MUSTANG

A MUltiple Space and Time scale Approach for the quaNtification of deep saline formations for CO2 storaGe

Project Number:227286

Work-Package: *WP03*

WP Title
Field quantification techniques

Deliverable *D032*
Design of new electrical observatory (including data transmission and analysis protocole) with 1500 m capacity, and construction for the Maguelone experimental site deployment at shallow depth.

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Contributing participants	ImaGaeu

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RE	Restricted to the consortium members, the SIRAB, the end-users and the EU officers	
CO	Confidential (only the consortium and the EU officers)	

Deliverable number	**D032**
Deliverable name	**Design of new electrical observatory (including data transmission and analysis protocol) with 1500 m capacity, and construction for the Maguelone experimental site deployment at shallow depth.**
Work-package	**WP03:** Field quantification techniques
Lead participant	**UGOE**

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Executive summary
A new downhole monitoring array based on near-field electrical resistivity probing has been design and constructed in 2010 by imaGeau. This new device will be deployed and tested in 2011 at shallow depth ≤ 25 m) at the Maguelone experimental site. Designed in view of future deployments down to 1500 m depth, the main feature of this new downhole sonde includes a double cask tube for possible gas injection or later calibration from induction logging through the inner tube.

Keywords	Electrical resistivity, CO2 detection, downhole monitoring, field experiment

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1. Background

Geological storage of CO_2 is still a new technology and many questions still remain open. This is in particular the case for the study of saline formations. These reservoirs have not been as thoroughly investigated in the past, mostly due to the lack of financial value. Detailed monitoring techniques to follow either the CO_2 injection process or the long-term sustainability of subsurface storage are needed.

For this, one of the key objectives of MUSTANG is to develop and disseminate a comprehensive set of generic tools and methodologies for the identification, assessment, characterization and evaluation of deep saline aquifers for CO_2 storage. In order to achieve this overall objective, a number of technical issues must be addressed. First, the needs for monitoring must be identified in terms of relevant parameters, extent, vertical and horizontal resolution, time span and frequency of measurements.

On the basis of field characterization methods beyond classical methods (geophysical surveys, well logging, core analyses, interference well tests and tracer tests), the objective is to provide innovative and CCS (carbon capture and storage) adapted characterization techniques to assess sustainability and safety of the storage process.

To achieve this objective, a "***Shallow Injection Monitoring Experiment*"** ("SIMEx") has been designed and planned for deployment at the Maguelone experimental site located south of Montpellier along the Mediterranean coast. In particular, SIMEx focuses on the deployment of a new downhole monitoring strategy designed on the basis of near-field electrical resistivity probing, and constructed in 2010 by imaGeau. Similar strategies have proven to be successful in the past in widely varying context (White, 1994; Chambers et al., 2002; Zhou et al., 2002; Dahlin & Zhou, 2004).

1.1 SIMEx ("Shallow Injection Monitoring Experiment")

The MUSTANG monitoring experiment was initially designed in early 2007 and started at Maguelone (Languedoc, France) in March 2010. It is limited within MUSTANG to the testing of the new electrical instrumentation in relation to gas injection (air to start with, and possibly CO_2 later) at shallow depth. This shallow MUSTANG experiment at Maguelone constitutes therefore a unique opportunity to test in a cost effective manner a full suite of coordinated monitoring techniques (electrical, acoustical, hydrodynamic with fluid sampling, time-lapse logging) either from surface and/or downhole.

On the basis of new integrated concept, this experiment was later expanded into the now called "SIMEx" project. Prior to deep deployment beyond 800 m depth, this shallow depth (< 25 m) monitoring experiment as part of MUSTANG will permit to associate and deploy, from surface and downhole, a multi-methods approach in order to propose strategies to be implemented later at a greater depth, keeping the experiment at a reasonable cost.

In-situ monitoring based on geophysical probing from permanent and autonomous observatories shall provide means to :

- (1) monitor the injection process in terms of pore space saturation,
- (2) validate the stability of the reservoir storage (over long periods of time),
- (3) evaluate the sealing capacity of the cap rock (over long periods of time).

In this report, the Maguelone experimental site is briefly presented from a historical point of view. The SIMEx-2010 experiment is described in a second phase; new field spread, drilling and completion of the downhole instrumentation are outlined. Finally, the design and construction of the new electrical observatory underwent by imaGeau is described in the form of figures summarizing the double cask strategy allowing future gas injection in the centre.

1.2 The Maguelone experimental site (Languedoc, France)

The Maguelone experimental site is located along the Mediterranean lido of the Gulf of Lions passive margin, 10 km to the south of Montpellier. Limited to the north by the Prevost coastal lagoon and to the south by the Mediterranean Sea *(Fig. 1)*, this site offers a natural laboratory to study porous coastal reservoirs in a clastic and clay-rich context saturated mostly with saline fluids.

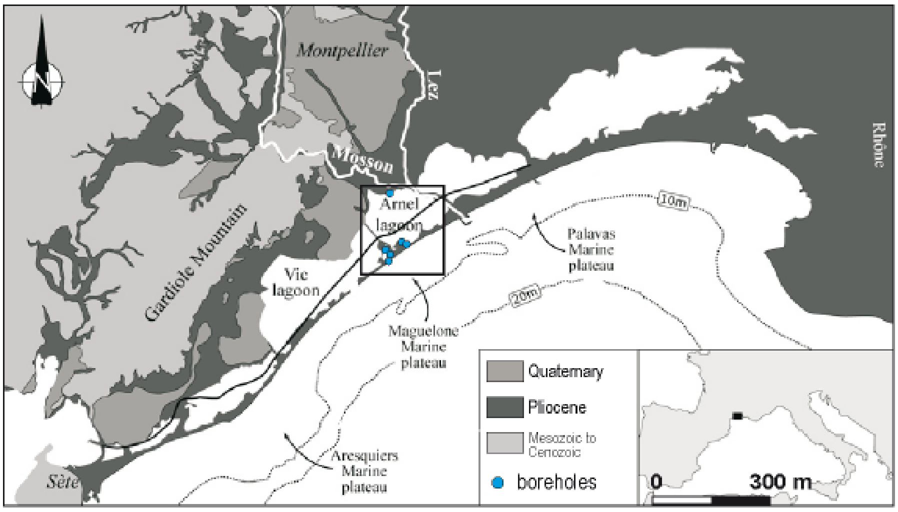


Figure 1. *Simplified geological context for the Maguelone site, located on a Lido limited to the NW by lagoons and to the SE by the Mediterranean sea (after Raynal et al., 2010).*

Five shallow boreholes (12 to 60 m deep) have been drilled from 2003 to 2004 at Maguelone over 5 km^2 for geological, hydrological and instrumental reasons in the framework of EC “ALIANCE” project *(Fig. 1)*. This FP5 project was dealing with the development and testing of new geophysical methods and instruments to document salt-water intrusion in porous coastal aquifers. For this, one of the boreholes (MAG4) allowed the deployment of the first in-situ observatory of electrical resistivity. This observatory provides daily and m-scale downhole resistivity profiles. It allows following the vertical and temporal high-resolution evolution of the salinity of the fluids that saturate porous environment.

1.3 Borehole drilling and instrumentation

With SIMEx, the field objectives of MUSTANG are expanded to test the new electrical instruments designed by imaGeau for deep deployment in combination with a large number of surface and downhole arrays. While gas injection hole will be restricted to the reservoir located from about 12-16 m in MAG1, all new holes were drilled down from 20 m depth (MAG 6-9) and 50 m (MAG 5), and instrumented over their entire length *(Fig.2)*.

MAG5 and MAG6 were fully cored for lithological study and laboratory petrophysical analyses. Continuous geological samples (from MAG5 & MAG6) and geophysical data from shallow boreholes allow detailing geological knowledge at the site in order to prepare most relevant geophysical monitoring.

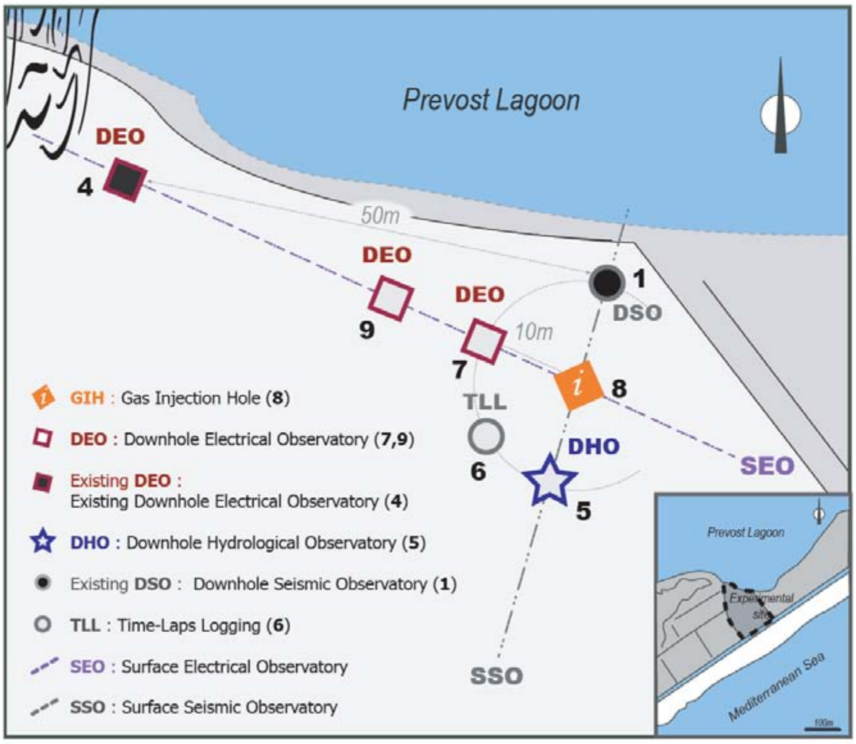


Figure 2. *Field spread at the Maguelone experimental site for the SIMEx-2010 integrated monitoring experiment. A set of 5 boreholes was added in 2010 to existing ones (MAG1, MAG4), with core taken in MAG5 and MAG6, and destructive hole for the other holes. Surface monitoring arrays was deployed in order to complement downhole approaches at larger scale.*

The new downhole field spread (*Figure 2*) includes, along with previously existing holes (MAG4 resistivity observatory and MAG1 PVC hole), a total of 7 nearby holes located within a maximum of 50 meters lateral distance from each other, as follows.

- **Existing DSO (MAG1)**: the first hole drilled and fully cored in 2003 to a depth of 60 m was equiped with a PVC liner down to 59 m, and with a slotted PVC liner from 59 to 63 m. In the new SIMEX spread, MAG1 is used to install a downhole seismic observatory in order to complete the overall geophysical strategy and study how different methods might be combined for a more efficient description of the saturation/desaturation process associated with gas injection in the conglomeratic reservoir.

- **Existing DEO (MAG4):** The first resistivity observatory prototype was constructed and set-up in June 2004 in a borehole (MAG4) located 50 m to the NW of MAG1. The observatory was equipped from surface to 41 m depth with permanent electrodes with a spacing of one meter.

- **New GIH (MAG8)**: an injection hole perforated over the 3 m along interval corresponding to the conglomeratic layer was firmly cemented above and below the target reservoir in order to allow for gas injection in the future. Prior to gas injection, this hole will be tested first with water in pumping and injection modes in 2011.

- **New TLL (MAG6)**: a single hole cased with thin PVC for rapid time-lapse logging measurements (whether electrical, sonic, neutron) dedicated to the calibration of timely continuous monitoring techniques during gas injection experiments (*Figures 8 & 9*).

- **New DHO (MAG5):** a downhole hydrodynamic observatory *(Figure 3)* based on a multi-packer completion from Schlumberger-WestBay (SWS).

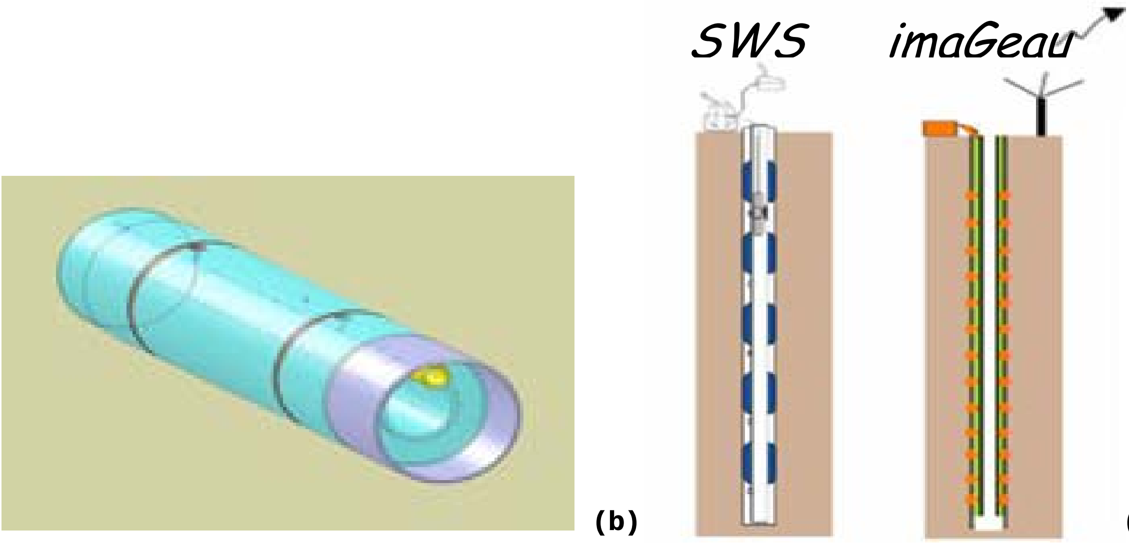
- **New DEO's (MAG7 & MAG9):** additional downhole electrical observatories (MAG7 & MAG9) will be drilled at respectively 10 m and 20 m from the injection hole (MAG8 or "GIH"). To the new "double cask" downhole technology developed by imaGeau as part of MUSTANG will be installed in MAG7. A second resistivity observatory, similar to that of MAG4 in design, was installed in MAG9 to allow for cross-hole and surface-to-hole tomography between the two holes. Both holes will be equipped down to 21 m with an array of electrodes with 35 cm spacing.

2. New sensor design and construction

The new "double cask" electrical observatory developed by imaGeau (*Figure 3*) and installed in MAG7 is designed to resist the aggressive conditions encountered in CO_2 underground storage, (using high grade, double shell PVC tubing with dedicated gold-plated electrodes), and pressure conditions down to 1500 m depth.

This new permanent instrumentation also allows:

- ✓ high resolution sampling rate (space) for detailed subsurface characterization,
- ✓ variable depth and length deployment for precise monitoring,
- ✓ high frequency sampling rate (time) for continuous description of subsurface flows,
- ✓ a petrophysical description of changes in pore structure and pore fluid content from electrical resistivity probing.



(a) (b) (c)

Figure 3. *Downhole observatories. From left to right: (a) 3D view of double cask completion of downhole electrical observatory by imaGeau; (b) downhole hydrodynamic observatory based on a multipacker completion from WestBay (provided by SWS); (c) downhole electrical observatory (provided by imaGeau).*

The sonde to be deployed early in 2011 has been designed by imaGeau based on a single well strategy suited to monitor condensate injection and storage in reservoirs down to 1.5 km depth with :

1) a double cask PVC completion including (*Figure 3*):
   - high pressure resistance
   - possibility of gas injection through the inner pipe
   - downhole logging through the inner pipe

2) a new bus and protocole for downhole communications to 1500 m

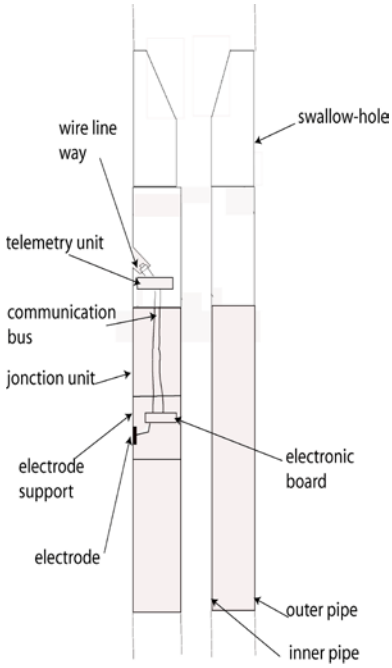


Figure 4. *General design of the downhole electrical apparatus.*

3) an miniature electronic design (electrode support and jonction module)
   - Fitting of electronic board and communication bus

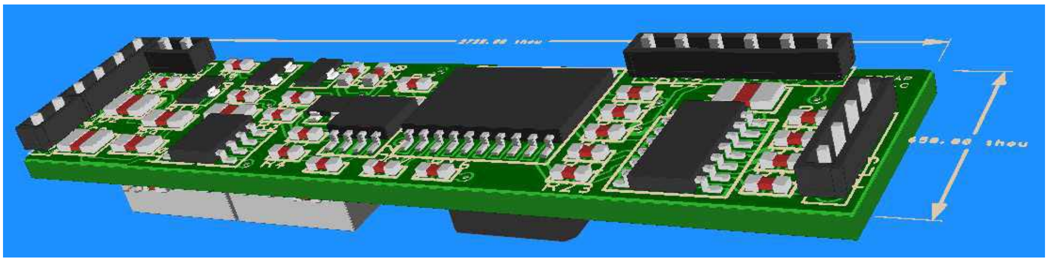


Figure 5. *Electronic board design for each electrode.*

   - Electrical contact, mechanical contact, resistance and waterproofness (*Figure 6*)

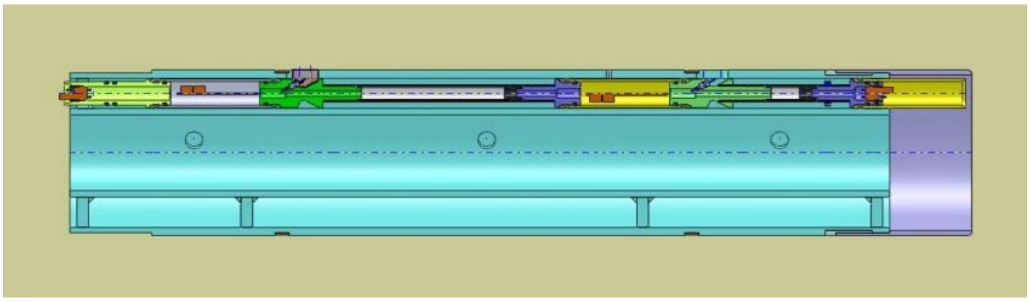


Figure 6. *View of downhole bus electronic fitting in the double cask shell.*

The design of the double cask PVC completion for the electrical apparatus was achieved by mid 2010.

The building of mechanical and electronic parts was achieved by the end of 2010, and the tests (on desk) of electronic modules are in progress.

Figure 7. *View of a double cask PVC section and the assembled electronic bus to be fitted between the inner and the outer shell.*

3. Discussion

The objective is to deploy and test the new instrument as part of SIMEx by mid-2011 in order to demonstrate, in the long run, that geoelectrical monitoring is an accurate and efficient method in term of cost and reliability for CO_2 storage monitoring over long periods of time.

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