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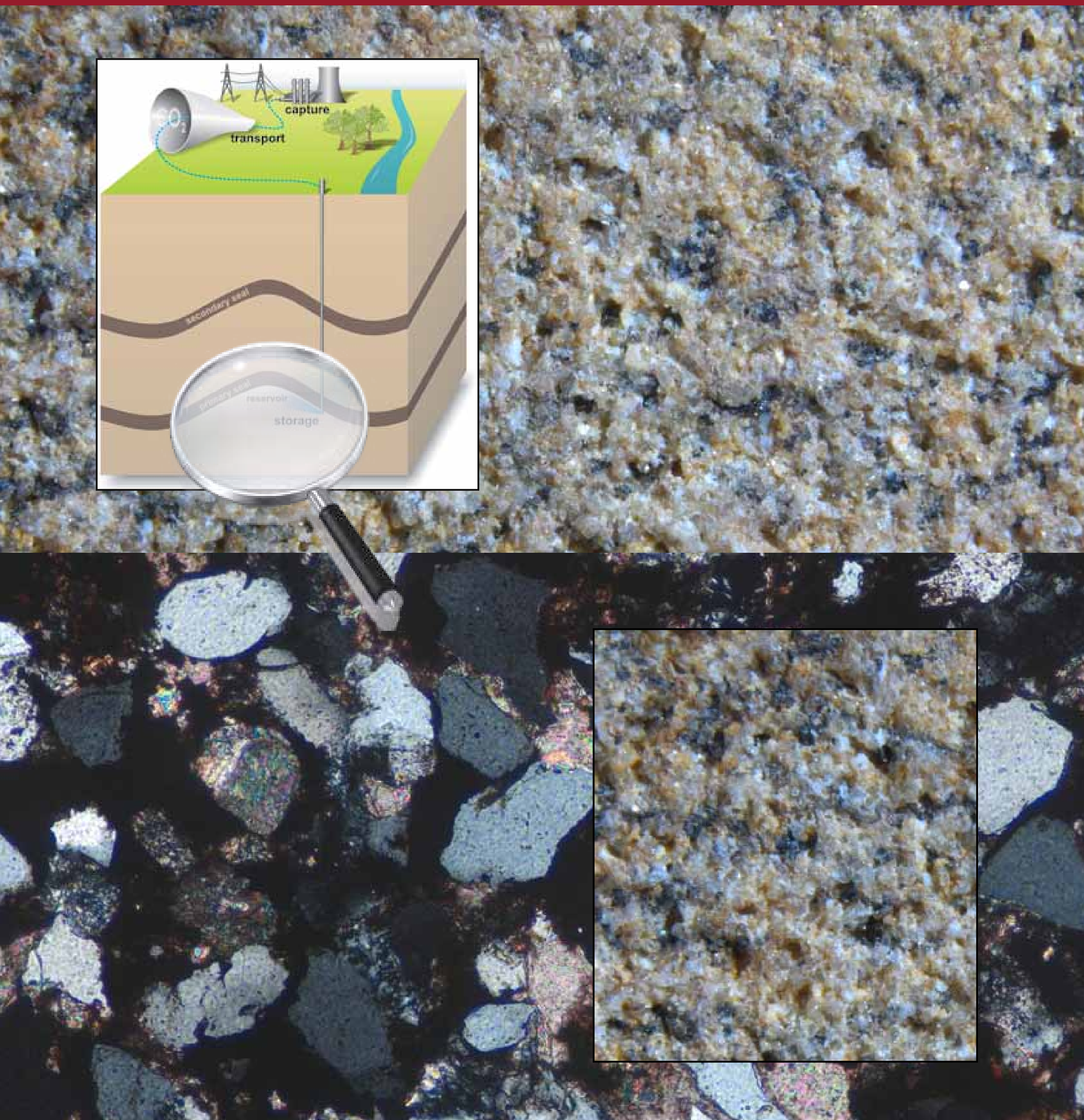
Carbon, capture and storage - potential in Europe and barriers to take up



The potential options of storing CO_2 in saline reservoirs in Hungary

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Hungary has more than 40 years of industrial experience in subsurface injection of large volumes of carbon dioxide (CO_2), related to enhanced oil recovery (EOR) activities. Furthermore, the results of the preliminary-stage assessment of storage capacities in Hungarian saline reservoirs show significant storage volumes that could be used for the sequestration of industrial CO_2. Our paper gives a summary of CO_2 injection activities and provides an overview of the most favourable saline formation, its geological characteristics and estimated storage capacity.

La Hongrie bénéficie d'une expérience industrielle de plus de 40 ans dans le domaine de l'injection, à faible profondeur, d'importants volumes de CO_2, liée aux opérations de récupération accrue des hydrocarbures (Enhanced Oil Recovery). De plus, les résultats de l'étape initiale d'évaluation des capacités de stockage au sein de réservoirs salins hongrois montrent l'existence de volumes de stockage significatifs qui peuvent être utilisés pour le confinement du CO_2 industriel. Cet article résume les opérations d'injection de CO_2 et fournit une vue d'ensemble des structures salines les plus favorables, leurs caractéristiques géologiques et une estimation de leurs capacités de stockage.

Hungría tiene más de 40 años de experiencia en la inyección profunda de grandes volúmenes de CO_2 relacionado con las actividades de mejora de la recuperación de petróleo (EOR en sus siglas en inglés). Además los resultados preliminares de la evaluación de la capacidad de almacenaje de los almacenes salinos húngaros, muestran unos volúmenes de almacenamiento significativos que se podrían utilizarse para el almacenamiento de CO_2. Nuestro artículo aporta un resumen de las actividades de inyección de CO_2 y de las formaciones salinas más favorables, sus características geológicas y su capacidad de almacenaje estimado.

The most widespread potential carbon dioxide (CO_2) storage objects worldwide are "saline" reservoirs, which can be defined as porous and permeable reservoir rocks that contain salty water in their pore volume. These rocks are located much deeper than the normal potable water reservoirs and because of their high salinity and depth they are economically non-exploitable. For long-term, safe storage of CO_2, the following conditions must be met by the potential reservoirs (after Chadwick *et al.*, 2006):

- adequate reservoir depth (900 - 3000 m)
- the integrity and low permeability of overlying cap rock, or closure
- large enough volume for economic CO_2 storage
- appropriate reservoir geological parameters
- sufficient separation from potable and thermal water systems.

If the studied reservoir conditions fulfill these requirements, as many of the saline aquifers do, worldwide, it is theoretically suitable for CO_2 storage. However, further aspects, such as the conflict of use, should be considered. Decades-long experience in subsurface injection of large volumes of CO_2 for EOR purposes is one important advantage that Hungarian geoscience possesses.

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In the following paper we give a brief overview of the most promising aquifer storage formation and summarize over 40 years of experience of CO_2 injection-related EOR activity, which provides a solid basis for the large-scale industrial application of carbon capture and storage (CCS) technology in Hungary.

Summary of earlier EOR activities in Hungary

Hydrocarbon exploitation by CO_2 flooding has been tested in some of the major oil fields in Hungary. *Budafa* and *Lovászi*, the two oldest oil (and gas) fields in the SW part of Hungary, discovered in 1937 and 1940, respectively, are sandstone reservoirs. Hydrocarbon production was started in both fields using natural reservoir energies. Already in 1939 and 1944, re-injection of hydrocarbon gas was used as a secondary recovery method. Later, edge and subsequent areal water flooding was used as additional recovery. Natural CO_2 from a nearby source was injected into the depleted reservoir to increase oil recovery. The aim of flooding was to increase the pressure in the depleted reservoir to its initial value. The process was immiscible. The additional recovery factor of oil in the reservoir was around 10%.

The bulk of the oil in the *Nagylengyel* oil field (SW Hungary), discovered in 1951, is accumulated in karstic Cretaceous rudistic limestone and Triassic dolomite. During the primary recovery, unlimited water inflow was the dominant driving mechanism. Water encroachment became more and more intensive by the end of the 1970s. CO_2 was injected to establish an artificial gas cap in the karstic reservoir. During the blow down of the gas cap, the oil moved upward and was recovered by water drive. The process was immiscible and the additional recovery factor was again around 10%.

The *Szank*-field reservoir is a special massive type reservoir. The exploitation started, using natural energies in 1969. The predominant displacement mechanism has been the water inflow from the edge. By 1990, production wells located at the edge of the reservoir watered out and the production rate decreased dramatically. The injected 95-98 mole % CO_2 comes from the enrichment of the gas in

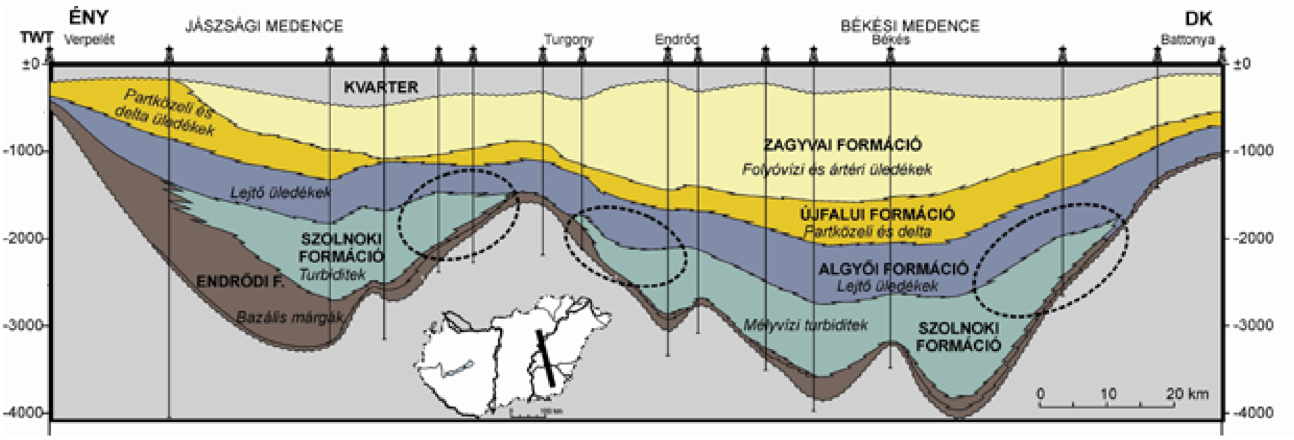

Figure 1: NW - SE lithostratigraphic and sedimentological cross section in the Pannonian s.l. sequence. From Verpelét through the Jászság Basin, the Middle Hungarian basement high and the Békés Basin to Battonya (Juhász, 1992). The approximate location of the cross-section is shown on the inset map.

fields near the studied metamorphic reservoir.

CO_2-related EOR activities were motivated by the possibility of practical use of the substantial reserves of natural CO_2 in Hungary. The conditions of field-scale applications have varied over a wide range, from immiscible displacement in sandstone and karstic reservoirs to miscible displacement in metamorphic and mixed rock type reservoirs. Results show that CO_2 gas injection can be used successfully in various lithology types. The additional oil recovery varies from 5 to 14% depending on the type of reservoir and the technology applied.

Extensive EOR activity in recent decades has led to valuable expertise that can be used to exploit saline aquifers for CO_2 storage.

Characterization and areal distribution of Pannonian (Upper Miocene) sediments potential for saline reservoir storage

Following a basic selection procedure with the criteriashown above,suitable saline storage reservoirs can be considered mainlyin Upper Miocene (Pannonian) sediments. Among these basin filling facies units, the Lower Pannonian Szolnok Formation and the Upper Pannonian Újfalu Formations have the required thickness to potentially store the CO_2.

These formations not only fulfill the volumetric minimum requirements, but they also satisfy other necessary conditions. Both formations are covered by thick, low-permeability formations (Zagyva Formation for Újfaluand the Algyő Formation for Szolnok - ***Fig. 1***). Taking into account other considerations, such as conflict of use, the Szolnok and Algyő Formations are suggested to be the most prospectivestorage and sealing formations, respectively. The actual storage is considered to take place in the vicinity of basement highs where onlapping and pinching out of sandstone layers and the formation of pseudo-anticlines occur.

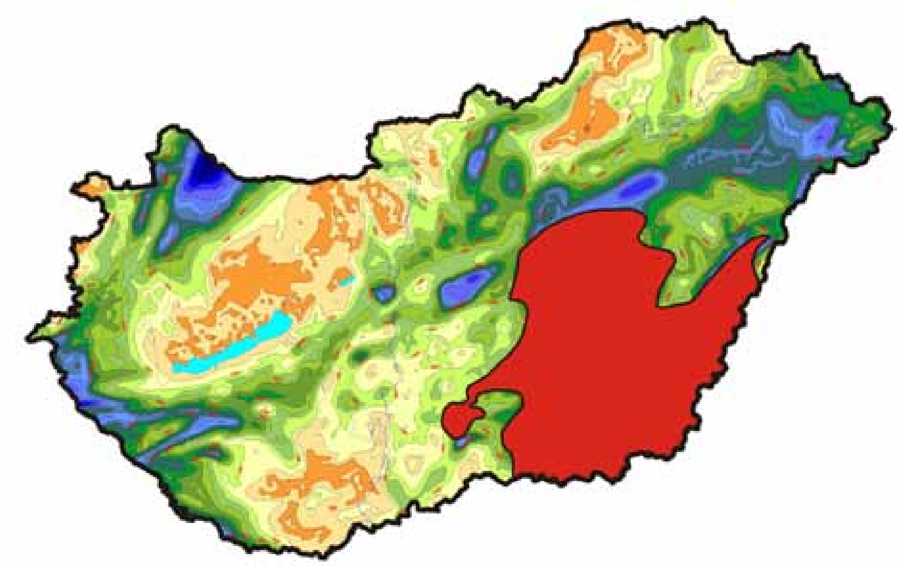

Figure 2: Areal distribution of the Szolnok Formation (turbiditic sandstone – in red) on the Great Hungarian Plain plotted on the pre-Tertiary basement depth map from Kummer (2003).

The areal distribution of turbidites is shown in ***Figure 2***. The highlighted area covers the region where the thickness of the Szolnok Formation exceeds 200 m and the top of the formation is deeper than 900 m. The thickness of the formations can reach 900 min some of the deep basins.

The Szolnok Formation is limited to the zones of deep basin areas. The top of the formation follows the basement morphology. In the western and northern part of the Great Hungarian Plain, the surface of the formation rises to approximately 1000-1500 m, whereas the deepest zones are below 3500 m.

The turbiditic sandstone sequences of the Szolnok Formation may be easily followed on seismic sections. The lithology of the potential storage formation is fine-grained sandstone, and clayey marl layers alternating with siltstone. Even the thicker sandstone layers are built up by smaller lamellae. The turbidite sandstone layers have heterogeneous geometry and spatial distribution. (Juhász, 1998).

A large variety of trap structures occurs in the Szolnok Formation. The most frequently developing trap type is the structural trap that is related to compaction (pseudo-) anticlines. However, stratigraphic traps, as well as lithological traps, are also very common. Tectonic traps develop near troughs and tectonic zones that crosscut or occur within the formation. Tectonic traps are formed near to the protrusions in tectonically disturbed areas.

Estimation of storage capacity in the designated area

Before carrying out the storage volume calculations, the selected areas were filtered according to their minimum thickness. Hence, volume estimations were limited to those areas where formation thickness reached 200 m. We have used a conservative approach for the volume estimation coming from the decades-long experience of natural gas storage in Hungary, applying the following formula:

The storage capacity in the selected area was found to be between 1.5 and $2.0*10^8$ t on the northern and between 5.0 and $5.5*10^8$ t in the southern part of the Great Hungarian Plain. The total potential geological CO_2 storage volume of the Szolnok Formation is about 650 - 750 million tons in the Great Hungarian Plain. The estimated CO_2 storage volume for the Szolnok Formation in Hungary is estimated to be around 1000 million t.

It is important to note that the values shown above represent the quantity of CO_2 that could be stored in a given area in the formation, assuming that the whole volume behaves as a single hydraulic unit.

	ΔV – regional aquifer or trap storage capacity (m^3)
$\Delta V = \Phi \times c \times V \times \Delta p$	*Φ - average reservoir porosity of regional aquifer or trap structure (-)*
	c - eff. compressibility (1/bar), 1/bar) value ~$5*10^{-5}$ for rock and pores
	Δp - built-up pressures; value: Δp~0.2x hydrostatic pressure at given depth (bar)
	V - volume of regional or trap aquifer (m^3)
	ρCO2 - density of CO_2 at reservoir pressure and temperature
$M = \Delta V \times \rho CO2/1000$	*M - Theoretical mass of maximum storable CO_2 in regional aquifer [t]*

Summary and future work

The results of our calculations show that the CO_2 storage potential of the Szolnok Formation in the study area is about 650-750 million tons. However, we have only considered the storage capacity without calculating mineral reactions and dissolution processes. The actual storage volume is strongly influenced by the size and geometry of closed structures and the volume of hydraulically interconnected water bodies, as well as other crucial parameters, such as, injectivity, pressure build-up, reservoir heterogeneity, etc. Such information is not yet available.

Therefore, the next step to facilitate storage in the"saline" storage reservoirs should be the detailed mapping of closed structures within the formation and allocation of the hydrodynamic units.

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