Some Requirements

No involvement in active tectonics: low seismicity low crustal velocity;

Ground deformation: weak or absent

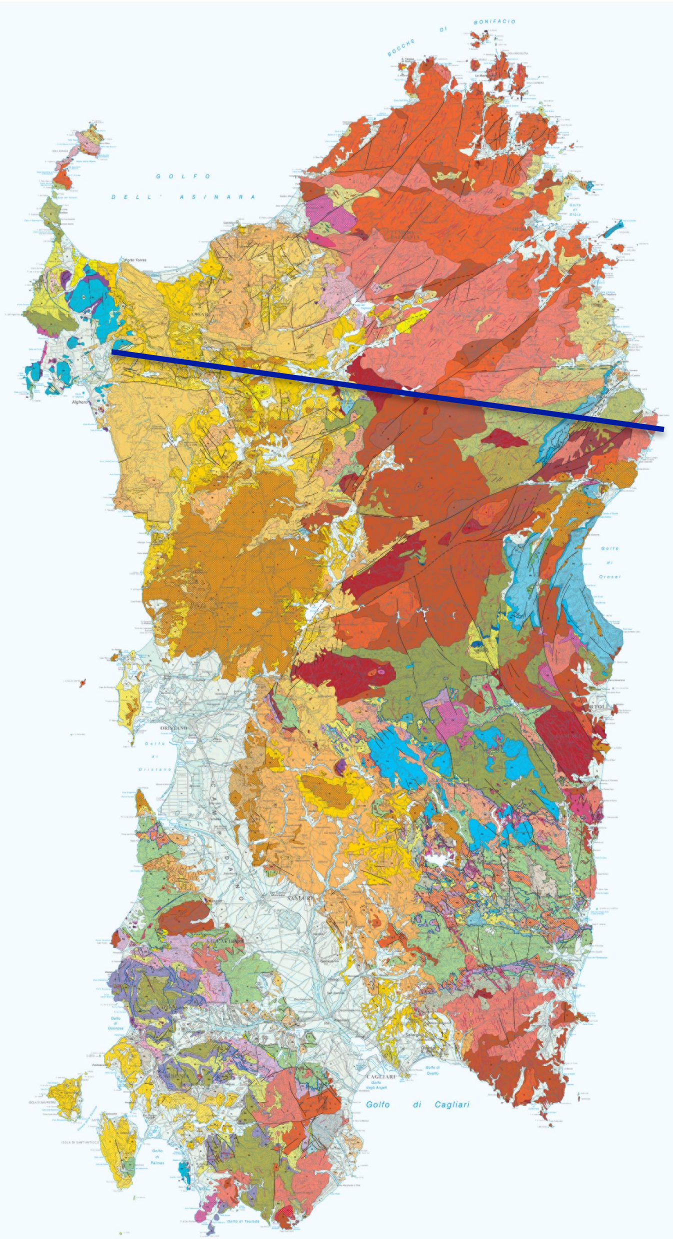
Good geomechanical properties of the rocks along the Tunnels and caverns

Few groundwater (dry conditions are better but unachievable)

Rocks with limited radon emission (low ^{238}U, low porosity)

Low environmental impact

How Lula site satisfies   them

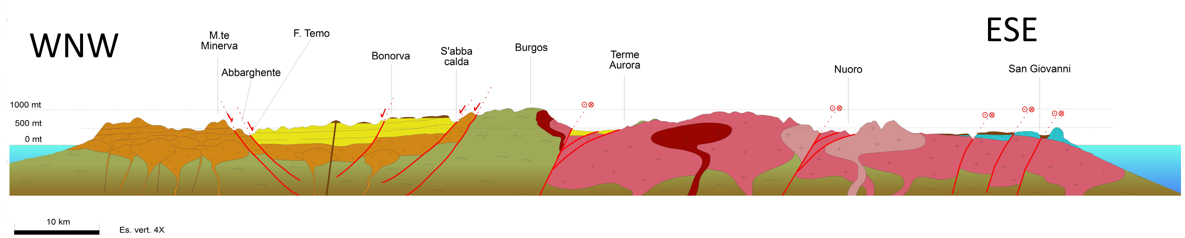


Metamorphic basement widely intruded by Carboniferous-Permian Granitoids (Variscan structuration; 360-290 Ma)

Deeply eroded Mesozoic carbonate cover

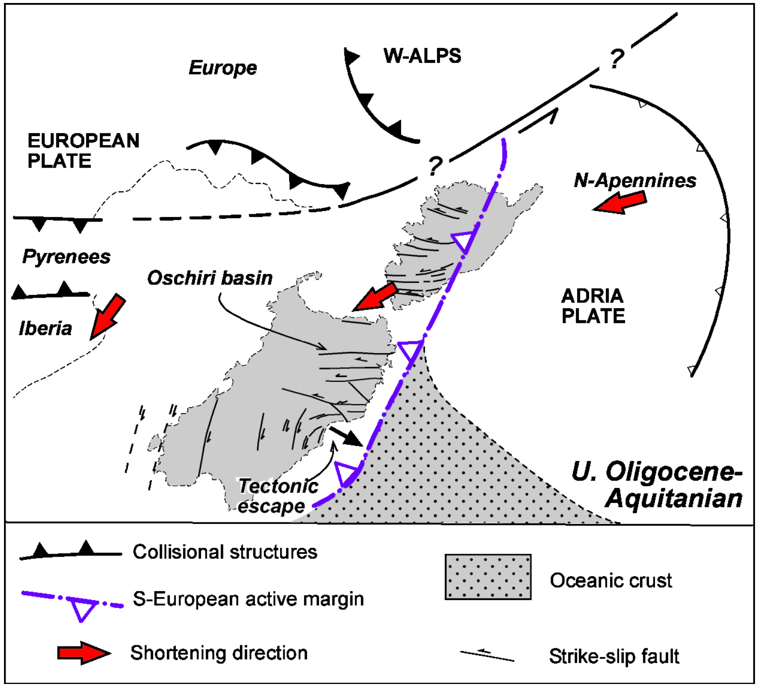
Tertiary sedimentary and volcanic covers

Quaternary alluvial deposits and minor within-plate basalt flows

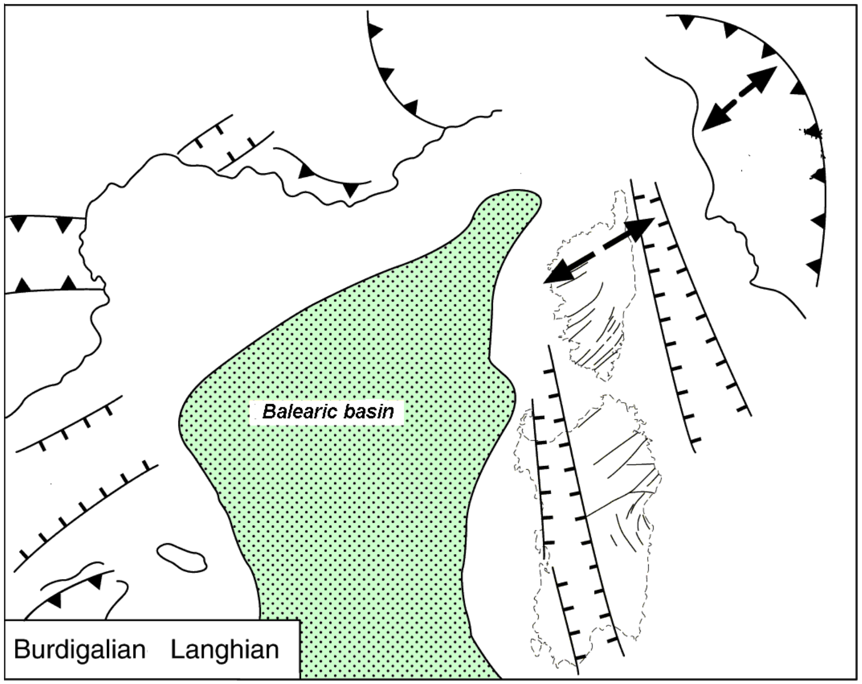


Tertiary geodinamics and related structures

Aquitanian 22 ma



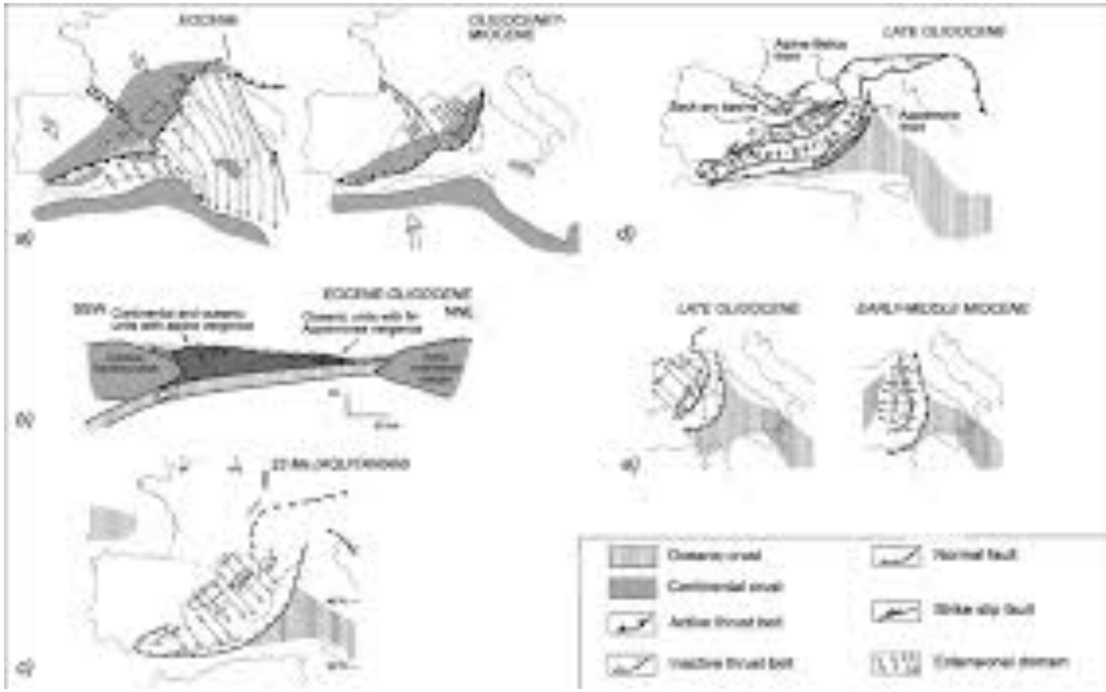
Upper Burdigalian 17 Ma



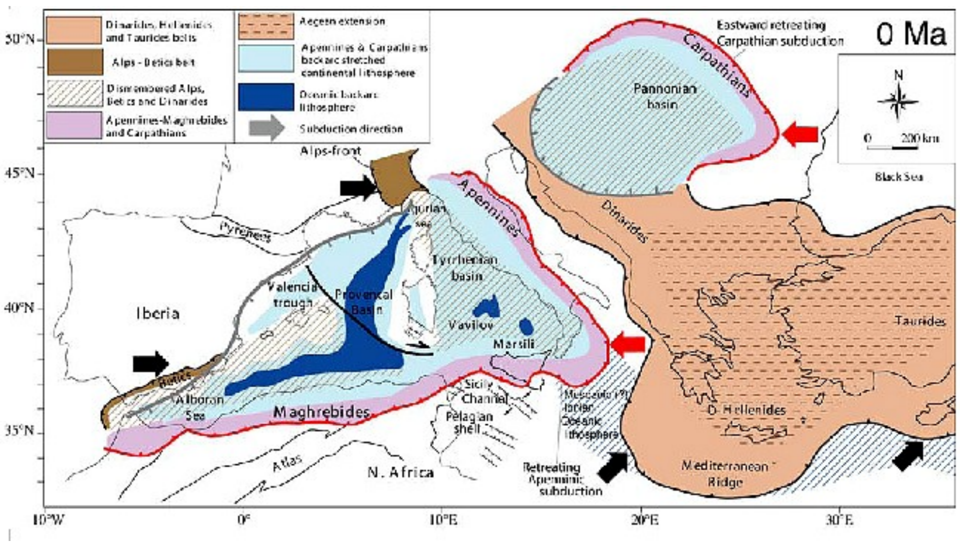
After Carmignani et al. (1998; 2004)

Sardinia, as part of the south European Margin, was involved int he collision/ convergence between Adria and Europe. The main structures related to this dynamic are strike slip faults, trust and Folds, which developed along transpressive Corridors. Sstrike-slip Basins are the transtensive counterpart in correspondence of releasing bends

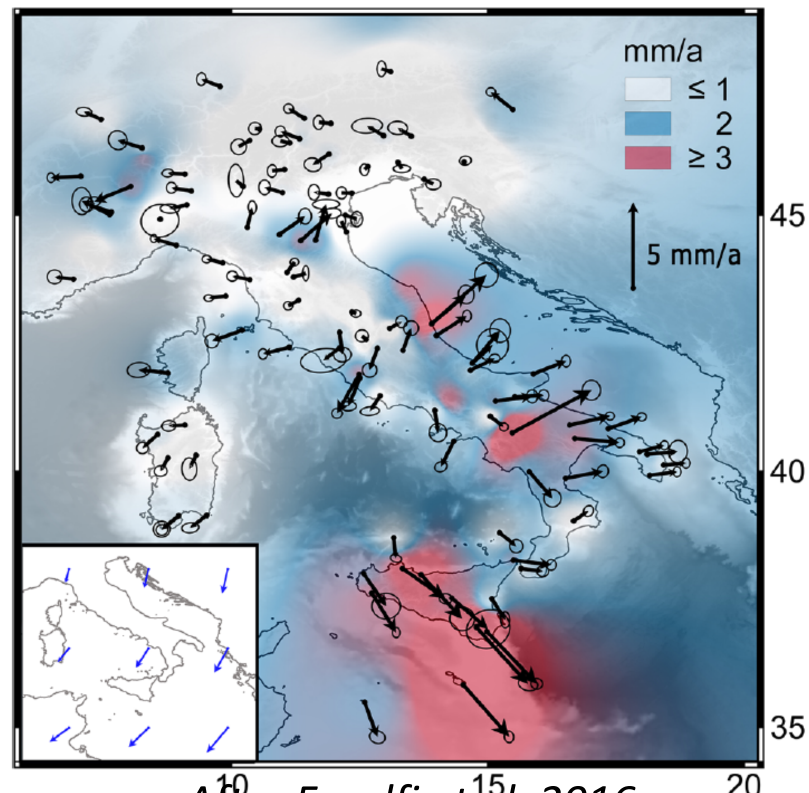
The retreat of the Adria slab, in Burdigalian, time caused the counterclockwise rotation of the Sardinia-Corsica microplate, the opening of the Ligurian Provencal Basin and a general NE-SW extention that led to the opening of several NW-SE trending basins.



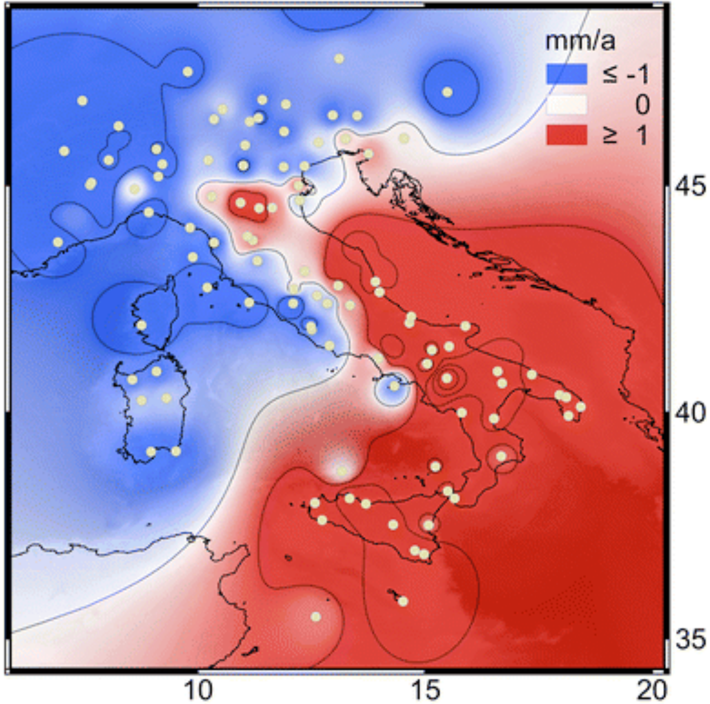
After Oggiano et al. (2009)



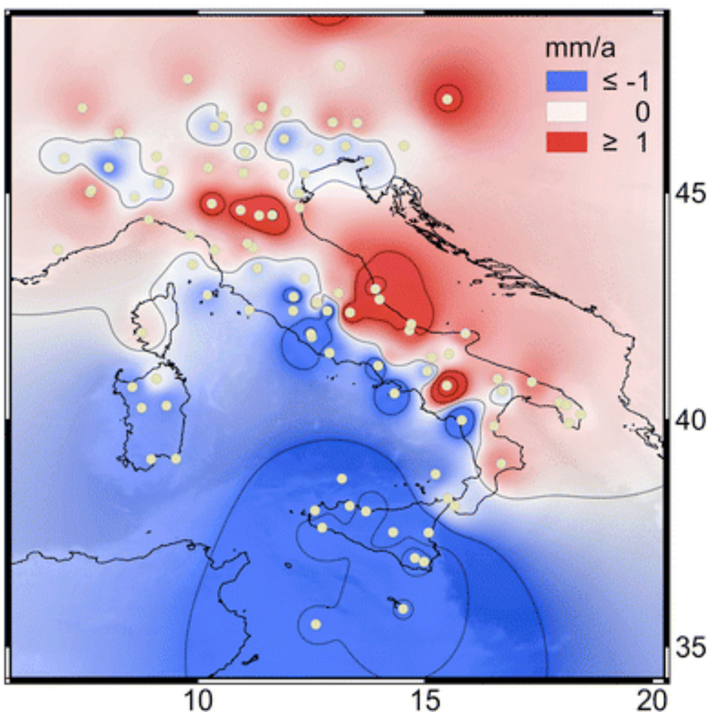
Hence… themain reason Sardinia is rather stable and pratically unafectedby meaningful seismic activity, is because the present-day geodynamic of the Mediterranean domain does not involve this microplate. Also the intra-plate horizontal velocities, as a consequence, are minimal, as shown by the interpolated velocity field (in the Mediterranean local reference frame) from global navigation satellite system (GNSS)



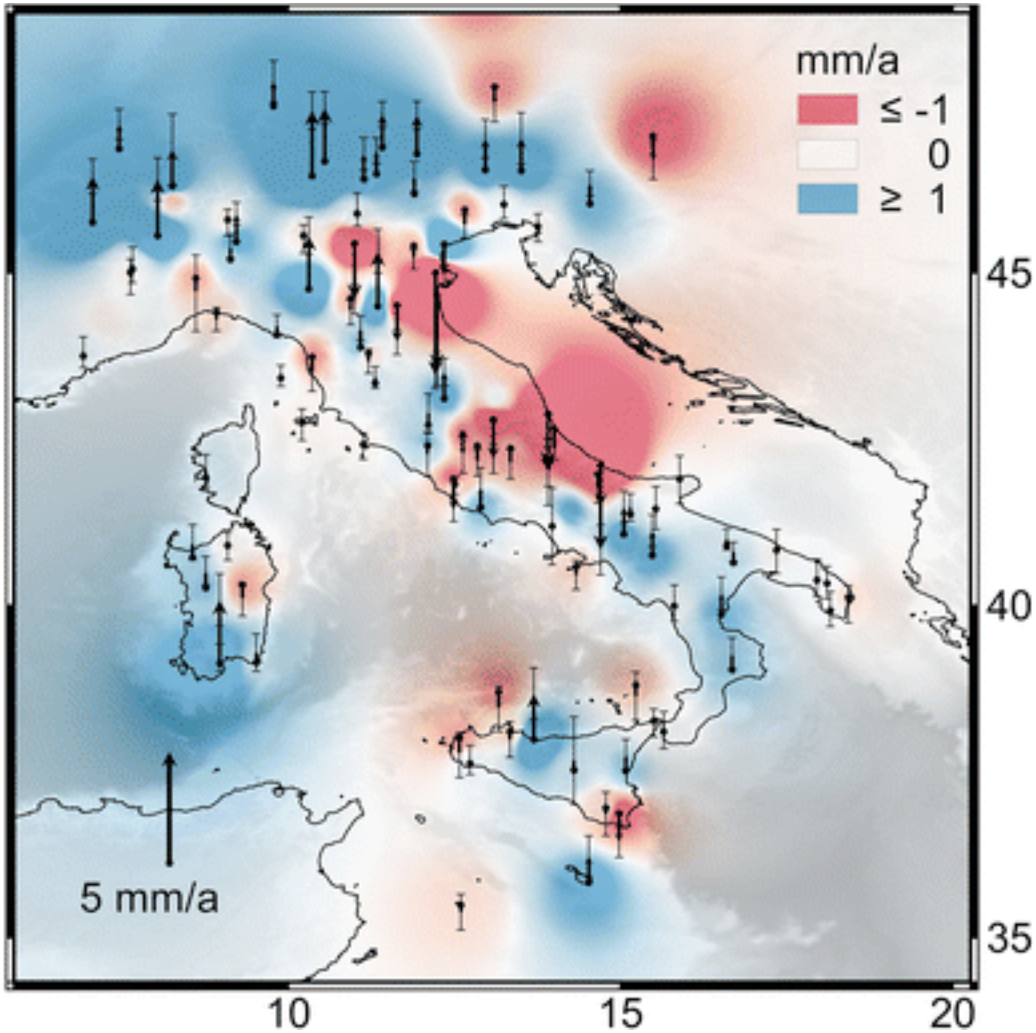
After Farolfi et al. 2016



Velocity field components contour plot in the local reference frame defined for Alpine Mediterranean area. In red scale color are plotted displacements toward north; in blue toward south. In the bottom map toward the east

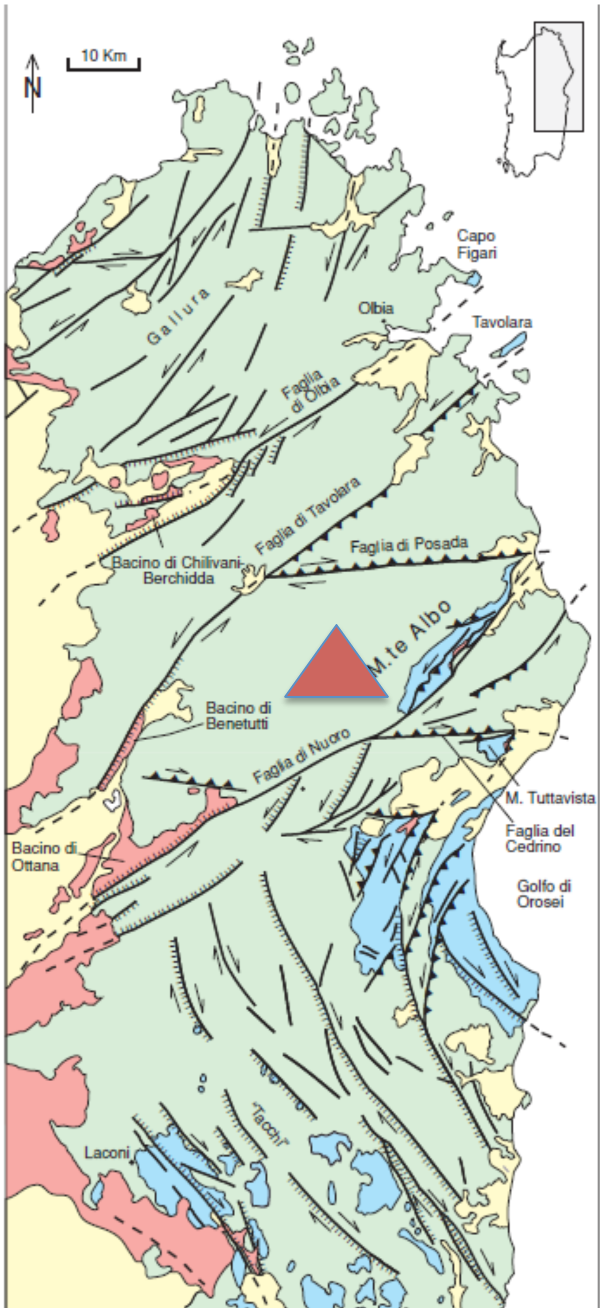


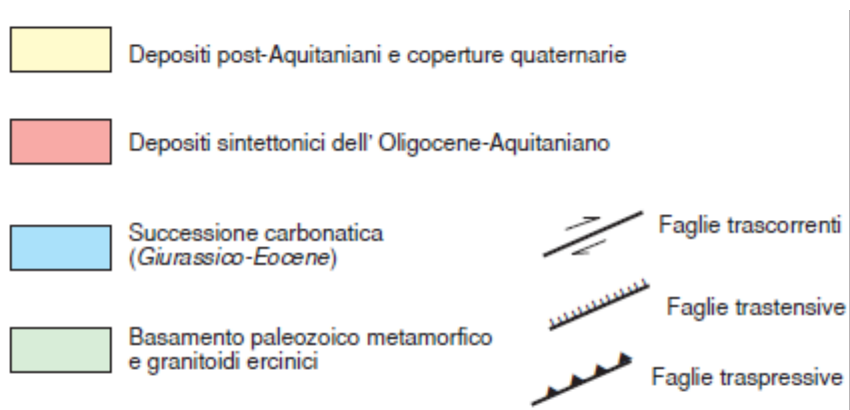
113 GNSS permanent stations, including eight International GNSS Service (IGS) stations that provide datum alignment. The observation window spans from January 2008 to June 2014.



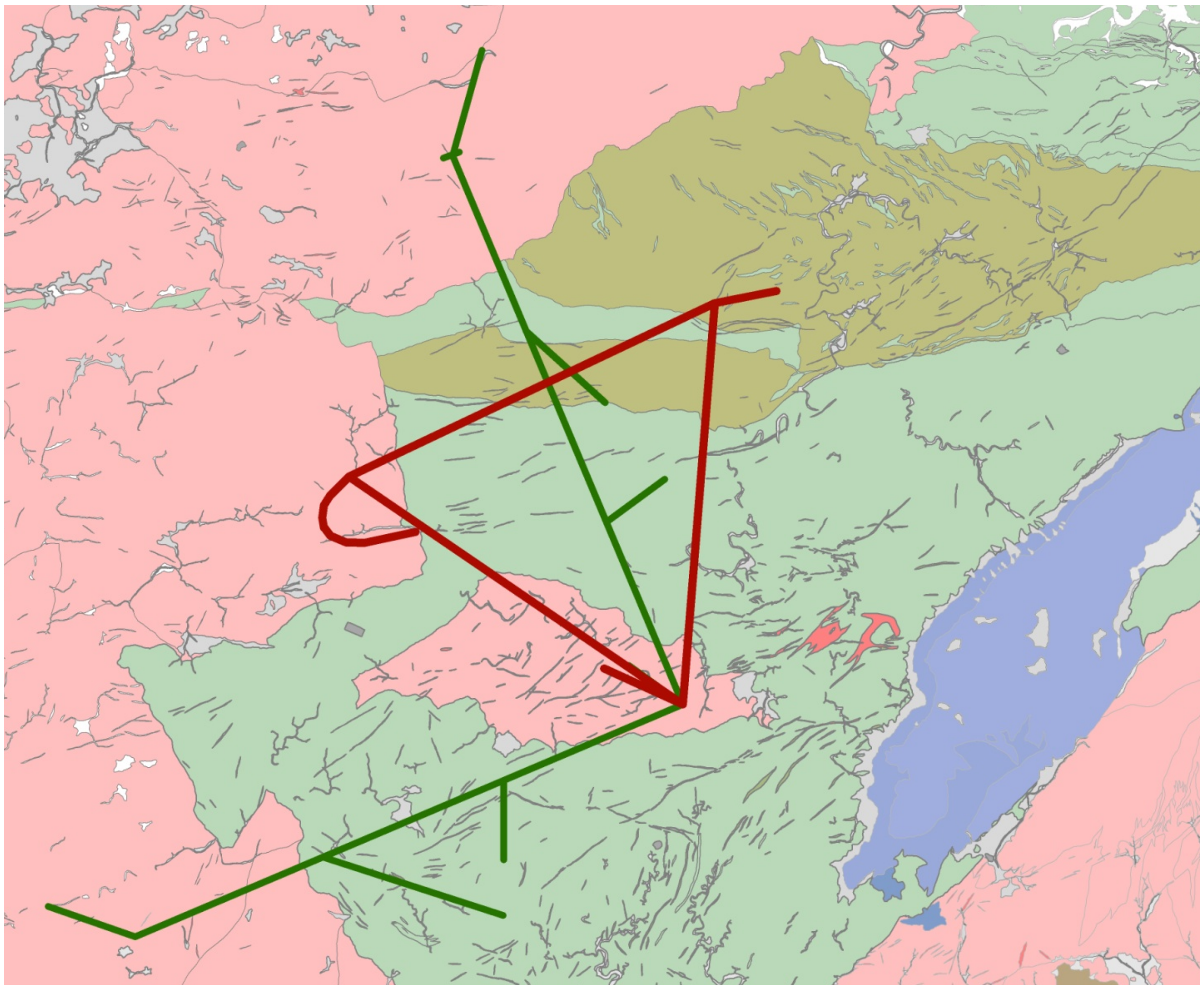
Vertical velocities and error bars with 95 % confidence level. The interpolated vertical velocity field is displayed by a graduated color scale. White represents stable area, blue is for uplift ≥1.0 mm/a and red subsidence ≤−1.0 mm/a

Oligocene stike-slip faults
that in some case were reactivated as normal faults
during Pliocene



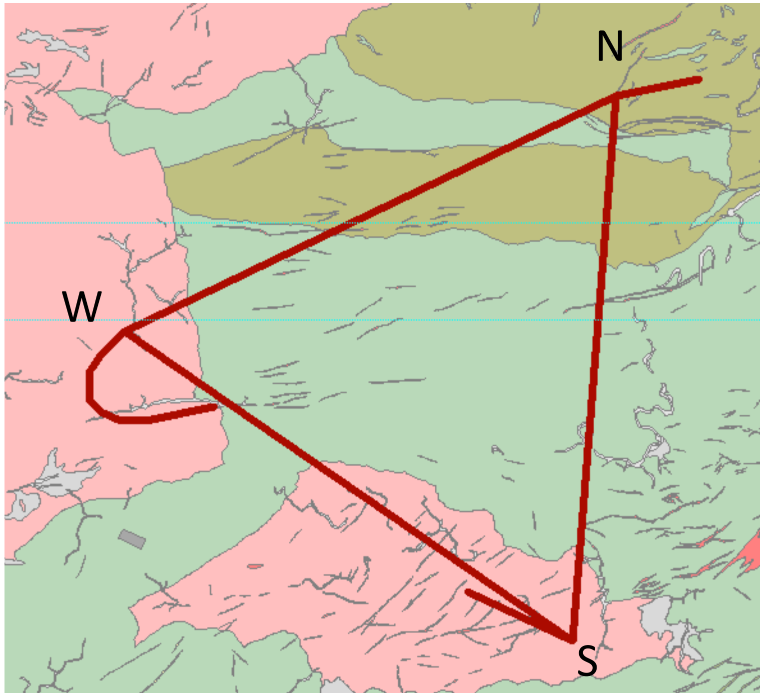


Geology and possible infrastructure



Main lithological units:

- Sedimentary covers
- Mesozoic limestones
- Variscan granitoids
- Ortogneiss
- Micaschists and quartzites

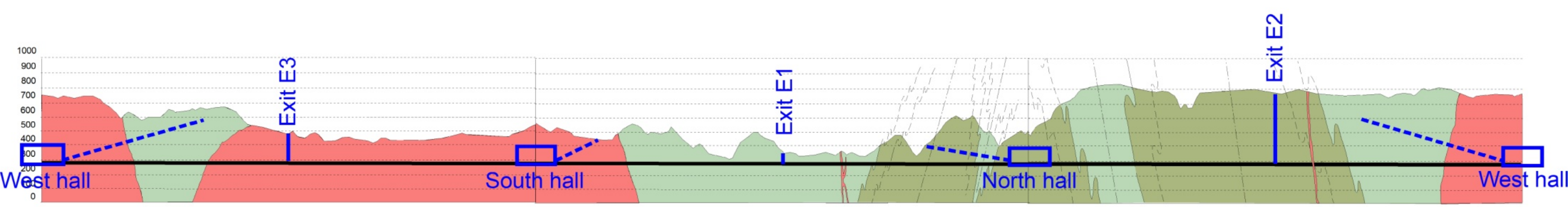


Legend

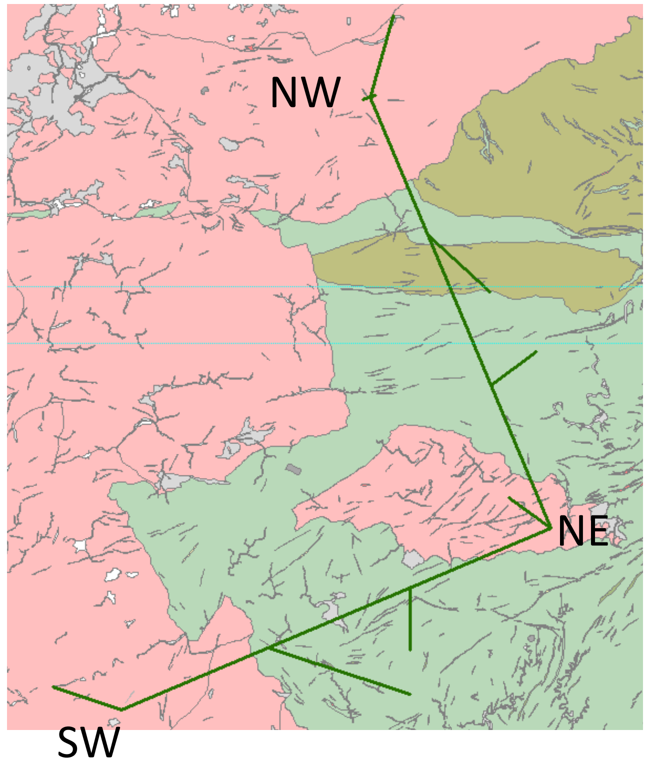
- Intrusive complex (granodiorites and monzogranites)

Metamorphic basement

- Orthogneiss
- Phyllites, micaschist and paragneiss



vertical exaggeration 3x



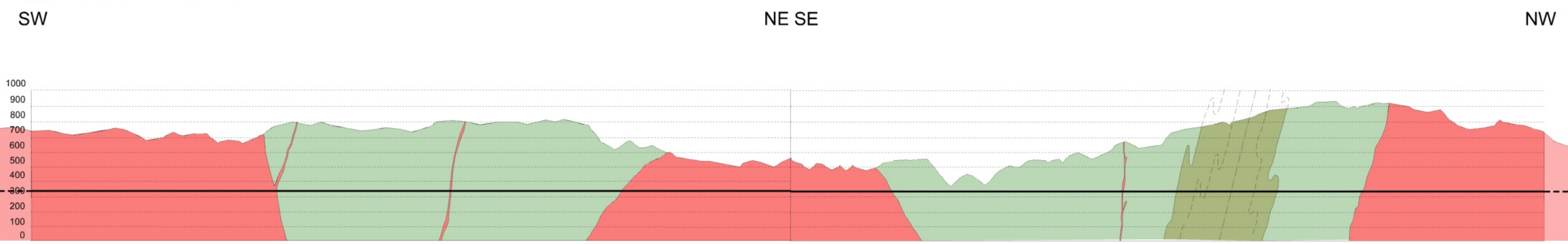
Legend

Intrusive complex (granodiorites and monzogranites)

Metamorphic basement

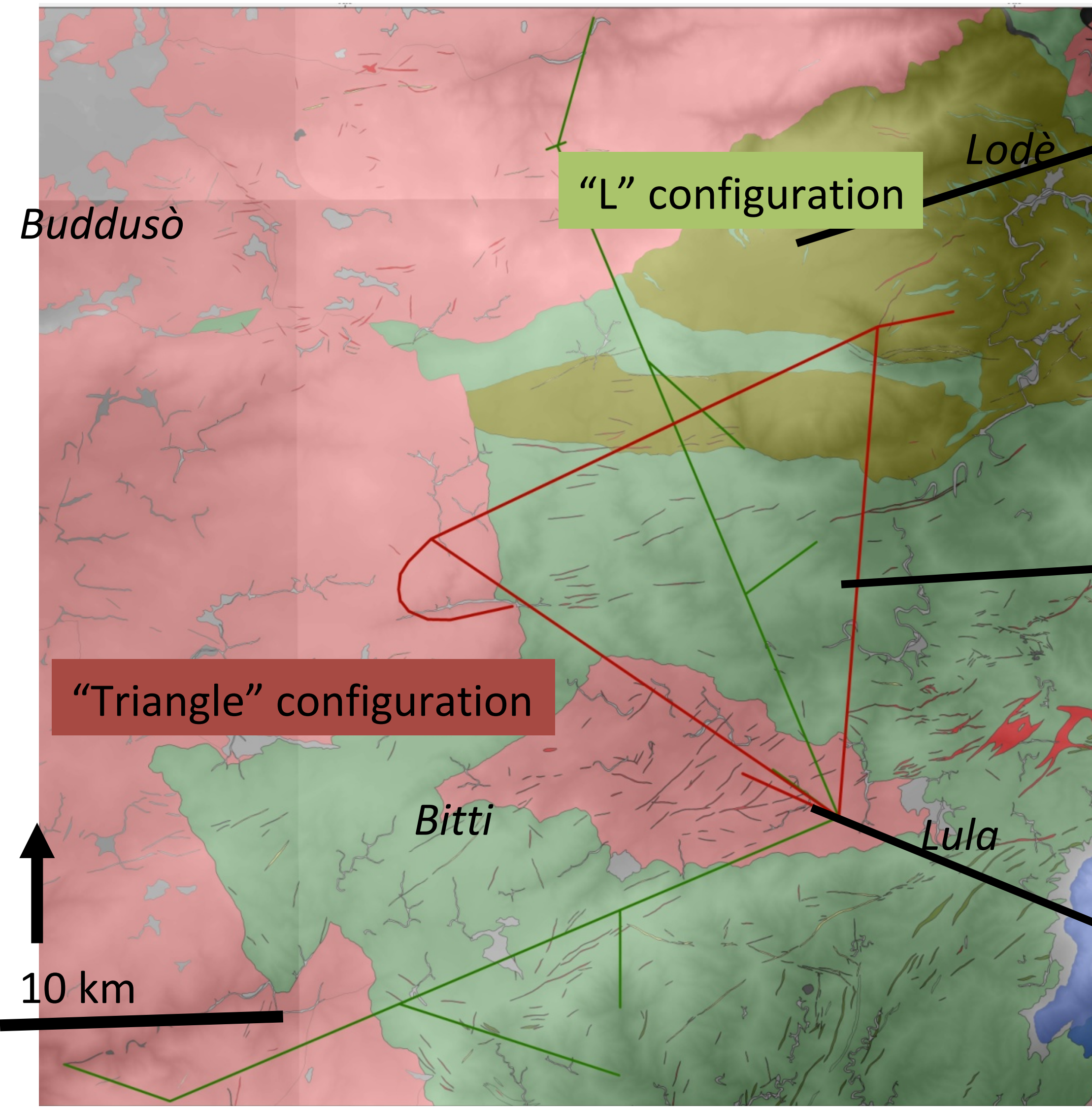
Orthogneiss

Phyllites, micaschist and paragneiss



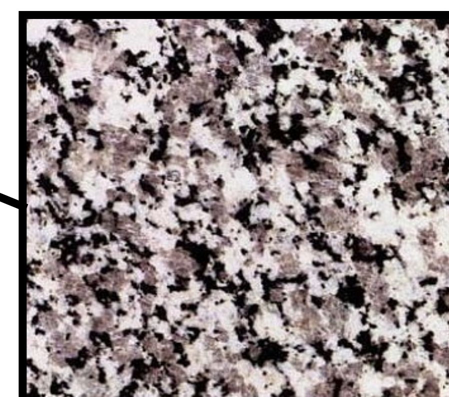
vertical exaggeration 3x

Local geology and rocks



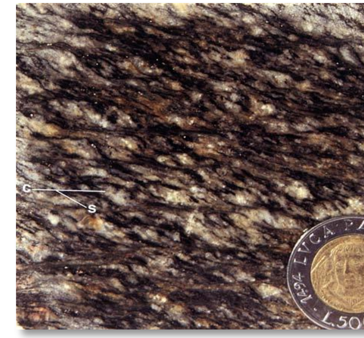
Orthogneiss "Lodè type"
UCS: 92.6 / 60.8 Mpa

Micaschist/paragneiss/quartzite
UCS: 9.9/8.8 Mpa



Granodiorite "Bitti type"
UCS: 72.1 Mpa

Uniaxial compressive strength



Lithotype	Uniaxial compressive strength (MPa) – Average *load perpendicular to anisotropy*	Resistenza compressione uniassiale (MPa) – valore medio *Load parallel to anisotropy*
Ortogneiss “Lodè type”	92.6	60.83
Quarzite	68.68	53.44
Paragneiss	9.96	8.82

Lithotype	Uniaxial compressive strength (MPa) – Average
Granodiorite “Bitti type”	72.09

Uniaxial compressive strength
Detail on quartzites (Q)

		angle between anisotropy and load	MPa
Media	*Qsc*	0°	98.51
Min	*Qsc*	0°	31.61
Max	*Qsc*	0°	207.75

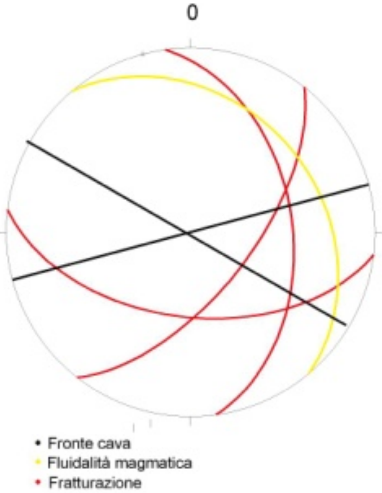
Media	*Qsc*	90°	60.27
Min	*Qsc*	90°	40.75
Max	*Qsc*	90°	94.06

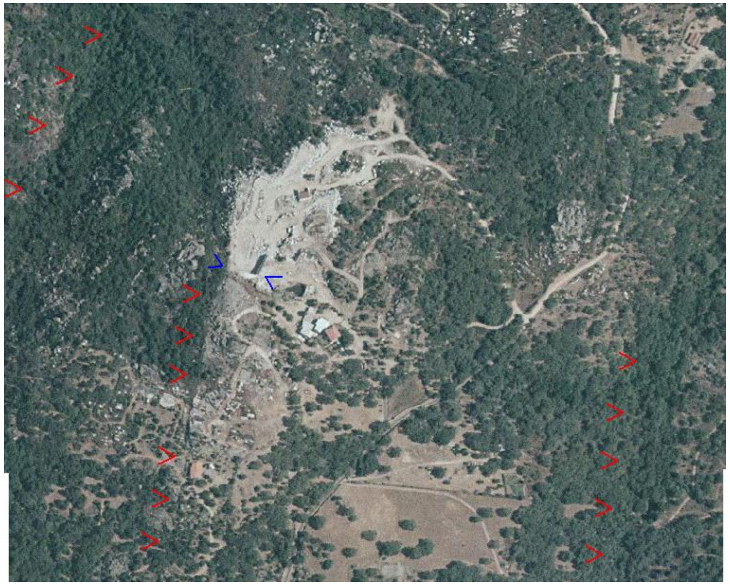
Media	*Qgall*	20°	36.1
Min	*Qgall*	20°	22.22
Max	*Qgall*	20°	64.29

Media	*Qgall*	70°	87.69
Min	*Qgall*	70°	28.8
Max	*Qgall*	70°	122.16

Average	***Q***		**70.64**

Structural characterization of granite



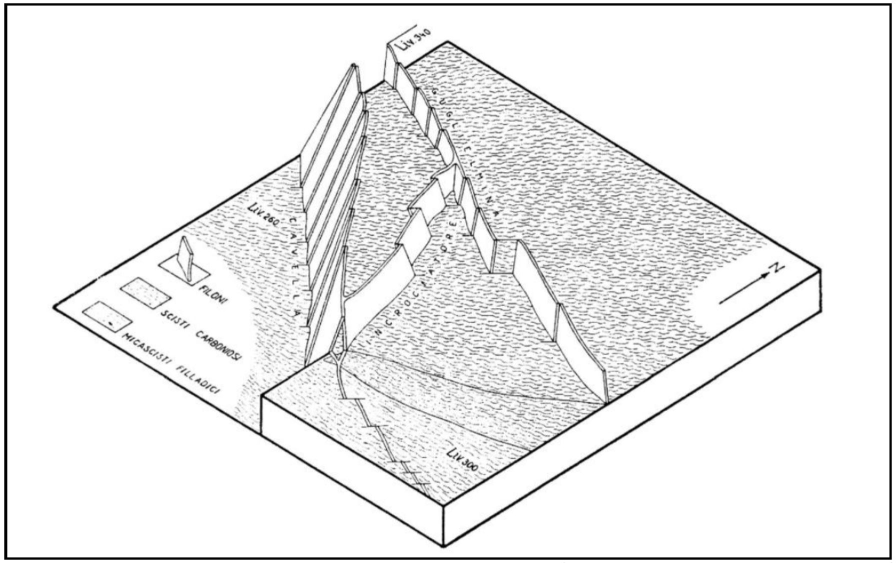


Close to main faults   intesification of joints
Joint spacing relevant for:

i) Quality of rock mass ;
ii) Permeability

Hints from The mine

At Sos Enattos the works developed, at different levels, along the lodes for several tens of kilometres in metamorphic rocks. Hence the mine is a good test bench,, in this kind of rocks, for:
i)the excavations and geo-mechanical properties; ii) the concerns about water circulation; iii) radon misurements



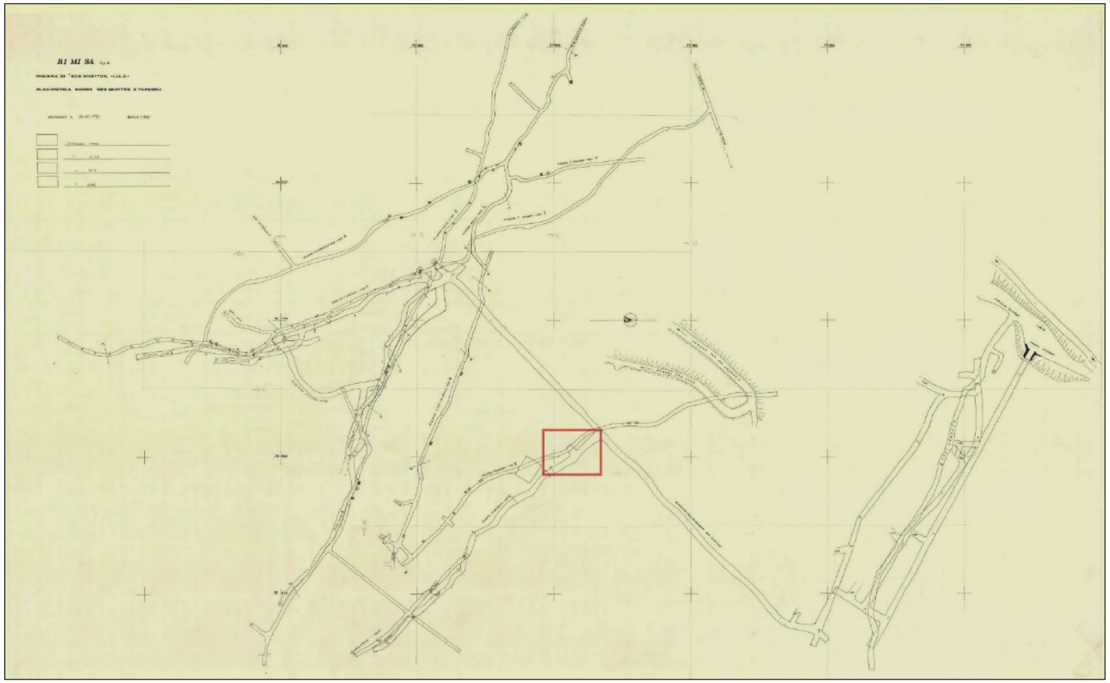
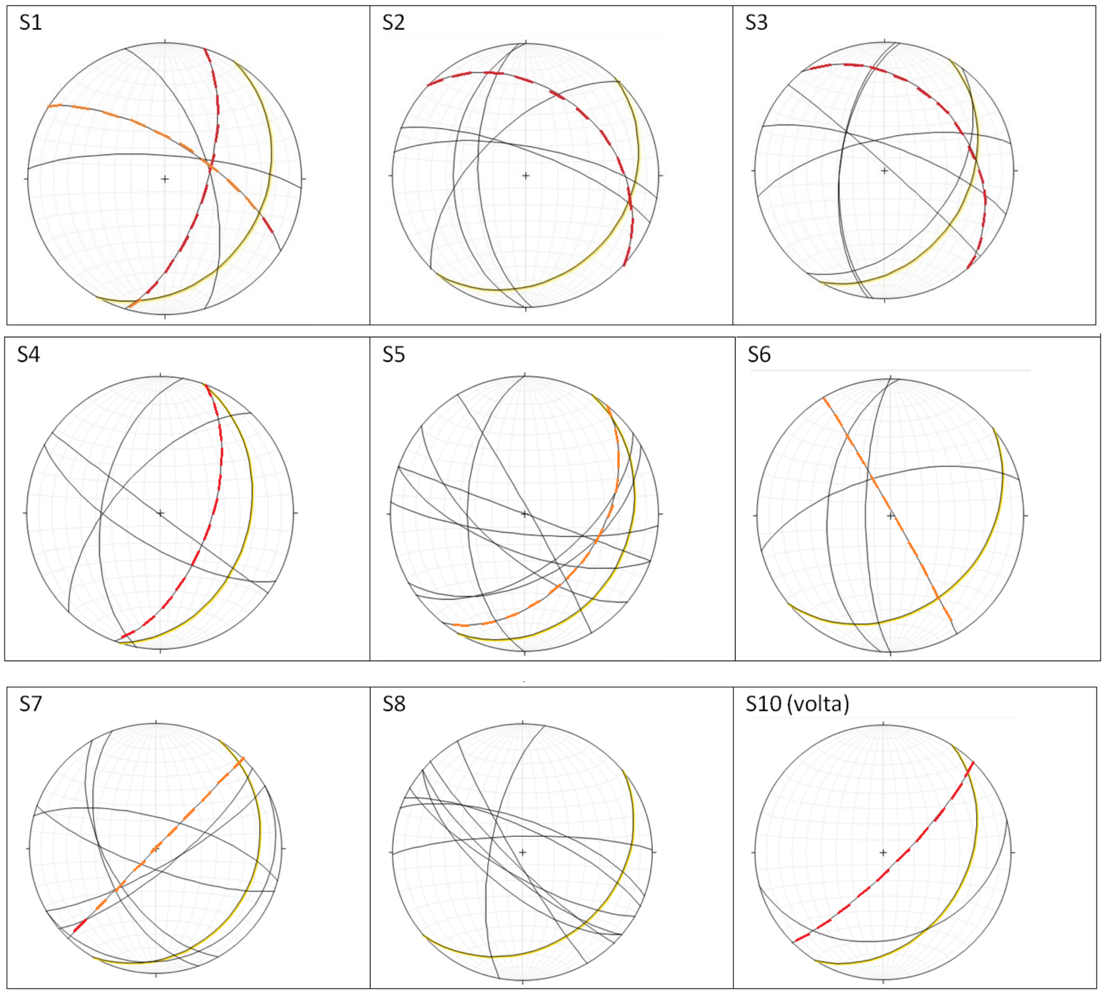
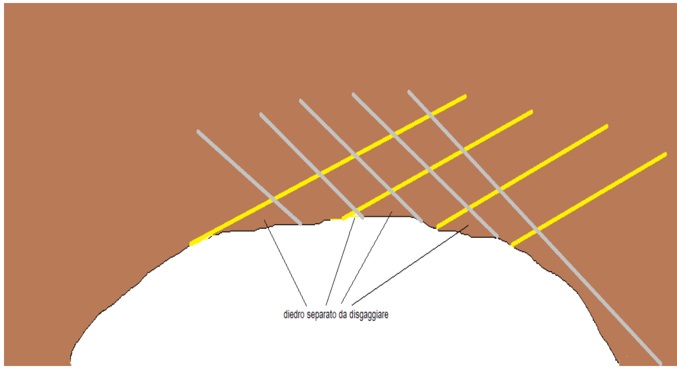


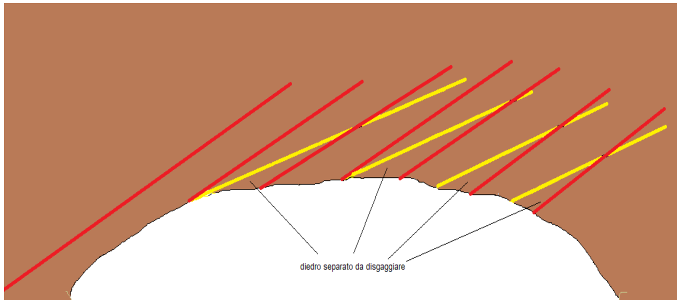
Fig. 7. Piano minerario della miniera di Sos Enattos con evidenziata l'area individuata come idonea al fine della realizzazione del laboratorio

Structural characterization in metamorphic rocks with dominant quartzites

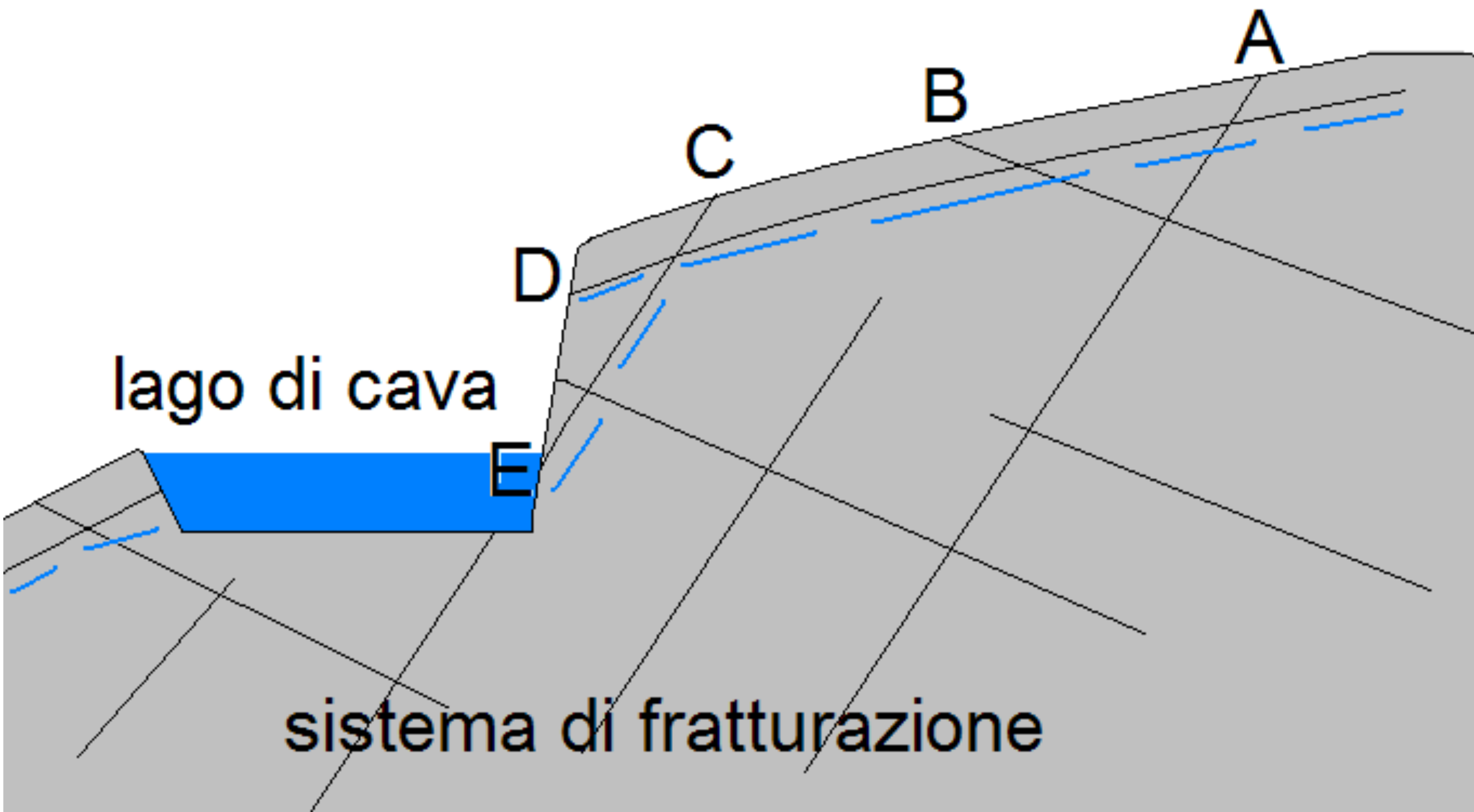


Isolated block in the roof

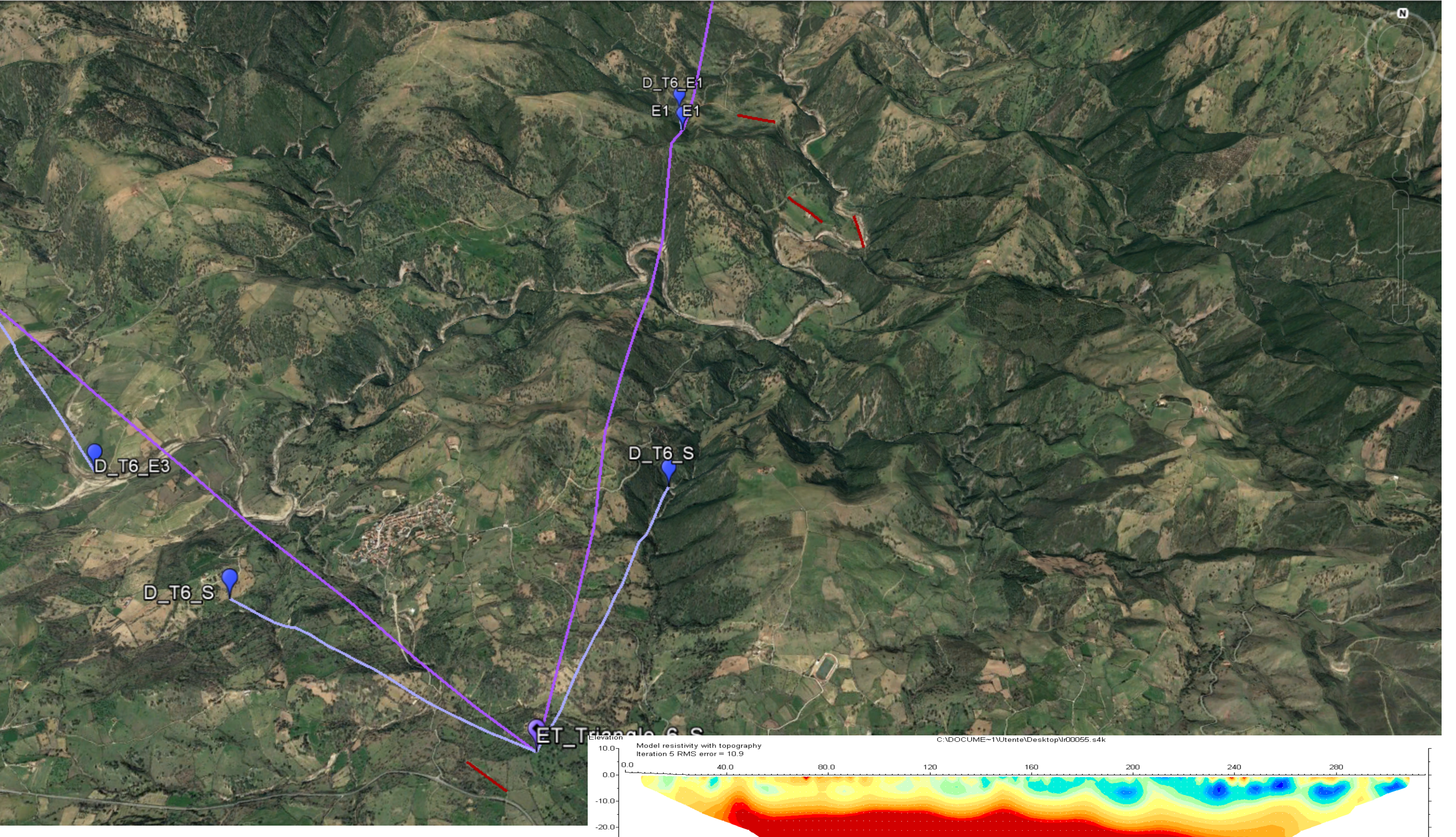


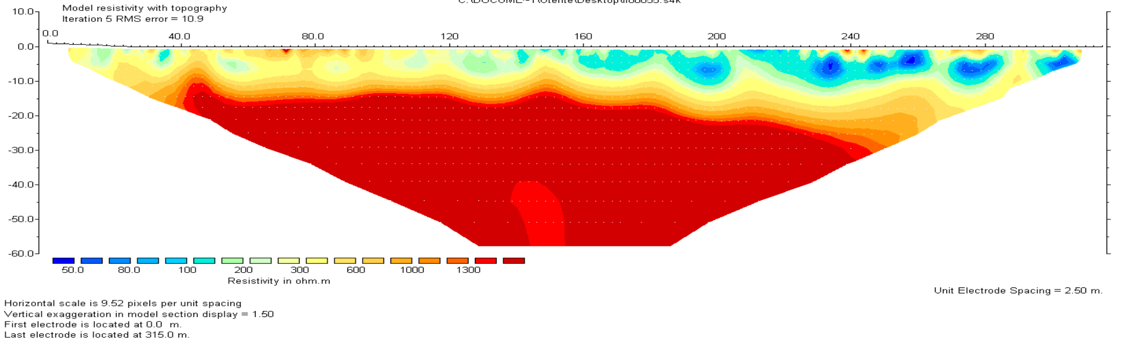


Fracture-induced permeability in surficial granite.



Near surface open joints are often pathway for groundwater

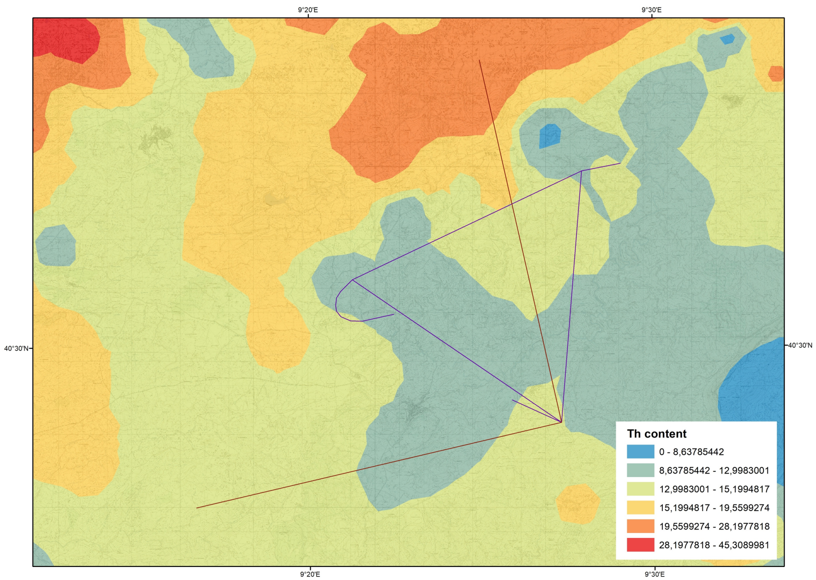

D_T6_E1
E1
E1
D_T6_S
D_T6_E3
D_T6_S
ET_Triangle_6_S

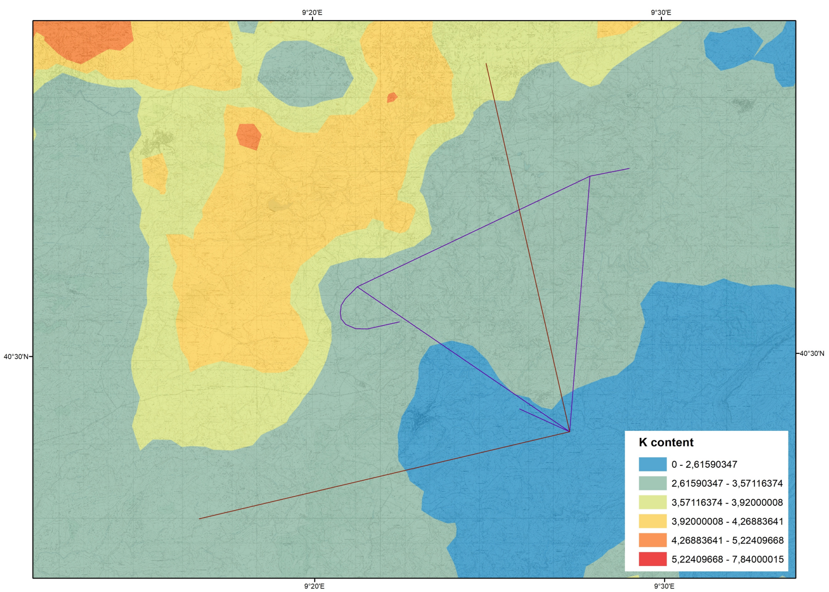

C:\DOCUME~1\Utente\Desktop\lr00055.s4k
Elevation
Model resistivity with topography
Iteration 5 RMS error = 10.9
0.0
40.0
80.0
120
160
200
240
280
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
50.0
80.0
100
200
300
600
1000
1300
Resistivity in ohm.m
Unit Electrode Spacing = 2.50 m.
Horizontal scale is 9.52 pixels per unit spacing
Vertical exaggeration in model section display = 1.50
First electrode is located at 0.0 m.
Last electrode is located at 315.0 m.

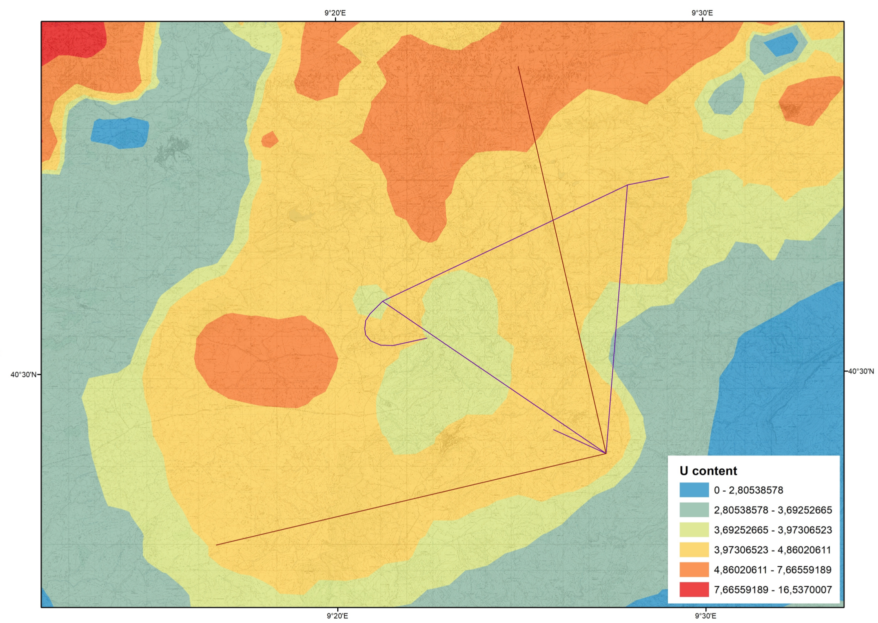
Background radiation

U-238
K- 40
Th-232

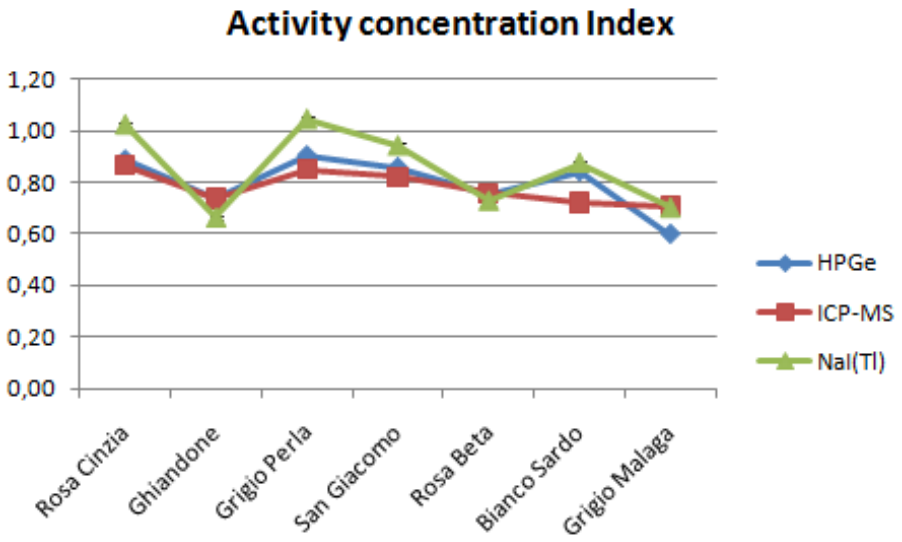
Uranium and Thorium (in ppm), expressed as equivalent units, **and Potassium concentration** (in %).



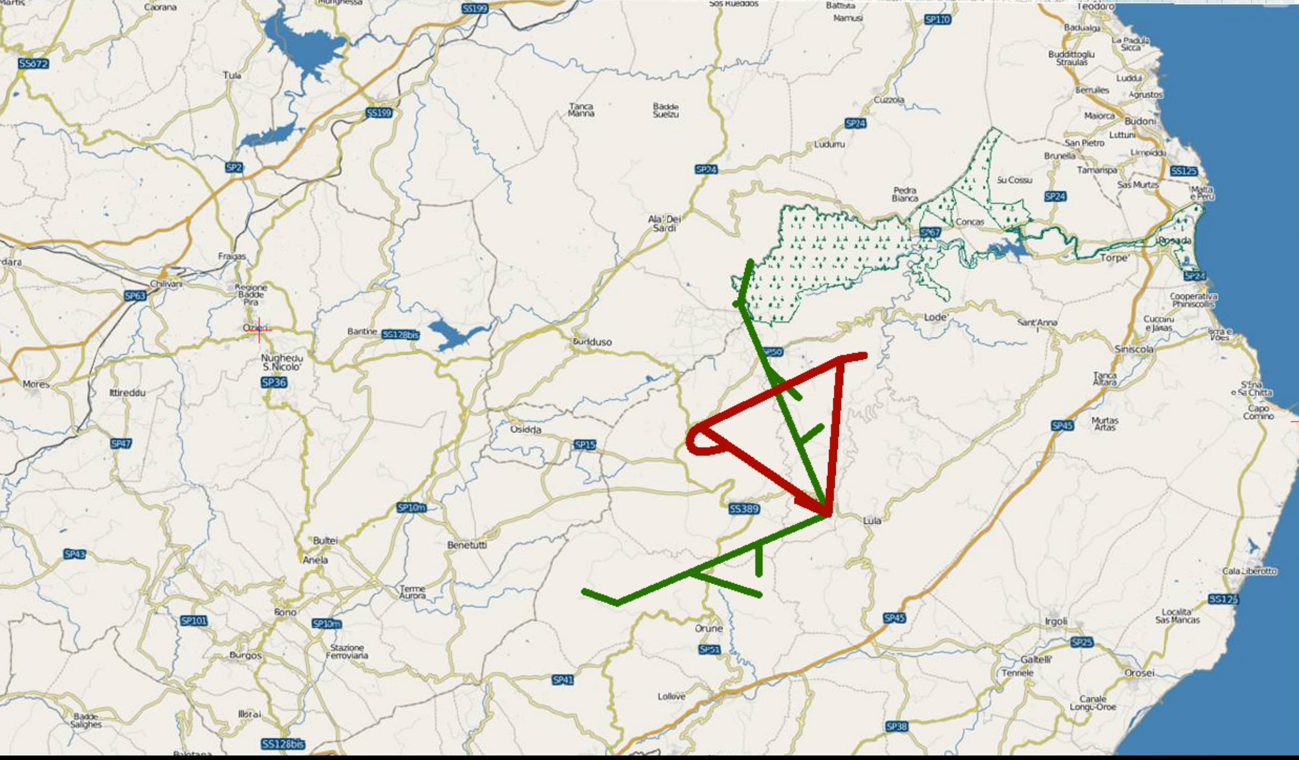




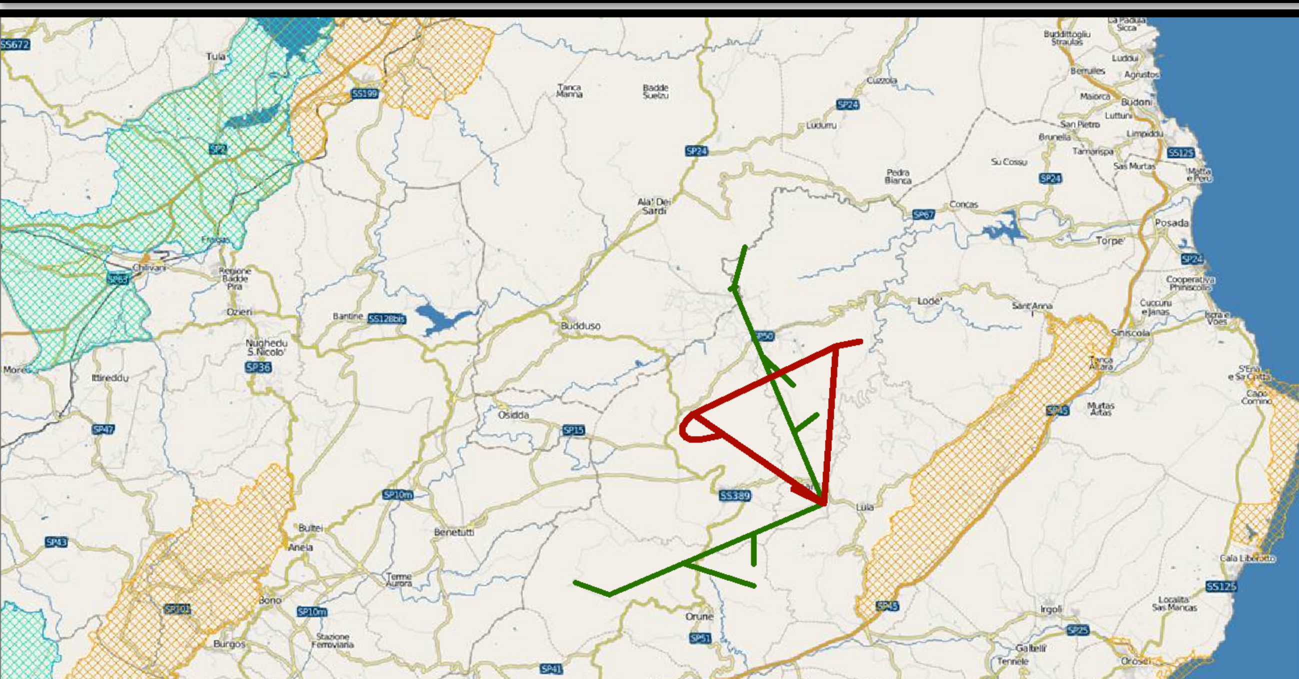
Portable Gamma Spectrometer vs. Lab analisys



Environmental issues



Regional parks

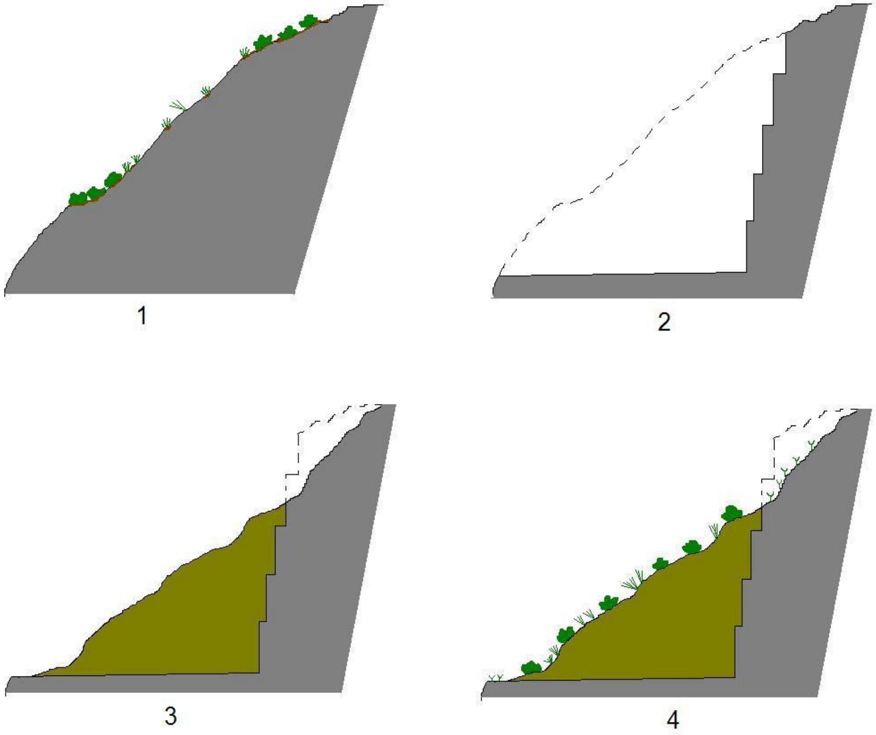


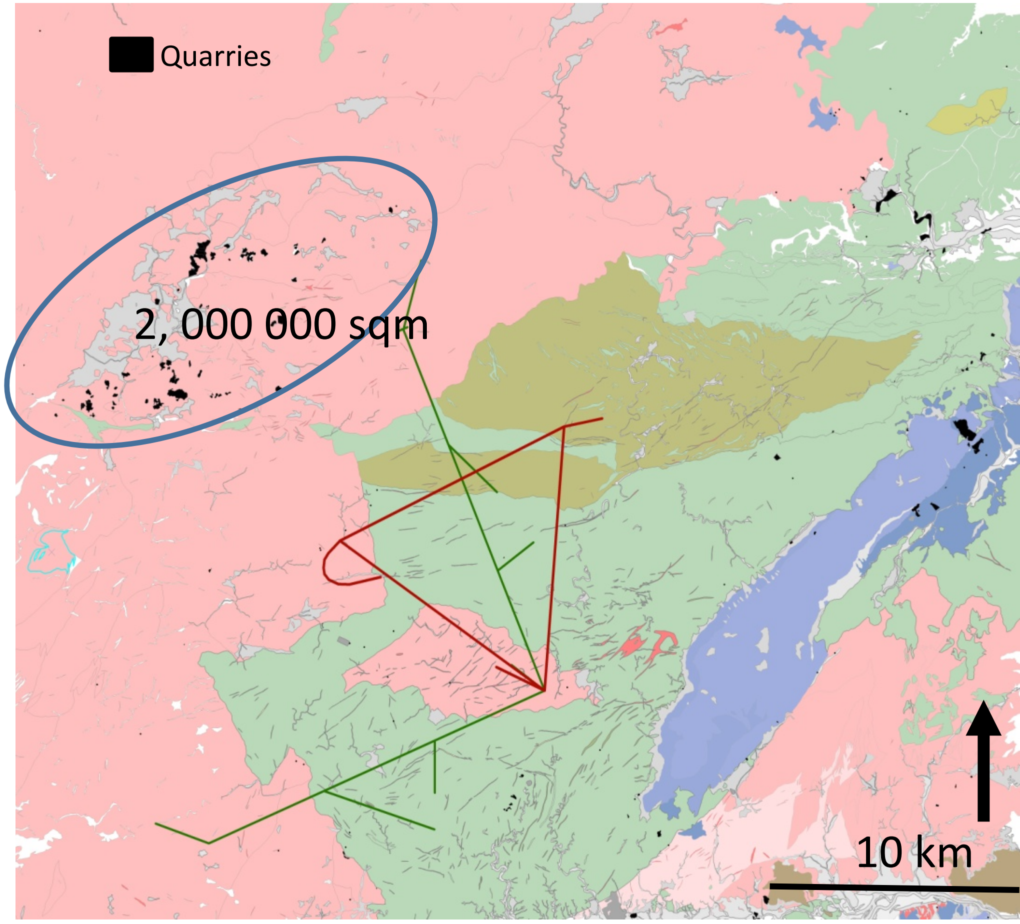
SIC -ZPS

Where to place the excavation dumps?

In the neighboring areas
there **was** diffuse granite quarrying

The approximative volum of 4 millions cubic metres
of dumps could be emploied in the recovery of the nearby quarry sites. The past granite quarring genarated in the Buddusò district similar to 2 millions square meters of quarried surface.
The damp produced by the excavations could be easily employed in landscape rehabilitation





What next?

Aseismic (creeping) faults: long and mid term (10^{5}-10^{4} y) slip rate inferred by the displacement of datable geological features (sediments, palaeosoils, concretions, travertine)

Active ground deformations : detection by Ps-INSAR methodologies,

in situ permeability measurements, possible groundwater paths, occurrence of deep or perched aquifers, chemical features of groundwater. (boreholes needed)

Further geotechnical characterization of lithotypes and rock mass