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On-going and future research at the Sulcis site in Sardinia, Italy – characterization and experimentation at a possible future CCS pilot

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Abstract

National Italian funding has recently been allocated for the construction of a 350 MWe coal-fired power plant / CCS demonstration plant in the Sulcis area of SW Sardinia, Italy. In addition, the recently approved EC-funded ENOS project (ENabling Onshore CO_2 Storage in Europe) will use the Sulcis site as one of its main field research laboratories. Site characterization is already ongoing, and work has begun to design gas injection experiments at 100-200 m depth in a fault. This article gives an overview of results to date and plans for the future from the Sapienza University of Rome research group.

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Keywords: gas injection experiment; monitoring; baseline; Sulcis; ENOS; fault; migration; groundwater; soil gas.

1. Introduction

The Eocene Sulcis Coal Basin, located in the south-western corner of the Island of Sardinia (Italy), hosts extensive sub-bituminous coal deposits that cover an area of approximately 800 km^2 and have estimated reserves of 1.2 billion tons. To continue the use of this resource in an environmentally friendly way, an Italian law was recently

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passed (law No. 9 of 21 February 2014) that will subsidize the construction of a 350 MWe coal-fired power plant / CCS demonstration plant in the Sulcis area, with the eventual injection of the recovered CO_2 into a >1000 m deep saline carbonate aquifer beneath the coal formation. Within this framework a three-year research program has been funded by the Region of Sardinia and the Italian Ministry of Economic Development to collect data and information that will lead to the design and construction of the CCS pilot plant, covering the entire geological storage cycle under "real life" conditions. This will include site characterization, baseline monitoring, medium depth injection tests, and the eventual creation of a pilot site. The total national funding for this first phase is on the order of 3-4 million Euros, with a planned subsequent 10-year R&D program worth 30 M€.

In addition, the European Community has recently approved ENOS (ENabling Onshore CO_2 Storage in Europe), a 4 year, 12.5 M€, Horizon 2020 project involving 21 partners from 17 European countries. As alluded to in its name, the project aims to contribute to the creation of a favorable environment for onshore storage across Europe and to develop, test and demonstrate in the field various key technologies specifically adapted to onshore contexts. Much of the proposed work will revolve around three field laboratories where CO_2 will be injected at different depths in the subsurface (Hontomin, Spain; GeoEnergy Test Bed, UK; Sulcis, Italy). These experiments will be conducted to better understand sub-surface flow and migration, test monitoring technologies, and conduct out-reach activities with the local populations. Work within ENOS at the Italian site will consist of gas injection tests and monitoring at the Sulcis Fault Lab (SFL). The SFL will consist of injection and monitoring infrastructure created with the national funding described above, thereby leveraging research funds from different sources to maximize the amount of quality data possible. Research will focus on gas migration and leakage along faults, geological and fluid flow modelling, as well as the testing of state-of-the-art monitoring tools.

The present article describes the on-going and planned work being performed at the Sulcis site by the CERI research institute and the Department of Earth Sciences at the Università di Roma “La Sapienza” (Rome, Italy), collectively referred to here by its acronym in the ENOS project - UniRoma1.

2. Site description

The study site is located in the coastal region of south-western Sardinia, Italy, within an area where permission has been granted to conduct CCS-related research (Figure 1a). Surface geology is dominated by 1-200 m of Pleistocene and Holocene marine, lacustrine, fluvial, and alluvial unconsolidated sediments, with surrounding hills and topographic highs being formed by rhyolitic flow and fall pyroclastic rocks. The sub-surface geology is quite well defined in the northern part of the Sulcis basin due to coal mining activities, whereas it is less certain to the south. Research is being conducted by the consortium to improve our understanding of this area.

The oldest stratigraphic unit in the area (Figure 1b) is Paleozoic in age, consisting of metamorphosed sediments and volcanics as well as granitoids related to the Hercynian orogeny [1,2]. These are locally overlain by Permian-Carboniferous terrigenous and volcanic complexes and Mesozoic sediments and carbonates. The Early Eocene Miliolitico Fm is next in the succession [3]. This carbonate unit, proposed as the CO_2 injection reservoir, is about 30-40 m thick and consists of wackestones and grainstones that grade upwards to increased intervals of carbonate mud. In addition to limited primary porosity this formation has extensive secondary fracturing and paleo-karstic features that contribute to its overall storage capacity. The cap-rock above the proposed reservoir consists of three formations. First, the 30-70m thick Produttivo Fm consists of interbedded sequences of siliciclastic sediments, marly limestones / lagoon marls, and lignite coal deposits [4], and it is this interval that is locally mined. An unconformity separates the Produttivo Fm from the overlying Cixerri Fm, which is a 210-320 m thick mollase succession of silts and sands with lesser conglomerates deposited in an alluvial plain setting [5]. Collision of the Corsica block with the northwestern Adria margin at the end of the Balearic stage [1] subsequently resulted in the unconformable deposition of predominantly dacitic to rhyolitic pyroclastic fall and flow deposits during the Oligocene to Miocene. These volcanic rocks, which reach up to 900 m in thickness, form the uplands seen in the surface geology map (Figure 1a). The final units in the local stratigraphic sequence consist of Pleistocene alluvial gravels, sands and aeolian sandstones as well as Holocene lacustrine and alluvial deposits, in which near-surface aquifers are located.

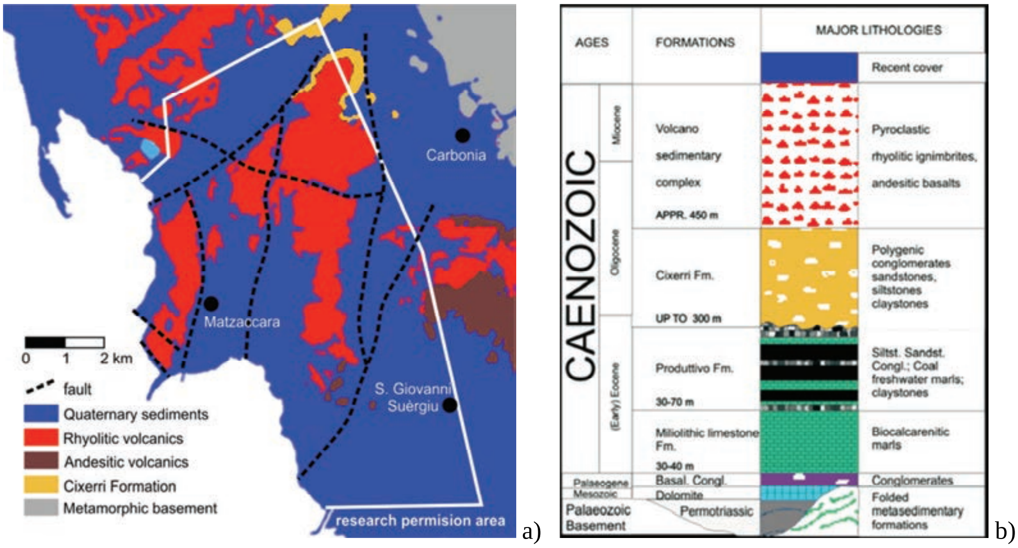


Figure 1. a) Simplified geological map of the area. b) Stratigraphic sequence of the Sulcis area (after [6]).

The southern sector of the Sulcis basin is tilted southwestward, such that the Produttivo Fm outcrops to the east and dips progressively westward. This large monocline is predominantly affected by high angle normal faults, mainly linked with Miocene extension, which generated a series of tilted blocks within half-grabens. The NE-trending Monte Ulmus Fault and the E-W trending Paringianu Fault are present in the northern portion of the basin, whereas the E-W trending, buried, normal Conca de Monserrato Fault separates the southern and northern sectors with an offset of hundreds of meters. In the southern sector seismic lines and well log analysis also identified the important N-S trending Serbariu-Sirai Fault, which bounds the Sulcis basin to the east and separates this area from those areas in the vicinity of the towns of Carbonia and S. Giovanni Suèrgiu. In the central part of the research permission area the main tectonic feature consists of the buried Matzaccara half-graben, located to the west of the village of Matzaccara. Here a N-S trending normal fault system offsets the substratum by a few hundred meters and clearly controls the thickness of Quaternary deposits. These normal faults, which were probably active during the Quaternary and can be considered as the youngest features of the area, will be the focus of the SFL and associated injection tests.

3. Site characterization and baseline monitoring

Although we performed an initial reconnaissance gas geochemistry survey in the Sulcis area in 2009 [7], our work related specifically to baseline monitoring and site characterization for the planned pilot began in 2014. Results show the potential of the proposed site. A brief summary of the goals and results of this research is given below.

3.1. Fault analysis and fracture modelling

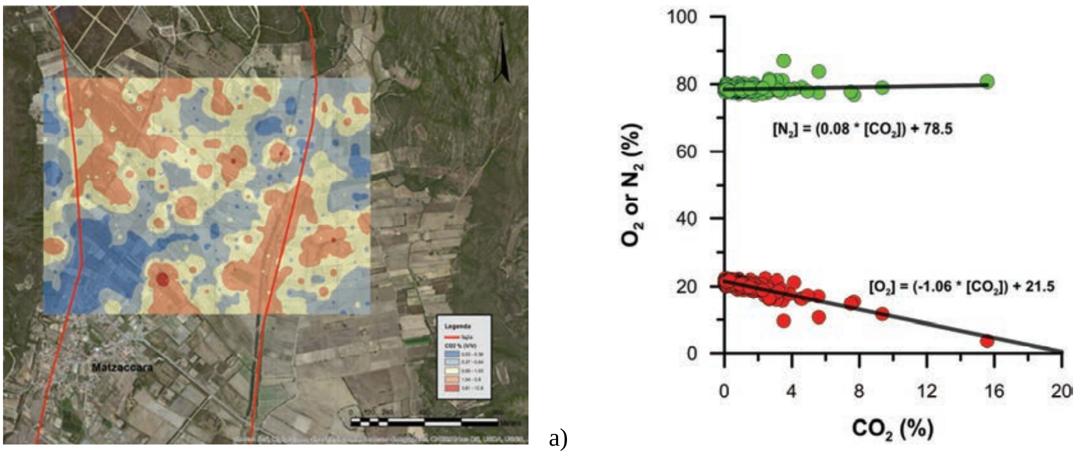
Structural analyses were performed for two main purposes: i) to estimate the storage potential of the proposed reservoir (i.e., the Miliolitico Fm, plus the underlying Mesozoic and Palaeozoic carbonates); and ii) to evaluate the potential for leakage through the caprock sequences (i.e., the Cixerri and overlying volcanic successions). Given the low primary porosity in the reservoir and the low K_V of the overlying stratified caprock, storage capacity and leakage potential will both be strongly influenced by the presence of fracture networks and, more importantly, their geometric characteristics (fracture density, lengths, apertures and inter-connectivity). To obtain the required fracture data, scanline and scan area surveys [8,9] were conducted on 30 surface outcrops close to the proposed pilot location in the south of the study area as well as at 400 m depth on 5 measurement sites in the Mt Sinni coal mine in the north. These data have been modelled using the software package Move 2015 (Midland Valley) to reconstruct the fracture patterns, estimate total porosity, and assess fluid flow.

Regarding the study of the reservoir, several Discrete Fracture Network (DFN) models were generated to calibrate and scale the field results, with the surface data being modelled using a representative volume of the reservoir while the coal mine data were modelled using an equivalent volume of the mine gallery. The porosity values obtained from the DFN models generated from both the outcrop and the mine data are comparable, ranging from 3 to 5%. An assessment of the caprock permeability is being conducted, however preliminary results show that fault zone architecture does not appear to be controlled by lithology and that many faults have well-developed damage zones which could potentially act as fluid migration pathways in the shallow crustal levels. Research is on-going to confirm these results (including the gas injection tests into a fault described below) and to assess potential risk levels.

3.2. Near surface gas geochemistry surveys

Near surface gas geochemistry involves the measurement of gas concentrations in the unsaturated zone and flux of gases across the soil-atmosphere boundary. For the present work soil gas was collected with a 6 mm steel tube installed at a depth of 50 to 80 cm, with the collected samples analyzed in the field for CO_2, H_2, and H_2S and in the laboratory for CO_2, O_2+Ar, N_2, light hydrocarbons, and helium. CO_2 flux was measured using the accumulation chamber technique. Two field campaigns have been conducted in the area near Matzaccara since the start of this new research phase, one each in the summers of 2014 and 2015.

In 2014 a total of 423 samples were collected along 6 transects (2 km-long and 0.5 wide) in the Carbonia valley and 3 E-W oriented profiles in the Quaternary graben in the southern sector of the basin. The average CO_2 concentration was 1.8% while the maximum value was 8.4%. The second survey in 2015 was conducted in the general area where it is hoped that the Sulcis Fault Lab will be constructed, that being on the western side of the Matzaccara graben. Over 600 samples were collected during this high density survey (180 samples km^{-2}), conducted to define the baseline in this specific area and to better localize the spatial distribution of any anomalies. The average CO_2 value was 1.2%, however tens of samples had concentrations greater than 4%. Although there are aligned anomalies that appear to lie along at least one mapped fault (Figure 2a), a graph of CO_2 versus O_2 and N_2 values (Figure 2b) indicate a biogenic origin [10,11]. This interpretation is supported by $\delta^{13}C$-CO_2 values of -17 and -21‰ from two soil gas samples collected in this area in the summer of 2016. The concentrations of other gas species (light hydrocarbons and helium) were generally very low, similar to atmospheric values, although a few samples had CH_4 concentrations up to 40 ppm.



b)

Figure 2. a) Contour map of soil gas CO_2 measured during the summer of 2015. b) Plot of soil gas CO_2 versus O_2+Ar and N_2, showing a clear biogenic respiration trend.

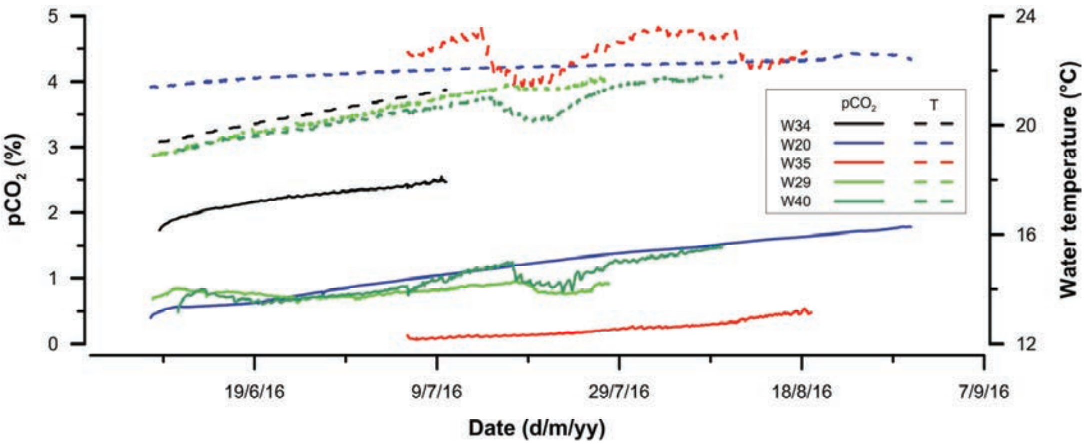


Figure 3. Temperature and pCO_2 values measured in five shallow wells in the Sulcis study area over three months during the summer of 2016 using GasPro sensors.

3.3. Continuous monitoring of groundwater temperature and pCO_2

Up to 15 GasPro pCO_2 / temperature sensors [12] have been deployed for varying periods in numerous groundwater wells distributed throughout the study area. These wells can generally be divided into two main types: i) shallow (5-10m), hand-dug, wide diameter (up to 2m) wells that access the unconfined aquifer in the Quaternary sediments of the coastal plains; and ii) deep (up to 100m), modern, cased and screened boreholes that tend to be located in the uplands and access confined aquifers in volcanic or carbonate rocks. One of the main findings thus far of this baseline temporal monitoring is the distinctly different behaviors of temperature and pCO_2 in these two well types, with the shallow wells showing clear seasonally-related trends while the deep wells do not. For example, data from five wells over the summer months of 2016 (Figure 3) show a clear increase in temperature that is matched by a similar pCO_2 trend. Such a relationship is likely linked to microbial respiration, possibly in semi-stagnant water within the large-volume excavations (which are used for irrigation). Although such wells may not be totally representative of the surrounding groundwater, they do represent a potential site that could be sampled during injection, also by third-parties, and thus if natural variability is not determined beforehand there is the possibility that any anomalies related to near-surface biological processes could be misinterpreted.

4. Planned gas injection experiment

Although faults are widely quoted as being a potential leakage pathway, the difficulty of working in such environments has meant that most, if not all, previous injection tests have been performed in porous media. To address this lack of data, the creation of the Sulcis Fault Lab (SFL) was proposed to provide the infrastructure necessary for the injection of CO_2 into a fault at a depth of between 100-200 m. As stated above, the SFL will be constructed using national funds while the actual initial gas injection tests will be performed within the ENOS project. This field laboratory will consist of a 100-200m deep inclined injection borehole that terminates in faulted sediments, two deep monitoring wells on either side of the fault, and 5-15 shallow observation wells. Total CO_2 injection rates and amounts will be decided in the near future based on modelling results and logistical constraints. An overview of the research to be conducted at the SFL by UniRoma1 is given below.

Vadose zone and surface gas geochemistry measurements will consist of both intermittent surveys and continuous monitoring. The surveys will involve soil gas sampling at a depth of 60-80 cm on a regular grid over the injection point with field analysis of CO_2 and O_2 as well as selective laboratory analyses for light hydrocarbons, helium, and carbon isotopes of CO_2 and CH_4; CO_2 flux will also be measured at the same time and locations. In addition, a new tool originally proposed and developed by UniRoma1 [13,14], which measures the concentration of CO_2 at the boundary layer between the soil and the atmosphere where limited wind mixing can allow for accumulation of soilreleased gases, will be used for high resolution and rapid mapping and monitoring. Continuous monitoring will instead be conducted with the deployment of a large number of GasPro sensors at a depth of about 50cm in the unsaturated zone. These sensors, developed by UniRoma1 and tested in individual deployments in the soil [7,11] and multiple, spatial deployments in seawater [12] will allow for real-time measurement of soil CO_2, both for defining the spatial / temporal variability of the baseline as well as for leakage monitoring.

Similarly, groundwater monitoring will also involve both intermittent and continuous monitoring. Existing wells and purpose built observation piezometers will be sampled for dissolved gases and for major and trace elements to determine if there is any impact on shallow groundwater quality. This data, combined with mineralogical and bulk-rock chemistry of core samples, will be used for geochemical modelling. Newly developed UniRoma1 probes will also be deployed in select wells to continuously monitor pCO_2, T, P, conductivity, and Eh.

Data from the SFL injection tests will be modelled using dedicated software to determine such parameters as flow rates, migration pathways, and potential changes to the pre-injection stress field.

Acknowledgements

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