ET EINSTEIN TELESCOPE

Updates on Site Studies @Sardinia

Outline

- Geology studies
- News from P2 and P3 Geophysical studies
- Seismic measurement updates
- Magnetic measurement updates
- Future plans

Thanks to L. Cardello, L. Naticchioni, R. De Rosa and F. Villani for their materials

Geological investigations

RECAP ON:

- SARDINIA GEOLOGY AND REASONS WHY THE ET INFRASTRUCTURE SHOULD BE HERE
- PREVIOUS WORK OF SASSARI UNIVERSITY ON THE PROJECT

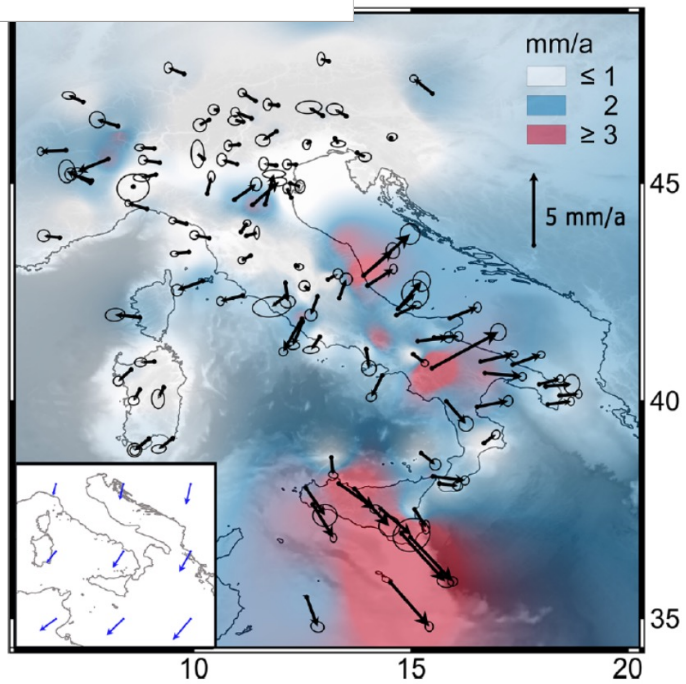
OUR NEW RESULTS:

- STRUCTURAL MAP ADVANCES
- FAULT CHARACTERIZATION
- MULTISCALE GEOLOGICAL CHARACTERIZATION OF BOREHOLE SURROUNDINGS BY MEANS OF:
  - STRUCTURAL GEOLOGY
  - STRUCTURAL GEOMORPHOLOGY
  - GEOELECTRICS

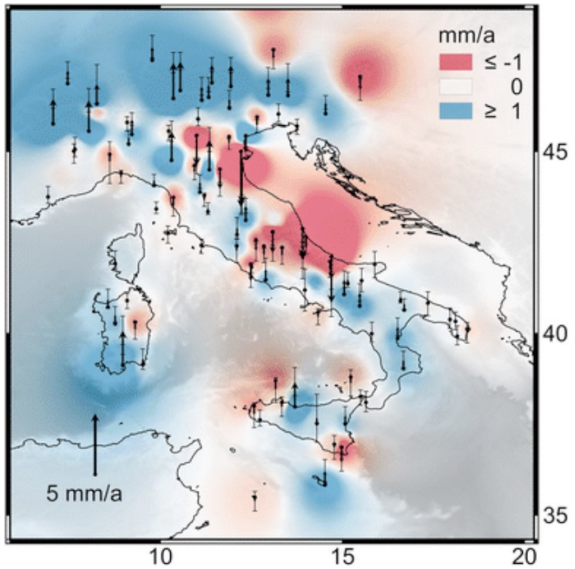
SARDINIA VERTICAL MOVEMENTS ?

In Sardinia, Intra-plate horizontal velocities are very low.

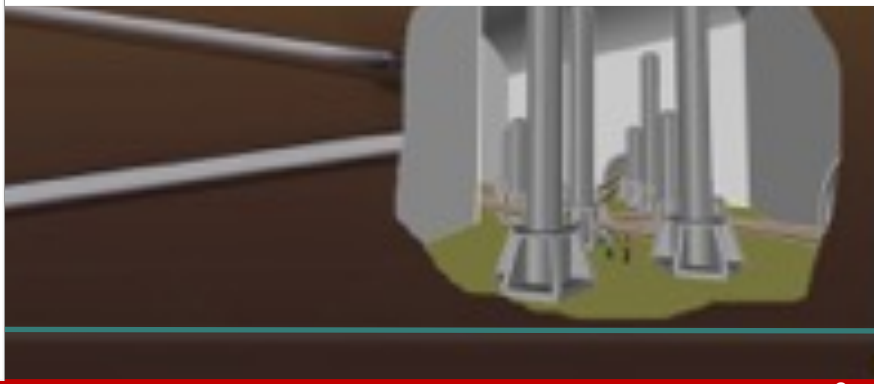
Have a look at the interpolated results of the velocity field in the local reference frame from global navigation satellite system (GNSS).



Farolfi et al. 2016



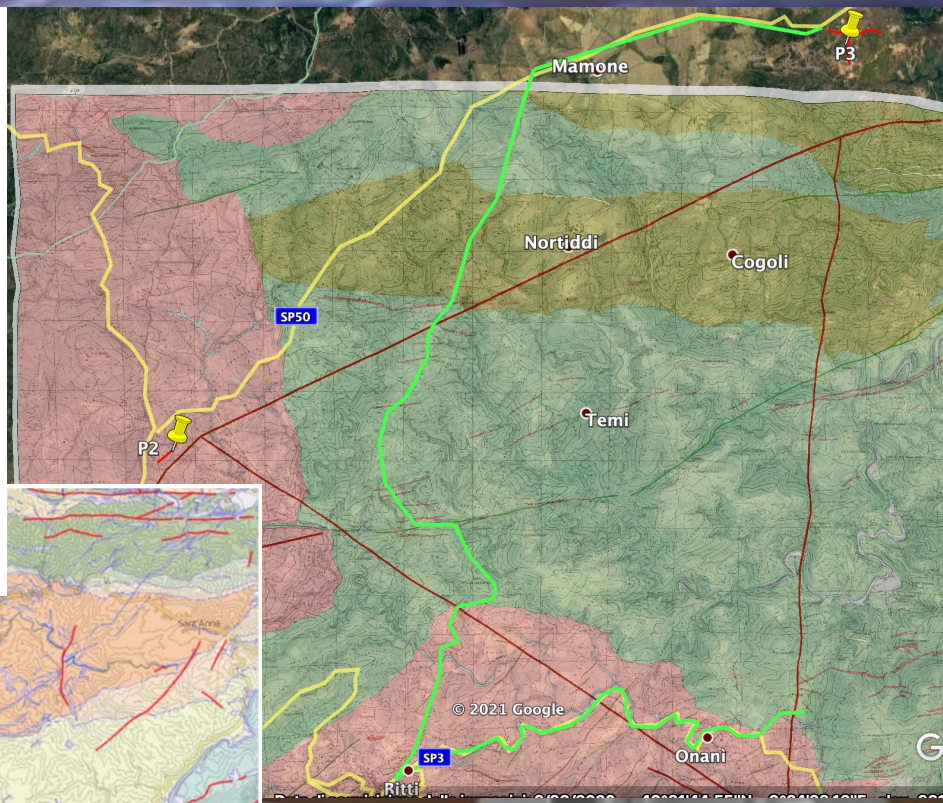
elocities and error bars with 95 % confidence level. The interpolated vertical
d is displayed by a graduated color scale. White represents stable area, blue is
for uplift ≥1.0 mm/a and red subsidence ≤−1.0 mm/a

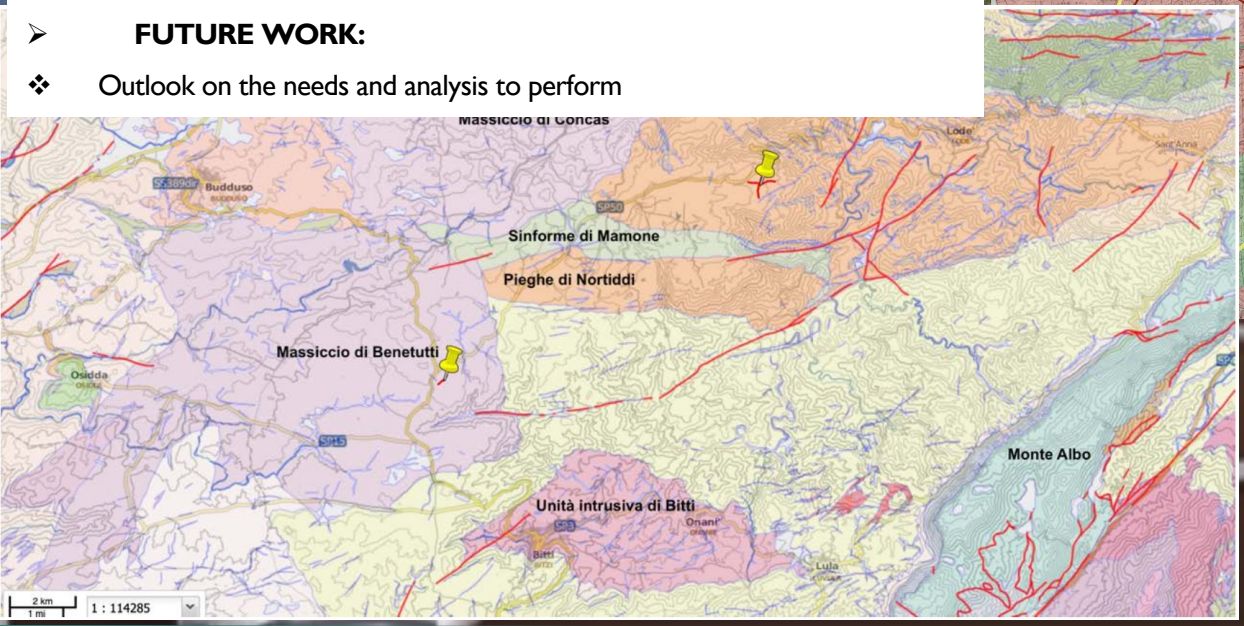


Geological and geoelectrical survey of the metamorphic and intrusive rocks on the Einstein Telescope site (Sardinia, Italy) G.L. Cardello et al.

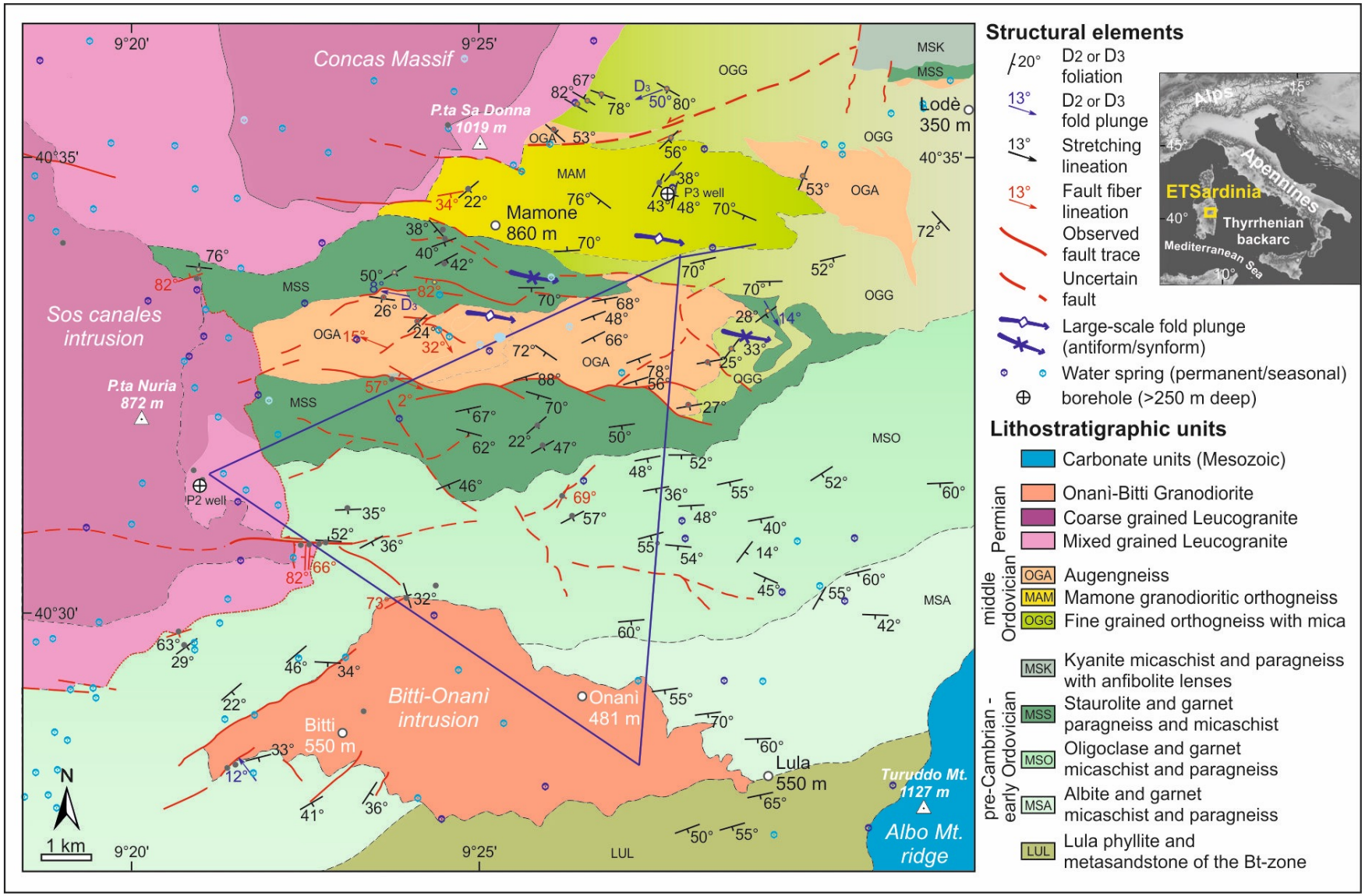
Geological map

- **PAST SASSARI'S WORK AND COMMON GROUND:**
  - Physical-mechanical, radiological, Lula-mine structural characterization
- **PRESENT WORK (DETAILS FROM PREVIOUS PRESENTATION):**
  - Geological structural Map
  - Fault characterization
  - Multiscale geological characterization of borehole surroundings by means of:
    - STRUCTURAL GEOLOGY
    - STRUCTURAL GEOMORPHOLOGY
    - GEOELECTRICS
- **FUTURE WORK:**
  - Outlook on the needs and analysis to perform





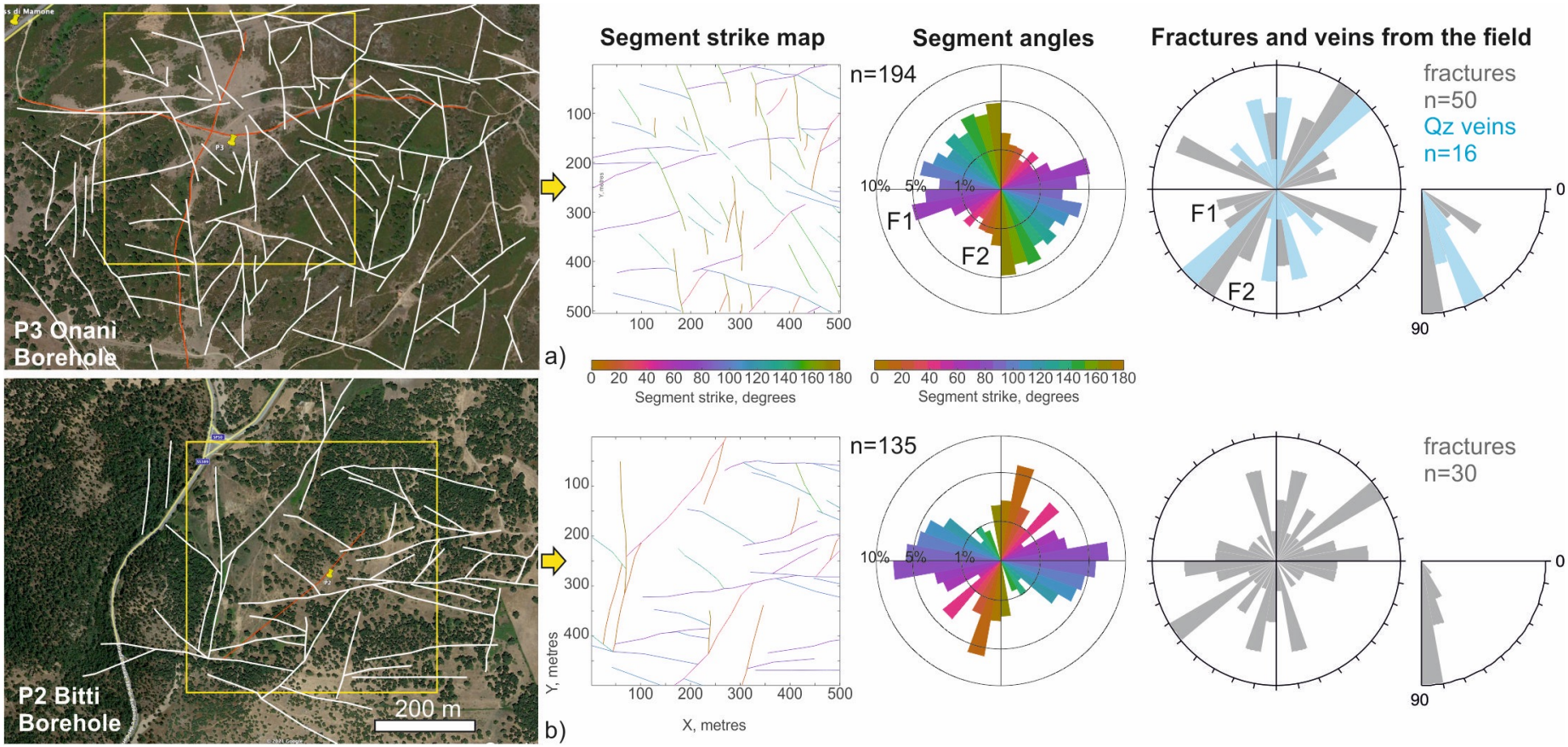
A NEW STRUCTURAL MAP



We have merged the lithologic information from published maps (also by comparing satellite images) and added new data collected in the field.

Courtesy of G.L. Cardello et al.

FRACTURES AT BOREHOLE SITES



Morpho-structural segment trace maps at P3 and P2 boreholes, created from the interpretation of satellite images, used to estimate fault segment orientation using FracPaQ (Healy et al., 2016). On the right, comparison of stereographic projects of both interpreted segments and measured fractures in the field.

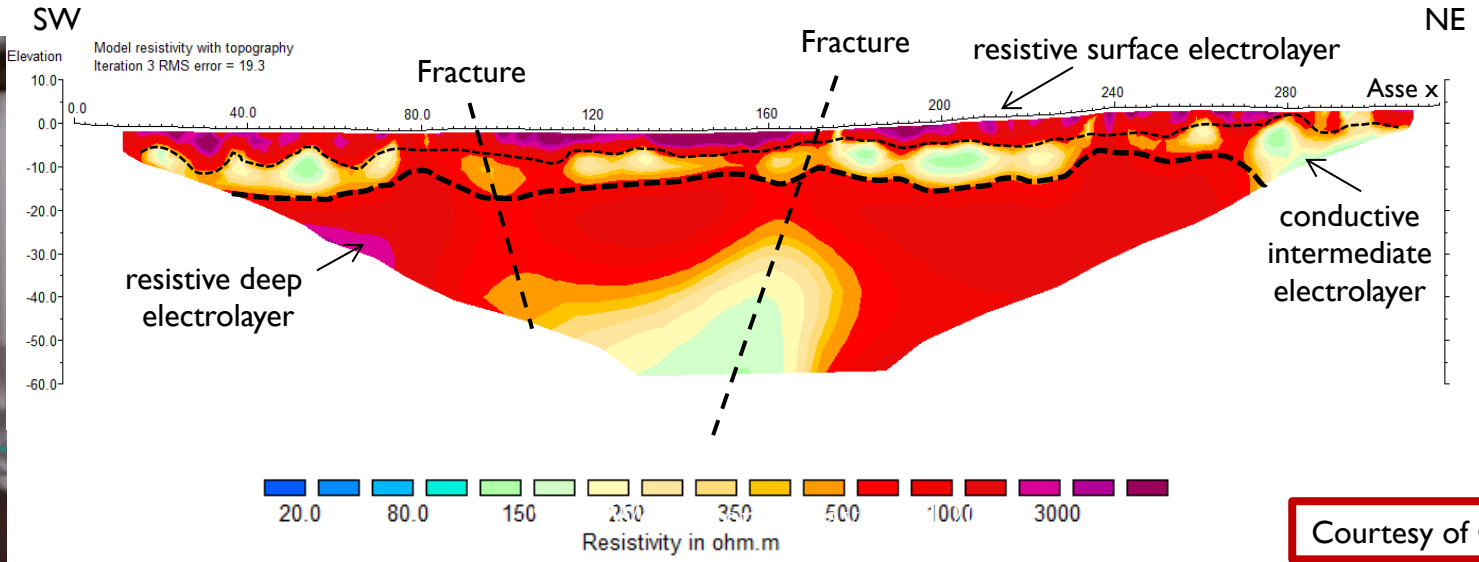
Courtesy of G.L. Cardello et al.

ERT RESULTS AT BITTI BOREHOLE

uniss
UNIVERSITÀ DEGLI STUDI DI SASSARI

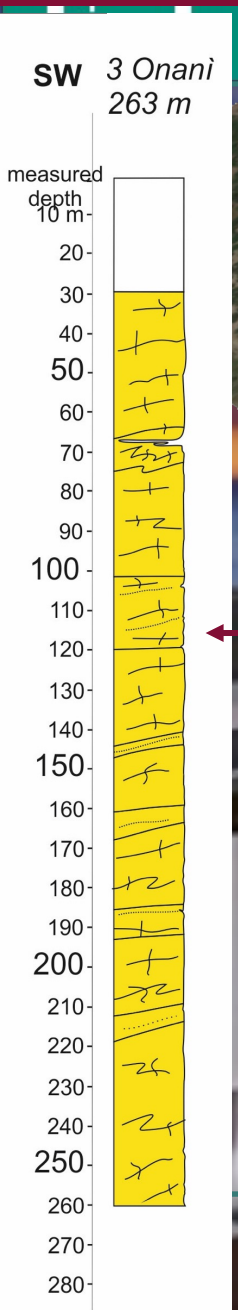
The tomography of the Bitti vertex
shows a stratified resistivity array composed of:

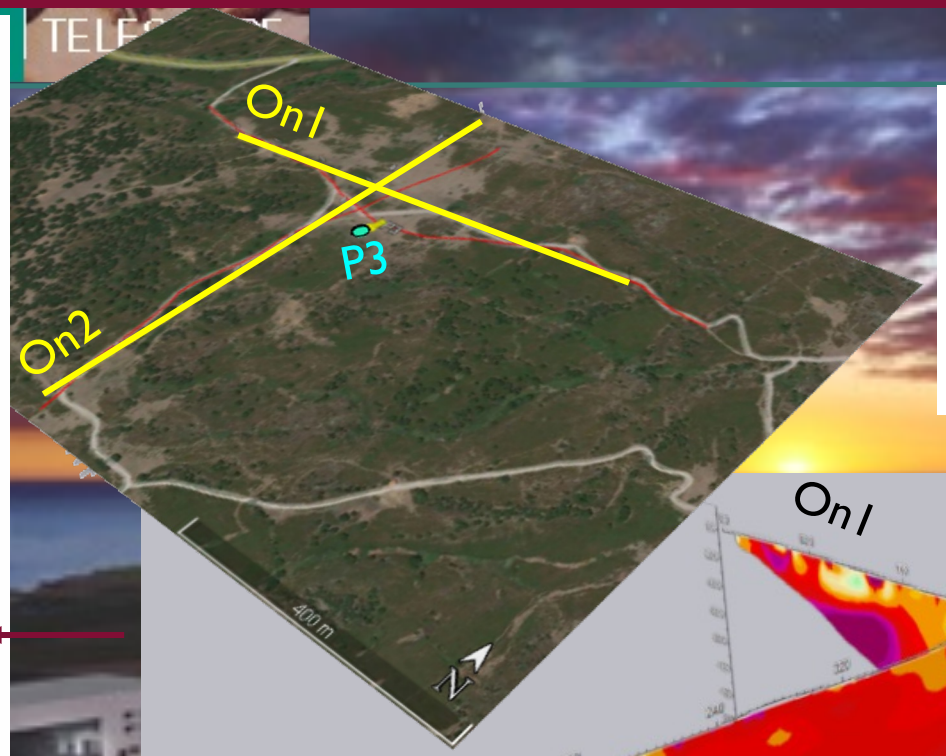
i) a near-surface resistive electrolayer
ii) an intermediate conductive layer
iii) a resistive deep electrolayer, which is characterized by a large deep conductive anomaly that is bounded by suddenly graded fault-related resistivity drop



Courtesy of G.L. Cardello et al.

ERT RESULTS AT ONANI' BOREHOLE

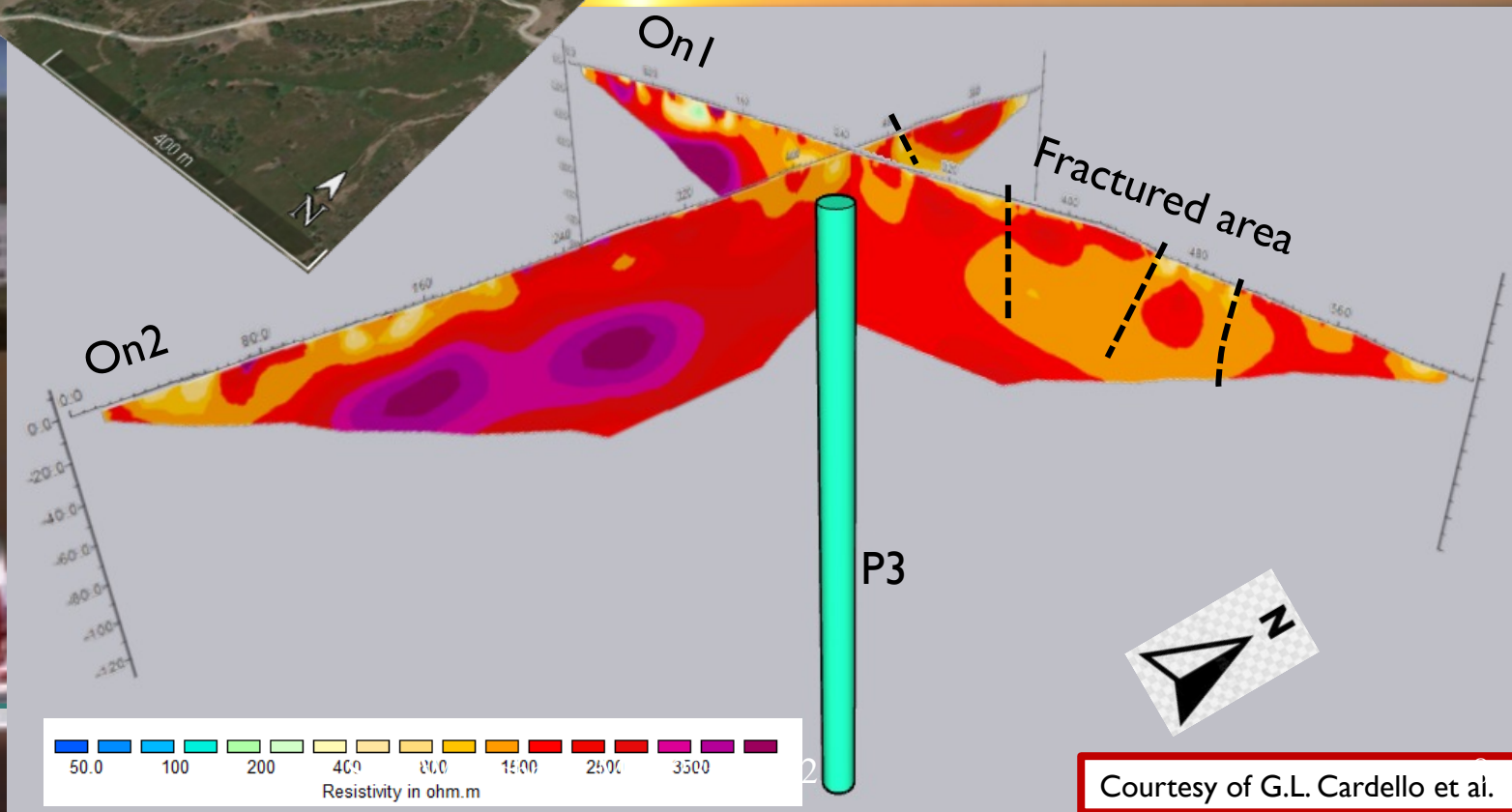




conductive layer occurs either as:

i) a discontinuous and well-localized layer near the surface (up to 20 m thick), or as

ii) a broader anomaly zone of values around 1000 Ωm that locally occurs at a depth of 30-90 meters.



Courtesy of G.L. Cardello et al.

General Conclusions

- New insights on the lithological distribution and nature of contacts and fault zones, which are relevant for the prediction of mechanic behaviour of the rocks along the tunnel tracks.

- **Geological results:**

Preliminary structural map of the ET Sardinia area

Definition of lithologies and structures

Relative chronology of deformation events

- **ERT results:**

Recognize the thickness of altered zones above the bedrock

identify superficial or suspended aquifers

Reconstruct the geometry of fault and fracture systems of limited extension and interconnectivity

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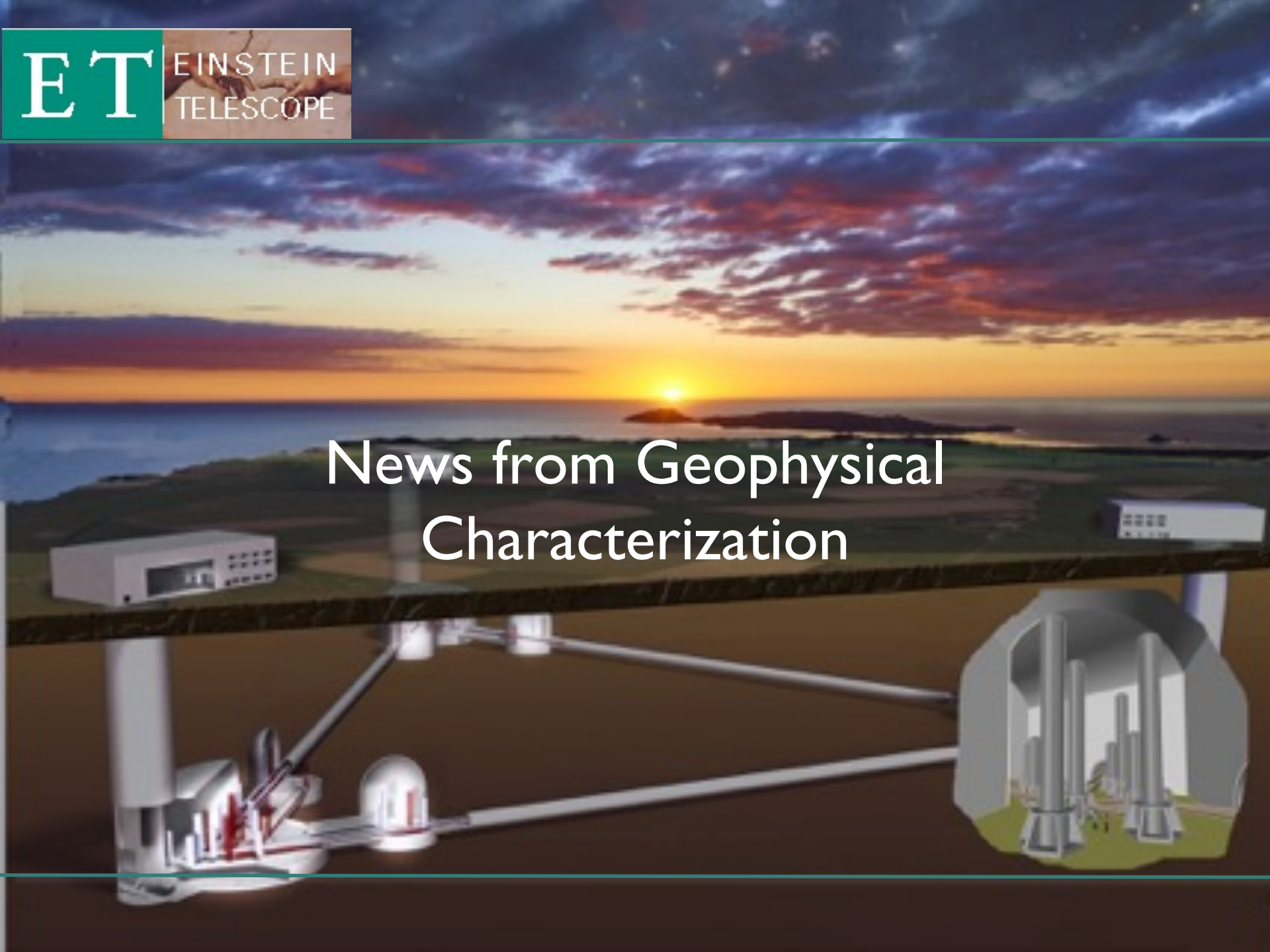
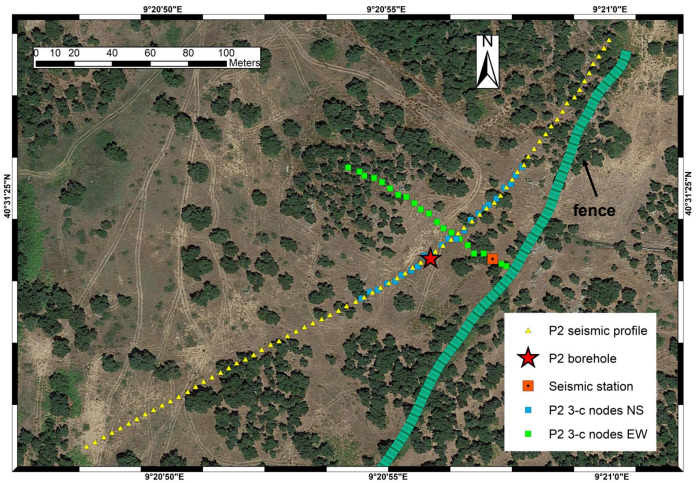
News from Geophysical Characterization



Measurements @ P2,P3



Site P2
location map and seismic surveys

Unfavourable local logi conditions hampered acquisition of two long (> 35 and intersecting seismic profile

Thus, we have collected:

1 high-resolution sei profile
1 vertical seismic pr (downhole)

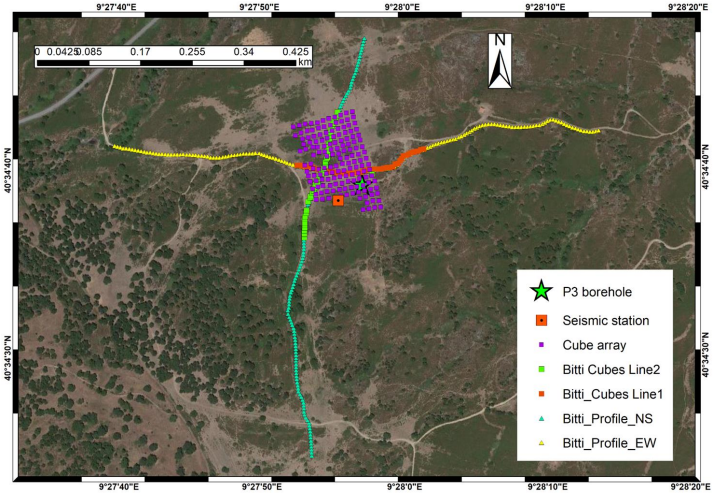
Instruments deployed by other te
2 linear arrays of 3-c nodes (**K.I.T**
1 broadband station (**INGV-Pisa**)

Site P3: surveys
1 vertical seismic profile

2 high-resolution seismic profiles with multi-fold wide-aperture geometry

Deployment by other teams:

nodal array of 153 3-D component cubes (K.I.T.)
2 linear arrays of 3-D component cubes (K.I.T.)
DAS vertical array (K.I.T.)
1 broadband seismic station (INGV-Pisa)



Site P2:
active-source seismic data

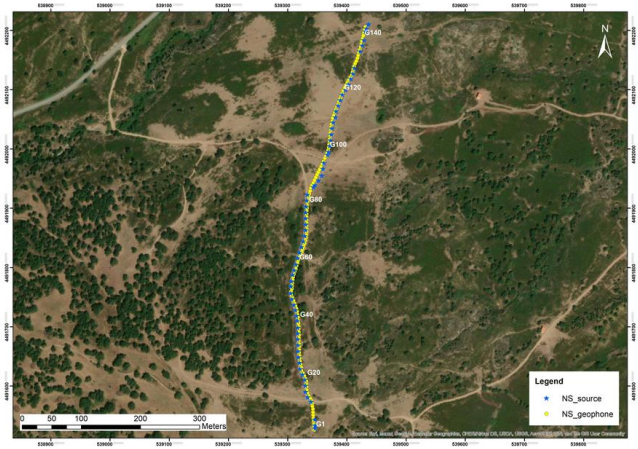
All the available space in the site was used.
It was not possible to deploy profiles > 360 m long

Seismic Profile	
Source	**Minibang**
N° Sources	39
Sources spacing	10 m
N° Geophones	72
Geophones spacing	5 m
Profile lenght	360 m
Total traveltime readings	2,520

Vertical Seismic Profile	
Source	**Minibang**
N° Sources	100
Maximum depth	234 m
Acquisition interval	2-4 m

N-S HR seismic profile	
Source	**IVI-Minivib**
N° Sources	69
Sources spacing	10 m
N° Geophones	144
Geophones spacing	5 m
Profile lenght	720 m

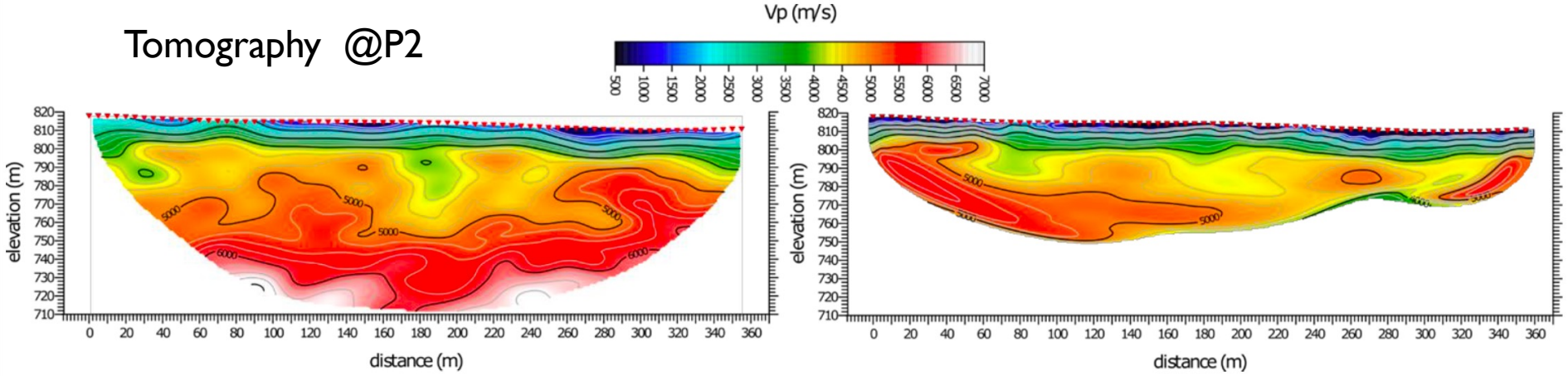
Site P3: seismic profile N-S



Courtesy of F.Villani et al.

P2: interpretation of the Vp model

Tomography @P2



Invdfe code (final rms = 1.29 ms)

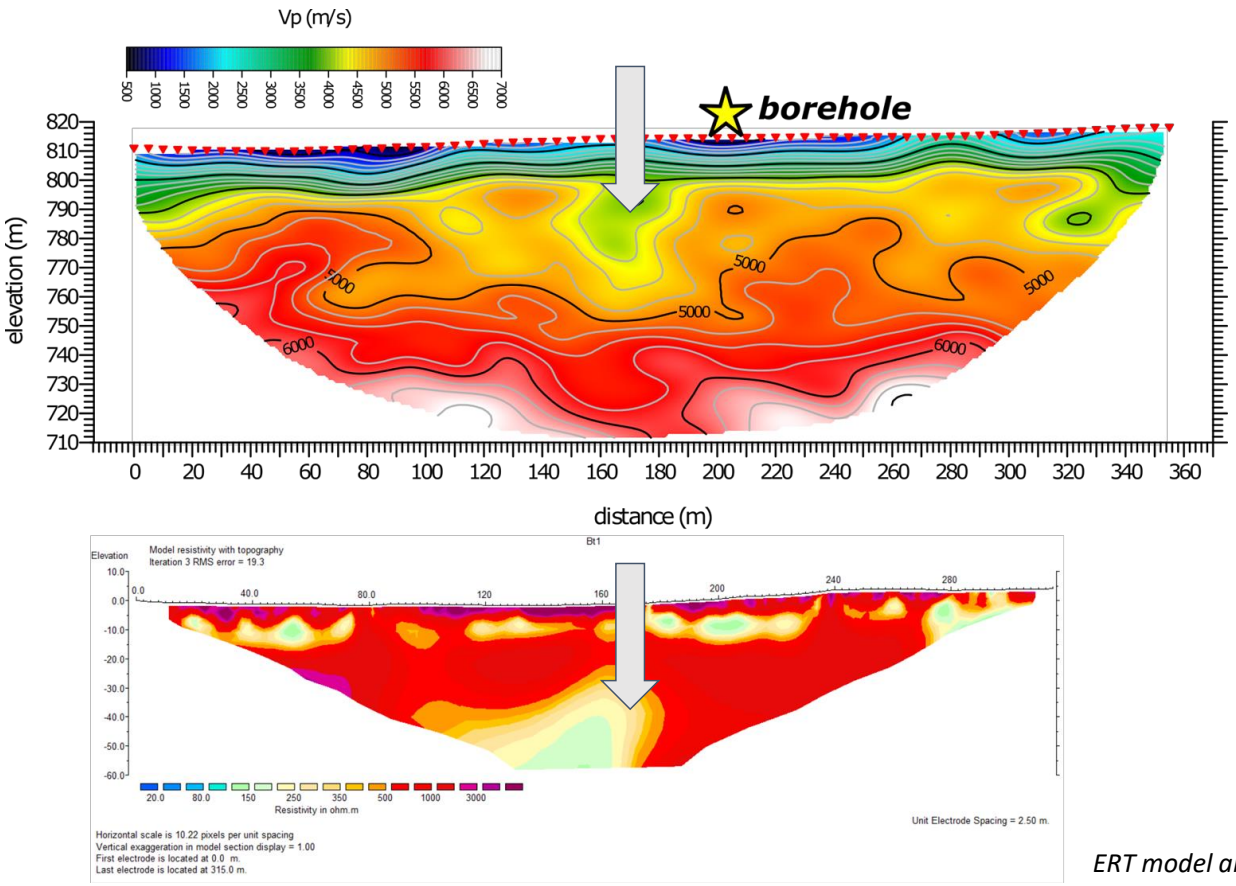
Rayfract© (final rms = 1.89 ms)

The models obtained with the two techniques show similar Vp range.
The multi-scale approach of the Invdfe code enables a deeper investigation depth.

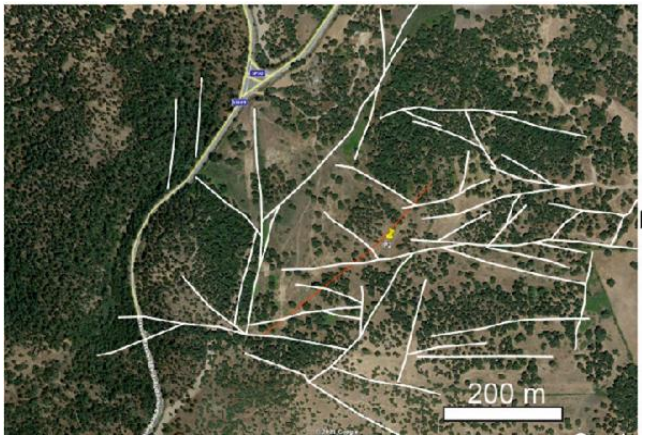
1. Near-surface high-Vp (about 3000m/s) agrees with exposed granites
2. The relatively thin shallow layer with very high vertical gradient defines the granite weathered zone
3. Vp values around 5000 m/s indicate a low degree of fracturing of the granitoids
4. Higher Vp on the southern side suggest poorly fractured or stiffer granitoids
5. A narrow vertical anomaly with relatively low Vp (4000-4500 m/s) indicates a fractured zone to the south of the borehole
6. We estimate a thickness of the presumed fractured zone < 10 m (resolution test)

Courtesy of F.Villani et al.

Seismic profile Site P2: comparison of 2-D Vp with ERT model



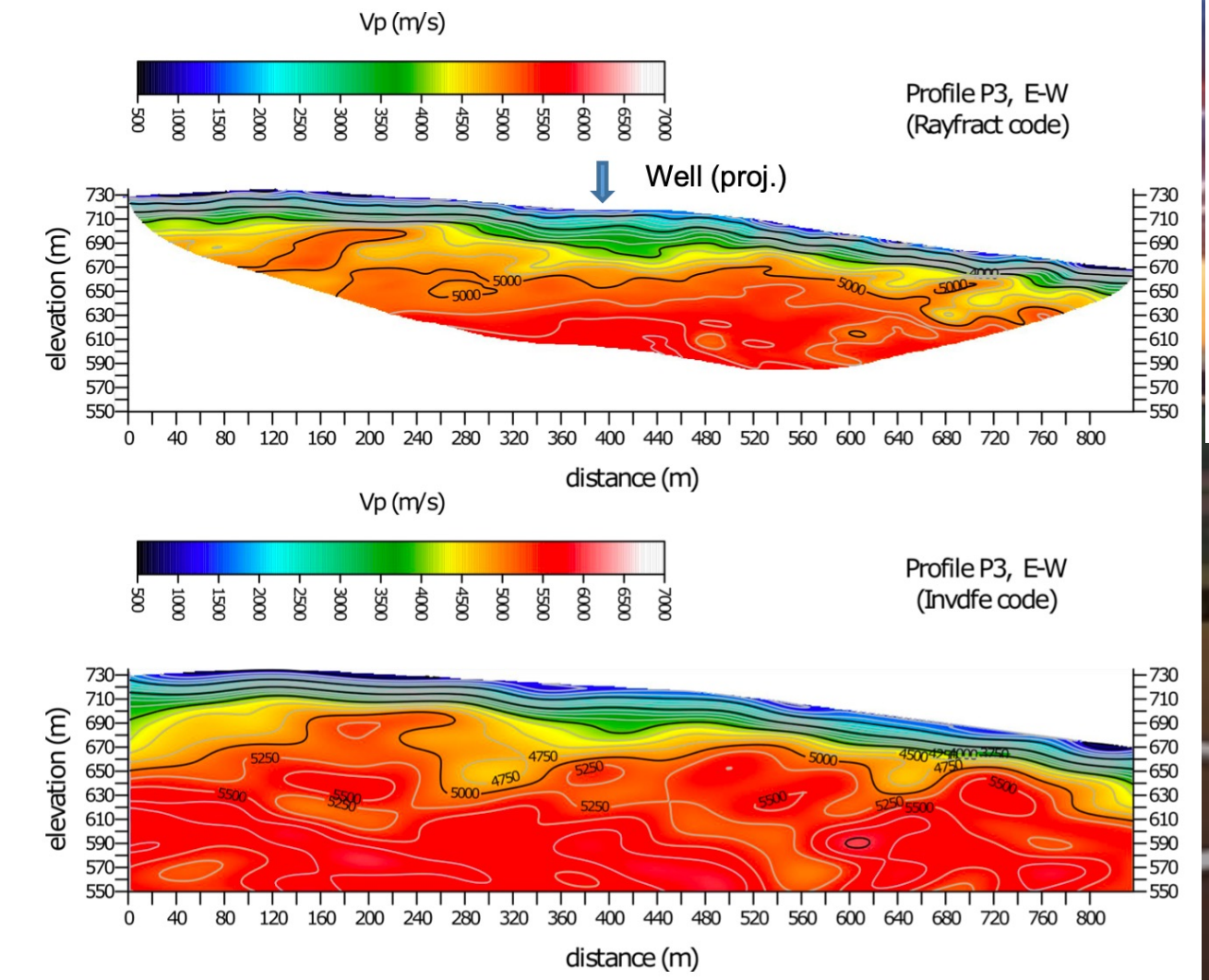
1) Seismic tomography and ERT agree in the thickness of the near-surface low-Vp/conductive layer (weathered granitoides)
2) Very high Vp and resistivity point to a weakly fractured bedrock
3) The vertical low-Vp zone agrees with a low resistivity region, confirming the presence of a steeply dipping fractured zone to the south of the borehole



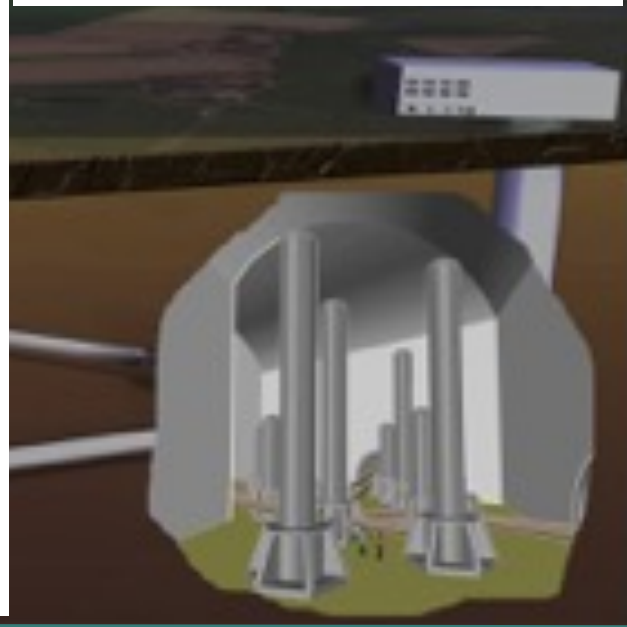
ERT model and fracture map courtesy of:
V. Longo, G. Cardello, G. Oggiano, D. D'Urso (University of Sassari)

Courtesy of F.Villani et al.

P3 E-W:Invdfe and Rayfract codes



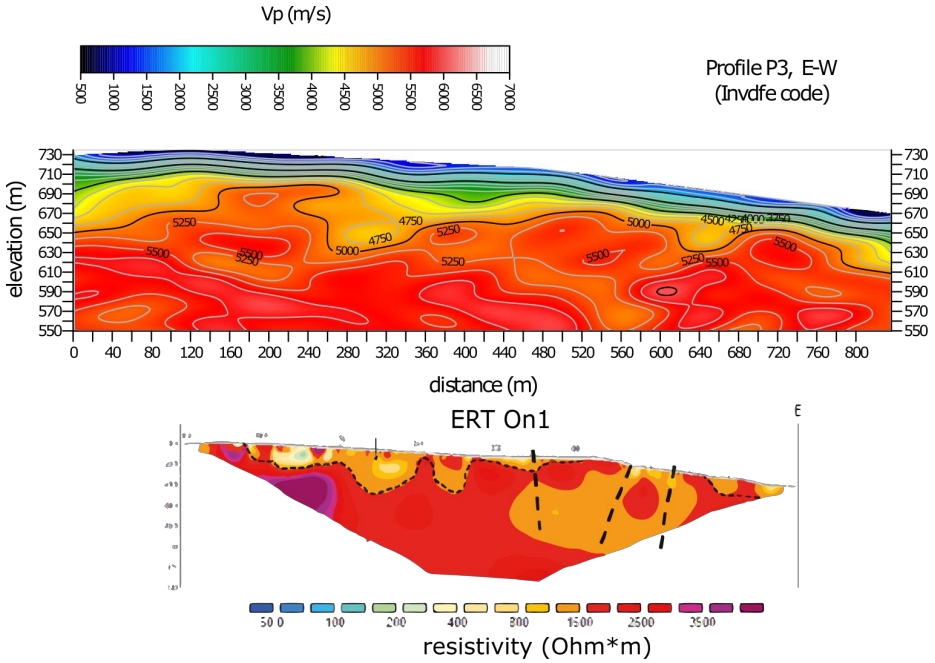
The velocity structure obtained with the two inversion codes is very similar but the multi-scale inversion strategy of **Invdfe** code allows to retrieve a slightly deeper model

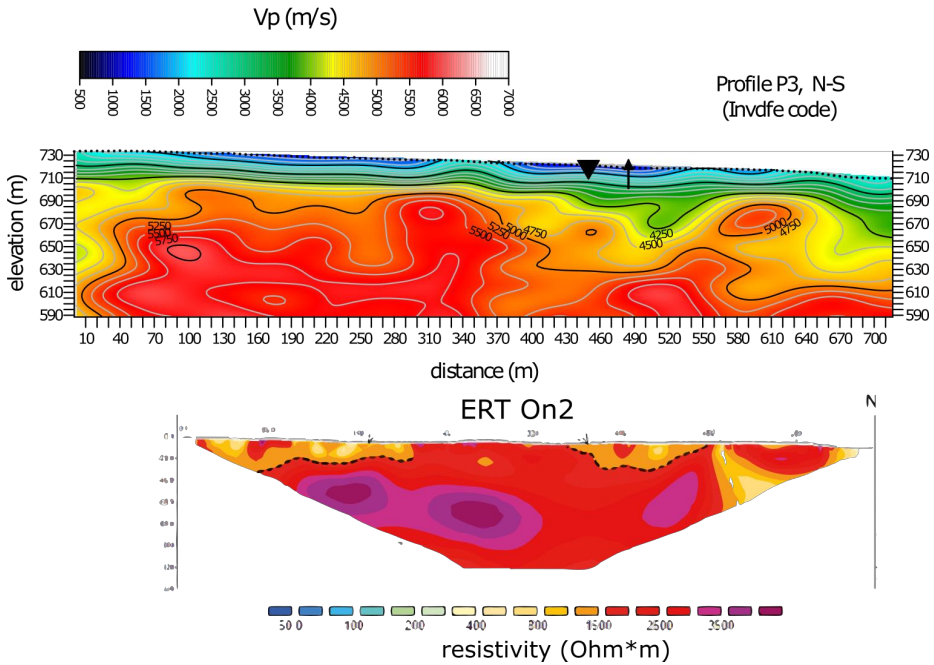


Courtesy of F.Villani et al.

Comparison between Vp refraction tomography and ERT models in site P3

ERT model courtesy of: V. Longo, G. Cardello, G. Oggiano, D. D'Urso (University of Sassari)





- In the E-W profile, to the west the high-Vp and high resistivity bodies are very shallow. The region at x 480-540 m with weak resistivity does not correspond to an evident decrease in velocity. The near surface weathered zone is very thin in the western slope.
- In the N-S profile, there is a good match between the high-Vp body (5500 m/s) and the high resisitivy region (3000 Ohm*m) The thinning of the very low-Vp near surface layer matches the region with low resistivity in the near surface.
- The lateral variation of resistivity at 500 m may be related to the region of low-Vp (4000-5000 m) to the north of the well: change in the physical properties of the bedrock?

Courtesy of F.Villani et al.

Conclusions

- The geological environment in the survey sites is not suitable for seismic reflection techniques due to the absence of important seismic impedance contrasts
- From 2-D tomographic models presence of very stiff crystalline bedrock (Vp 5000- 5500 m/s), in agreement with a shallow propagation of seismic waves (50-90 m), despite the use of 720 and 835 m long arrays (with maximum offset of first arrival traveltimes readings of 715-725 m).
- The results of seismic surveys pointed out the absence of deep important fault zones with significant changes in the elastic properties in site P3.
- In site P2, there is hint for a fractured zone close to the drill site, in agreement with ERT models.

Courtesy of F.Villani et al.

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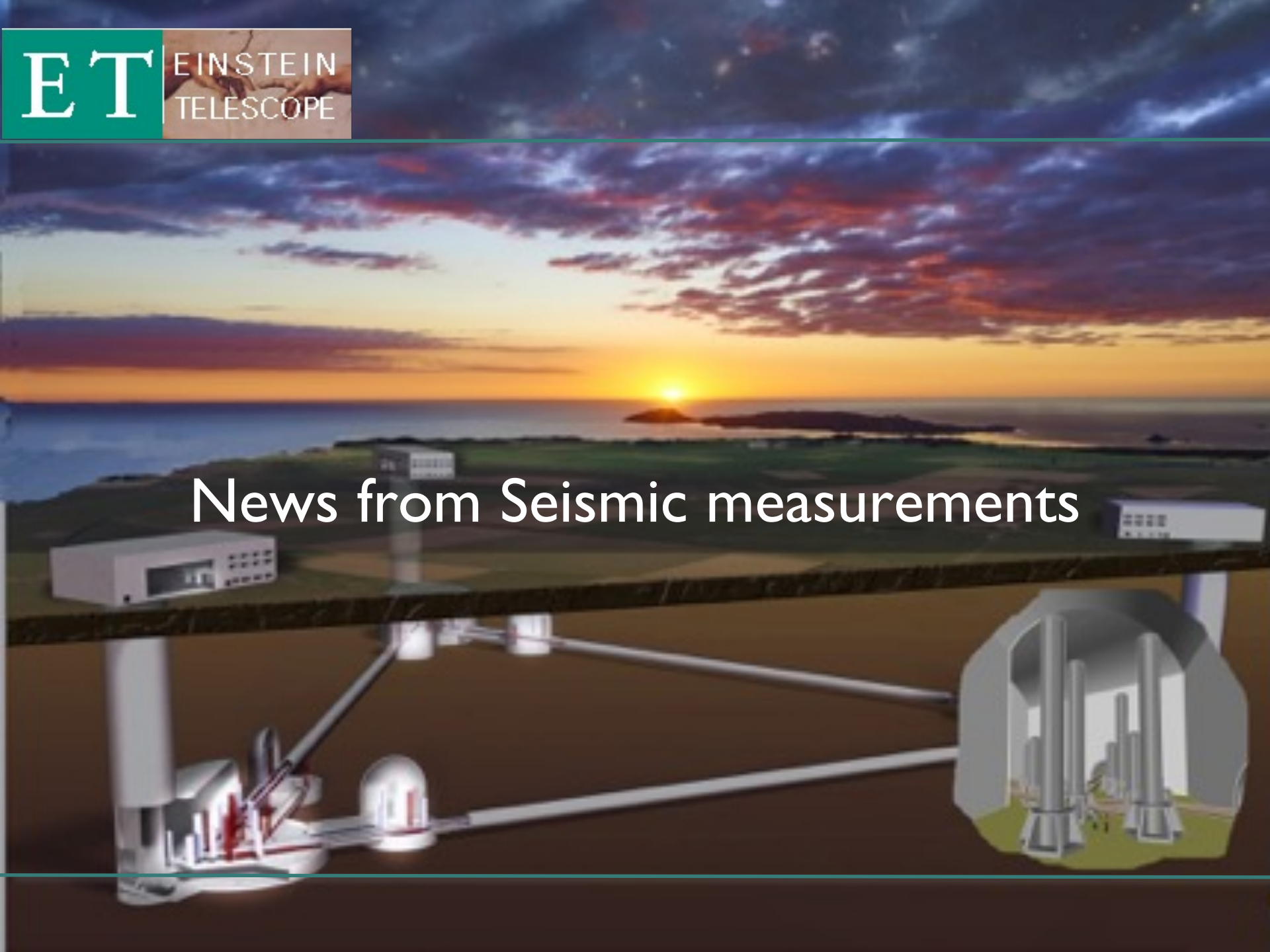
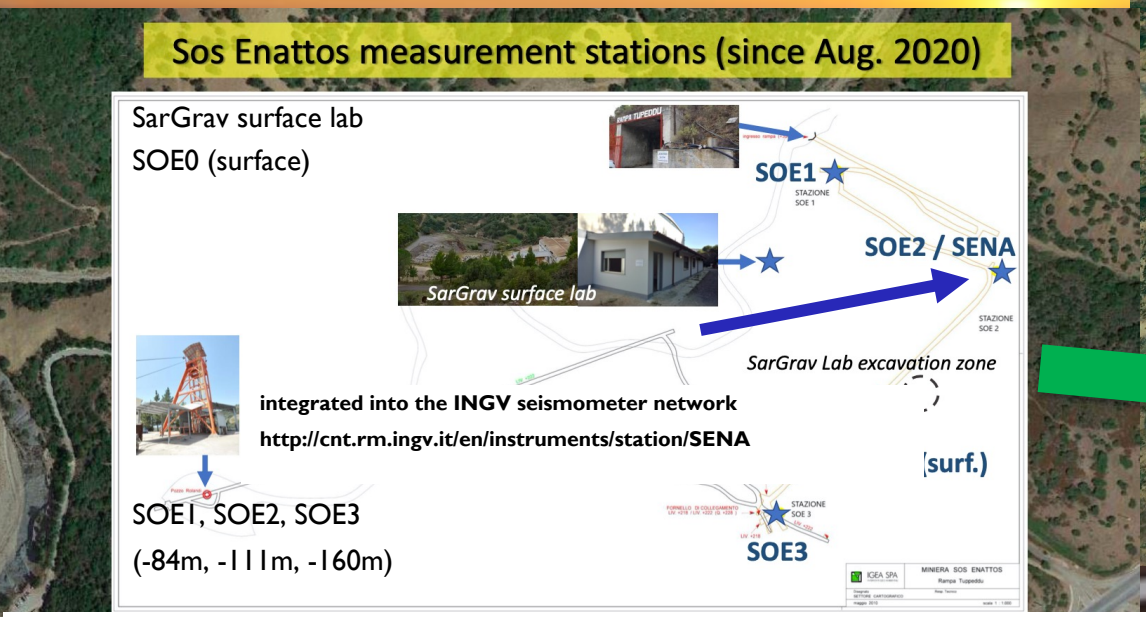
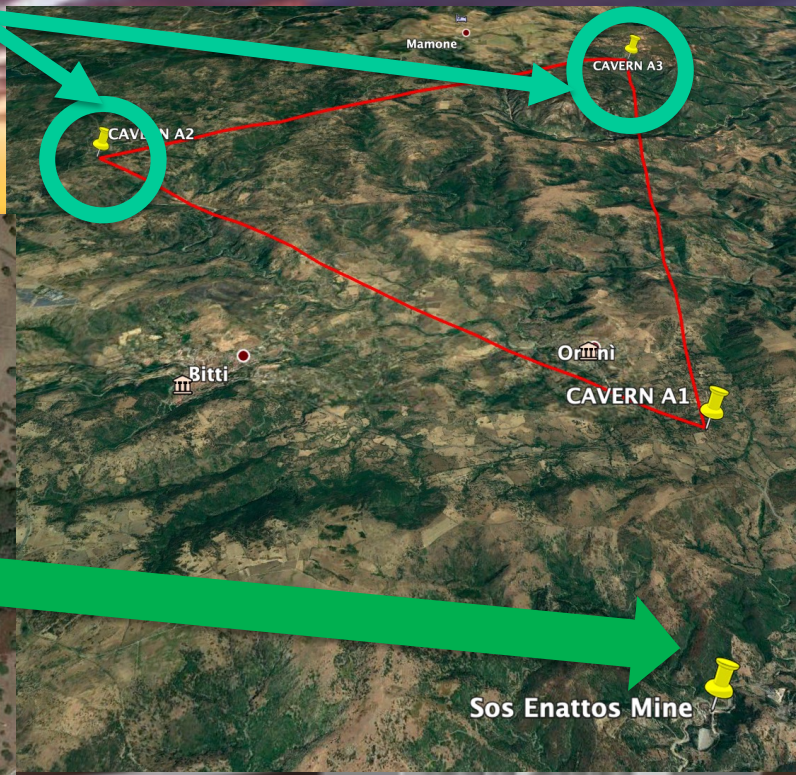
News from Seismic measurements



Measurement in Sardinia

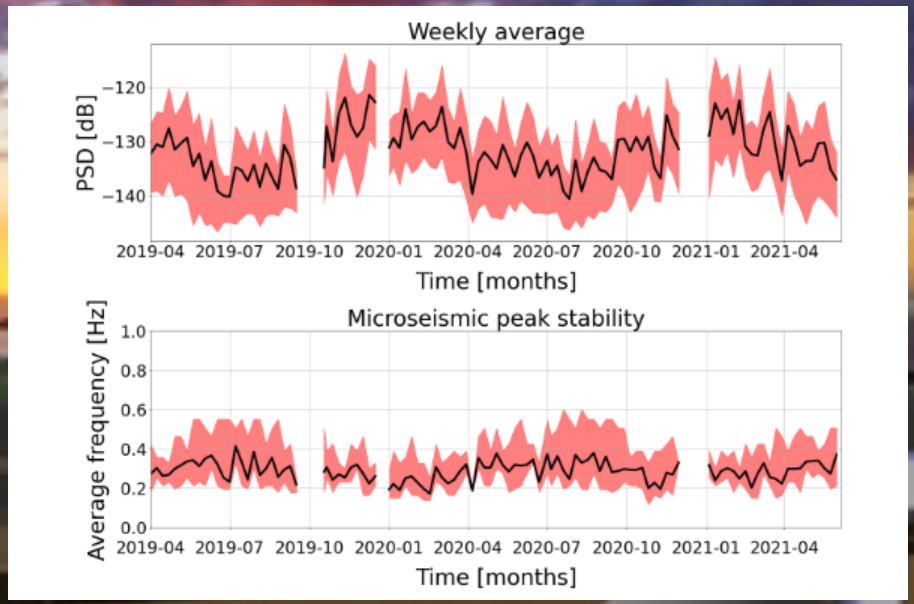
Characterization of the Bitti and Onanì corners: Surface and underground seismic and environmental measurements





4 broadband seismometers, 3 short-period seismometers, 2 magnetometers, 1 tiltmeter distributed over underground and surface stations

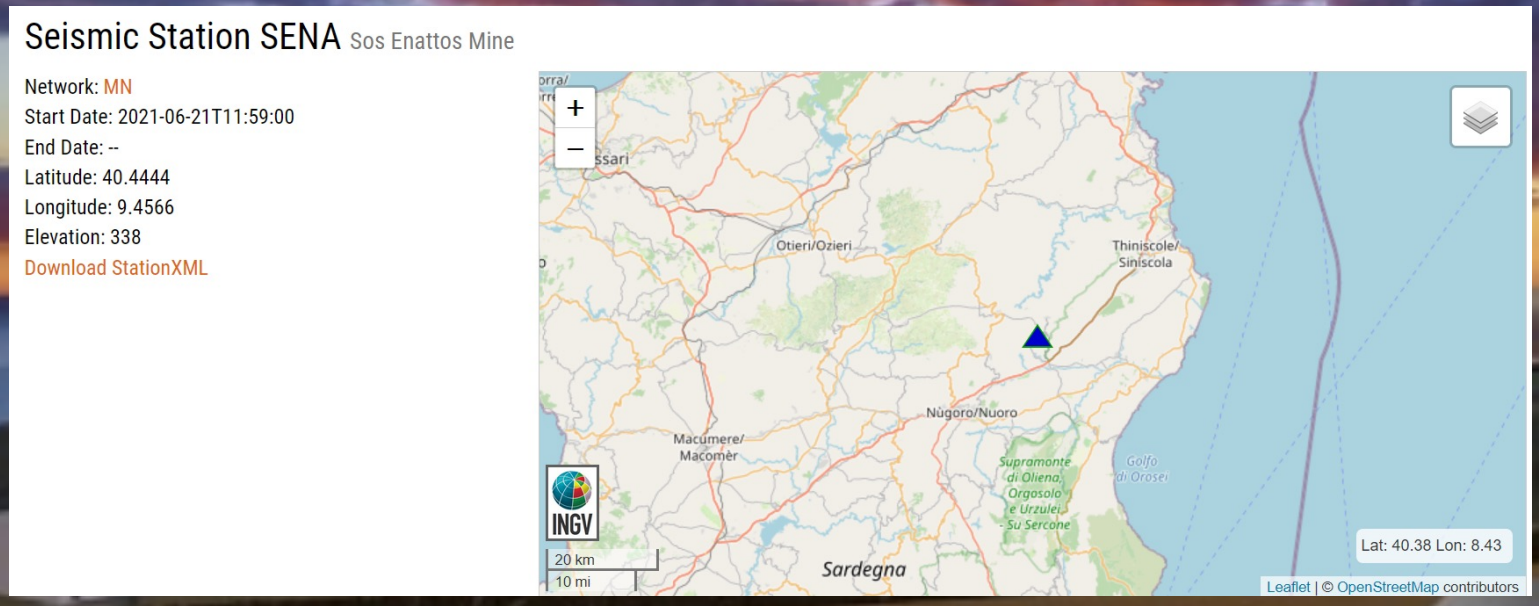
Updates from Sos Enattos (PI)



- A new T360 seismometer was added to the network at SOE1 (April 22nd 2022);
- Study of seasonal natural and anthropogenic noise:
  - **M. Di Giovanni's talk** (paper ready for submission, internal review)

Courtesy of L. Naticchioni et al.

Updates from Sos Enattos (PI)

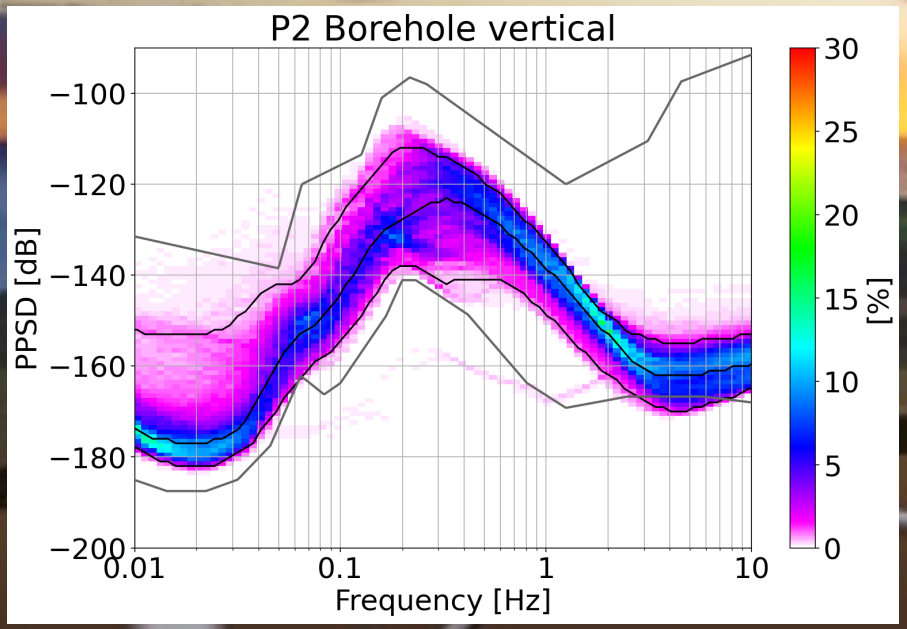


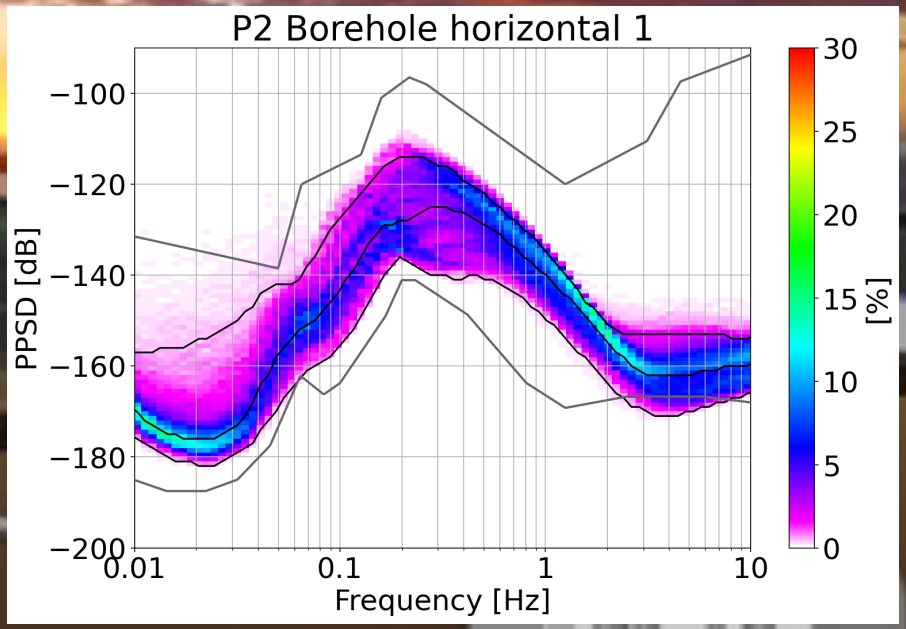
- SOE2 (SENA) station at -111m was moved from the IV (*Italian Seismic Network*) to MN (*Mediterranean Very Broadband Seismic Network*) on February 1st 2022. To access the public data after that date the network must be changed accordingly.
- More info at: http://terremoti.ingv.it/en/instruments/station/SENA

Courtesy of L. Naticchioni et al.

Updates from P2 and P3

About half-year of continuous underground seismic measurements from the P2 and P3 boreholes, e.g.:



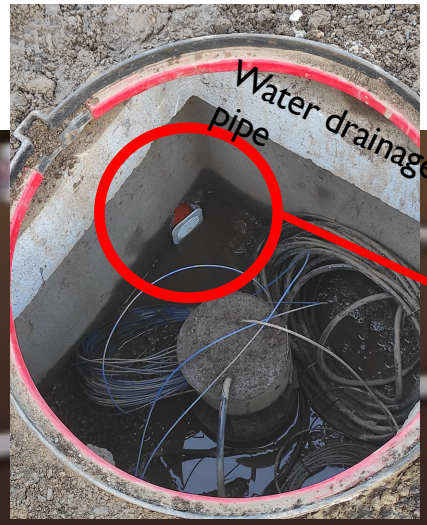


P2 (-264m) : 01 October 2021 – 20 March 2022

Courtesy of L. Naticchioni et al.

Updates from P2 and P3

- P2 and P3 borehole stations operative since mid Sept. 2021, but:
  - Final configuration of the DAQ input ranges fixed in October 2021;
  - During winter months we realized the need for an installation improvement (mainly to allow rainwater drainage from the pits);
  - Surface sensors offline from 15th March to 21st-22nd April to allow excavation works;
  - Improvement works completed in March 2022;
  - We are setting flags to exclude data taken during noisy excavation works (e.g. 25th and 29th March).



Courtesy of L. Naticchioni et al.

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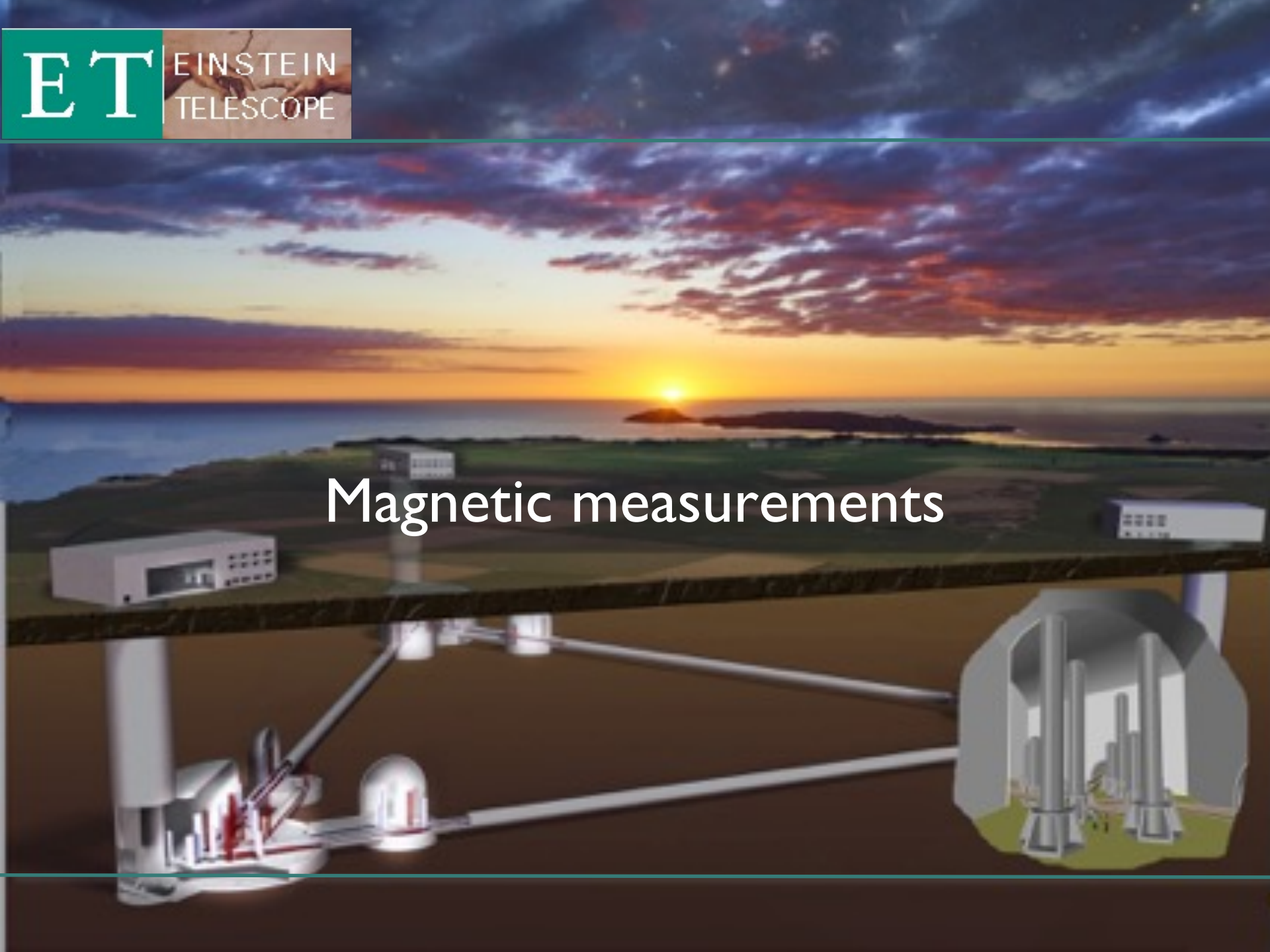
Magnetic measurements



Magnetic Noise Measurements

Motivation

- The noise from natural or anthropogenic electromagnetic fields can affect the sensitivity of a gravitational wave interferometer in different ways:
  - Direct coupling with actuators of the mirror and suspension systems;
  - Coupling with electronic devices managing the interferometer;
- A special role, among the possible noise sources, is played by the Schumann resonances: a world-wide electromagnetic field sustained by the lightning discharges between the Earth surface and the ionosphere.
- Due to their global character, the Schumann resonances could set a strong limit in the detection capability of selected class of sources (e.g GW stochastic noise);

Courtesy of R. De Rosa et al.

Magnetic Probes

- A new magnetometer was installed in SOE2 (-111 m);
- Perpendicular to the old one;
- Data available from 2021 December 11;
- All probes are Metronix MFS-06/06e, band: 0.25 mHz – 500 Hz;

Probes at Bitti (P2)

- Last September 17 a couple of magnetometers were instal in P2 (Bitti – NU), N-S and E-W orientation;
- The probes are the same used for Sos Enattos, with a different data logger (Metronix ADU 08) sampling at 512 Hz;

- The surface magnetometer (SOE0: N-S orientation) is also active.
- Several stops during the last years.
- Data taking periods:
  - 1 - 2020 August 6 to November 9;
  - 2 – 2021 March 13 to April 30;
  - 3 – 2021 July 27 to September 14;
  - 4 – 2021 October 16 ongoing

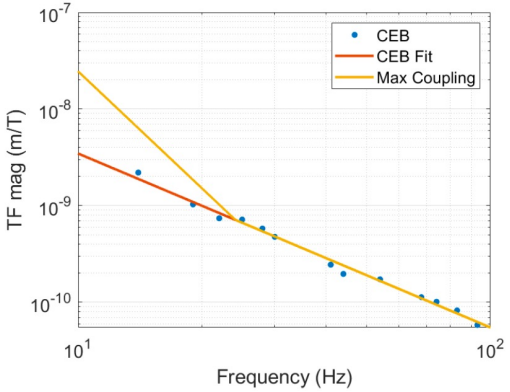
Few weeks ago, by taking advantage of the works for the water drainage in P2 and P3, the installation of the vertical magnetometers was prepared;

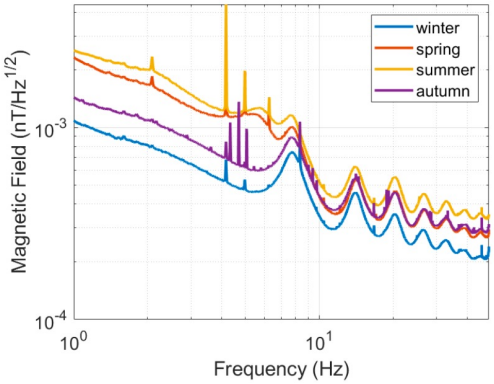
The sensor for P2 is already available, while the sensors for P3 should arrive in a couple of months;

Courtesy of R. De Rosa et al.

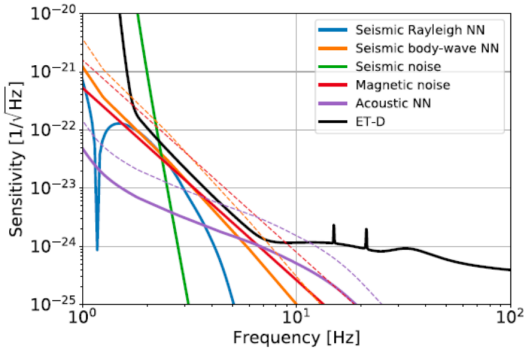
Magnetic Noise Projection

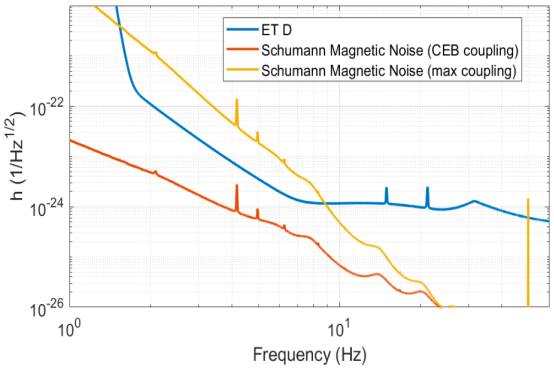
- The Magnetic field measured at SOE2 was used to estimate the effect of this noise on the ET floor;
- The coupling function was estimated by the result of the magnetic noise injections performed in Virgo during O3 (VIR-0291A-20). Warning: no direct measurement under 10 Hz;



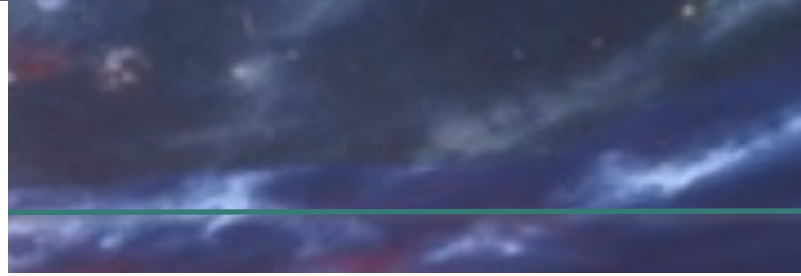


- With this assumption the magnetic noise (measured at SOE2), depending on the coupling model, the magnetic noise can limit the sensitivity;
- Warning: difference in the magnetic noise background

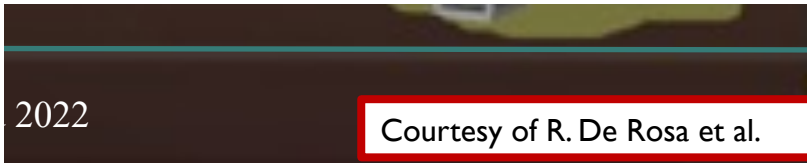




F. Amann et al. Rev Sci Instrum 91 (2020) 094504
K. Janssens et al. PhysRevD 104 (2021) 122006



- Projection in a very quiet environment;
- Coupling below 10 Hz just extrapolated by the fit;
- We expect a significant background noise increase in the final ET environment;
- More inputs are needed to estimate the magnetic coupling, both at low as at high frequencies



2022

Courtesy of R. De Rosa et al.

Future Plans

- Geology:
  - Geophysical campaign (geoelectrics and seismic lines along roads)
  - Complete the structural review of the area => Field survey
  - Hydrogeological model
  - Characterize fracture system => from LIDAR images
  - Perform microstructural studies => thin sections
  - Collect new samples for dating and chemical characterization
  - 3D geological modelling
- Site Measurements
  - Complete the long-term measurements
  - two additional magnetometer stations: SOE3 and P3
  - Interaction with windmills
- PNRR projects supporting ET in Sardinia:
  - INFN: a Reference System Network for geodetic survey (in coll. with ASI), strainmeter, Environmental Impact Assessment, Feasibility Design for surface works, Feasibility Design for technological systems, Feasibility Design of the Underground works
  - INGV: realization of a geophysical lab in the Sos Enattos area with additional 6 boreholes

Natural Radioactivity

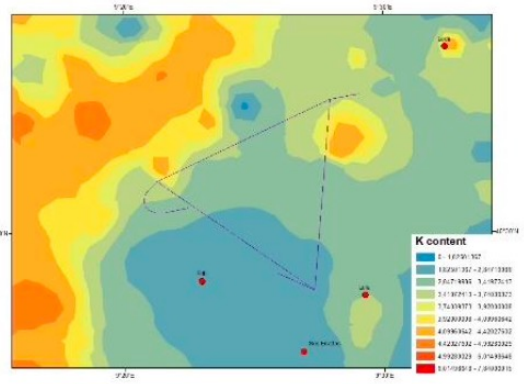


Fig. 9: *Contour map* dell'abbondanza naturale del ^{40}K.

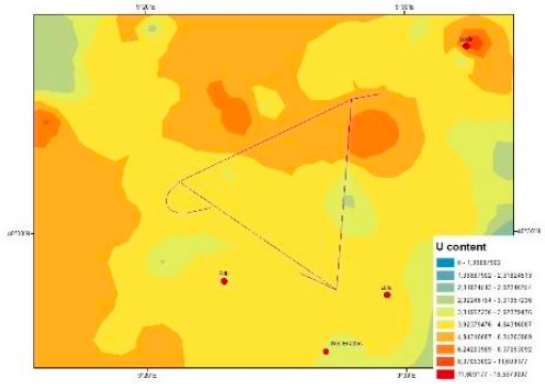


Fig. 10: *Contour map* dell'abbondanza naturale del ^{238}U.

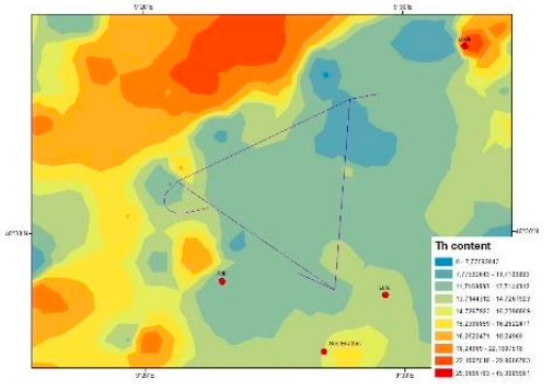


Fig. 11: *Contour map* dell'abbondanza naturale del ^{232}Th.

Courtesy of L. Cardello & Oggiano

Courtesy of A. Cardini et al.