Deep Geological Conditions and Constrains for CO_2 Storage in the Setúbal Peninsula, Portugal

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Abstract — This paper describes the research conducted in order to identify potential CO_2 storage reservoirs in the Setúbal Peninsula, Portugal. The studied area is located in the southern sector of the Lusitanian Basin, the largest Portuguese Mesozoic sedimentary basin. Data from deep geological conditions was collected from oil and gas exploration wells and structural maps of the target geological horizons were processed from seismic reflection profiles. A potential reservoir for CO_2 storage in the Lower Cretaceous was identified and its volume was calculated based on kriging interpolation methods. Net-to-gross ratio and porosities were determined from geological logs. A total CO_2 storage capacity of 42 Mt was estimated. However, the lack of data about the lateral continuity of the seal, the presence of the most important Portuguese groundwater resources at shallower depths and the relatively high earthquake hazard, hinders the studied reservoir from offering the necessary geological conditions for a safe CO_2 storage in the studied area.

Keywords — CO_2 storage, reservoir and cap-rock, groundwater resources, seismicity, Portugal.

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1 INTRODUCTION

The research described in this paper was carried out as part of the 'COMET' project launched under the European 7th Framework Programme, which aims to define an integrated transport infrastructure linking CO_2 sources and sinks for geological CO_2 storage in Portugal, Spain and Morocco. In Portugal, several potential sedimentary basins for CO_2 storage in deep saline aquifers were screened. The most important sedimentary basin is the Lusitanian Mesozoic Basin, in the south of which the studied area is located. In this work we describe the multi-disciplinary techniques used to assess potential geological CO2 sinks in the Setúbal Peninsula. Geological data was collected from existing geophysical logs, from oil and gas well data, from seismic reflection profiles and from reported geological studies of the reservoir horizons where they outcrop. Such an approach allowed quantifying the CO2 storage capacity and assessing the potential of the reservoir for safe CO_2 storage.

2. GEOLOGICAL SETTING OF THE SETÚBAL PENINSULA

The Setúbal Peninsula is located at the southern sector of the Lusitanian basin, which was formed over a sequence of rift pulses and subsequent opening of the North Atlantic Ocean, between the Late Triassic and Early Cretaceous [1, 2, 3, 4]. The southern sector of the Lusitanian basin is limited to the north by the Tagus valley fault system and to the South by the Arrábida fault [5] (Fig. 1). The N-S Pinhal Novo Fault is the eastern border of the basin, separating the Paleozoic and overlying Cenozoic sediments from the more than 3 km thick Mesozoic sediments of the Setúbal peninsula. The Setúbal Peninsula is an open synclinal of Ceno-Mesozoic sediments, with an E-W trending axis. At the south border, the Cretaceous and Jurassic crop out at the Arrábida compressive chain. The lower and medium Jurassic sediments are affected by

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N-S faults and are sealed by the Upper Jurassic [5].

3. DATA AND METHODS

The site identification process relied on existing data from deep wells and seismic profiles. Information from oil and gas exploration wells was combined with structural maps of deep geological horizons from [6] and from [7].

3.1 Reservoir selection based on deep-wells

This study used geological information from the oil and gas exploration wells Br-1, Br-2, Br-3, Br-4 (near Barreiro), PN1 (Pinhal Novo), Mj1 (Montijo) and Sa-1A (Samora Correia) (Fig. 1). The potential CO_2 reservoirs and seal rocks were selected according to the criteria defined by Chadwick et al. [8], summarized in table 1.

Table 2 outlines the key geological aspects (lithology, thickness, depth) of the selected reservoirs and seals identified from the studied wells.

Table 1: Key geological criteria/indicators for storage site suitability (adapted from [8]).

	Positive Indicators	Cautionary Indicators
Reservoir properties		
Depth	> 1000 m < 2500 m	< 800 m, > 2500 m
Thickness	> 50 m	< 20 m
Porosity	> 20%	< 10%
Permeability	> 300 mD	< 10-100 mD
Salinity	> 100 gL^{-1}	< 30 gL^{-1}
Caprock properties		
Lateral continuity	Un-faulted	Lateral variations, faulting
Thickness	> 100 m	< 20 m

Coarse detrital rocks, mainly sandstone, were considered as potential reservoir rocks and thick clay-rich intervals as good cap-rocks, and these lithologies that were the target of the well logs analysis.

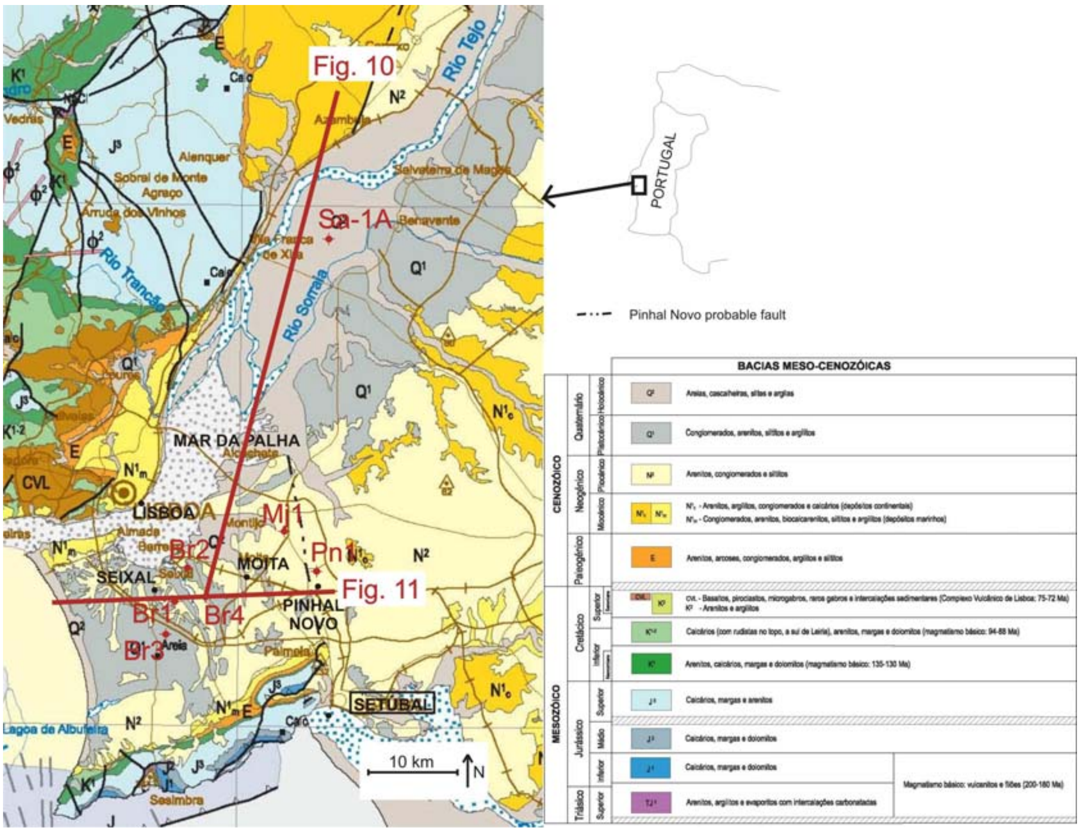

Figure 1: Geological map [9] with the location of the deep wells considered and the cross sections presented on figures 10 and 11.

Table 2: Summary of the identified reservoir and seal rocks based on the studied wells.

Well	Seal		Reservoir		Favorable?
Br-1	1150 - 1170 m Red clays (Oligocene)	Favorable, although slightly thin	1170-1190 m Dolomitic limestone interbedded with sandstone, marlstone and limestone (Early Cretaceous) 1190 - 1240 m Sandstone with marly cement (Early Cretaceous)		medium favorable
Br-2	645 - 685 m Carbonated and sandy clay (Cenozoic)	Favorable lithology but not ideal; does not fits the depth criteria	685 - 735 m Fine to coarse sandstone with carbonate cement, clay limestone with clay levels (Cenozoic)	Does not fit the depth criteria	unfavorable
Br-2	1100 - 1155 m Red clays (Cenozoic)	Suitable	1155 - 1185 m Sandy marlstone (Early Cretaceous.) 1185 - 1325 m Poorly consolidated sandstone with sandy marlstone and carbonated clay levels (Early Cretaceous)		highly favorable
Br-3	865-925 m Carbonated clay intercalated with marly sandstone (Oligocene)	Favorable lithology	925 - 1240 m Sandy marl, coarse sandstone with carbonate cement, and dolomite interbedded with marlstone, limestone and carbonate-cemented sandstone (Early to Upper Cretaceous) 1240 - 1330 m Clay-cemented sandstone with sandy clay levels (Upper Jurassic.)	The presence of clay/marl could stratify the reservoir	medium favorable unfavorable /3
Br-4	1030 - 1151 m Sandstone with clay layers interbedded with clay (Paleogene)	Low to Medium Favorable	1210 - 1430 m Sandstone with clay layers interbedded with limestone (Early to Mid Cretaceous) 1430 - 1657 m Sandstone interbedded with clay and limestone (Upper Jurassic)	Low to Medium Favorable	unfavorable

3.2 Analysis of time structure maps of selected geological horizons

The analysis of seismic reflection profiles enabled to characterize the overall geological structure of the study area. Four seismic horizons were considered, which correspond to surfaces inside the possible reservoir or cap-rocks: i) Intra-Neogene; ii) Approximate Top of the Paleogene; iii) Base of the Paleogene/aproximate Top of the Cretaceous; iv) Approximate Top of the Jurassic. These horizons were obtained from a seismic to well-tie using well logs calibrated with check-shots, vertical seismic profiles and synthetic seismograms. The seismic reflection profiles were interpreted using the original processing by Lomholt et al. [7], later reprocessed and reinterpreted by Carvalho [6]. Figures 2 to 5 show the depth and structure maps of these horizons [6].

Horizon 1: Intra-Neogene (sandstone, marlstone and limestone interbedded with clay; the reflector is a limestone bed)

This horizon intersected in well Br-4 at a depth of 300 m, and in well SA1a at a depth of 560 m. Towards the NNE of the Barreiro wells, this horizon is present in two NNE-SSW trending basins, separated by a ridge, at depths of 925-1075m and 1075–1250 m [6] (Fig. 2).

To the W, SW and S of Barreiro, the Lomholt et al. Time-map [7] indicates that this horizon occurs at progressively shallower depths.

The Neogene occurs at favorable depths in two small basins, which are cut and bounded by possible active faults [10]. However, as a reservoir, the Neogene is of no interest since the thickness of the sandstones within the succession is unknown, while significant volume of unsuitable rock types, such as limestones and marls, are present. As a seal, the Neogene also does not appear to be interesting because the thickness and lateral continuity of the clay layers are not known.

Horizon 2: Approximate Top of the Paleogene (sandstone interbedded with clay and minor limestone levels (Br-4); in Br-1 and Br-2 this

horizon reaches thicknesses of several tens of meters)

The Top of Paleogene (Fig. 3) is intersected in well Br-1 at a depth of 846 m; at well Br-2 at an uncertain depth (the likely base of the Paleogene is at 1165 m); at well Br-3 at a depth of 805 m; and well Br-4 at a depth of 843 m.

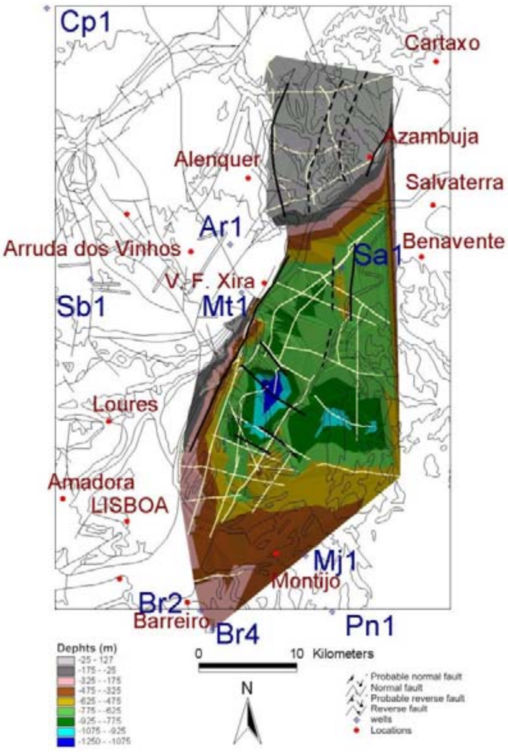

Figure 2: Depth and structure of the Intra-Neogene horizon in the Setúbal Peninsula (from [6]).

To the NNE of the Barreiro wells, this horizon constitutes a NNE-SSW trending basin, down to a depth of 2500 m [6]. This basin coincides with the present-day Mar da Palha and with the Western basin identified in the intra-Neogene horizon (Fig. 2).

The Lomholt et al. [7] Time-map confirms the presence of this basin and suggests the presence of another, smaller and deeper one to the East of Barreiro, roughly corresponding to the area of Moita.

The Paleogene has no interest as a reservoir, but can be a good seal. This formation is locally known as Formação de Benfica and is observed in wells Br-1 and Br-2, in which they display favorable, although thin (20 and 55 m), clay levels. Its lateral continuity could not be assessed, but the formation is often described as a highly heterogeneous continental formation [11] composed of sequences of red conglomerates, sandstones, clay layers and marls. Permeability is usually low, even when conglomerates predominate, due to the presence of clay cement.

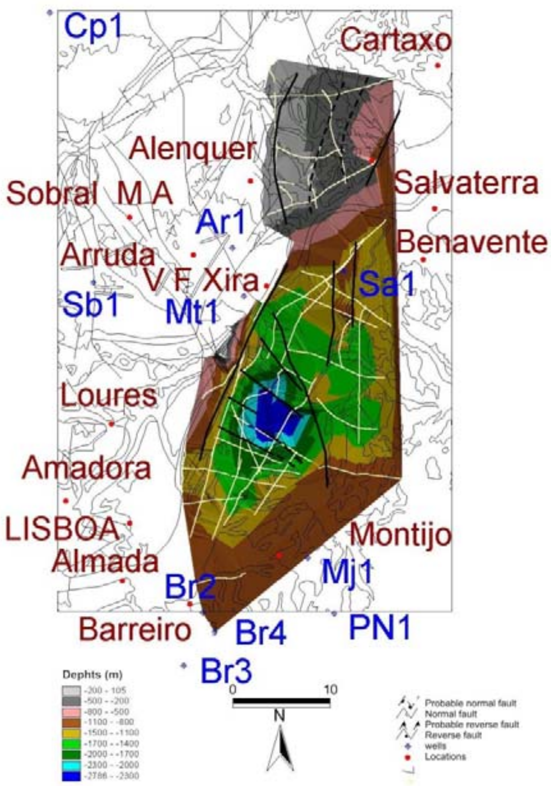

Figure 3: Depth and structure of the top of the Paleogene horizon in the Setúbal Peninsula (from [6]).

Horizon 3: Base of the Paleogene/approximate Top of the Cretaceous (mostly sandstone)

This horizon occurs at depths in wells: Br-1 – 1166 m; Br-2 – 1155 m; Br-3 – 925 m; Br-4 – 1200 m. It is present at reasonable depths (below 800 m) in practically all the Setúbal Peninsula, Mar da Palha and Left bank of the Tagus River. In addition to the two basins mentioned for horizon 2 (Mar da Palha and Moita), a third basin can be defined in the Bay of Seixal. However, during the Cretaceous, the Mar da Palha depocenter appears to have shifted towards the South in comparison to its location during the

Paleogene, at depths of 2000 – 2235 m according to Carvalho [6] or at a depth of 1800 m according to Lomholt et al. [7] (Fig. 4). At the Seixal and Moita basins this horizon occurs at a depth of 1300-1400m [7].

The Cretaceous sandstones have good reservoir characteristics since they occur at favorable depths and have enough thickness. The information from the wells show that this sandstone sequence contains thin marlstone and limestone layers, and a thickness of 70 m (Br-1), 170 m (Br-2), 220 m (Br-4) and 310 m (Br-3).

Figure 4: Depth and structure of the top of the Cretaceous horizon in the Setúbal Peninsula (from [6]).

Horizon 4: Approximate Top of the Jurassic (mostly sandstone with thin layers of limestone and claystone). This horizon occurs at the following depths in wells: Br-4 – 1432 m; Br-3 – 1240 m. In the remaining wells this horizon is mainly composed by limestone.

This horizon occurs at favorable depths (below 800m) throughout the Setúbal Peninsula, Mar da Palha and Left bank of the Tagus River. It defines the same three basins as described for the Cretaceous, however the Mar da Palha depocenter again shifted, but this time towards the North, in comparison to its location during the Cretaceous (Fig. 5). To the NE of the Pinhal Novo fault this horizon is not recognized.

The Upper Jurassic sandstone has good reservoir characteristics, occurring at favorable depths.

The wells show a thickness of 90 m (Br-3) and 220 m (Br-4) for this sandstone, which is interbedded with thin layers of limestone and claystone. This reservoir is in continuity with the overlapping Cretaceous reservoir.

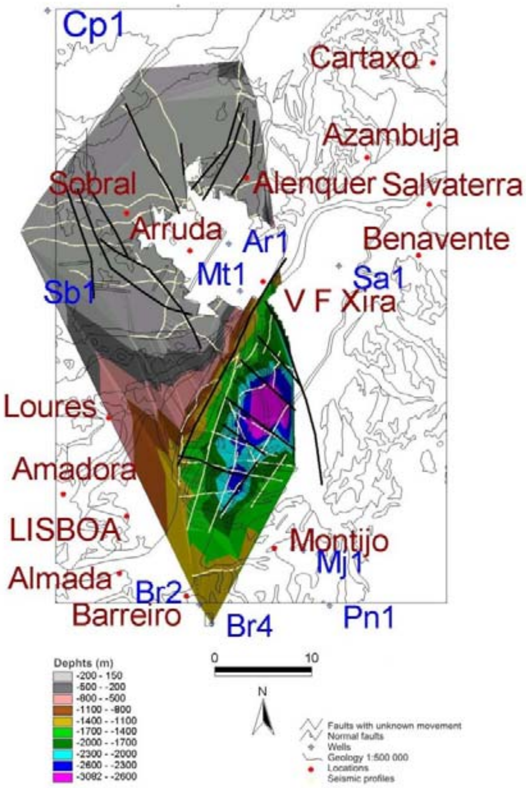

Figure 5: Depth and structure of the top of the Jurassic horizon in the Setúbal Peninsula (from [6]).

The remaining horizons identified on the existing seismic survey could not be identified at the studied wells and, therefore, are not addressed in this study.

4. CO_2 storage capacity

Considering the Lower Cretaceous formations as a potential CO_2 storage reservoir, the CO_2 Storage Capacity (MCO_2) was estimated based on the following analytical solution [8]:

$$MCO_2 = A \cdot H \cdot \varphi \cdot S_{eff} \cdot NG \cdot \rho CO_2$$

Where A is the area of the whole reservoir, H is thickness, φ is porosity, NG is the Net-to-Gross ratio, S_{eff} is the storage efficiency (or sweep efficiency) and ρCO_2 is the CO_2 density at the reservoir pressure and temperature.

The weighted means values of porosity (φ = 6.6%) and net-to-gross (NG = 59%) were calculated based on the technical reports of boreholes Br-1, Br-2, Br-3 and Br-4. The typical mean porosity values of the reported Lower Cretaceous lithologies (sandstones, claystones and limestones) were taken from Custodio and Llamas [14]. From such calculations were excluded the Upper Jurassic formations.

The default values of storage efficiency (S_{eff} = 2%) and of CO_2 density (ρCO_2 = 650 kg/m^3) were used. The volume (A · H) of the Lower Cretaceous reservoir was calculated by smoothing interpolation using a computational kriging method. In figure 6, the upper and lower surfaces of the reservoir are depicted. These surfaces were obtained from the time-structure maps interpreted in the MILUPOBAS project [11]. The reservoir volume was calculated for the depth equal or greater than 800 m and corresponds to about 82 km^3.

Based on these values, a Regional Bulk CO_2 Storage Capacity of 42 Mt CO_2 was obtained for the Lower Cretaceous. This capacity could allow the storage of 5 years of CO_2 emissions from the main Portuguese coal power plant, at Sines, where approximately 8 Mton of CO_2 are produced yearly.

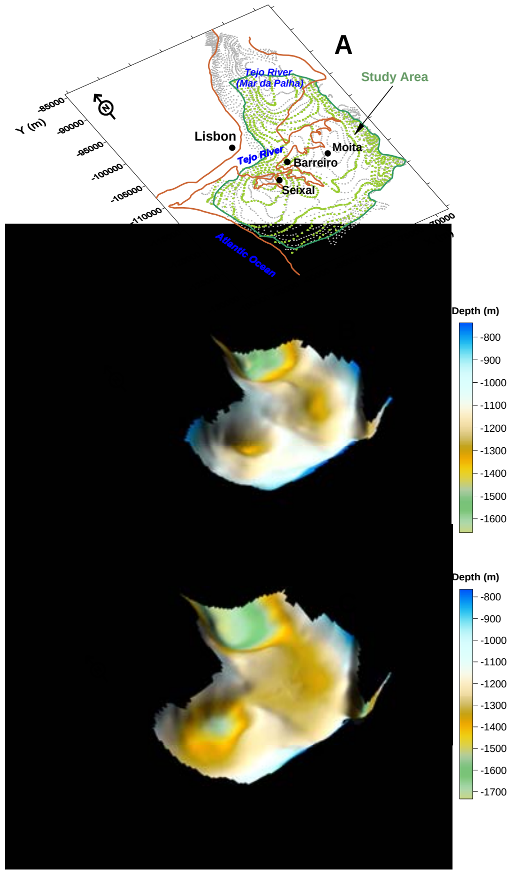

Figure 6: 3D modeling of the Lower Cretaceous obtained by kriging interpolation. A: study area (limited by the green countour), B – Surface of the top Cretaceous and C – Surface of the bottom of Cretaceous.

5. RISK FACTORS

The identified reservoir/seal pair occur at suitable depths in the three sub-basins mentioned above, and depicted in figure 7:

- Mar da Palha sub-basin
- Moita sub-basin
- Seixal sub-basin

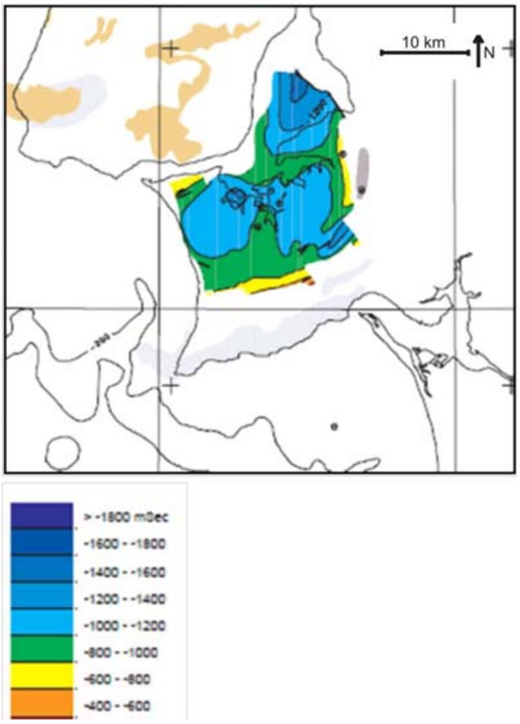

Figure 7: Structure map (in milliseconds) of the Nearly Top Jurassic, suggesting the existence of three sub-basins in the study area [3].

However, for CO_2 storage to be considered at the study area, the risk factors should be clearly identified. The main risk factors in the study area are related to:

- Groundwater resources;
- Nature of the cap-rocks;
- Neo-tectonics and seismicity;
- Geological structure.

5.1. Groundwater resources

The region includes one of the most productive aquifer systems in Portugal; know as the Left Margin of the Tejo-Sado Basin. This multi-layered-aquifer system consists of porous formations ranging from the Miocene to modern alluvial deposits, reaching depths of at least 600 m. Greater depth are unknown from the hydrogeological point of view. This aquifer system is semi-confine to confine and leakage between the stratified porous layers occurs due to hydraulic pressure differences. The groundwater quality is high and many wells exploit this aquifer system for the public supply to all municipalities in the area, as well as to water supply for industrial and agricultural purposes. According to Almeida et al. [12], the pumped volumes in the Setúbal Peninsula alone accounts to 58 hm^3/yr. Thus, this aquifer system is a vital strategic groundwater resource for the region, since it is the only one available.

Because of the importance of this groundwater resource, any intention of CO_2 storage in the underlying geological formations, such as the Early Cretaceous, must be cautiously approached. Despite of some confinement of these formations, the risk of groundwater contamination due to ascending CO_2 migration cannot be discarded. Ultimately, any CO_2 storage could increase substantially the vulnerability of the overlying multi-aquifer system. In fact, that is the case in the Mar da Palha sub-basin, where several extensive faults (see section 4) could act as pathways for ascending CO_2.

Albeit the lack of groundwater hydrochemical data for the Lower Cretaceous, salinity measurements reported in the Br-1 geotechnical log, indicate freshwater in the underlying Upper Jurassic. At the depth of 2285-2323 m, salinity was found to range between 320-900 mg/L. Such freshwater values do not fall within the salinity criteria defined in Chadwick et al. 2006 [5], which require values to be high above 30000 mg/L. Due to the existence of freshwater in the geological formations above and below the Lower Cretaceous, it is not expected to find saline water in this reservoir, therefore the water salinity criteria for CO_2 storage is not fulfilled.

5.2 Nature and lateral continuity of the cap-rocks

The seal identified for the Cretaceous and Jurassic reservoirs are the low permeability layers of the Early Cenozoic (Paleogene), locally known as Formação de Benfica. At outcrop, namely on the right bank of the Tagus river, this formation is often described as a highly heterogeneous continental formation [11]. Still, the permeability is usually low, even when

conglomerates predominate, due to the presence of clay cement. This highly heterogeneous, mostly clastic formation with abundant facies variation appears to be a favorable seal near de Barreiro wells. However, it is doubtful that this formation can constitute a reliable regional cap-rock, since the clay layers are not likely to be continuous on the scale of tens to hundreds of km^2 as required for CO_2 storage purposes. Furthermore, the presence of conglomeratic layers may lead to the development of preferential migration pathways for CO_2 leakage. Additionally, several extensional faults that cut and bound the Mar da Palha sub-basin [6] also affect the Paleogene (Fig. 10). Thus, it is not undisputable that the Paleogene can provide a proper sealing between any CO_2 reservoirs and the overlying freshwater resources.

5.3 Neotectonics and seismicity

The CO_2 storage site selection criteria require that storage sites should not be located in tectonically active areas. Figure 8 depicts the expected seismic intensity (Modified Mercalli scale) with 5% probability of being exceeded in 975 years. Notice the high intensity values in the study area, where the expected intensity range from IX to X. This high seismic hazard is not just a consequence of distant, plate-boundary earthquake, but also due to local earthquake sources. In fact, the seismic records show several important earthquakes having its epicenter close to the study area (Fig. 9).

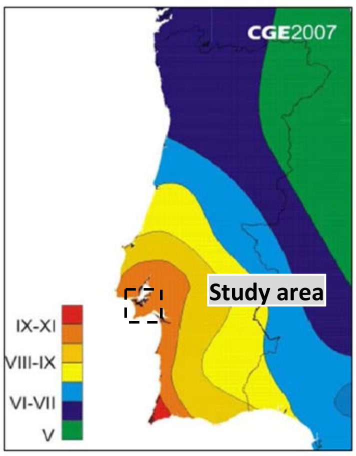

Figure 8: Seismic hazard in Portugal, exceeding 5% probability in 975 years. Modified Mercalli Scale, In Bezzeghoud et al. 2007 and adapted from Peláez e Lopez Casado [14].

Furthermore, several known active faults cross the study area (Fig. 9), the most important of which is the Lower Tagus System Faults, located right along the Mar da Palha sub-basin, making it unsuitable for CO_2 storage purposes.

The other two sub-basins (Seixal and Moita) are also very close to active faults, although the existing information is rather scarce, and it is difficult to say with certainty if those sub-basins are crossed by active faults.

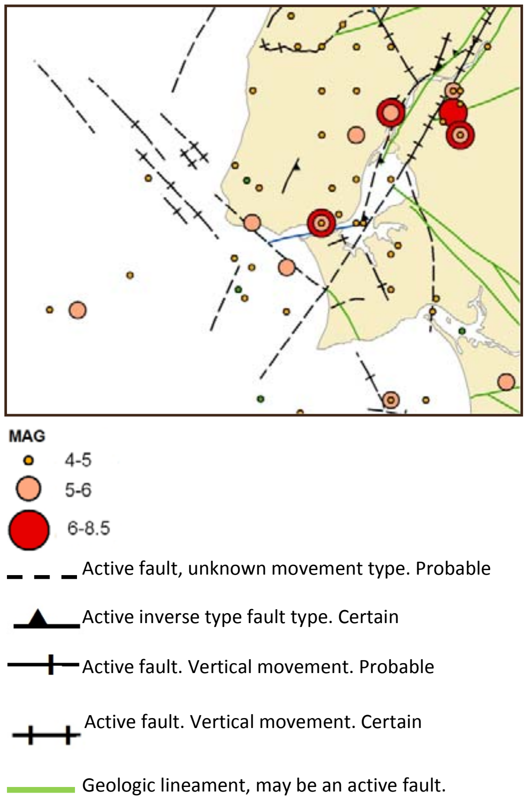

Figure 9: Active faults and epicentres of earthquakes with magnitude higher than 4 for the study area (circles proportional to magnitude).

5.4 Structure of reservoirs and seals in the Setúbal peninsula

The significant lateral facies variations of the sequences intercepted by the Barreiro (Br) wells raise doubts about the existence of a reservoir with regional extension. Despite such constraints, it was possible to conclude that locally the Cretaceous and Upper Jurassic sandstones have good reservoir characteristics, and the Paleogenic Formação de Benfica can act

as a seal, although its wide heterogeneity needs to be taken into account.

This Upper Jurassic to Paleogenuic sequence occurs at favorable depths in the Mar da Palha, Moita and Seixal basins and at the Barreiro wells area. However, the seismic data shows several extensional faults that cut and bound the Mar da Palha Basin, limiting its interest for CO_2 storage because of possible leakage (see figures 10 and 11 and figure 1 for location of the cross-sections). The same may happen in the Moita basin, where seismic data is incomplete.

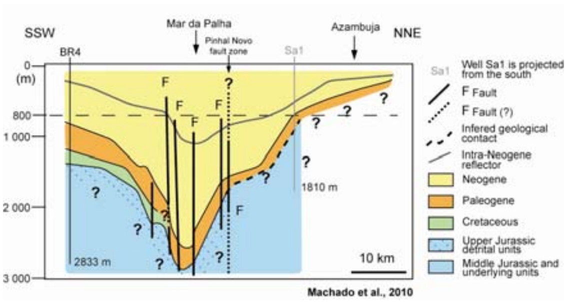

Figure 10: Schematic cross section showing the Mar da Palha basin based on data from [6] (see Fig. 1 for location).

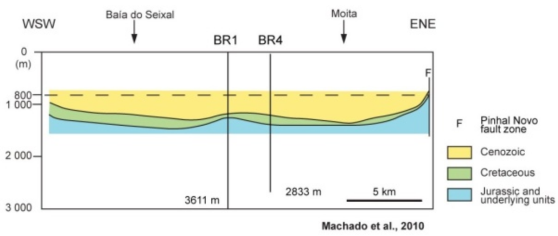

Figure 11: Schematic cross section showing the Seixal and Moita basins based on depth maps of [7] (see fig 1 for location).

At the Barreiro wells area, the geological units with good reservoir characteristics reach thicknesses of 400 m (Br-3 e Br-4). The absence of wells at the Moita basin does not allow an accurate evaluation of the selected reservoir and seal thicknesses.

6. CONCLUSIONS

At the Setúbal Peninsula three sub-basins (Mar da Palha, Seixal and Moita) were identified, where potential CO_2 reservoirs occur at the required depths. However, the risk factors identified for the area, namely the importance of the freshwater aquifers overlying the potential reservoirs, the geological heterogeneity of the cap-rocks and the striking seismicity hazard due to active faults crossing the Mar da Palha sub-basin and the geological structure of the Seixal and Moita sub-basins, represent very relevant unfavorable conditions for CO_2 storage and discourage its injection in this region. Additionally, the presence of a geological structure favorable to CO_2 storage (dome, anticline) and saline waters was not confirmed, and it was showed that the geological units are horizontal or defining an open structure to the surface. Such geometries are not favorable for CO_2 storage.

The storage capacity of the study area amounts to around 42 Mt, a relatively small volume taking into account the annual emissions at the main power plants in Portugal. Given the risk factors and the low storage capacity it was decided that Setúbal Península would not be indicated as possible target for CO_2 storage.

ACKNOWLEDGMENT

The authors thank DPEP/DGEG the access to data of Milupobas project [7].

REFERENCES

1. Wilson, R. C. L., Hiscott, R. N., Willis, M. G., Gradstein, F. M., 1989, The Lusitanian basin of west-central Portugal: Mesozoic and Tertiary tectonic, stratigraphy, and subsidence history, in A. J. Tankard and H. R. Balkwill, eds., Extensional tectonics and stratigraphy of the North Atlantic margins: AAPG Memoir 40, p.341-361.
2. Pinheiro, L.M., Wilson. R.C.L., Pena dos Reis, R., Whitmarsh, R.B.W. and Ribeiro, A. (1996). The Western Iberian Margin: a Geophysical and Geological Overview. In Whitmarsh, R.B., Daywer, D., Klaus, A. and Masson, D.G. (Eds.). Proceedings of the Ocean Drilling Program, Leg 149, Scientific Results Volume, 3-23.
3. Rasmussen, E. S., S. Lomholt, C. Andersen, and O. V. Vejbæk (1998), Aspects of the structural evolution of the Lusitanian Basin in Portugal and the shelf and slope area offshore Portugal, Tectonophysics, 300(1-4), 199-225.
4. Alves, T. M., Moita, C., Cunha, T., Ullnaess, M., Myklebust, R., Monteiro, J. H., Manuppella, G., 2009. Diachronous evolution of Late Jurassic-Cretaceous continental rifting in the northeast Atlantic (west Iberian margin), Tectonics, vol. 28, p.32.
5. Kullberg, J. C. (2000) Evolução tectónica mesozóica da Bacia Lusitaniana, PhThesis, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa.
6. Carvalho, J. (2003) Sísmica de alta resolução aplicada à prospecção, geotecnia e risco sísmico. PhD Thesis on Physics (Internal geophysics), 265 p.

7. Lomholt, S., Rasmussen, E.S., Andersen, C., Vejbæk, O.V., Madsen, L., Steinhardt, H. (1996) Seismic interpretation and mapping of the Lusitanian Basin, Portugal. Contribution to the E.S. Rasmussen et al. / Tectonophysics 300 (1998) 199–225 225 MILUPOBAS project, EC Contract No. JOU2-CT94-0348, Geological Survey of Denmark, 70 pp.
8. Chadwick, A.; Arts, R.; Berstone, C.; May, F.; Thibeau, S. & Zweigel, P. (2006) – Best Practice for the Storage of CO_2 in Saline Aquifers (Observations and guidelines from the SACS and CO2STORE projects), 273 p
9. LNEG-LGM (2010) Carta Geológica de Portugal à escala 1:1 000 000, LNEG-LGM, Lisboa.
10. Carvalho, J., Cabral, J., Gonçalves, R., Torres, L., Mendes-Victor, L., 2006, 'Geophysical Methods Applied to Fault Characterization and Earthquake Potential Assessment in the Lower Tagus Valley, Portugal, Tectonophysics, Vol. 418, 3-4, 277-297.
11. Ribeiro, A., Antunes, M., Ferreira, M., Rocha, R., Soares, A., Zbyszewski, G., Almeida, F., Carvalho, D., Monteiro, J., 1979. Introduction à la Géologie du Portugal. Serviços Geológicos de Portugal, Lisboa, 114
12. Almeida, C., Mendonça, J. J. L., Jesus, M. R., Gomes, A. J. (2000). Sistemas aquíferos de Portugal Continental. – Sistema aquífero: Bacia do Tejo-Sado/Margem Esquerda (T3). Instituto da Água, Lisboa.
13. Peláez, J.A. and López Casado, C. (2002). Seismic hazard estimate at the Iberian Peninsula. Pure Appl. Geophys. 159, 2699-2713
14. Custodio, E. & Llamas, M. R. (1996) – Hidrologia Subterranea. Ediciones Omega, S.A, Barcelona. Segunda Edición, Tomos I-II, 2347 p.
15. Machado, S.; Rosa, C.; Rosa, D. e Carvalho, J. (2010) WP3, Task 2: Identify and select seal/reservoir pair for potential storage sites in the Setúbal-Bacia do Tejo peninsula and on the on-shore of Sines. Internal report from COMET project.