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ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

INGV

Active and passive seismic measurements at the Sardinia ET vertices

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MEET MONITORING EARTH'S EVOLUTION AND TECTONICS

SARDINIA FABER FAR FAULT OBSERVATORY

ET ITALY Einstein Telescope

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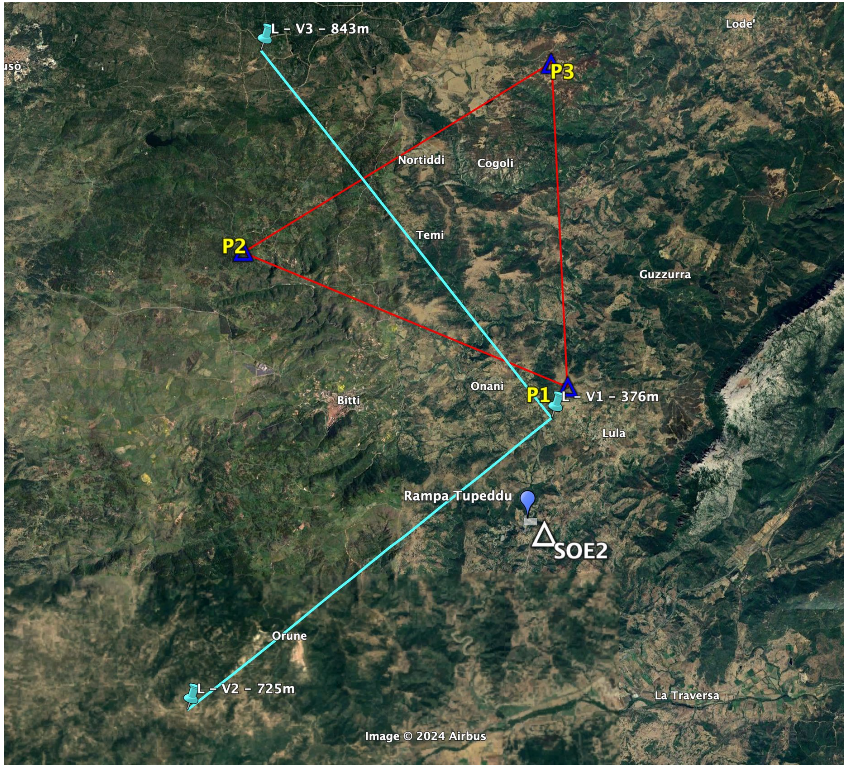
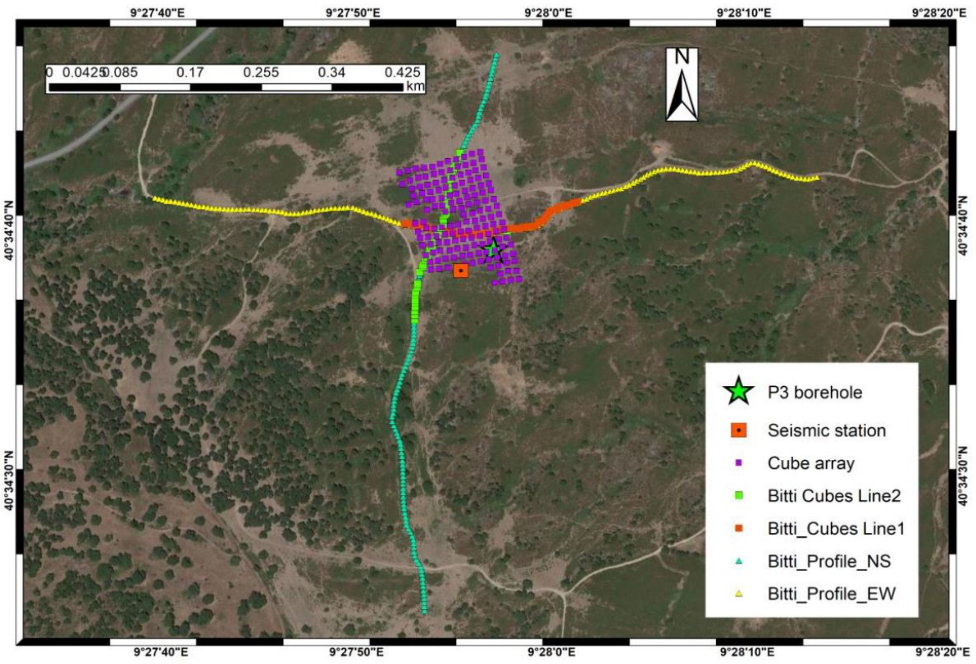
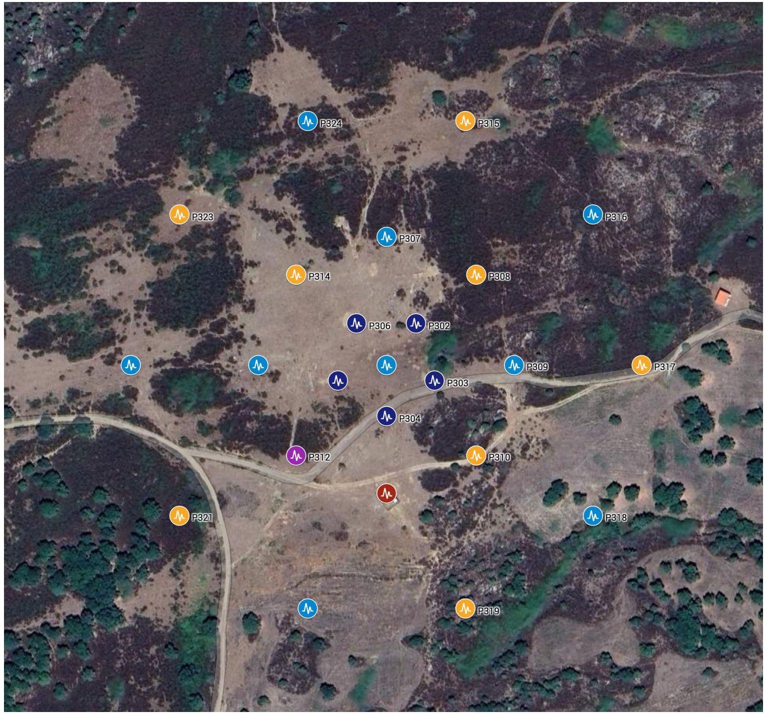
Overview of the measurements at vertices

Sos Enattos	Multiparametric network Passive Seismic array	2019 01/2021
P2	Borehole Active seismic survey Passive seismic array WINE (wind park)	09/2021 09/2021 09/2021 04/2023
P3	Active seismic survey Borehole Passive seismic array	7/2021 9/2021 10/2021



P3 CORNER


9°27'40"E
9°27'50"E
9°28'0"E
9°28'10"E
9°28'20"E
40°34'40"N
40°34'30"N
0 0.0425 0.085 0.17 0.255 0.34 0.425
km
N
P3 borehole
Seismic station
Cube array
Bitti Cubes Line2
Bitti_Cubes Line1
Bitti_Profile_NS
Bitti_Profile_EW


P324
P315
P323
P316
P307
P314
P308
P306
P302
P309
P317
P303
P304
P312
P310
P321
P318
P319

Active seismic survey@P3 CORNER

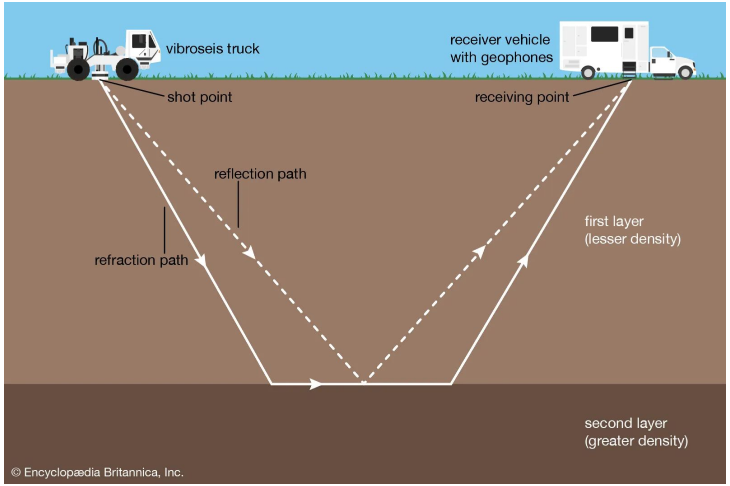
- Minivib (6 ton truck with 168 kg mass)
- up to 168 4.5 Hz geophones connected to several recorders (~ every 5 m)
- NS profile 720m
- EW profile 840m
- 1 shot every 10 m

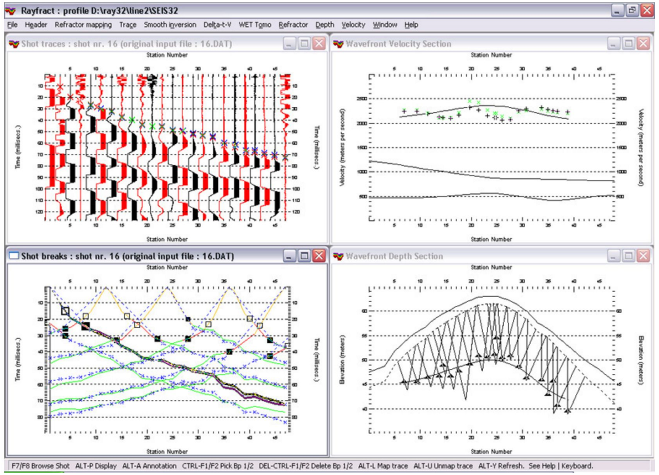
Refraction tomography

- Survey
- data gathering
- preprocessing
- pick of first arrivals
- imaging of P velocity

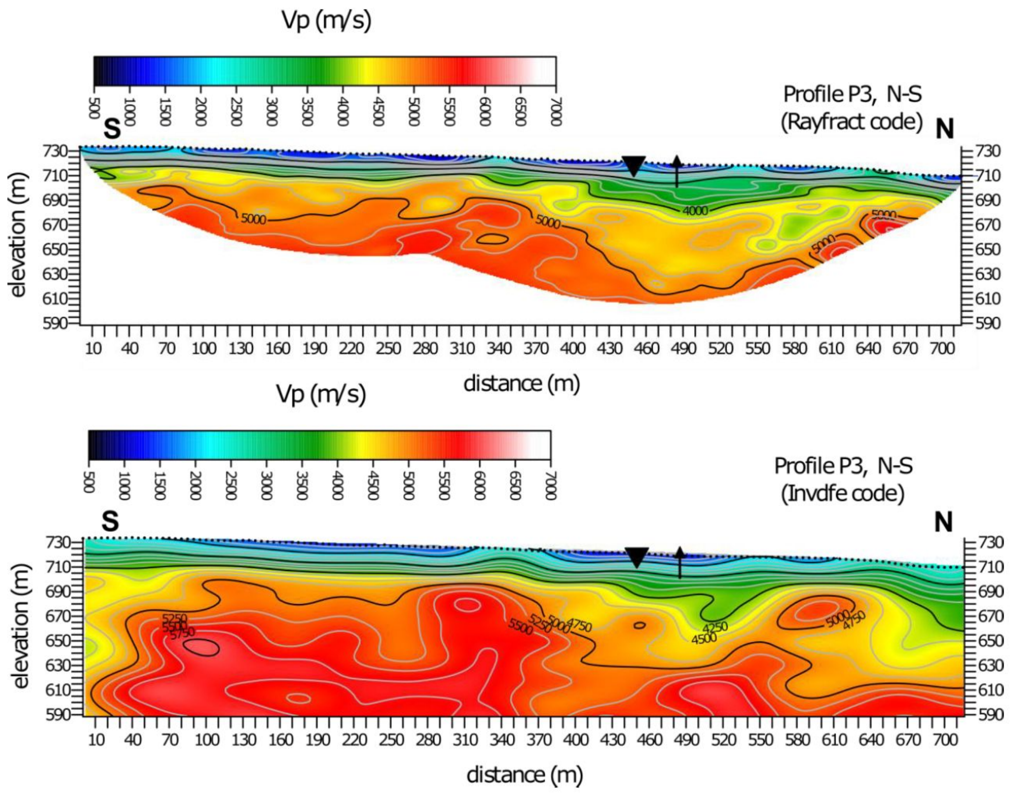
Inversions are performed by two methods

- Rayfract (commercial software)
  - rapid and robust Vp inversion
  - generate initial smooth velocity model
  - refinement to minimize observed delays
- INVFDE (research code)
  - multiscale approach
  - nonlinear inversion scheme (Monte Carlo + Simplex)
  - increasing number of parameters to minimize misfit
  - adaptive resolution for finer details of velocity structure





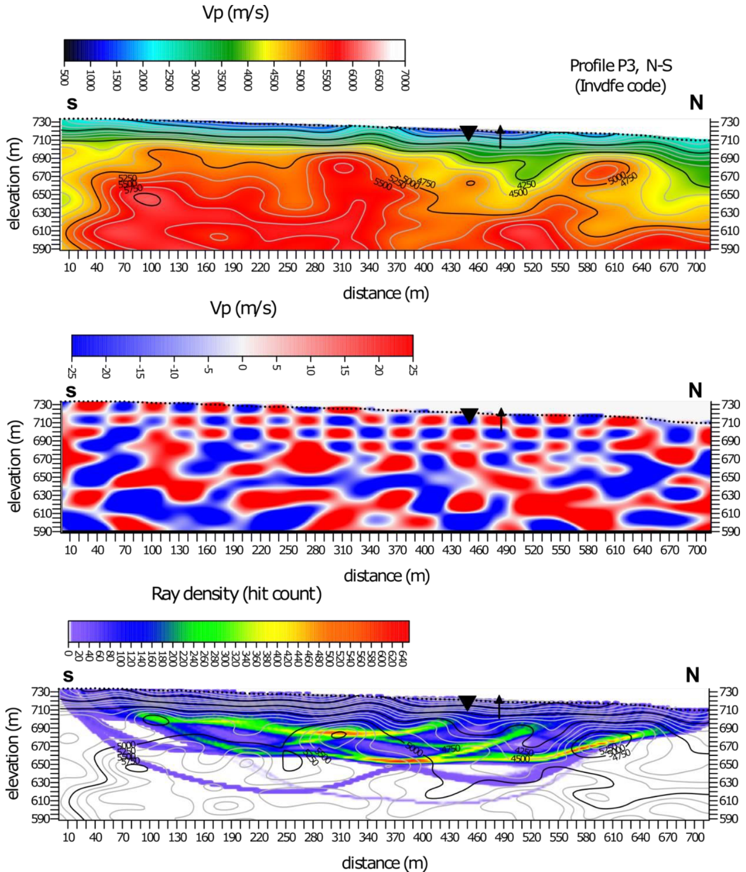
P3 NS profile: Rayfract vs Invfde (7,994 arrival times)



- good agreement
- better depth resolution for Invfde
- first 30-40 m are “slow”
- below 30-40 are very fast
- no significant lateral variations

De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

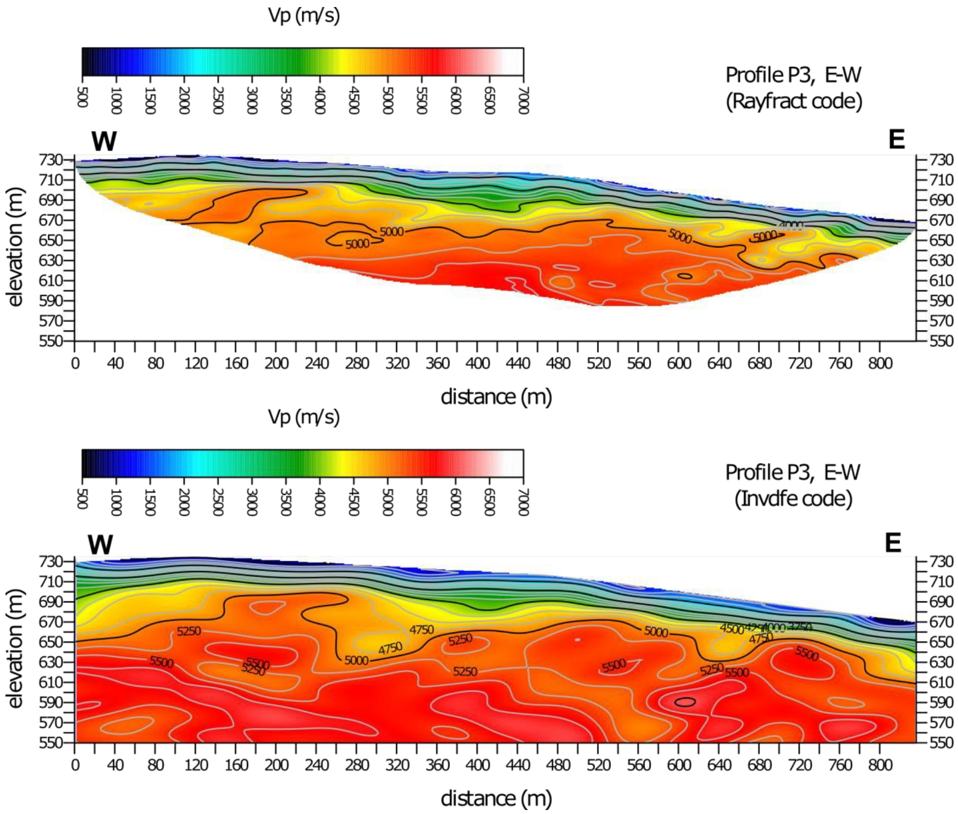
Invfde resolution test



- Invfde depth resolution is validated by a checkerboard test
- Good resolution at S end and middle part of the profile (70-80 m)
- Poor resolution in the N end
- Confirmed by the ray density plot
- Fast lithologies “squeeze” rays upward

De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

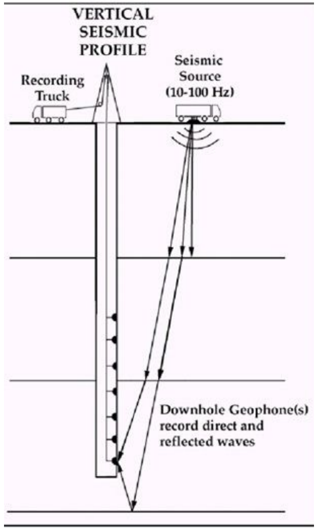
P3 EW profile (9,359 arrival times)

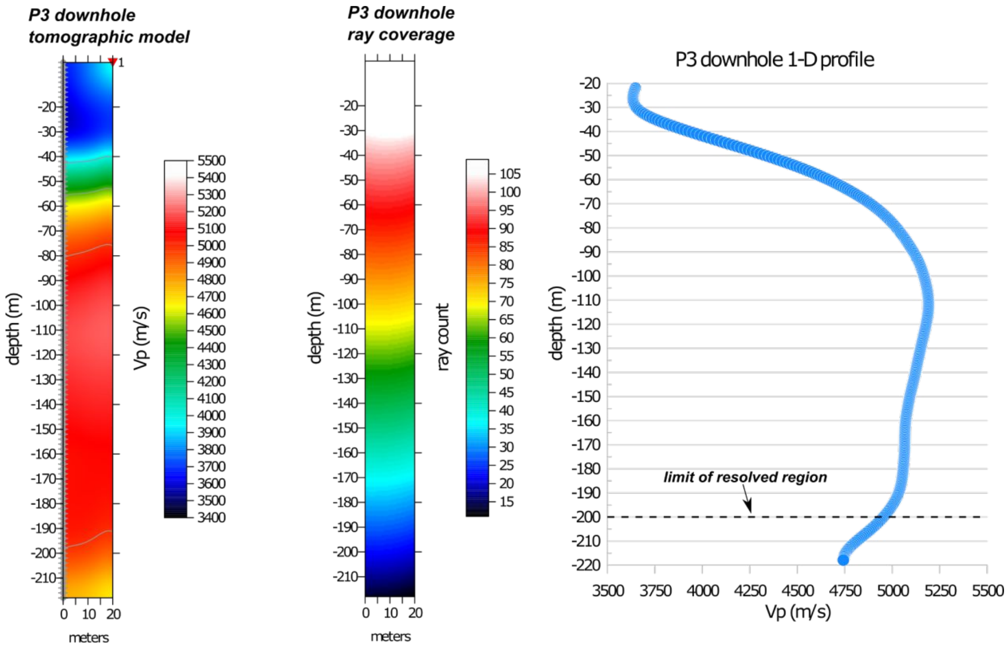


- no lateral discontinuities
- fast velocities below 30-40 m depth
- model resolved down to 50 m depth in the W part
- model resolved down to 80-90 m in central and E part

De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

P3 corner - Downhole

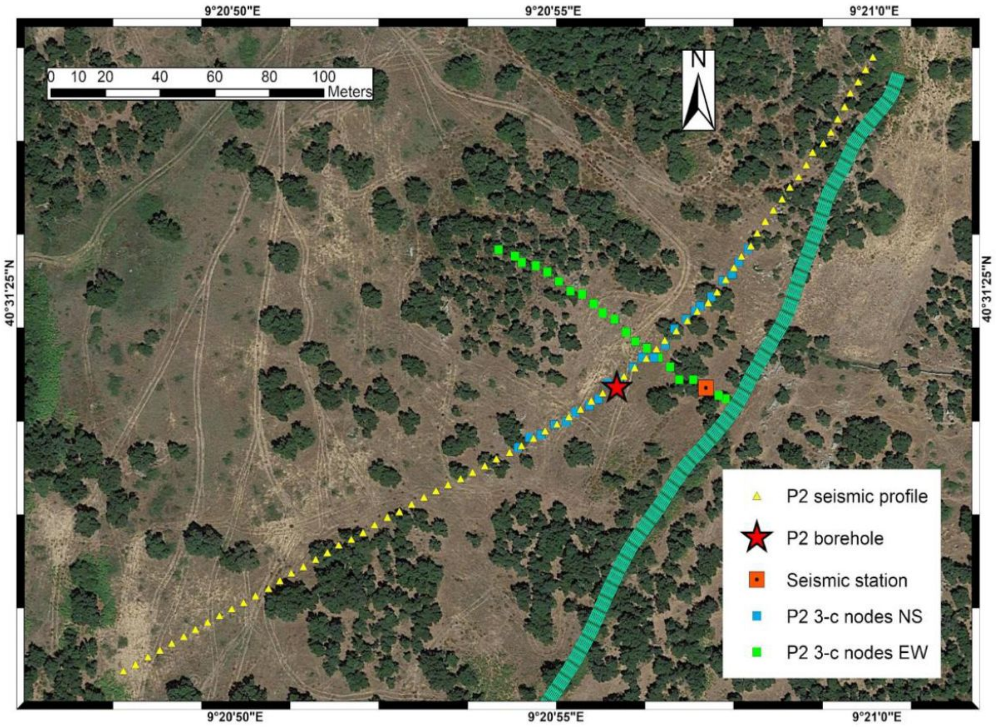


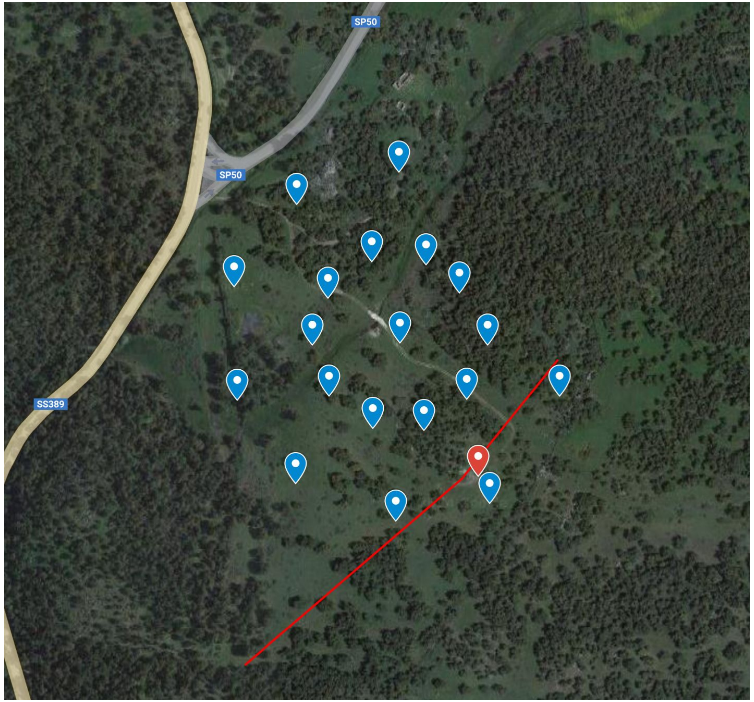


- Downhole data are processed by a tomographic technique allowing for curvature of rays
- Granitoids are altered in the first 30-40 m (Vp < 4000 m/s)
- Linear increase down to 110 m
- Homogeneous layers down to the resolved depth (~ 200 m)

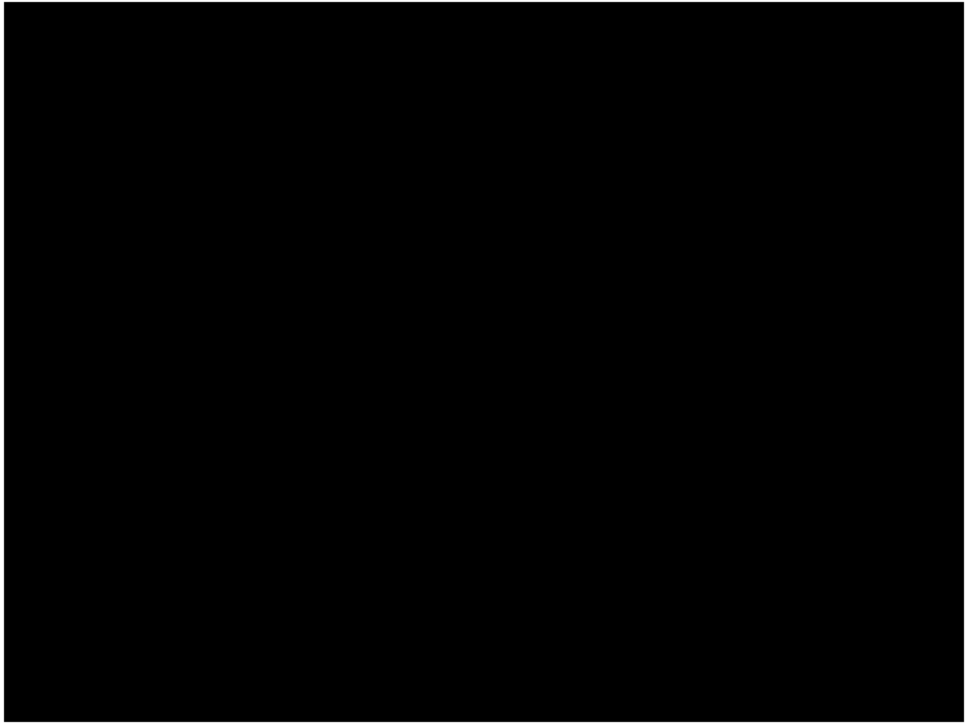
De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

P2 CORNER


9°20'50"E
9°20'55"E
9°21'0"E
40°31'25"N
0 10 20 40 60 80 100
Meters
N
P2 seismic profile
P2 borehole
Seismic station
P2 3-c nodes NS
P2 3-c nodes EW

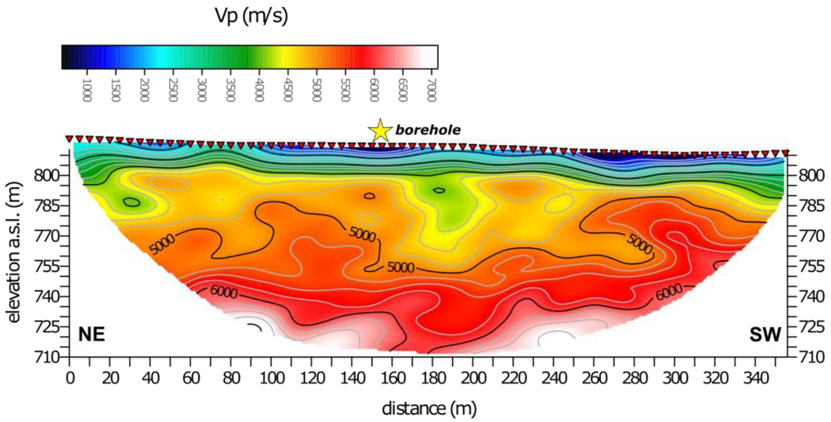

SP50
SP50
SS389

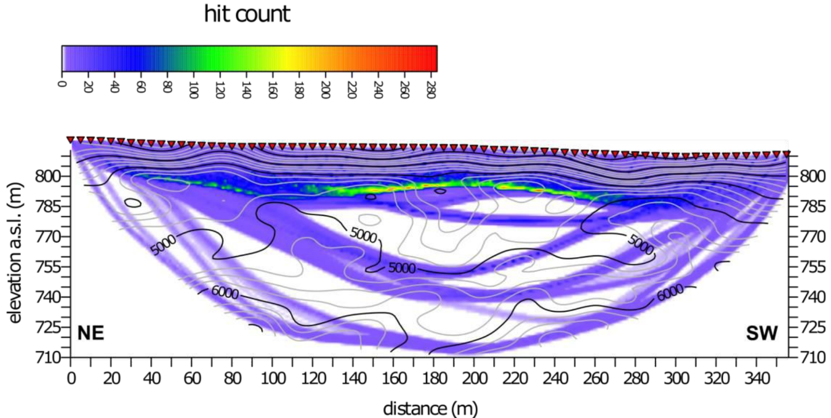
P2 CORNER Active seismic survey



- Truck unable to access the site
- Seismic gun (minibang) used as active source
- Only one profile (360 m length. SW-NE)
- 39 bangs (1 every 5 m)
- ~2,500 seismograms recorded

P2 SW-NE Profile

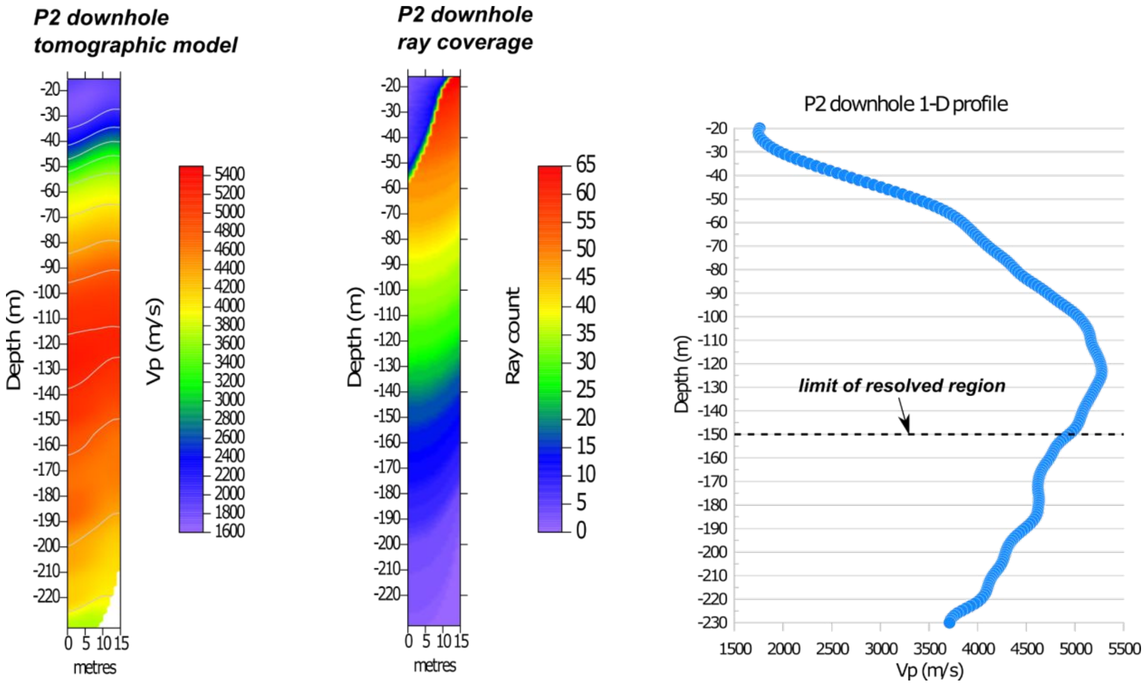




- Maximum resolution depth ~ 80m
- High velocities gradients at the surface due to alteration
- “low” velocity zone (green blob) SW of the borehole could indicate a fractured zone of about ~10 m width
- stiffer granitoids SW of the borehole (red blobs)

De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

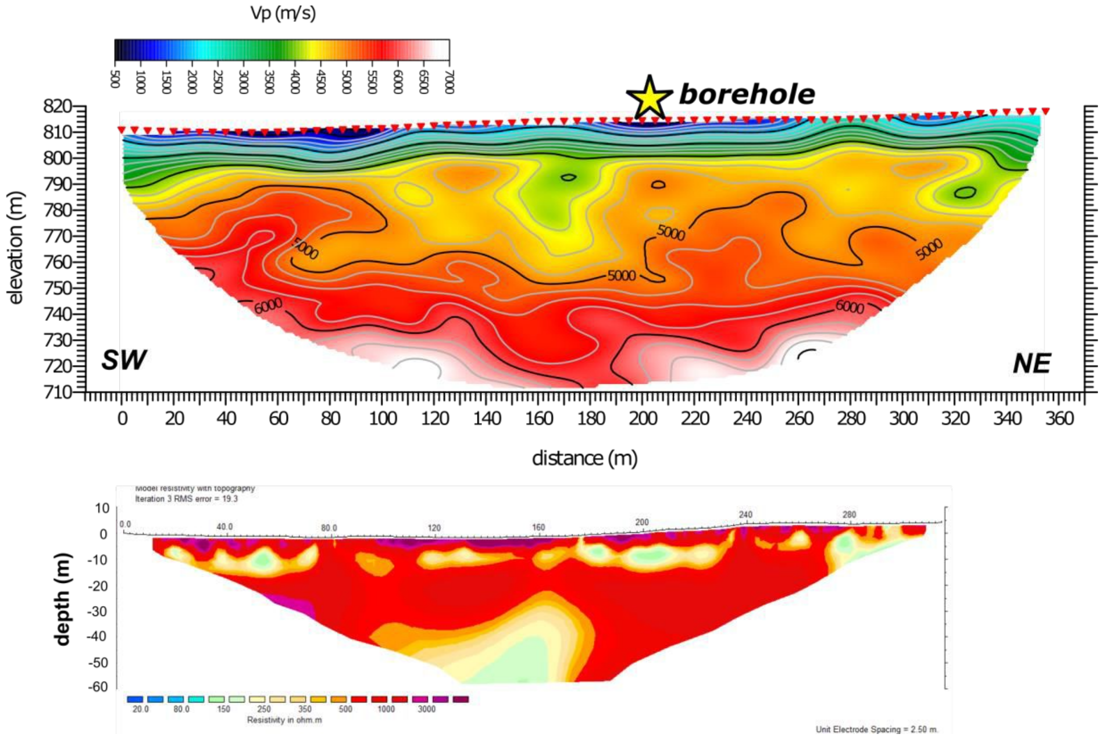
P2 downhole profile



- Profile resolved to 150 m depth
- Very strong gradient to 50 m depth (2000 to 4000 m/s)
- Increase to 5500 m/s from 50 to 120m
- Slight inversion from 120 to 150 m

De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

P2 Comparison with ERT survey

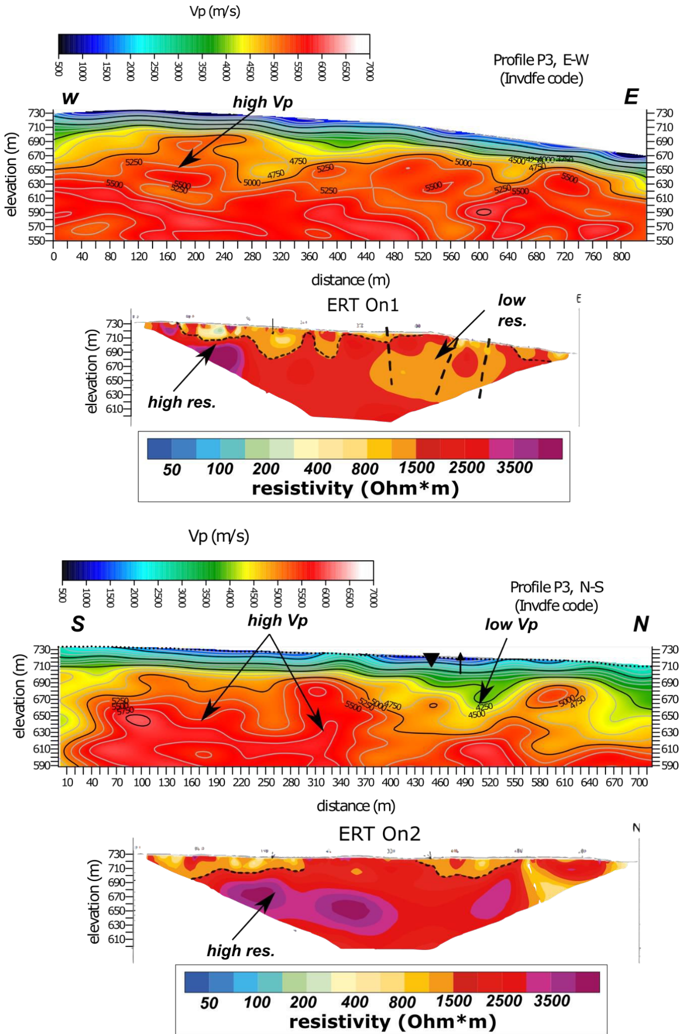


- ERT performed by UniSS (Longo & Cardello, 2021))
- 10 m alterated layer (highly conductive and seismically slow)
- low fractured and stiff bedrock shallower in the SW part of the profile matches high resistivity patch
- low seismic velocity/low resistivity anomaly in the middle of the profile (confined to 50-70 m depth as shown by refraction tomography)

De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

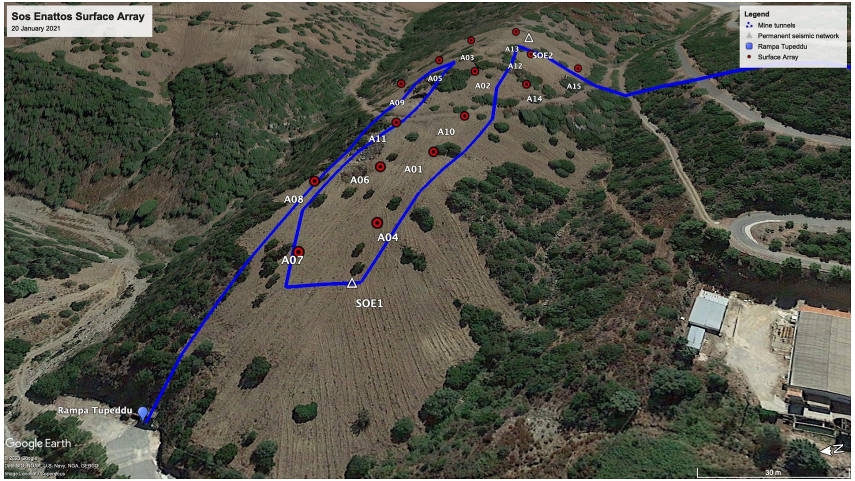
P3 comparison with ERT survey

- Much harder to compare since:
  - profiles not perfectly co-located
  - depth of investigation of ERT very limited at the edges of the profile
- Some general features :
  - high seismic velocity bodies match high resistivity patches
  - not all low resistivity changes corresponds to seismic velocity anomalies (e.g EW profile)
- Difficult interpretation about what is going on N of the borehole in the NS profile



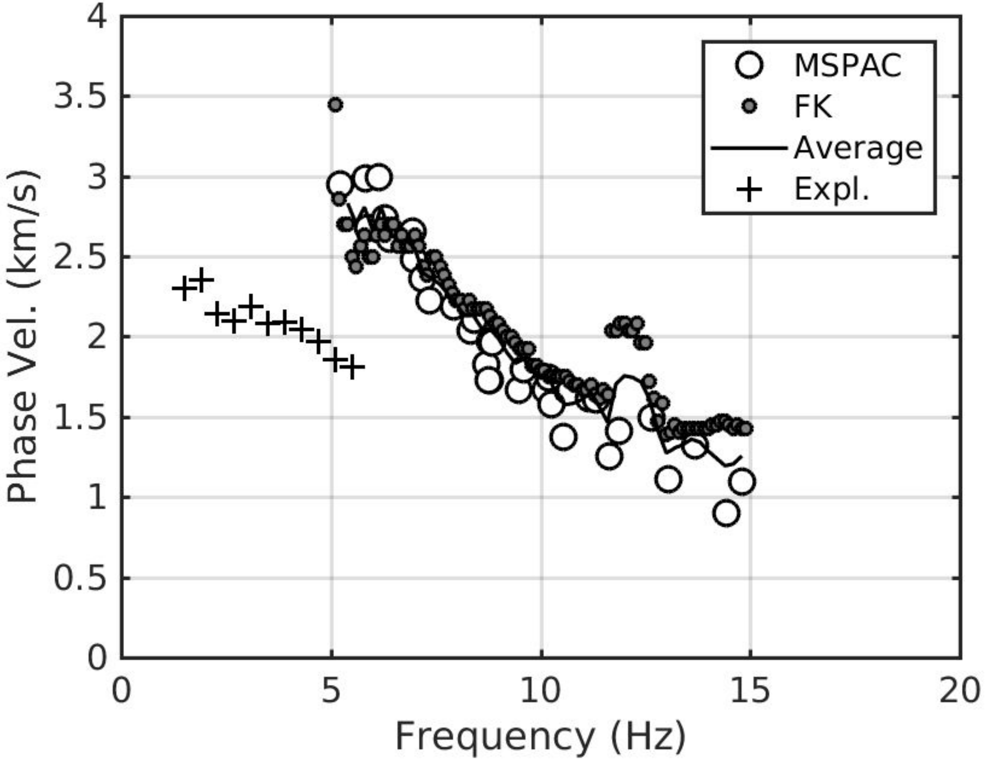
De Martini et al., 2022 https://apps.et-gw.eu/tds/ql/?c=16341

Sos Enattos (P1) Passive Array



- 15 broadband seismometers
- 15 days of recording time (21/01/21 to 05/02/2021)
- array aperture 100 x 250 m
- target Rayleigh wave @ 5 Hz (l= 400 m)
- main target noise characterization

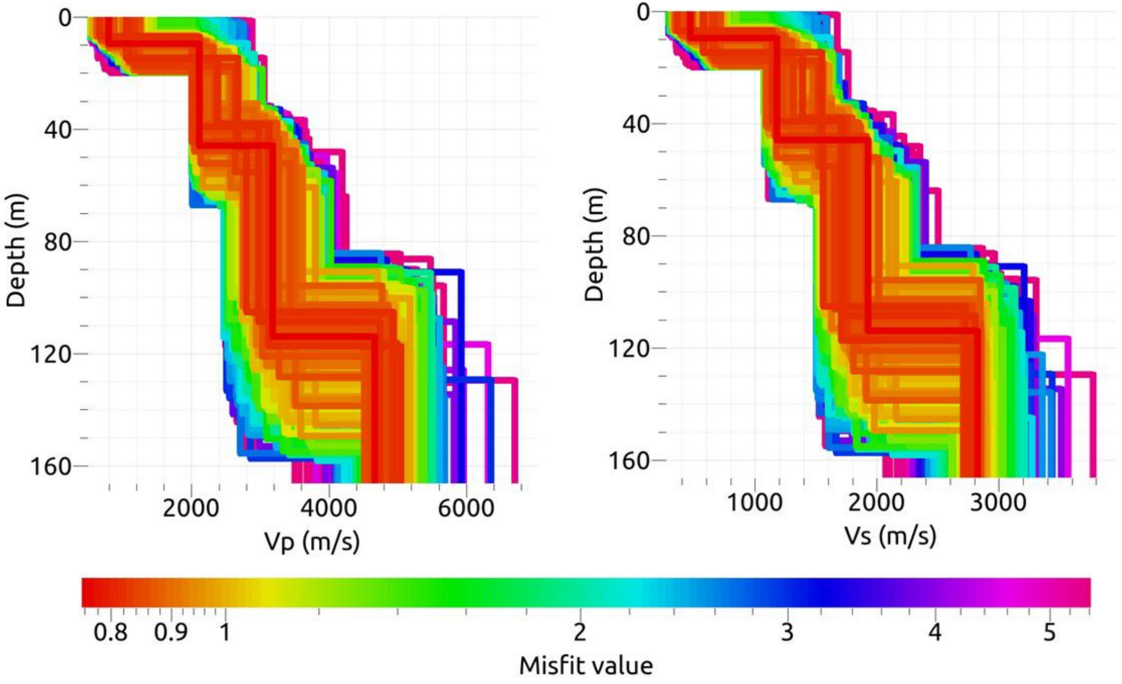
Results from ambient noise correlation: phase velocity



- Ambient noise interferometry: correlations of noise between stations pairs is a way to retrieve Green’s functions (virtual source-receiver)
- Dispersion curve of Rayleigh phase velocity obtained by FK and MSPAC methods
- Evidence of multimodal propagation of RW

Saccorotti et al., 2023 https://doi.org/10.1140/epjp/s13360-023-04395-2

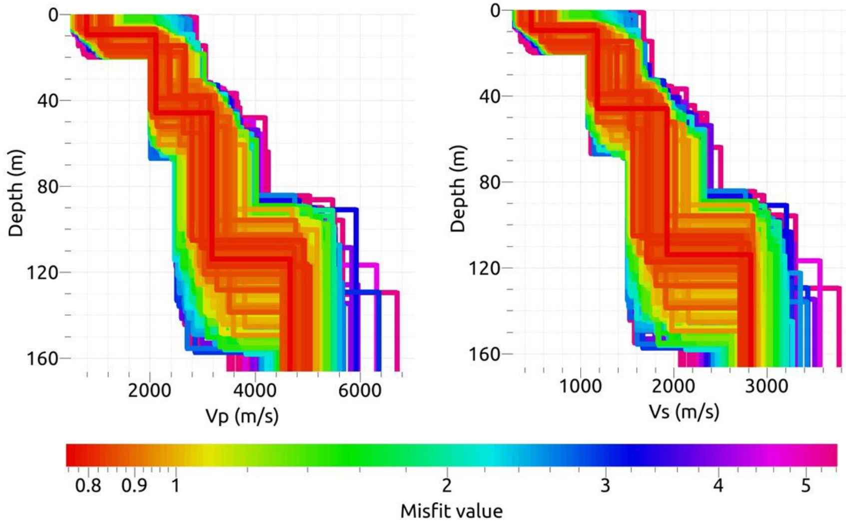
Results from ambient noise correlation: Vp and Vs profiles



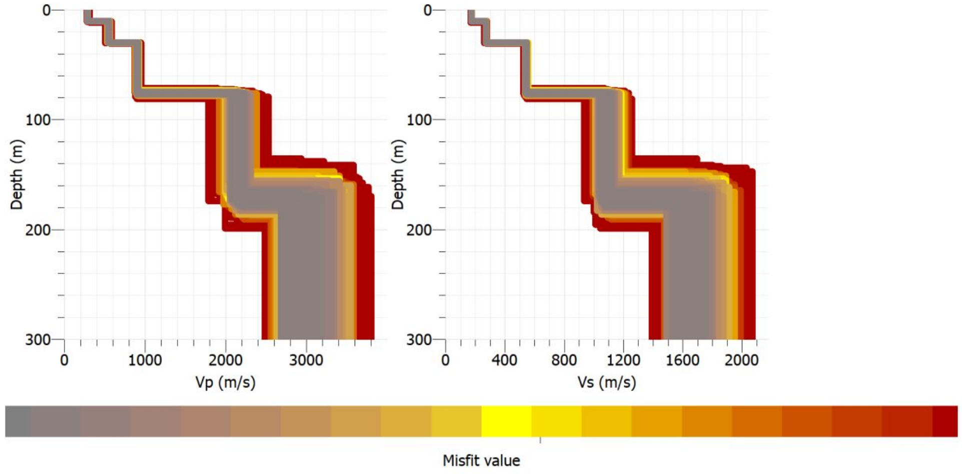
- Surface wave dispersion depends on the body waves velocities, density and thickness of the layers
- Vp and Vs inversion is performed under the hypothesis that fundamental mode and first order mode are represented by the explosion and ambient noise data
- 3 layers + half space model
- High velocities just below the surface consistent with active seismic surveys results

Saccorotti et al., 2023 https://doi.org/10.1140/epjp/s13360-023-04395-2

Comparison: Sardinia vs Euregio

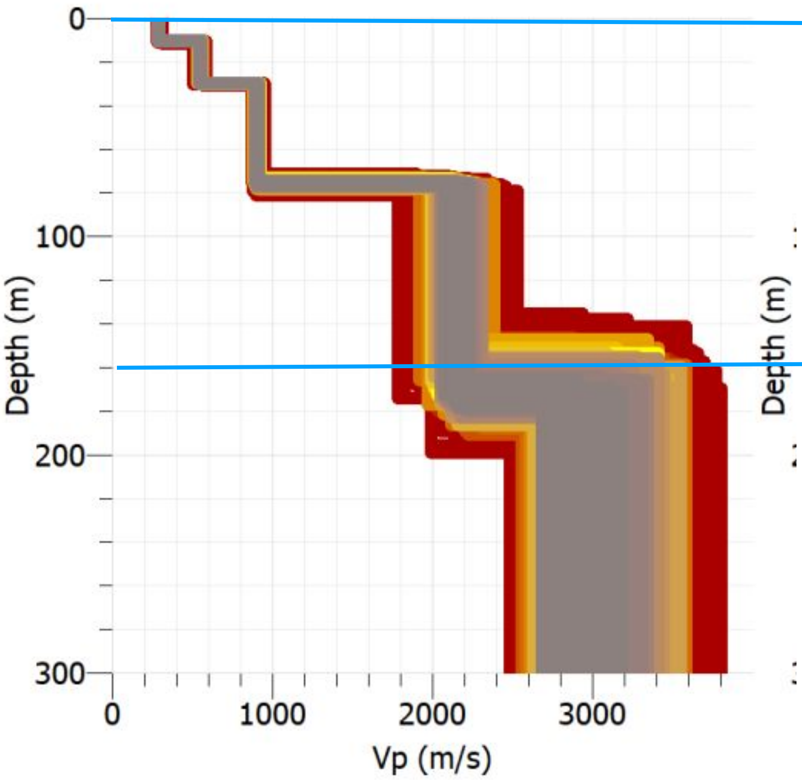


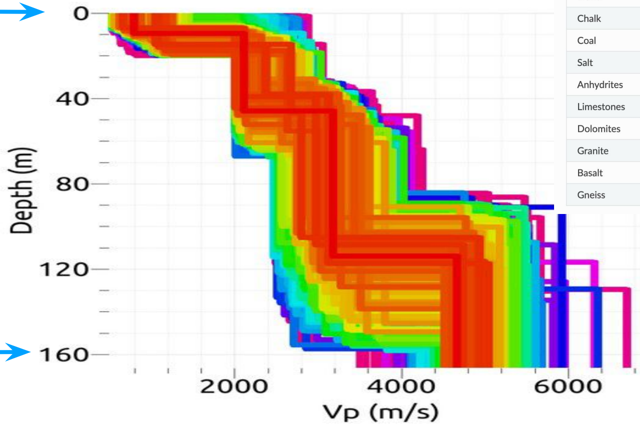
Saccorotti et al., 2023
https://doi.org/10.1140/epjp/s13360-023-04395-2



Koley et al., 2023
XII ET Symposium, Cagliari

Comparison: Sardinia vs Euregio





Seismic Velocities of Rocks and Variou

Material	P-wave (m/s)	S-wave (m/s)
Air	343	N/A
Water	1450 - 1500	N/A
Ice	3400 - 3800	1700 - 1900
Oil	1200 - 1250	N/A
Vegetal Soil	300 - 700	100 - 300
Dry Sands	400 - 1200	100 - 500
Wet Sands	1500 - 2000	400 - 600
Saturated Shales and Clays	1100 - 2500	200 - 800
Porous and Saturated Sandstones	2000 - 3500	800 - 1800
Marls	2000 - 3000	750 - 1500
Chalk	2300 - 2600	1100 - 1300
Coal	2200 - 2700	1000 - 1400
Salt	4500 - 5500	2500 - 3100
Anhydrites	4000 - 5500	2200 - 3100
Limestones	3500 - 6000	2000 - 3300
Dolomites	3500 - 6500	1900 - 3600
Granite	4500 - 6000	2500 - 3300
Basalt	5000 - 6000	2800 - 2400
Gneiss	4400 - 5200	2700 - 3200

High mechanical quality of Sardinia soils is quite evident

Summary of geophysical observations at the vertices

What has been learned about the seismic velocity structure at depth?

- Both passive and active seismic studies show the presence of rather homogeneous and stiff crystalline bedrock characterized by high seismic velocities
- Very poor impedance contrasts, no major faults or discontinuities
- So far so good, but…

Towards a 3D model of the Lula/Bitti/Onanì area…

- Doing active seismic surveys is hard in Sardinia:
  - Logistics is complex due to topography and low anthropization (no roads)
  - Rock outcrops are very difficult to energize
  - While the depth of investigation of a refraction seismic survey is between ⅓ and ¼ of the profile length in Sardinia this depth is reduced to 1/8
  - Seismic surveys just scratched the surface:
    - tomography just reached 80-100 m
    - downhole reached 150 m
    - no information below 150 m (no reflections)
- Doing passive seismic studies is equally hard:
  - seismic ambient noise for frequency > 1 Hz is quite low
  - intrinsic noise of geophones maybe higher than ambient noise level
  - doing ambient noise interferometry with broadband sensors is a huge effort
  - same logistics problems as for active seismic survey

Airborne surveys (gravimetry and EM) could help!

What’s next: actions, perspectives, and goals

- Adriarray experiment will provide some constraints on the lithospheric structure of Sardinia
- Passive seismic arrays data at P2, P3 have still to be processed (G. Diaferia): we lack dedicated full time geophysicists
- Geophysical/geotechnical investigations carried out in ETIC WP6 will focus on the design infrastructure depth (250 m)
- A full 3D model of the Lula/Bitti/Onanì area requires probably additional investigations
- Broad scale characterization of Sardinia upper crust is an interesting scientific topic for geology and geophysics