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UNDERGROUND CO_2 STORAGE – CASE STUDY OF JASTRZĄBKA STARA STRUCTURE, SE POLAND

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Abstract: Carbon dioxide injection into depleted oil fields is widely used. The injection enhances oil recovery and generates other advantages like: (1) decrease of carbon dioxide concentration in the atmosphere and (2) the possibility for CO_2 emission trade. Geological and reservoir parameters of Jastrząbka Stara structure are discussed in this paper in the context of possible CO_2 sequestration. Reservoir absorptivity and tightness, overburden thickness, storage capacity as well as social and economical aspects are taken into consideration. Based upon these factors, Jastrząbka Stara oil deposits may be classified as potential carbon dioxide storage site.Detailed data cannot be published due to Polish Oil and Gas Company (PGNiG SA) confidentiality requirements.

Key words: geological sequestration, sequestration criteria, enhanced oil recovery

INTRODUCTION

Industrialization and the development of civilization are the main reason for greenhouse gas emission. To prevent unfavourable changes, the global society decided to reduce their global emission. Carbon dioxide is one of those gases. It occurs in the atmosphere as a product of natural Earth's processes like volcanic eruption and as a result of human activity. Anthropogenic carbon dioxide emission is associated with fossil fuels combustion. As such fuels still remain irreplaceable, global society decided to invite and implement new technologies, which allow fossil fuel combustion without any carbon dioxide emission to atmosphere. One of these technologies is carbon dioxide capture and injection into geological structures (Carbon Capture and Storage – CSS).

Carbon dioxide is supposed to be stored in sedimentary basins. Considering the appropriate basin for carbon dioxide sequestration is it is necessary to analyze its tectonics activity, tectonic regimes and resources (coal, salt, hydrocarbons). Other issues are: range of industrial development, infrastructure and social aspects as economic developments level, environmental protection and public education (Bachu 2000). Location of sedimentary basins within specific elements of continental crust is also considered. The most adequate locations are intracontinental basins or lying at the edge of continental plates. The possibility of long – term carbon dioxide storage is related to the stable structure of such settings. Three major types of structures are distinguished for anthropogenic carbon dioxide storage: (i) depleted oil and gas fields, (ii) deep saline formations, and (iii) coal basins (Metz et al. 2005, 2008, Tarkowski et al. 2009). There are many criteria to that must be met for a geological structure to be accepted as a potential site for carbon dioxide injection and storage (for example: Bachu 2000, Uliasz-Misiak 2009).

Depleted oil and gas fields tend to be perfect structures for carbon dioxide injection. They are natural traps holding reservoir liquids and, in case of hydrocarbon exploration and production sites. are well researched. In addition, they are equipped with the infrastructure necessary to perform the injection. Furthermore, enhanced oil recovery has economic advantages (Ferguson et al. 2009).

Enhanced oil recovery is a common method used all over the world. Carbon dioxide injection is one of the cheapest enhanced oil recovery methods. It is cheap, and easy to obtain from the atmosphere. CO_2 injected in a supercritical phase dissolves in oil and therefore reduces its viscosity. For this reason oil is capable of flowing in the reservoir again. In addition, the injected gas causes an increase in the reservoir pressure. These two factors result in the oil production increase (Todd & Grand 1993).

To classify a geological structure as potential for carbon dioxide storage, it's parameters should be compared with those suggested by various authors. Not all of them must be strictly adhered to, but a combination of geological parameters should result in a satisfactory effect.

The main purpose of this article is to discuss the geological parameters of trap closures as potential structures for carbon dioxide storage using the Jastrząbka Stara oil deposit as an example. In this study we apply various classifications, following Chadwick (2008) and Wójcicki et al. (2010).

GEOLOGICAL AND PETROPHYSICAL CHARACTERISTICS OF JASTRZĄBKA STARA OIL DEPOSIT

The Jastrząbka Stara oil deposit is located in SE Poland (Fig. 1). The deposit was discovered in 1987 (Karnkowski 1999). From a geological point of view, it occurs in the Mesozoic sedimentary cover of the Paleozoic Platform, in the basement of Carpathian Foredeep (Narkiewicz & Dadlez 2008). Sandstones prospective for hydrocarbon exploration are of the Upper Cretaceous Cenomanian age and occur as intercalations in the carbonate Senonian sediments (limestones, marls). In the discussed region, the Mesozoic strata are gently folded and faulted. Anticlinal trap closure is located along NW-SE line and dislocated by fault (Fig. 2).

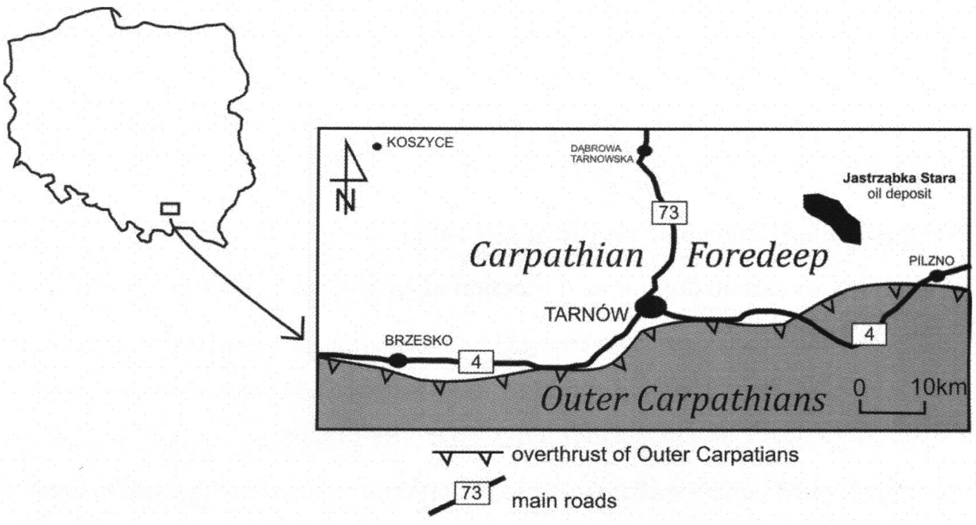

Fig. 1. Location of Jastrząbka Stara oil deposit

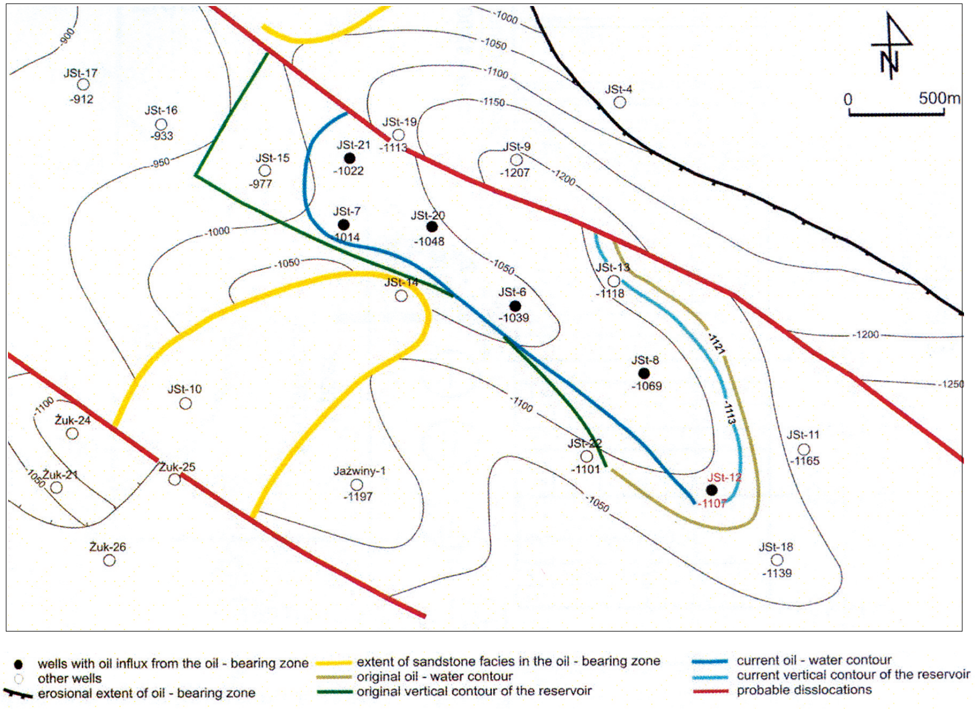

Fig. 2. Jastrząbka Stara oil deposit. Map of the top of the Senonian sandstone layer I (based on Gawlik 2001)

The Jastrząbka Stara oil deposit is located within Senonian sandstones in the Upper Creataceous strata. These sandstones occur as three separate layers numbered III, II and I, starting from the bottom to the top of the profile. Cap rocks are formed by Upper Cretaceous rocks (thickness between 80 m and 260 m) and Miocene rocks from 1000 m to 1300 m thick (Fig. 3).

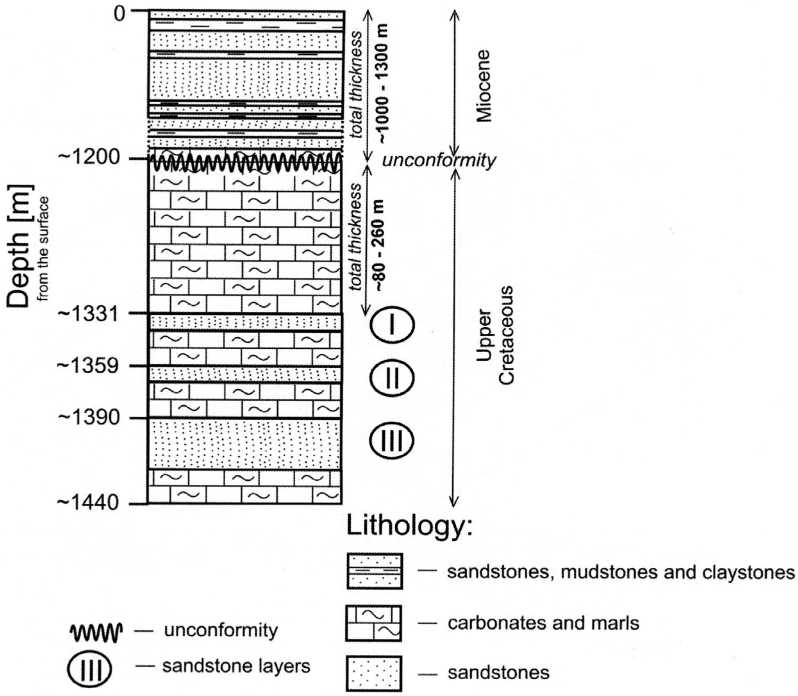

Fig. 3. Synthetic, litostratighaphic profile of Jastrząbka Stara region

In this paper, the sandstones of the I layer was chosen for CO_2 injection testing in relation to its petrophysical parameters and a stage of identification. The top of the I sandstone layer occurs at an average depth of 1331 m below surface. The total thickness of the I sandstone layer varies from a couple to 11 m, but the effective thickness of the reservoir rock was estimated as 6.5 m (Gawlik 2001, Przybyła & Bąk 2008).

The laboratory analyses of the core samples from I sandstone layer in the Jastrząbka Stara 10 and 14 wells indicate that the average porosity of sandstones is about 5%. Effective porosity was defined from the sonic log and calculated as 7–14%. Permeability varies from 0.4 mD to 25.5 mD, unfortunately with the predominance of low values (Karnkowski 1999, Gawlik 2001, Marcinkowski & Kozimor 2005).

The underlying waters of an oil deposit are Cl-Ca brines in W.A. Sulin classification (see: Pazdro 1983). They are relict waters with proper hydrogeological tightness, with specific gravity 1.027–1.085 g/dm^3. The salinity of those brines ranges from 98.7 g/dm^3 to 116.9 g/dm^3.

Production was obtained in four wells, from three horizons at a depth interval of 1207–1366 m (Fig. 3). The initial reserve estimations gave $385 \cdot 10^3$ tonnes of oil with a density of 0.836 g/cm^3 (Karnkowski 1999, Gawlik 2001).

CRITERIA USED FOR CARBON DIOXIDE STORAGE

To accept a geological structure as a potential for CO_2 storage geological, reservoir, technical, social, environmental and economical criteria should be considered. Nowadays, there is no uniform standard for geological sequestration, but the basic parameters to be taken into consideration include geological and technical tightness, depth of formation presence, type of overburden, storage capacity, thickness and absorptivity of the formation, reservoirs porosity and permeability, the salinity of underlying waters, no conflict of interests and the distance from the source of CO_2 (Chadwick et al. 2008). Most important factors are listed in Table 1.

Table 1

Key geological indicators for storage site suitability
(based on Tarkowski et al. 2009, modified, in italics: after Chadwick et al. 2006)

	Positive indicators	Warning indicators	Negative indicators
Depth of formation [m]	>800 m, <2500 *>1000, <2500*	2500–3000	<800, >3500
Reservoir thickness [m]	>50	20–50	<20
Porosity [%]	>20	10–20	<10
Permeability [mD]	>300 *>500*	300–100	<100–10 *<200*
Salinity of underlaying waters [g/dm^3]	>100	100–30	<30
Faults	No faults *Small or no faults*	Faults expired in storage formation	Faults expired in overburden *Medium to large faults*

The most important criterion is tightness before, during and after the injection. We can distinguish two main types of tightness: geological and technical (Tarkowski et al. 2009). Geological tightness is the natural ability of the geological structure to maintain the gas without significant losses before and after the injection (Tarkowski et al. 2009). Technical tightness includes the stability of all the technical and drilling equipment associated with carbon dioxide injection (Tarkowski & Uliasz-Misiak 2005).

The best phase for geological storage is the supercritical phase, in which carbon dioxide is not flammable and not explosive (Fig. 4). The increase in temperature and pressure with depth affects the phase in which CO_2 is injected into the subsurface, so preferred structures should be located from 800 m to 3000 m below surface, where the carbon dioxide will have a density of 500–900 kg/m^3 in the subsurface conditions, depending on the prevailing pressure (Bachu 2000).

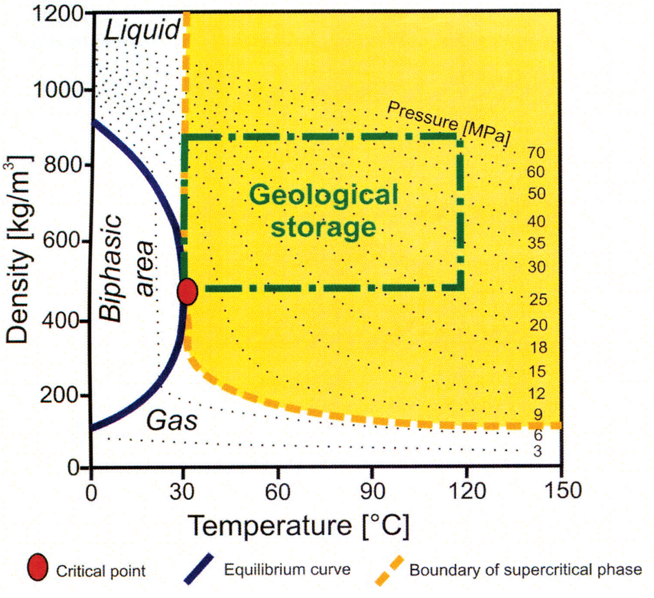

Fig. 4. Variability of carbon dioxide as a function of temperature and pressure (based on Parczewski 2008, modified)

The overburden guarantees the tightness of the reservoir. It is responsible for the safety and prevents the migration of stored gas to the surface. Tight and tectonically undisturbed overburden should have thickness in the range of 20–50 m, the best one is more than 100 m (Uliasz-Misiak 2009).

Capacity of storage results from the area and thickness of the structure. It should be larger than global emission of the industrial plant. This capacity is the amount of gas, which can be placed in the geological structure. It depends on the size and thickness of the structure, porosity, PVT conditions, CO_2 density and the type of reservoir fluids filled the structure (Lubaś et al. 2010).

Absorptivity is the parameter, which allows for the injection of a defined amount of the gas to the geological structure in time unit. It results from porosity and permeability. The minimal porosity of a reservoir rock is 10%, but the perfect on expected is 20%. Minimal permeability should range from 10 mD to 100 mD. Preferred permeabilities are over 200 mD (Bachu 2000).

Other criteria are no conflict of interests and the distance from the source of CO_2. They are not as relevant as the previously mentioned ones, but have quite a large impact on choosing the potential geological structure. No conflict of interests is defined as no possibility of stored gas contact with drinkable water and no occurrence of other mineral resources in the neighbourhood. The distance from the source of carbon dioxide determines the economics of the project. Distance should be minimized, which reduces the cost of gas transportation.

DISCUSSION

In this paper, geological parameters of the Jastrząbka Stara structure such as reservoir depth, thickness, porosity and permeability, salinity of underlying waters and overburden thickness, were compared to two independent criteria. First was presented in *Polish National Program for Assessment of formations and structures for safe CO_2 geological storage, along with their monitoring program* (Wójcicki et al. 2010), second in *Best practice for the storage of CO_2 in saline aquifers* (Chadwick et al. 2008) (Tab. 2).

Table 2

Comparison of criteria used for selection of structures for carbon dioxide storage with geological parameters of the Jastrząbka Stara structure

	Criteria from Wójcicki et al. (2010)	Criteria from Chadwick et al. (2008)	Parameters of sandstone layer I in Jastrząbka Stara oil deposit
Depth [m]	from 800–1000 to 2000–2500	min. 800, max. 2500–3000	~1331 (top)
Reservoir thickness [m]	min. 20	20–50	~11 (6.5 of effective thickness)
Porosity [%]	min. 10	min. 10	14
Permeability [mD]	min. 100	10–100	0.4–25.5 (with predominance of lower values)
Salinity of underlaying waters [g/cm^3]	min. 30	min. 30	98.7–116.9
Overburden thickness [m]	min. 50	20–50, best more than 100	thickness of rocks: – Upper Cretaceous: 80–260 – Miocene: up to 1000

Depth of the formation, below 1300 m, and higher than 1000 m overburden thickness consisting of the Upper Cretaceous and Miocene sedimentary rocks are perfect for CO_2 storage. Taking into account the geothermal degree in this area varying 40–50 m/^{o}C (Majorowicz 1971), it is possible to consider that injected CO_2 will be in expected supercritical phase. Furthermore, the thick overburden and tectonic stability of the region guarantee storage safety. The performed drilling within this structure does not breach the initial sealing. Confirmation of reservoir tightness is also the result of reservoir pressure measurements. Current pressures are calculated from wellhead pressures and the fluid level in the borehole, and they range from 1.7 MPa in sandstone layer III to 9.3 MPa in layer I (Marcinkowski 2007). Tightness tests performed on wells confirmed the technical tightness. Production out of this deposit took 17 years and during this period no leakages were observed (Przybyła & Bąk 2008). The study of the geochemical background around the disused wells did not show abnormal methane concentration in the solid air (Przybyła & Bąk 2008). Reservoir rock, represented by the Senonian sandstones with 14% porosity, enables us to perform the injection.

Reservoir rock parameters like 6.5 m effective thickness and permeability ranging from 0.4 to 25.5 mD with a predominance of lower values, are lower than those proposed in the published classifications. They will result in poor absorption and lower storage capacity of the reservoir. Lower pressure on a wellhead would solve the problem of low permeability of reservoir level. Salinity of the underlying waters is more than three times higher than that proposed in the classifications. The high salinity of brines prevents contact with drinking water.

The injection of carbon dioxide to the Jastrząbka Stara structure would bring profits to the Azoty Tarnów company due to the CO_2 emission trade. This nitrogen plant is located about 25 km from the deposit (Fig. 2). Therefore, gas transport by tankers would not generate high costs. On the other hand, enhanced oil recovery processes would give economical advantages to the field operator – Polish Oil and Gas Company (PGNiG SA).

CONCLUSIONS

Even though certain parameters of the Jastrząbka Stara oil deposit are lower than requested by Wójcicki et al. (2010) and Chadwick (2008), the results of this study suggest that this deposit may be classified as potential carbon dioxide storage site. Detailed data cannot be published due to Polish Oil and Gas Company (PGNiG S.A.) confidentiality rules.

Summarising, the injection of carbon dioxide to the Jastrząbka Stara oil deposit will bring several benefits:

- increase in the reservoir pressure and decrease in oil viscosity with relation to miscible enhanced oil recovery processes,
- increase in production from the deposit, thus profits for the field operator,
- possibility for CO_2 emission trade for Azoty Tarnów.

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