# Monitoring of CO2 storage methods and challenges

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# Topics of the presentation

- Introductory notes on monitoring of CO2 storage:
  - why and when the storage monitoring is needed
  - monitoring methods
  - monitoring examples
- Challenges:
  - improvement of methods and their sensibility
  - improvement of cost/benefits
  - examples of superficial monitoring methods

# Introduction

➔ Carbon capture and storage (CCS) has been shown to be a realistic and safe approach to rapidly decrease man-made greenhouse gas emissions

Weyburn

Sleipner

In Salah

# Introduction

- When and for how long should a site be monitored?

The life cycle of a storage site can be divided into the following phases, each of which will have different reservoir conditions :

- **Injection**. During this period pressures will be highest
- **Post-injection and closure**. Pressures will decrease because of lateral fluid movements and the dissolution of more $CO_2$ into the pore water
- **Post closure**. Dissolution will continue, density flow may move some dissolved $CO_2$ downwards, and slow mineral reactions may permanently trap some $CO_2$

# Introduction

- Many techniques already exist
  - Direct vs indirect methods
  - Deep vs near-surface methods
- Methods can be subdivided based on their discipline:
  - Geochemical
  - Geophysical
  - Biological
  - Remote sensing

# IEA-GHG monitoring tool

http://www.co2captureandstorage.info/co2monitoringt

$CO_2$ Capture and S

## Monitoring Selection Tool

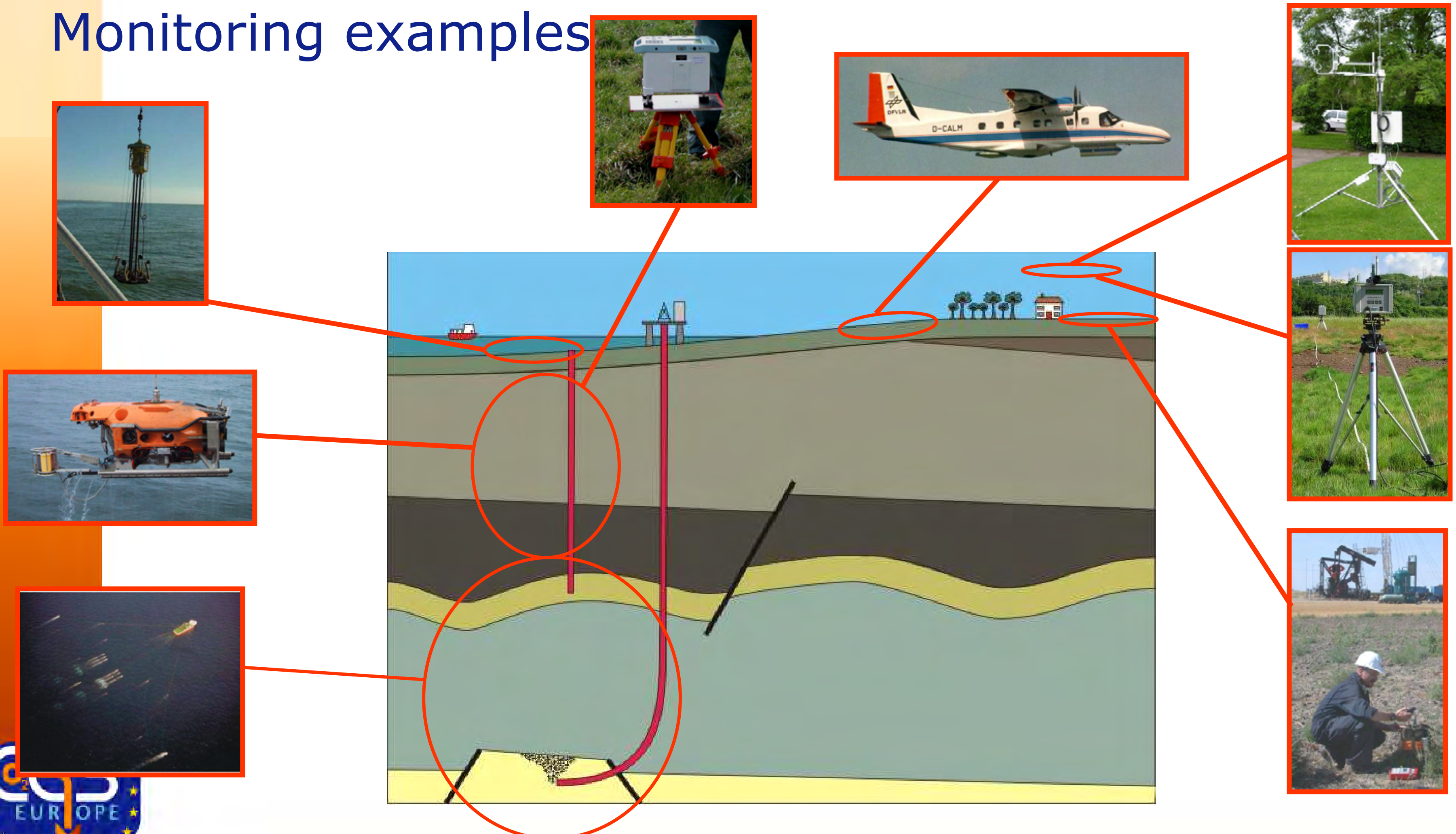
**Scenario summary:** New Scenario [2010-08-13 15:28:01]

**Location:** Offshore; **Depth:** 1500 to 2500 m; **Type:** Aquifer; **Quantity:** 20.000 Mt (1.000 Mt/yr for 20.0

| Tool | Rating % | Plume | Seal | Migration | Quantification | Efficiency | Calibration |
|---|---|---|---|---|---|---|---|
| 3D surface seismic | 75 | 4.0 | 4.0 | 4.0 | 4.0 | 3.0 | 4.0 |
| Downhole fluid chemistry | 55 | 1.0 | 2.0 | 3.0 | 2.0 | 2.0 | 3.0 |
| 2D surface seismic | 45 | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 2.0 |
| Geophysical logs | 42 | 1.0 | 2.0 | 0.0 | 2.0 | 4.0 | 3.0 |
| Downhole pressure/temperature | 38 | 1.0 | 3.0 | 0.0 | 2.0 | 2.0 | 3.0 |
| Microseismic monitoring | 16 | 0.9 | 0.9 | 0.7 | 0.0 | 0.0 | 0.4 |

# Monitoring methods

## Monitoring examples



# CO2 storage monitoring examples

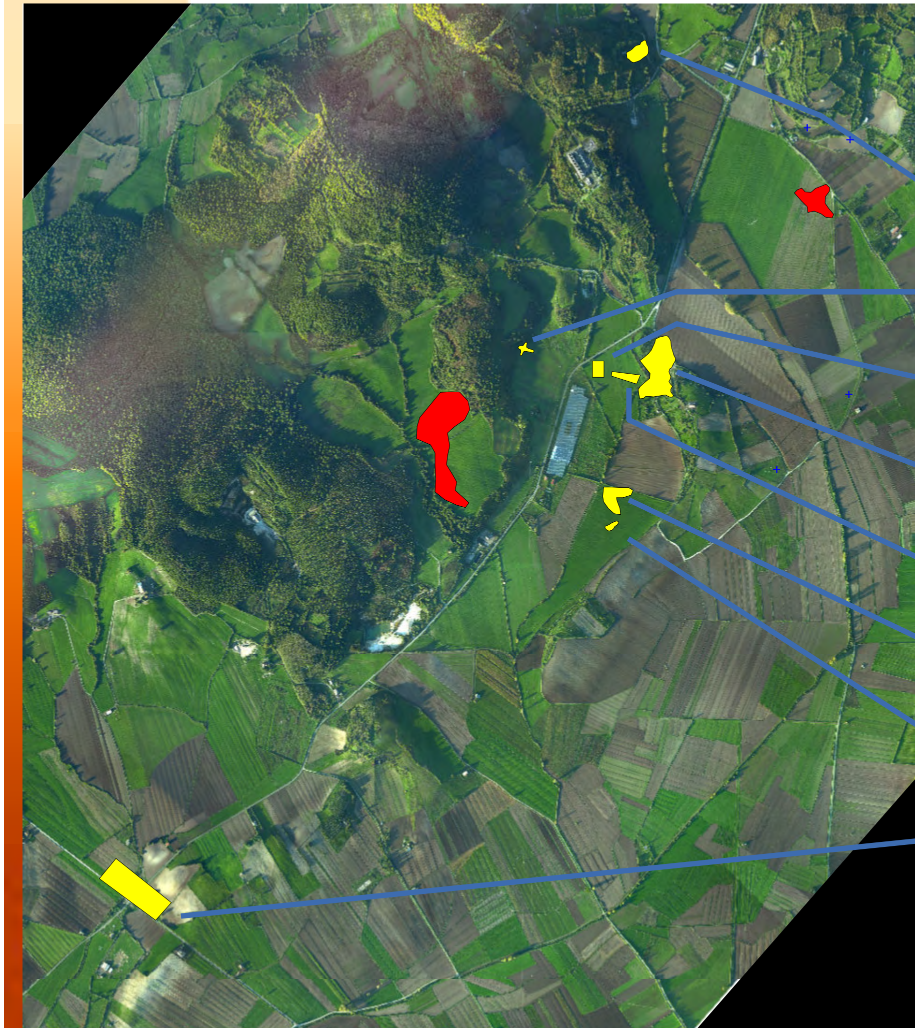
## Monitoring gas migration at natural laboratory Latera Caldera, central Italy

# Methods applied at Lcaldera

- Soil gas and $CO_2$ flux
- Structural survey
- Ground Penetrating Radar
- Microgravity
- Magnetometer
- Seismic data
- Electromagnetic survey
- Geo-electrical survey (resistivity survey)
- Spectral induced polarization
- Self Potential Mapping
- Time Domain EM
- Vertical Electrical Sounding (VES)
- Surface water conductivity survey

# Can we detect leakage: Main $CO_2$ vents at Latera

# Can we detect leakage: $CO_2$ flux – calculated values: Latera

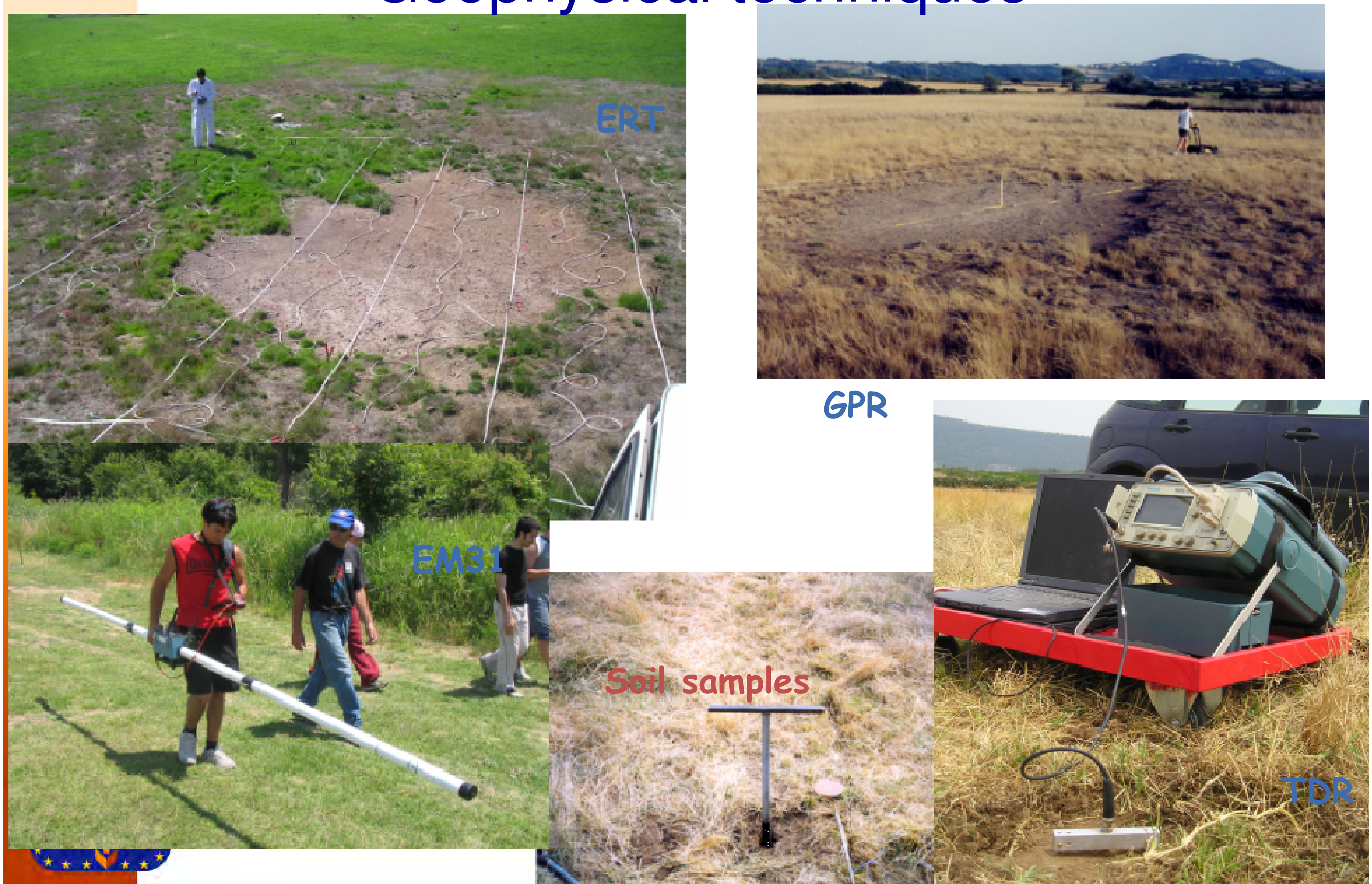


| site | $CO_2$ flux tonnes/day |
|---|---|
| 1 | 6.60 |
| 2 | 0.09 |
| 3 | 0.15 |
| 4 | 6.47 |
| 5 | 0.07 |
| 6 | 0.04 |
| 7 | 0.20 |
| 8 | 7.54 |
| | |
| total | 21.15 |

3 locations account for 97.5% of $CO_2$ flux

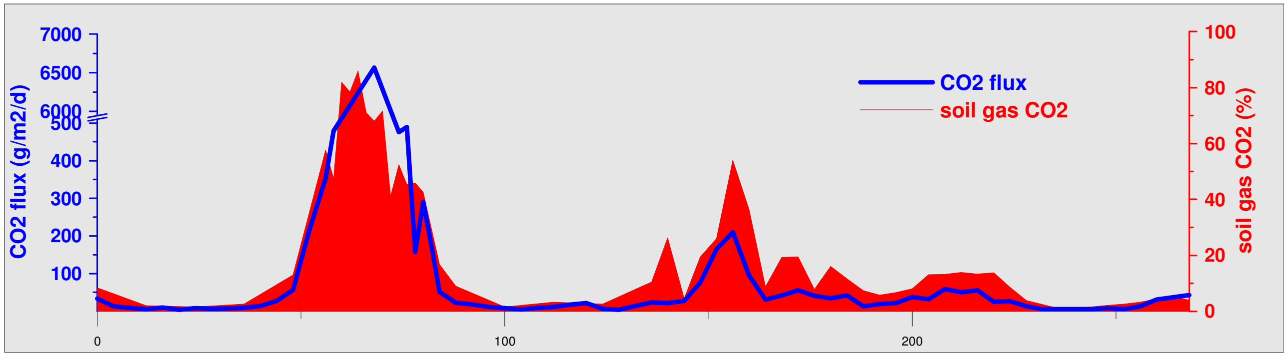
- Total $CO_2$ flux is 7.7 k tonnes / year

# Geophysical techniques

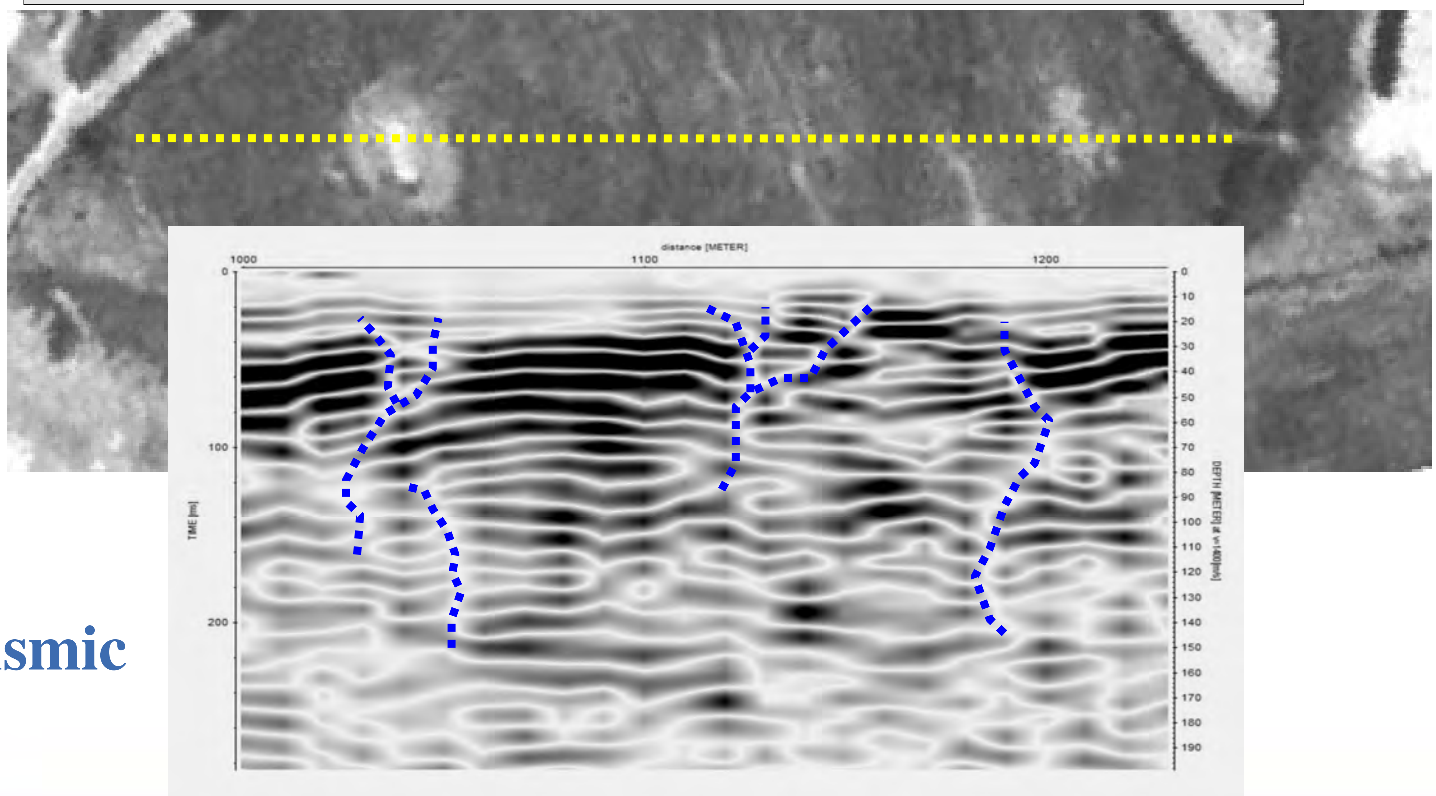



TDR

# Monitoring  gas emanation at Latera Caldera – central Italy

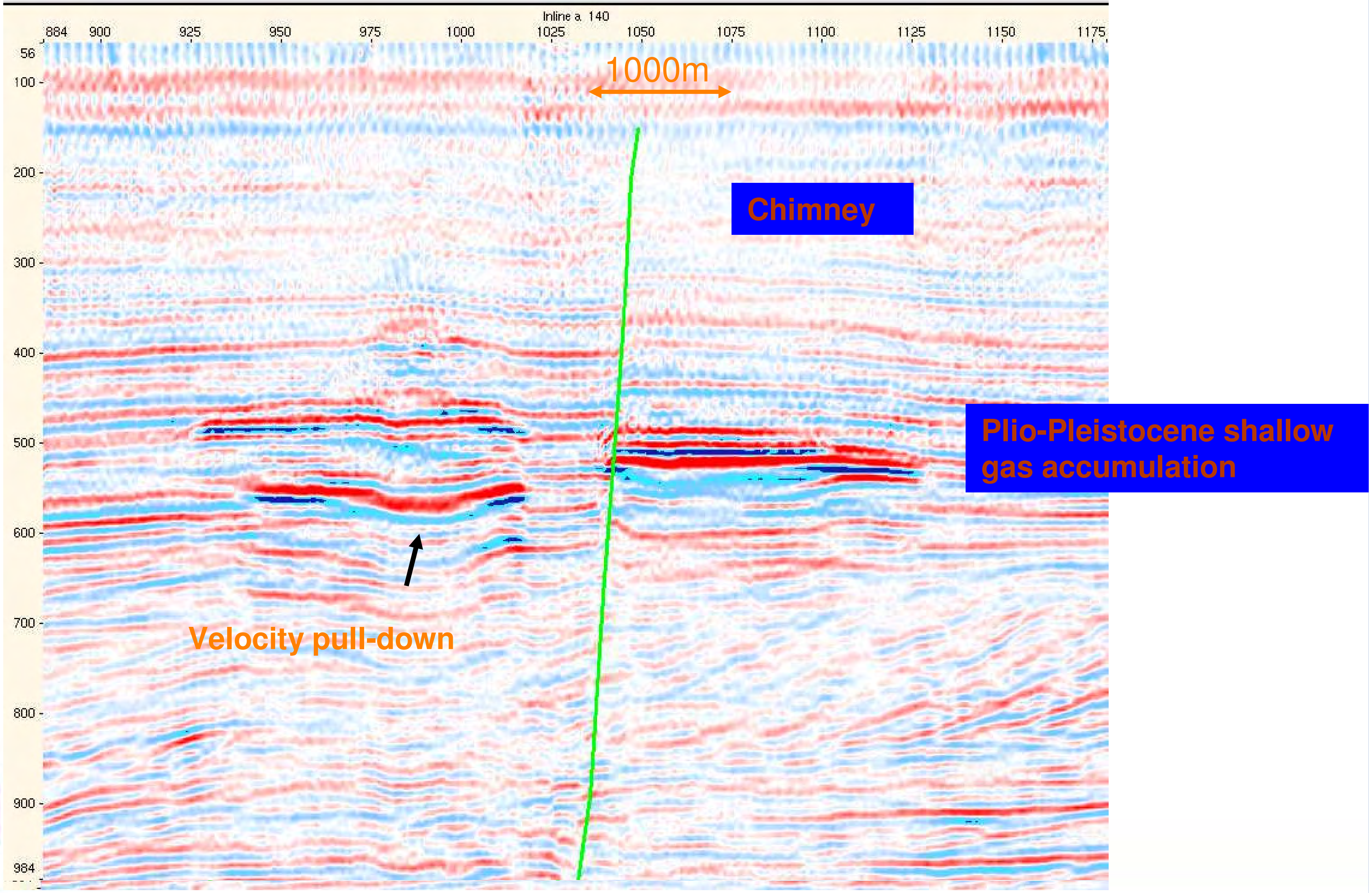



Aerial photo

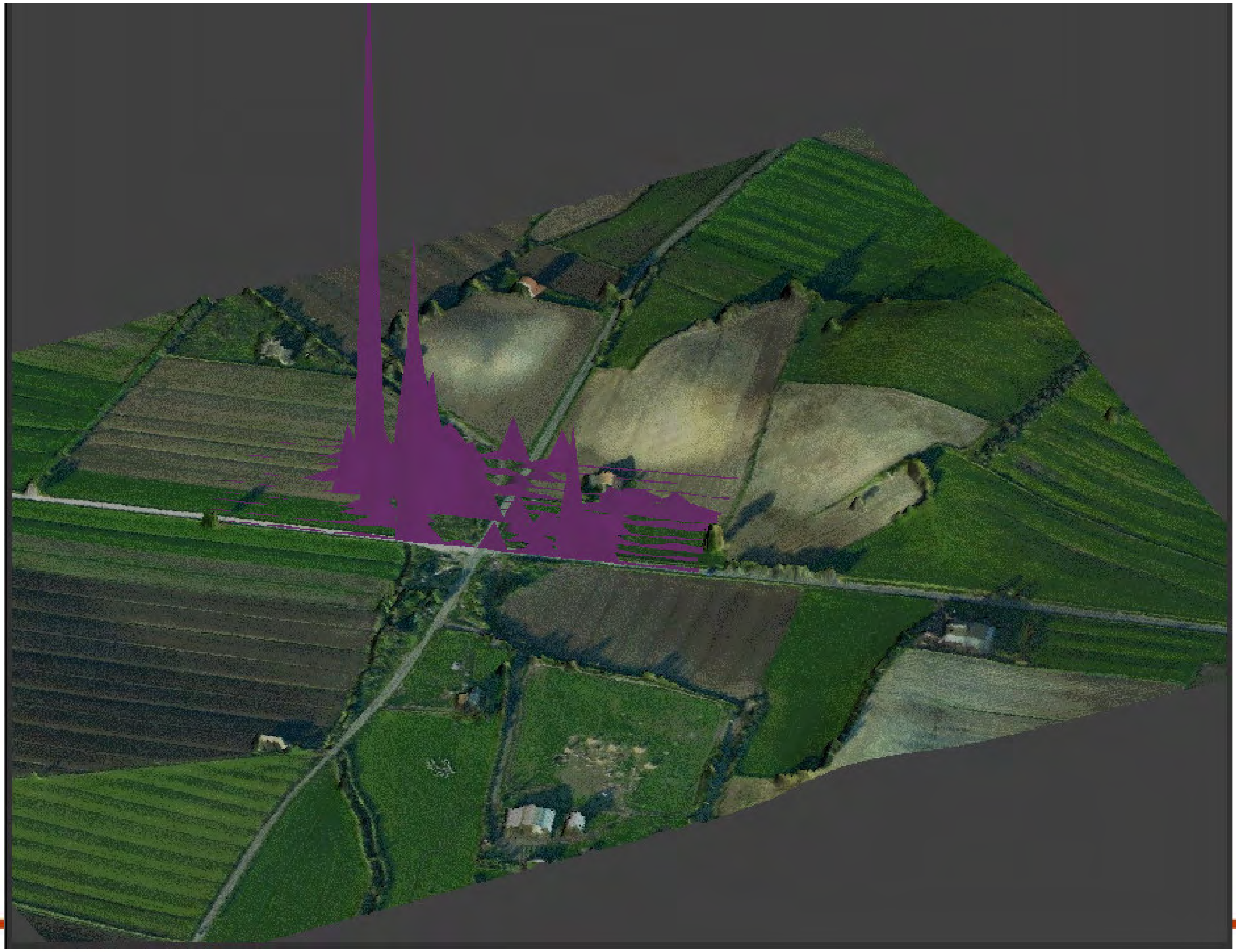


Gun seismic

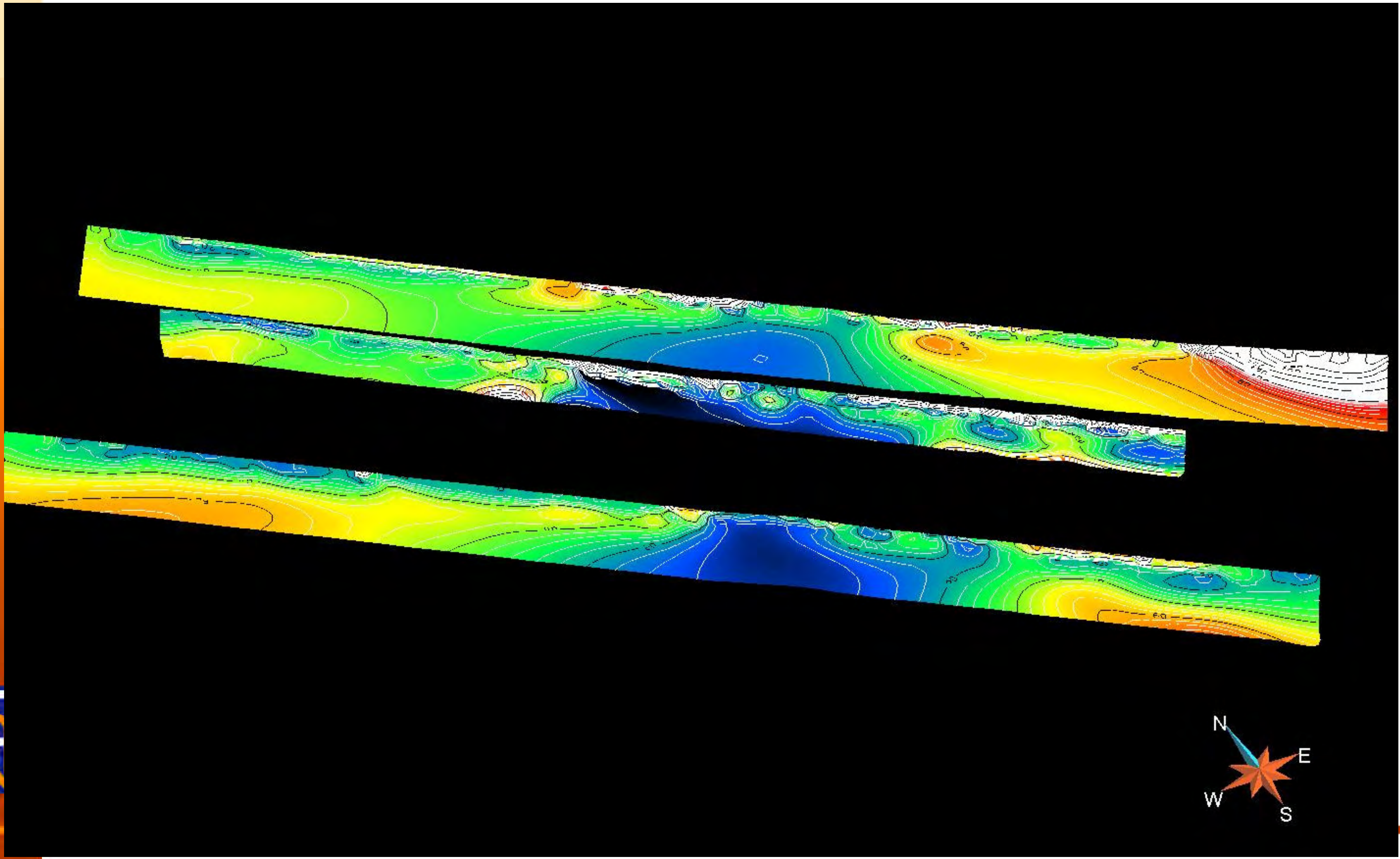
# Seismic Anomalies Indicating Leakage:
## F3/F6 Gas chimney above Plio-Pleistocene bright spot



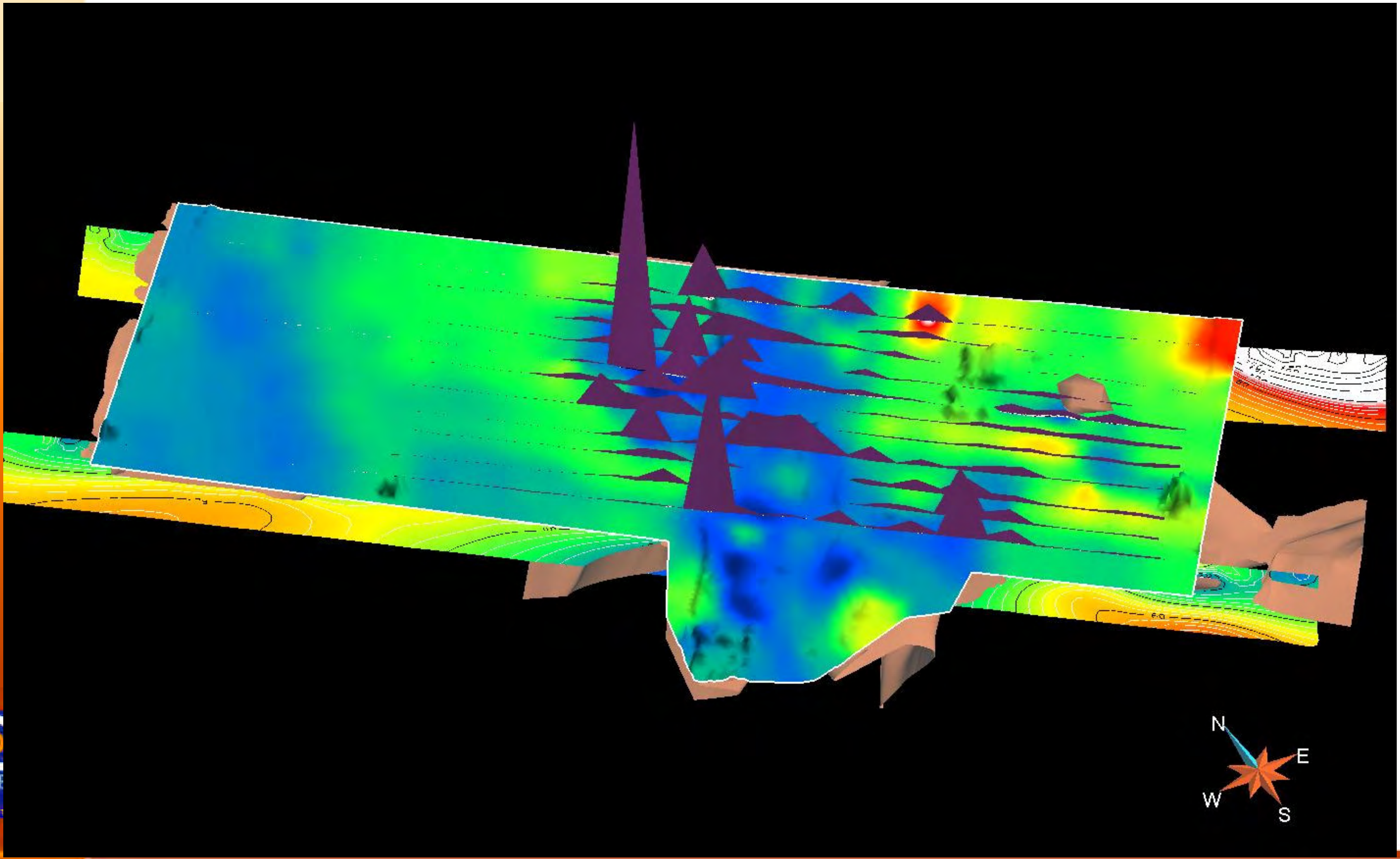
# Can we detect leakage: Main $CO_2$ vent at Latera



# Can we detect leakage:
## Resistivity lines over the area



# Can we detect leakage: Correlation with EM data and $CO_2$ fluxes



# Micro leaks at Latera caldera

**Micro seeps can not be seen**

**Micro seeps can be detected only by analytical equipment**

**Micro seeps have no impact on the shallow environment and are part of the baseline values**

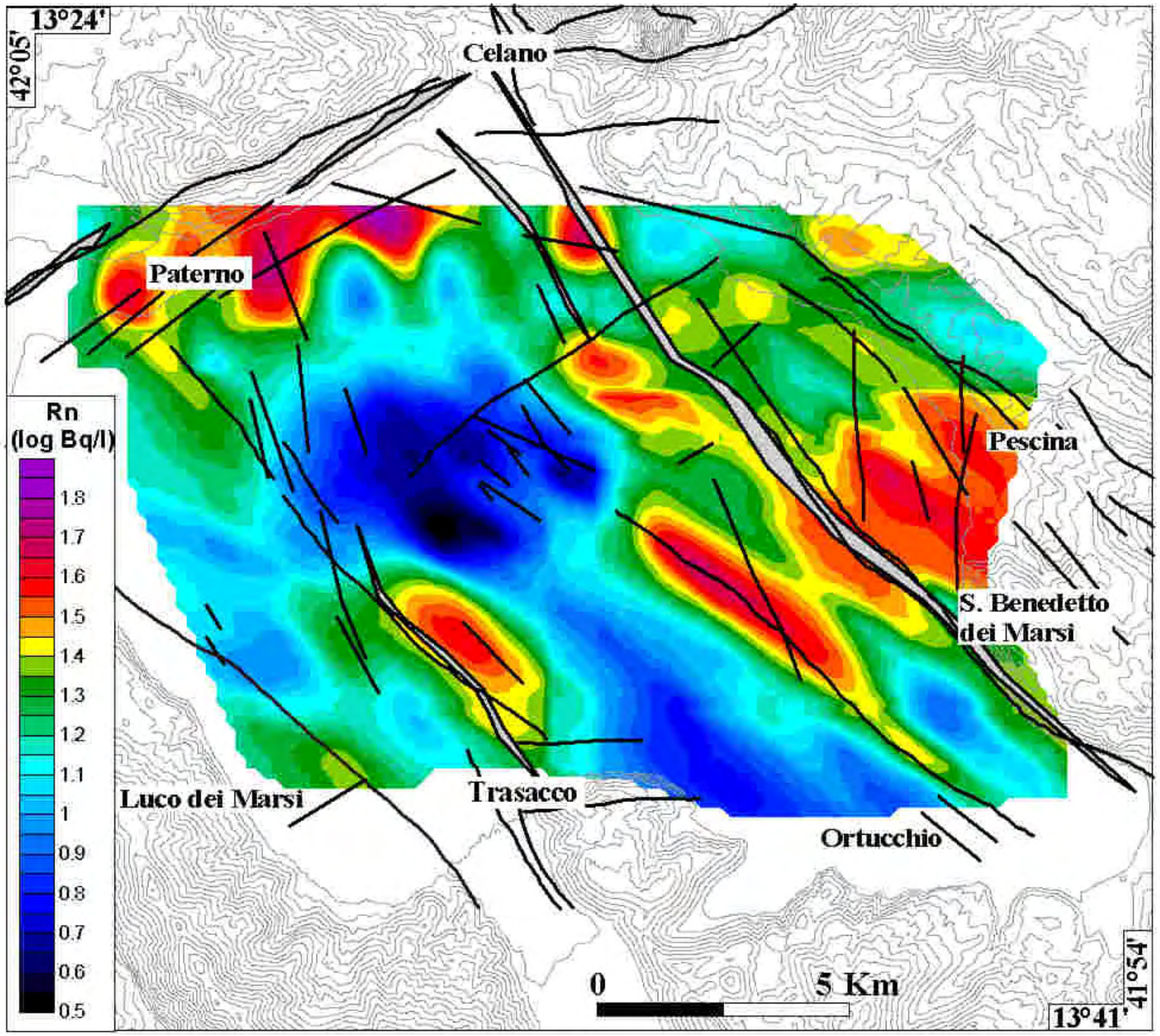
# Why micro leaks are so important?

They may be used to detect potential migration pathways

And as possible precursor signal of gas migration towards the surface

# Fucino valley

Micro seeps occur over the faults activeted by the 1905 earthquake (M>6)



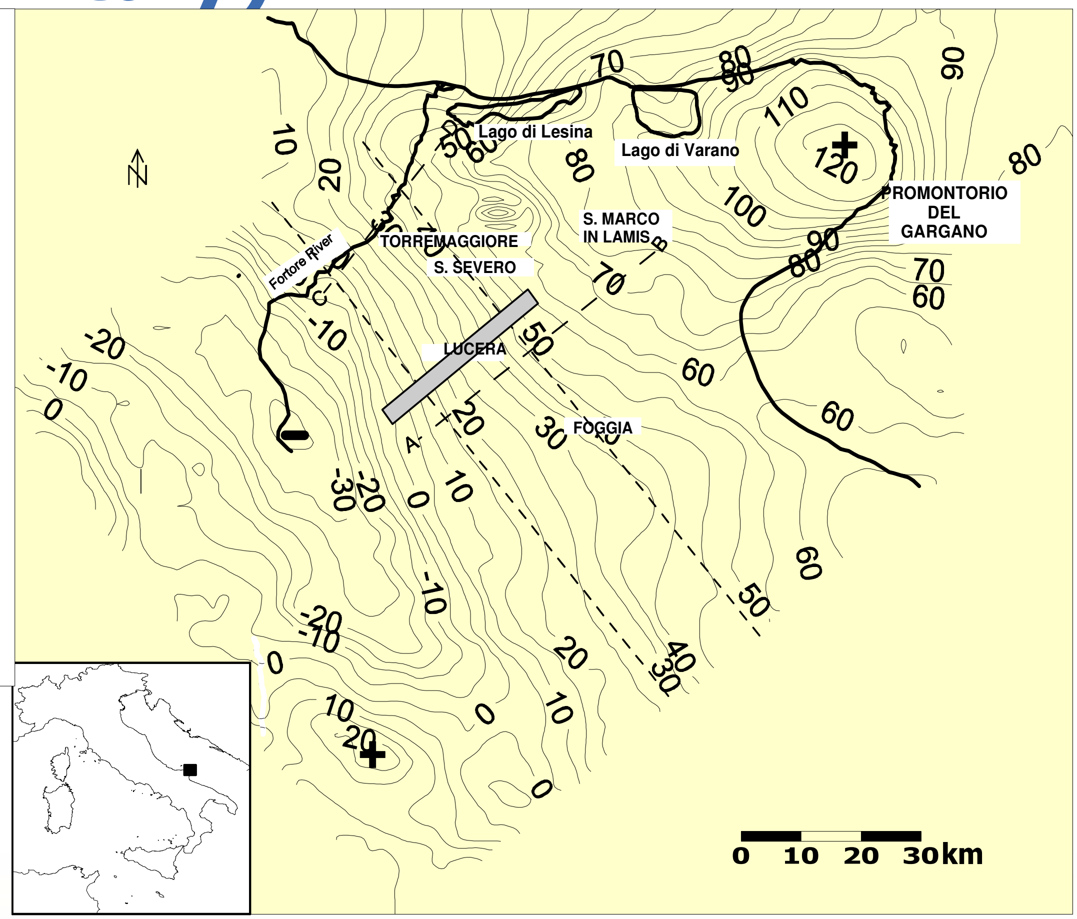

Rn soil gas map (1998 survey)

# Detection of hidden faults

## Gravimetric map – Lucera plain (South Italy)

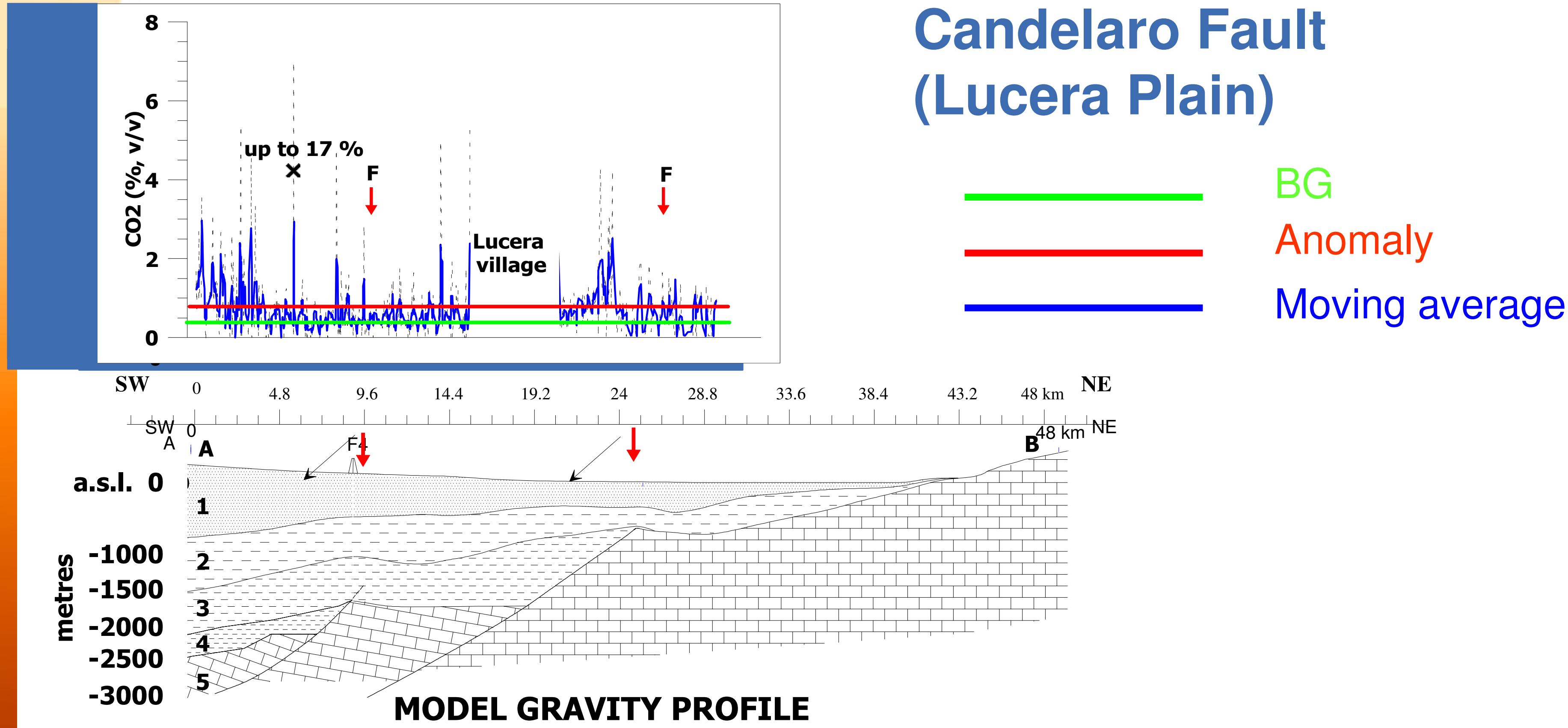
**LEGEND**

- 20 — **Contour interval: 5 mGal**
- A——B **Cross - Section**
- **–** **Gravimetric minimum**
- **+** **Gravimetric maximum**
- (grey bar) **Soil-gas transect**
- - - - - - - **Inferred fault**



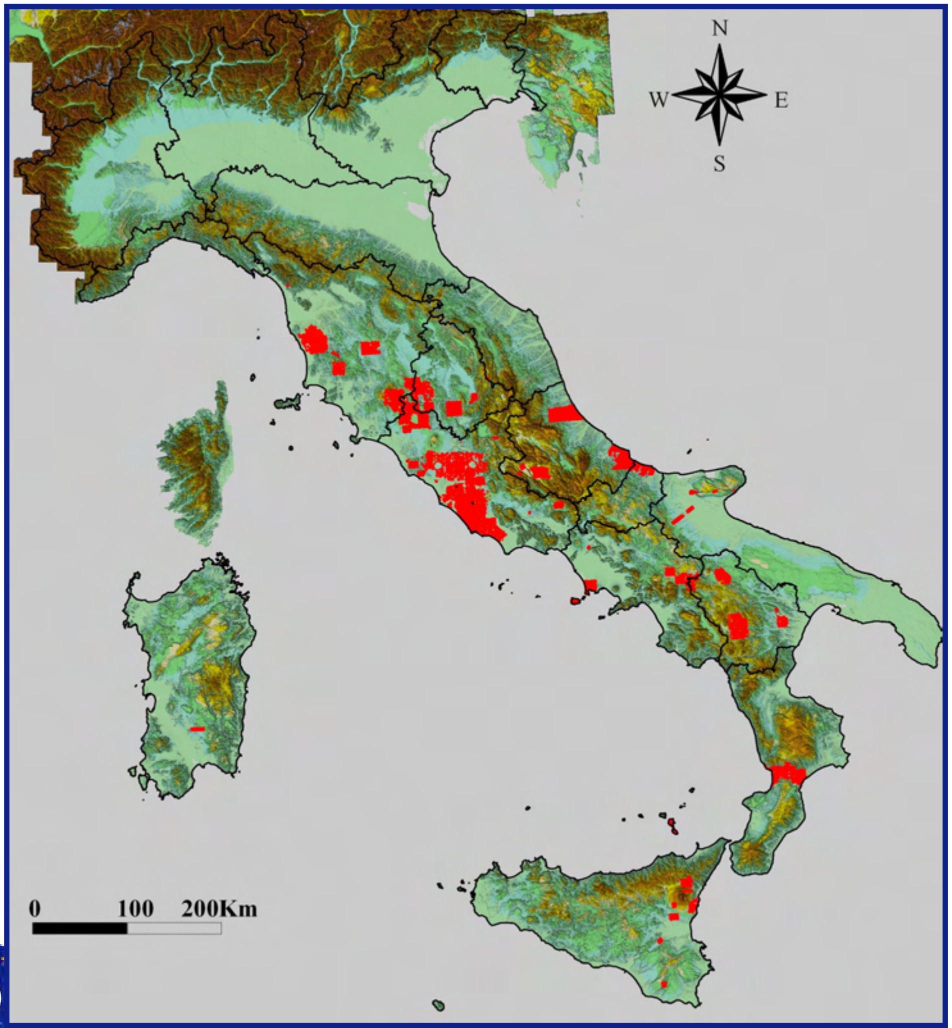
# Detection of hidden faults

## Soil gas anomalies at Candelaro Fault (Lucera Plain)




(Di Filippo et al., 1997)

# Soil gas data base



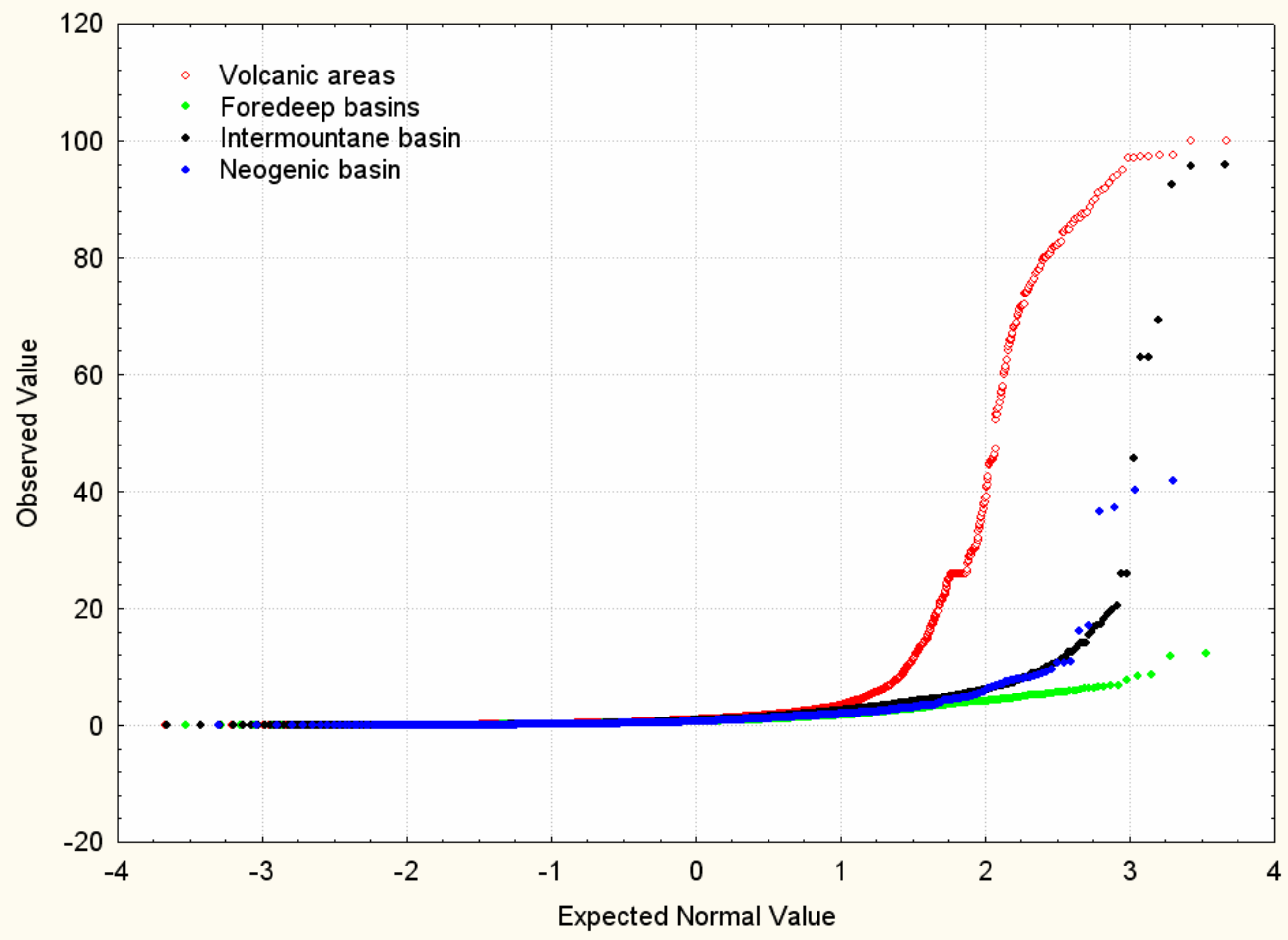

**More than 40000 soil gas data have been collected in Italy on an area of about 25,000m² in different geological scenarios since 1980**

**Over 15,000 data of CO2 concentration in soil air have been used for the following statistics**

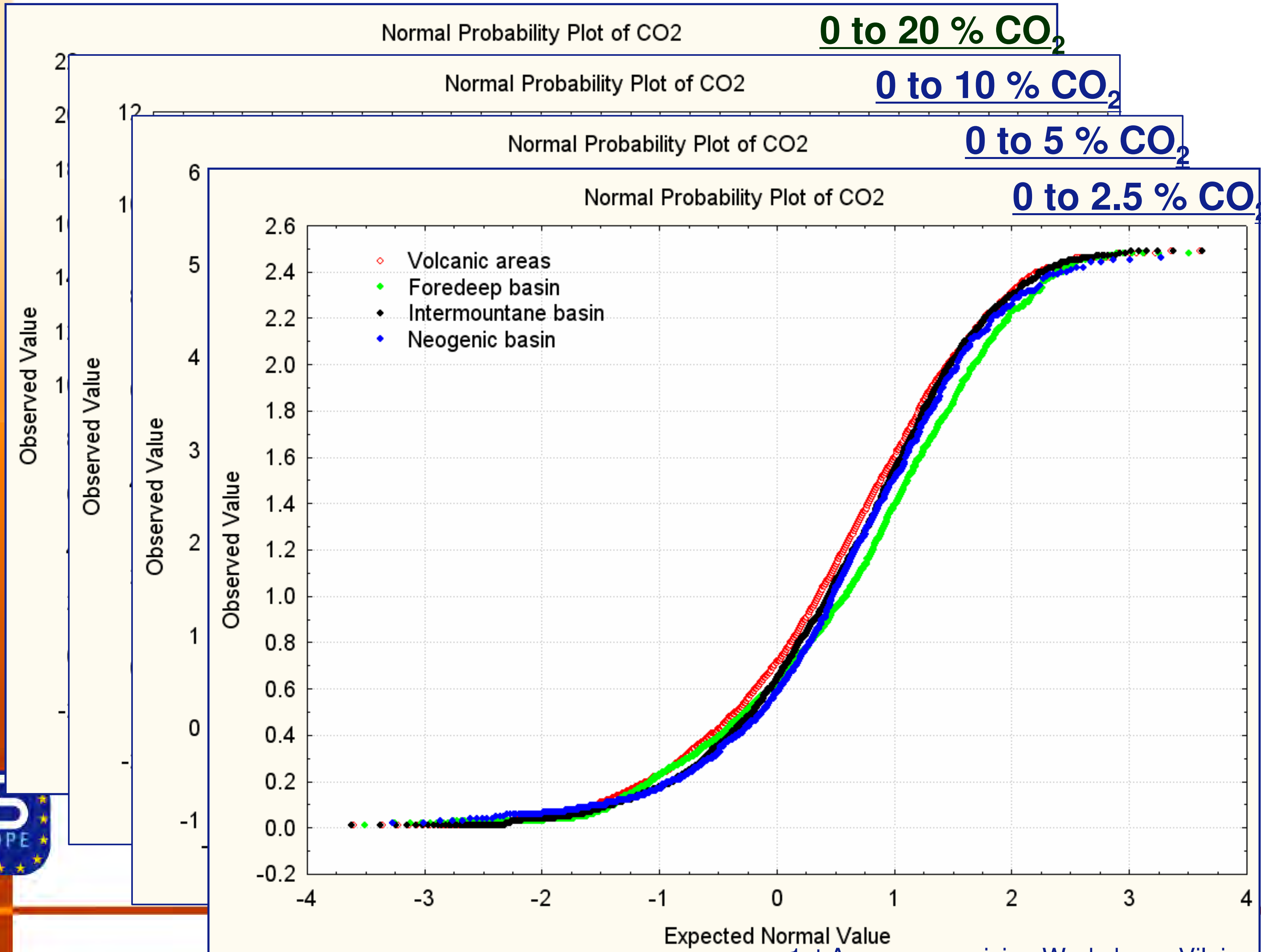
# The URS Italian soil gas database

<u>Soil gas $CO_2$</u>

- 0-100%
- Strong difference between different geological settings



# The URS Italian database



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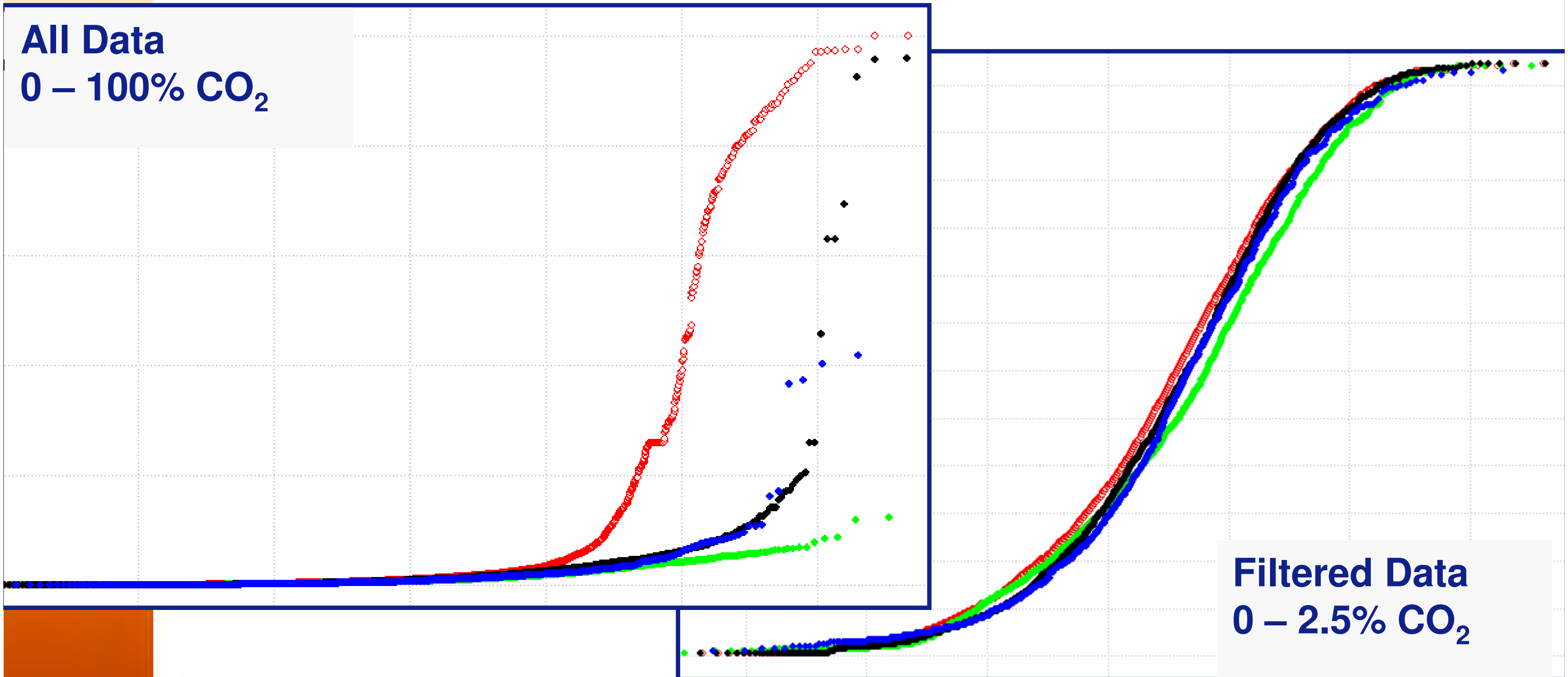


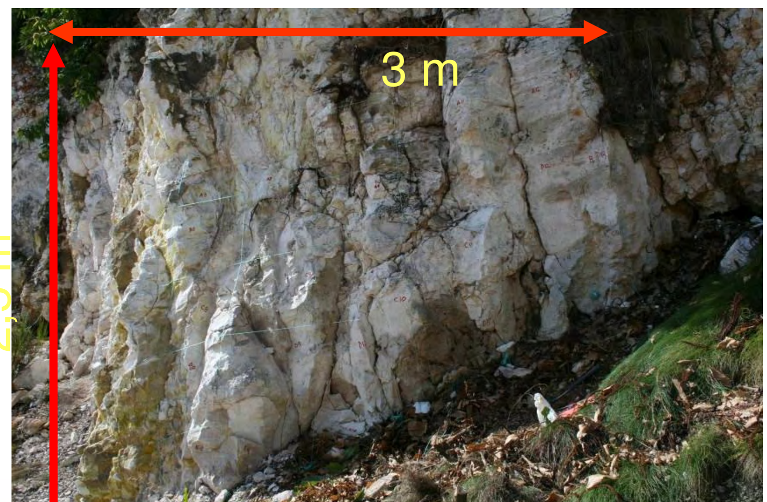

- Despite large differences in trends when using all data, at levels expected for biogenic baseline values the areas are very similar (almost Gausian in middle interval).

# Latera Caldera – Understanding gas migration in fractured rocks


**First face**


N 30° W

**Second face**




N 60° W

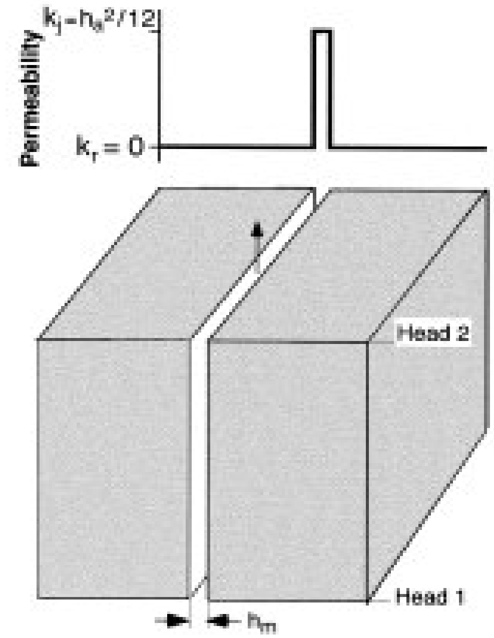
# Fracture classification

## Extensional fracture (open mode I)

"Closed" (0.5 mm)

"opened" (10 mm)

Plate Parallel Model



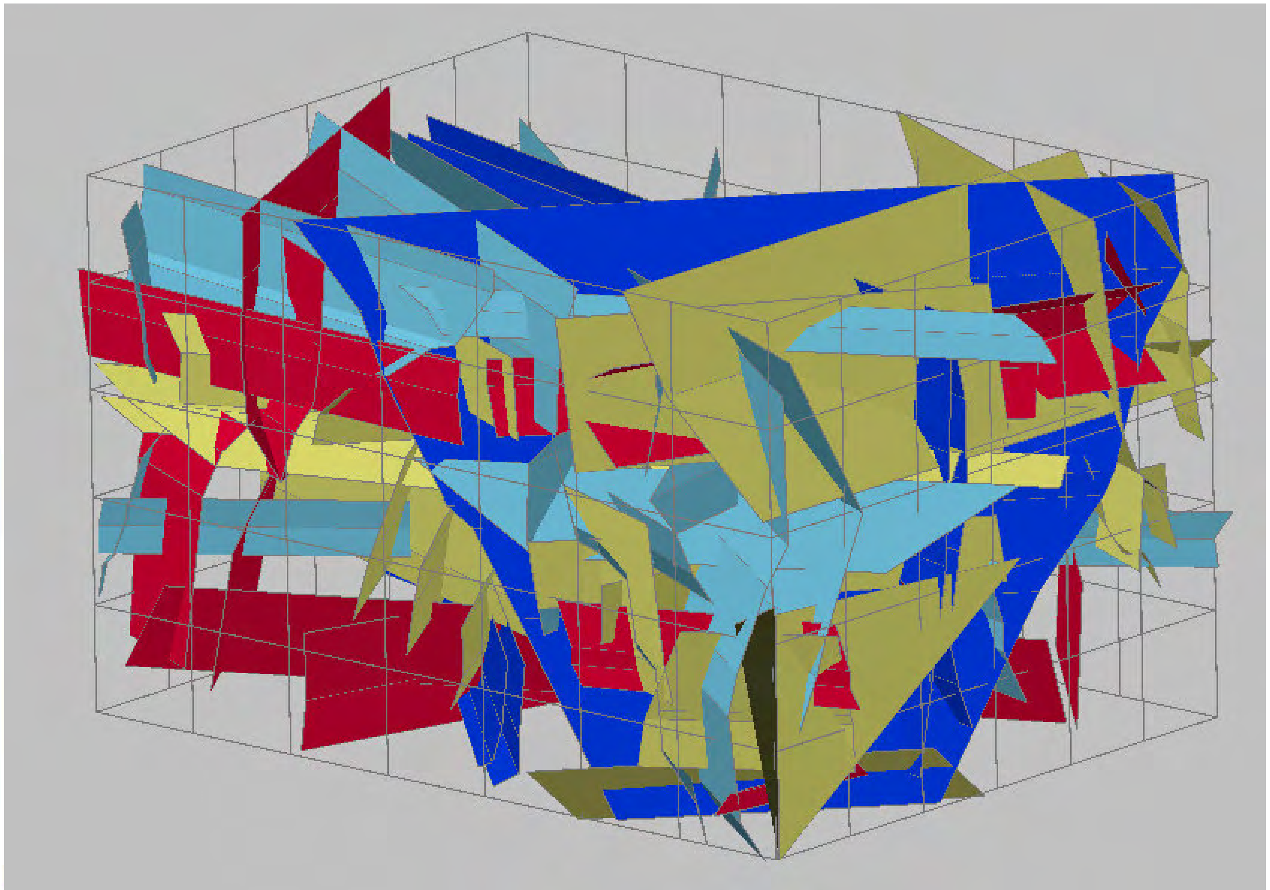

$$K = \frac{b^2}{12}$$

Shear fractures and small faults (open mode II and III) filled by clayey material (fault gouge)

Gouge fill up to 5 mm

Fault (gouge fill up to 15 mm)

# 3D model of the fractures and their physical characteristics



Opened

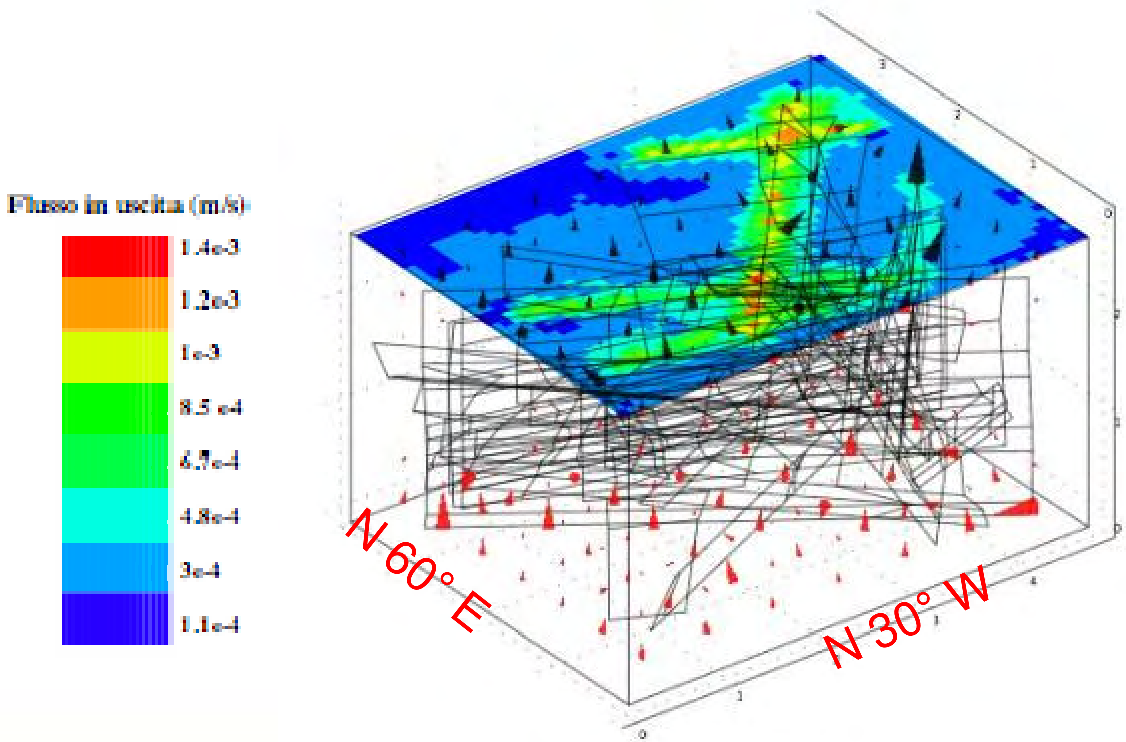
Closed

Cataclastic fractures

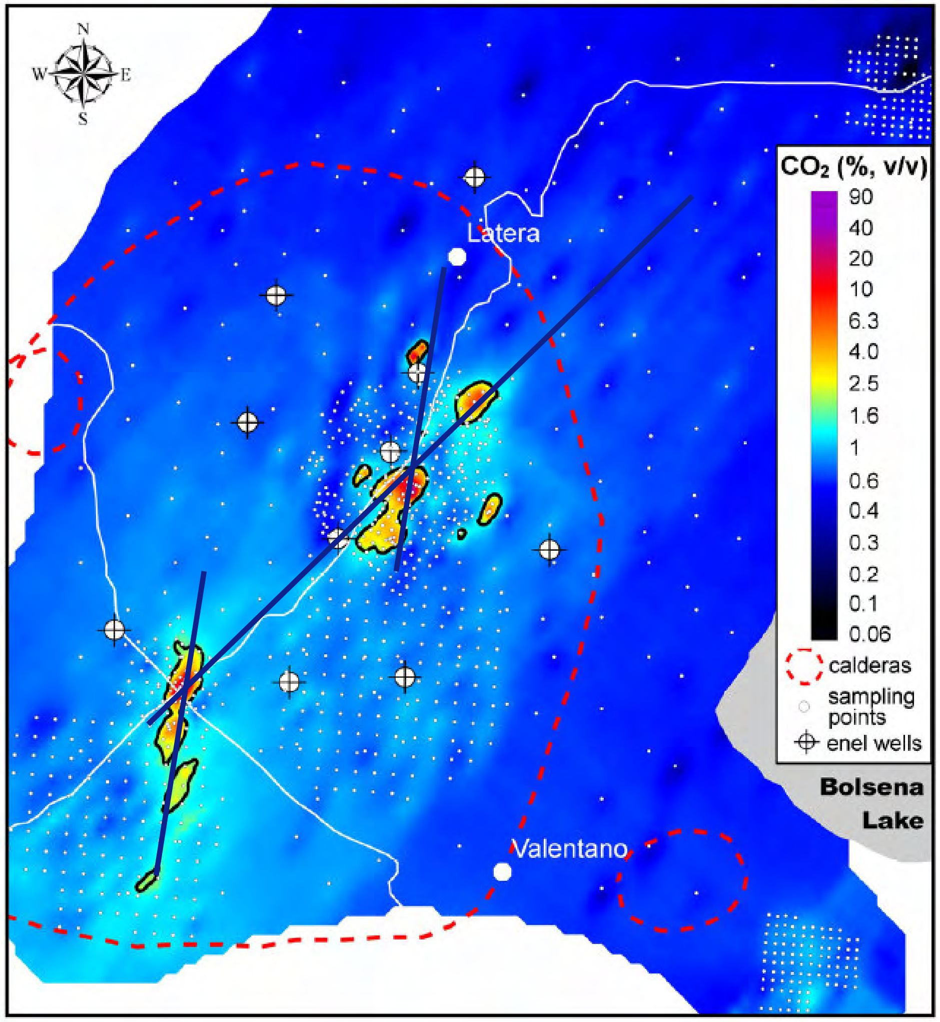
Small faults

# Numerical model of fluid flow (Comsol Multiphysics)

**Numerical model of fluid flow using measured data**



# Latera – regional $CO_2$ leakage




- ➔ Regional soil gas $CO_2$ surveys of the Latera caldera
- ➔ Local N-S trends
- ➔ Regional SW-NE trend
  - Same as structural trends
  - But not continuous along entire fault length

# Final remarks

- A wide range of monitoring methods already exist
- They may give information on gas migration from the reservoir rocks up to the surface
- No single method can provide all the information that is needed for site monitoring,
- Thus a suite of methods will be chosen that are *most appropriate* for the specific characteristics of a given site

- Never the less some of them require refinement
- Reduction of costs
- Continuous monitoring should be improved both inland and ofshore

THANK YOU FOR THE ATTENTION