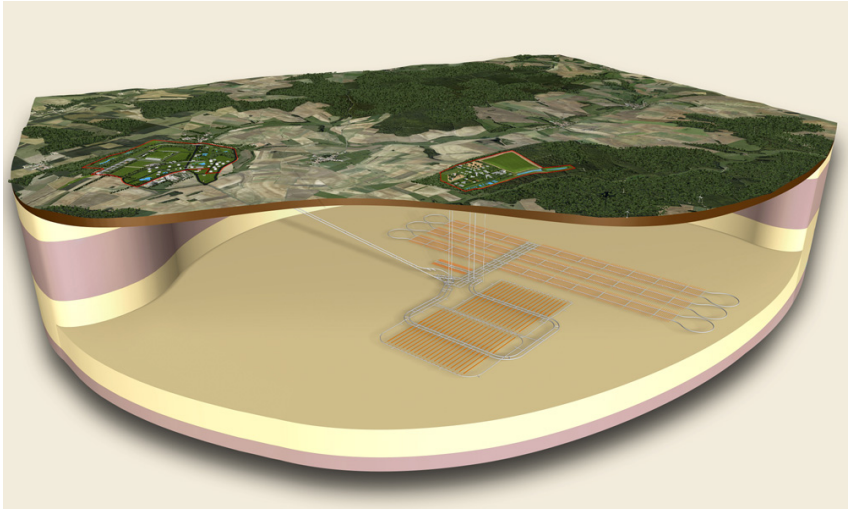
N. Lesparre - J. Cabrera - C. Gélis - J. Marteau

Potential of muon flux density and electrical resistivity imageries for detecting and characterizing discontinuities in a clay medium at the Tournemire URL

1. **Context**
2. The **TOMUEX** project: Tomography experience by analysis of the muons' flux applied to the massif of Tournemire
3. **Electrical resistivity imagery**
4. **Conclusions**

Nuclear waste storage

Cigeo: project of deep nuclear waste storage by ANDRA hosted in a clay layer of low permeability at Bure (Meuse)

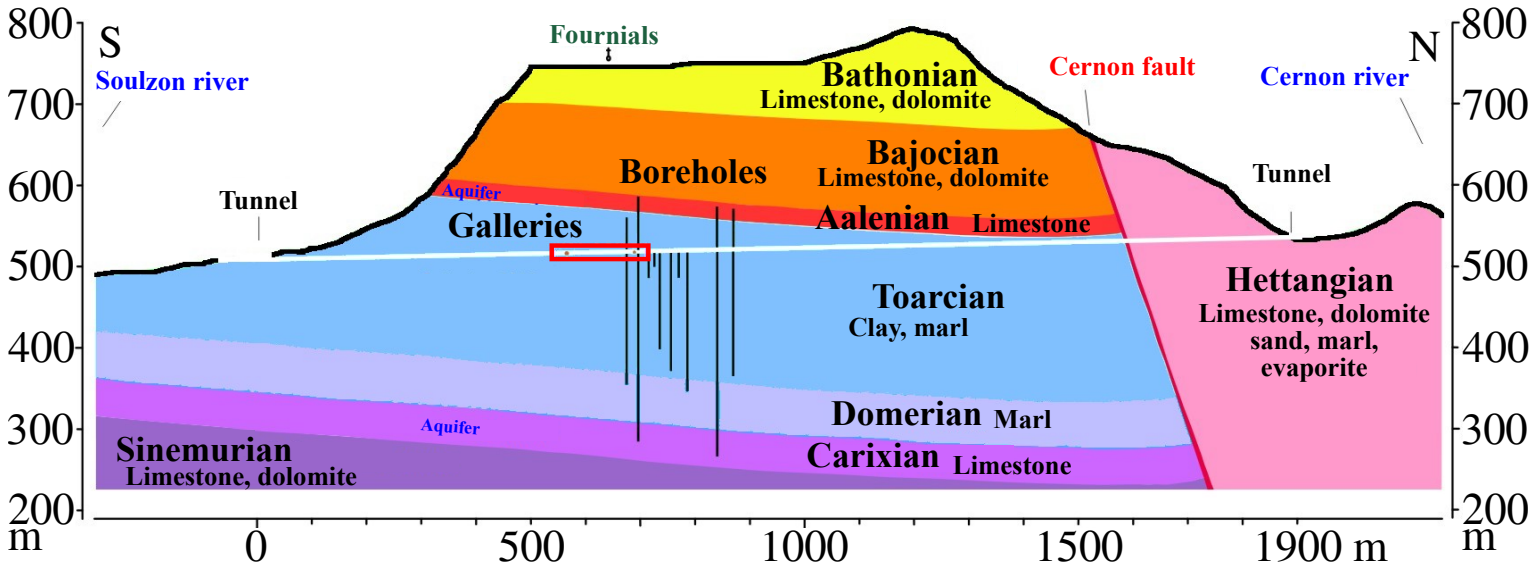


Issue: Presence of discontinuities in the hosting rock ?
$\rightarrow$ modification of the medium retention properties

$\Rightarrow$ **Geophysical imagery in the surrounding rock:**
$\rightarrow$ localise structures allowing radionuclide circulation to the biosphere

Tournemire experimental platform

A platform dedicated to experimental tests for supporting expertise



- Geological context similar to Cigeo
  → clay layer with a low permeability.
- Geological structures delimited
  → geometry relatively well known.

Objectives

Evaluate the capacity of geophysical methods to detect tectonic faults of small displacement

Objects

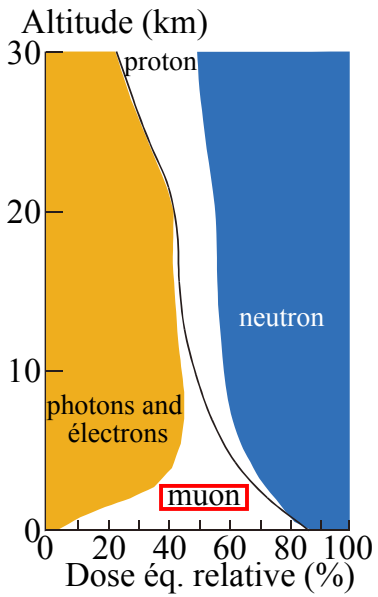
- **Structures observed on gallery walls and boreholes:**
  → strike-slip faults of small vertical displacements.
- **Structures observed in the region:**
  → karstic systems that may present huge cavities.

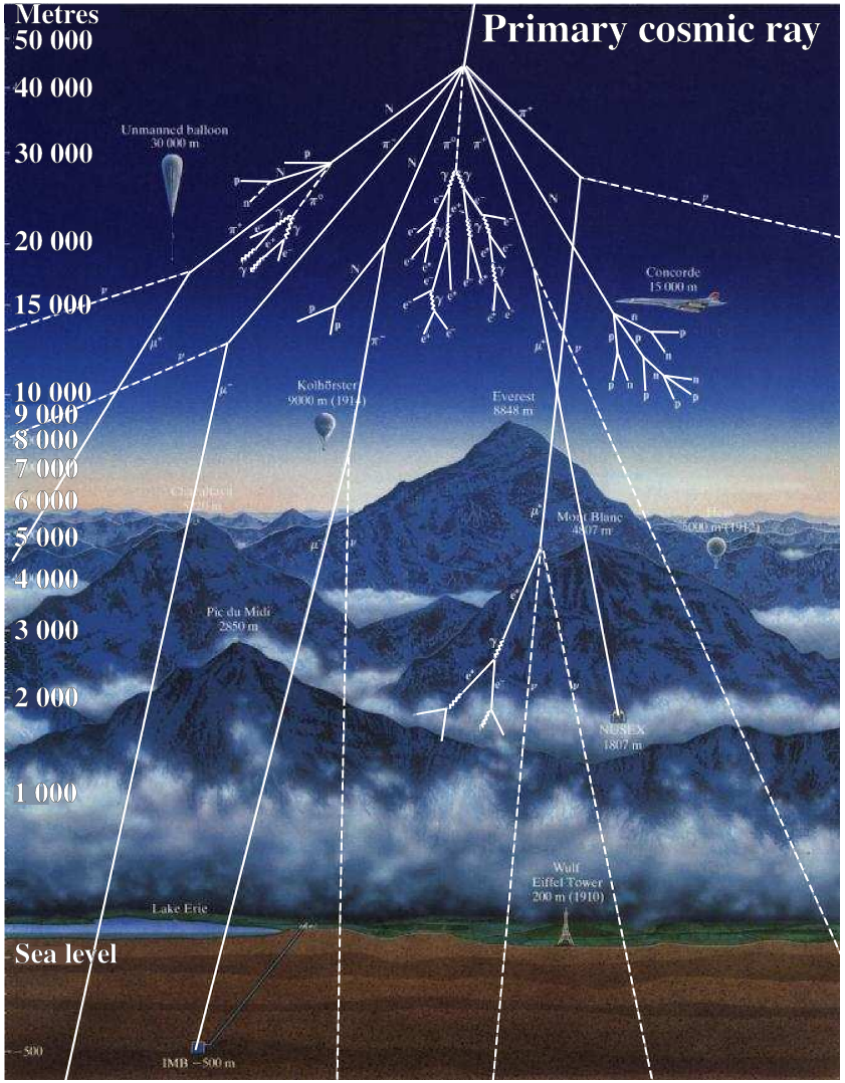
Methods

- **Muons flux density imagery:**
  → localize macro-porous regions.
- **Electrical resistivity imagery:**
  → localize fractured regions allowing water penetration.

Muons: definition

- Charged particles produced in atmospheric particles shower,
- Rest mass: 105 MeV/c^2 (electrons $\rightarrow$ 0.5 MeV/c^2) ,
- Lifetime: 2.2 μs,
- Weak cross-section $\rightarrow$ low interactions with matter.



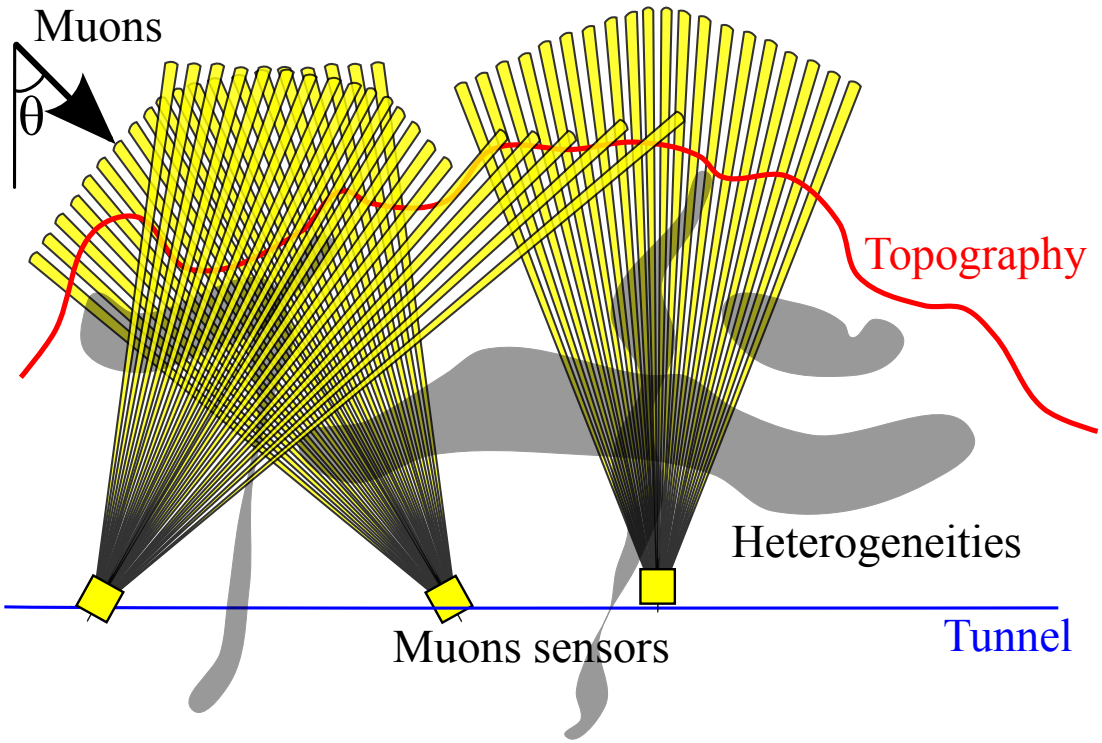


(Anderson & Neddermeyer, 1936 ; Bartlett, 2004).

Operational principle

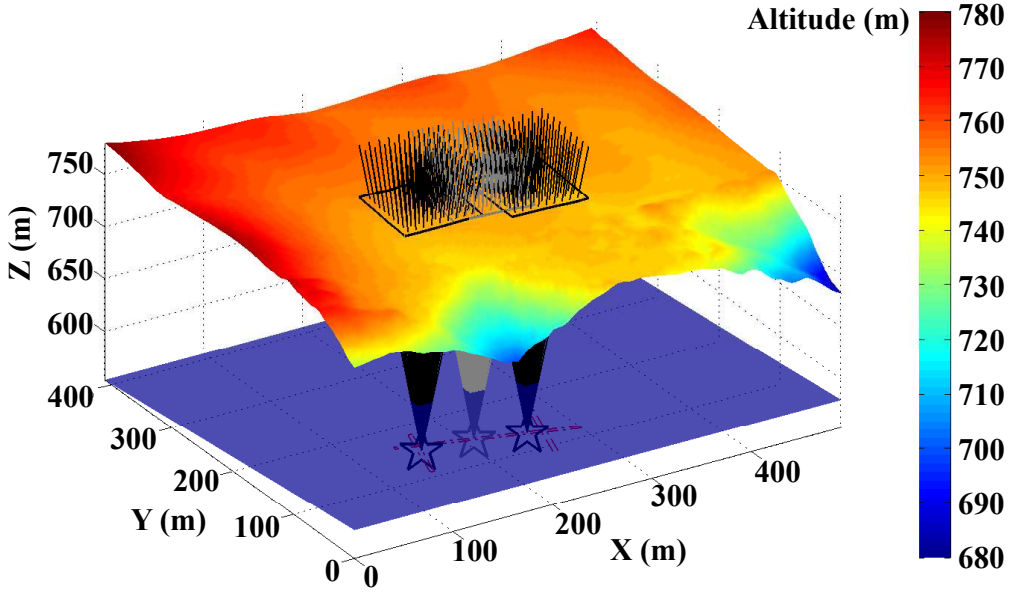
- Rock crossing $\rightarrow$ **attenuation** of the muons' flux,
  $\rightarrow$ measure of the medium **opacity** : $\varrho = \int_L \rho(x)\mathrm{d}x$ (g/cm^2).

$\Rightarrow$ Deduction of the **density** distribution



Simulation of an experience

- Telescopes' angles and capacity of detection model;
- knowledge of the topography
  $\rightarrow$ thickness of the sounded rocks ;
- knowledge of the medium geology
  $\rightarrow$ computation of the rock opacity $\Rightarrow$ **muons' flux estimation**;

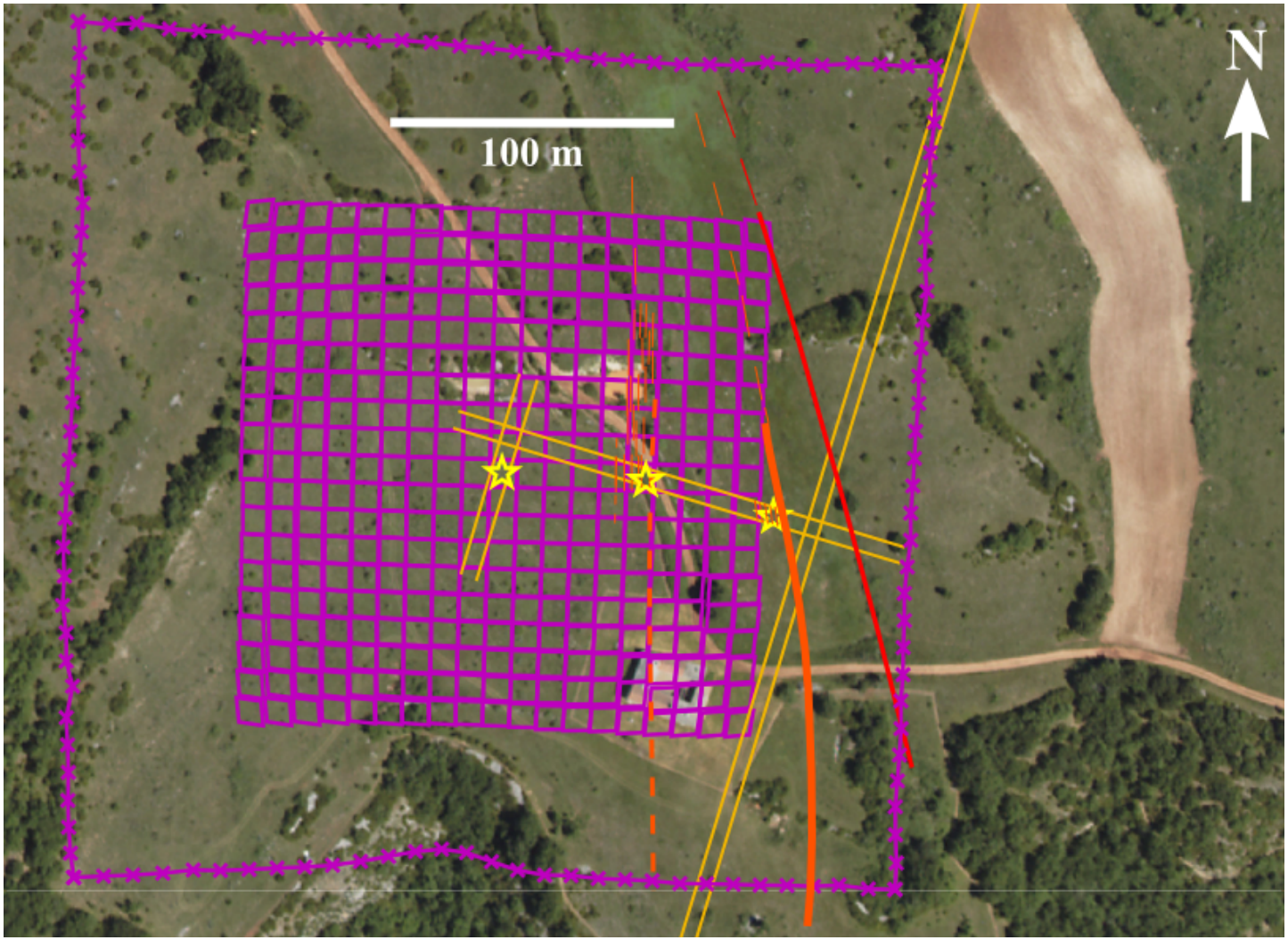


$$\theta = 70^\circ$$
$$\rho = 2.65\ \mathrm{g/cm^3}$$
$$\mathcal{T} = 20\ \mathrm{cm^2.sr}$$

Rock thickness	Muons flux
50 m	243 per day
100 m	75 per day
500 m	2 per day
1000 m	0.1 per day

Tomography of the massif of Tournemire

Configuration of the acquisition network: aerial view



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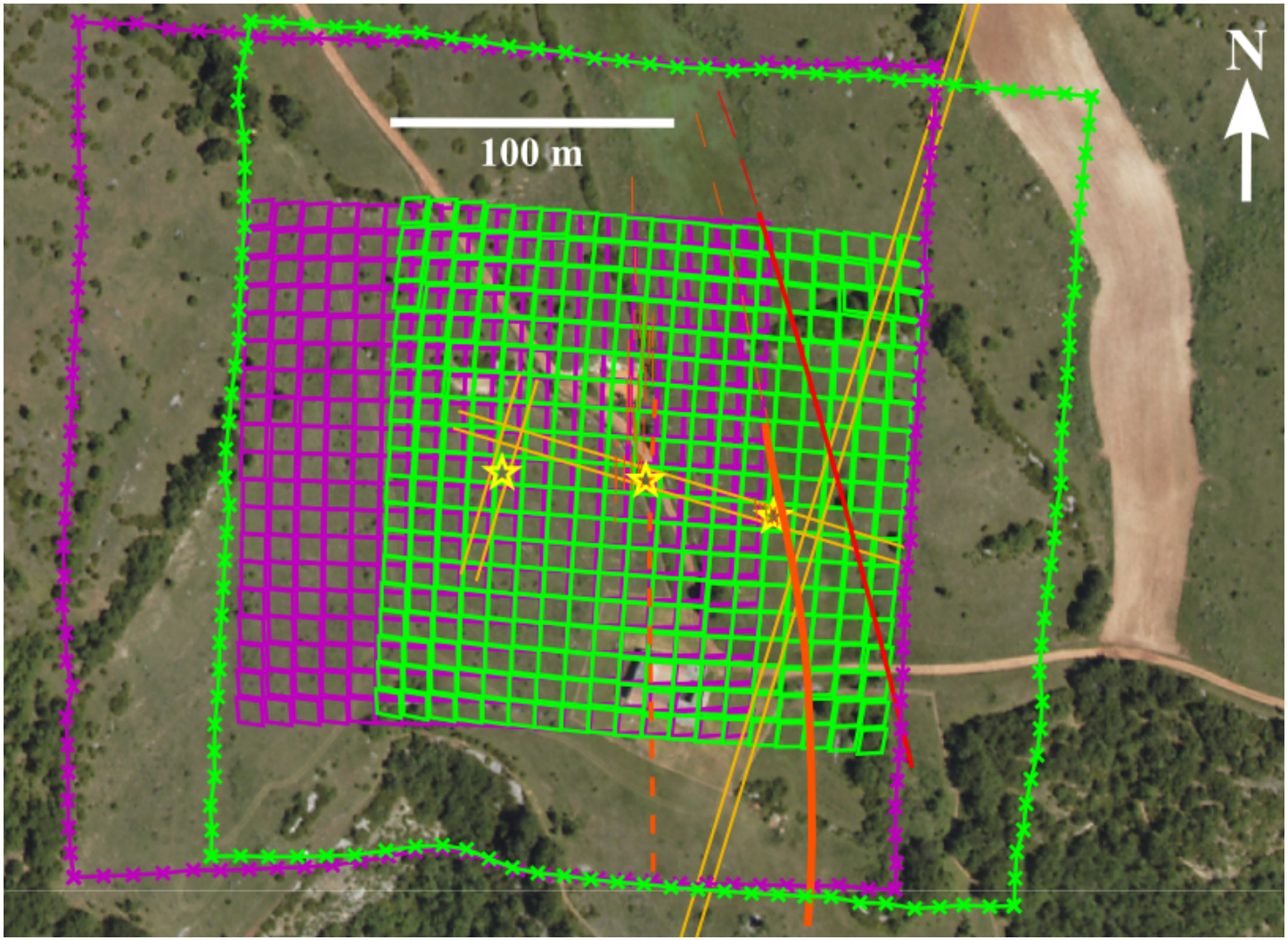

Tomography of the massif of Tournemire

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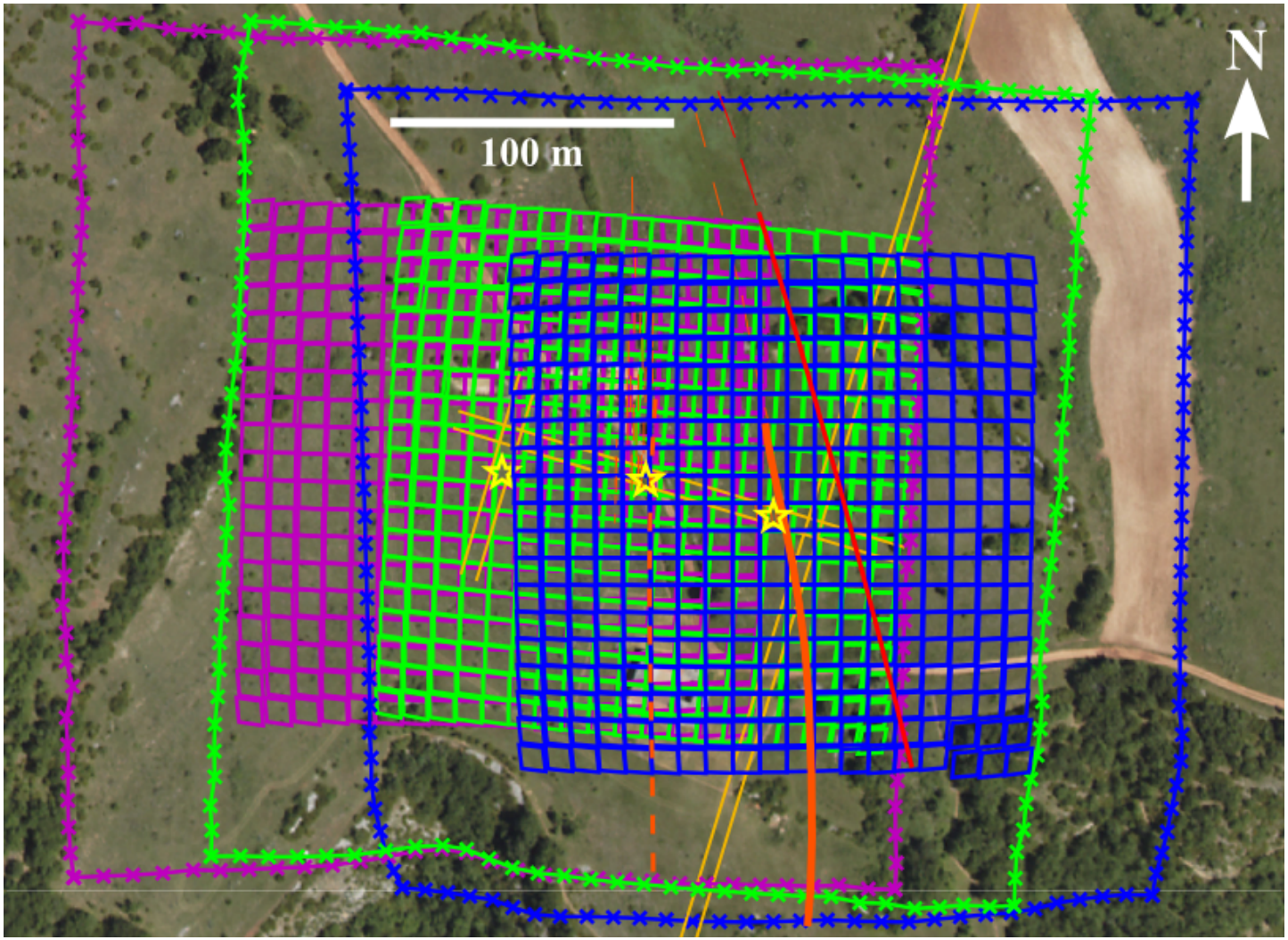
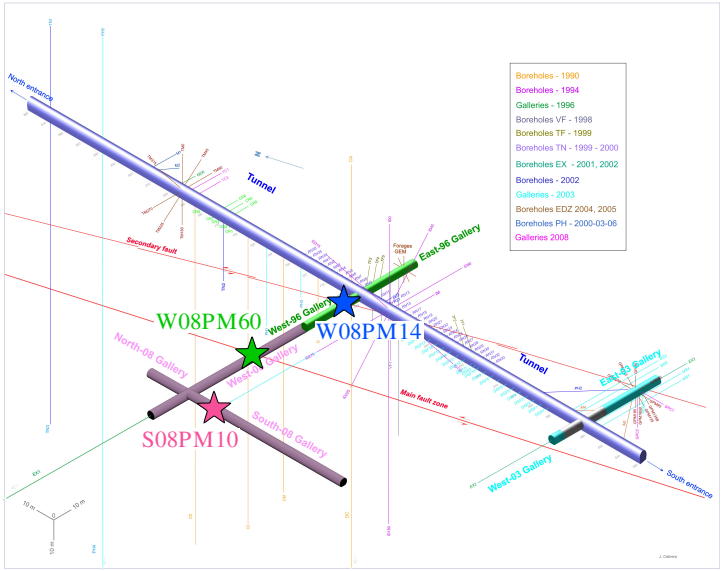
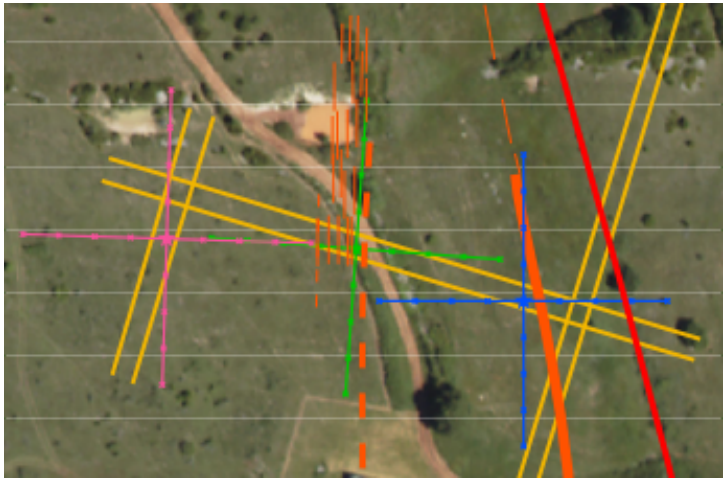


Muons' flux to density

Comparison of measurements

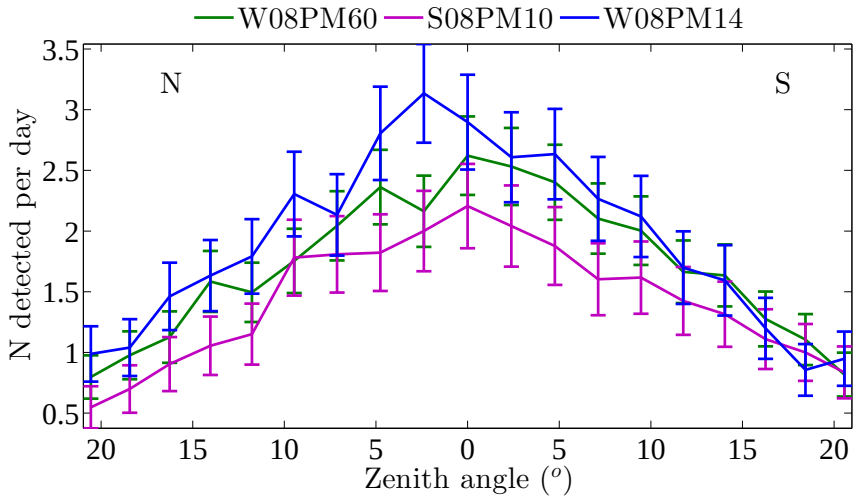


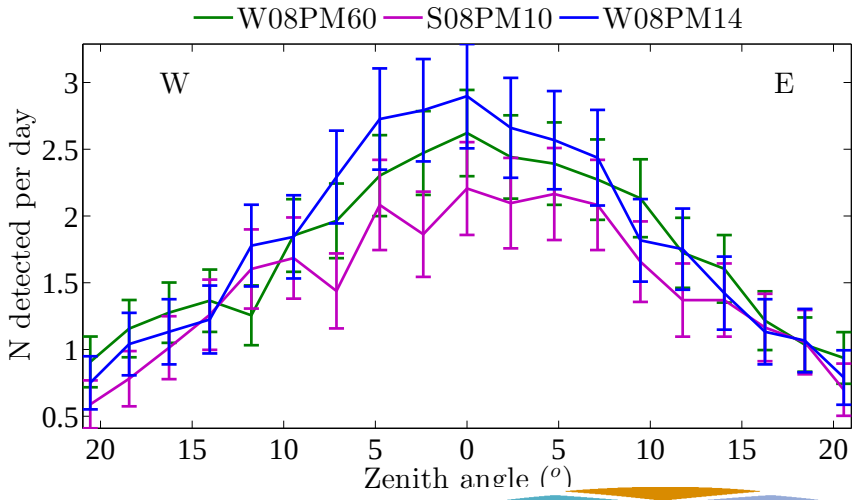


W08 PM60 $\rightarrow \Delta T = 100$ days

S08 PM10 $\rightarrow \Delta T = 78$ days

W08 PM14 $\rightarrow \Delta T = 77$ days





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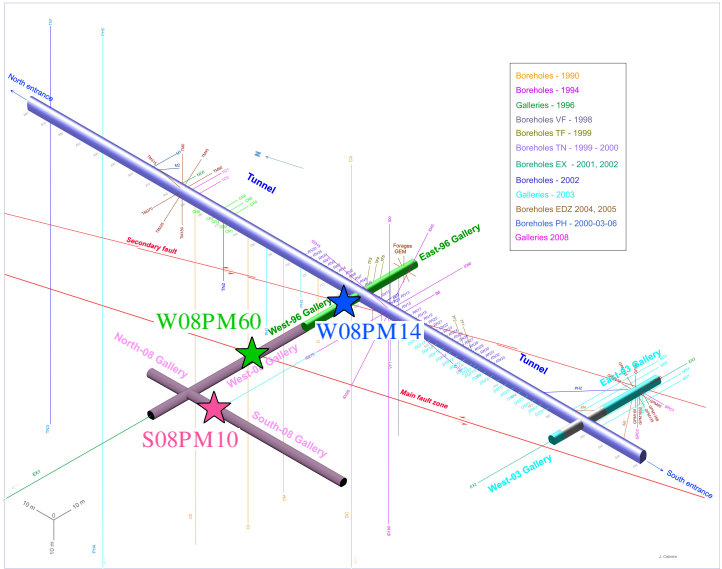

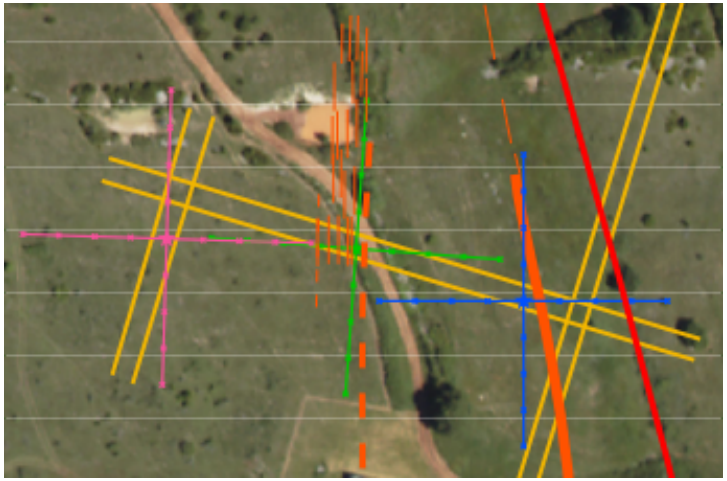

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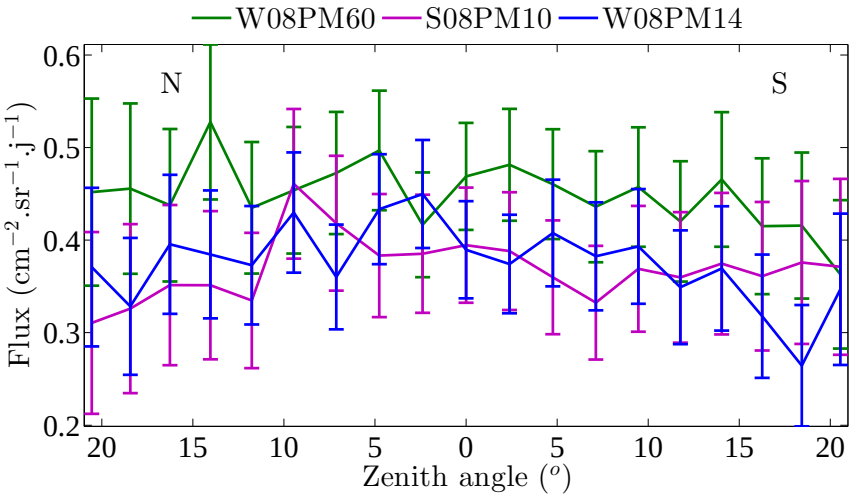

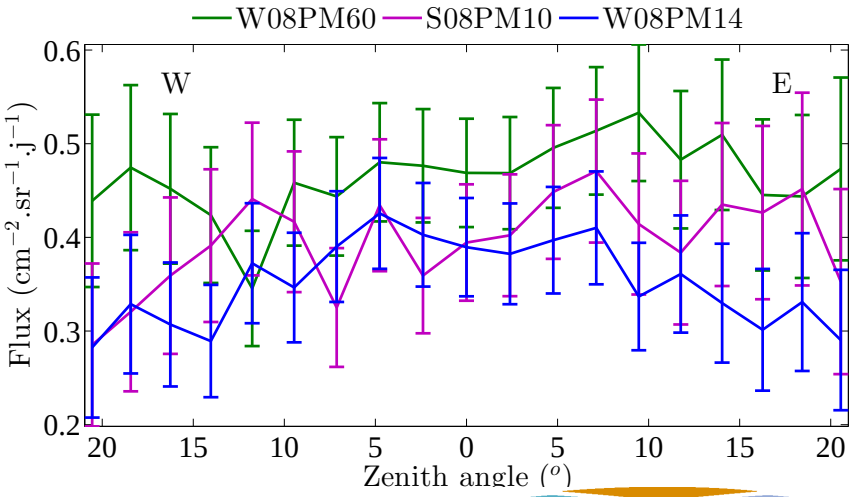

Muons' flux to density

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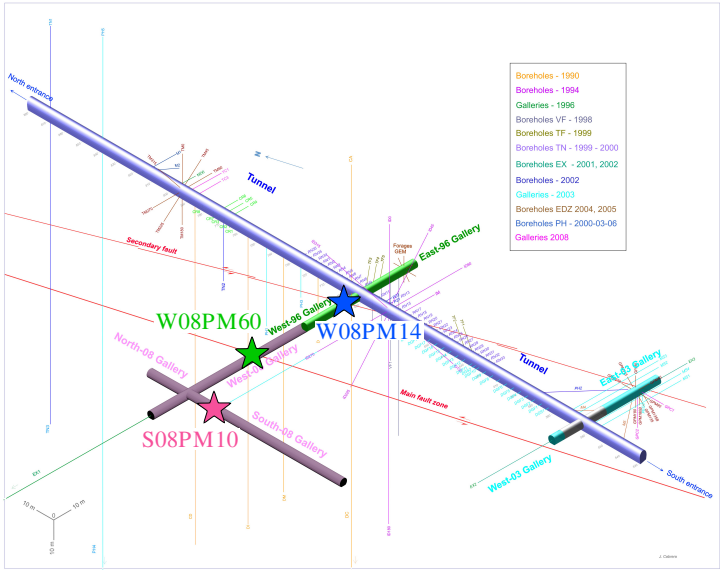

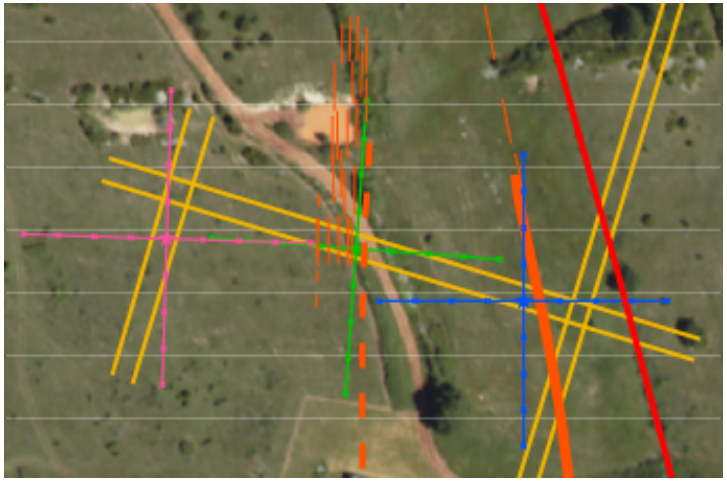

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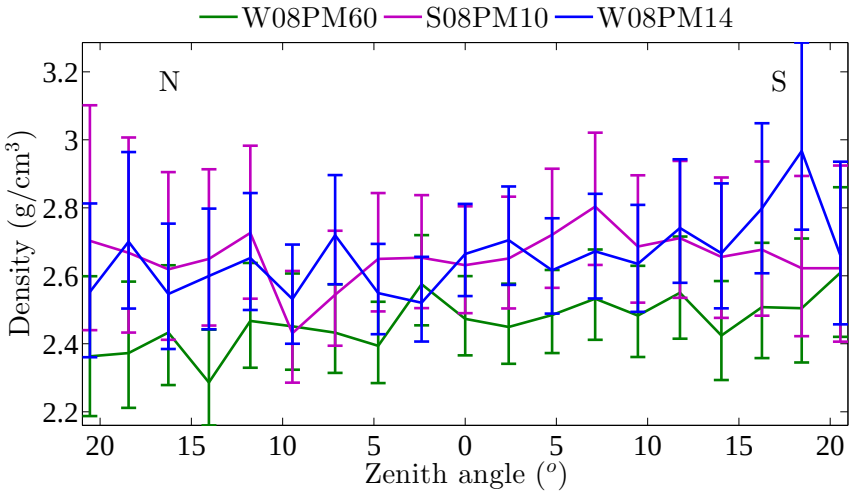
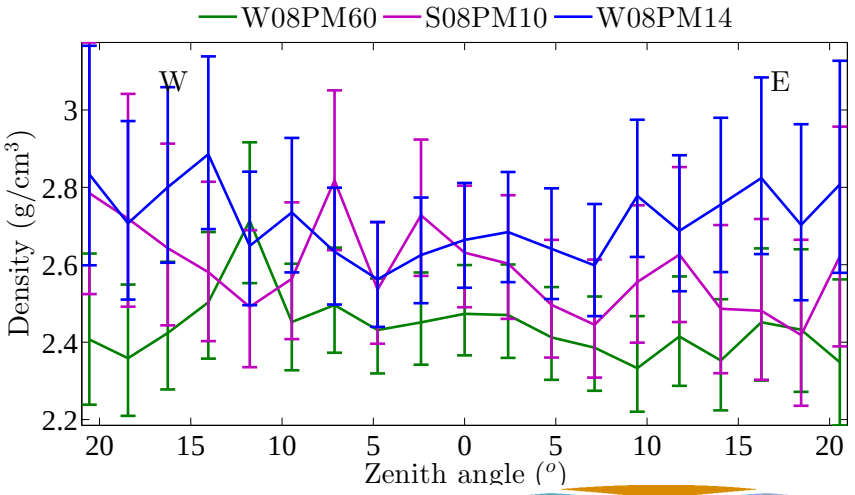
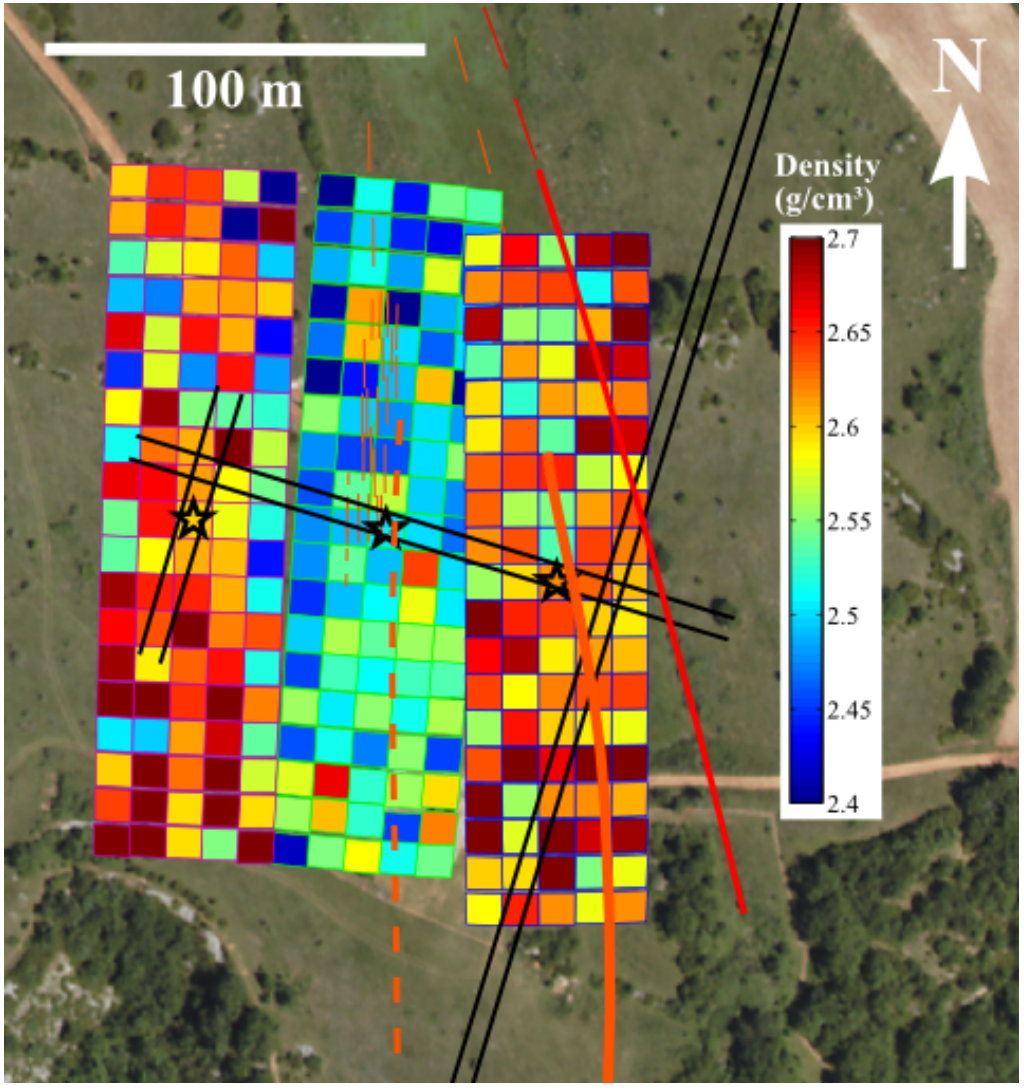




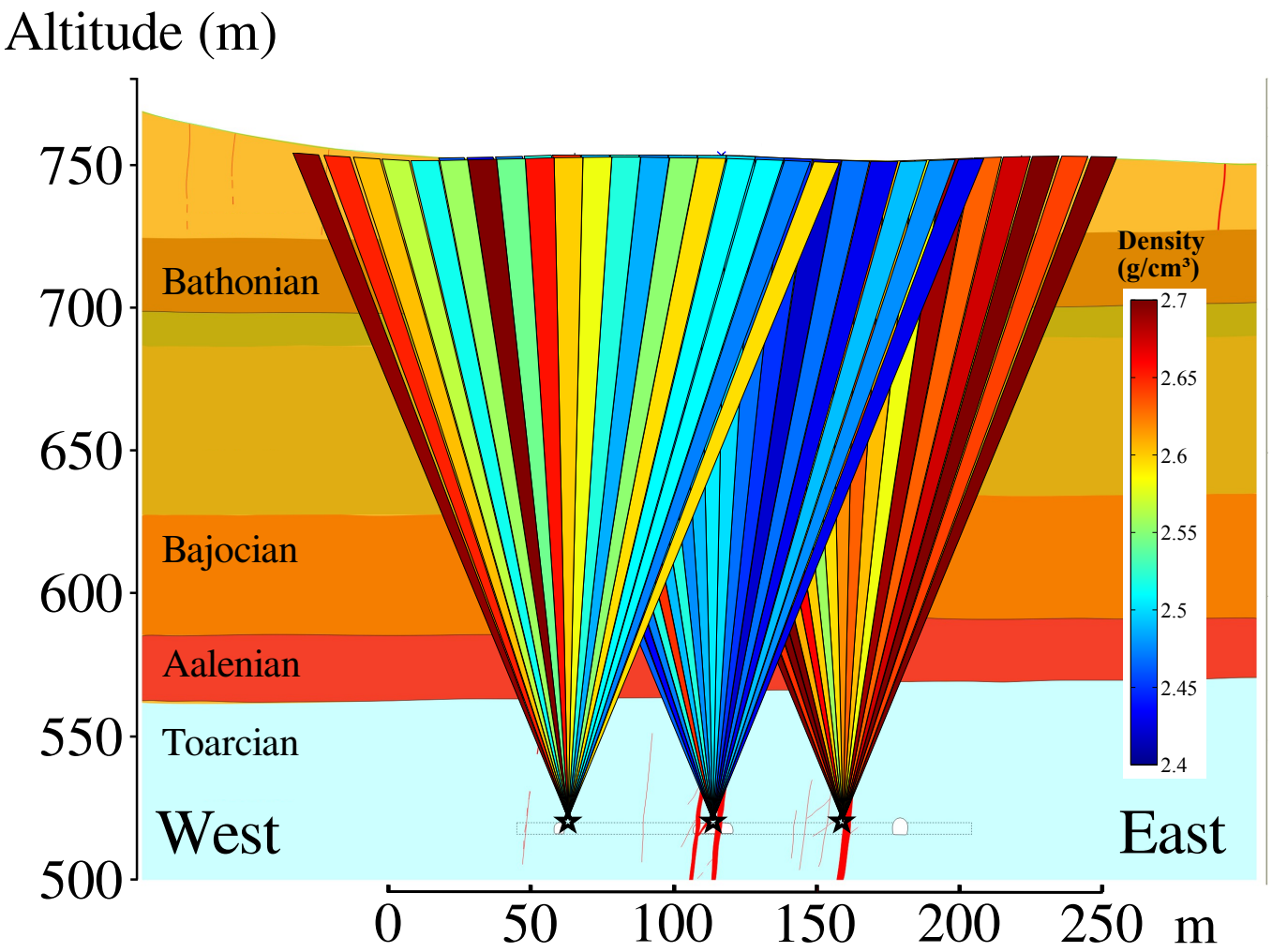
Location of the density contrasts

Aerial view

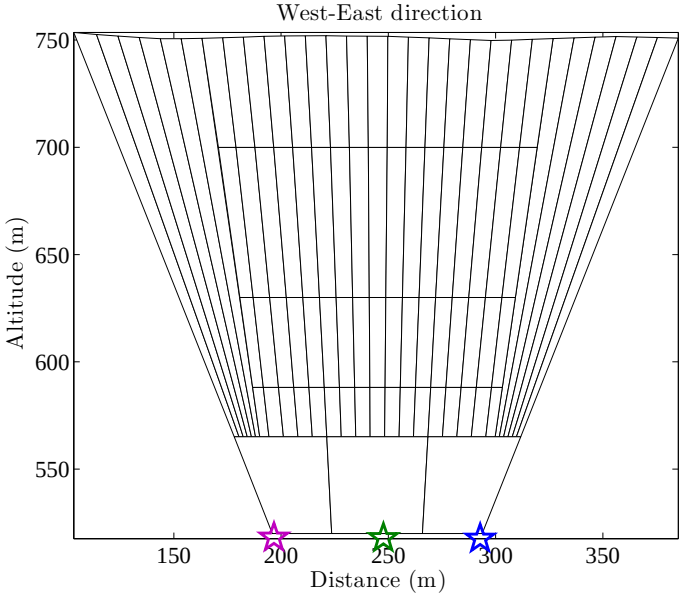


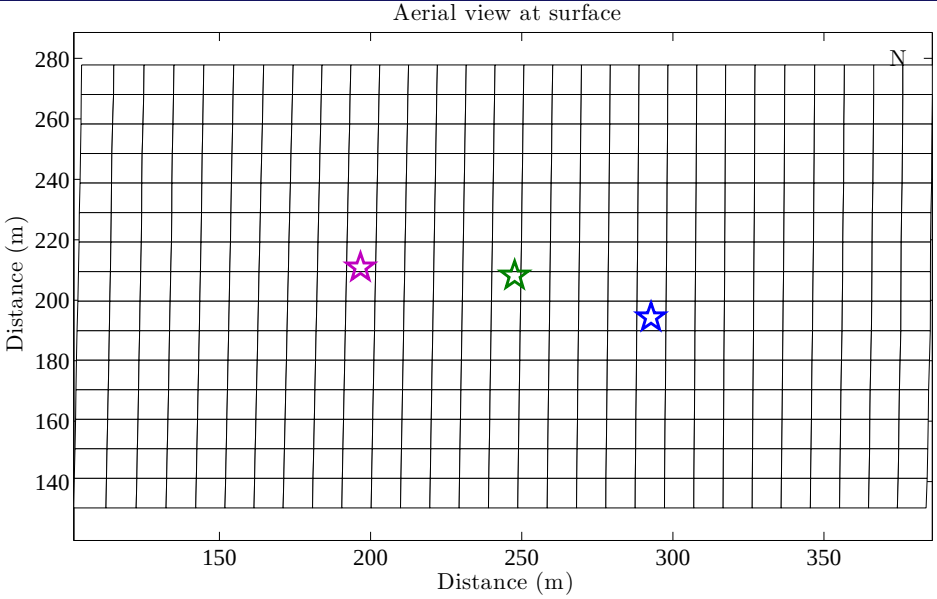
Location of the density contrasts

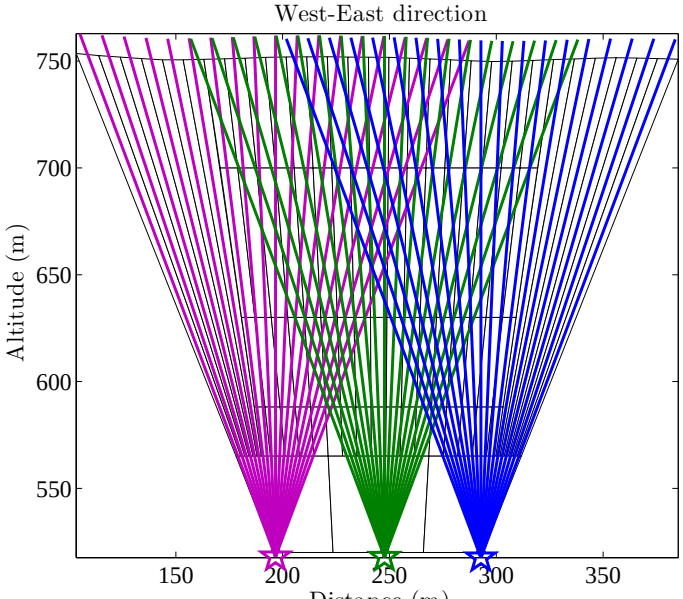
Profile view

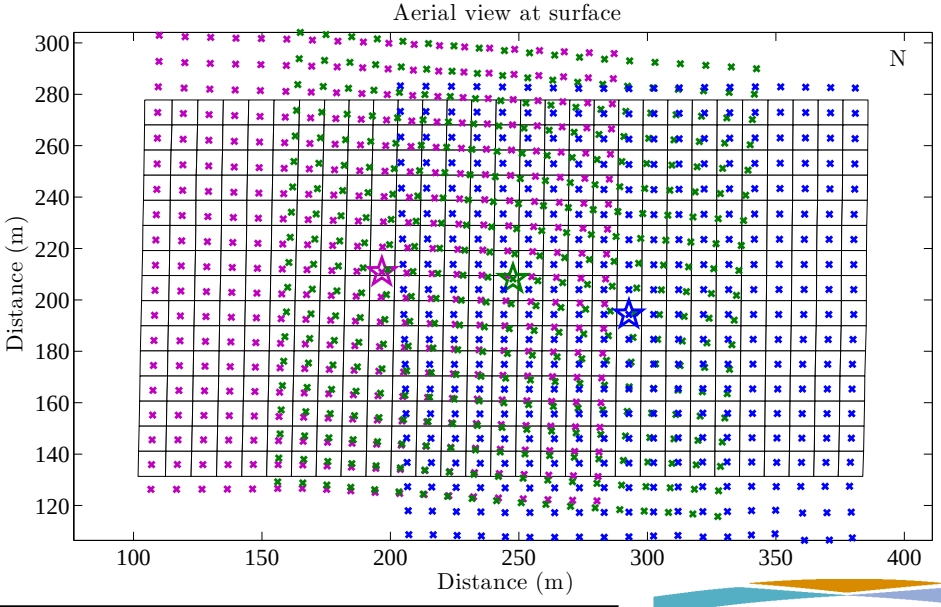


Density inversion

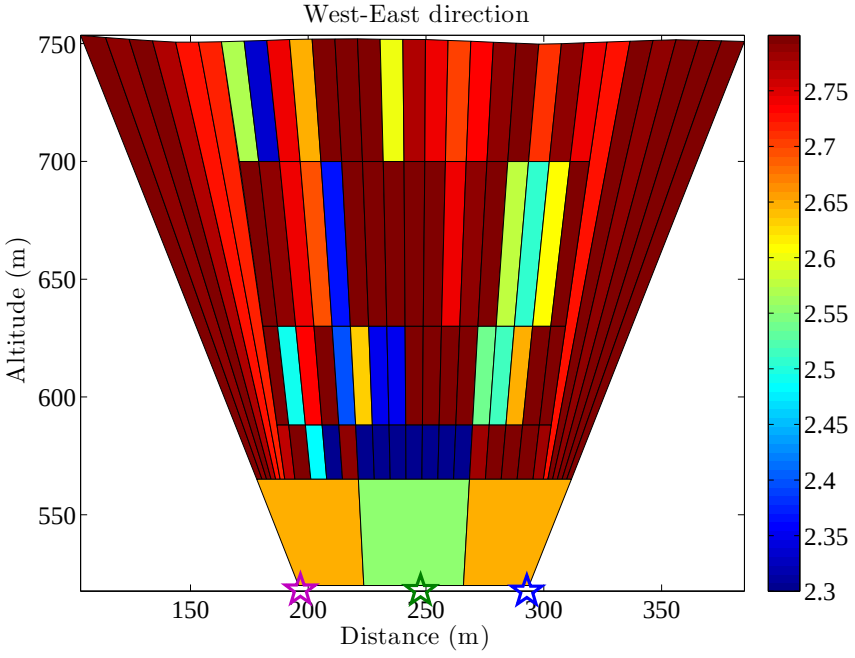


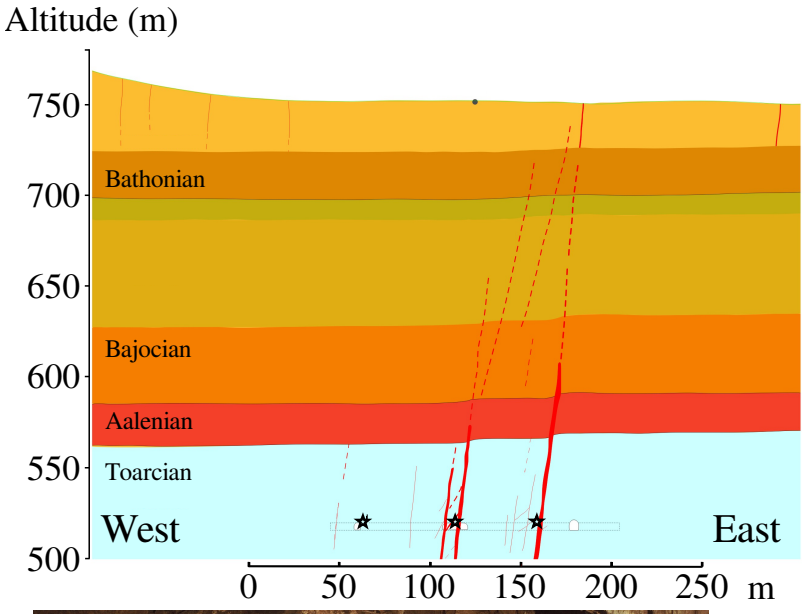


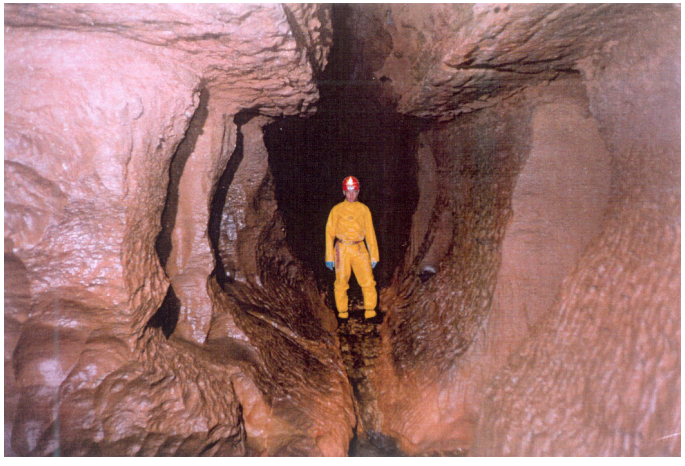




First results

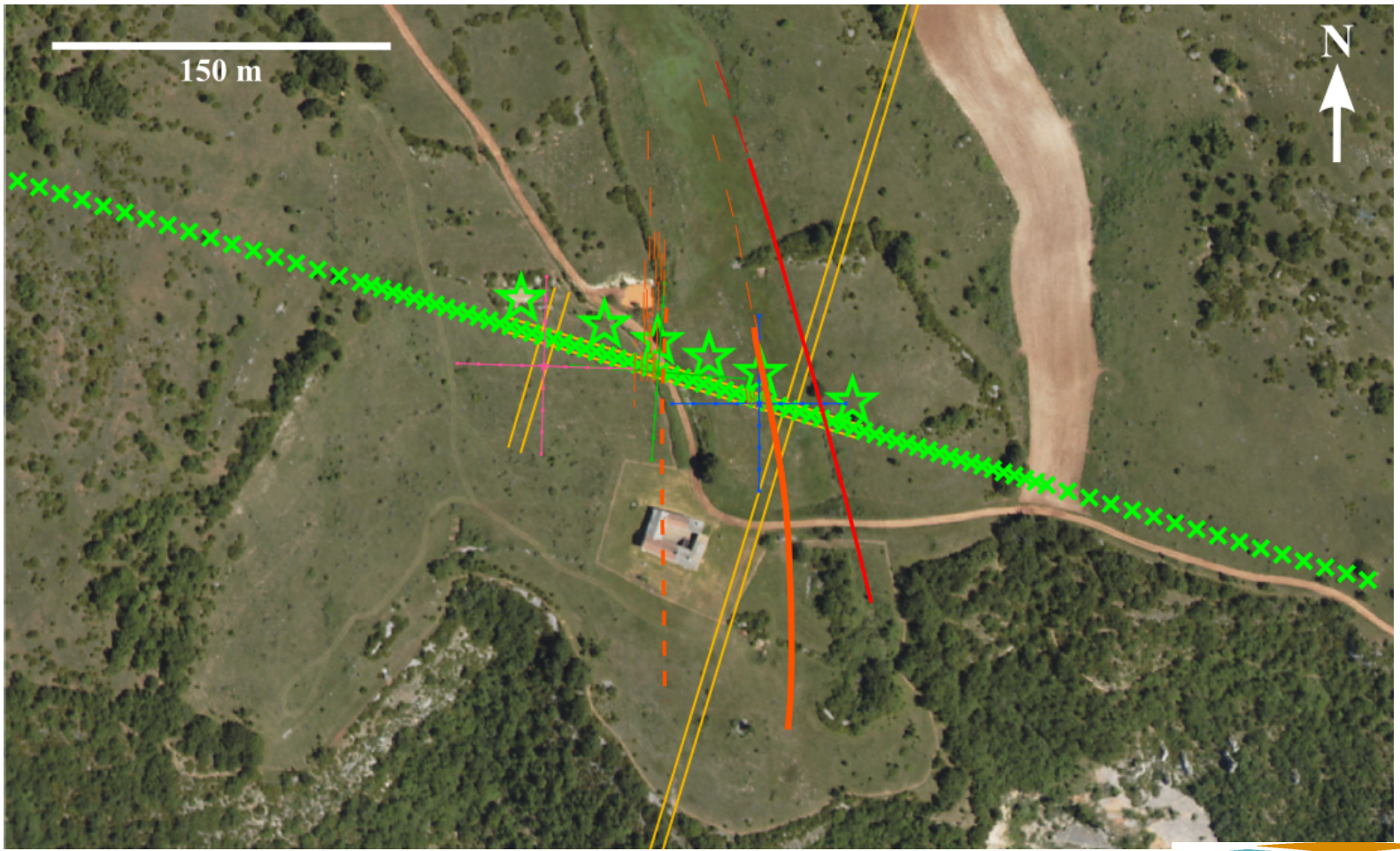






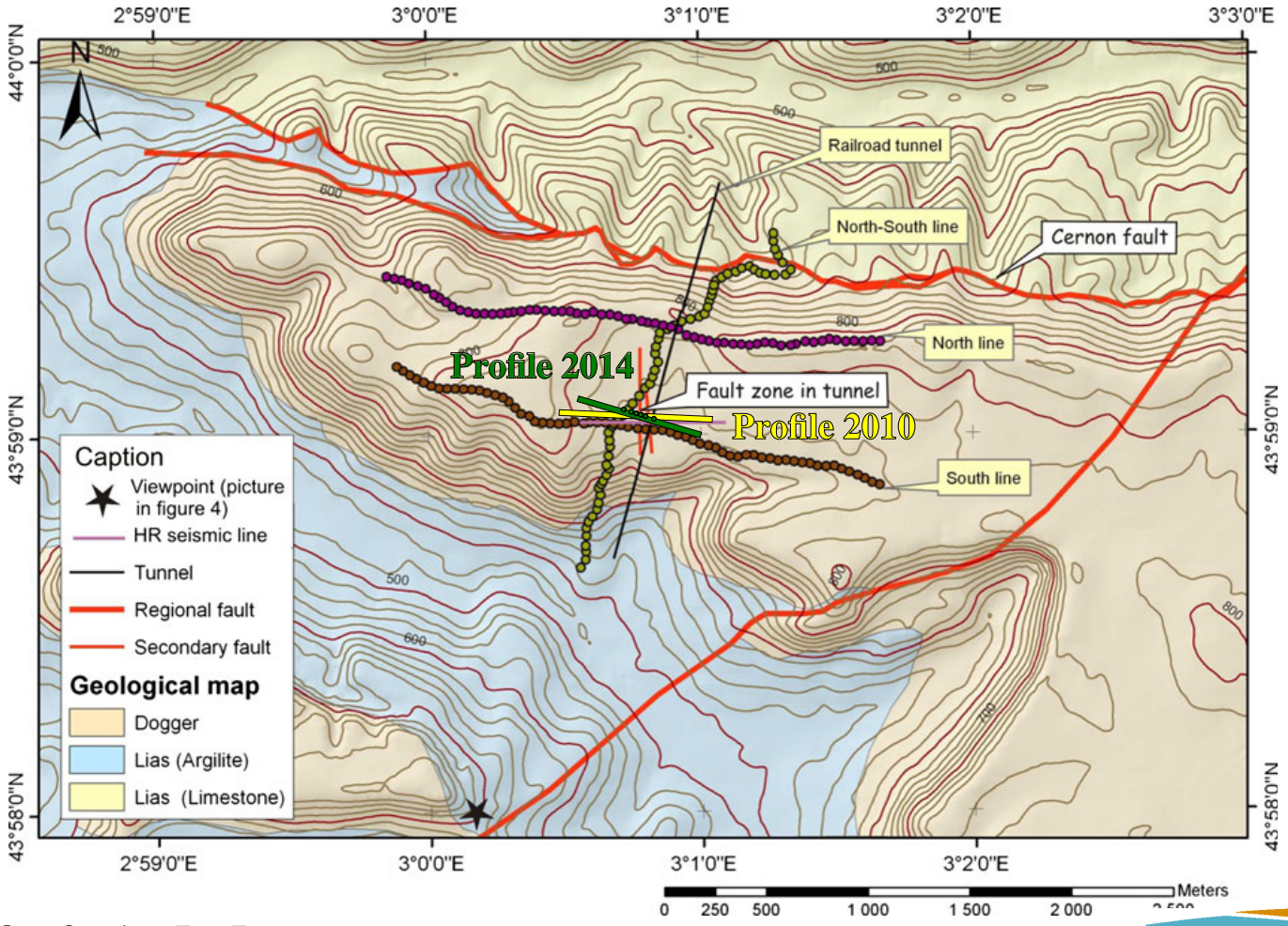
Configuration of the electrode network

- At surface: 96 electrodes, inter-electrode distances 5 to 10 m;
- In depth: 6 electrodes at the end of 10 m long boreholes.



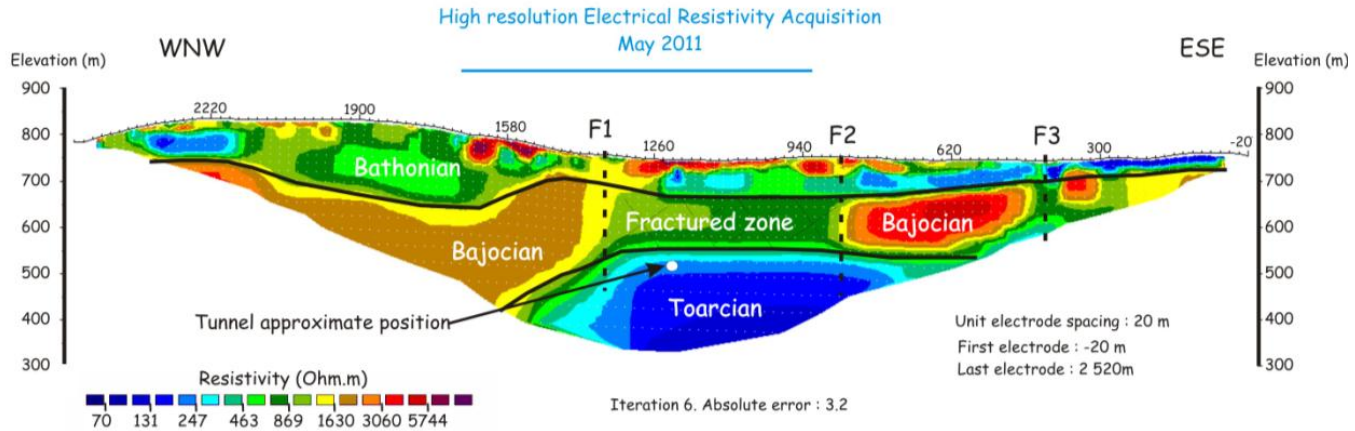
Comparison to previous experiments

- Data acquired at large scale in 2007 ($\Delta E = 40$ m);
- Data acquired with a smaller resolution in 2010 ($\Delta E = 2; 4; 8$ m).

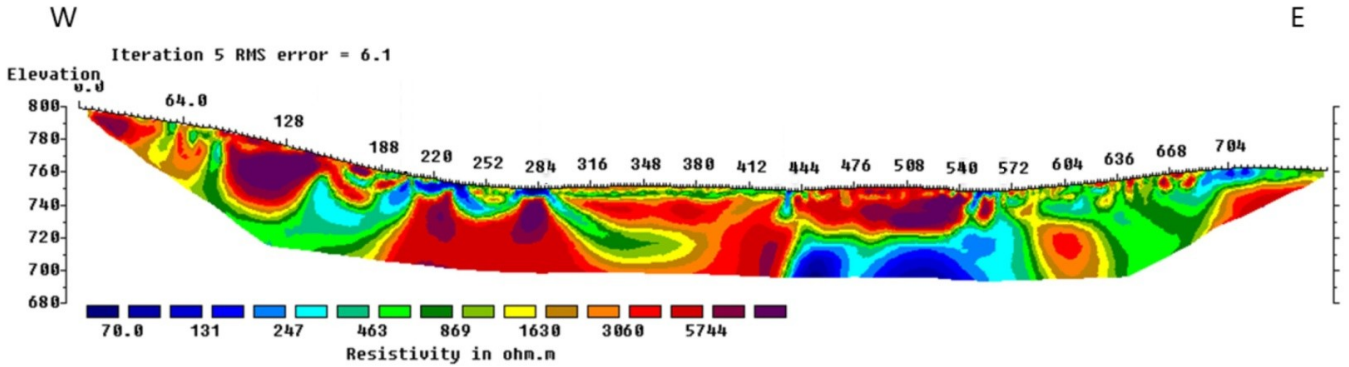


Comparison to previous experiments

2007



2010



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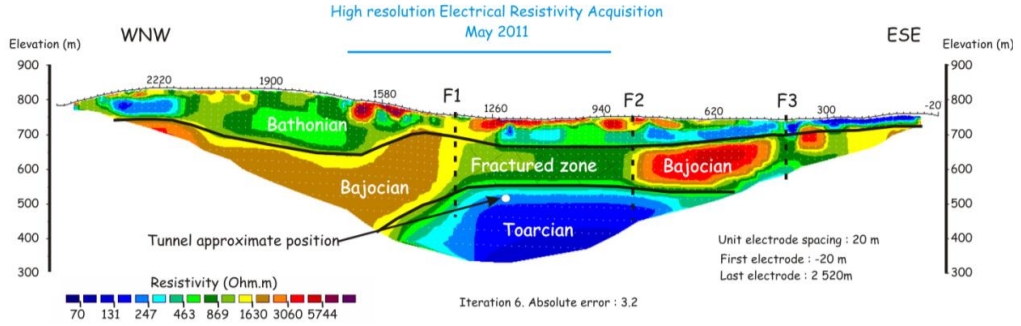
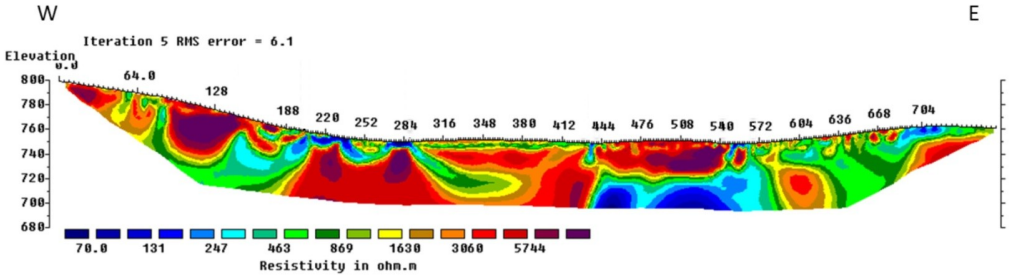
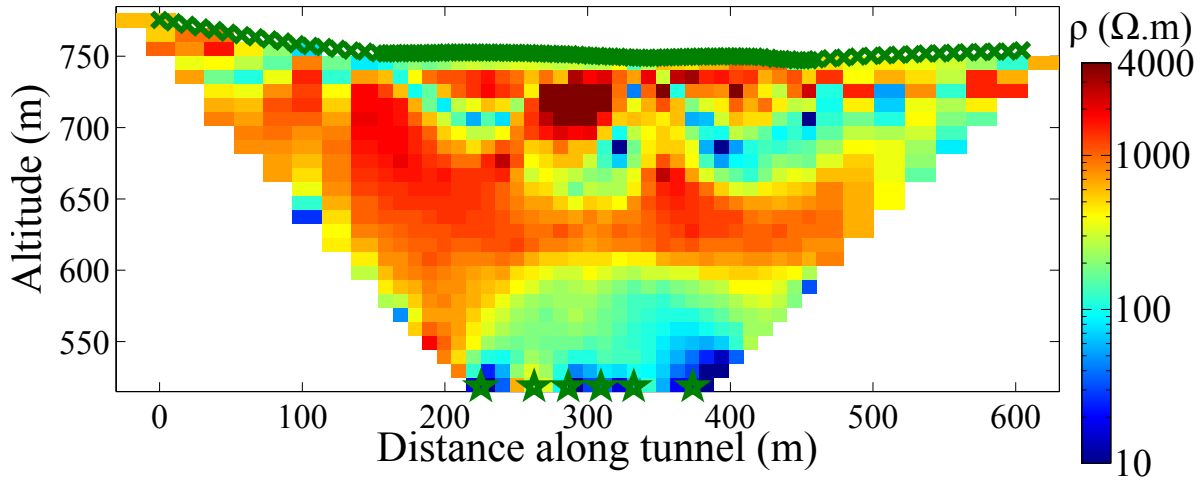
2007



2010



2014



Conclusions

Muons' flux experiment:

- Detection of muons' flux from three locations;
- Reconstruction of the medium density distribution.

Observations:

- Very low density region in the Aalenian layer → karstic cavities.
- Low density zones in limestones → sub-vertical fractures.

Electrical imagery experiment:

- Data acquisition in transmission between surface and galleries ;
- Model of the experiment and first inversion.

Observations:

- Resistivity contrasts in agreement with previous experiments;
- High heterogeneity of the limestone layers;
- Resistivity contrasts in the clay layer.

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