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Preliminary results of geological characterization and geochemical monitoring of Sulcis Basin (Sardinia), as a potential CCS site.

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Abstract

The Sulcis Basin is an area situated in SW Sardinia (Italy) and is a potential site for the development of CCS in Italy. This paper illustrates the preliminary results of geological characterization of fractured carbonate reservoir (Miliolitico Fm.) and the sealing sequence, composed by clay, marl and volcanic rocks, with a total thickness of more than 900 m. To characterize the reservoir-caprock system an extensive structural-geological survey at the outcrop was conducted. It was also performed a study of the geochemical monitoring, to define the baseline conditions, measuring CO_2 concentrations and flux in the study site.

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Keywords: CCS; Fractured carbonate reservoir; geochemical baseline; site characterization; monitoring; modelling

1. Introduction

The permanent storage of anthropogenic CO_2 in deep geological reservoirs, known as Carbon Capture and Storage (CCS), has been studied since the 1990’s as a bridging technology that will allow the continued use of hydrocarbon fuels while giving mankind the time needed to improve the technology and reduce the costs of renewable energy. To

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attain this goal extensive research has been conducted over the last 20 years on increasingly complex and larger-scale processes, as well as more sophisticated monitoring techniques, to assess the feasibility and safety of the approach. At the present day, in the European countries carbon dioxide storage has been tested in several sites at pilot, demo and industrial scale. In most of these sites, the reservoirs are sandstones, with high porosity and permeability. However, fractured carbonate reservoirs are considered among the potential long-term storage sites and are particularly interesting for the south of Europe, where most of the stratigraphy is composed by carbonate rocks. In Italy, one of these potential sites is located in Sardinia, in the sub-region named Sulcis. The Sulcis coal basin is located in South-West Sardinia and it is the only region of Italy where the exploitation of coal is active since the last century. Thanks to data available from several national and international project, as well as from the mining activities, it has been possible to recognize a potential reservoir-caprock system, suitable for CCS purpose.

In this work, we present the preliminary results of the geological characterization, consisting of structural analysis and fracture modelling of the reservoir, and the characterization of the geochemical baseline.

2. Geological setting

The studied area is an alluvial plain near the little town of Matzaccara, which is bordered by volcanic hills (Fig. 1). Here, it is possible to recognize the entire succession, from the Paleozoic basement to the Quaternary deposits. The Hercynian basement is made of low grade metamorphic rocks (sandstones and carbonate rocks, Cambrian to Carboniferous) and large volumes of granitoids relating to the Hercynian orogeny [1, 2]. The basement is covered by Permo-Carboniferous terrigenous and volcanic complexes and by a Triassic succession in Germanic facies [3]. These sequences are covered by Mesozoic carbonates. The Paleogene rocks consists of a transgressive-regressive sedimentary cycle [4] represented by: i) macro foraminifera limestone; ii) carbonate wackestone and mudstone with an oligotypical miliolid fauna (50-60 m thick), belonging to the Miliolitico Formation; iii) a rhythmic succession of siliciclastic to carbonate deposits with interbedded lignite (Produttivo complex) [5]; iv) a thick succession of siltones, sandstone and conglomerates [6, 7, 8], (Cixerri Fm) [9]. A thick (up to 900 m) volcanic sequence (Oligo-Miocene Volcanism) covers in unconformity the Cixerri Formation, ranging from basaltic to riolitic composition. The Pliocene-Quaternary sequence, over the Miocene volcanic rocks, consists of continental and marine sediments.

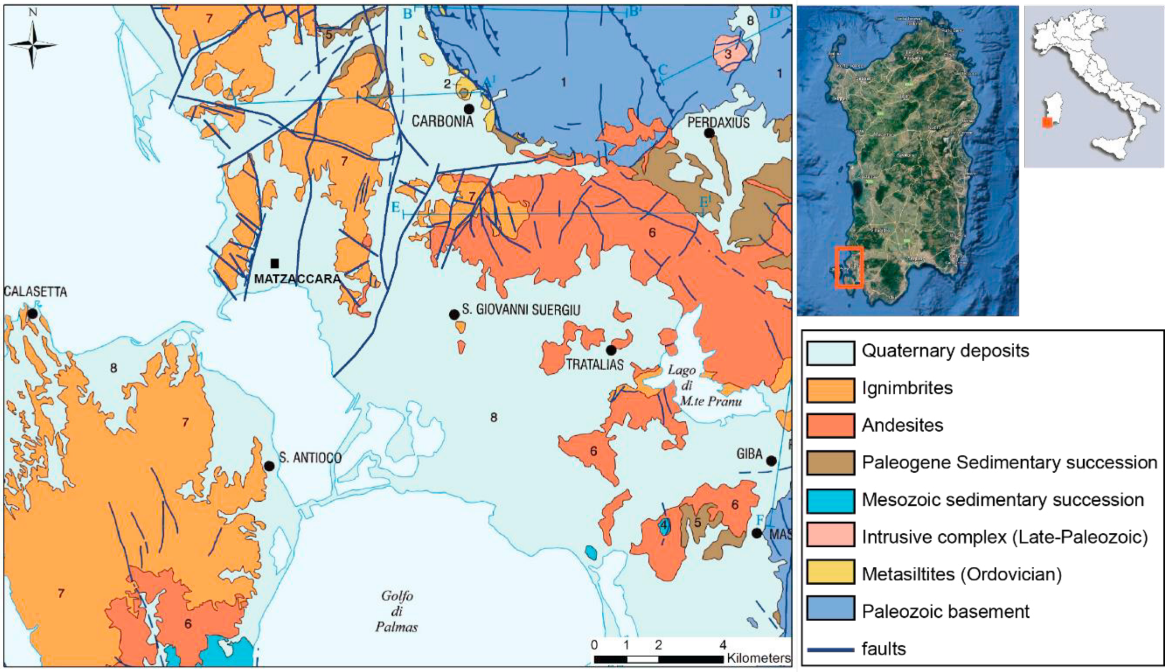

Fig. 1. Geological map of the Southern part of Sulcis Basin; The study area is near Matzaccara (modified after ISPRA, F°564 – Carbonia).

This complex stratigraphic setting is dissected by E-W, N-S and NE-SW normal faults generated during the Miocene extensional phases.

For geological storage purposes, the fractured carbonate of Miliolitico Fm as well as the underlying Cretaceous carbonates has been identified as a potential reservoir. As caprock, the thick sequence of sedimentary (Cixerri Fm) and volcanic rocks provide a reliable seal succession.

3. Geological characterization

The main objective of the site characterization is to provide the geological information required for identify the principal features of a site, such as storage capacity, injectivity, containment, trapping mechanisms [10].

In order to better define the reservoir - caprock system and its petrophysical properties, a revision of the superficial geological data and a structural analysis of the outcropping structure were completed, along with a detailed fracture analysis of the formation at the outcrop. Moreover the geological model of the area (Fig. 2) was built using data from literature, the geological survey as well as geoelectrical and seismic profiles (Sotacarbo, confidential data); the main faults and horizons were modelled in 3D using the software Move 2017 (*Midland Valley*).

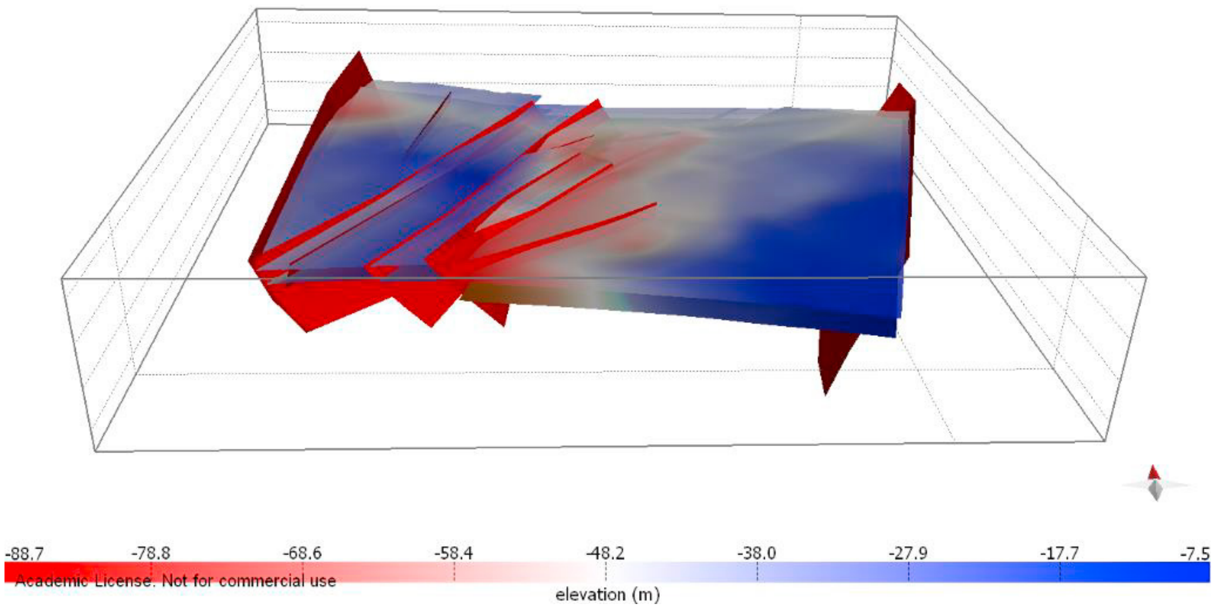

Fig. 2. Geological model of the Matzaccara valley, in the Sulcis Basin; the upper surface represents the top of Miocene volcanic complex, and the sub-vertical red surfaces are the interpreted principal normal faults.

As the carbonates of the Miliolitico Fm. have a low primary porosity and permeability (5% and <0.1 mD [11]), the potential reservoir is an heterogeneous system, composed by a dual porosity/ dual permeability system, represented by matrix and fracture network [12].

In order to study the geometry and the parameters of fracture network, we performed an extensive field work at the outcropping analogues rocks of the reservoir, using the scan lines and scan areas techniques [13 and reference therein]. The collected fracture parameters were orientation, length, aperture, spacing and type of termination of fractures. This kind of analysis were performed on the carbonate formations (Miliolitico, Mesozoic and Paleozoic carbonates) and allow to determine fracture spacing (along scan lines) and areal density (e.g. number of fracture or trace length sum per areal unit). The structural data was used as input to build a Discrete Fracture Network (DFN) model, which is used to calculate the secondary permeability and porosity due to the fracturing; we used a representative volume of the reservoir. Several DFN were calculated using Move 2017, by varying the length and the aperture of the fractures. The estimated porosity available is only through secondary porosity and ranges between 3-5%. A localized increment of average porosity occurs only in proximity of the main faults, which show a conduit behavior [14].

4. Geochemical baseline

The monitoring of the integrity of onshore geological carbon capture and storage sites requires the integration of various methods with different spatial and temporal resolutions. One method proven to be quite effective for site assessment, leakage monitoring, and leakage verification is near-surface gas geochemistry, which includes soil gas concentration and gas flux measurements. Anomalous concentrations or fluxes, relative to the natural background values, can indicate the potential occurrence of a leak. However, the natural background can be quite variable, especially for CO_2, due to biological production and accumulation in the soil that changes as a function of soil type, land use, geology, temperature, water content, and various other parameters [15].

Baseline surveys, which measure the natural background concentration and flux values at a proposed CCS site prior to injection, have been proposed to help interpret monitoring results by defining the natural spatial and temporal variability of a site and the range of values that can typically be associated with local near-surface processes [16, 17, 18]. A robust determination of baseline is particularly important for geological carbon storage to help distinguish potential leakage of the injected CO_2.

In the study area, both discontinuous and continuous monitoring is ongoing. More in details, discontinuous soil gas surveys have been performed three times during the last 8 years (2009, 2014 and 2015) at regional and local scale, measuring the concentrations of different gases (such as, CO_2, hydrocarbon C1-C6, helium, oxygen, nitrogen) and the CO_2 flux. The soil gas sample is collected at about 0.4 – 1 m depth, according to the different kind of soil, using a steel probe of about 150 cm long, with a diameter of 4 mm (Fig. 3a). The depth is also influenced by the occurrence of water in the soil, but usually is not less than 60 cm, to avoid the contamination of atmospheric air [19].

Fig. 3. a) sampling of soil gas using a steel probe and a syringe; b) map of CO_2 concentration of the high resolution soil gas survey in the Matzaccara valley.

In the Matzaccara valley, a specific soil gas survey has been performed using a high sampling density (Fig. 3b). The soil gas concentrations are generally rather low, also due to the type of soils. The analysis of the associations of gases (mainly CO_2 and CH_4) has identified a very small area near Matzaccara where the concentrations of both gases are anomalous. These could be linked to a strong biological activity associated with an endogenous contribution. This hypothesis is not supported by helium data, however, whose concentrations are similar to atmospheric values. Nevertheless, a geostatistical analysis has highlighted the presence of anomalous concentrations aligned mostly along the two major faults.

The continuous monitoring has the aims to define the variation of CO_2 concentration in the aquifers with respect to seasons and/or other natural or anthropogenic factors, and, in this way to complete the definition of the baseline of the area. The GasPro-pCO2 Monitoring Probe (Fig. 4) is designed to measure, together with temperature and pressure, the concentration of dissolved CO_2 in ground water [20].

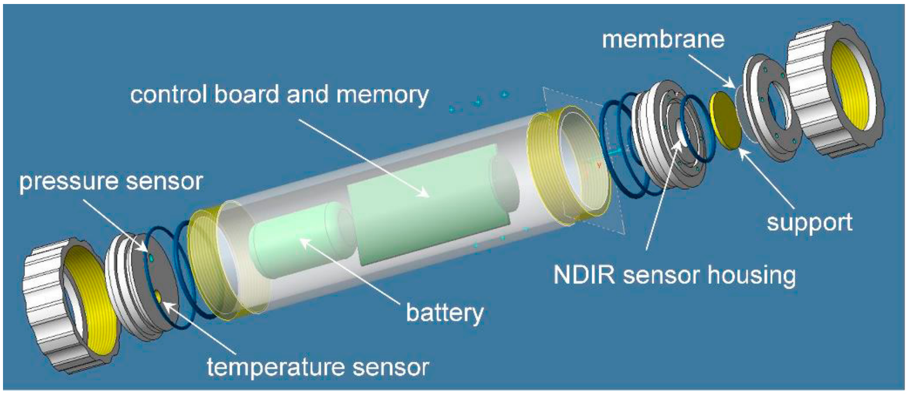

Fig. 4. Schematic drawing of the GasPro probe (from [20]).

A total of 11 GasPro-pCO_2 probes were deployed in both shallow and deep wells to monitor the fluctuation of dissolved gas concentrations. The wells in which the GasPro continuous monitoring probes were installed can be subdivided into two main types: i) shallow, hand-dug wells near the coast that occur in Holocene sediments and access a shallow, unconfined aquifer; and ii) deeper, modern boreholes located inland at higher elevations and drilled into Miocene volcanic rocks.

Regarding the shallow wells (Fig. 5a), water temperature and pCO_2 increase in all locations over the monitoring period. The overall trends and similar behaviours of these parameters imply significant influence of insolation and surface heating during the hot summer months.

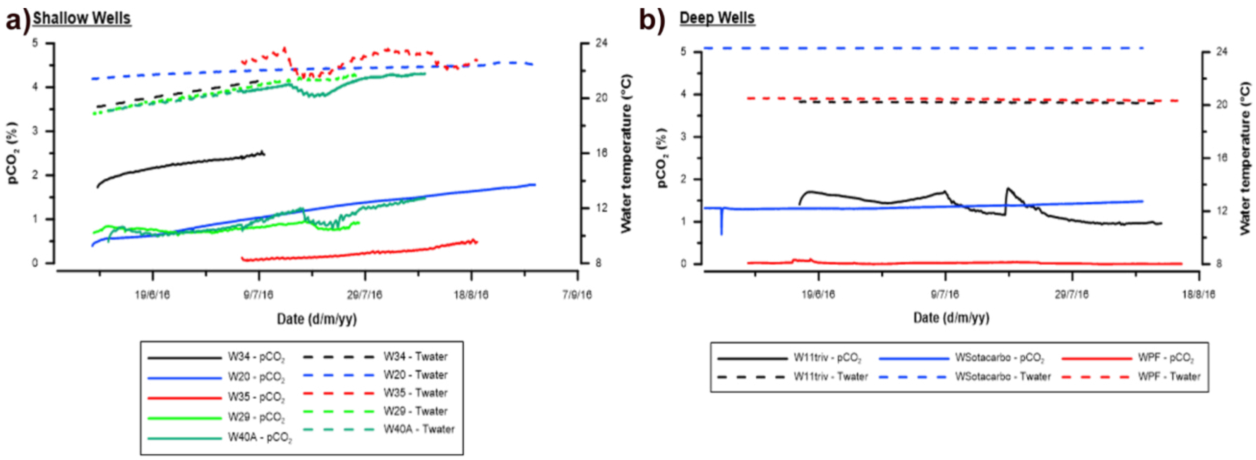

Fig. 5. The graphs show some of the results of continuous monitoring in a) shallow wells and b) deep wells. The lines in the plots are temperature of water (dashed line) and pCO_2 (continuous line), respectively.

The deep wells present a behaviour that is quite different (Fig. 5b); temperature and pCO_2 values are much more stable, and more representative of the aquifer conditions, because they are less influenced by surface effects.

5. Conclusion

The characterization of a site suitable for carbon geological storage is a very complex process, requiring a multidisciplinary approach, involving structural geology, geophysics, petro-physics, geochemistry among others. To determine some important parameters, such as porosity, permeability, geochemical variables, it is needed to acquire large datasets to well define these characteristic of the reservoir-caprock system.

In this study, it has been shown the preliminary result of the characterization of the southern part of Sulcis Basin, where a fractured carbonate formation (Miliolitico Fm.) has been identified as a potential reservoir. These limestones have very low porosity and permeability, so that it was necessary to study the fracture network to determine the storage volume, represented by fractures. With this aim, a Discrete Fracture Model of the reservoir was constructed, allowing an estimate of a secondary porosity in the range of 3-5%.

With regards to geochemical baseline studies, in the last years both continuous and discontinuous monitoring of the area, at different scale were performed. These monitoring surveys point to determine the seasonal variability of geochemical parameters (e.g. temperature, CO_2 and CH_4 concentrations) and to identify potential migration pathways along faults.

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