On going investigations to design the monitoring program for a CO_2 storage project in the Paris Basin (France)

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Introduction

In the framework of the PICOREF project of CO_2 storage in the Paris Basin (France), a specific project, untitled Géocarbone-Monitoring, is being carried out since 2006 to evaluate and test the different monitoring methods that could be applied to this specific geological context. The targeted reservoirs are either depleted reservoirs in the carbonate Dogger formation (depths ranging from 1500 down to 1800 m depth) or saline aquifers in the silico-clastic formations of the Trias (depths ranging from 2000 down to 2500 m depth). The main objectives of Géocarbone-Monitoring are: 1) to evaluate which methods would be able to detect and image the CO_2 plume; and 2) to detect CO_2 leakages from the reservoir up to the surface. Two approaches are used: simulations studies and field studies at real scale, either on seasonal gas storages or on natural analogues. Development of specific tools is also planned, for example for gas sampling in wells.

Simulation and development of tools

The ability of geophysical methods to detect CO_2 in the storage formation is first tested using simulation tools. Respect to active seismic, a synthetic 2-D petroacoustic model of a depleted oil reservoir was established at first, using the existing information of well logs from a small oil field located in the Southwest part of the Paris Basin. Then, in order to simulate the injection of CO_2 along time, the seismic response of different saturations and partial pressures of CO_2 was calculated with the Gassmann Herz-Midlin model and using ray shooting from the surface. First results indicate that an increase in Dt (Difference in transit time) up to 0.45 ms, is expected and can allow to measure the gas height in the reservoir. This results from a decrease in Vp velocity due to the difference of compressibility between the injected CO_2 and the pre-existing fluid. The CO_2 injection rate must be slow enough to do not change significantly the stress conditions in the reservoir, and consequently the CO_2 height estimation remains unbiased. Since the fracturation of the formation was not taken into account, this effect was underestimated. The expected average variations of amplitude, ca. 4-6 %, are below the usual detection threshold of time lapse 2D seismic. The largest variations (> 15 %) are due to karstified levels which thickness is close to the tunning. The variations of amplitude are more explained by the vertical distribution of porosity at different levels in the reservoirs than by the injected volume of gas. Figure 1 shows the effect of gas saturation on amplitudes. Taking into account fracturation, as well as improved data processing, could help to better characterize amplitude variations below the noise level.

Application of electrical resistivity methods to CO_2 detection is based on the contrast of resistivity between the resistive supercritical CO_2 and the conductive saline fluid originally in the formation. Difficulties arise from the depth and the thinness of the storage formation. Modelling shows that injecting an alternative current directly into the deep conductive layers via a pair of metallic casings (used as long electrodes) could improve the signal to noise ratio with a factor 10, respect to standard measurement at the surface (Fig. 2). Standard measurements of the electric and magnetic fields at the ground surface (in a similar way to electric potential measured with standard “point” electrodes) will preserve a high horizontal resolution and a normal vertical resolution. Using a more realistic 1 D geoelectrical model will allow to refine this new method in order to precise distance between wells and the characteristics of the experiment.

Tools to CO_2 sampling in the overlying aquifers are under development and being tested in different contexts, down to 1000 m depth. Simulation of leakage (i.e. injection of. 3 cm^3 during 3 min at 200 m depth) showed that very low quantities of CO_2 can be detected. Regarding surface measurements, an accumulation chamber was adapted to measure very low fluxes (< 0,05 $cm^3/min/m^2$).

Testing methods on natural analogues or gas storage sites

In Géocarbone-monitoring, geochemical methods are focused on soil gas and atmospheric measurements, since the quantification of CO_2 at the surface will be of primarily importance for the health, safety and environment (HSE) and verification matters. Leakage towards neighbouring aquifers can occur by dissolution and transport of CO_2-charged waters by groundwater flow. Leakage through abandoned wells can be induced by chemical or physical alteration of casing and plugs. Four partners of the project have compared their different tools and methods at two analogues sites located in France: the natural CO_2 reservoir of Montmiral, exploited since 1990, and Sainte Marguerite, located in a volcano-sedimentary area. Montmiral site is constituted by a natural reservoir of gas with more than 97 mole% of CO_2 located in the Triassic rock formation at 2500m depth. The reservoir is considered to be closed since a long time with no gas leakage towards the atmosphere. At the opposite, the Ste Marguerite site is marked by numerous spots of gas emission along the Allier River. CO_2 emissions come from the granitic basement at the limit with the Tertiary limestones and dolostones. Two kinds of experiments were considered:
1) in the case of Montmiral: continuous measurements of CO_2 at a single point with FTIR spectrometers close to the extracting well at 1.5 m depth and in the atmosphere (Pironon et al., 2006); and 2) soil gas analysis of different gases (CO_2, CH_4, O_2, Rn, He) on a spatial grid, aiming at mapping spatial variations. First surveys show similarities between the different tools, but variability in time and space measurements needs still to be inferred by new surveys. Figure 3 shows a map of CO_2 concentrations measured around the site of Montmiral. Sampling points where concentrations are higher than 1 % are located along known faults or lineaments (mainly NS).

Time-lapse gravity is currently being tested at Sleipner (Nooner et al., 2006). Feasibility of time-lapse gravity in the Paris Basin was evaluated performing repetitive measurements at a seasonal gas storage site, primarily to quantify the influence of shallow effects, e.g. the variation of the water table level and soil moisture. Two quasi parallel lines of 19 stations each and crossing the gas storage geological structure have already been measured twice. First repetition of measurements with a 10 µgal precision shows differences ranging from -40 to 25 µGal. No clear correlations are observed with gas storage extension but possible hydrological effects were not yet analysed.

The InSAR remote sensing method (Interferometry with Synthetic Radar Aperture) could be useful to detect ground deformation linked to geomechanical changes in the reservoir. Nevertheless such deformations should be expected after a period of injection of many years, it is interesting to evaluate the sensibility of this method. It was tested on the same gas storage site used for gravity monitoring during the period July 1995-March 1997. No significant changes were observed during this period for couples of images acquired with temporal baselines of more than 70 days and within the precision range of the method (ca. 1 cm). As the test site is located in a vegetated area, the interferograms were not coherent enough to conclude in many cases. In order to overcome this difficulty and to increase the precision, further processing using the Permanent Scatterers (PS) method will be intended.

Between now and the end of the project (end of 2007), repetitions will be carried out regarding gravity, soil and atmospheric gas measurements as well as improvements in the different geophysical simulations, i.e. seismic and electrical resistivity imaging. An airborne hyperspectral survey is also forecast at Mon,tmiral and Sainte Marguerite site in order to detect changes in the vegetation linked to potential CO_2 leakages. At the end of the project, the different results and acquired experiences will be integrated in a best practice guide dedicated to monitoring of CO_2 storage in the Paris basin. A monitoring program will be also designed, taking into account the results and conclusions from the other Géocarbone projects dedicated to site characterisation, injectivity of the reservoir, integrity of both wells and cap rock and risk assessment.

Acknowledgements

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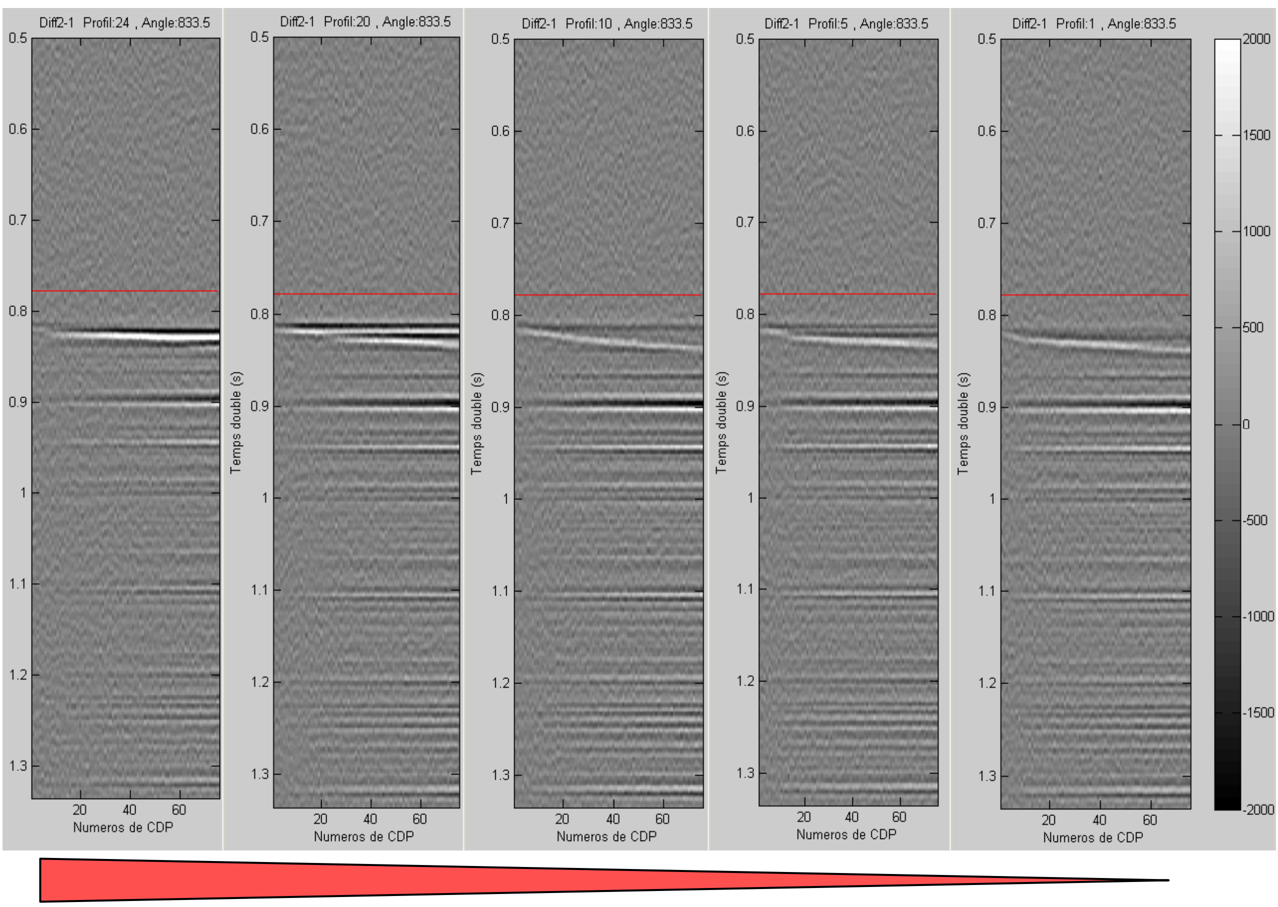

Figure 1: Variations of the amplitude for different CO2 concentrations. The largest variations are observed on the left side, where contrasts of saturation are the most important, mainly due to karstified levels. In red: variations of the product porosity (Phi) by gas saturation, Sg.

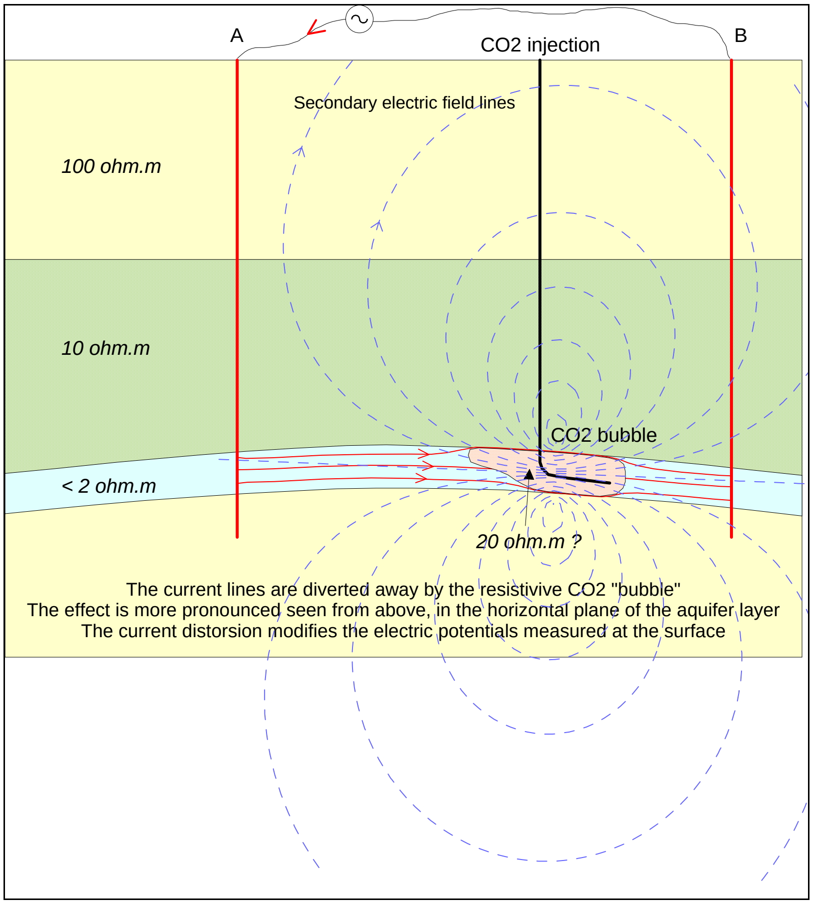

Figure 2: Field layout of the "Long electrode Mise à la masse" experiment

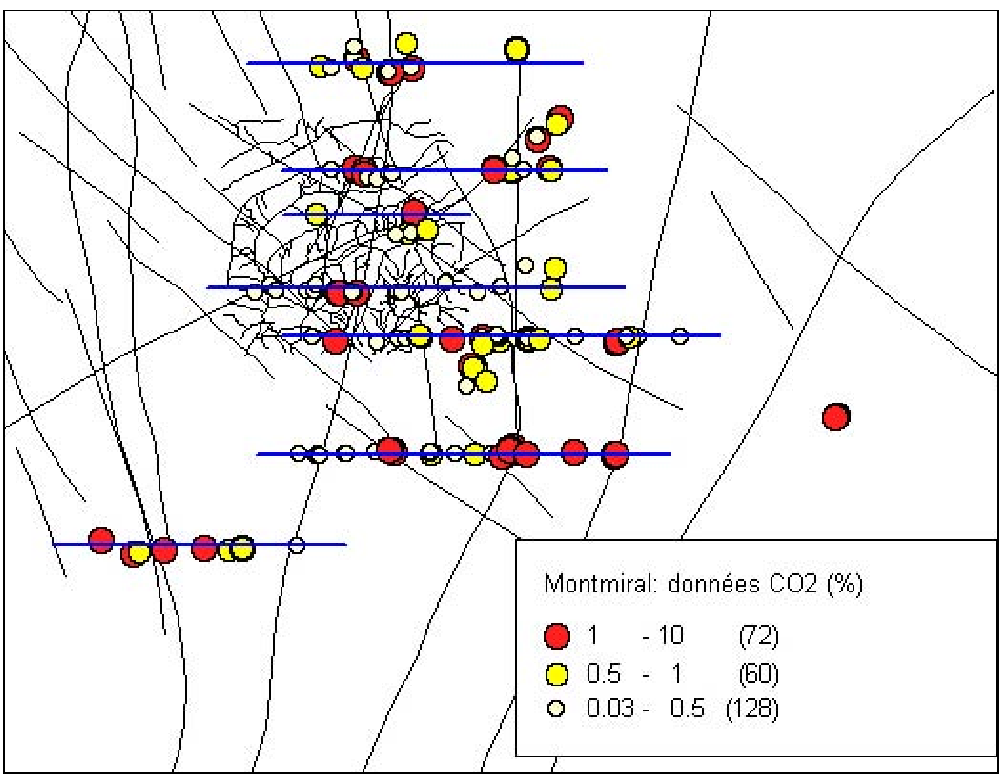

Figure 3: Map of CO_2 concentrations around the Montmiral site. Lines indicate known faults and lineaments determined by remote sensing.