Workshops on Carbon Capture and Storage
Instituto de Ingeniería, UNAM

Research Ideas in Monitoring the Hontomin CO_2 Geological Storage Site

Ramon Carbonell

CSIC

GOBIERNO DE ESPAÑA
ciudad de la energía

The Compostilla Project OXYCFB300

European Energy Programme for Recovery

March 2012

CIUDEN: Spanish government foundation to promote, among other things, Carbon Capture and Storage

Hontomin is the Tech Demonstration Plant of the Compostilla OXYCFB300 EEPR project, run by ENDESA, in collaboration with CIUDEN and FOSTER-WHEELER

EEPR "European Energy Programme for Recovery" will help to speed up and secure investments on infrastructure and technology projects in the energy sector, will help to improve the security of supply of the Member States and will help to speed up the implementation of the 20/20/20 objectives for 2020.

CSIC is the "Spanish Council for Scientific Research", a network of research institutes.

The Players

The Research Team:

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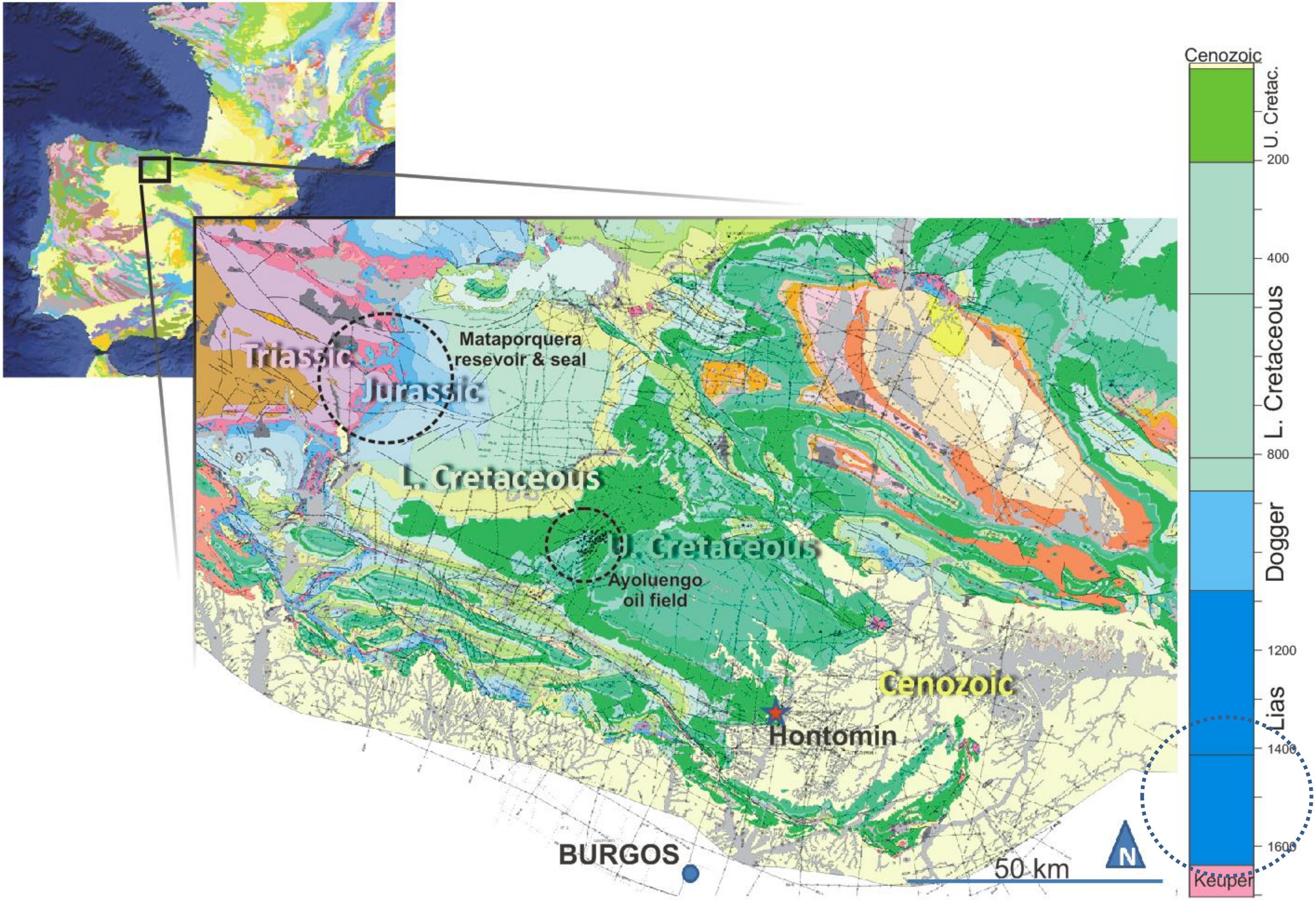
5. IGME, Geological and Mining Institute of Spain
6. Hydrogeology Group, UPC
7. Institute of Environmental Assessment and Water Research, CSIC



Triassic
Jurassic
Mataporquera
resevoir & seal
L. Cretaceous
U. Cretaceous
Ayoluengo
oil field
Cenozoic
Hontomin
BURGOS
50 km
N
Cenozoic
U. Cretac.
200
400
L. Cretaceous
800
Dogger
1200
Lias
1400
1600
Keuper

TDP Characterization 2009-2011

Structural studies

- Geological and structural mapping
- Petrophysical studies
- **3D seismics**
- **Electromagnetic survey 3D**
- **High resolution gravimetry**
- 3D geological model

Baseline studies

- Hydrogeology and hydrochemistry
- Natural gas emissions
- Seismicity
- Geothermal studies
- Surface deformations by SAR
- Floral Biodiversity
- Bio-indicators
- ....

Baseline Data

Geophysical Data sets acquired for the Baseline Characterization

- 3D Seismic Reection
- 2D 3 Component Seismic Reection transects
- Seismic Tomography Model Grid of P & S seismic velocities
- Seismovie CGGVeritas
- VSP (programmed after drilling phase)
- Borehole logging
- High resolutoin Geodesy
- High resolution Gravity
- Other Geophysics (MT, Resistivity etc.)

Site Instrumentation

- Seismovie well receivers
- Seismovie piezoelectric sources
- Permanent Seismic Array
- Accelerograph
- Downhole seismic data system
- Cemented Source Pads
- Data acquisition system 300 channels
- Data storage/management system

Monitoring Approaches

Seismic Data acquisition Experiments

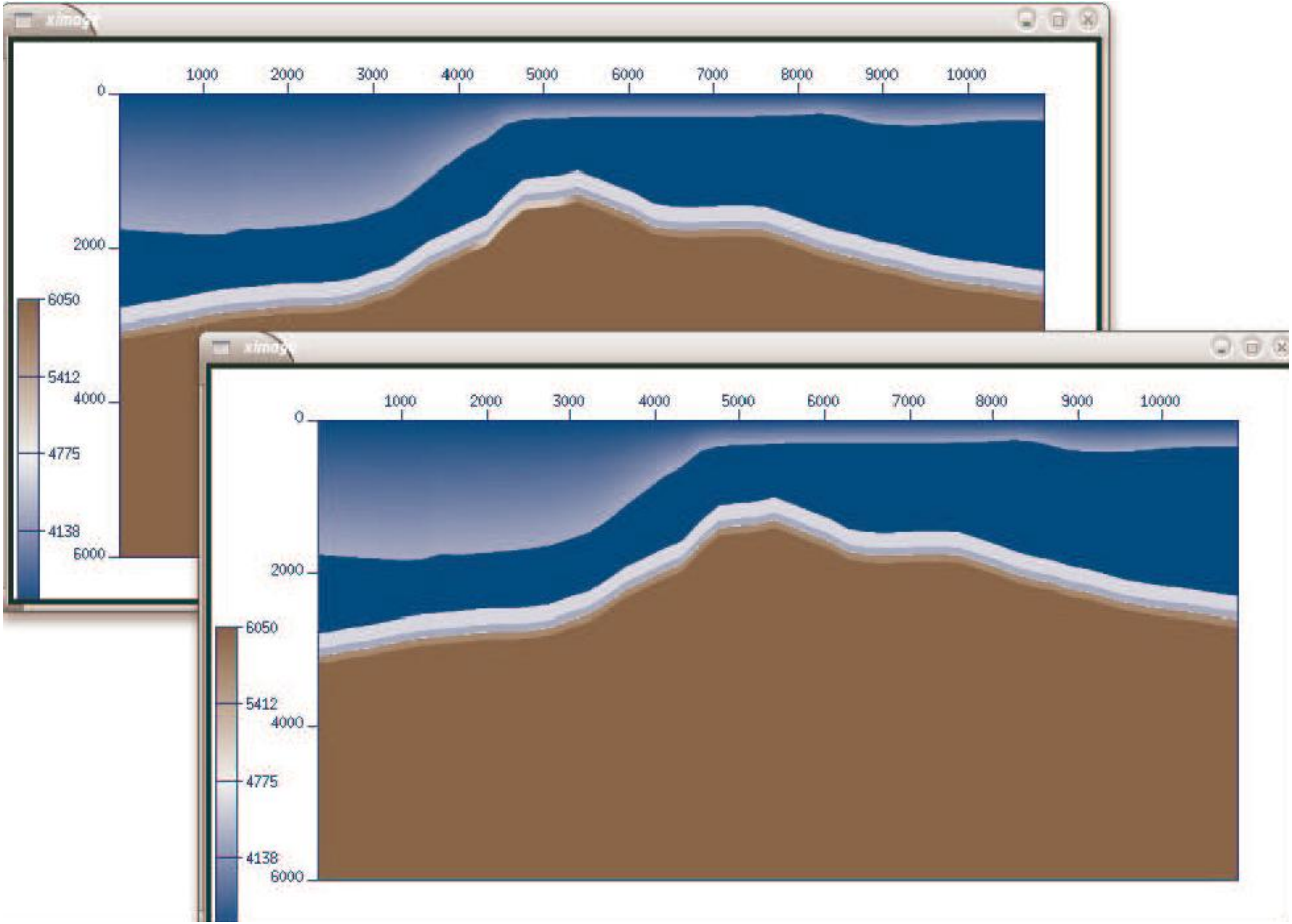
Active Source Seismics

- 3D seismic reection
- 2D 3 Component Seismic Reection
- Transects
- Seismic Tomography Model Grid of
- P & S seismic velocities.
- Seismovie
- VSP (walk away, 3D, etc)

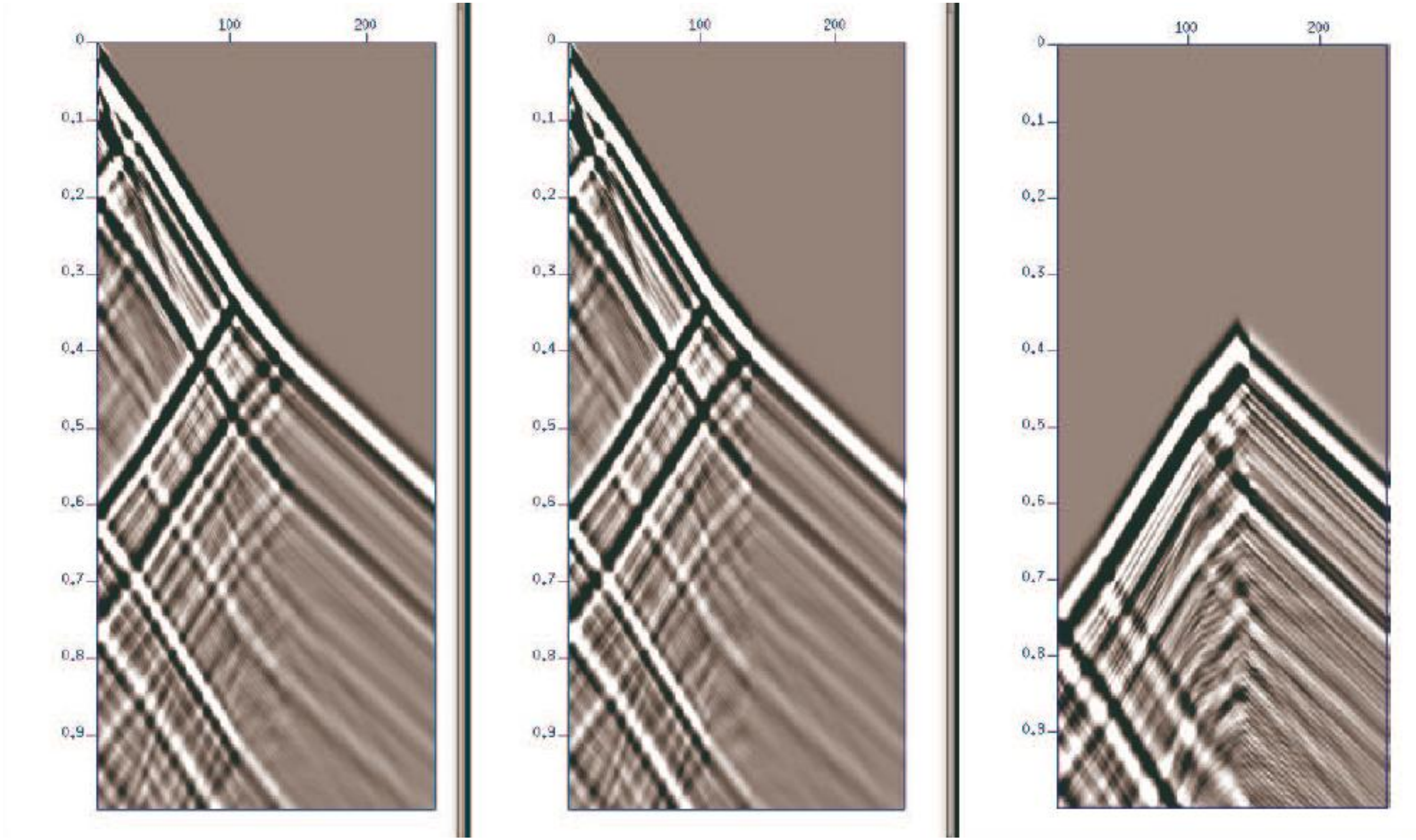
Passive Source & Advance Processing

- Microseismicity
- Backprojection microseismic events
- Noise Interferometry
- Virtual Sources
- Adjoint Fullwaveform Tomography

Numerical Simulations: Models & Wavefield



Numerical Simulations: Data, VSP

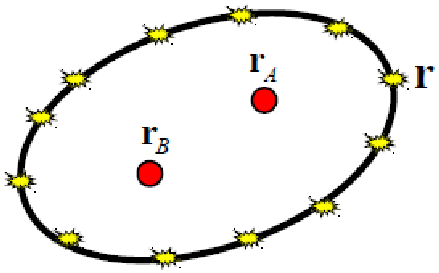


Synthetic seismic VSP data acquired using an elastic propagation of seismic saves considering the reservoir, empty and with CO2. TheCO2 content cause a 4 to a 10 % change in the seismic velocities.

Noise Interferometry

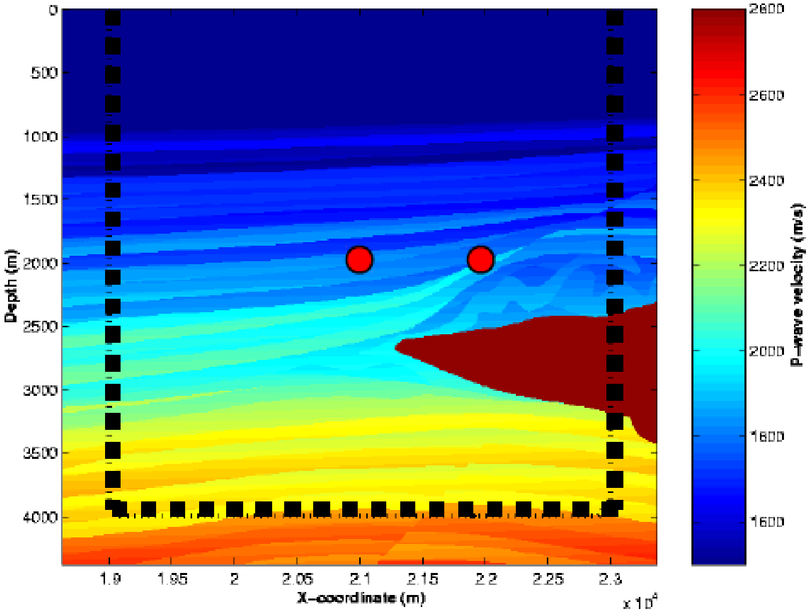
Virtual-sources

$$G(\mathbf{r}_A,\mathbf{r}_B)+G^*(\mathbf{r}_A,\mathbf{r}_B)=2\oint\frac{1}{\rho c}G^*(\mathbf{r}_A,\mathbf{r})G(\mathbf{r}_B,\mathbf{r})\,dS$$



(Wapenaar, Fokkema, and Snieder, JASA, **118**, 2783-2786 2005
heuristic derivation: Derode et al., JASA, **113**, 2973-2976, 2003)

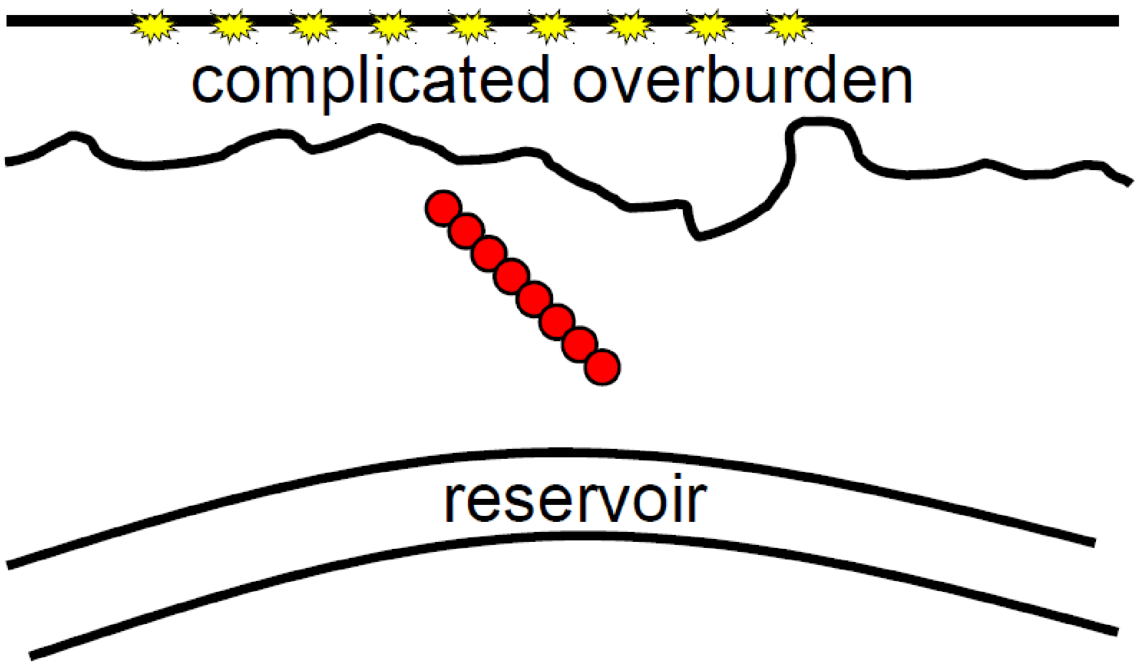
Computing synthetic seismograms



(Van Manen et al., Phys. Rev. Lett., **94**, 164301,2005)

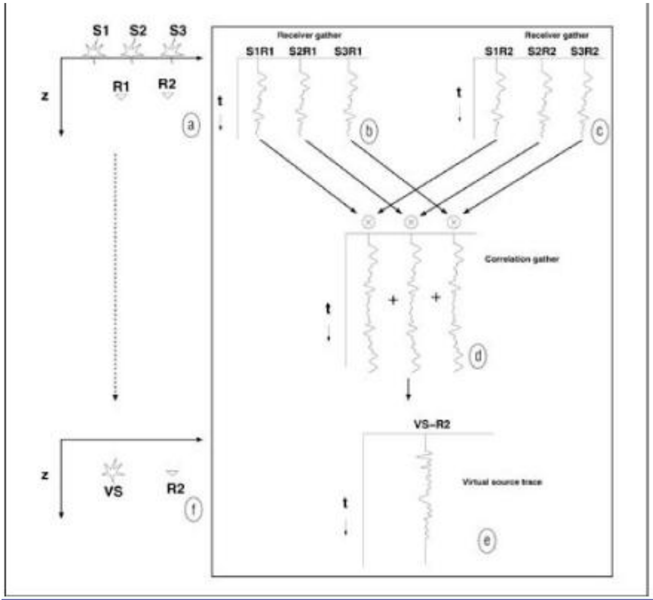
Noise Interferometry

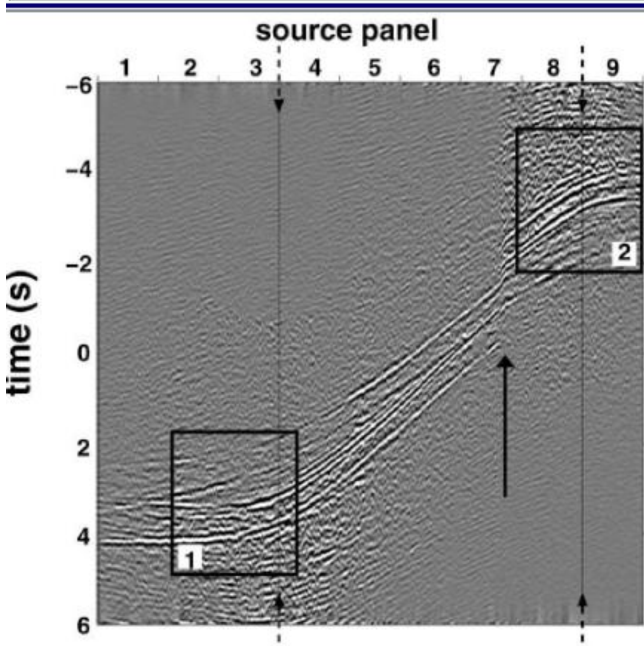
Field example of virtual sources

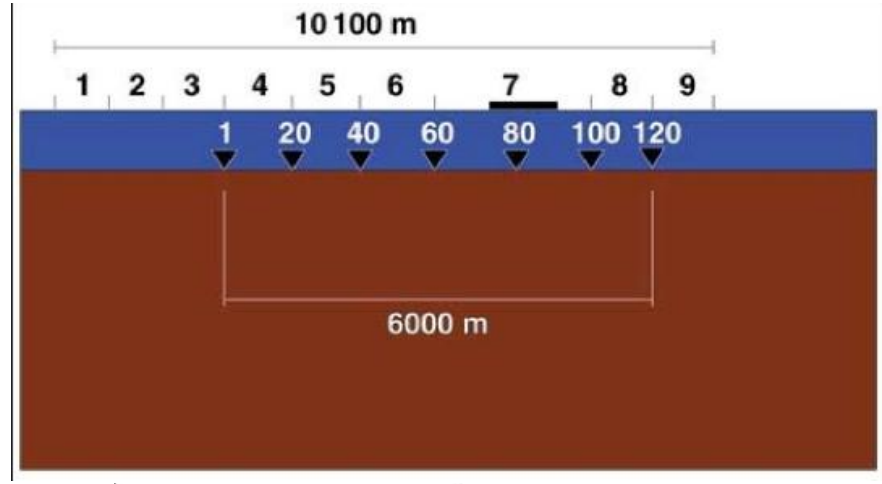


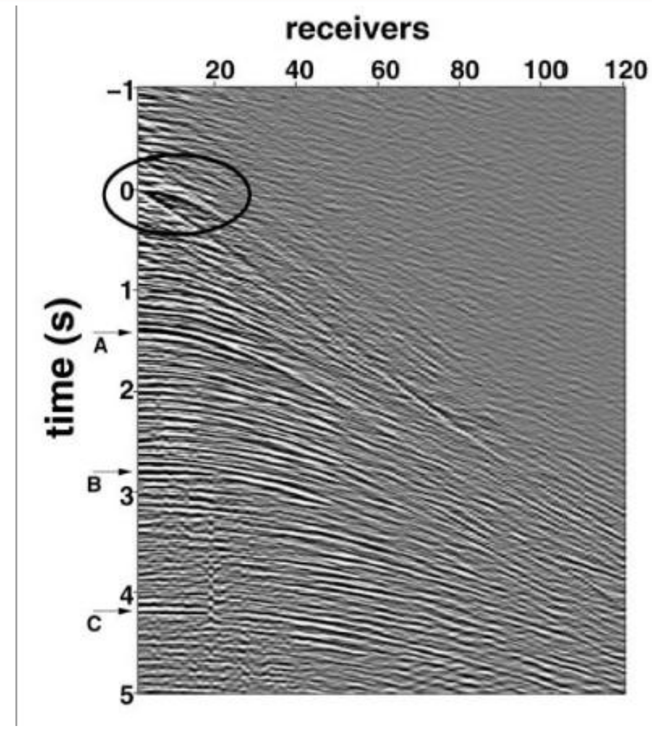
(Bakulin and Calvert, SEG expanded abstracts, 2477-2480, 2004)

Real Data Example

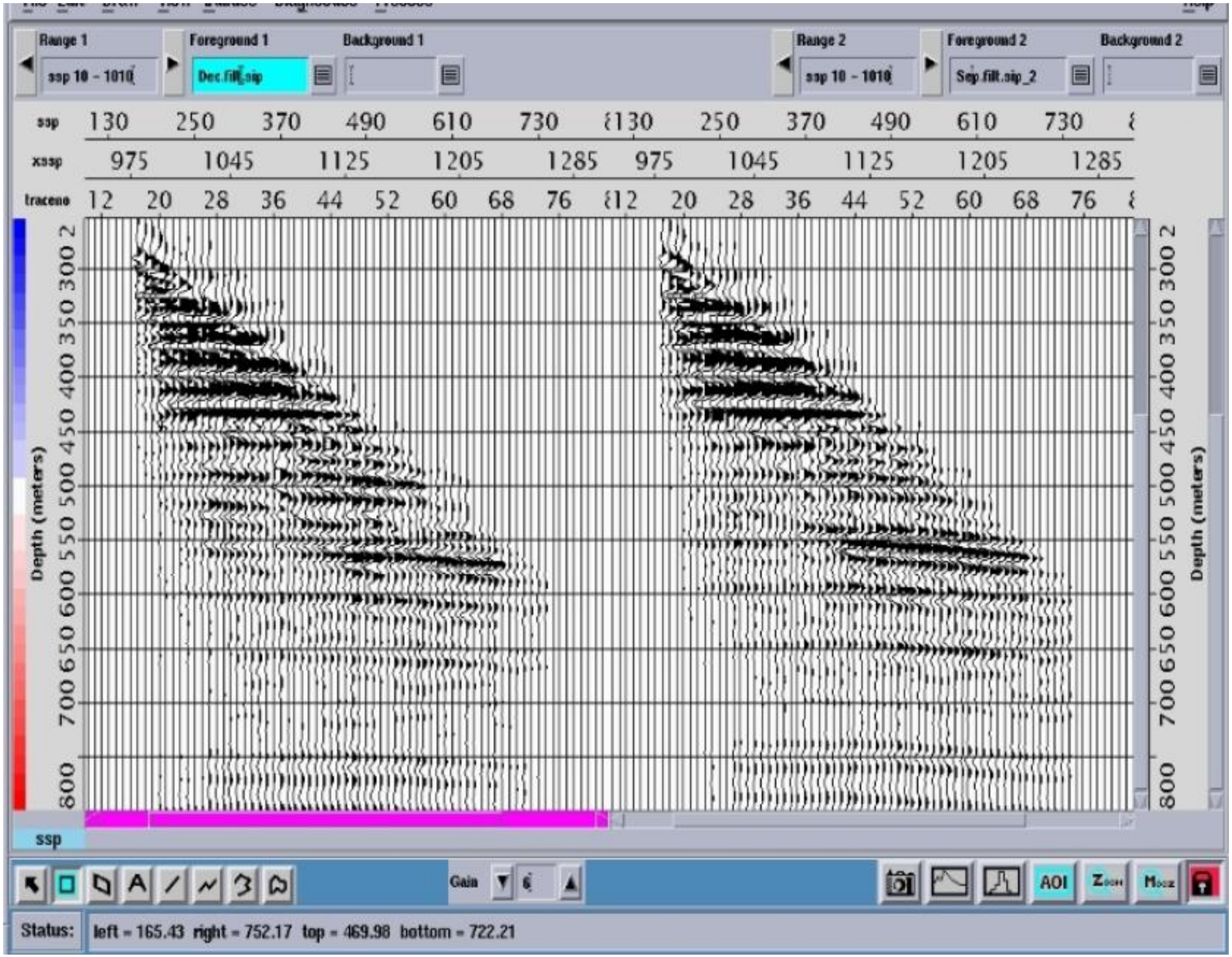








Virtual Shot Records



Summary

Ideas & Monitoring Approaches
Seismic Data acquisition Experiments

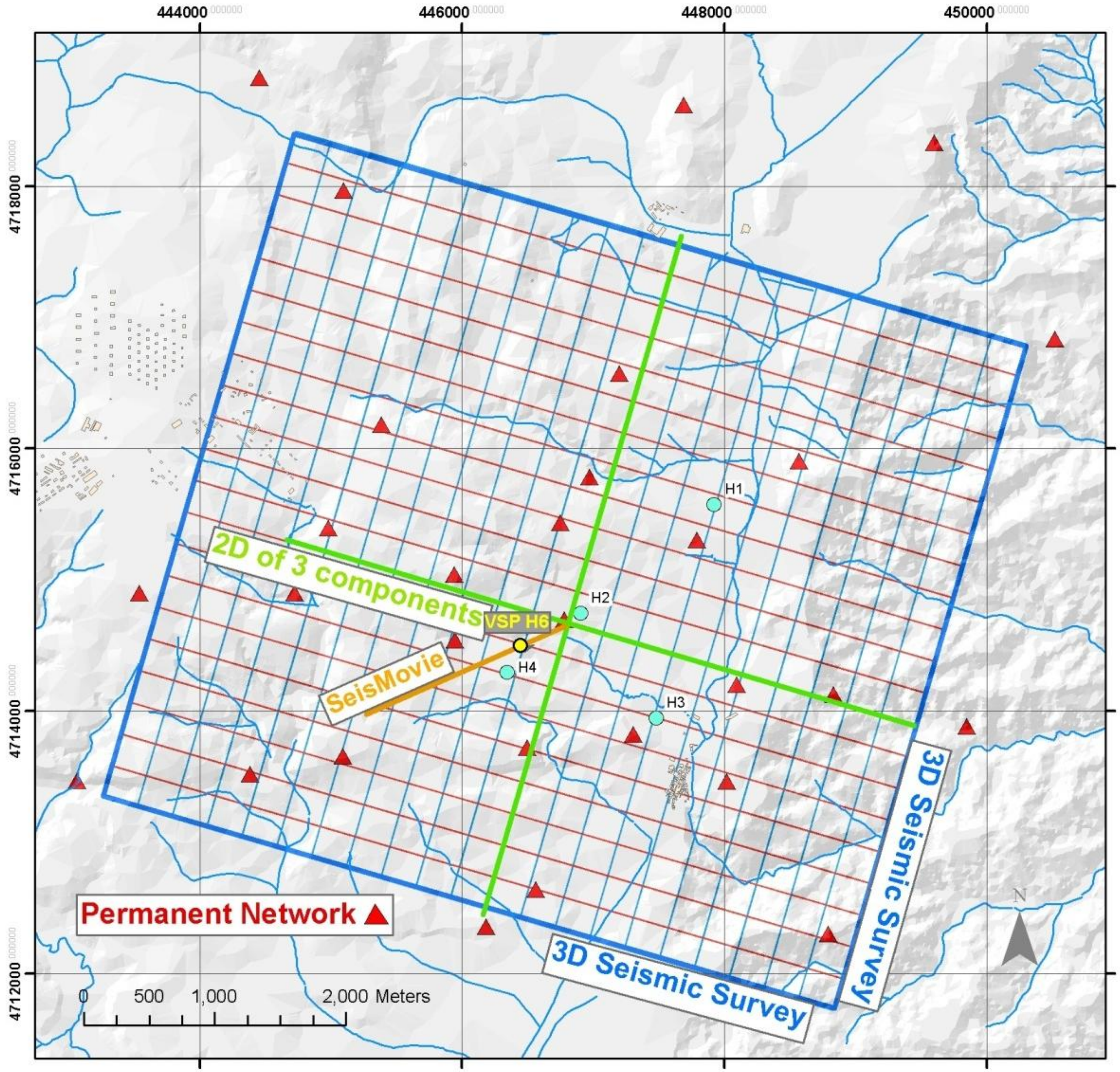
Ideas & Monitoring Approaches

- Seismic Data acquisition Experiments
- Active Source Seismics
- 3D seismic reection
- 2D 3 Component Seismic Reection
- Transects
- Seismic Tomography Model Grid of
- P & S seismic velocities.
- Seismovie
- VSP (walk away, 3D, etc)

Passive Source & Advance Processing

- Microseismicity
- Noise Interferometry
- Virtual Sources
- Adjoint Fullwaveform Tomography
- Backprojection microseismic events

Seismic studies conducted in Hontomin



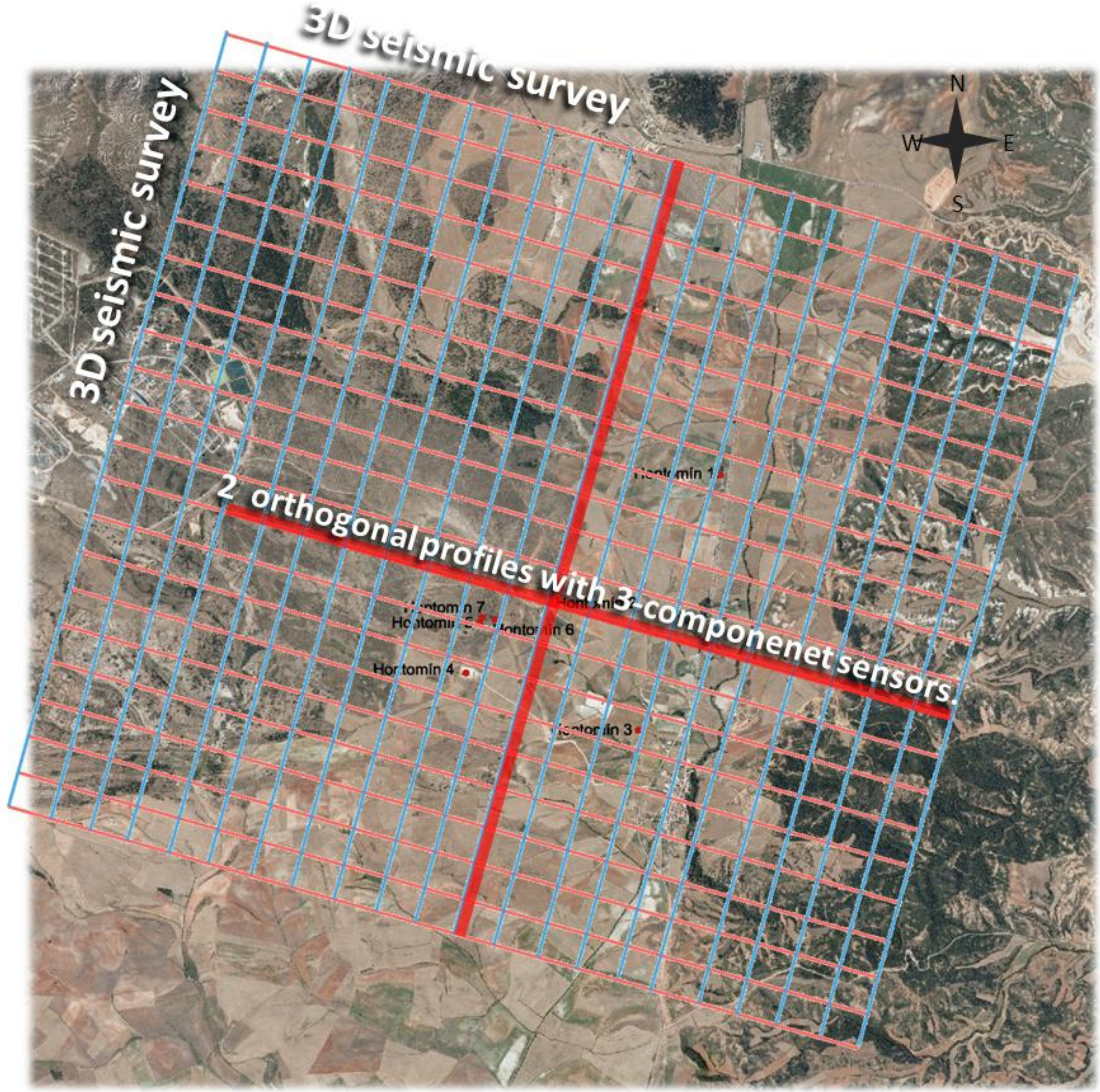
Seismic for structural characterization

- 3D
- 2D 3-components

•Detailed characterization of the tectonic structure of the injection zone.

•Determine the geometry of the reservoir.

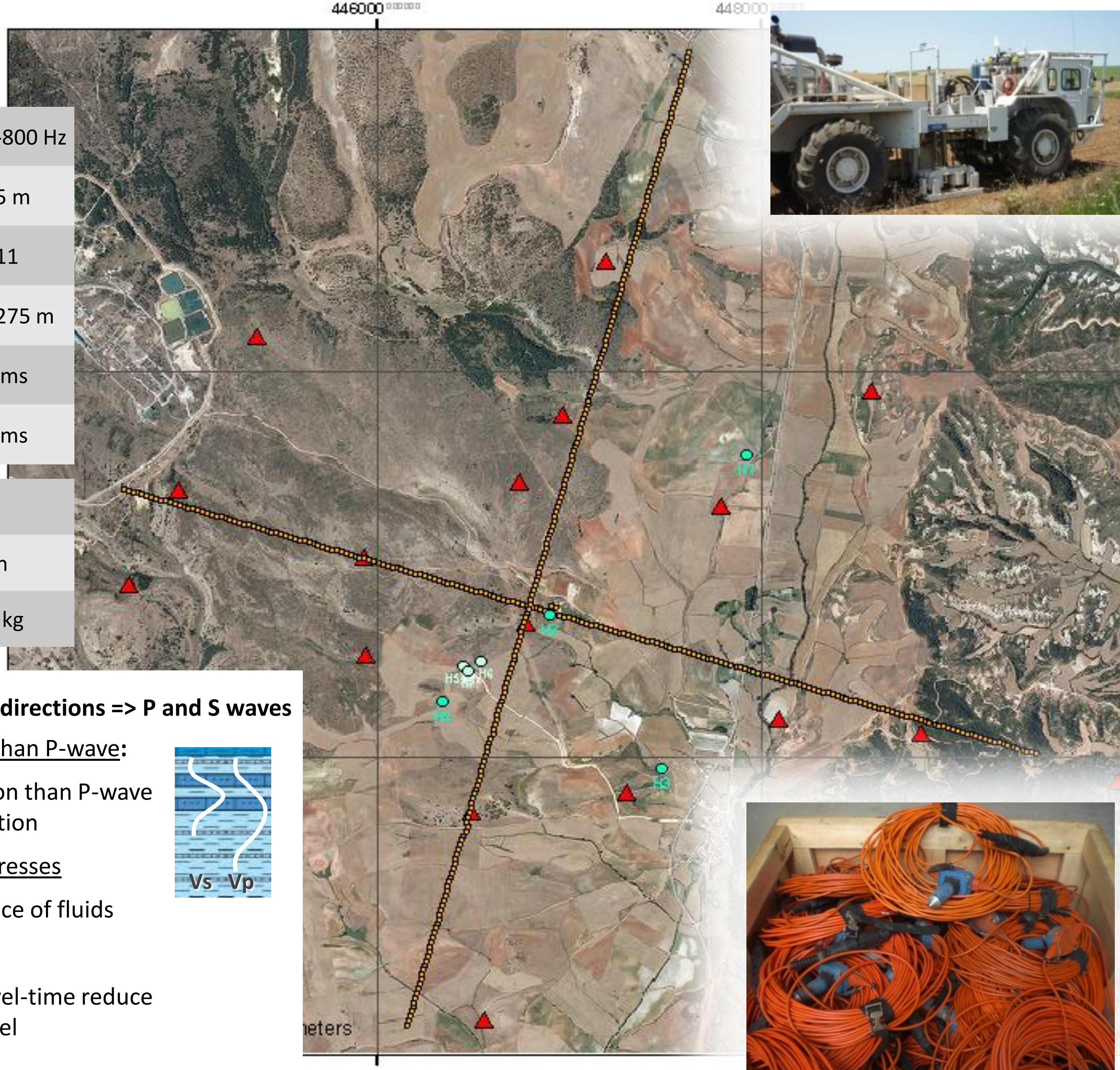
•Estimate mechanical properties of reservoir and seal



2D 3-components

Geophones SERCEL DSU-3C	0-800 Hz
Receivers distance	25 m
Nº receivers / line	211
Total line length	5275 m
Sample rate	1 ms
Final time	4 ms

Seismic source (during 3D survey)	
Vibroseis trucks	4 * 15 Tn
Explosives (Pop-shot)	3 * 0.15 kg



Registrate waves popagating in 3 directions => P and S waves

- S-wave has higher frequency than P-wave:

  => S-wave has higher resolution than P-wave
  => S-images has higher resolution

- Fluids do not support shear stresses

  => Vs is sensible to the presence of fluids

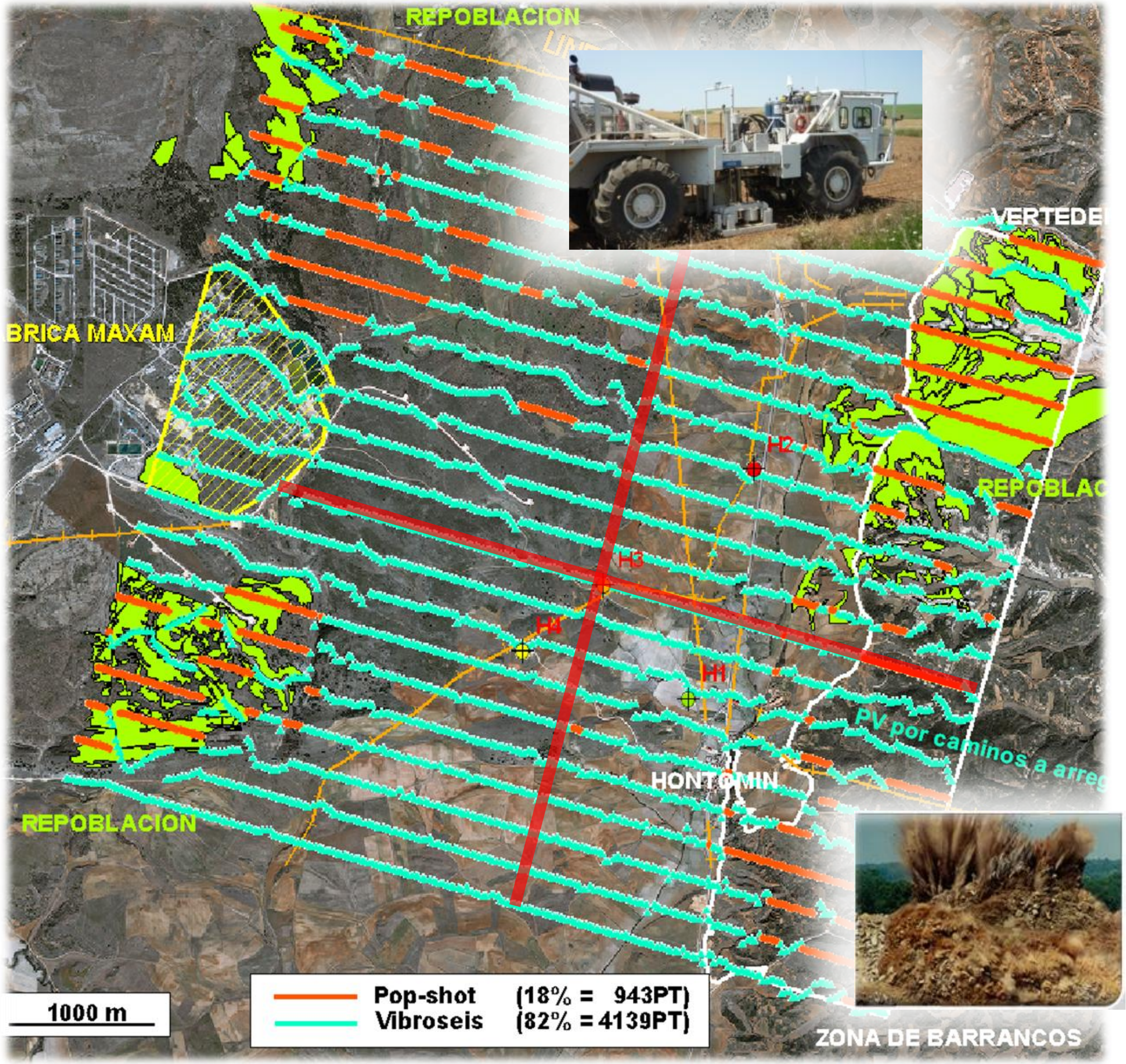
- Tomography

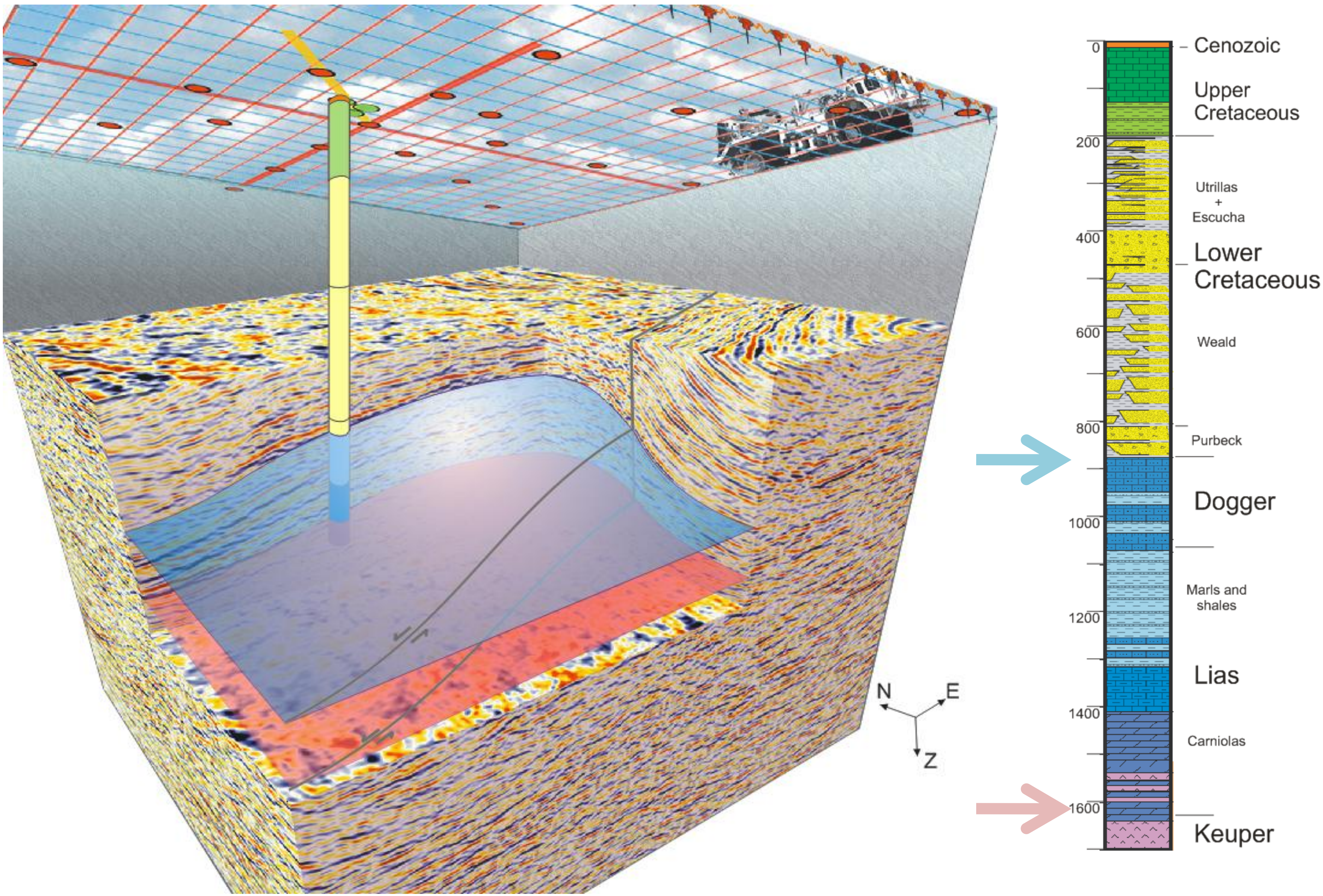
  Joint inversion for P and S travel-time reduce ambiguity of the velocity model

3D seismic

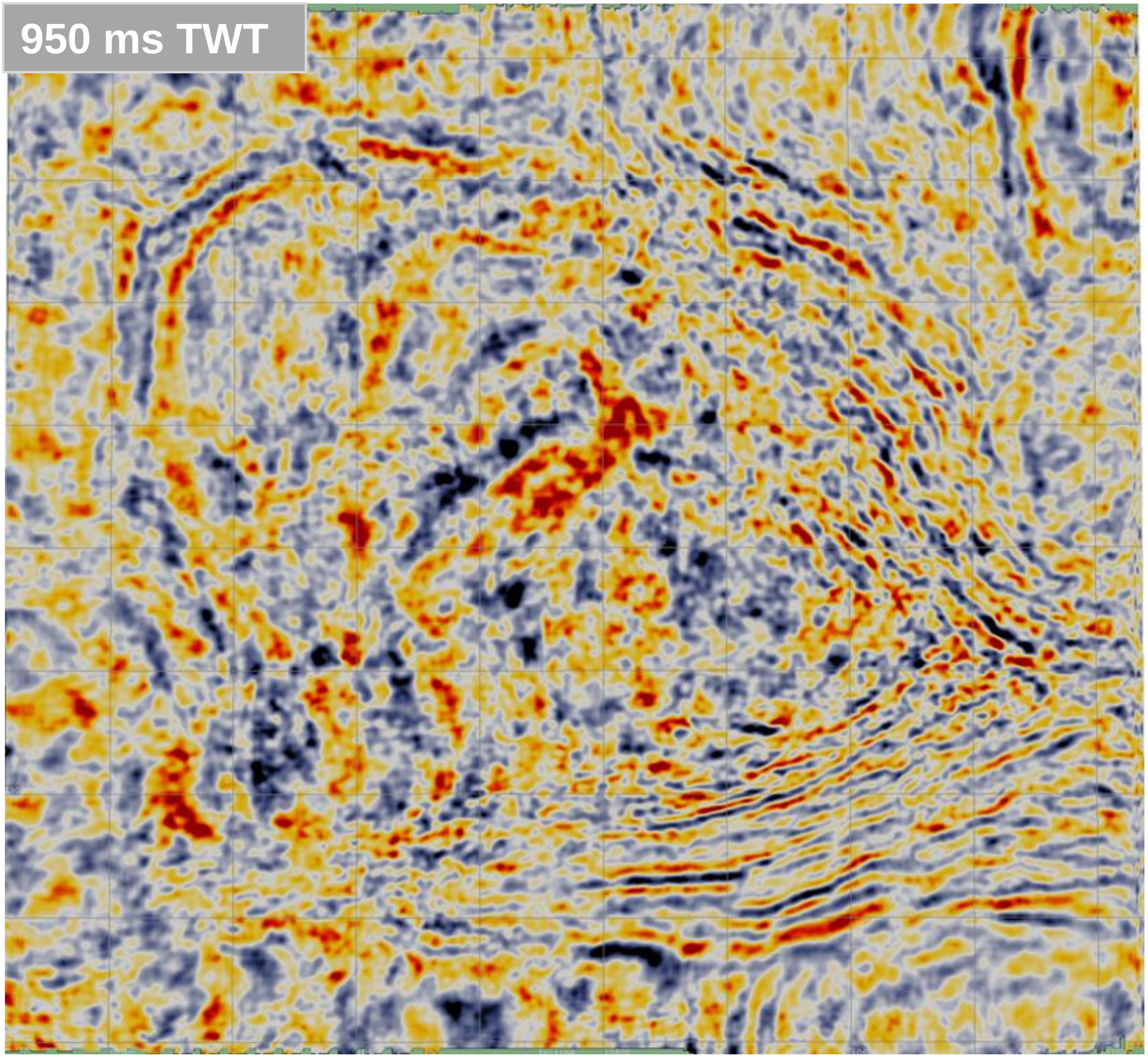
Acquisition area	~35 km^2
Receivers	6 (10 Hz)
Receivers distance	25 m
No. Inlines	463
Inline distance	250 m
No. Crosslines	431
Crosslines distance	275 m
Fold/bin (CDP)	36

Vibroseis M221	4 * 15 Tn
Sweep	16 seg.
Pop-shot	3 * 1.5 kg
Vibración/shot distance	25 m

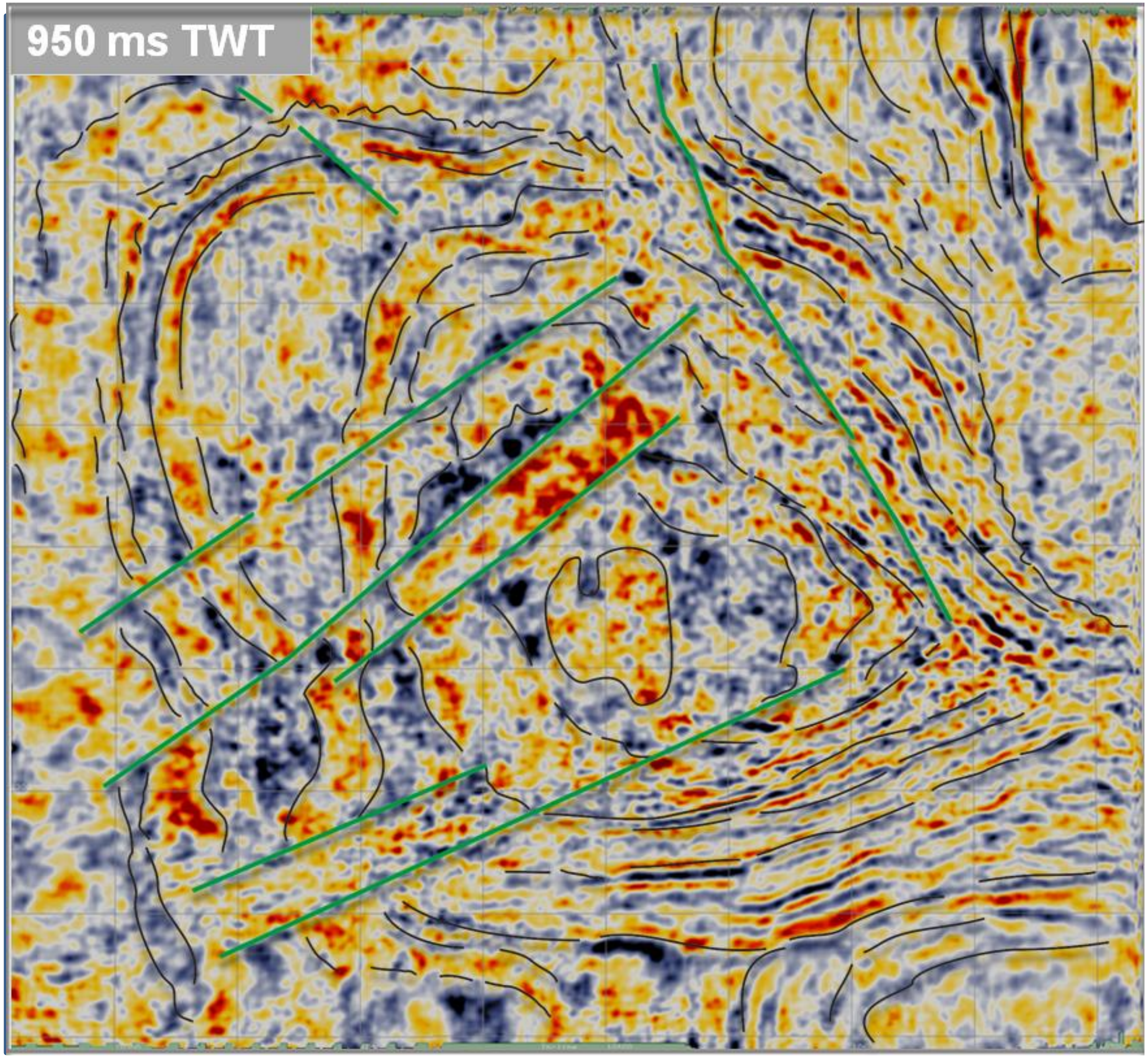




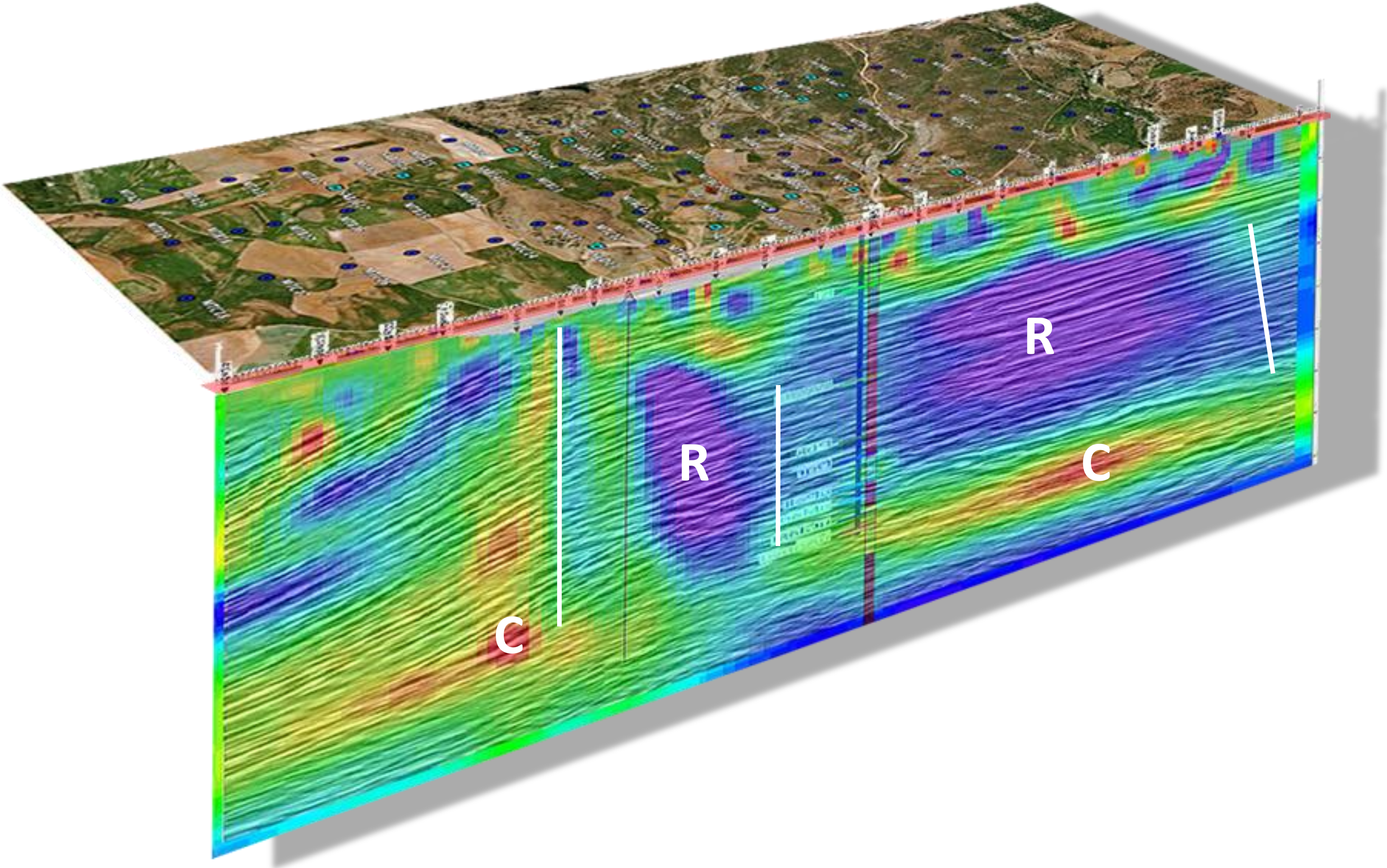
N
E
Z
0
200
400
600
800
1000
1200
1400
1600
Cenozoic
Upper Cretaceous
Utrillas + Escucha
Lower Cretaceous
Weald
Purbeck
Dogger
Marls and shales
Lias
Carniolas
Keuper



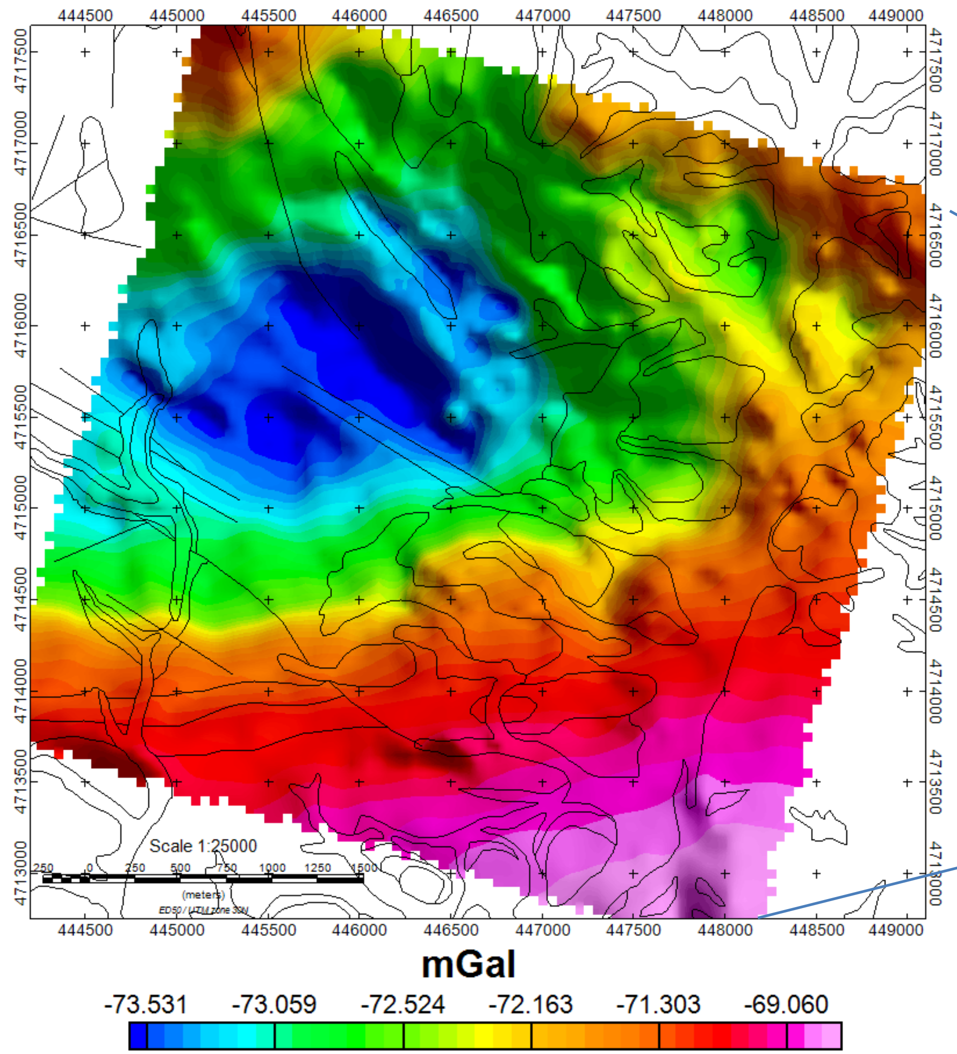
IJA-CSIC

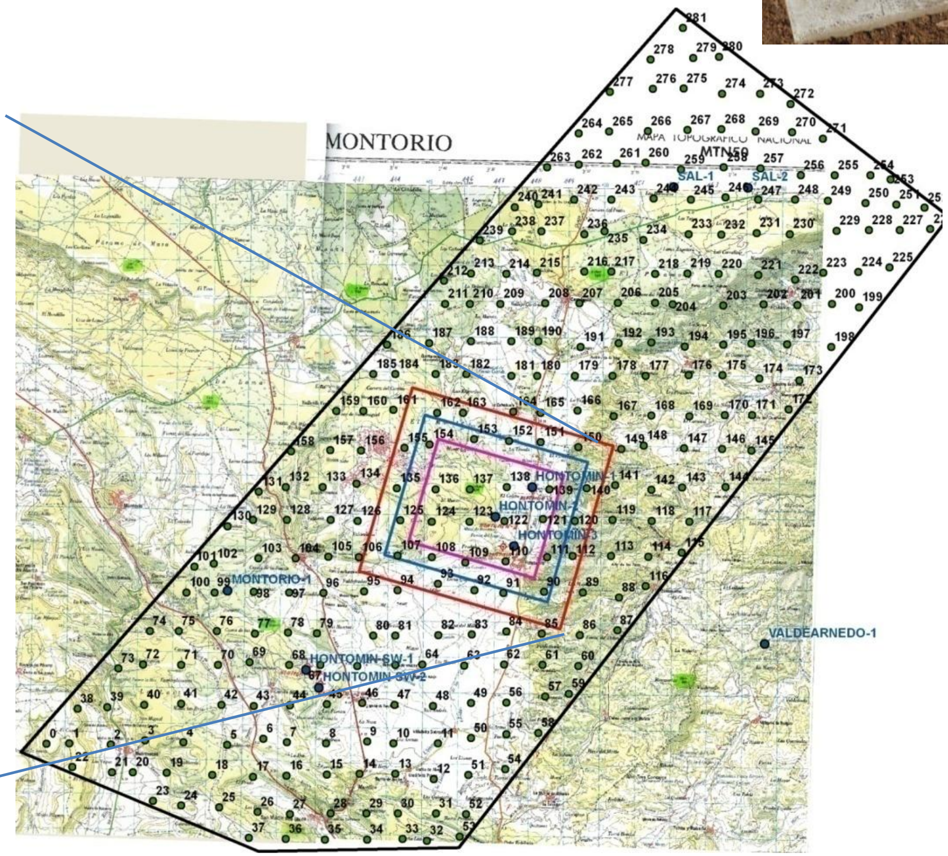


IJA-CSIC


R
R
C
C

Gravimetry and High resolution gravimetry



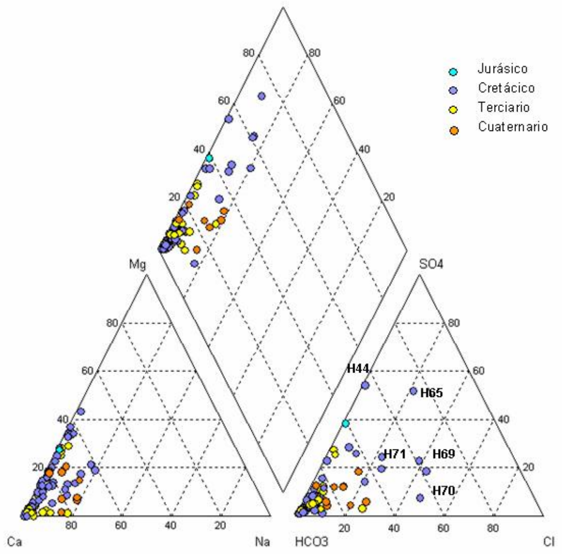


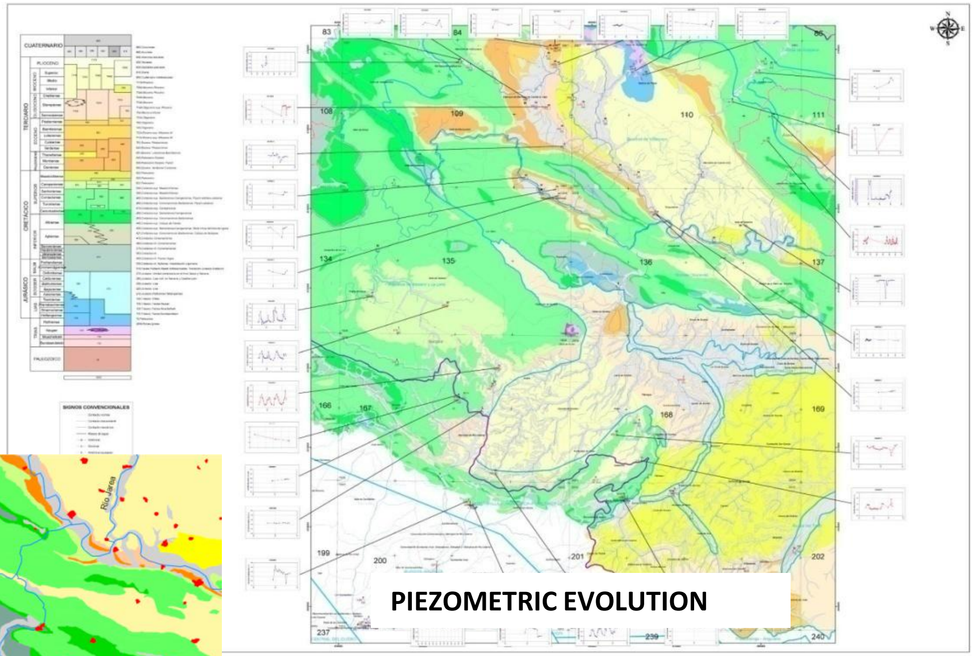
IGME, 2010

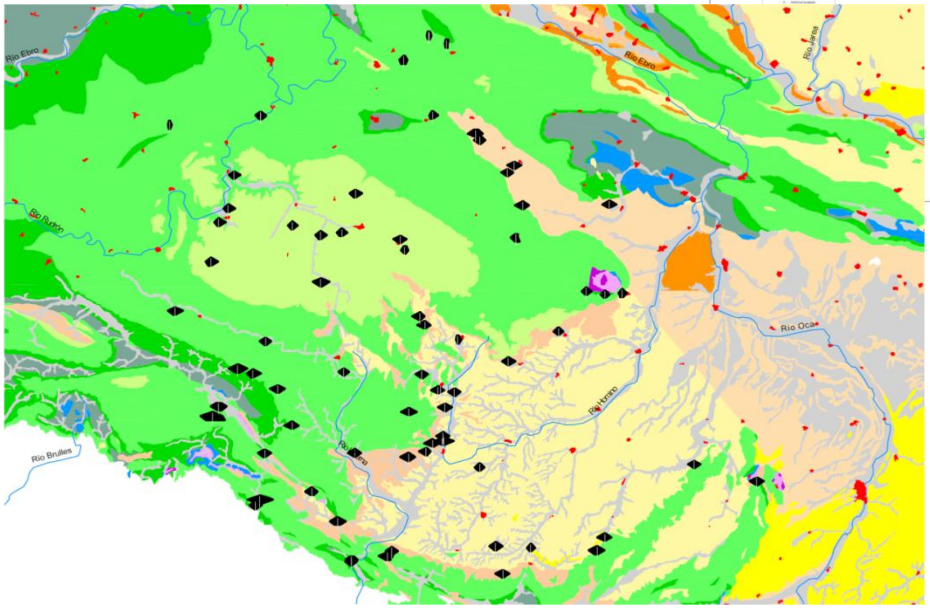
Hontomin PDT Monitoring Techniques	
Atmospheric	CO2 Detectors (Isotopic Analysis)
	Secondary Technology (to be defined)
Near Surface	Water Geochemical Analysis
	Hydrogeological Monitoring
	Bioindicators
	Soil gas flux: direct measurements (accumulation chamber) and CO2 detectors in the future. / Isotopic Analysis
	DinSAR & Ground-Based SAR

* planned activities	* on going activities

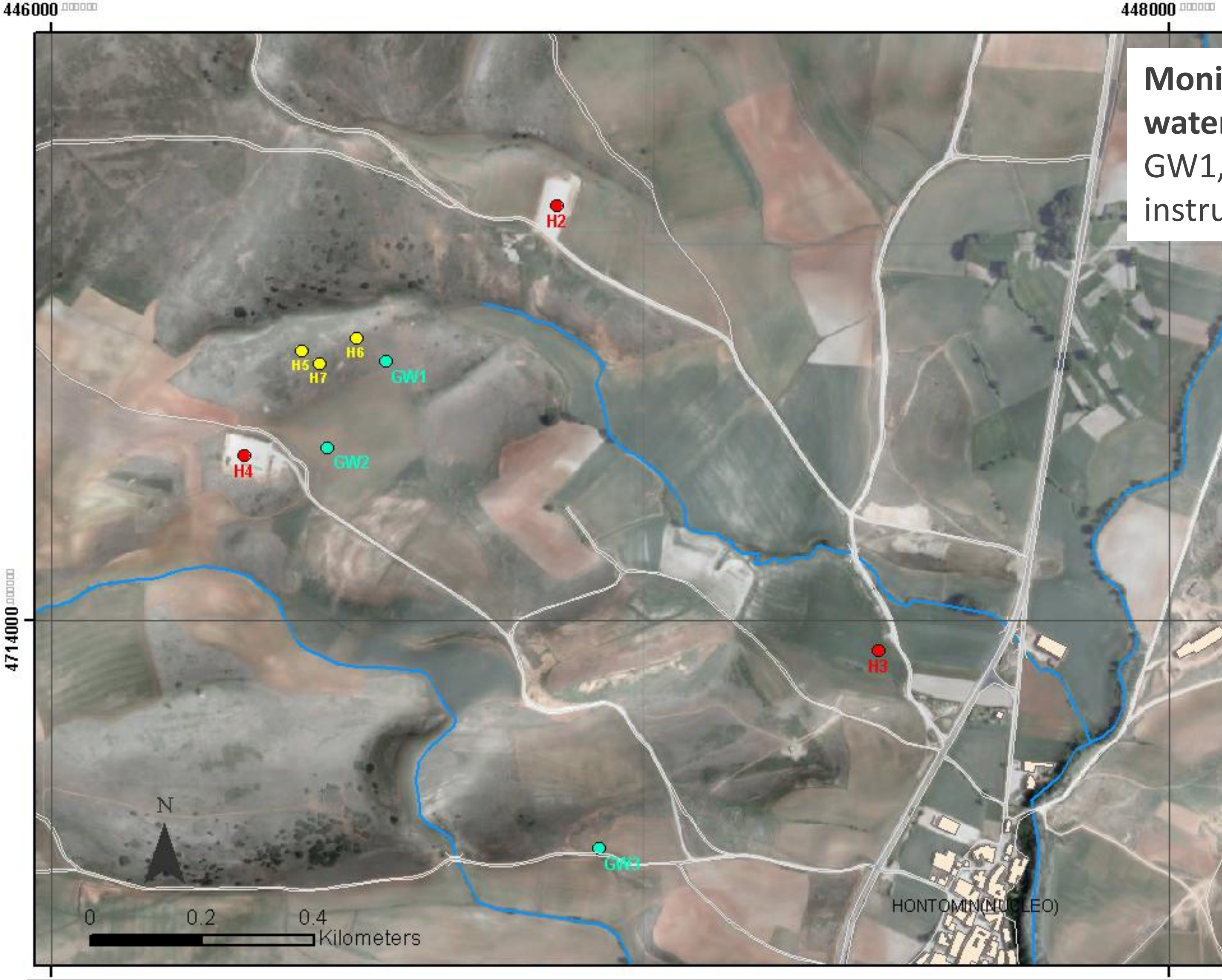
Hydrogeological and Hydrogeochemical characterization







AITEMIN, 2010; CIEMAT, 2010

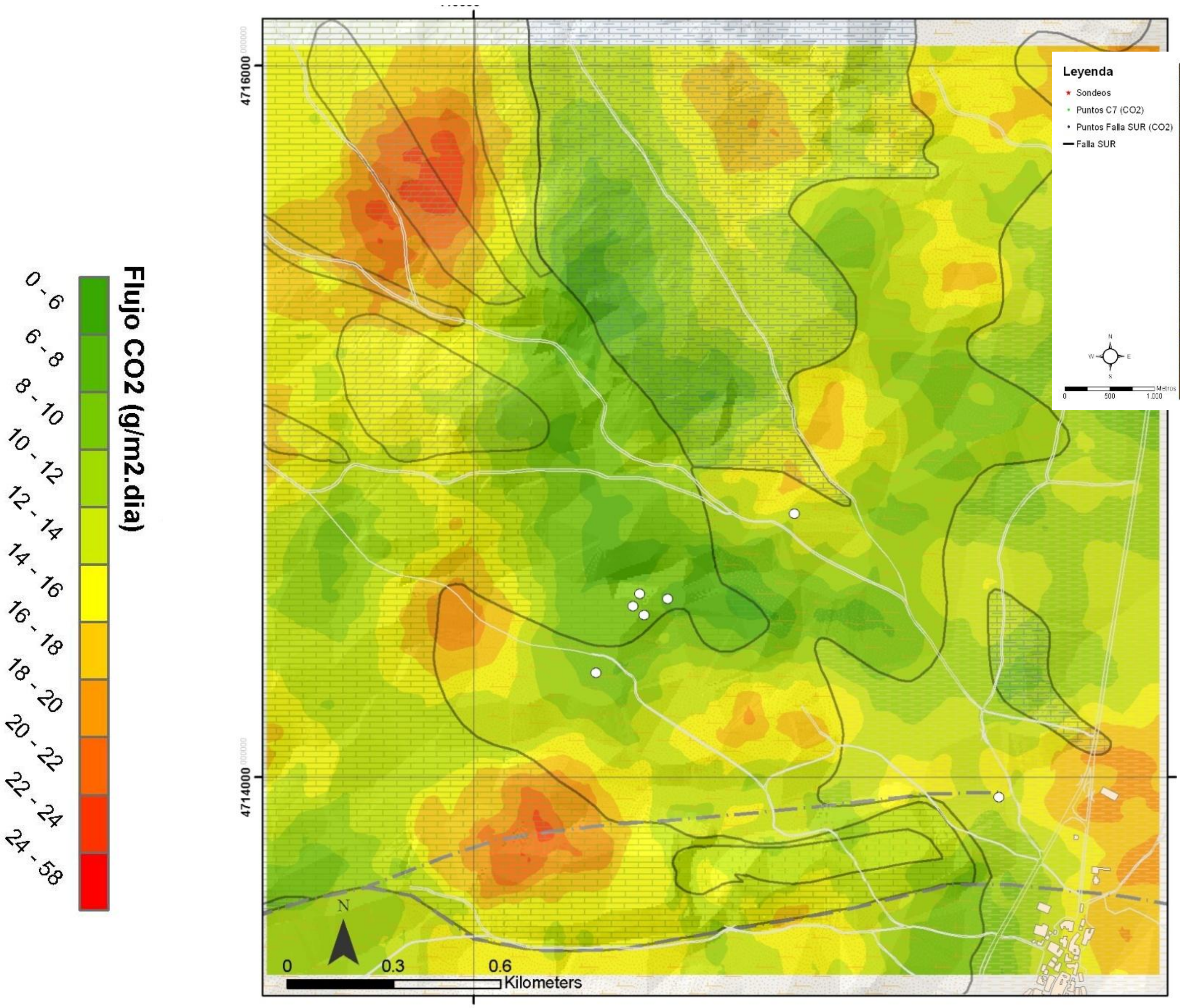


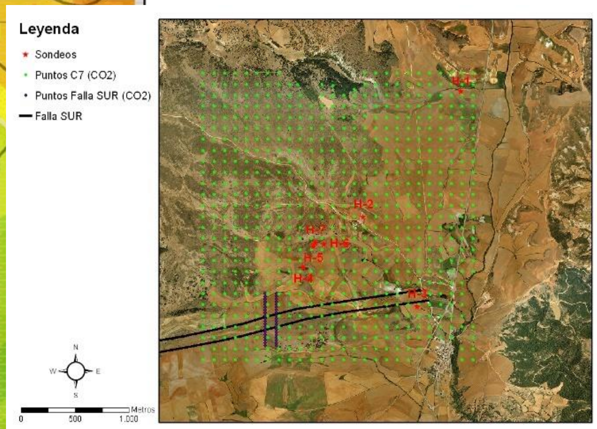
Monitoring of shallow water aquifers.
GW1, GW2, GW3 instrumented boreholes

SONDEO	GW-1	GW-2	GW-3
Cota emboquille:	s.n.m.	s.n.m.	s.n.m.
Profundidad aprox. (m):	400	400	150
Objetivo:	Fm. Utrillas	Fm. Utrillas	Falla Sur

AITEMIN, CIEMAT 2012

Natural CO2 Pre-injection Phase

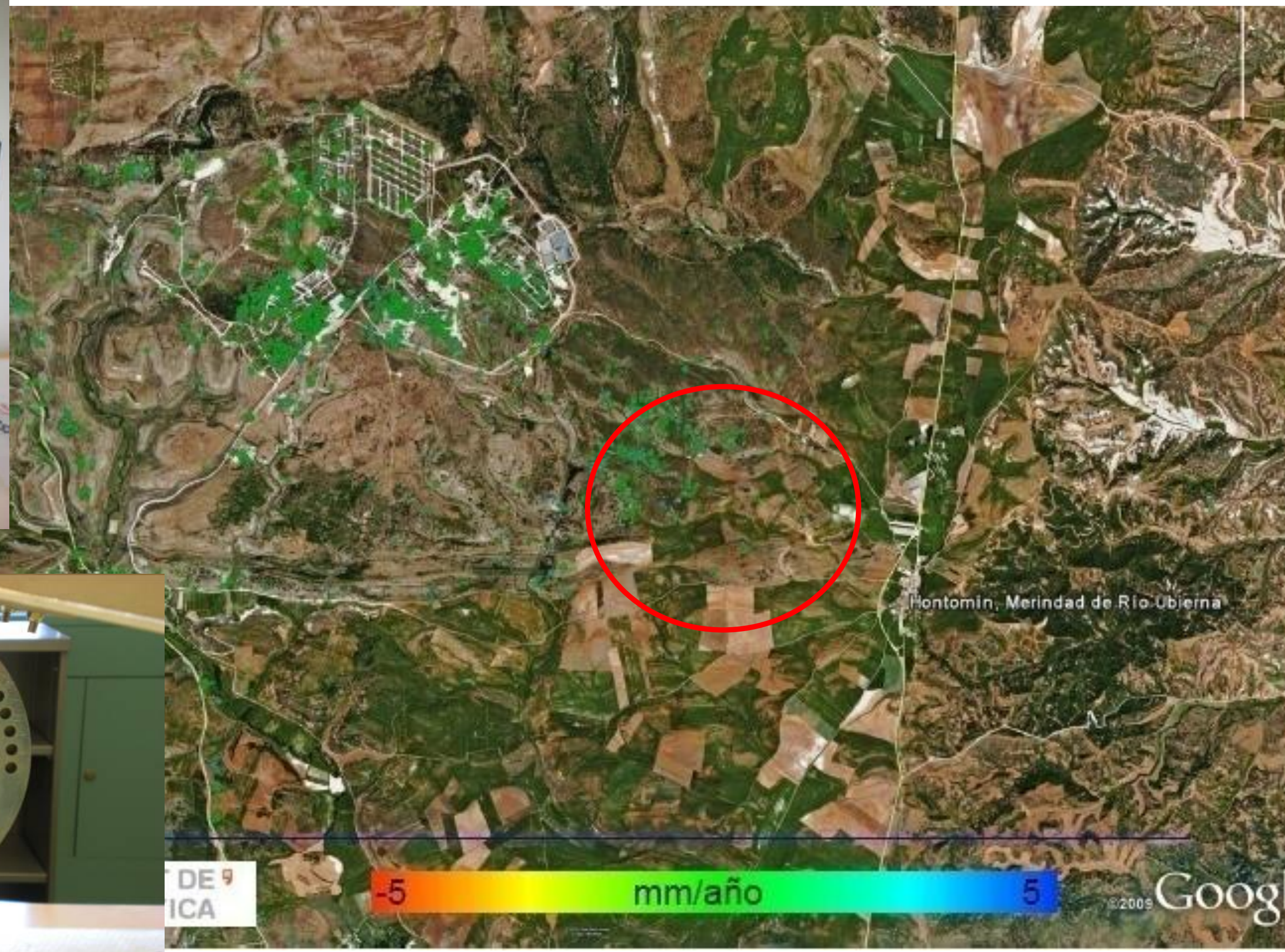




De Lio et al., 2010. UPM- Amphos 21 et al.

Displacement Measures

DInSAR - existing reflectors - Hontomin

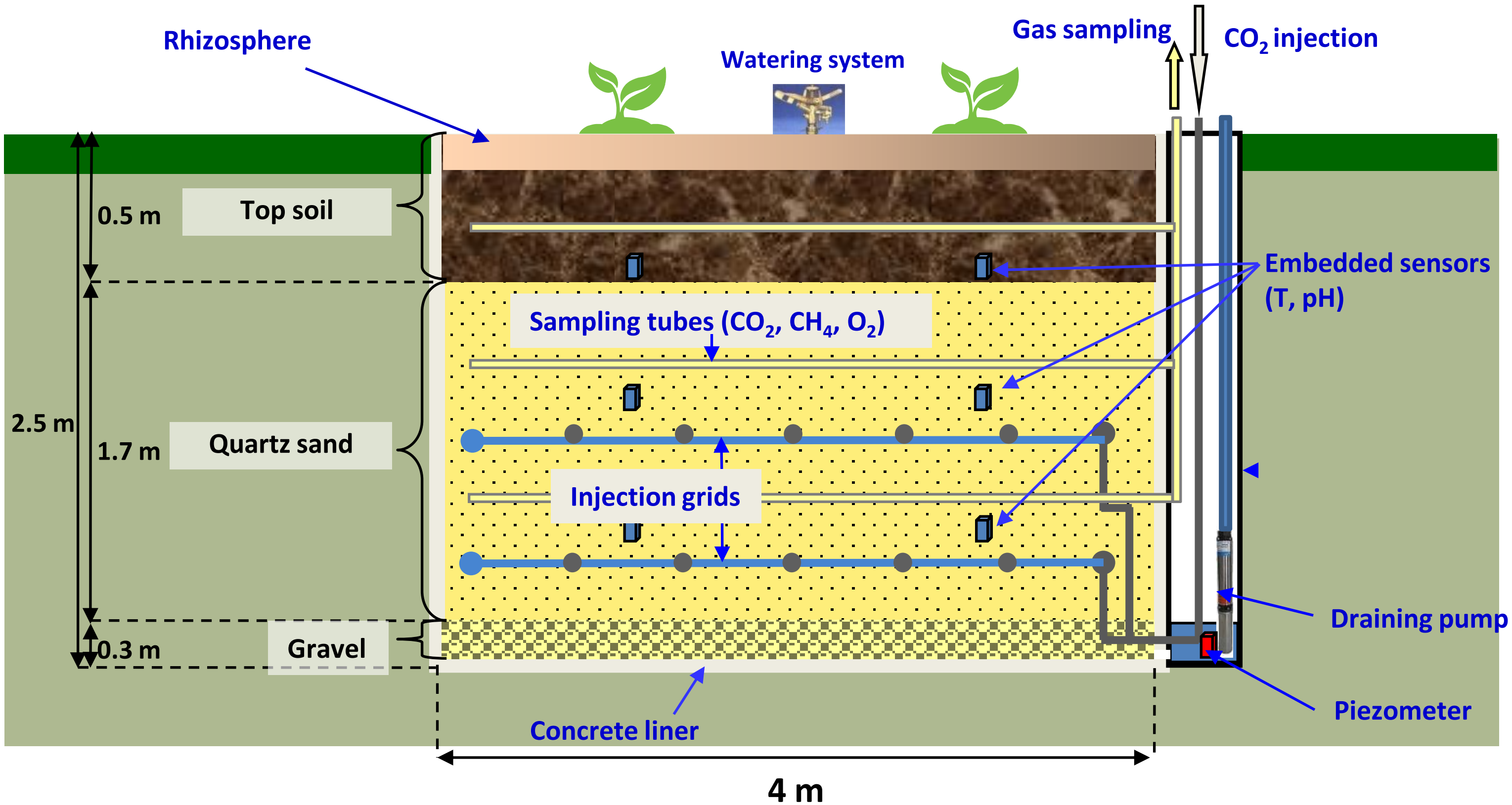


Ground-based SAR (GBSAR) + DInSAR

PISCO2 project

Goal: Assesement of Ecosystem Impact related to CO2 injection.

- Impact on different Biotopes looking for Bioindicators
- Identification of best Bioindicators to introduce in Hontomín TDP



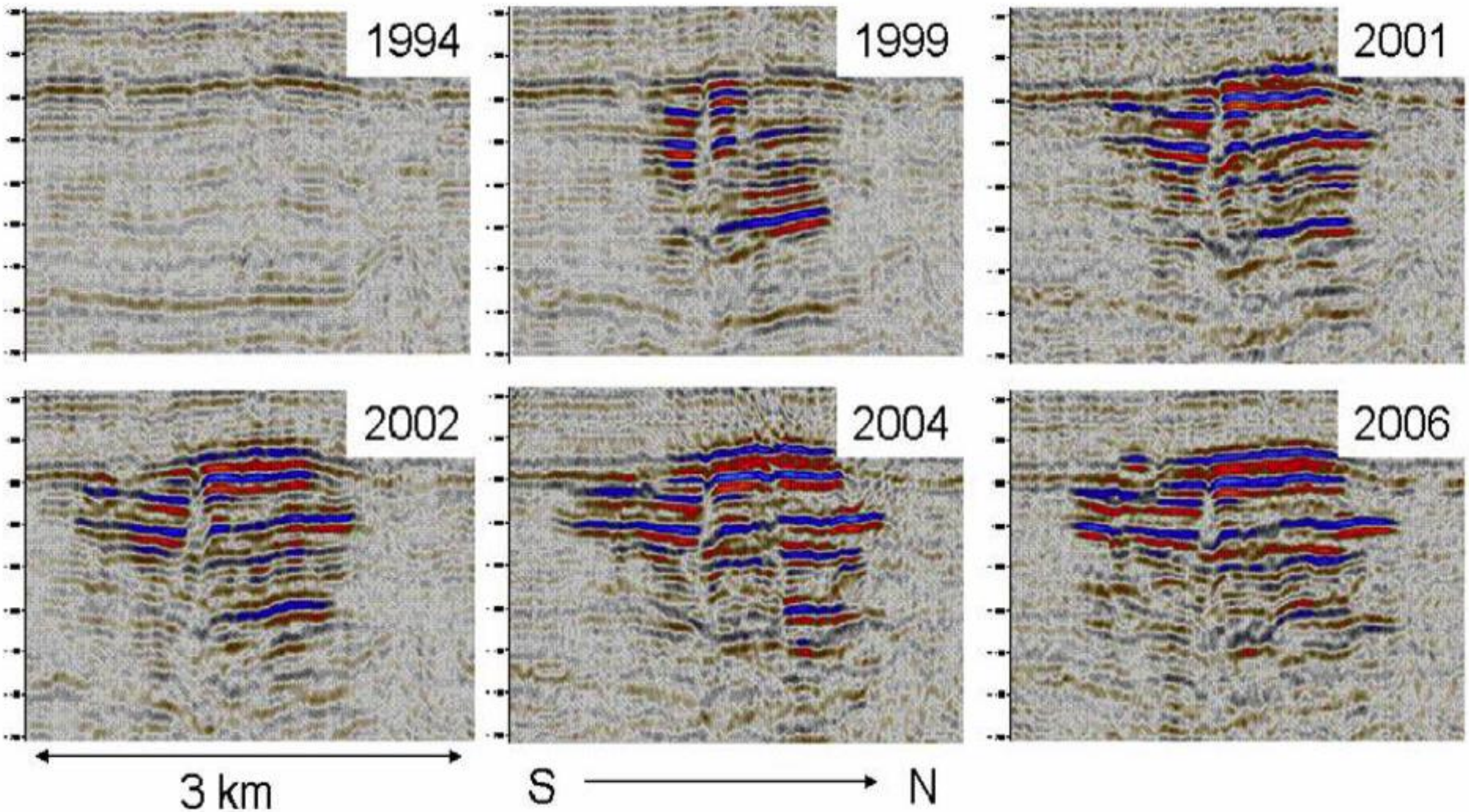
U. León, Amphos, AITEMIN

Subsurface	
	Passive Seismic Monitoring / Permanent Seismic Network
	Microseismic time reversal imaging
	High resolution noise Interferometry (PII)
	Full-waveform inversion (3D Velocity Model)
	Virtual Sources Methodology
	Time Lapse Monitoring
	Seismovie Monitoring (4D)
	VSP (4D)
	Gravity Survey (3D)
	CSEM/Electric (4D)
	ERT (4D)
	Geochemical Sampling for the Reservoir
	Temperature (DTS) / Presure (fluids)
	Extensometers in Boreholes

** planned activities*	** on going activities*

Modeling Prediction
vs
Monitoring Data

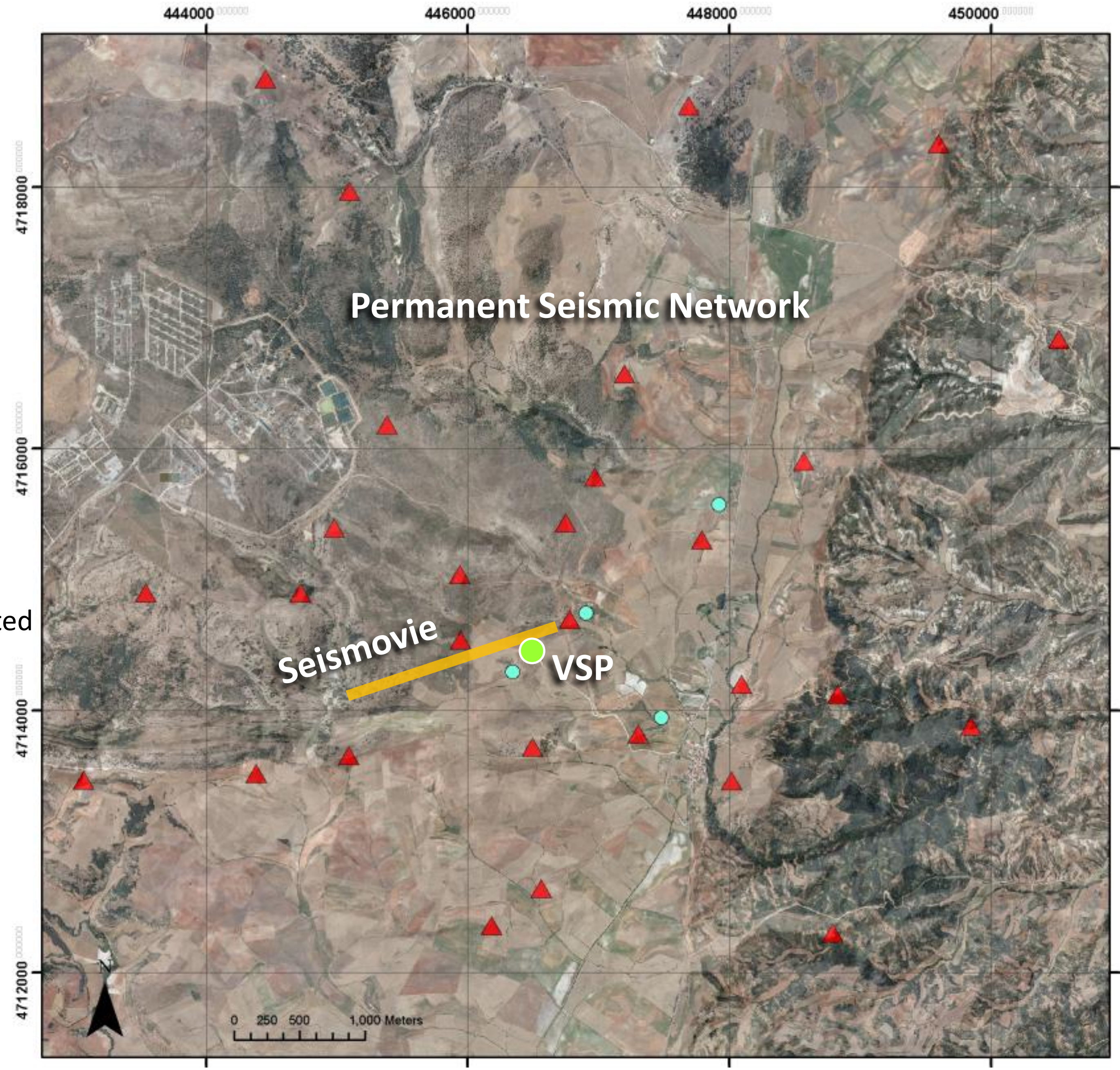
Time-lapse seismic datasets of CO_2 stored in Utsira formation



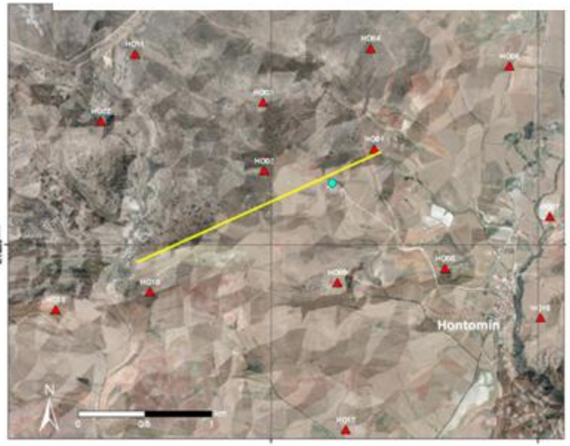
Seismic for monitoring

- Seismovie
- VSP
- Seismic Network
- New 2D

- Detect changes in physical and mechanical properties.
- Track the evolution of the injected gas/fluid.
- Distribution/diffusion of CO_2, migration pathways.
- Induced seismic activity
- microfractures characterization

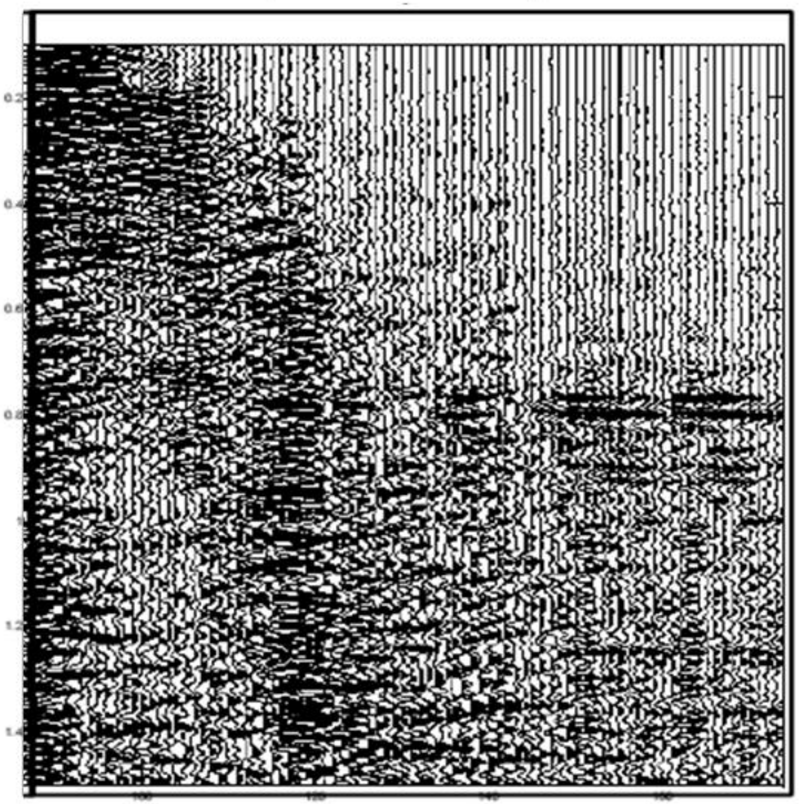


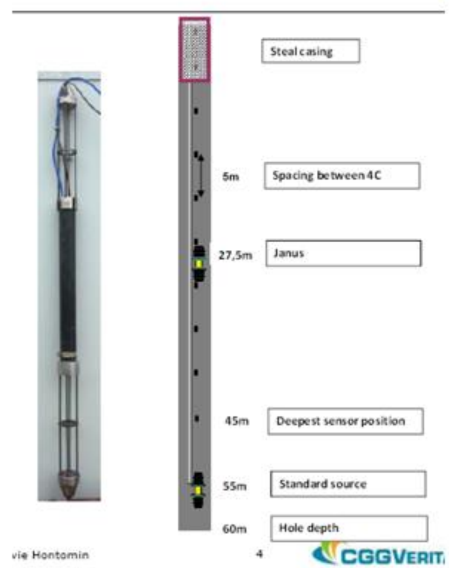
Seismovie: Continuous High-Resolution Reservoir Monitoring

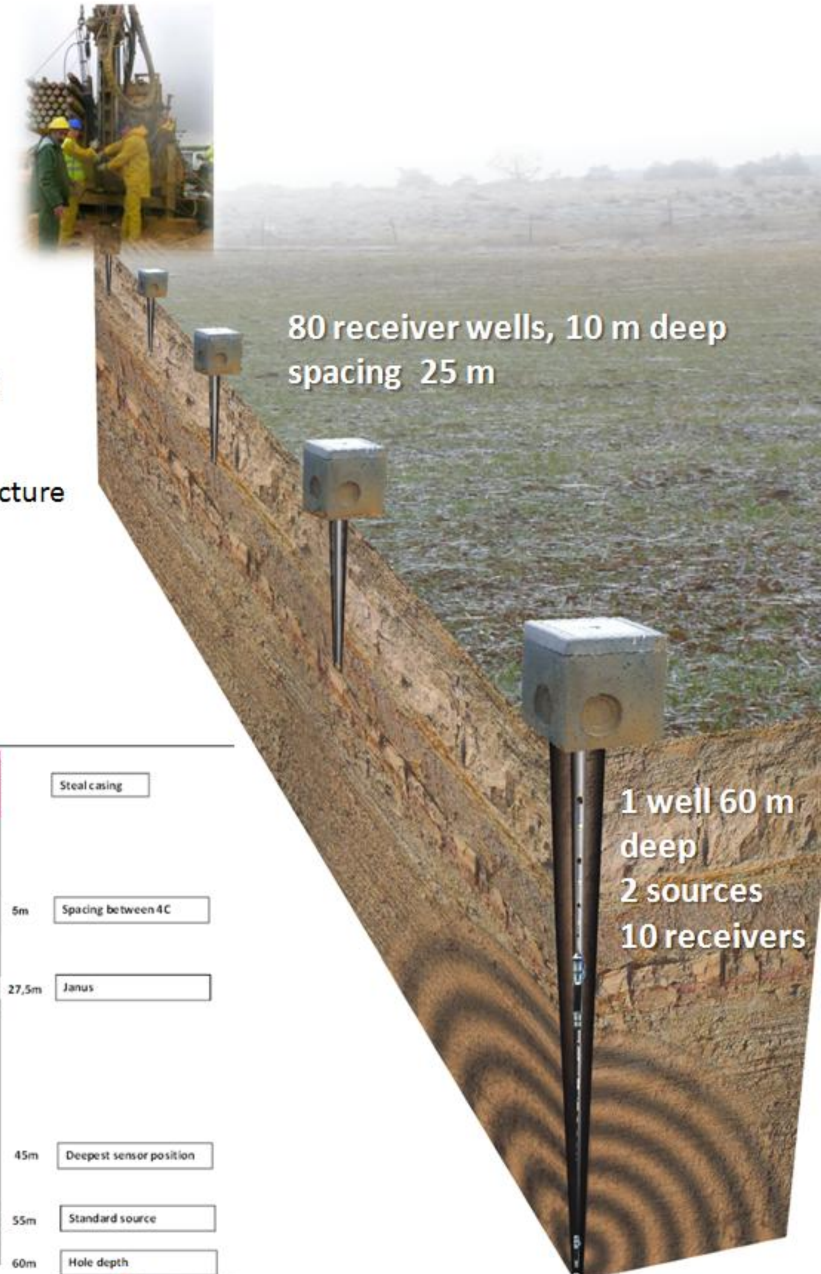


Main features:

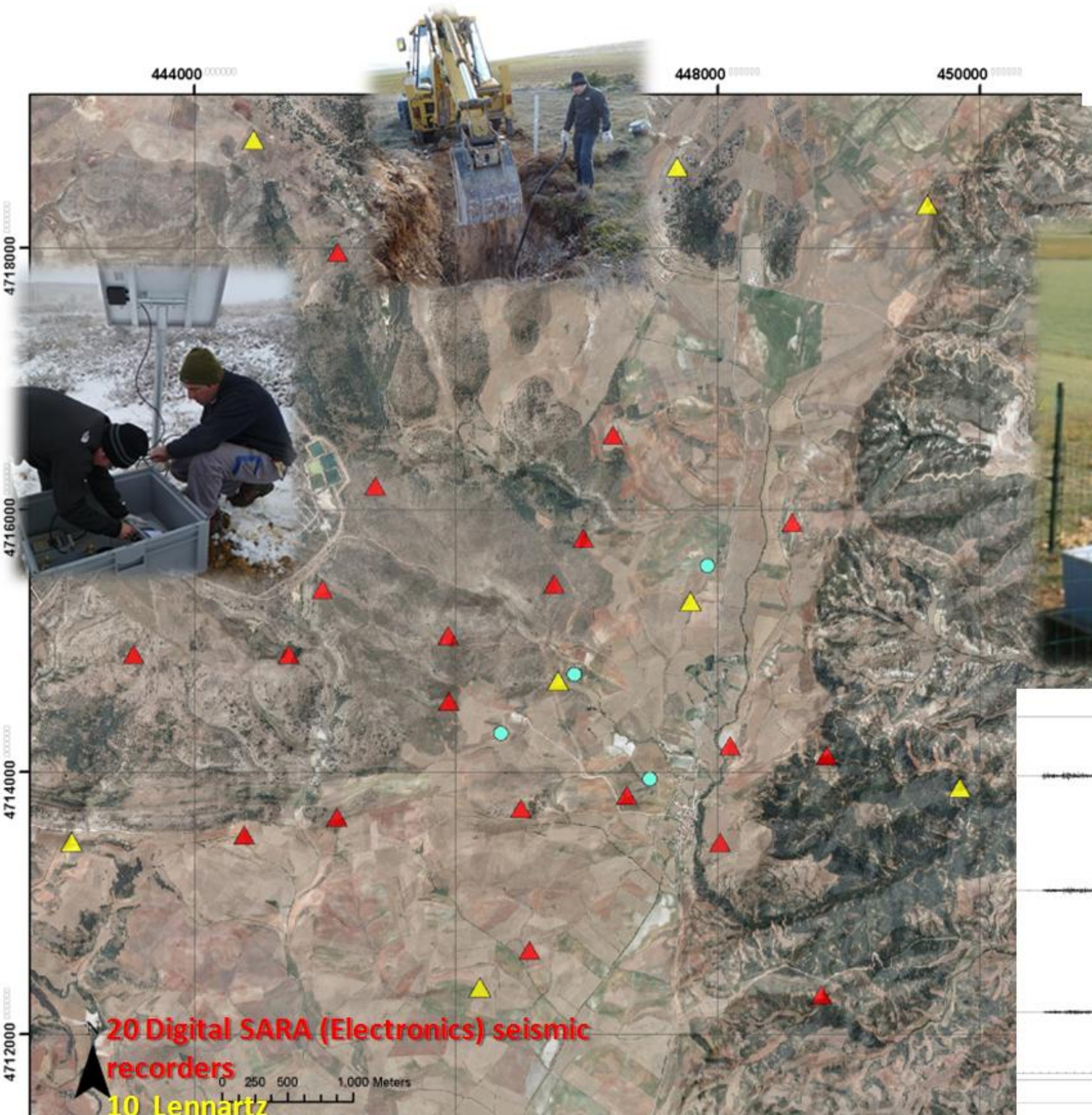
- Low cost
- Continuous automated monitoring
- Remote operation and recording
- Permanent and discreet Infraestructure





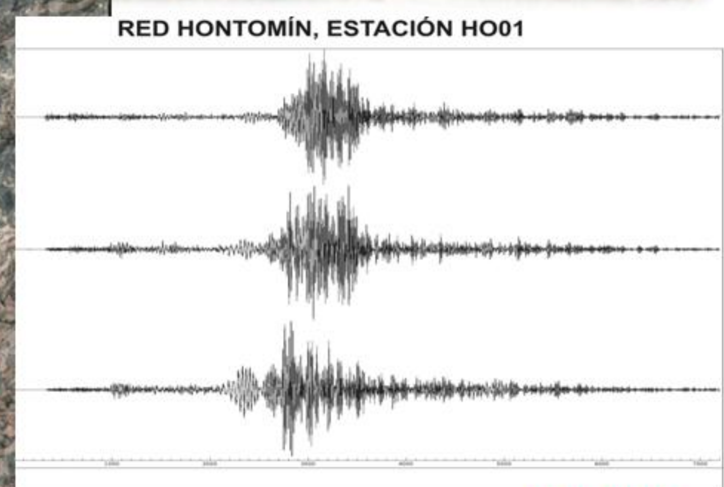


Permanent seismic network



Goals

- Detect changes in physical and mechanical properties.
- Track the evolution of the injected gas/fluid.
- Induced seismic activity



Terremoto Japón 11/03/2011, Mw=9.0

IJA-CSIC

New Strategies and/or Developments in Seismic Monitoring of CO2 Geological Storage Reservoirs

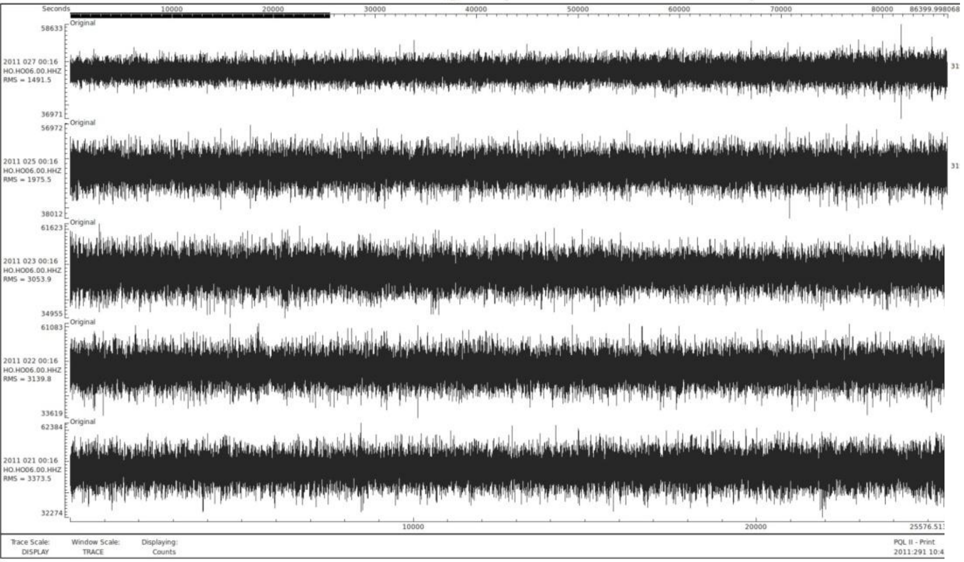
- **Microseismic time reversal imaging** using microseismic events. Seismic records are propagated backwards in time (time reversal modelling) visualizing the development of the induced seismicity (Tromp et al., 2005; Larmat et al., 2006; 2008; Lokmer et al, 2009; Tape et al., 2009).

- **High resolution noise interferometry**. Extraction of body wave signals from noise records by using advanced analytical signal processing techniques (phase cross-correlation and time-frequency phase-weighted stacks (Vasconcelos et al. 2011; Schimmel et al., 2011)).

- **Full-waveform inversion** for obtaining a 3D Velocity Model using seismic tomography.

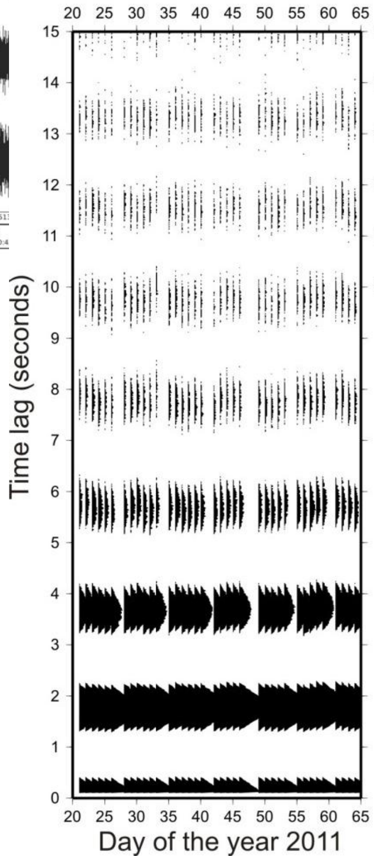
- **Virtual Sources Methodology** for seismic imaging monitoring (Bakulin, et al. 2007; Yu et al., 2009; Byun et al., 2010).

Noise recordings (Station HO06)

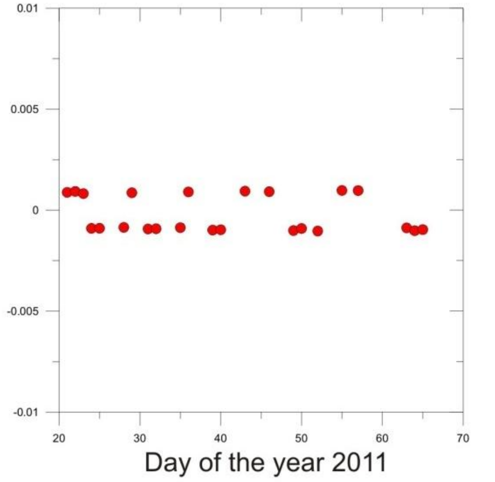


Autocorrelation functions
Using noise recordings

Autocorrelation



Relative velocity variations

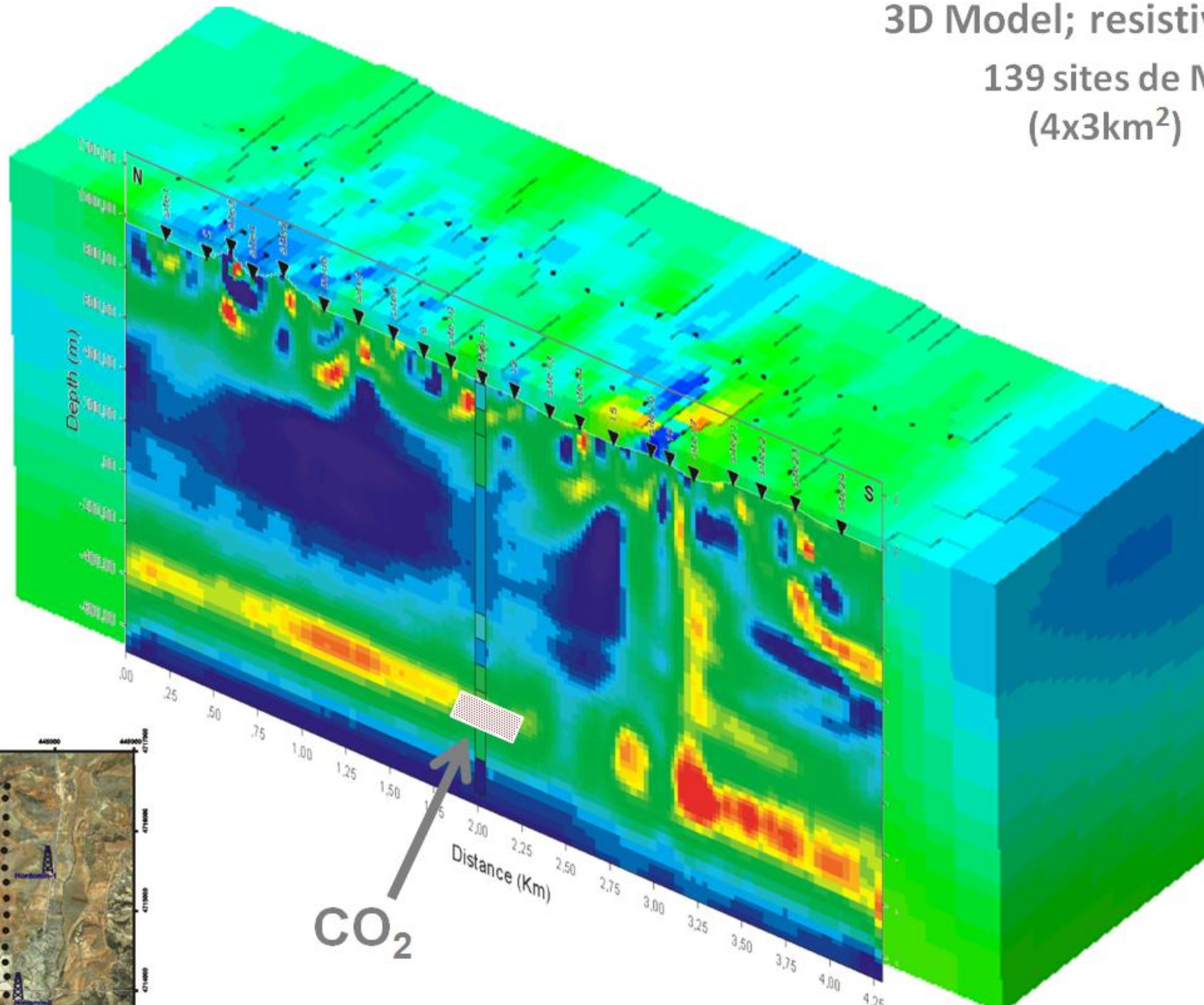


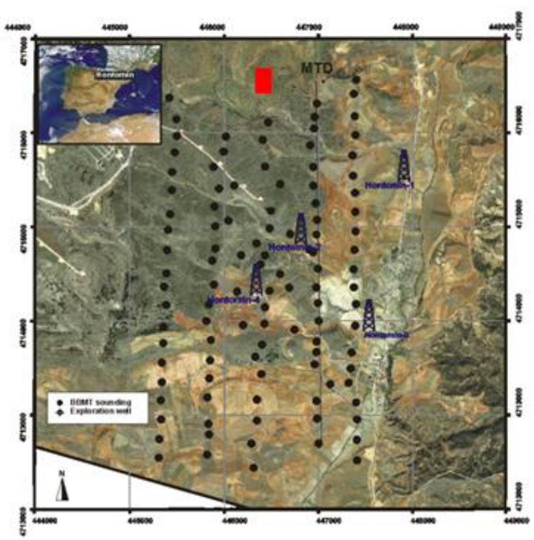
One day noise recordings
5 days January 2011

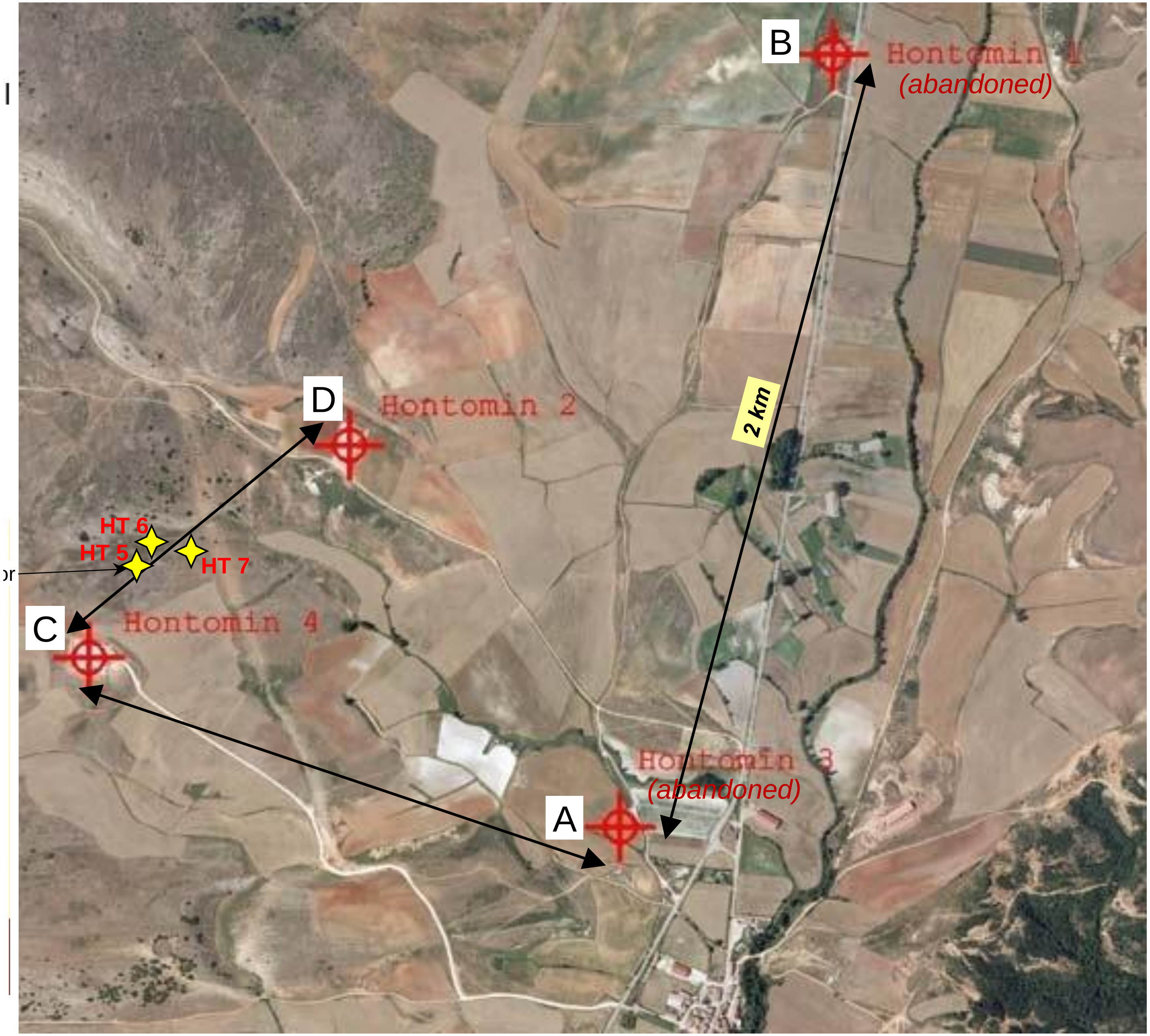
IJA-CSIC, Ugalde et al. 2011

3D Model; resistivities

139 sites de MT
($4x3km^2$)

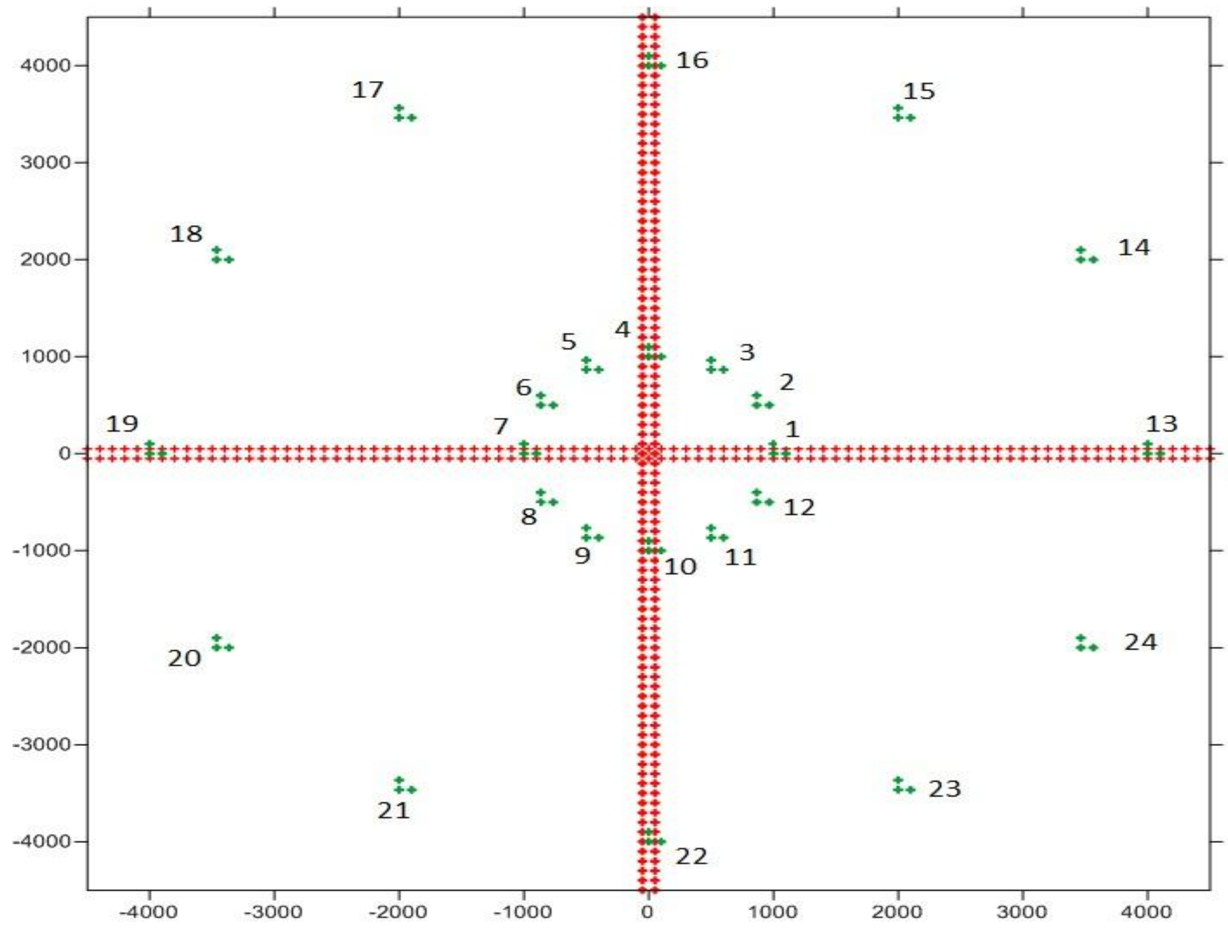






A, B, C, D: existing boreholes

ANR-SEED project: BRGM, CCGVeritas CIUDEN



Scheme of the two receiver configurations considered. Red symbols correspond to the cross-shaped design and green symbols, to the circle-shaped one.

The cross-shaped configuration is 2 * 2 parallel lines (3km long aprox.), 124 electrodes, buried 2m and 100m distance.

ANR-SEED project: BRGM, CCGVeritas CIUDEN

Cross Hole Electrical Resistivity Tomography

The electrodes and cabling can be mounted on the **outside of non-conductive well casing**

(A, B: current electrodes; M, N: potential electrodes)

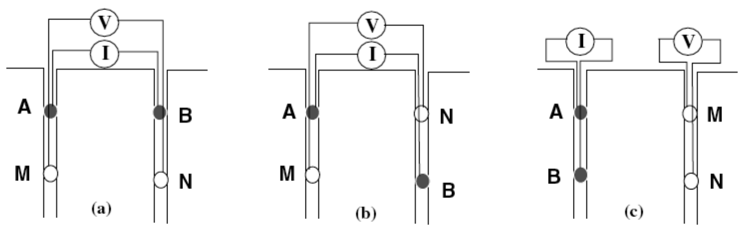
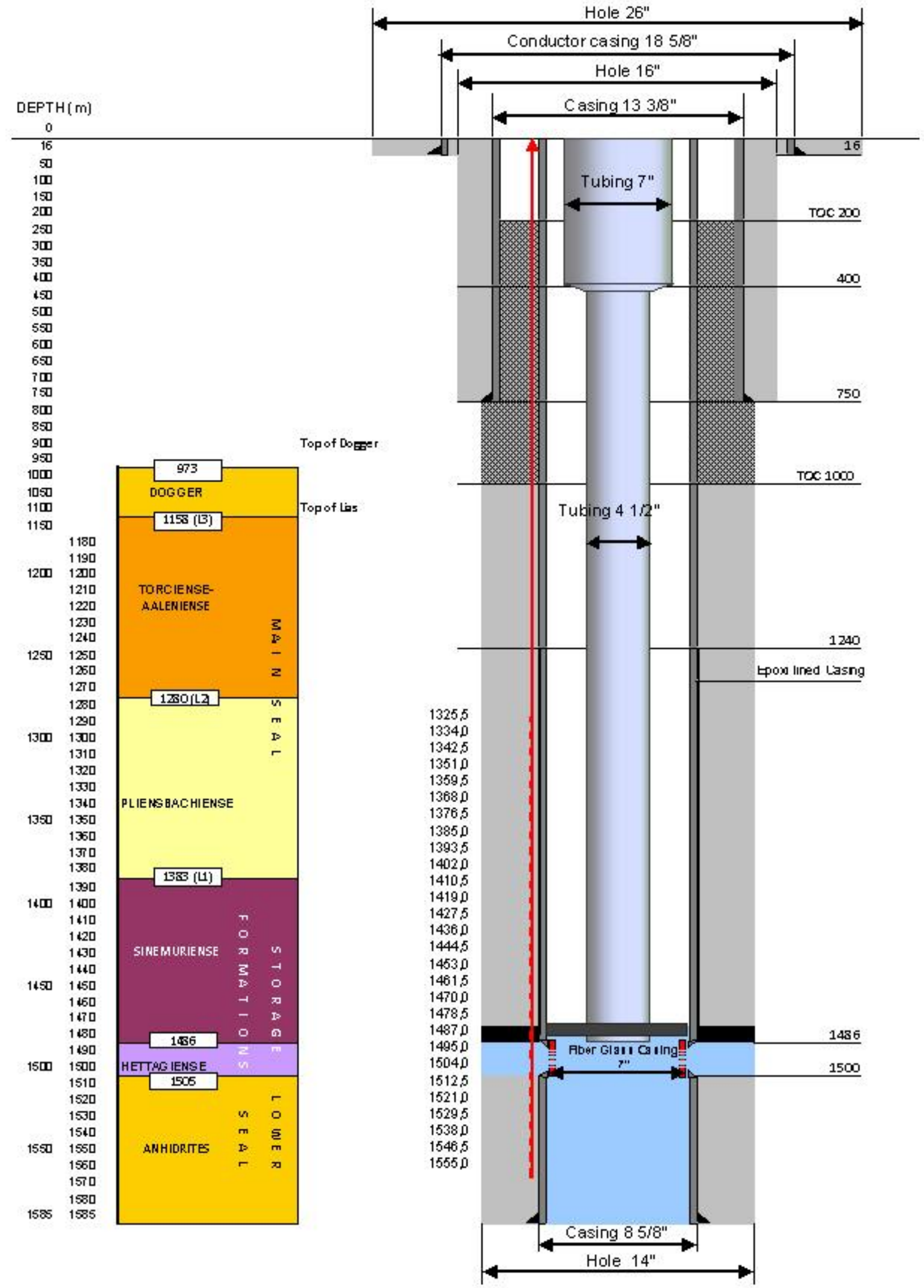
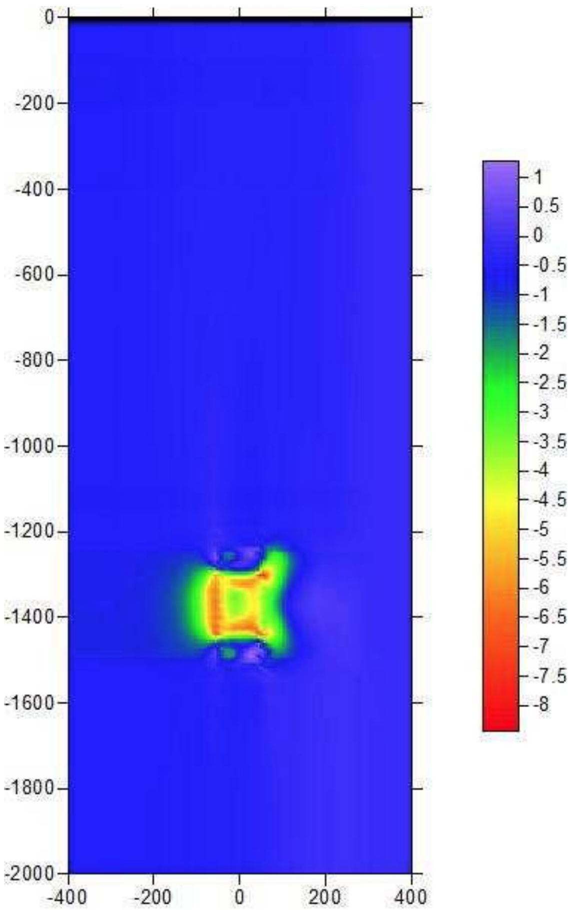


Figure 3. Three independent configurations for cross-hole bipole–bipole measurements: (a) *AM–BN*, (b) *AM–NB* and (c) *AB–MN*.

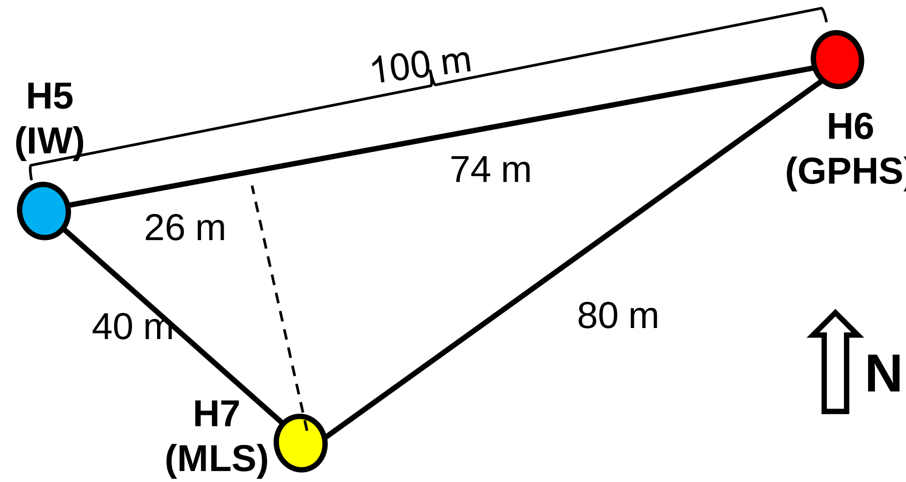


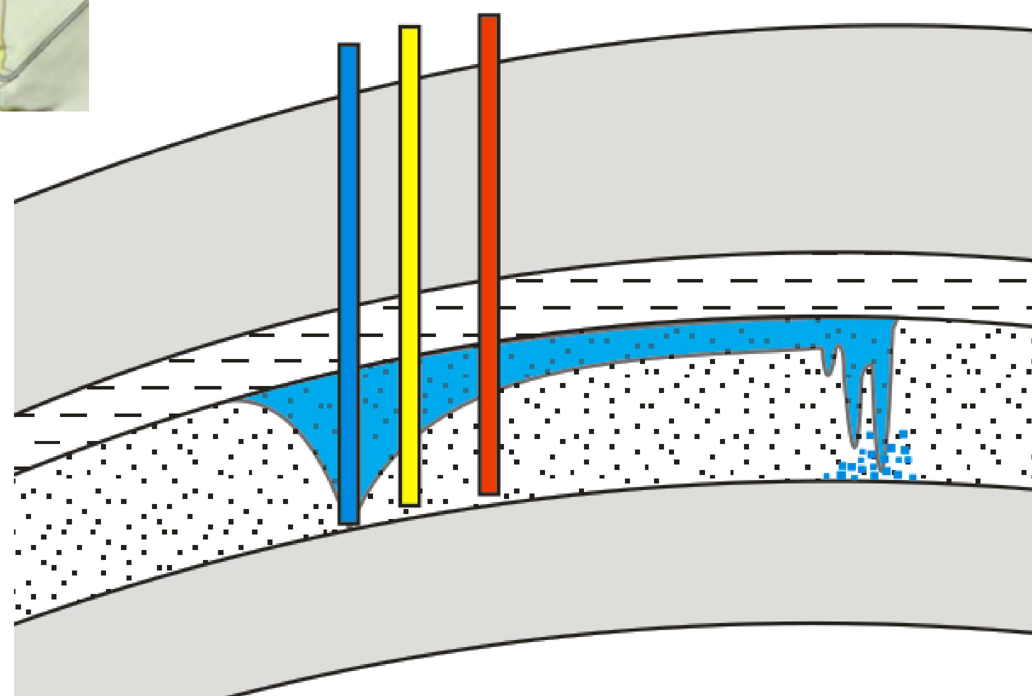
Cross Hole Electrical Resistivity Tomography

Resistivity change in percentage between the inversion models obtained from the synthetic data



Planned wells

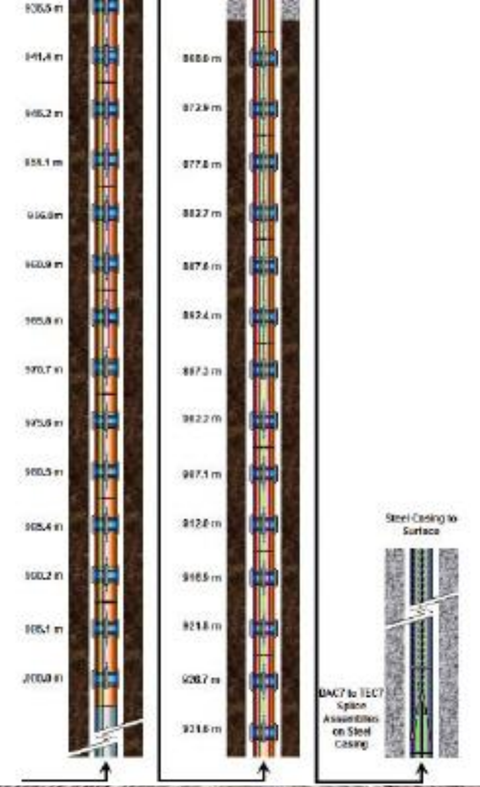




3 wells ~1500m

- **H5:** Injection (IW)
- **H6:** Monitoring (GPHS, GeoPHysical System)
- **H7:** Monitoring (Multi Level System)

Summary of Borehole Instrumentation



H5. Injection well (IW)

- ❑ Distributed Temperature Sensing (DTS) with optic fiber and heat element.
- ❑ Extensometers of fiber optic.
- ❑ Pressure of fluid (at least pressure of injection).
- ❑ ERT electrodes

H6. Geophysical well (GPHS)

- ❑ Geophones.
- ❑ Distributed Temperature Sensing (DTS) with optic fiber and heat element.
- ❑ Pressure of fluid (?).
- ❑ Extensometers of fiber optic.
- ❑ ERT electrodes.

H7. Sampling well (MLS)

- ❑ Geochemical sampling.
- ❑ Pressure of fluid.
- ❑ Distributed Temperature Sensing (DTS) with optic fiber and heat element.
- ❑ Extensometers (incorporated in packers).
- ❑ ERT electrodes .

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Hontomin monitoring plan: Key challenges

Major general challenges

- Sensitivity analysis of base line datasets, what are the error bars in the baseline parameters
- Sensitivity analysis of the datasets and parameters during and after injection. Benchmarking of different methodologies
- Cost evaluation

Specific challenges/topics in current development

- Joint inversion of geophysical data
- Multiseismic 4D imaging
  - High resolution noise interferometry
  - Time reversal imaging
  - Full wave-form inversion
- Electrical/CSEM methods for monitoring the CO_2
- INSAR Methodologies
- Bio-indicators

- CIUDEN´s public engagement strategy started at the very beginning of its field activities.
- CIUDEN maintains a permanent communication and engagement with the stakeholders.
- These activities will be reinforced with the Visitor´s Centre that will be located next to the TDP.

Thanks for your attention