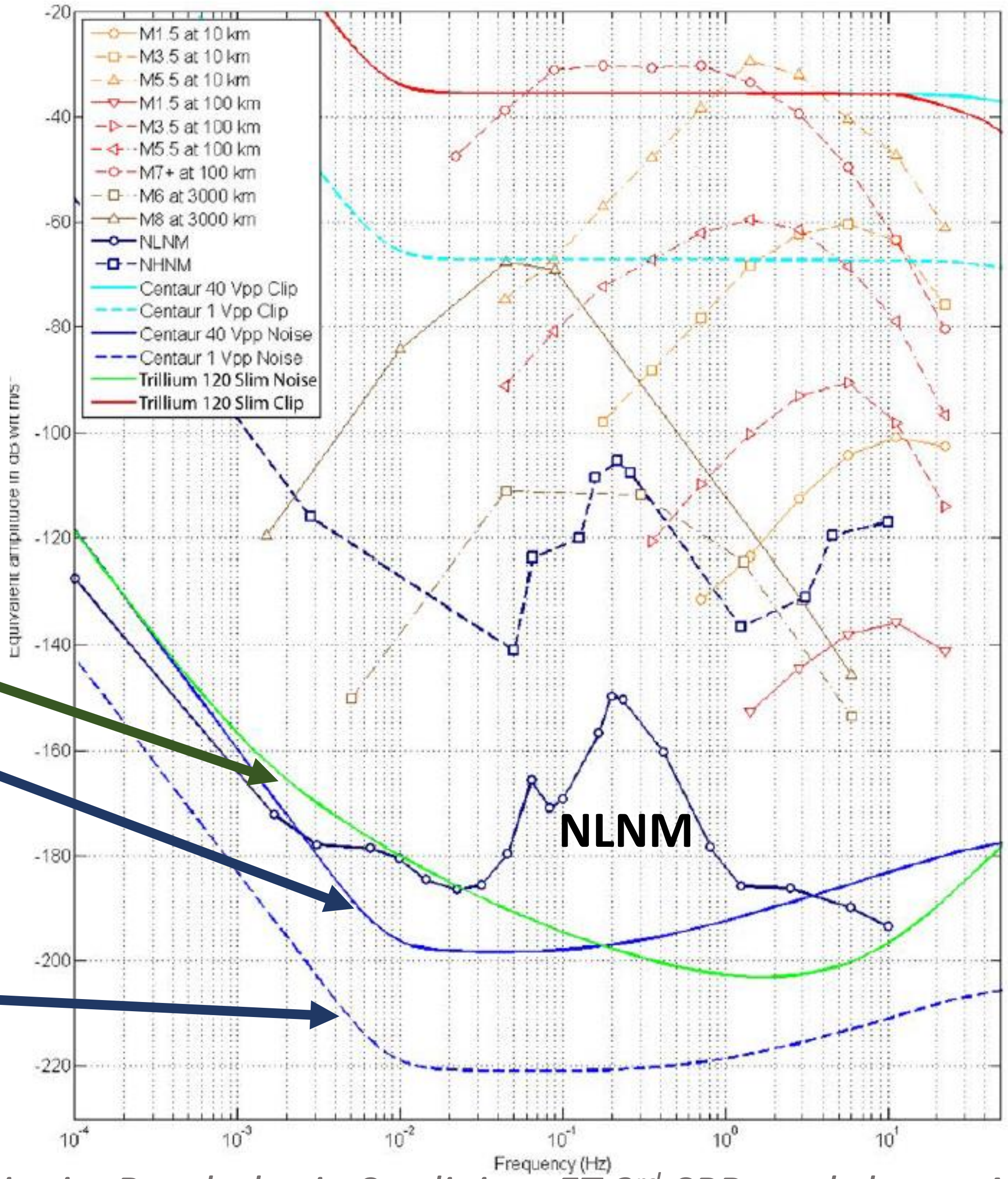
Trillium 120-SPH2

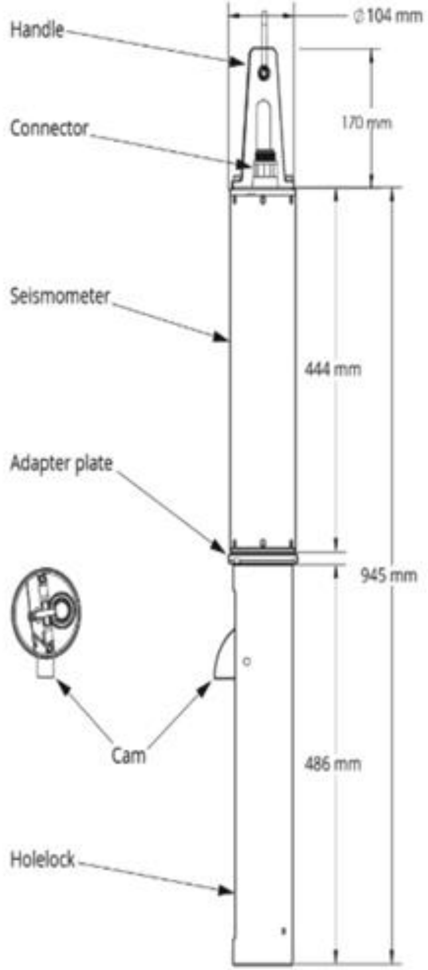
Broadband triaxial seismometer

Sensor self-noise

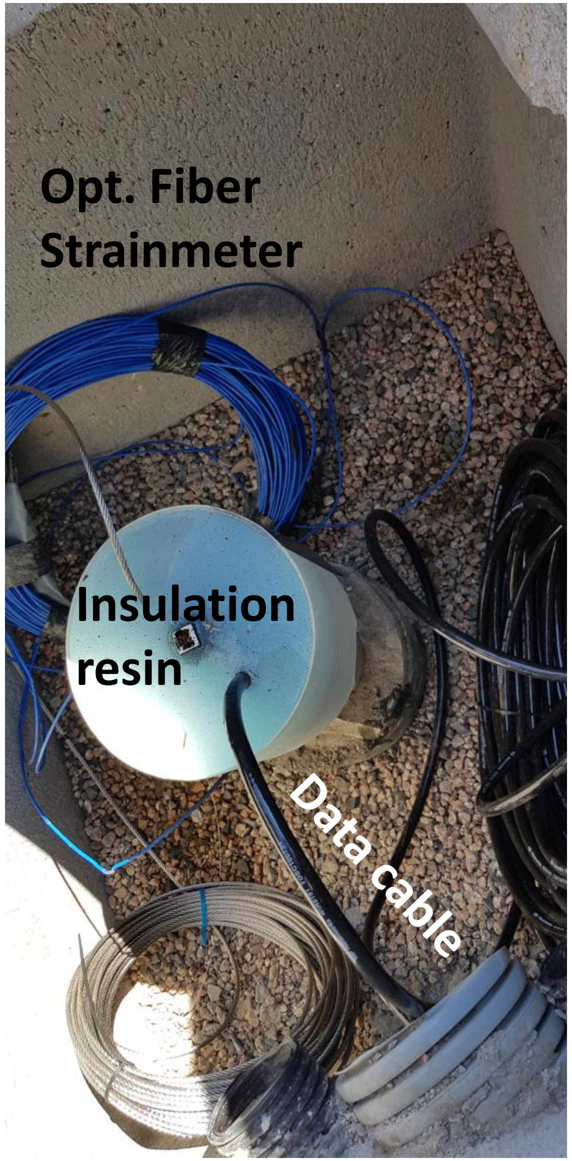
DAQ 40V self-noise

DAQ 1V (max gain) self-noise





BH Seismometer installation



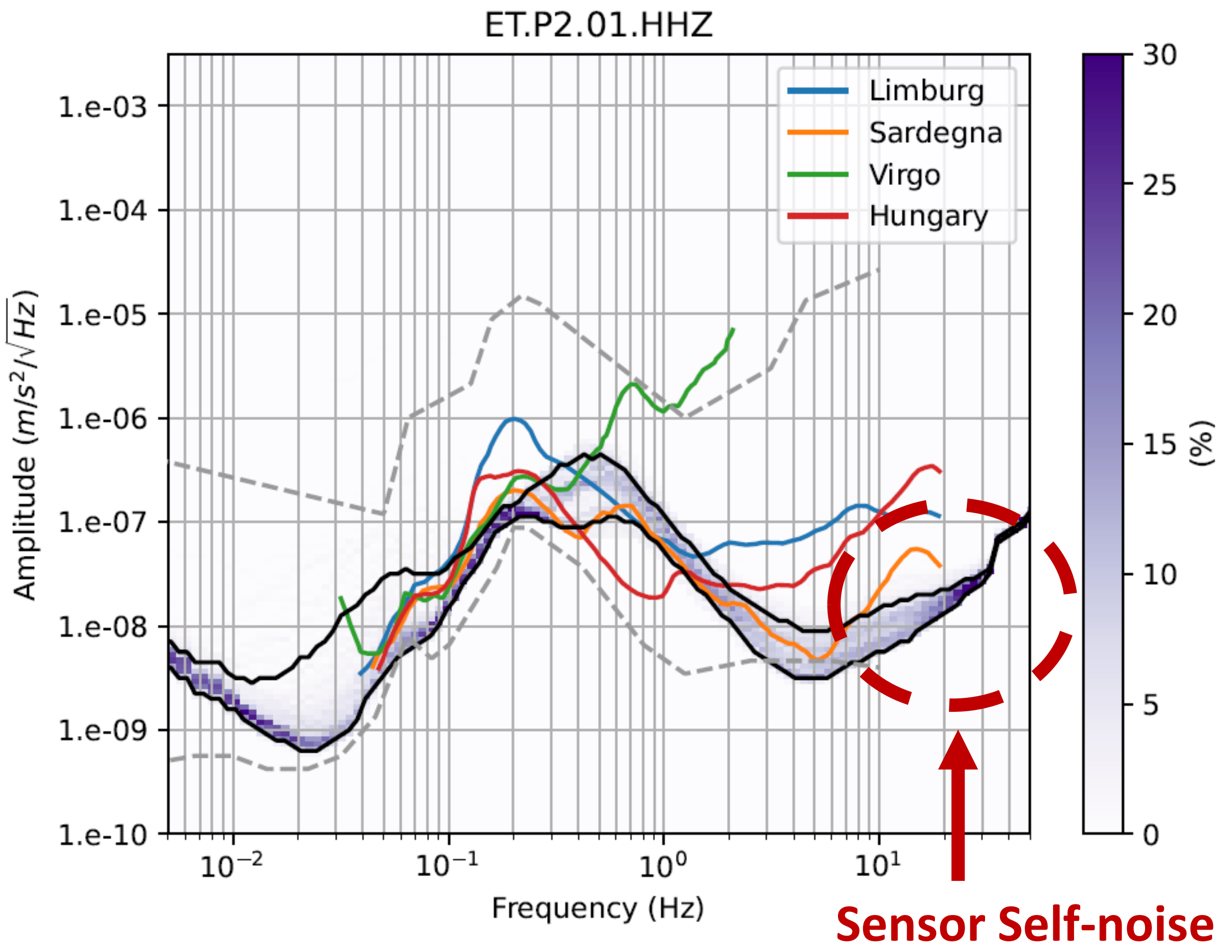
BH Sensor	P2	P3
Depth	-264 m	-252 m
Tilt	1°	3.5°
Digitizer input range	1Vpp	2Vpp

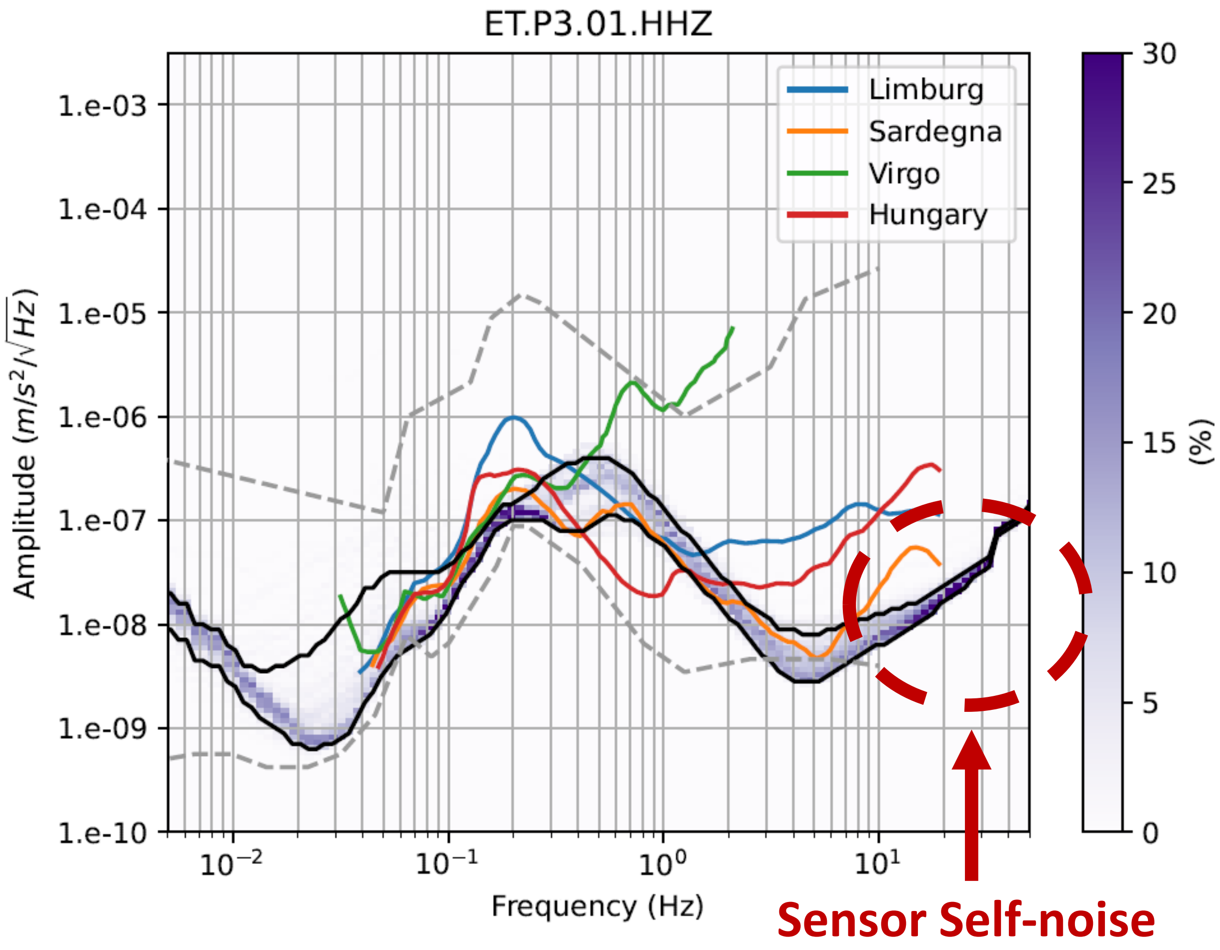
NS – EW rotation have to be corrected with rotation matrix to be calculated observing teleseisms.

BH Seismometer installation

As surface reference we deployed two **Trillium 120 Horizon** in a vault installation. In both cases, the digitizers are running with an input range of 4Vpp.

PSD from the two boreholes





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Borehole

Borehole for a broadband seismometer deployment

From our experience in Sardinia:

drilling, pipes, consolidation, assuming a final inner diameter of 119mm:

- **Cost***: ~50k€/100m
- **Time****: ~1 month for drilling (~250m), 1 week for consolidation with steel pipes + concrete

**Here we did not take into account the post-covid19 cost increase of materials*

***: if no major issues are encountered*

NB: cost for increasing diameter scales with the volume of the steel of the pipes used for the consolidation.

COST SENSITIVITY ANALYSIS

A cost sensitivity analysis is carried out as a support for the feasibility study of the sensor network for the ET infrastructure.

Main assumptions:

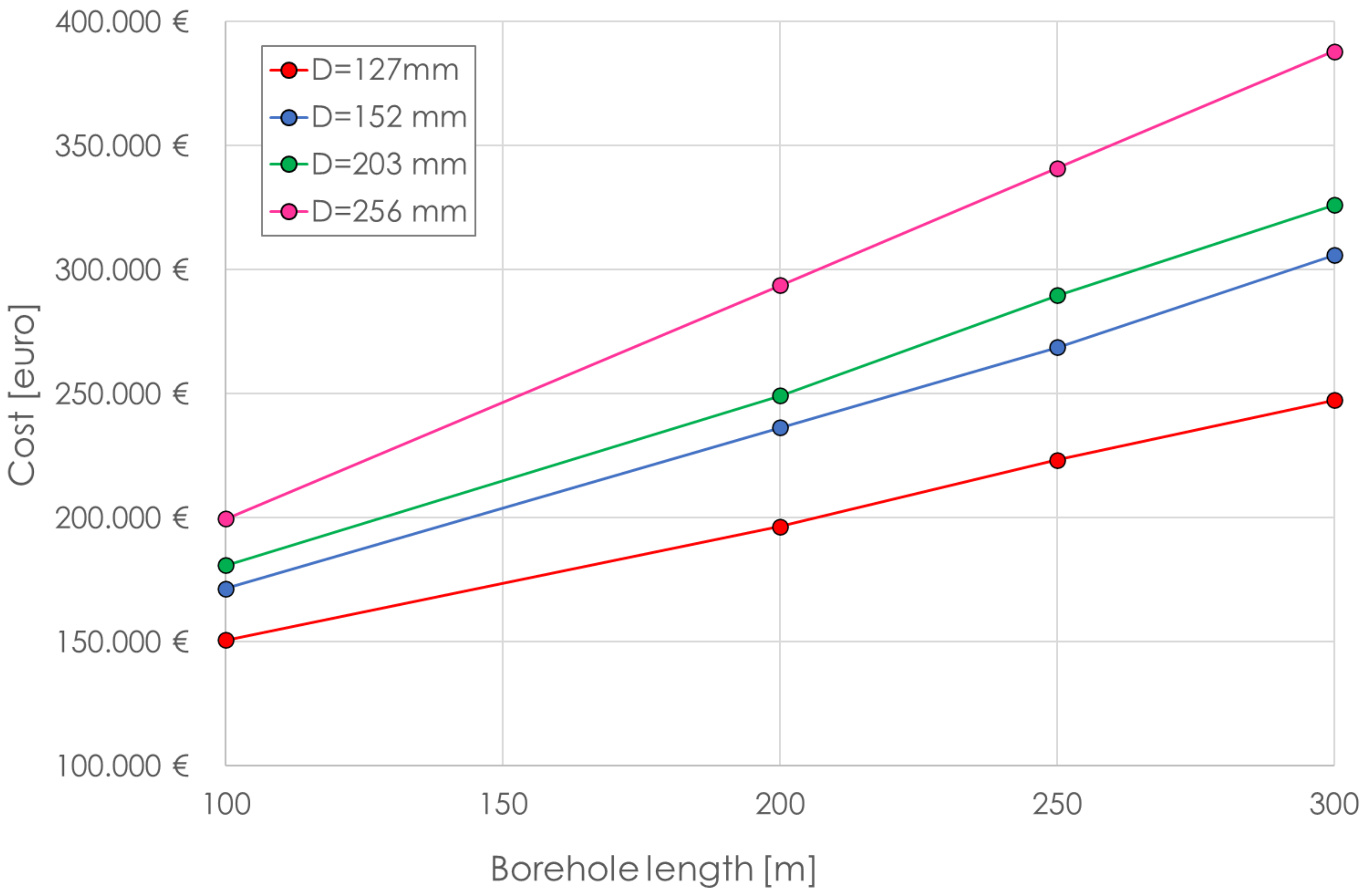
- Boreholes depth: 100, 200, 250, 300 m
- Steel lining external diameter: from 114,3 mm (4.5 inch) to 254 mm (10 inch)
- unit prices from the regional or national reference price list
- Included in the cost: site installation, borehole drilling and completion, surface infrastructures, safety
- Not included in the cost: instrumentation and sensors, solar panels, electrical equipment

Courtesy of C. Rossini

COST SENSITIVITY ANALYSIS

Courtesy of C. Rossini

COST SENSITIVITY ANALYSIS



Courtesy of C. Rossini

Borehole

Borehole for a broadband seismometer deployment

From our experience in Sardinia:

- Slim borehole sensor choice is a *cost-saving* solution for the borehole excavation/consolidation.
- 119mm diameter is ok for a Trillium 120 slim-class broadband seismometer (which can be installed in a 114-241mm range, depending on the holelock used).
- A “slim” broadband seismometer **has more stringent requirements for the vertical tilt**. E.g.: the T120BH slim must be installed with a tilt < 4° (*i.e. the verticality of the borehole is crucial. To be monitored during the drilling*).

Sensor installation

Broadband seismometers for boreholes

Costs:

- A Trillium120-class sensor: ~15-20k€
- 300m-long data cable: ~20k€
- DAQ: ~8k€
- Accessories: ~4k€

Total: ~52k€

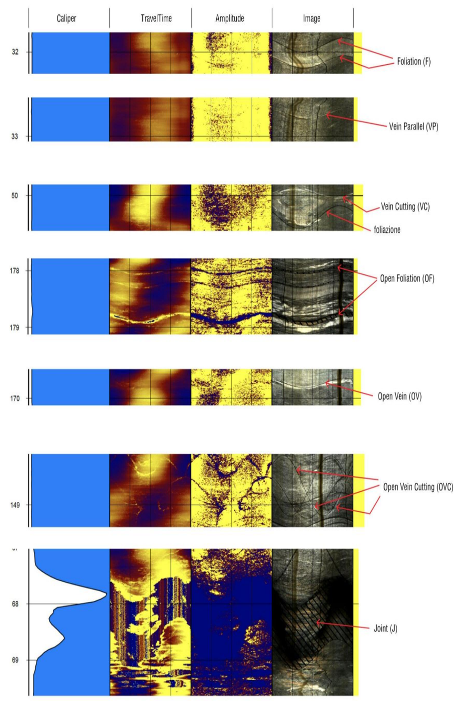
- Assistance, e.g. from Nanometrics (or authorised local company) for a state-of-art installation (including tools): ~10k€/installation

Sensor installation

Broadband seismometers for boreholes

Installation:

- **Good mechanical contact** with the surrounding rock mass is crucial: a well-done borehole consolidation (good concrete injection) is required.
- *Before the consolidation*: **logs** are important to identify the most important discontinuities in the borehole walls.
- **The seismometer should be installed avoiding fractured sectors of the borehole**.
- Surface structures/setup: avoid to inject additional vibration noise (e.g. support structures of solar panels vs wind)



Conclusions

- On July 2021 the characterisation of the two other corners (P2,P3) of ET in Sardinia has begun.

- Two boreholes excavated (about 270m and 260m deep).

- Geophysical/structural logs done in granites (P2) and orthogneiss (P3).

- Borehole equipped with optical fiber strainmeters and broadband seismometers.

- First results are impressive: the attenuation of the seismic background measured with the borehole seismometer is evident above 1Hz, in particular in the band 2-7Hz, where the background noise crosses the Peterson's New Low Noise Model (NLNM).

Thanks for your attention!