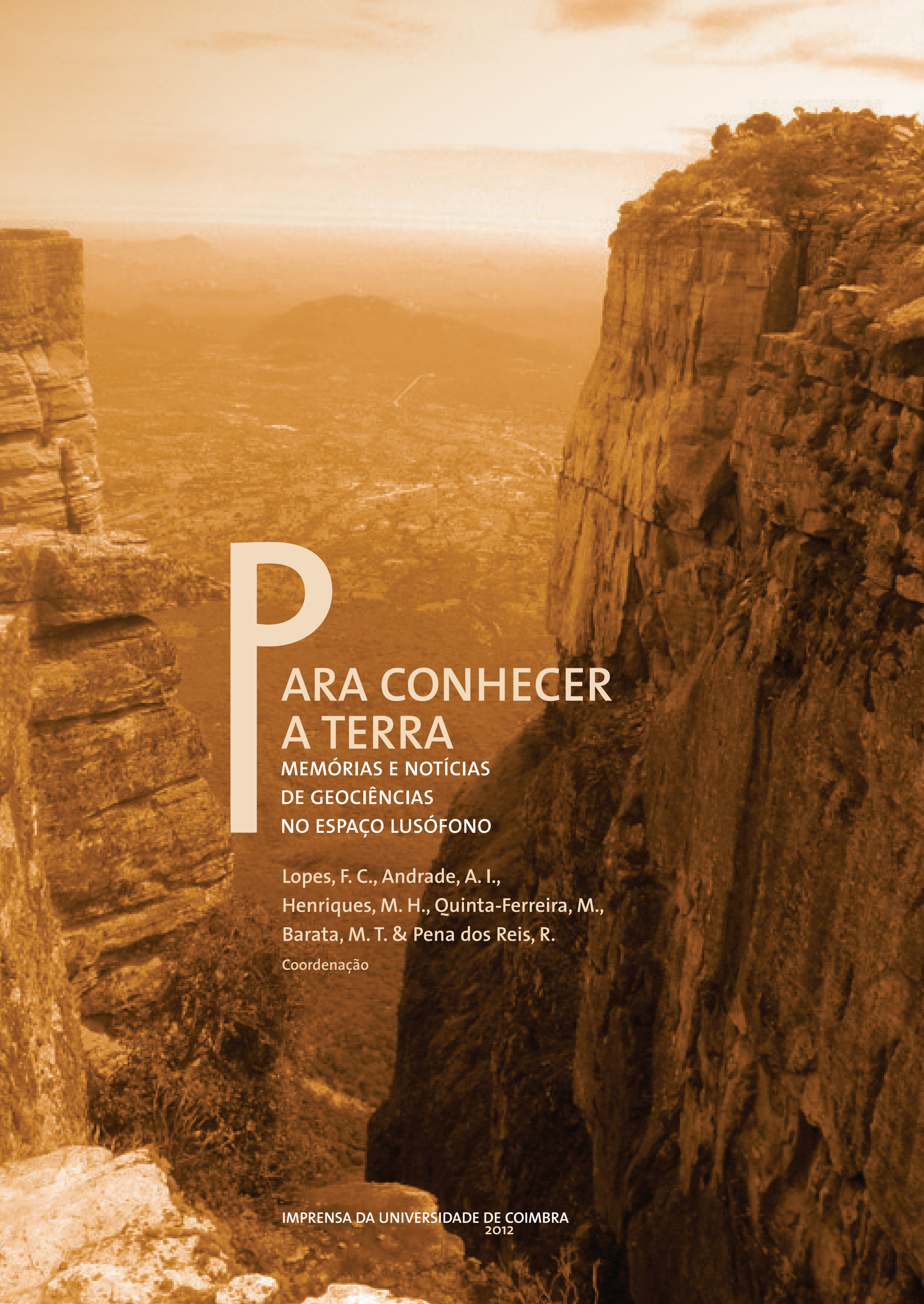

PARA CONHECER A TERRA

MEMÓRIAS E NOTÍCIAS DE GEOCIÊNCIAS NO ESPAÇO LUSÓFONO

Lopes, F. C., Andrade, A. I.,
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Coordenação

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THE POTENTIAL FOR CO_2 GEOLOGICAL STORAGE IN THE PORTO BASIN (OFFSHORE NORTH PORTUGAL)

POTENCIAL DE ARMAZENAMENTO DE CO_2 NA BACIA DO PORTO (OFFHORE NORTE DE PORTUGAL)

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Abstract – The storage of CO_2 is an up to date topic involving numerous governmental, academic and commercial institutions. COMET is a joint research project co-financed by the European Seventh Framework Programme that aims at identifying and assessing the most cost effective CO_2 transport and storage infrastructure able to serve the West Mediterranean area, namely Portugal, Spain and Morocco. In this project a preliminary assessment of the potential reservoir and storage capacity in the Porto Basin was made. To be considered geological units for potential storage of CO_2 certain geological criteria must be obeyed, including depth, porosity, and permeability, among others. Through the analysis of simplified porosity-depth profiles, two formations were identified as potential reservoirs for CO_2 storage: the Torres Vedras and Silves formations. In the Porto Basin, between the recommended depths, the maximum porous volume available for storage was estimated to be 2364 km^3 for the Torres Vedras Formation and 334 km^3 for the Grés Silves Formation.

Keywords – Portugal; CO_2 storage; Porto offshore basin

Resumo – *O armazenamento de CO_2 é um tema que, até a data, envolve diversas instituições governamentais, académicas e comerciais. COMET é um projeto de investigação co-financiado pelo 7º Programa-Quadro Europeu que visa identificar e avaliar os custos de uma infraestrutura eficaz de transporte e armazenamento geológico de CO_2, que possa servir a*

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zona do Mediterrâneo Ocidental (Portugal, Espanha e Marrocos), bem como a localização, capacidade e potencial de armazenamento de CO_2 em formações geológicas na região. No âmbito deste projeto foi feita uma avaliação preliminar sobre o potencial reservatório e a capacidade de armazenamento na Bacia do Porto. Para determinada unidade geológica ser considerada bom potencial em armazenar CO_2 têm que se obedecer a determinados critérios geológicos, nomeadamente a profundidade, a porosidade e a permeabilidade, entre outros. Através da análise de perfis simplificados de porosidade-profundidade, duas formações foram identificadas como potencial reservatório para o armazenamento de CO_2: as formações de Torres Vedras e Grés de Silves. Para a Bacia do Porto, no intervalo de profundidades recomendadas, o volume poroso máximo estimado para o armazenamento foi 2364 km^3 para a Formação de Torres Vedras e 334 km^3 para a Formação Grés de Silves.

Palavras-chave *– Portugal; armazenamento de CO_2; Bacia do Porto*

1 – Introdution

Since the mid-1800's human activity led to an increase in greenhouse gases (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2) and chlorofluorocarbons (CFCs). Of all the greenhouse gases, CO_2, whose atmospheric concentrations have risen from pre-industrial levels of 280 ppm to 380 ppm in 2005 (IPCC 2007), is the most important, being responsible for an estimated two-thirds of the enhanced greenhouse effect (IPCC 2007, BRYANT, 1997). This increase in greenhouse gases emissions is believed to be responsible for the observed global climate change and the ocean acidification which are accompanied by severe consequences for the ecosystems and the human society.

CO_2 capture and storage (CCS) is considered as one of the options for reducing atmospheric emissions of CO_2 from human activities (IPCC, 2005). This technology involves capturing the CO_2 from local sources (*e.g.*, fossil fuel power plants, cement factories, refineries and other energy intensive industries) and storing it in geological formations.

This study is integrated in project COMET, which aims to identify and assess the most cost effective CO_2 transport and storage infrastructure able to serve the West Mediterranean region, including Portugal, Spain and Morocco. This is achieved considering the time and spatial aspects of the energy sector development and other prominent industrial activities in those countries, as well as the location, capacity and availability of potential CO_2 storage geological formations (BOAVIDA *et al.*, 2011). This paper focuses on the potential for CO_2 storage in the Porto Basin (offshore northern Portugal).

2 – Geological Framework of Porto Basin

The Porto Basin is located in the northern West Iberia Margin (WIM), extending approximately between Vigo and Aveiro (Fig.1a). The margin evolved through a sequence of rift episodes, between the Late Triassic and Early Cretaceous, and the structure of its marginal basins is strongly controlled by prominent Variscan lineaments, mainly inherited from a late Carboniferous-early Permian phase of variscan strike-slip deformation (RIBEIRO *et al.*, 1979; PINHEIRO *et al.*, 1996). These lineaments include the NNE-SSW and NNW-SSE to NW-SE listric and/or planar normal faults and NE-SW to ENE-WSW transverse faults, which delimit the main depositional systems identified along the margin (WILSON *et al.*, 1989; MURILLAS *et al.*, 1990; PINHEIRO *et al.*, 1996; ALVES *et al.,* 2006). During the Alpine compression, from the late Cretaceous onwards, some of these features were reactivated as reverse or thrust faults, sometimes with a strike-slip component (BOILLOT *et al.*, 1979; MASSON *et al.*, 1994).

As depicted in Fig.1, the Porto Basin is about 50km wide, extending between the coast and the outer continental shelf and slope. The basin is located in the northward continuation of the Lusitanian Basin (Fig. 1), delimited to the east by the Porto-Tomar Fault, which has been active throughout most of the basin evolution (ALVES *et al.*, 2006; CUNHA, 2008). A horst block on its western side separates the Porto Basin from the Galicia Interior Basin (PINHEIRO *et al.*, 1996).

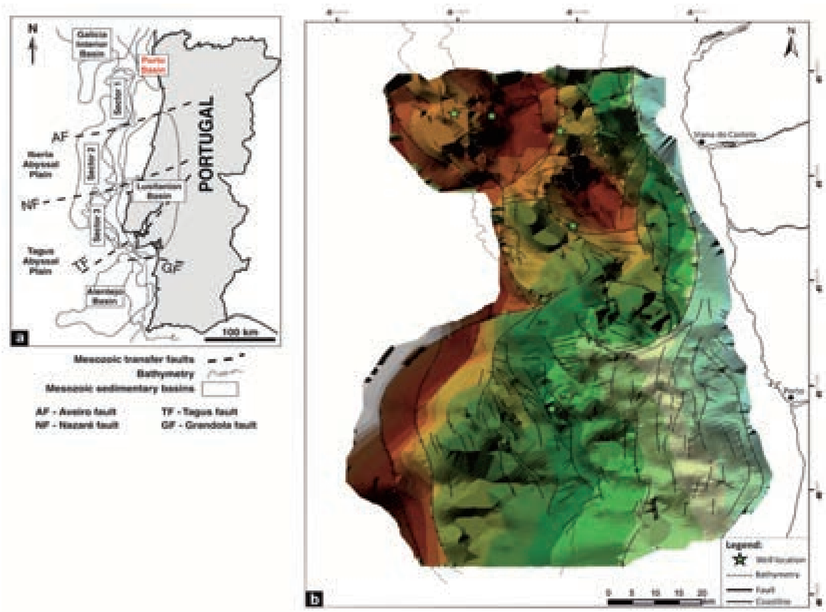


Fig. 1 – a) Inset showing the location of the Porto Basin in the West Iberia Margin (adapted from ALVES *et al.,* 2006); b) Structural map of Porto Basin, with the location of exploration wells. Color scale in Fig 2.

3 – Methodology and data presentation

3.1 – Structural maps in two-way time

The MILUPOBAS PROJECT (1998) interpreted a total of seven structural maps in the Porto Basin, based on commercial multichannel seismic data tied to the existent boreholes (see Table 1). The produced maps are in two way travel time (TWTT) and were used as the basis for this work. The maps were initially scanned and digitized, in order to produce TWTT grids of each horizon. Fig.2 shows six of the seven horizons produced for the Porto Basin. Horizon 2 did not cover most of the Porto Basin and was not considered in the analysis

Table 1 – Horizons interpreted by the Milupobas project.

Horizon	Designation
H1	Near Top Intra Late Cretaceous Carbonates
H2	Near Base Late Cretaceous Carbonates
H3	Base Early Cretaceous Unconformity
H4	Intra Late Jurassic Unconformity
H5	Near Top Intra Middle Jurassic Carbonates
H6	Near Top Hettangian Evaporitic Complex
H7	Near Top Paleozoic Basement

As depicted in Fig. 2, not all the horizons have the same area coverage. In order to facilitate the grid-to-grid operations, namely to convert the TWTT grids into meters, we interpolated all the grids within the same area. The limits of Horizon 3 were chosen as the more representative. In most horizons extrapolation artifacts occurred only in relatively small, peripheral areas. Horizon 5 was previously built using both Horizon 4 and 6, which truncate 5 at different places. The method of Natural Neighbors was used for the interpolation.

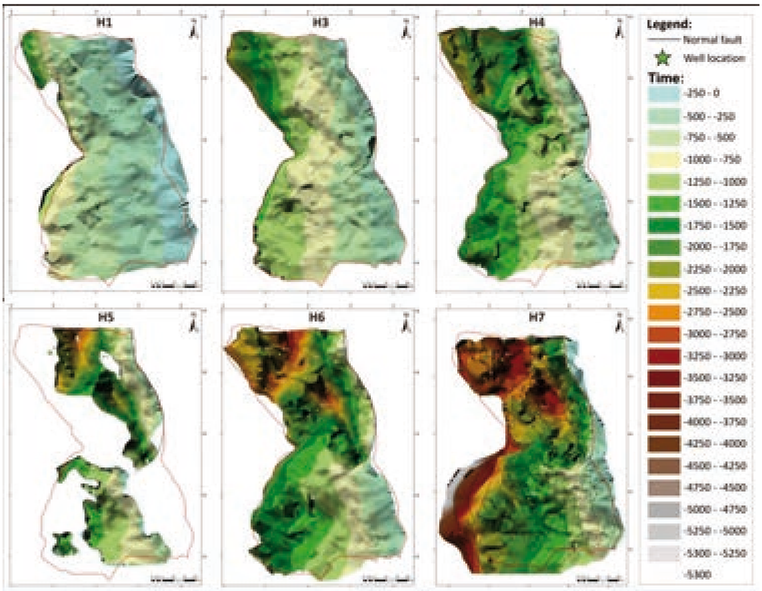


Fig. 2 – Original structural horizons for Porto Basin in TWTT (compiled from the Milupobas Project).

3.2 – Conversion of two-way travel time to meters

The conversion between TWTT and depth was performed based on the formations velocities obtained along oil exploration wells 5A-1 and Lu-1 (Table 2; see Fig.1 for location of the wells). Due to the large discrepancies in the velocities obtained in the two wells, reasonable values which could apply to the whole of the Porto Basin were estimated. Between the Surface and H1 and between H4 and H5 the velocities measured in the wells seemed extremely high, at least when compared with the velocities of similar formations in the Lusitanian Basin, measured along numerous exploration wells. The depth conversion was then calibrated by the wells log data (Fig. 3) and maximum errors of 100-200 metres were obtained between the calculated depth grids and the depth of the horizons in the wells.

Table 2 – Formations velocities measured in wells 5A-1 and Lula-1, and used for conversion of the horizons from TWTT to meters (see Figures 4 and 5).

	Velocity (m/s)		
	5 A-1	**Lula**	**Used**
S – H1	2850	2150	2700
H1-H3	3285	3341	3000
H3-H4	4110	4130	4000
H4-H5	4890	-	4250
H5-H6	5200	4060	4500
H6-H7	4750	4400	4500

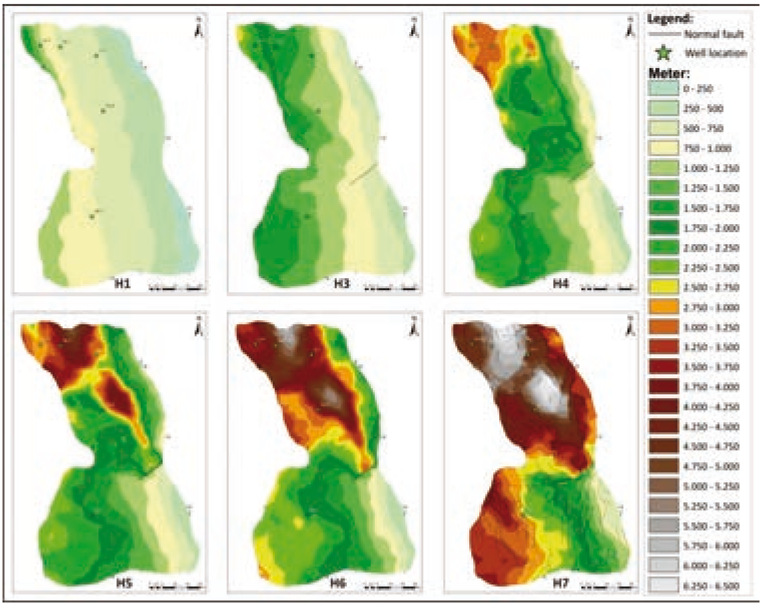
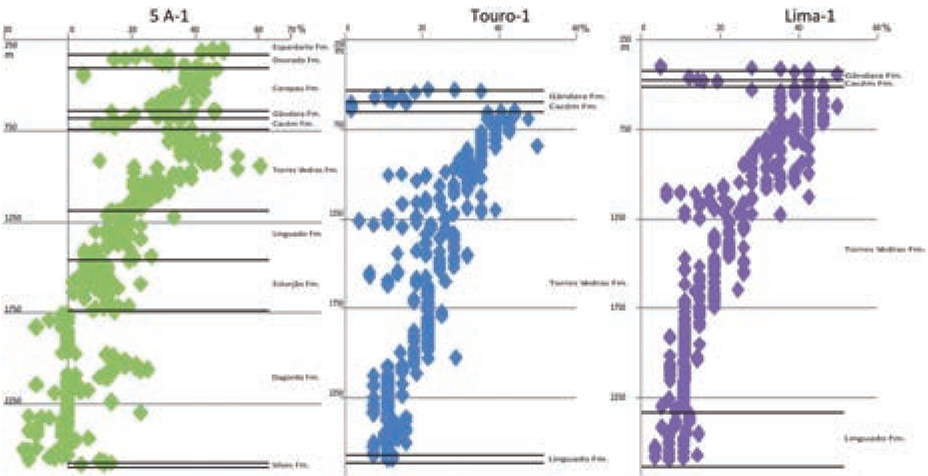


Fig. 3 – Structural maps of Porto Basin after TWTT-depth conversion.

4 – Petrophysic reservoir properties

A reservoir suitable for CO_2 storage must have some fundamental petrophysic properties. The basic parameters are the permeability and the porosity. High permeability values ensure an efficient injection of CO_2 into the reservoir, whilst the high porosities guarantee the capacity of the reservoir (EU GeoCapacity *report*).

A preliminary evaluation of the formations porosity was made based on the neutron and sonic logs from 3 commercial wells: 5A-1, Touro-1 and Lima-1 (Fig. 4; see Fig.1 for location of the wells). The reading of the sonic log was matrix corrected, using the Wyllie Time-Average Equation (WYLLIE *et al.*, 1958).



Depth (m)	Formation
300-325	Espadarte
325-400	Dourada
400-635	Carapau
635-680	Gândara
680-740	Cacém
740-1185	Torres Vedras
1185-1455	Linguado
1455-1730	Esturjão
1730-2560	Dagorda
2560-2585	Silves

Depth (m)	Formation
525-590	Gândara
590-645	Cacém
645-2555	Torres Vedras
2555-2600	Linguado

Depth (m)	Formation
400-455	Gândara
455-490	Cacém
490-2300	Torres Vedras
2300-2600	Linguado

Fig. 4 – Porosities from wells 5A-1, Touro-1 and Lima-1 of Porto Basin.
The values represented were obtained by reading a spacing of 5m.

Fig. 4 shows that whilst well 5A-1, in the southern Porto Basin, crosses the entire basin stratigraphic record, wells Touro-1 and Lima-1, towards the basin center (see Fig.1 for location) only sampled the Cretaceous and Late Jurassic units. It is noticeable, however, the thickening of these units towards the basin center.

From the simplified porosity-depth profiles, two formations outstand as possibly reservoirs for CO_2 storage. (1) The Torres Vedras Formation, with porosities ranging between 20% and 40% when buried above 1250m. The Torres Vedras Formation is sealed by the Cacém Formation, generally < 100 m thick, with minimum porosities of approximately 10%. (2) The Silves Formation and some strata within the Dagorda Formation, which exhibit porosities of up to 20%, sealed by very low porosity evaporites.

5 – Volume Capacity Calculation

The Porto Basin was sub-divided into a number of sub-areas, according to the main structural features and the physiography of the basin (Fig. 5). The storage volumes were then calculated for both the Torres Vedras Formation, defined between horizons H1 and H3, and the Silves-Dagorda formations, defined between horizons H6 and H7. For the calculations we assumed either a laterally constant 100 m thick layer (minimum storage) or the average thickness of the formations in the defined sub-areas (maximum storage; Table 3).

It is important to notice that the sub-areas were calculated for formation depths between 800 and 2500m, considered ideal for the CO_2 storage (EU GeoCapacity *report*, 2009). Sub-area 11 in Fig. 5 is the only region within the Porto Basin where the Silves Formations is within such depth range.

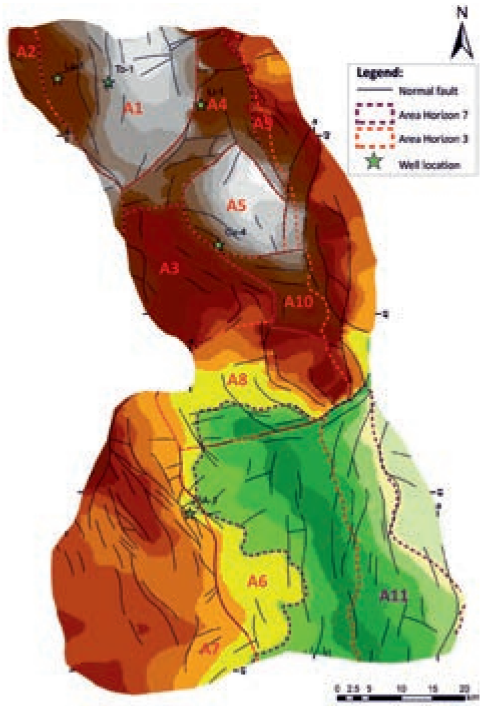


Fig. 5 – Sub-areas used for determining storage volumes. Red lines to Torres Vedras Formation (A1-A10) and violet line to Silves Formation (A11).

6 – Conclusions

A preliminary analysis of the formations porosities along the available oil exploration wells suggests that only the Torres Vedras Formation (Early Cretaceous), and possibly the Silves Formation and some strata within the Dagorda Formation, have reasonable porosities for CO_2 storage.

Table 3 – Area and porous volume calculated for the Torres Vedras Formations, between H2 and H3. Area (A11) and porous volume calculated for the Silves Formations is sub-area 11 (Fig. 5), between H6 and H7 (violet line).

A	Area (km^2)	Volume for 100m thick. (km^3)	Average thickness (m)	Volume (km^3)
A1	448	44.8	1910	856
A2	429	42.9	887	381
A3	290	29.0	607	176
A4	218	21.8	1810	395
A5	166	16.6	493	82
A6	993	99.3	419	416
A7	636	63.6	445	290
A8	343	34.3	421	144
A9	89	8.9	402	36
A10	44	4.4	371	16
A11	873	87.3	433	378

Within the recommended depth range for storage, i.e. between 800 and 2500m, a total area of 3656 km^2 was calculated for the Torres Vedras Formation and of 873 km^2 for the Silves Formations. In the Torres Vedras Formation the porous volume available for storage has been estimated between 365.6 and 2792 km^3, assuming a constant 100m thick layer or the average thickness of the formation. The Silves Formation is only within acceptable depth ranges along a narrow band sub-parallel to the coast, and porous volume available for storage has been estimated between 87.3 and 378 km^3.

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