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EVALUATION OF POSSIBILITIES OF CO_2 GEOSEQUESTRATION IN GEOLOGICAL STRUCTURES OF THE CZECH REPUBLIC

The present-day emissions of carbon dioxide (CO_2) generated by anthropogenic activities and the expected future growing production of them are even now a serious ecological problem. One of possibilities of solving this situation is CO_2 storage, i.e. the building of CO_2 storage sites in suitable parts of the rock mass. They are represented, in addition to ideal localities, which are mined-out deposits of natural gas and oil, by selected geological formations of sedimentary Carboniferous deposits of hard coal, it means localities of closed underground hard coal mines provided that they are "tight" enough. For the purposes of CO_2 geosequestration, theoretically all closed hard coalfields exploited using the underground method in the Czech Republic can be considered, namely the Rosice-Oslavany (RUD), Kladno, Žacléř-Svatoňovice and Most Coalfields, and partial localities (closed mines) in the Czech part of Upper Silesian Hard Coal Basin (Ostrava-Karviná Coalfield). Of hydrocarbon deposits situated especially in the Vienna Basin, the Poddvorov, Nitkovice, Kostelany-východ and Ždánice-západ structures seem to be most promising.

1. INTRODUCTION

One of important requirements for ensuring the sustainable development of humankind is the limitation of emissions of anthropogenic carbon dioxide (CO_2), the increased concentration of which in the atmosphere influences global climate changes. Massive

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research into and technical development in this area concentrate on the following two main pathways in reducing the CO_2 emissions:

- increasing the efficiency of transformations, and thus also decreasing the amount of emissions per unit of energy generated and
- CO_2 capturing and its following sequestration.

The capture and the storage of CO_2 (Carbon – Dioxide Capture and Storage – CCS) represent a concept of elimination of CO_2 from emissions from abundant sources, such as electric power plants, steel works and cement works. Carbon dioxide will be separated from emissions and compounds, and transported to storage sites in suitable geological structures (CO_2 geological sequestration).

For the long-term storage of captured carbon dioxide or a CO_2/N_2 mixture, mainly the following geological formations can be utilized: unmineable coal seams, deposits of oil and natural gas and saline aquifers.

2. SEQUESTRATION IN COAL SEAMS

The underground storage of CO_2 in coal seams is regarded as one of promising possibilities. As for this method of storage, combination with the production of coal bed methane (ECBM – enhanced coal bed methane) is expected. The advantage of the method concerned is the fact that injected carbon dioxide is preferentially adsorbed by coal, whereas the originally adsorbed methane is displaced with it. In addition to the storage capacity for carbon dioxide storage, a potential is generated for the capture of resorbed methane, and by its next use, e.g. cogeneration, costs of geosequestration can be reduced.

For the purpose of CO_2 geosequestration, theoretically all closed, underground-exploited hard coalfields in the Czech Republic can be considered, i.e. Rosice-Oslavany, Kladno, Žacléř-Svatoňovice, Most, and partial localities in the Czech part of the Upper Silesian Hard Coal Basin, i.e. so-called Ostrava-Karviná Coalfield (OKR) situated in the Moravian-Silesian Region.

With reference to the geological, ecological and also technological conditions, the Czech part of the Upper Silesian Hard Coal Basin (ČHP) seems to be most promising for CO_2 storage.

2.1. Czech Part of the Upper Silesian Basin

At present, the final delimitation of the Basin in the Czech territory is not completely clear yet. The surface area of that part of the Basin that is known at present is most frequently stated as about 1 550 km^2.

The surface area of mining claims (it means parts of the Basin verified by mining) amounts to 383.06 km^2, the surface area of exploration areas (it means deposits kept in the

national record) 636.75 km^2 and the surface area of partially verified prognoses amounts to 230.65 km^2. Altogether, by mining and exploration operations, 1250.46 km^2 have been verified in the area of Moravian-Silesian Region. Furthermore, prognostic areas without the estimation of resources (reserves) and also the calculation of surface areas can be taken into account – e.g. area south of the deposit of the ridge Žukovský hřbet as far as the fault Janovický zlom, area located south of the deposit Čeladná-Krásná, and especially the space south of the localities of Mořkov-Frenštát and Trojanovice, where the coal-bearing Carboniferous plunges, however, to the depths not verified yet. As prognostic area with not registered resources, the continuation at depths more than 1.400 m of individual mining claims and exploration areas (deposits) to the final depth of coal-bearing Carboniferous development must be taken.

CO_2 sequestration in coal seams depends on coal reserves in specific localities and also on the gas permeability and gas content of individual seams, including the tightness of overlying layers.

Coal Reserves as Potential Source for CO_2 Sequestration

Coal reserves in the Czech part of the Upper Silesian Basin are situated in about 410 seams (thin seams, benches), of which about 280 and 130 coal seams occur in the Ostrava Formation and the Karviná Formation, respectively.

As follows from Table 1, about $17 \cdot 10^9$ t of coal reserves are verified by mining and drilling operations in the mining claims and exploration areas at present. Including resources in prognostic areas, about $19 \cdot 10^9$ t of reserves in seams thicker than 40 cm are verified to the depth of 1.400 m below ground. It is probable that after possible additional calculations to the base of coal-bearing Carboniferous, this value could fluctuate around $20 \cdot 10^9$ t of reserves.

It is clear from the above-presented table that potential possibilities of CO_2 sequestration are, with regard to the overlying layers not affected by mining activity in localities of exploration areas in the Moravian-Silesian Region, high.

From the point of view of exploitability – for obtaining coal bed methane (Coal bed methane-CBM) by displacement of CO_2, the depth of reserves is a significant factor.

From the literature [3] it is obvious that from the general point of view, the richest depth interval in the Moravian-Silesian Basin moves from –600 to –700 m, which is, among other matters, given also by the size of surface area at this level, which is from the spatial point of view, one of the greatest areas. Approximately 70% of reserves are deposited at the depth from –500 to –1.100 m. This is given by the shape of the body of coal-bearing Carboniferous and its position within the depth intervals, where the above-mentioned interval is the vastest surface area. Within this interval, the thickest seams occur (Karviná area, Čeladná - Krásná exploration area and Trojanovice mining claim).

It follows from the above-mentioned facts that coal reserves in the Czech part of the Upper Silesian Basin are considerable and also represent a possible significant potential source of CBM.

Table 1

Total reserves (10^6 ton) in mining claims, exploration areas (deposits) and resources in prognostic areas [5]

Mining claims		Exploration areas (deposits)	
name	reserves [kt]	name	reserves [kt]
Mariánské Hory	78.9	Fryštát	621.3
Svinov	30.3	Dětmarovice – Petrovice	987.9
Vítkovice	125.0	Dětmarovice	299.6
Přívoz	224.8	Věřňovice	588.4
Heřmanice	159.8	Šilheřovice	107.9
Slezská Ostrava III	53.2	Zábřeh	150.9
Michálkovice	145.4	Paskov – západ	732.3
Slezská Ostrava I	27.5	Václavovická elevace	172.0
Paskov	241.1	Žukovský hřbet	580.4
Staříč	263.5	Oprechtice	26.8
Petřvald I		Příbor – sever	767.1
Petřvald II	154.8	Fryčovice	85.7
Radvanice		Příbor – západ	509.2
Poruba	127.6	Příbor - východ	558.8
Dolní Suchá	75.9	Mořkov – Frenštát	3 650.7
Lazy	173.2	Kopřivnice – Tichá	274.2
Doubrava	327.4	Čeladná - Krásná	1 337.0
Karviná Doly I	415.2	total	11 450.2
Karviná Doly II	217.1		
Darkov	280.8	Prognostic areas (resources)	
Horní Suchá	41.9	Bartovice – Hrabová	433.9
Stonava	115.9	Bludovice – Chotěbuz	910.3
Louky	670.9	Datyně – Baška	218.7
Trojanovice	1 526.6	Kozlovice - Janovice	486.9
total	5 476.8	total	2 049.8

Overview of Localities with Preliminarily Established Occurrence of CBM

In the course of the nineties, the geological exploration of deposits for coal bed methane exploitation was carried out in the Czech part of the Upper Silesian Basin. The

exploration was executed especially by means of vertical boreholes drilled from the surface to the Productive Carboniferous, in association with the completion of these boreholes, the hydraulic fracturing of promising seam horizons, and subsequent pumping tests to verify the extractability of coal bed methane reserves.

The exploration has proved that there are considerable reserves of coal bed methane in the Czech part of the Upper Silesian Basin.

A tabular overview of areas concerned is presented in Table 2 and a general map of exploration areas in ČHP is given in Figure 1.

By geological exploration, the total resources of coal bed methane were divided into two classes by the degree of exploration – documented resources are estimated at the total volume of $122 \cdot 10^9$ m^3 and prognosticated resources at $389 \cdot 10^9$ m^3 (Tab. 3).

Table 2

Surface areas of exploration areas in ČHP [5]

Exploration area	Surface area (km^2)
Paskov-západ (s.z.část)	28.79
Příbor-sever (záp.část)	23.68
Příbor-západ	31.79
Příbor-východ (záp.část)	16.33
Kopřivnice-Tichá (záp.č.)	6.49
Šilheřovice	20.68
Věřňovice	49.67
Žukov	83.96
Čeladná-Krásná	142.87
Datyně-Baška	69.02
Kozlovice-Frýdlant	54.54
Mořkov-Frenštát	74.04
Dětmarovice-Petrovice	27.96
Dětmarovice	12.31
Fryštát	10.26
Václavovice	16.8
Paskov-západ (j.v.část)	12.13
Fryčovice	8.50
Příbor-východ (j.v.část)	16.69
Příbor-sever (vých.č.)	16.07

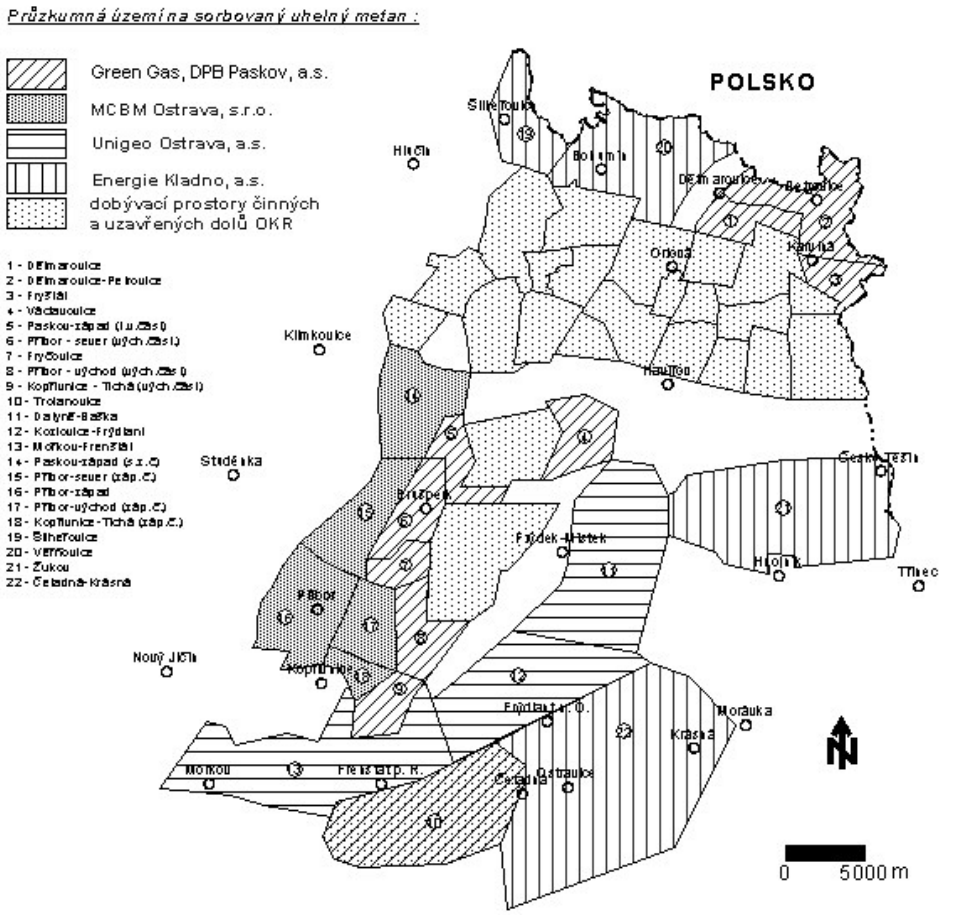

Fig. 1. A general map with the position of specific exploration areas in ČHP [5]

Documented reserves of coal bed methane are confined to economic and non-economic coal reserves. The documented methane reserves are divided into two categories: those that are confined to mineable coal in economic reserves and those that are bound to coal in unmineable or non-economic reserves.

From the presented tables it is evident that coal reserves are explored in the Czech part of the Upper Silesian Basin in more detail than the gas content of coal seams. Data on the gas content are known merely from the performed pilot exploration of CBM occurrence, and after multiplying by coal reserves represent expected prognosticated reserves of CBM in the minimum to maximum range.

The greatest expected prognosticated reserves can be probably found in the exploration areas of Mořkov-Frenštát, Čeladná-Krásná, Trojanovice, Věřňovice and Dětmarovice-Petrovice. The total minimum expected prognosticated reserves in 12 exploration areas amount to about $87 \cdot 10^9$ m^3 of CBM and the maximum expected prognosticated reserves then about $236 \cdot 10^9$ m^3 (Tab. 3).

Table 3

Estimated resources of coal bed methane in the Czech part of Upper Silesian Basin, in 10^9 m^3 [5]

In coal from mineable economic resources In coal in unmineable non-economic resources	63.96 57.34
Total documented reserves	121.30
Total prognosticated resources	
In coal of non-exploited reserves (including inactive mines) In coal of prognosticated reserves (not discovered yet)	252.59 136.90
Total prognosticated resources	389.49
Total resources (total documented + total prognosticated)	510.79

In the region there are many large industrial and energy companies that produce here a considerable amount of CO_2. The CO_2 storage in coal seams would bring economical effects, consisting in methane desorption from coal seams, and thus an increase in possibility of its extraction and subsequent utilization.

Another of possibilities of CO_2 storage is represented by localities of closed hard coal mines on the assumption of their sufficient "leak tightness". Then these are the localities where the minimum permeability of rock mass is ensured thanks to natural conditions (tectonics, physical-mechanical properties of accompanying rocks, mode of deposition of seams) and previous anthropogenic activities (development and long mine workings and also interconnection with the surrounding localities). In the Karviná part of OKR, it is a case of localities of František Mine, Barbora Mine, Doubrava Mine, Dukla Mine, in the Ostrava part of Ostrava-Karviná Coalfield then the Odra Mine, Heřmanice Mine, Šverma Mine, Hlubina Mine and Fučík Mine, and in the south part of OKR the locality of Paskov Mine.

3. SEQUESTRATION IN HYDROCARBON DEPOSITS

Deposits of oil and natural gas are suitable geological formations, because before the exploitation itself, reserves were tightly enclosed, and similarly after the exhaustion and the completion of injection into the deposit, carbon dioxide can be tightly enclosed too. Another advantage is the high degree of exploration of the deposits, and thus also a sufficient amount of information for the selection of suitable space for storage, control of its utilization and long-term monitoring is available. The capacity of the deposit of oil and natural gas for carbon dioxide storage depends on the pore space cleared due to exploited oil/natural gas and the water-filled pore space situated below oil/gas-bearing layers. By the injection of carbon dioxide into the oil deposit being exploited, the recovery of residual oil can be improved as well (EOR method = Enhanced Oil Recovery).

3.1. Occurrence of Hydrocarbon Deposits

From the geological point of view, the territory of the Czech Republic is divided into two regional megastructures – the Bohemian Massif and the Carpathians. The parting line

runs approximately along the zone of west boundary fault of Neogene Foredeep between Znojmo and Ostrava.

The Bohemian Massif as a structure consolidated by Variscan orogenesis plunges east of the mentioned line below the Neogene Foredeep and further below the Carpathians. The long-term process of denudation of the Bohemian Massif has reduced substantially the prospects of its exposed part for the preservation of hydrocarbon accumulations (see Tab. 4).

On the other hand, the Alpine folded Carpathian System with Late Tertiary depressions forms the main base as for the previous production of natural hydrocarbons as well as the prospective development of them. This is also supported by the long-term activity in individual areas, where above all the Vienna Basin occupies a special position following from the exceptional successfulness of exploration, the hydrocarbon potential of the Basin and the duration of industrial prospecting.

From the presented maps (Fig. 2 and 3) a rather high frequency of occurrence of hydrocarbon deposits in the area of south and north Moravia is obvious. In the selection of deposits suitable for geosequestration, the following criteria are taken as a basis:

- Especially protected interests – environmental protection. Some deposits are situated in the basins of the Morava River and the Dyje River, where several drinking water sources are there, which legislatively considerably complicates the possible utilization for the given purpose.
- Burial depth of the deposit. Generally, the depth more than 500 m is taken as safe for waste (CO_2) injection into a rock environment; some authors state up to 700 m. At these depths, the active groundwater cycle mostly stops, and thus a risk of leak is much reduced.
- Capacity of the deposit. One of basic preconditions for the cost effectiveness of injection process is the capacity of the deposit.
- Tectonics. Unclear and unverified communication between individual deposit blocks and individual boreholes is a considerably limiting factor.
- Large number of boreholes developing the deposit. With the large number of boreholes in the locality, costs of recompletion of each of such boreholes grow, and of course, the potential risk of leak of the medium injected into the surrounding environment grows as well.
- Deposit suitable for the construction of gas underground storage facilities. Deposits which can be considered for gas underground storage in the future.
- Presence of old decommissioned drill holes. Often even the quality of decommissioning works done is not known and the bores of old drill holes may thus serve as escape paths into the overlying layers.
- Distance between the deposit and the potential source.

On the basis of the above-mentioned limiting conditions, the following deposits were selected for the pilot projects of CO_2 geosequestration – and subsequent operational injection into the deposit: Lužice, Valtice, and Velké Bílovce.

Possibilities of CO_2 sequestration in saline aquifers have not been dealt with in the conditions of the Czech Republic in detail yet.

Fig. 2. Registered deposits of liquid hydrocarbons in the Czech Republic [8]

Fig. 3. Registered deposits of gas hydrocarbons in the Czech Republicas [8]

Table 4

An overview of basic statistical data on hydrocarbon reservoir in the Czech Republic as of Dec. 31, 2004, Geofond [7]

Year	2000	2001	2002	2003	2004
Total number of reservoir	22	28	28	28	28
of which under exploitation	15	16	17	18	19
Total reserves, kt	37 463	41 617	32 371	32 443	32 790
Economic explored	11055	11 734	12 785	12 484	12 824
Economic prospected	130496	17 091	8 183	8 557	8 567
Non-economic	12 912	12 793	11 403	11 402	11 399
Total production, kt	168	178	253	310	299

4. SUMMARY

From the presented overviews of localities of coal and also hydrocarbon deposits, extensive potential possibilities of CO_2 geosequestration in the Czech Republic follow clearly. The selection of a locality suitable for the pilot project and the proper realization of the pilot project seem to be a task for the nearest future. In the case of hydrocarbon deposits, the locality could be a structure.

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