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# CO2 storage assessment and effective capacity of deep saline aquifers in South –West of Algeria

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**Abstract**— The CO2 Capture and Storage techniques, improved energy efficiency, an increasein use of renewable resources (solar energy …) and more rational use of fossil fuels, can be a key instrument for reducing CO2 emissions in the atmosphere. Deep saline aquifers offer the greatest storage potential for all geological storage options and are widely distributed deep in the Earth. The Western region of the Saharan platform in Algeria includes several sedimentary basins characterized by a large production of dry gas with CO2 rates sometimes exceeding 9%. In order to reduce CO2 emissions; these basins are analyzed with the aim of determining those offering the largest potential for the geological sequestration of CO2 (GSC). The evaluation methodology of the basin potential uses qualitative criteria that are both geological and practical to which we have assigned normalized numerical values in order to perform an objective and quantitative comparison between the basins. An estimate of the CO2 storage capacity of some structures in the sedimentary basin of Ahnet-Gourara which has the greatest potential for GSC varies from 1Gt to over 5Gt Based on very cautious estimations, these structures would be able to contain the entire volume of the emitted CO2 for at least the next three decades.

**Index Terms**— Carbon Capture and Storage, Algeria, basin assessment, Screening, Storage capacity, Aquifers.

## 1 Introduction

It is widely believed that the main reason for which the earth temperature is rising is due to a very rapid increase of greenhouse gases in the atmosphere caused essentially by exponential growth in the quantities of carbon dioxide (CO2) released in the atmosphere since the industrial era. In 1993, Algeria ratified the Framework Convention of the United Nations on Climate Change (UNFCCC) developed on the Earth Summit in Rio in 1992and acceded to the Kyoto Protocol in 2004 thereby marking its will to participate in the international effort in fighting the climate change and its repercussions, particularly on the climate system, natural ecosystems and sustainability of economic development.). At present, global anthropogenic emissions are about 26 Gt per year [1]. In Algeria, CO2 emissions are approximately 117.310 million tons in 2000 [2].
As example; the different sources of emissions of CO2 in the south west Algeria are mentioned in (Fig 1b) established from the production of dry gas indifferent site Currently the CO2 capture and sequestration (CCS) is gaining interest as they represent, in the medium and short term, a viable potential solution for reducing anthropogenic CO2 emissions in the atmosphere [3] ,[4]. In fact, the CO2 sequestration technology in gas and oil reservoirs as well as in deep saline aquifers is now ready for use. Worldwide, the search for potential sites for geological CO2 sequestration is well underway in sedimentary basins that are known for the quality of their geological reservoirs. [5] The Southwestern Algeria which is characterized by high production of dry gas with CO2 levels exceeding sometimes 9%, is divided into several sedimentary basins that are analyzed to determine which offer the greatest potential for CO2 geological sequestration, additionally to an estimate of the storage capacity. This study represents the first assessment of potential storage in deep Algerian saline aquifers.

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## 2 Geological Setting

The Algerian sedimentary basins have a geological history which takes part in the global geodynamical process of plate tectonics that had structured Algeria into two areas, North Algeria and the Saharan platform which are separated by the South Atlas Fault.
The southwest of the Algerian Sahara, which is the subject of this study, is geologically linked to the western part of the African slab and is limited in the South by shield borders of the Reguibat (Egleb-Yetti) and Touareg (Hoggar)and the North by the deep South Atlas accident zone; separating the Precambrian and the Mesozoic active epi-Hercynian platforms[6] (Fig. 1a).
Sediments of the Paleozoic geo-structural era are most ubiquitous in the Algerian Sahara; this is the reason why it serves as a reference for the division of the Sahara into tectonic regions.
The various data collected on the field, during seismic campaigns, helped to distinguish the different tectonic phases that have affected the sedimentary cover in the region, such as the Pan-African phase or the Pan-African heritage which would have begun from 780 Ma, where large vertical movements occurred along with a calc-alkaline volcanic andesitic type "active margin" related to subduction phenomena (Drid, 1989).
Around 600 Ma, a continental collision took place corresponding to the major phase of the Pan-African orogeny, as a result of an E-W compression, inducing tightening between two cratons (rigid West African and East African Nilotic) in adequacy with meridian folds, metamorphism and granitisation.
The Algerian Sahara was submitted to these vertical movements accompanied by volcanic eruptions and uplifts that caused the erosion of the sedimentary cover.
One of the major structural features is the disposition in

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longitudinal compartments corresponding to horsts and grabens. The Accidents that separate them, with WNW-SSE orientations, correspond to major shears. Lateral movements can be very large and exceed a hundred kilometers [7] .

The most important structural elements of these basins were formed during the Hercynian orogenic phase. The post-Hercynian orogenic movements had little effect on their structures. The impact on the Hercynian unconformity is almost nil, except in the few places where slight deflections are hardly detectable [6]. The Tassili phase at the beginning of the Cambrian is reflected by the unconformity of the Cambrian deposits on the Precambrian basement. As for the Taconic phase, it was responsible for the erosion of Ordovician deposits. The Ardennes phase started at the end of the Silurian, during which a regime change in regressive tendency with positive decreased epirogenic movements, resulting in the tilting of the basin to the South during the Silurian

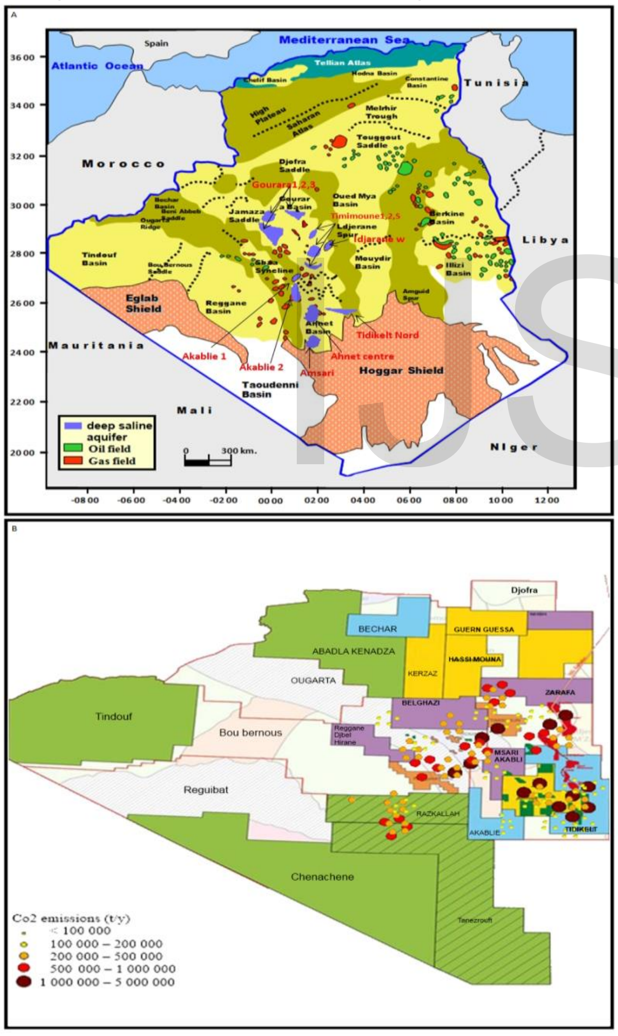


**Fig. 1.** Simplified geological map of Algeria (Beuf *et al.*, 1971) showing: (A) the location of the 12 potential areas, suitable for the CO2 geological storage; (B) the location of the major CO2 point sources (emissions > 0.1 Mt/year) in south west part of Algeria ; values are calculated from the production of dry gas of different field.

and to the North during the lower Devonian until the generalized marine transgression marked by the "Wall of China".

The Late-Hercynian phase is marked by the formation of direction folds N130 °folds parallel to the Ougarta chain [8]

Finally, an Alpine phase that generated folds direction N110° folds and reactivated the N-S strike-slip fault. [8] . Suggested the existence of Hercynian post-moscovian phases with an orientation NNE-SSW constraint. Therefore, it is a set of folds and relays with variable extensions associated with deep faults.

## 3 Evaluation of the Basins

The methodology followed for the evaluation of the potential of sedimentary basins for geological sequestration of CO2 is based on the work of Bachu (2003) [9] and CO2CRC (2008) [10]. This potential is determined based on several geological characteristics and practices. The methodology used allows for the conversion of these qualitative characteristics in order to quantitatively evaluate few specific criteria. The basins' analysis is based upon a set of criteria and classes, which are shown in table 1. The first step in the analysis is to determine to which qualitative class (j=1.....n) the basin belongs for each of the fifteen evaluation criteria (i=1…15). Three to five classes (n=3.4.5) are used for evaluating each of the criteria. The existing geological and geophysical data as well as the geographic

and geological knowledge of the basins are essential for properly evaluating the criteria. Each of the classes has an individual value ($F_{i,j}$) which helps move from qualitative values ( basin characteristics) to comparable quantitative values. The less and more favorable classes have the lowest and the highest values respectively. The individual value of each of the classes is determined depending on their importance for the geological sequestration of CO2. This way, if the classes have a similar importance, a linear variation of the class values is used. If conversely, the most favorable classes have a higher importance than the others, the variation of the values will rather have an exponential feature. Table 2 shows the values of the various classes used in t he framework of the study of the sedimentary basins in Southwest Algeria. The individual values of the classes ($F_{i,j}$) and the weight assigned to the criteria ($w_i$) were adapted in order to take into account the intrinsic characteristics of these basins.

In order to be able to compare the various class values of each of the evaluation criteria for a basin k, the individual values ($F_{i,j}$) are normalized in accordance with the equation :

$$P_i^k = \frac{F_{i,j}-F_{i,1}}{F_{i,n}-F_{i,1}} \qquad (1)$$

This equation helps distribute the class values between 0 and 1. Hence, for all evaluation criteria, the least favorable class always has a Pi value of 0 and the least favorable class, a Pi value of 1.Each basin k is thus characterized by 15 normalized individual values.

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Each criterion has a different importance in the evaluation of basins. Therefore, a criterion with a high incidence on the sequestration potential of CO2 will have a higher weight ($w_i$) compared to a least significant criterion. The weights of the criteria are shown in Table 2. The weights meet he following condition:

$$\sum_1^{15} W_i = 1 \qquad (2)$$

The final score of the basins ($R^k$) is ultimately calculated using a weighted average of the normalized individual values and the weights of the corresponding criteria:

$$R^k = \sum_1^{15} W_i \, P_i^k \qquad (3)$$

The basins which obtain the highest final score are those that display the highest potential for the geological sequestration of CO2. It is therefore possible to determine the basins that deserve to be studied in more details and to proceed to the evaluation of specific sites for the geological sequestration of C02.

## 4 Evaluation of Algerian reservoir formations suitable for CO2 geological storage

The determination of potential geological storage reservoir is one of the first steps for determining the most suitable basin for the geological storage of CO2.This basin must:

- Contain excellent reservoir-cover sets [3] ,
- have a large amount of seismic data and wells,
- accessibility and infrastructure development
- to be available
- in addition, saline aquifers in depth within the sedimentary sequence.

This criterion is used to calculate the final score of the basins and to better compare them objectively to determine the most appropriate geological sequestration of CO2.

The Characteristics of sedimentary basins in southwestern Algeria are summarized in a quantitative way in Table 3. Suitable geological formations for CO2 storage are at a depth of 800-1000m.Thes formations keep the injected CO2 in a supercritical state, a liquid-like density (about 500-800 $kgm^{-3}$), which provides the potential for efficient space filling of the underground storage. This density makes it possible to keep buoyancy and to lead it to a high storage capacity of CO2 [3] .

Therefore, in order to verify the location of geological formations with these characteristics in the basin Ahnet-Gourara southwest Algerian more than 250 wells and 45,000 km of 2D seismic profiles and 8750 $Km^2$ of 3D seismic 3D were put to our disposal by the National Agency for the Valorization of Hydrocarbon Resources (ALNAFT) and the National Society for Research, Production, Transportation, Processing, and Marketing of Hydrocarbons (SONATRACH) as part of a thesis project. This data was acquired by several oil companies since 1965.

Table 1 Evaluation criteria of the sedimentary basins potential for the geological sequestration of CO2. Modified from Bachu (2003), CO2CRC (2008) and Malo(2012).

| Criteria | | Classes | | | | |
|---|---|---|---|---|---|---|
| | | j=1 | j=2 | j=3 | j=4 | j=5 |
| i=1 | Seismicity | Very High | High | Intermediate | Weak | VeryWeak |
| i=2 | Area km2 | <1000 | 1000-5000 | 5000-25000 | 25000-50000 | >50 000 |
| i=3 | Depth (m) | VeryDeep <300 | Shallow (300-800) | Deep >3500 m | Intermediate (800-3500) | |
| i=4 | Deformation | Important | Moderate | Weak | | |
| i=5 | reservoir-coverage | Weak | Intermediate | Excellent | | |
| i=6 | Geothermal Power | Warm Basin (>40 °C/km) | Moderate Basin (30-40 °C/km) | Cold Basin (<30 °C/km) | | |
| i=7 | Potentialin hydrocarbon | None | Weak | Average | High | Huge |
| i=8 | Evaporites | None | Domes | Beds | | |
| i=9 | Coal | None | Deep (>800 m) | Shallow (200-800 m) | | |
| i=10 | Exploration Maturity | Not explored | Exploration | development | Mature | Super mature |
| i=11 | On/Offshore | In shallow Sea | In shallowSea | In Shallow sea and inland | Inland | |
| i=12 | Climate | Arctic | Subarctic | Desertic | Tropical | Temperate |
| i=13 | Accessibility | Inaccessible | Difficult | Acceptable | Easy | |
| i=14 | Infrastructure | None | Minor | Moderate | Important | |
| i=15 | Sources of CO2 | None | Little | Moderate | Significant | Several |

Table 1 Values and weight of the criteria and classes for the evaluation of sedimentary basins in South west of Algeria for the geological sequestration of CO2. Modified from Bachu (2003).

| Criteria | | Classes | | | | | Weight (wi) |
|---|---|---|---|---|---|---|---|
| | | j=1 | j=2 | j=3 | j=4 | j=5 | |
| i=1 | Seismicity | 1 | 3 | 7 | 15 | 15 | 0,1 |
| i=2 | Area | 1 | 3 | 5 | 8 | 10 | 0,06 |
| i=3 | Depth | 1 | 2 | 6 | 10 | | 0,1 |
| i=4 | Deformation | 1 | 4 | 10 | | | 0,08 |
| i=5 | reservoir-coverage | 1 | 4 | 10 | | | 0,1 |
| i=6 | Geothermal Power | 1 | 4 | 10 | | | 0,09 |
| i=7 | Potential in hydrocarbons | 1 | 3 | 7 | 14 | 21 | 0,04 |
| i=8 | Evaporites | 1 | 2 | 3 | | | 0,01 |
| i=9 | Coal | 1 | 2 | 5 | | | 0,04 |
| i=10 | Exploration Maturity | 1 | 3 | 4 | 8 | 10 | 0,08 |
| i=11 | On/Offshore | 1 | 5 | 10 | 15 | | 0,11 |
| i=12 | Climate | 1 | 2 | 4 | 7 | 10 | 0,04 |
| i=13 | Accessibility | 1 | 3 | 6 | 10 | | 0,04 |
| i=14 | Infrastructure | 1 | 3 | 7 | 10 | | 0,05 |
| i=15 | CO2 Sources | 1 | 3 | 7 | 11 | 15 | 0,06 |

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Table 2 Evaluation of the criteria and ranking of the potential of southwesterernAlgeria sedimentary basins for CO2 storage

| Criteria | | Sedimentary basins | | | | | | Weight (wi) |
|---|---|---|---|---|---|---|---|---|
| | | **Bechar** | **Tindouf** | **Reggane** | **Cuvette de Sbaa** | **Ahnet** | **Gourara** | |
| i=1 | Seismicity | **5** | **5** | **5** | **5** | **5** | **5** | 0,1 |
| i=2 | Area | **3** | **5** | **5** | **3** | **5** | **5** | 0,06 |
| i=3 | Depth | **2** | **2** | **4** | **4** | **4** | **4** | 0,1 |
| i=4 | Deformation | **2** | **2** | **2** | **2** | **3** | **3** | 0,08 |
| i=5 | reservoir-coverage | **2** | **2** | **2** | **2** | **3** | **3** | 0,1 |
| i=6 | Geothermal Power | **3** | **3** | **2** | **2** | **2** | **2** | 0,09 |
| i=7 | Potential in hydrocarbons | **2** | **2** | **4** | **4** | **5** | **5** | 0,04 |
| i=8 | Evaporites | **2** | **2** | **2** | **2** | **2** | **2** | 0,01 |
| i=9 | Coal | **1** | **1** | **1** | **1** | **1** | **1** | 0,04 |
| i=10 | Exploration Maturity | **2** | **2** | **3** | **3** | **5** | **5** | 0,08 |
| i=11 | On/Offshore | **4** | **4** | **4** | **4** | **4** | **4** | 0,11 |
| i=12 | Climate | **3** | **3** | **3** | **3** | **3** | **3** | 0,04 |
| i=13 | Accessibility | **2** | **2** | **3** | **3** | **4** | **4** | 0,04 |
| i=14 | Infrastructure | **1** | **1** | **2** | **3** | **4** | **4** | 0,05 |
| i=15 | CO2 Sources | **1** | **1** | **3** | **4** | **5** | **5** | 0,06 |
| | | **0,48** | **0,51** | **0,62** | **0,63** | **0,90** | **0,91** | |



The methodology used to evaluate the geological storage capacity in the basin Ahnet-Gourara enables to calculate the effectiveness storage capacity of CO2 (CO2 mass) according to the techno-economic pyramid resources [5]. The effective capacity is defined as a subset of the total capacity of the reservoir, or the theoretical capacity, which is obtained by restricting the ability with of the techniques and geological boundaries.

According to the methodology adopted by the National Atlas of Canada and U.S Department of Energy (2008) [11] , the effective storage capacity of a basin is limited by a minimum depth as well as an effective storage of CO2 in saline aquifers factor. This minimum depth is 800m and aims to ensure the safety of storage sites [12]. The efficiency factors allow to estimate of the proportion of the volume of the reservoir which could be occupied by the injected CO2.

The volumetric capacity calculation is done using the equation below:

$M_{co2}= E_{salin}*A* h*\Phi * \rho_{CO2}$ (4)

Where $\mathbf{M_{CO2}}$ is the effective storage capacity (tonnes), $\mathbf{E_{salin}}$ is the storage efficiency factor, **A** is the area that defines the basin or the region occupied by the aquifer (m²), h is the effective thickness, i.e. average thickness of aquifer × average net to gross ratio (m), **Φ** is the average reservoir porosity (%), and $\boldsymbol{\rho_{CO2}}$ is the density of carbon dioxide at reservoir conditions ($kgm^{-3}$).

The CO2 storage efficiency factors for the saline aquifers vary according to the lithology reservoir units. The most favorable lithology for CO2 storage are dolomites, followed by clastic rocks then by limestone

The efficiencies factors calculated for deep saline aquifers [13] , should be take into consideration:

- the fraction of the aquifer can be occupied by CO2,
- the fraction of the unit with adequate porosity and permeability for the CO2 injection,
- the fraction of the porosity which is interconnected,
- the efficiency of horizontal and vertical movement,
- the efficiency of the displacement pores and buoyancy CO2 scale [14], This factor is between 1% and 4% [11]. In the case of the EU Geo-Capacity Project a 2% value was suggested for a cautious estimate of the CO2 storage capacity in the regional saline aquifers [15].

The reservoir area in m², the surface was determined after identification of reservoirs and caprock formations on the basis of the interpretation of 2D and 3D seismic profiles in combination with the vertical seismic profiles for setting the horizon using the Schlumberger Petrel software. Special attention was also given to the structural modeling to reveal any structural characteristics, faults, at the caprock-reservoir system, which could represent preferential conduits for CO2 leakage.

Rock porosity can be obtained from the sonic log, density log, or the neutron log. The tool response is affected by the formation porosity, fluid and matrix. If the fluid and matrix effects are known or can be determined, the tool response can be related to porosity. Therefore, these devices are often referred to as porosity logs. All three logging techniques respond to the characteristics of the rock immediately adjacent to the borehole. Their depth of investigation is very shallow and therefore generally within the flushed zone

Other petro-physical measurements, such as micro resistivity or nuclear magnetism or electromagnetic propagation, are sometimes used to determine porosity. However these devices are also greatly influenced by the fluid saturating the rock pores

Effective porosity reservoirs (%) (PHY, volume of interconnected pores through which fluid can flow) in saline aquifers have been determined by using Techlog software of Schlumberger, from logs density probe gamma-gamma (density porosity DPHI or overall density RHOB, porosity neutron probe (NPHI) and natural gamma probe (GR). Two different methods were used depending on the availability of the logging of the photoelectric factor (PEF) in addition to the empirical method using the Sonic logs [16].

If PEF is present, the relative volumes of the minerals forming rock (silica, calcite, dolomite and shale) and PHIE are then calculated by the method of Doveton method [17]:

PHIE=PHIT/(1-VSH) (5 )

PHIT is the total porosity calculated from the lithology and VSH is shale volume.

PHIT = (RHMC-RHOB)/(RHMC-RHOF) (6)

RHMC is the density of the matrix obtained from the

lithology, RHOB is the global density, RHOF is the density of fluid presented in the pores.
If PEF is unavailable, PHY is calculated as
PHIE = ((DPHI+NPHI)/2.0)*(1-VSH) (7)
DPHI is porosity obtained from the density probe and the

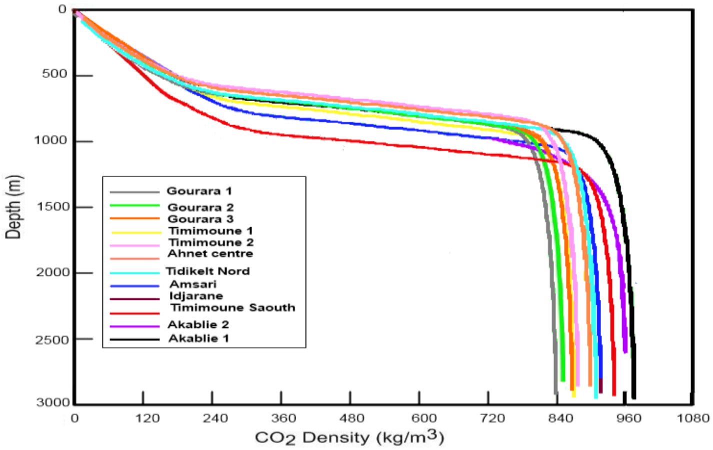


Fig. 2. Graph of CO2 density as a function of depth in the different sites of confinement

NPHI is porosity obtained from neutron probe.
ϱCO2: CO2 density in depth (kg/m3) varies depending on the temperature and pressure which varies with depth in a gradient of temperature and pressure. The temperature is defined by the equation:
T= Ts + (Δz *geothermal gradient) (8)
T is temperature at depth (in meters) ,Ts is surface temperature (in meters),Δz is depth from the surface (in meters) and Gradient is geothermal gradient calculated (° C / m).
As for the pressure is defined by the equation:
P= Δz *pressure gradient *1.1 (9)
P is pressure at depth (MPa)
Particular attention was given to these two parameters that affect the density of CO2, which in turn affects the storage capacity [9]. CO2 density was calculated by using a program written in Fortran developed at the Ruhr-Universität Bochum and based on the work of Span and Wagner [18], the results are shown in (Fig 2).
The effective thickness was calculated considering the sum of the thicknesses of each porous permeable layer inside the reservoir. A minimum threshold of porosity (porosity cut off) and permeability K (md) (permeability cut off) was established for the determination of favorable CO2 injection intervals, and also offering more pore volumes available for controlling storage of CO2. Gamma ray (GR) provided a measure of the thickness of clay intercalations.

## 5 Results

The analysis of the potential of the sedimentary basins in South West Algeria for the sequestration of CO2 has allowed us to highlight the interesting potential of the Ahnet-Gourar basin. In fact, its final score of 0.92% (table 3) differs from that of other basin as it is the priority basin for further investigations in order to identify specific sites and basins for CO2 injection. The research and analytical work we have carried out have led us to the identification of 12 suitable areas represented by deep saline confined and semi-confined aquifers(Please refer to Table 4 and Fig.1).

Table 4 Key parameters of the Ahnet-Gourara potential reservoirs for the evaluation of the CO2 storage capacity input data from Sonatrach.

| Site name | Avarage reservoir depth (m) | Area (km2) | Effective thickness (m) | Porosity (%) | Geothermal gradient (°C/km) | storage capacity (Mt) Seff=1% | storage capacity (Mt) Seff=5% |
|---|---|---|---|---|---|---|---|
| Akablie 1 | 1250 | 100 | 160 | 15 | 30 | 23,3 | 116,4 |
| Akablie 2 | 1165 | 480 | 500 | 15 | 30.5 | 345,6 | 1728 |
| Tidikelt Nord | 1200 | 1150 | 250 | 18 | 30 | 476,1 | 2380,5 |
| Ahnet centre | 1300 | 180 | 120 | 14 | 31.04 | 27,8 | 139,1 |
| Amsari | 1000 | 120 | 100 | 13 | 30 | 14,3 | 71,4 |
| Idjarane west | 1100 | 80 | 80 | 16 | 30 | 9,4 | 46,8 |
| Timimoune1 | 1550 | 100 | 75 | 13 | 30.2 | 8,6 | 42,9 |
| Timimoune2 | 1800 | 800 | 50 | 14 | 30.2 | 49,8 | 249,2 |
| Timimoune saouth | 1500 | 95 | 68 | 17 | 30.3 | 10,3 | 51,3 |
| Gourara 1 | 1400 | 1000 | 50 | 8 | 31.4 | 34,0 | 170 |
| Gourara 2 | 1320 | 168 | 90 | 13 | 31.4 | 17,1 | 85,5 |
| Gourara 3 | 1360 | 180 | 90 | 12 | 31.5 | 16,3 | 81,6 |
| Total | | | | | | 1032,6 | 5162,8 |



The purpose of site characterization is to determine whether a site is suitable and safe for sequestration, and to compile the necessary data for the permit application. The process includes geologic, geophysical, and engineering evaluation. Characterization is designed to provide the geologic and hydrologic data needed to design the infrastructure, develop reservoir models, and design the monitoring program. In this phase of site development, a determination is made of whether the reservoir has adequate porosity, permeability, and continuity for long-term injection. A determination is also made about the ability of overlying units to confine the injected CO2 and prevent vertical movement. This includes evaluation for the presence of non-sealing faults or other potential pathways for migration.
This analysis was mainly focused on geology (stratigraphy and structure) and geophysical (seismic reflection and logging) for the characterization of potential reservoir-caprock system.
Suitable areas are characterized by thick sediment, porous and permeable formations with saline water saturations that sometimes exceed 97% and a very low caprock porosity acting as an impermeable waterproof covering, the various characteristic of these reservoirs are in Table 4.
Based on studies of Bachu [9], twelve potential areas can be considered moderately hot basins with geothermal not

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exceeding 32° C / km, it lying at 1100m and 2200m depth, with temperatures and pressures ensure the supercritical state and the buoyancy of $CO_2$ injected, most of these saline aquifers are favorable to store $CO_2$ mainly of Cambro-Ordovician constitute thick layers of quartztic sandstone with a clay intercalation laminated, while dispersed clay constitute the matrix. As for the cap rock is a minimum thickness of 200m constitute mainly Silurian clay which gives a complete seal to these structures.

This first assessment of the capacity for geological storage of $CO_2$ in Algerian deep saline aquifers found difficulties mainly related to storage efficiency factor $E_{salin}$, the calculations of the potential storage capacity were made, assuming that 0.54% or 5.4 % of the total pore volume that can be filled or saturated [13]. Our calculations give a very conservative estimation of the effective capacity of the pro-sequestration of $CO_2$ that have been determined areas, about 1GT or 5Gt (Seff = 1% and 5%, respectively) please refer to Table 4.

Below, we present the main characteristics of the most promising area for the application of CCS in Algeria; namely basin Ahnet and structure the most favorable to $CO_2$ sequestration; we noted a significant number of structures of varying size with a control mapping the surface outcrops.

Analysis of seismic maps shows a degree of intense structuring of this area, which contains interesting mix of prospects and structurally complex types.

The basin of Ahnet differs from other areas of the Saharan platform by its degree of intense structuring linked certainly the evolutionary history of the West African craton junction, considered stable, there are about 2 billion years, East African craton is considered mobile and cratonic when Pan-African orogeny (about 550-600 million years ago), by its good position, the basin of Ahnet is related to the joint area of these two (02) cratons. Their collision has certainly created a brittle tectonic of the substratum level; this is probably tectonic Paleozoic [19]. This old tectonic was taken during phases:

- Taconic (late Ordovician)
- Caledonian (Late Silurian beginning Devonian (Siegenien).
- Hercynian: The most important phase (late Permian).
- Austria: phase essentially post-Hercynian compression (Upper Cretaceous).

The current structural image was mainly gained during the Hercynian orogeny that completely modeled this basin (faults, gouge zones, anticlinal structures, intense erosion, etc ...). Phase Austrian wrinkling caused replays in which slip gave birth to drive folds along preferential axes.

Moreover, this basin has been also strongly influenced by tectonics linked to Hoggar. This tectonics is characterized by the presence of structural trends of submeridian direction which is attached to the extension thong; the north deformations of the base are typical in the Hoggar.

Below we present the main characteristics of two of the most promising areas for the application of the CCS techniques in Algeria. They are located in southwestern Algeria and in the onshoreand have been named "Tidikelt North" and "Akabli 02" respectively (Fig. 1A).

### 5.1 Tidikelt North

is a land in the basin of Ahnet and specifically the sub-basin Ouallen which is limited fromthe east and to the west by large accidents is filled by a thick sedimentary series of more than 7000m, including lower terms outcrop to the east and the west than the terms which represents one of the main structural elements of the field. Drilling and seismic companion established in the region shows purple surmounted by a series Cambro-Ordovicianunconformityor infra-tasilienne unconformitylocated at a depth of 1200 m and a thickness of 700m with an oblique stratification(Fig.3).

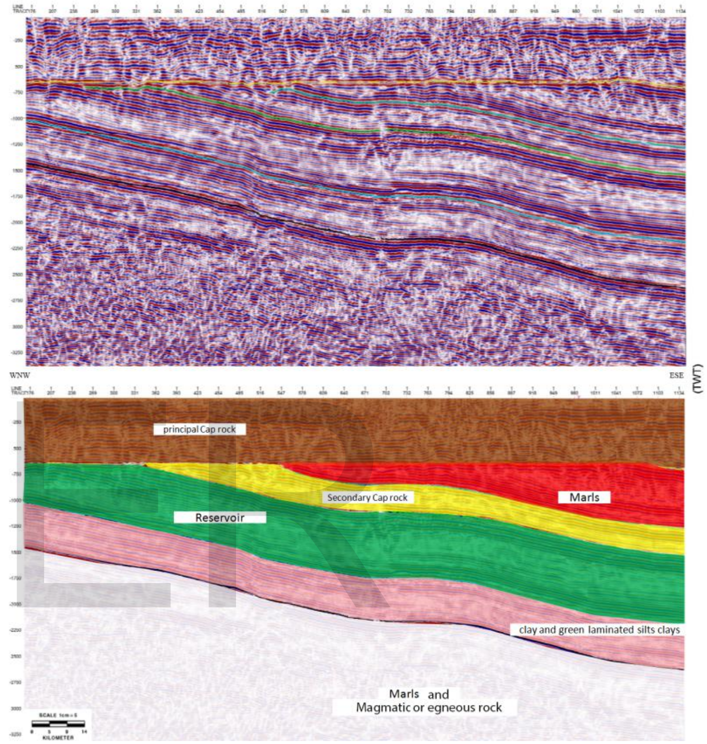


Fig.3 .Example of multi-channel seismic line collected across the "Tidikelt North " and its interpretation

accidents is filled by a thick sedimentary series of more than 7000m, including lower terms outcrop to the east and the west than the terms which represents one of the main structural elements of the field. Drilling and seismic companion established in the region shows purple surmounted by a series Cambro-Ordovicianunconformityor infra-tasilienne unconformitylocated at a depth of 1200 m and a thickness of 700m with an oblique stratification(Fig.3).

The potential reservoir formations suggest an eolian deposit which is consisted of sands and silty sands of the Precambrian. Those deposits have been interpreted as the bottom of the sub-basin. The reservoir is locally more than 500 m thick, with an effective thickness exceeding 250 m, recorded by several drill holes. Sand layers are often saturated with salt water, as evidenced by the spontaneous potential and resistivity logs in addition to analysis of the formation water which shows a saturation salt 120 to 180 g / l. All wells drilled in this region contain the logging and petrophysics of the logging recordings

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pulled or the carrot, a porosity of 18% information was assessed through the combination of different logs the logging namely Sonic the neutron and density and more photoelectric factor and proven by carrots.
From the point of seismo-stratigraphic and seismic view, these deposits are represented by a considerable amplitude, subparallel and continuous reflection and overcome a Cambro-Ordovician unconformity or infra tasilienne unconformity and a thick sedimentary series loan 1200m with shales of the Ordovician and specifically El Gassi Clay playing the rolle of caprock in addition to the Silurian shales represents regional coverage for Cambro-Ordovician reservoirs. To the west of the reservoir series based on infra Cambrian formations of clay and green finely laminated silts clays often contain pebbles dropped (dropstone) the depositional environment corresponds to a sea or lake environment (Fig 4).
With an area of almost 1150km$^2$ this structure is one of the most promising sites for $CO_2$ sequestration with a density of around 920kg $CO_2$ / m$^3$(Fig.2) this site can store over 476Mt.

### 5.2 Akabli 02

Is locate in the region of Akabli North West Ahnet The current geometry of the region is marked by superimposing various major structural axes resulting from a complex polyphase history:
North-South directions and North West-South East approximately follows the collision front line between the rigid Precambrian craton West Africa and the entire East Africa already resulting from terrane accretion more distorted.
The direction (NW-SE) control sedimentation from the Silurian with the opening of the basin to the north, then mark the structuring of the region due to the reversal of paroxysmal movements Hercynian to late Carboniferous Finally, the directions East-West and North East South West evidenced transgressive movements in Hercynien.
The area is generally subsiding during the Mesozoic, and the impact of tectonic Cretaceous and Tertiary is relatively limited at the basin scale. Structural traps, mainly formed during the Carboniferous are usually associated with large reverse faults with a rejection of up to several hundred meters. They are of high amplitude but of moderate size (some expansion kilometers along the axis of the structure).
Akabli 02 is a high-amplitude anticline , the axis WSW-ENE, approximately 380 km$^2$ at its structural closure to the roof of the Ordovician (-1165 m / sea). The structure is located in a relay zone between two reverse faults trending sinistral N70 showing an unhooking game.
This structure is affected by numerous faults related to tectonic style mainly unhooking the zone. it is pinched between two beams of thrust faults with strong rejection likely a slight sinistral strike slip motion ( Fig 4).Its establishment is associated with a principal stress oriented N120, which corresponds to the direction of Hercynian compression observed in the region.
Regional data show that the Cambrian deposits are regular and very uniform over large distances. They are the main area of the reservoir.
Cambrian sands were deposited in a continental environment as infilling amalgamate1d into braids.
Closer episodes of an estuarine environment are also described in the core drilling intervals and are reflected and increased to a little thinner and clay sediment. This depositional environment explains the lack of contrast and outstanding figures on the logs, making it difficult to correlate. The homogeneity of the reservoir resulting from its filings mode, is reflected in the absence of reliable subdivision within the Cambrian and significant extension to fluid flow barrier. However, at the top of the Cambrian unit is individualized from the responses tools of porosity, particularly density and sonic. This interval called Cambrian which is the main reservoir. Regional data show that this reservoir was deposited relatively uniformly over large areas and over large thicknesses. This reservoir is modeled with a thickness of 250m, uniform structure with porosities of 15% through other forma tion during drilling can be taken as secondary reservoirs such training were evaluated by means of logs that have proven the existence of salt water it is:
Ordovician (Unit IV& II): This unit is primarily sandstone with past micro conglomeratic clays. This reservoir is main gas reservoir in the basin of Ahnet. Porosities exceed 15% in the southern edge of the region, and are around 6-8% in the central part.
Tournaisian: It contains fine sandstone with presence of glauconite and bioclastic. they are in the form of bars marine 50m. The characteristics of the reservoir are generally good. Porosities exceed 15% and permeability exceeds 100 Mdbut it is not considered a favorable reservoir because of its depth.
Strunien: It often corresponds to sandstones in communication with the Tournaisian sandstones; it is essentially aquifer. The average porosities is above 20% at the top and decrease in depth. Permeability's rarely exceeds 100 Md. but it is not considered a favorable reservoir because of its depth.
Gedinnian:It corresponds to sandstones bar type, thus sandstone bioturbated and clay. Porosities range between 8 to 16% and permeability's are rarely above 1 Md. The thicknesses are variable and sometimes reach more than 95 m.The log showed a column of 82m with porosity of up to 14%
Givetian : It consists of bioclastic calcareous alternating with clay and sandstone. The thicknesses are variable and sometimes reach more than 50 m. The log showed a column of 48m with porosity of up to 25%.
Coverage of these reservoirs is provided by the Silurian clays. Regionally well developed, they provide a good coverage of cambro-ordovician reservoirs. The basis of these clays is highly radioactive with abnormally high pressures, in this manner it increasing the effectiveness of this coverage. The reservoir sandstones of Tournai are covered by Tournaisian and Namurian clays, the Middle and Upper Devonian clays ensure the caprock of Gedinnian Siegenien sandstones .
The different relationship porosity / permeability and Cortege clay are mentioned in (Fig.5). With an area of almost 380km$^2$ this structure is one of the most promising sites for $CO_2$ sequestration with a density of around 960kg $CO_2$ / m$^3$ (Fig.2)this site can store over 345Mt.

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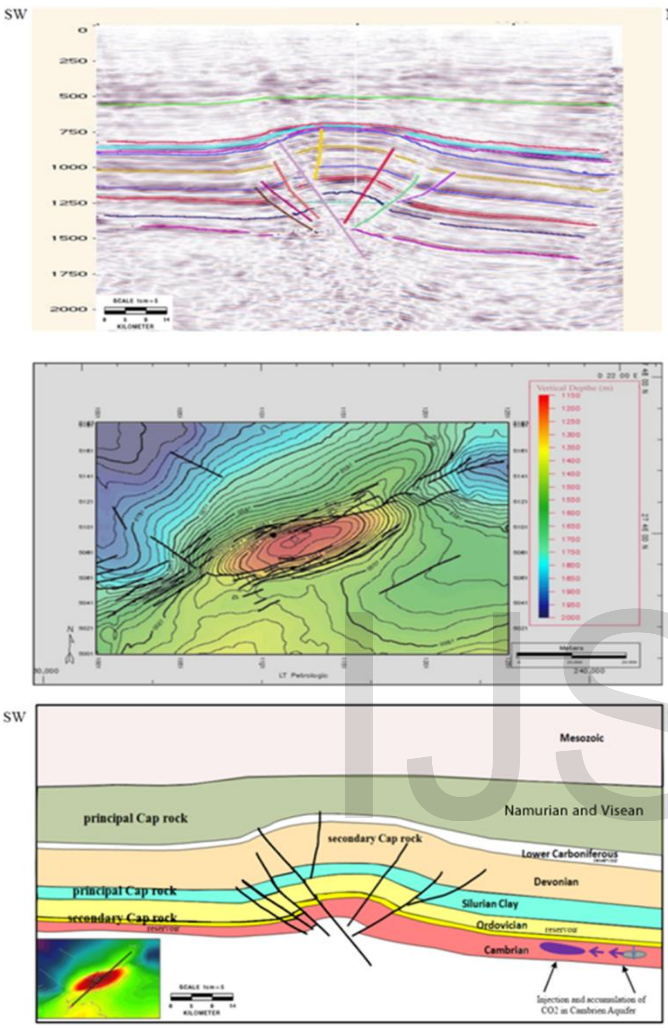


Fig.4 Example of multi-channel seismic line collected across the "Akabli 02" and its interpretation Despite the uncertainties, it is the first time the potential and storage capacity of deep saline aquifers in Algeria were estimated

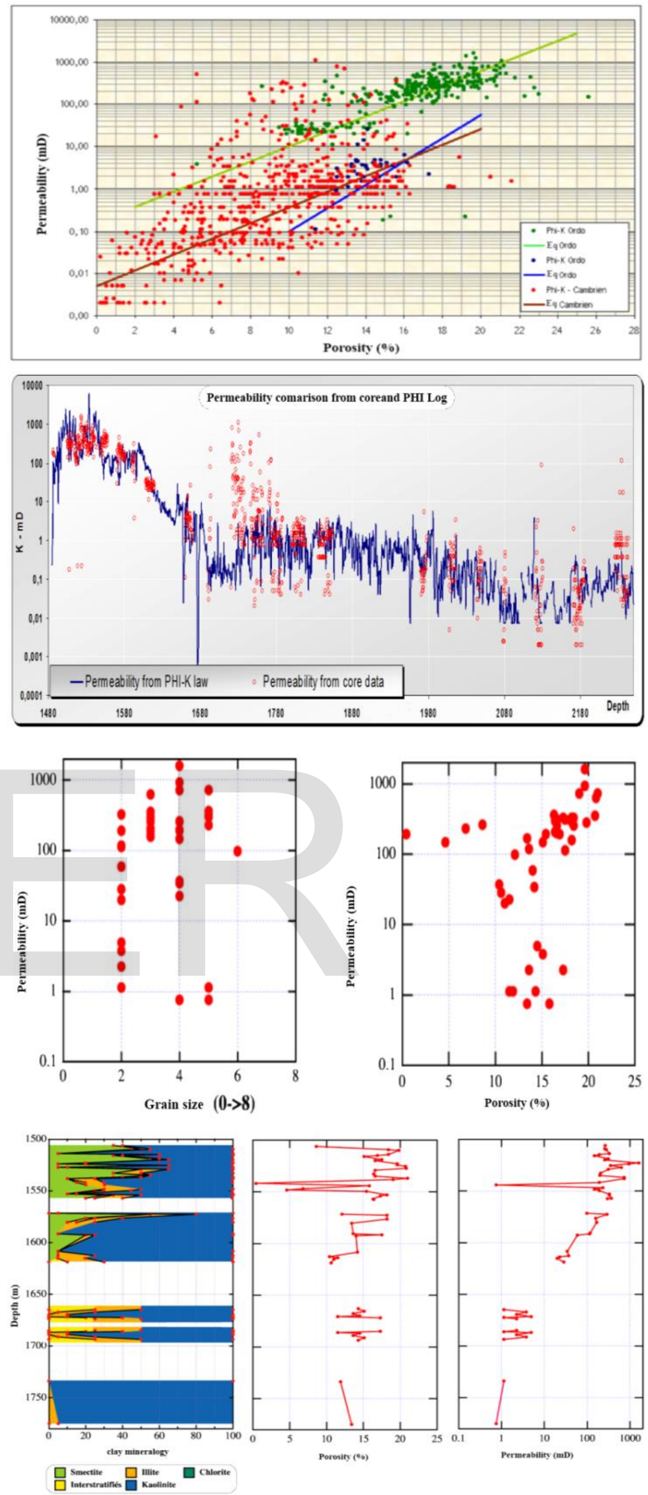


Fig.5 .The relations between porosity and permeability and clay mineralogy in Akablie 02

## 6 Discussion and Conclusions

The analysis of the potential of sedimentary basins in southwestern Algeria for geological CO2 sequestration allowed highlighting the interesting potential of the basin

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Ahnet-Gourar. Indeed, his final score stands out from other basins, and actually, the basin prioritizes for further studies to determine and identify specific sites and reservoirs for CO2 injection.

Our assessment of the total storage capacity of CO2 in the basin Ahnet-Gourar allowed the identification of 12 suitable areas that could potentially store the annual CO2 emissions of Algeria for the next 50 years. This value represents a very conservative estimate of capacity for geological storage of CO2 in deep saline aquifers Ahnet-Gourara because other promising reservoirs could be found in areas where data are not available at this time as ponds Bechar and Tindouf that are being explored.

. This study demonstrates that CO2 storage in deep saline aquifers is a viable option for Algeria. However, due to lack of multiple types of data (such as the physical and mechanical properties of the reservoir caprock our assessment on capacity storage in deep saline aquifers Algeria is far from tion during drilling can be taken as secondary reservoirs such training were evaluated by means of logs that have proven the existence of salt water it is:

Ordovician (Unit IV& II): This unit is primarily sandstone with past micro conglomeratic clays. This reservoir is main gas reservoir in the basin of Ahnet. Porosities exceed 15% in the southern edge of the region, and are around 6-8% in the central part.

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