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Synthesis of the exploration of formations with a potential of CO_2 storage: Intermediate Depression and Madrid Basin

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Abstract

As a part and continuation of the work that is being done under the GeoCapacity Project, Spanish Geological Survey (IGME) has developed a selection of CO_2 storages in the great sedimentary basins of Spain. This presentation is a result of these studies in the Tagus River Basin, including the two zones in which this basin is traditionally divided in geological publications: Intermediate Depression and Madrid Basin. Using information from hydrocarbon exploration campaigns, mostly seismic and borehole logging, as a starting point, storage- seal pairs have been identified, attending to different criteria, such as depth, height, porosity or salinity of the formation water. Through the analysis of these parameters two geological formations have been selected as the most promising: Buntsandstein sandstone Formation, with a primary seal in Röt clays and a secondary seal in Keuper clays, and Utrillas sandstone Formation (Lower Cretaceous) with a seal in the Superior Evaporitical Formation (Upper Cretaceous).

On the other hand, as a special case study of the GeoCapacity Project, a detailed study of a selected structure is being carried out in the Tagus River Basin, about 70 Km to the South East from Madrid. This structure is a long double-domed anticline detected under a thick Tertiary deposit that is not folded. Two different formations have been selected as potential storages:

- Utrillas sandstone (L-M Cretaceous): It completely covers the extension of the structure, and it is sealed by Tertiary marls and gypsum. Average porosity varies from 7 to 18% and height is about 120 m at a depth of 1550 m.
- Buntsandstein sandstone (L Triassic): It is only deposited in the Eastern dome of the structure, sealed by Röt clays of the Middle Triassic. Average porosity is 14% and height is about 50 m at a depth of 1700 m.

Total capacity of the structure has been evaluated at a first stage in 812 Mt in the case both formations can be used as storage.

Keywords: Geological storage, CO_2, capacity estimation, Spain.

1. Introduction

The GeoCapacity Project includes some specific case studies as its most detailed set of information. Every country that has participated in the evaluation of saline aquifers and hydrocarbon fields as potential storages for CO_2

has selected the two most promising sites and has developed a detailed study of the complete CCS case, including a precise estimation of the potential capacity of the sites.

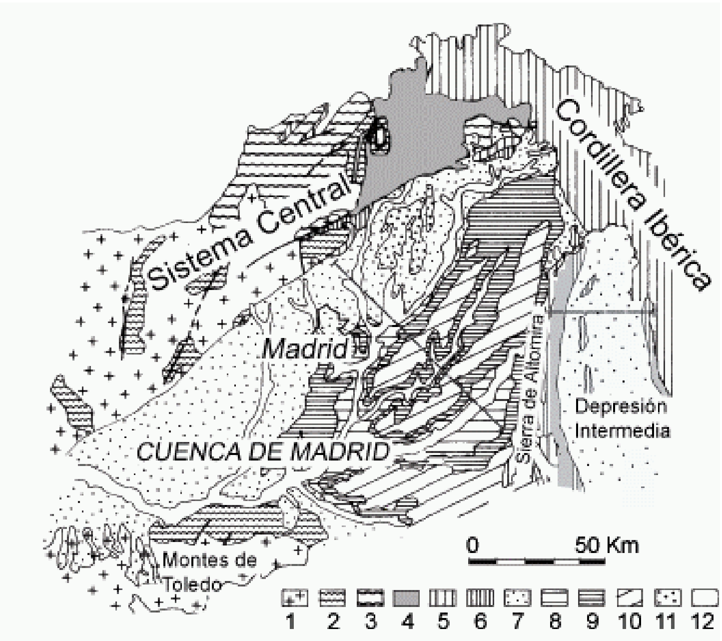
In this case, one of the Spanish case studies is presented. After regional works, and through a complete revision of subsurface information (i.e. geophysics and boreholes), it was found that the Madrid basin was one of the most interesting regions to find viable geological storages of CO_2. Higher possibilities were found in the Mesozoic formations, which were easier to find at the depth of 800 meters or lower, and presented adequate physical parameters, especially in the case of sandstones.

Tielmes structure was then selected, because of its big size and low distance to Madrid industries. The case study was evaluated and two formation were selected: Utrillas Sandstone (Cretaceous) and Buntsandstein Formation (Triassic). These formations are present in this double domed structure and a precise description of the process of capacity estimation is described here.

2. Geographical Location and Geological Background of the Work

The Madrid Basin and the Intermediate Depression are areas located in the central part of the Iberian Peninsular and belong to the Tajo Basin with an extension of some 20,000 km^2

The Madrid Basin is an intracratonic basin that consists of the greater part of the province of Madrid and which is limited in the east by the Altomira Basin, the uplifting of which produced the individualisation of this area of the Intermediate Depression. It is limited on the west by the Central System. The Intermediate Depression is a basin, at least for inferior piggyback units (Vera, 2004), produced during the Alpine Orogeny; it extends through the provinces of Cuenca and Guadalajara and is limited by the *Sierra de Bascuñana* in the east, and the *Sierra de Altomira* to the west. In its most northerly section, both basins are connected by the outcropping of Cenozoic materials at *Cubeta de la Alcarria* and limited by the first Mesozoic reliefs of the interference between the Iberian and Central system Cordilleras.



The structural directions that characterise the *Sierra de Bascuñana* and the *Sierra de Altomira* (NNW-SSE and N-S) were the consequence of the Alpine Orogeny, which originated the main piggybacks and folds, leaving a negative relief between the two, the Intermediate Depression, which is filled with Cenozoic materials. In addition to the NNW-SSE and N-S directions of the *Sierra de Altomira*, the Madrid Basin is also characterised by NE-SW directions of the Central system, the tectonic origin of which is also Alpine.

FIGURE 1. *Geological map of the Tajo Basin and its margins. Legend: 1. Plutonic rocks; 2. Slates, marbles, quartzites and gneisses; 3. Slates and metagreywacke; 4. Slates, quartzites and, metavulcanites; 5. Mesozoic; 6. Early Tertiary; 7. Undifferentiated Miocene; 8. Lower Miocene Unit; 9. Intermediate Miocene unit; 10. Upper Miocene unit; 11. Pliocene; 12. Quaternary.*

The two basins develop Mesozoic and Cenozoic series up to 3,000 metres in length over a Palaeozoic substrate, comprising igneous (granites) and metamorphic materials (slates, sandstones, schists and gneisses). In general, the Mesozoic commences with Germanic facies (Buntsandstein, Muschelkalk and Keuper) and these are crossed in all deep boreholes drilled in the Intermediate Depression, however, there is an erosive limit in the Madrid Basin that explains the lack of these facies in some of the western sector boreholes. With respect to the Jurassic Series, these do not appear in all the boreholes, but the Cretaceous do, emphasising the continuity of the Utrillas siliciclastic facies, together with the Upper Cenomanense formation, because it is in the Mesozoic where the sought-after store-seal pair is found that is necessary to achieve CO_2 storage. The majority of outcropping materials in the area are from the Cenozoic.

3. Analysis of the subsoil information

Subsoil information compilation work was carried out for the areas in which the survey took place in order to identify the formations capable of storing CO2. On the one hand, the goal is to obtain a storage formation that allows guaranteeing the entry of CO2 so that deep formations are sought after with adequate porosity and permeability values in siliciclastic or carbonated facies and this search has to be completed with supra-adjacent formations that enable us to obtain storage certainty. They must, therefore, be formations with clay or chalk facies that provide good performance as seals. With this general viewpoint, general storage formations were identified in both basins, together with their adjacent seals which are described below: the Buntsandstein formation with its lithology of red sandstone from the Lower Triassic, and its seal formed by the Röt formation made up of red clay from the same geological period, also being able to identify a secondary seal in the Keuper formation, Upper Triassic clays. The second goal is a store of siliciclastic facies, Upper Cretaceous Utrillas facies with an Upper Evaporitic formation seal from the Upper Cretaceous.

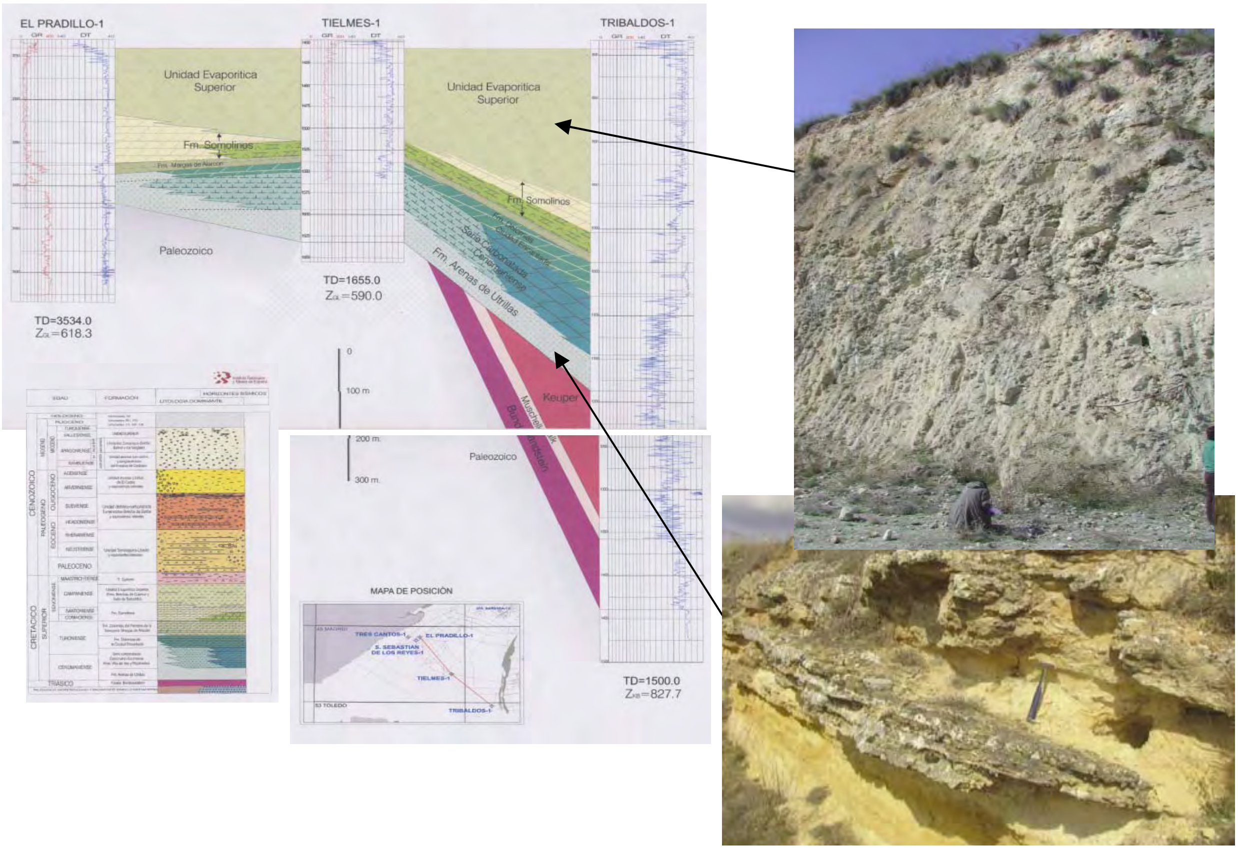


Figure 2: Stratigraphic correlation between boreholes and outcropping facies recognition

The result is reached after thorough analysis of the deep boreholes that were drilled in the area, mainly in the 60s and 70s as a result of the hydrocarbon surveys in Spain. Four borehole results were consulted in the Madrid Basin: Tribaldos 1, El Pradillo 1, Baides and Tielmes, together with eight in the Intermediate Depression: El Hito-1, Huete XI-1, Villanueva de los Escuderos-1, Torralba-1, San Lorenzo de la Parilla-1, Belmontejo-1A, El Gabaldón-1, Santa Bárbara-1

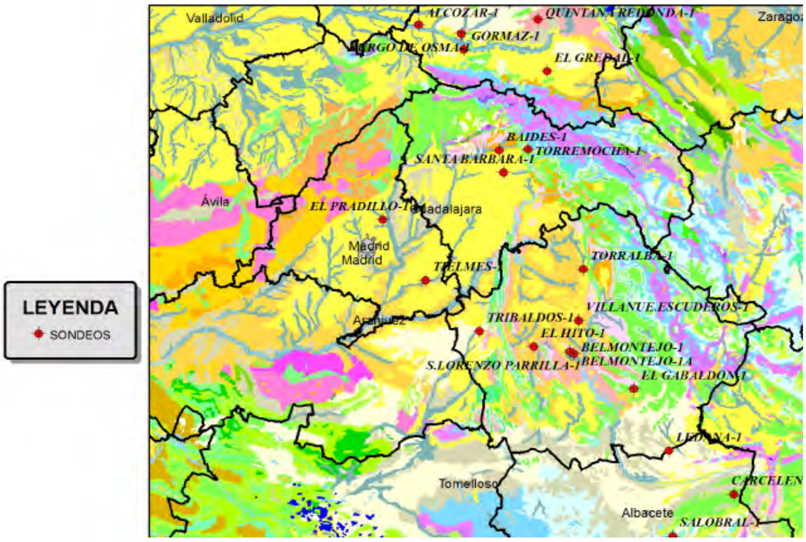


Figure 3: Location of the consulted deep boreholes

As a result of these surveys, it was determined that the Cretaceous objective (for store-seal), marked as possible in general terms in the Tajo Basin, has to be discarded in the Intermediate Depression, since although the porosity values are sufficient for positive validation, in none of the cases do the salinity values exceed 15,000 ppm, the figure set by the IGME CO_2 Storage Working Group as the lower limit for considering the formation as a possible CO_2 store (Martínez, 2006). Therefore, a single objective is fixed for this area, Buntsandstein, which does posses the right conditions for both porosity, 10-11 % in the El Hito-1 borehole, as well as salinity, 15,000 ppm - 20,000 ppm in the Torralba-1 borehole.

It was possible to establish two traps for the two store-seal objectives in the Madrid Basin. With respect to the Utrillas formation store, here we do have data on sufficient salinity levels with values of 67,000 ppm at a depth of 1,500 metres in the Tielmes borehole. In addition, we have a secondary store in the Upper Cretaceous carbonates, whish were cut in all consulted boreholes. The erosive chamfer that affects the Buntsandstein series in the Triassic store in the Madrid Basin and causes its disappearance in the western sector was taken into account when determining the surface of this Buntsandstein objective. The dolomites of the Muschelkalk facies were also considered to be a secondary objective.

4. Petrological and Petrophysical Assessment of the store formations

Once the information was processed for the boreholes to which access was possible, salinity values of 15,000 ppm to 20,000 ppm and porosity of between 2 and 10%, with thickness from 21 metres in some boreholes to 134 metres which were cut in others, were obtained in the store objective, Buntsandstein-Muschelkalk, with Keuper seal in the Loranca Basin. This objective was not considered in the Madrid Basin because of the erosive limit in the Triassic (interpreted and established by the company Shell 1978/1980). It was possible to establish this objective in the eastern sector and, although there are no specific salinity data for these formations, an induced saline character has been considered, since there are always salinity values exceeding 15,000 ppm in higher stratigraphic series.

The Utrillas facies appear in both basins in a continuous fashion, but with favourable storage characteristics only in the Madrid Basin because the water salinity values in the Intermediate Depression indicate its fresh or brackish water nature which, in all cases is less then 15,000 ppm. The thickness range is from 37 to 72 metres, with a porosity variation of 15% to 18%. The supra-adjacent Utrillas facies carbonates are also considered to be a secondary store because of their intermediate position between the main store and its seal, because although they do not posses any especially favourable characteristics for being considered a priority store (porosity is around 7% with medium-low qualitative permeability), they could contribute to the overall storage capacity in the trap.

5. Pre-selection and classification of structures

Based on an analysis of the former seismic campaigns conducted in these areas, a pre-selection of structures has been made. They have been classified into two different categories; some have been listed as priorities and others as potential objectives. Those considered as priorities have sufficient information available to undertake an in-depth future study with certain guarantees, and those seen as potential areas are ones in which their petrological and structural characteristics indicate they are suitable for investigation, if the necessary information were available, which would require a data acquisition campaign.

6. Intermediate depression structures

The priority objectives marked out are:

Puerta Pareja structure, located between these two municipalities. It is located in the vicinity of the *Entrepeñas* dam, 50 km from Guadalajara. It is an anticlinal structure with a Buntsandstein reservoir and Keuper cachet. It is related to the compression of the *Sierra de Altomira*, and located in one of its folds. The longitudinal axis of the structure extends in an N-S direction, and is delimited on the W by a main thrust on the surface and by several smaller-sized ones (all with a western convergence).

Tribaldos structure, located to the SE of the town of *Arganda del Rey* in Madrid. It is an anticline and the objective is twofold: Buntsandstein reservoir and Keuper seal with an Early Cretaceous reservoir and Late Cretaceous seal. It stretches in a N-S direction, the same as the *Sierra de Altomira*, to which it belongs structurally. It is delimited to the E and W by the western convergence of thrusts that lift the chain. In this case, the Cretaceous series have also been considered as reservoirs due to the proximity of the Tielmes probe, which have an estimated 67,000 ppm concentration of salt in the Cretaceous zone and which is considered structurally disconnected from the intermediate depression, where the entire Cretaceous presents concentrations of brackish-fresh water.

The potential objectives marked out are:

Continuation of the Puerta Pareja structure, possible belt of anticlinal structures, all along the *Sierra de Altomira*, similar to the previously described *Puerta Pareja* structure.

Altomira Allochtonous Face, set of anticlinal structures with convergence to the W and characteristics similar to those of the priority objective, the Tribaldos structure.

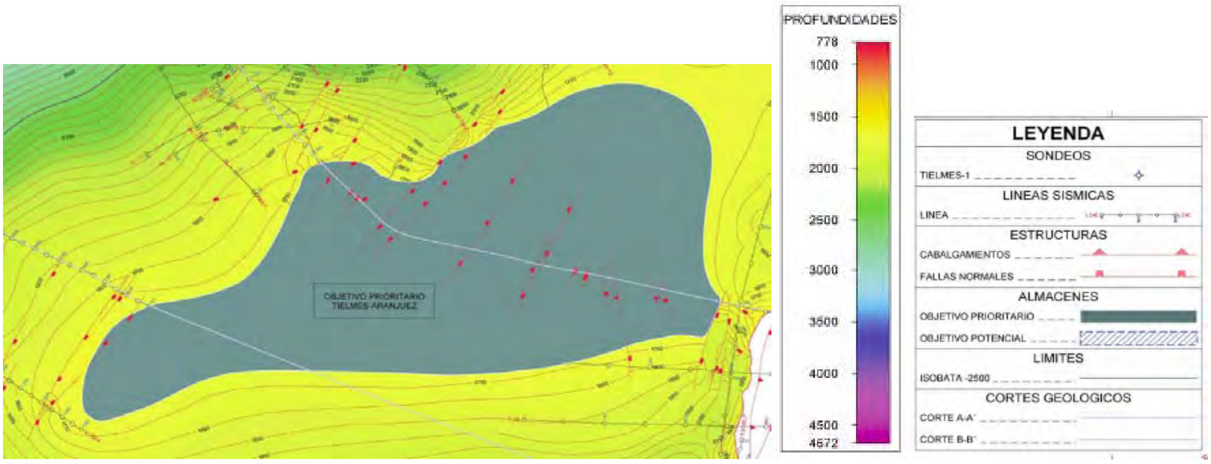
7. Structures of the Madrid Basin

Potential objectives:

Baides Occidental and Baides Oriental structures. These two structures are located in a lifted block, related to the Madrid fault that lifts the Central System. They are delimited to the S by a thrust with a SE convergence and to the north by the Madrid fault, which also has a southern convergence. By operating as an independent block of the basin and with relatively continuous lifting over time, there has been a compression of the series causing the Baides-1 probe to find a very constant sedimentary record (with the exception of the Jurassic) from the Triassic until the Palaeogene. This condensation causes the base of the Cretaceous to appear above the minimum depth of 800 m, marked as a limit for storing CO_2 in a supercritical state and thus optimising the capacity of the structure (Calvo *et al*, 2007). Therefore, the only possible objective is the Buntsandstein-Muschelkalk reservoir with a Keuper seal, which it is located around that depth. In setting these Triassic series as objectives, it must be taken into account that in the western zone they are affected by an erosive limit, thereby reducing the area available for storage of CO2.

Tielmes structure, located 50 km to the SE of Madrid. The objective is constituted by the Buntsandstein reservoir with Röt formation seal and Keuper facies. The structural catch is an anticlinal and one could also mention a stratigraphic catch because it is delimited on the west by the Triassic erosion limit.

Tielmes-Aranjuez Structure, very flat anticlinal structure that extends from to the vicinity of the *Sierra de Altomira*. We consider the reservoir here to be the Utrillas facies of the Early cretaceous and the carbonates of the Late Cretaceous and the evaporitic formation of the Late Cretaceous. This structure almost completely overlaps that of the Tielmes. The area this structure occupies has the largest extension of all those studied in the Tajo basin.



Objetivo Prioritario: ***Tielmes-Aranjuez***		
Trampa:	Estructural	
Almacén	Litología	Facies Utrillas: Arenas Cretácico Sup.: Carbonatos
	Potencia	Utrillas:50m Carbonatos:110m
	Porosidad Media	Utrillas:18% Carbonatos:7%(Sta. B)
	Profundidad del techo	Utrillas:1555m Carbonatos:1530m
Sello	Litología	Margas y Evaporitas (Fm. Evaporítica Superior) Arcillas(Utrillas)
	Potencia	90m(Fm. Evaporítica Superior) 25(Utrillas)
Superficie total	1.175km²	
Salinidad	67.000ppm.	

Figure 4. Map of isobaths from the Cretaceous limit and summary of results of analysis of the structure

The potential objectives are:

The Autochthonous Altomira, possible set of artificial type anticlinal structures under the main *Sierra de Altomira* thrust. The reservoir is formed by the sandstone of the Utrillas facies and by carbonates of the late Cretaceous. There are two types of seal formations for this objective, on the one hand, the clays of the Utrillas roof formation and on the other the evaporite of the upper evaporitic formation.

8. Acknowledgements

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