

MUON TOMOGRAPHY IN THE LOUSAL MINE

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IN COLLABORATION WITH LOUMU TEAM



LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia



UNIVERSIDADE
DE ÉVORA

Centro
Ciência Viva
do Lousal
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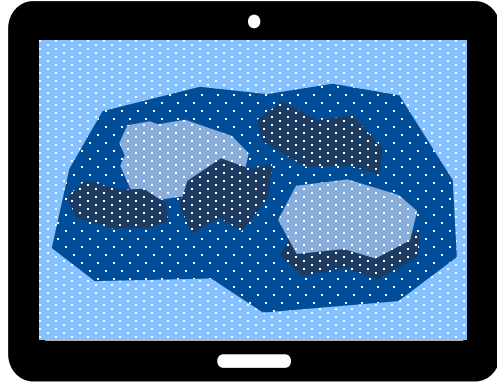
MUON TOMOGRAPHY

OVERVIEW

MUON TRANSMISSION TOMOGRAPHY

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MUOGRAPH



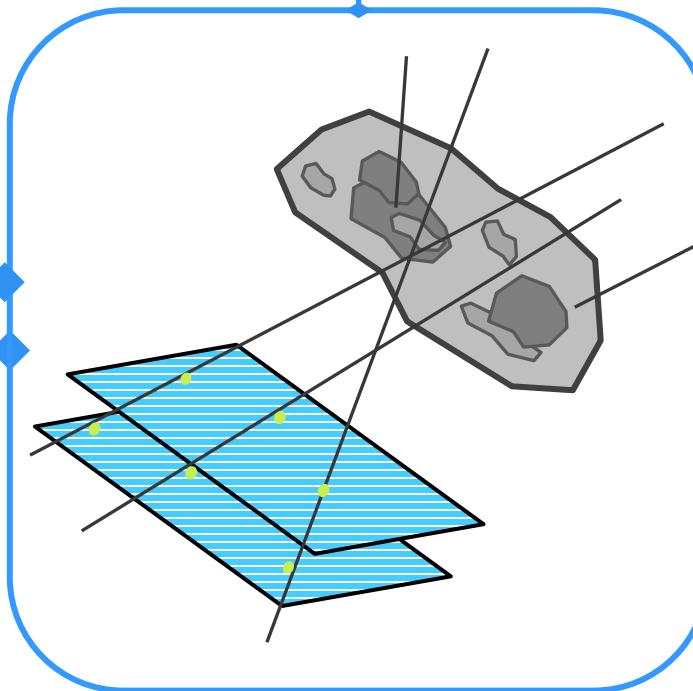
TECHNIQUE

- Transmission of the muons through matter
- Detection of the muon flux in one telescope
- Denser matter means less muons detected

COSMIC RAYS

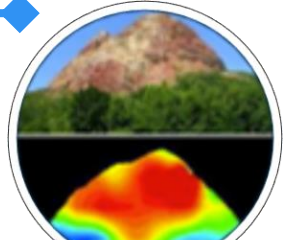
PARTICLE SHOWERS

MUONS



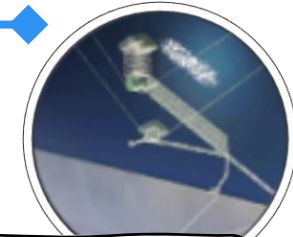
APPLICATIONS IN DIFFERENT FIELDS

AVERAGE DENSITY PROFILE OF MT. ASAMA



VOLCANOLOGY

HIDDEN CHAMBER CHEOPS PYRAMID



ARCHAEOLOGY

BUILDING STABILITY MONITORIZATION

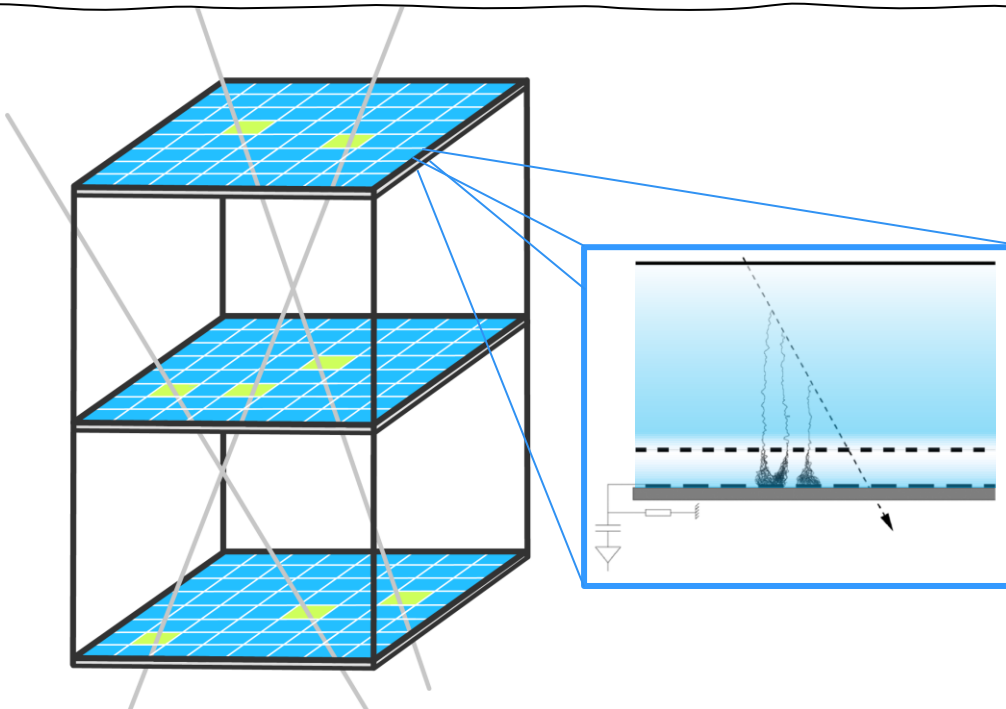


CIVIL ENGINEERING

MUON TELESCOPE

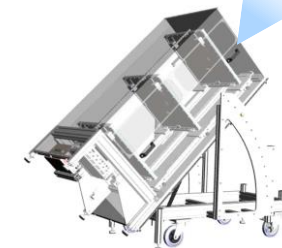
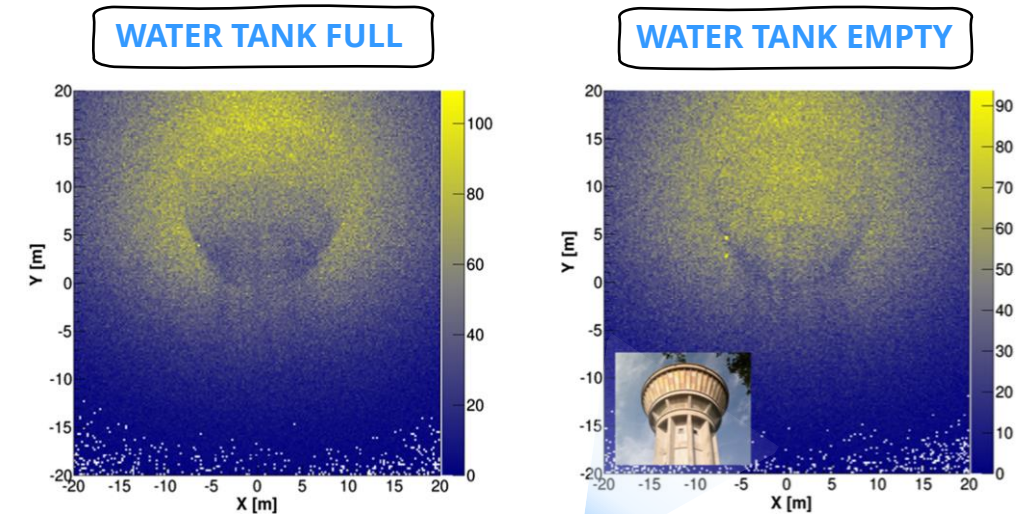
RPC DETECTORS

- Resistive Plate Chambers or RPC are gaseous particle detectors
- The muons ionize the gas and produce an electrical signal
- Consecutive detections give the trajectory of the muons



| EXAMPLE | MUOGRAPHY USED IN A WATER TOWER (FRANCE)

- 4 days of exposure for each muograph
- Density variances observed

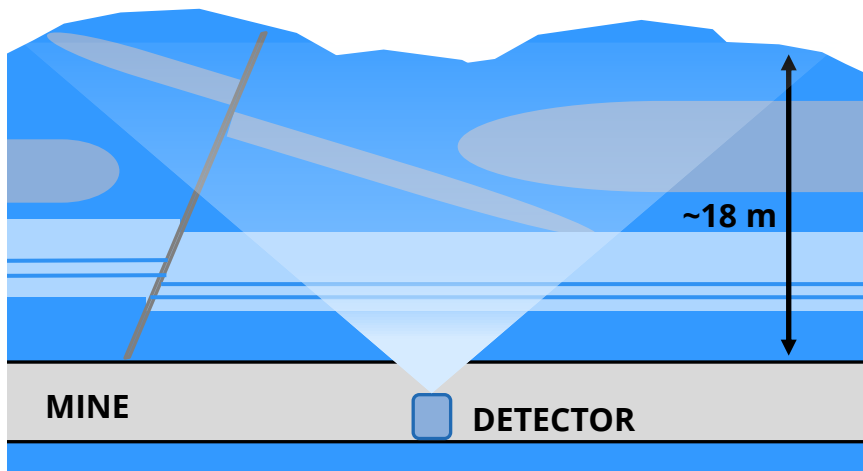


Boutille *et al.*, 2016)

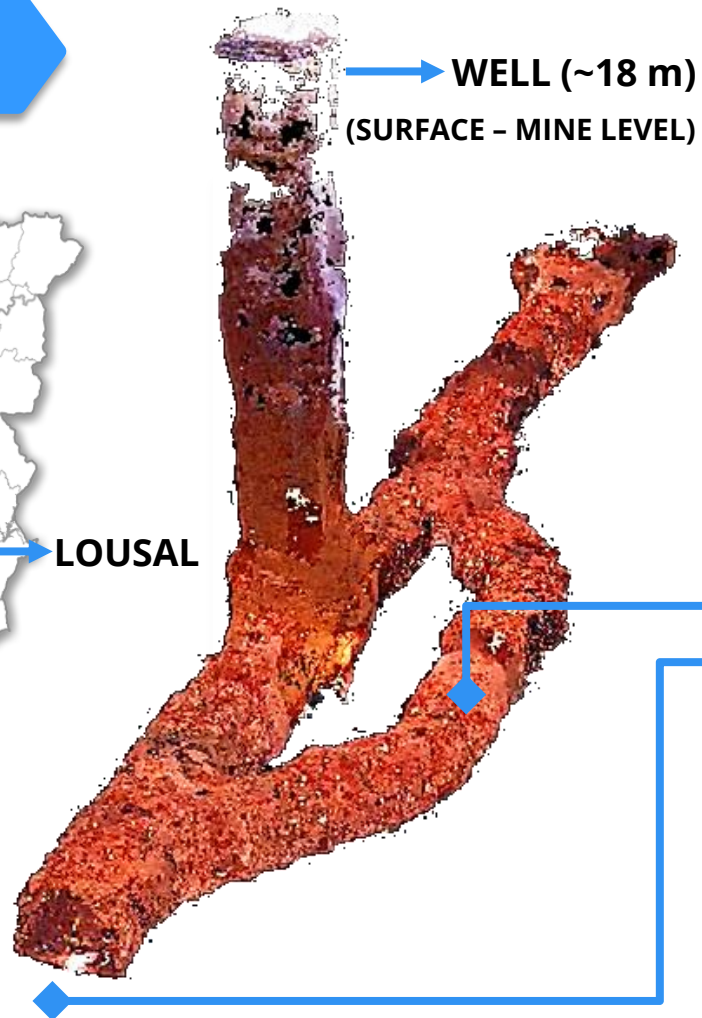
MUON TOMOGRAPHY

LOUMU PROJECT

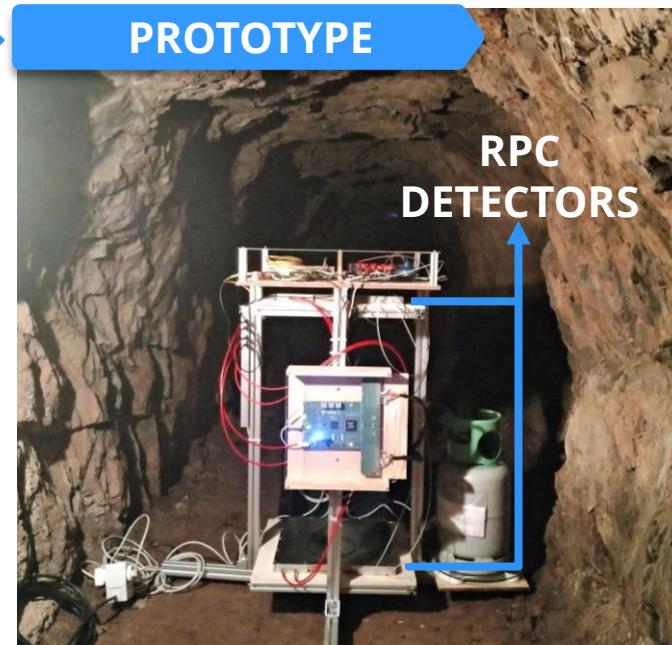
LOUSAL MINE



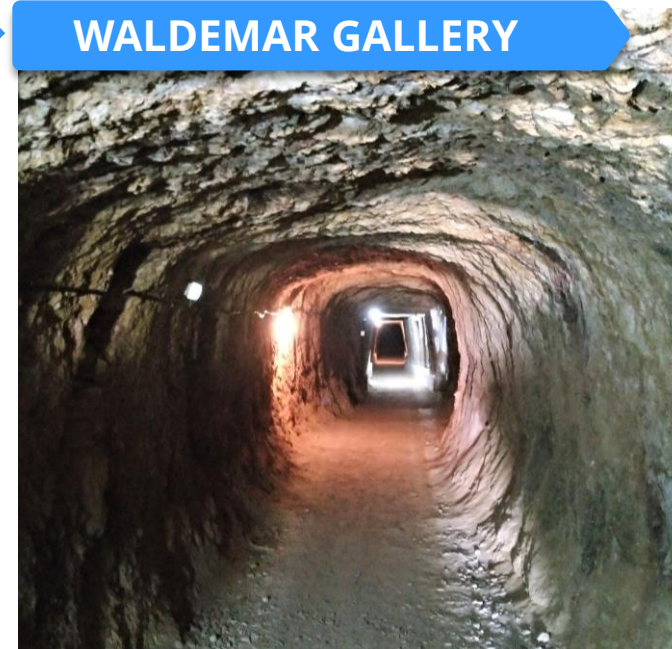
LOUSAL



PROTOTYPE



WALDEMAR GALLERY

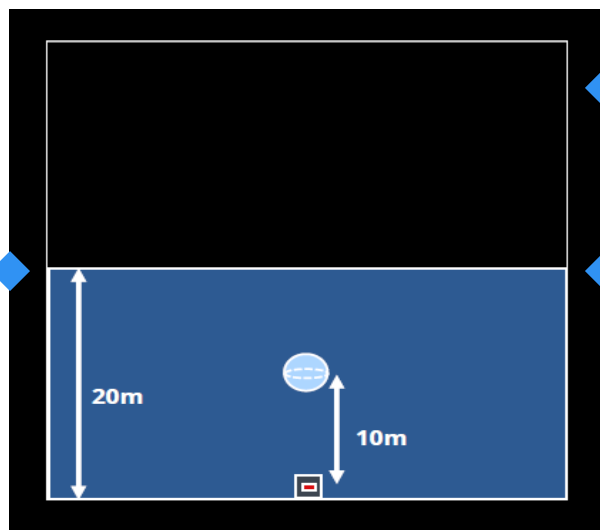
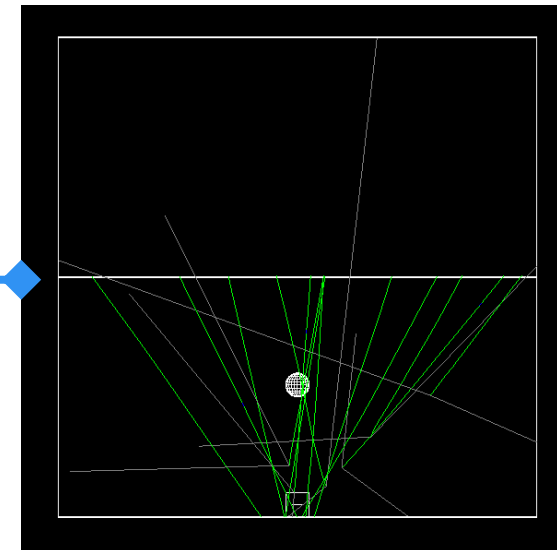
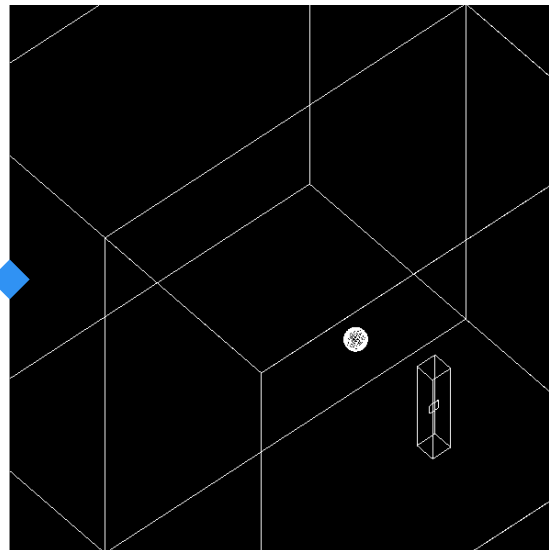
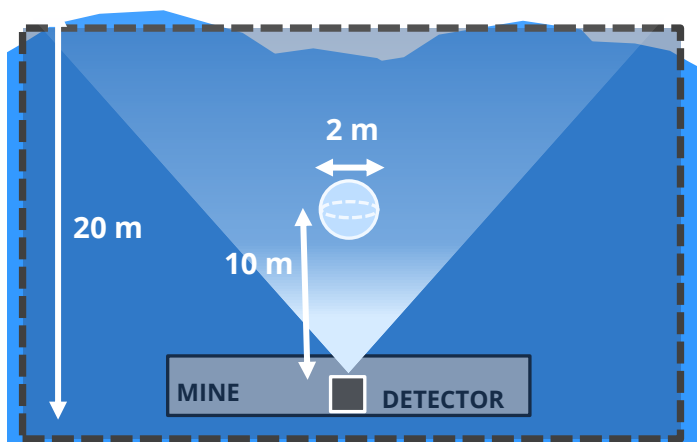


OBJECTIVE: to do a geological reconnaissance of the ground above the mine while testing the performance and the sensitivity of the telescope.

MUON TOMOGRAPHY

GEANT SIMULATIONS

BUILDING A SIMPLE GEOMETRY



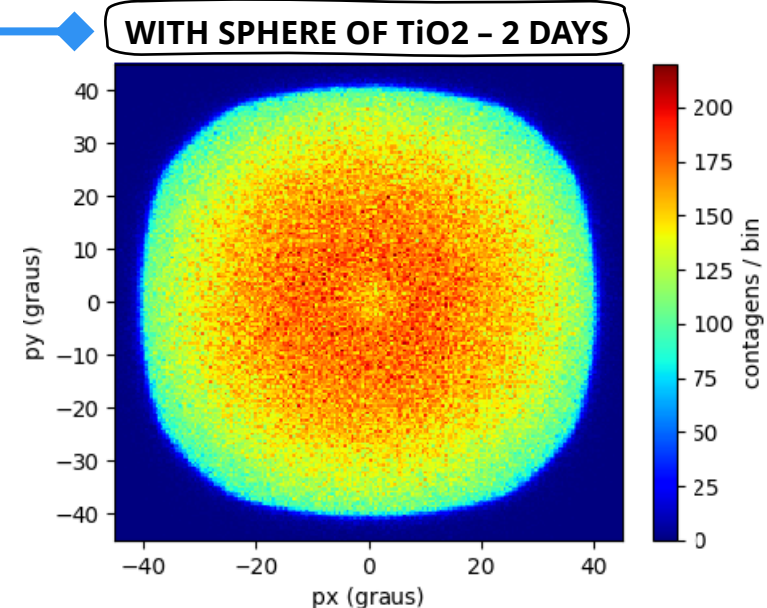
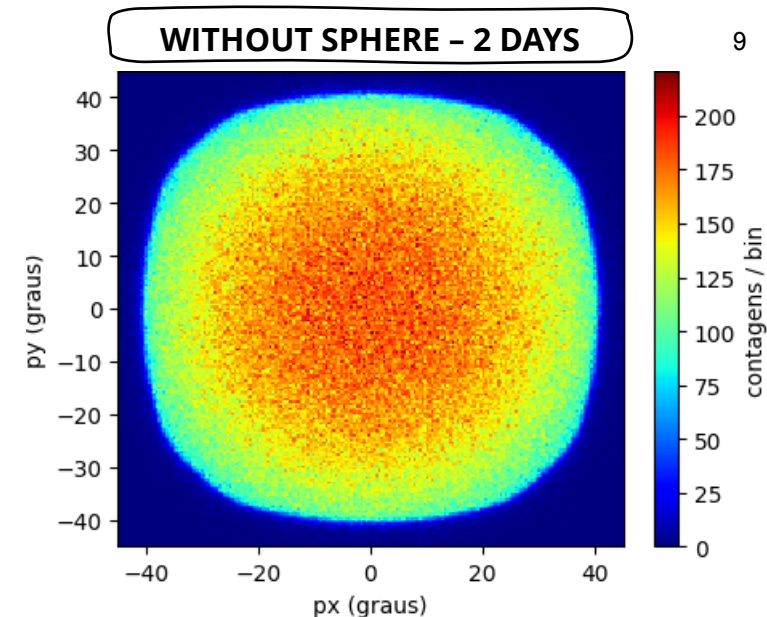
- The simulations are used as references to analyse the muography data.
- In a first step, the detection site is simulated with a simple geometry.
- The mine and the detector are placed 20 m deep underground, there is a sphere in the centre and the ground is made of a homogeneous chemical compound equivalent to shale, as observed in the mine.

GEANT4 SIMULATIONS

ANALYSING THE RESULTS

Materials	Density (g/cm3)		1 day	2 days	4 days	8days	16 days	32 days
Air	0.0012	-2.599	O	O	O	O	O	O
Water	1	-1.6	O	O	O	O	O	O
Bone	1.85	-0.75	X	X	V	O	O	O
Lithium Oxide (Li2O)	2.013	-0.587	X	V	V	O	O	O
Concrete	2.3	-0.3	X	X	X	X	Y	V
Glass Plate	2.4	-0.2	x	x	x	x	X	X
Sodium Carbonate (Na2CO3)	2.54	-0.06	x	x	x	x	x	X
Shale (medium)	2.6	0	x	x	x	x	x	x
Silica (SiO2)	2.648	0.048	x	x	x	x	x	x
Aluminium (Al)	2.7	0.1	x	x	x	x	x	X
Magnesium Carbonate (MgCO3)	2.958	0.358	X	X	X	X	X	Y
Calcium Oxide (CaO)	3.34	0.74	X	X	V	O	O	O
Aluminium Oxide (Al2O3)	3.987	1.387	X	V	O	O	O	O
Titanium Dioxide (TiO2)	4.23	1.63	O	O	O	O	O	O
Ferric Oxide (Fe2O3)	5.25	2.65	O	O	O	O	O	O
Silver Bromide (AgBr)	6.473	3.873	O	O	O	O	O	O
Lead Oxide (PbO)	9.53	6.93	O	O	O	O	O	O
Plutonium Dioxide (PuO2)	11.5	8.9	O	O	O	O	O	O
Gold (Au)	19.3	16.7	O	O	O	O	O	O

- For the sphere, a list of different materials was tested to analyze the contrast and the time of exposure necessary to distinguish between different densities

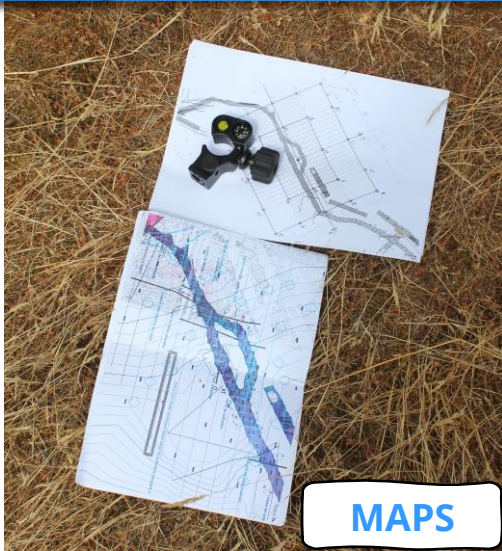


MUON TOMOGRAPHY

FIRST GEOPHYSICAL SURVEY

SITE PREPARATION

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MAPS



GPS EQUIPMENT



PHOTOGRAMMETRY



DRONE

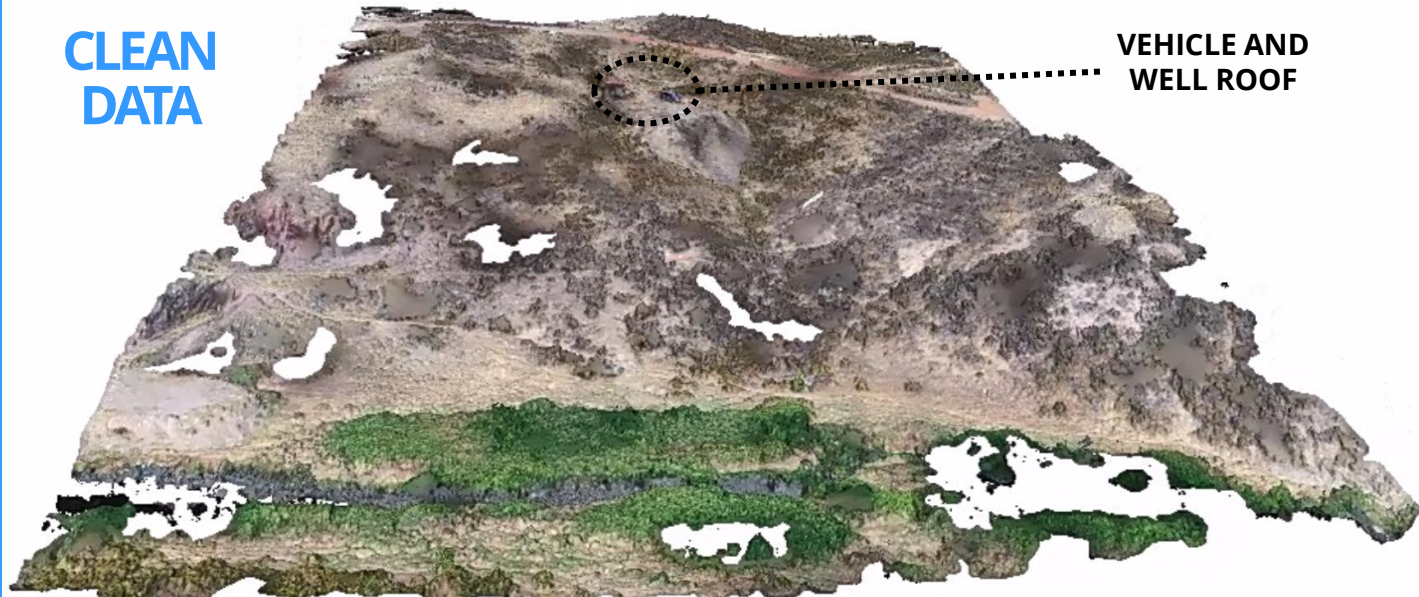


DIGITAL MAP SURFACE

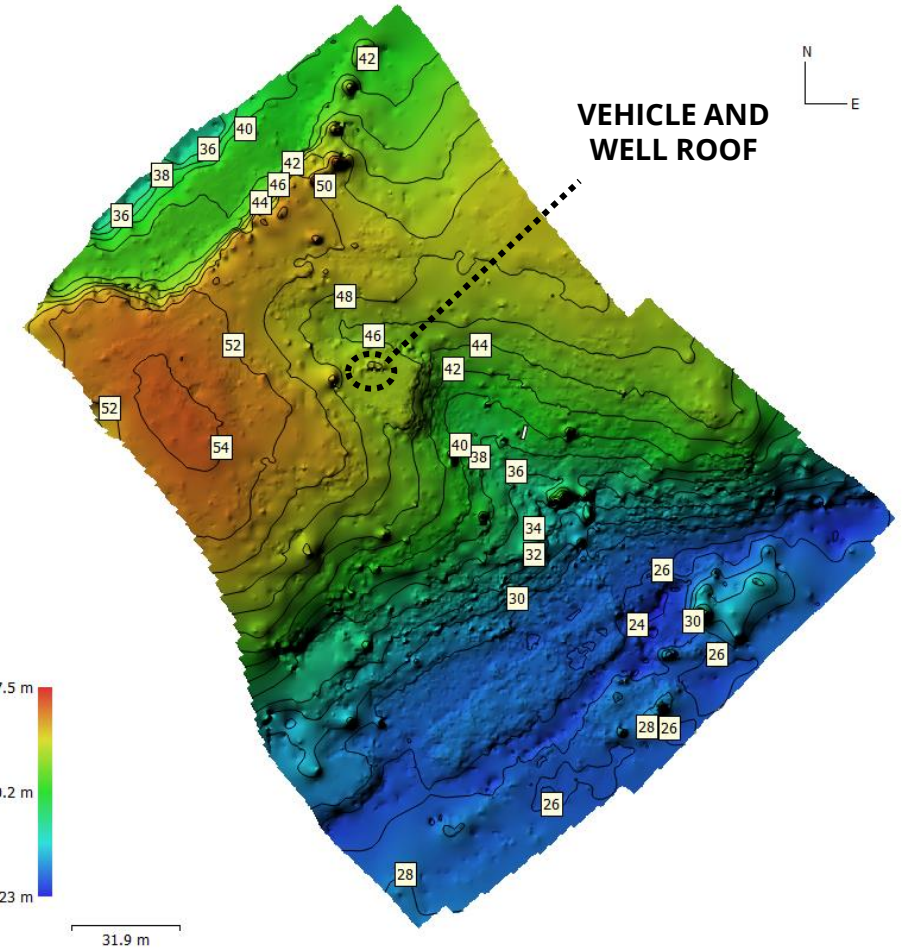
RAW
DATA



CLEAN
DATA



DIGITAL ELEVATION MAP



- A detailed description of the topology is necessary to compare the observed information with the expected results.

GPR – GROUND PENETRATING RADAR

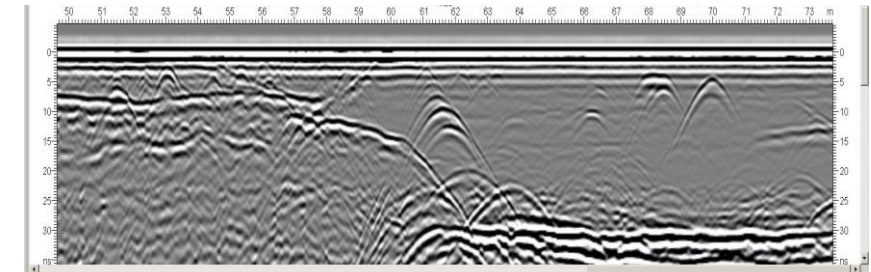
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GPR ANTENNA



- It measures the electrical resistivity of the materials.



GPR PROFILE (EXAMPLE FROM OTHER WORK)

SEISMIC REFRACTION



SEISMIC SENSORS



- It measures the speed propagation of the seismic waves.



WELL ROOF

WORK PROGRESSION

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STANDARD TECHNIQUES

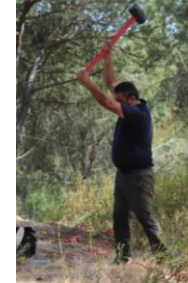
PHOTOGRAMMETRY



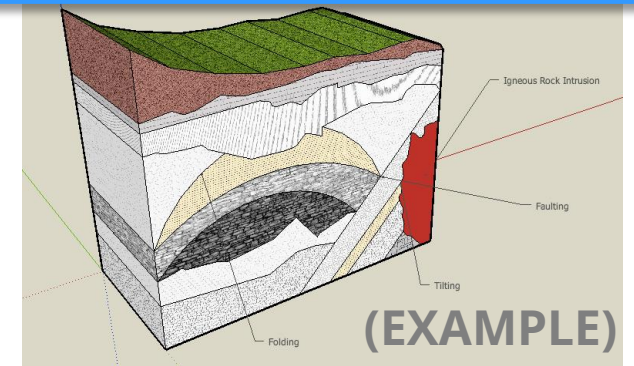
GPR



SEISMIC REFRACTION

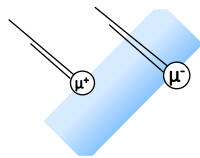


REFERENCE GEOLOGICAL PROFILE



FOCUS TECHNIQUE

MUOGRAPHY



$$\phi \propto \frac{1}{\rho}$$

$$g \propto \rho$$



JOINT INVERSION

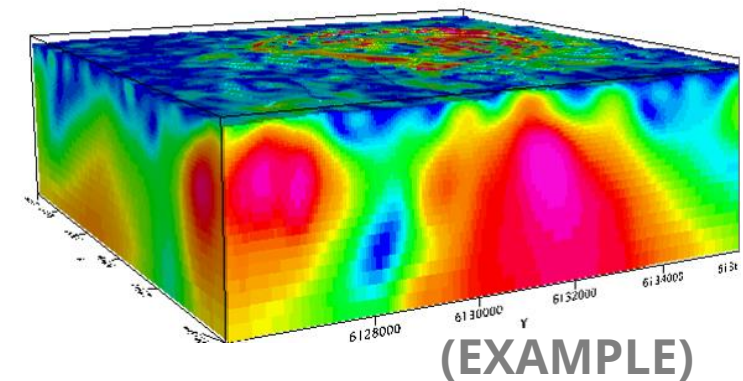
MUOGRAPHY

obtains the density through the attenuation of the muon flux

GRAVIMETRY

obtains the density through the strength of the gravitational field

RECONSTRUCTED 3D DENSITY PROFILE





THANK YOU!



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