Case for CO_2 geological storage - site Bzovík Central Slovakia Volcanic Area

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Abstract. Regional aquifers in which is hidden the biggest CO_2 storage potential are covered by younger geological units, often varied genesis and therefore their identification necessitates thorough study of older materials. Such type of locality has been found in South part of Slovakia, where The Central Slovakia Neovolcanics form surface and subsurface feature of landscape. Regional gravity mapping carried out in the sixties of the last century revealed a depression structure in the fundament of Neovolcanics complex. Consecutive deep borehole confirmed this buried structure. Due to convenient lithological development as well as structural - tectonic features, this locality was considered and studied as the possible place for CO_2 storage. A tentative storage capacity calculation was performed, with variable approaches and it was assigned at negative and positive factors in the case CO_2 storage site construction. However it is clear, that in such case this locality in question will have to be suggested to further particular investigation, its applicability is emphasized by proximity of big CO_2 source – the gas transform station Veľké Zlievce, which emissions could be stored here.

Key words: The Central Slovakian Neovolcanic Field, Bzovík Depression, CO_2 storage, capacity calculation, possible scenario discussion

1. Introduction

CO_2 storage conception in geological complexes took place throughout of the last decade in the sphere of carbon dioxide abatement. In term of actual knowledge applicable almost in the whole world, the biggest potential capacity for CO_2 storage is in the deep saline aquifers (Chadwick, et al., 2008). On the other hand, number of credible knowledge about these objects is inadequate and therefore a space for targeted investigation is widely open. However from the lithological point of view, as reservoirs have been almost in any case considered various facies of sandstones in the suitable depths that satisfy supercritical state of this gas, needed for safety and permanent storage. Variability in geological pattern of some areas offers an opportunity to consider as storage site rocks with another geochemical background e.g. carbonates, or not sedimentary (or partly sedimentary) rocks. The most suitable places for CO_2 storage in Slovakia are the marginal, smaller basins of the main or large Pannonian basin. We would like to mention the "so called" hidden possible reservoir, covered by younger geological formations presented by both, sedimentary and volcanic rocks. (Fig.1).

Such site has been found out after the reviewing of general geological pattern of Slovakia with older data of geophysical methods and deep structural boreholes as well. This site is situated in the central part of Slovakia, its south zone. There in the vicinity of village Bzovík, a complex of volcanic- sedimentary formation outcrops on the surface (Neogeneous age). Its fundament is created by older stratigraphical units. The object exhibits structural - morphological feature that can be utilized for purpose of our investigation.

2. Geological and Geophysical background

The studied area belongs from geomorphologic point of view to Krupinská upland zone. The density of settlement is not so high – there is only one township site (Krupina) in the framework of Krupina zone. Larger towns are situated at 30 – 50 km to the North – Zvolen, Banská Bystrica.

The locality is geologically created by complex of volcano sedimentary formation which represents part of Inner Molasse in the West Carpathians. Situation of locality is depicted on the Fig. 1.

Sedimentary and volcano-sedimentary complex consists of following geological units:

The **early Molasse stage** is dated to the kiscel and egerian units, which are created by rocks of Buda Paleogene. While the older kiscel is represented on the base by various facies sandstones and sands with intercalation fine – grained conglomerates overburden layers are created by marlaceous silts (schliers) and/or marly claystones. The maximum thickness of this complex is less than 300 m.

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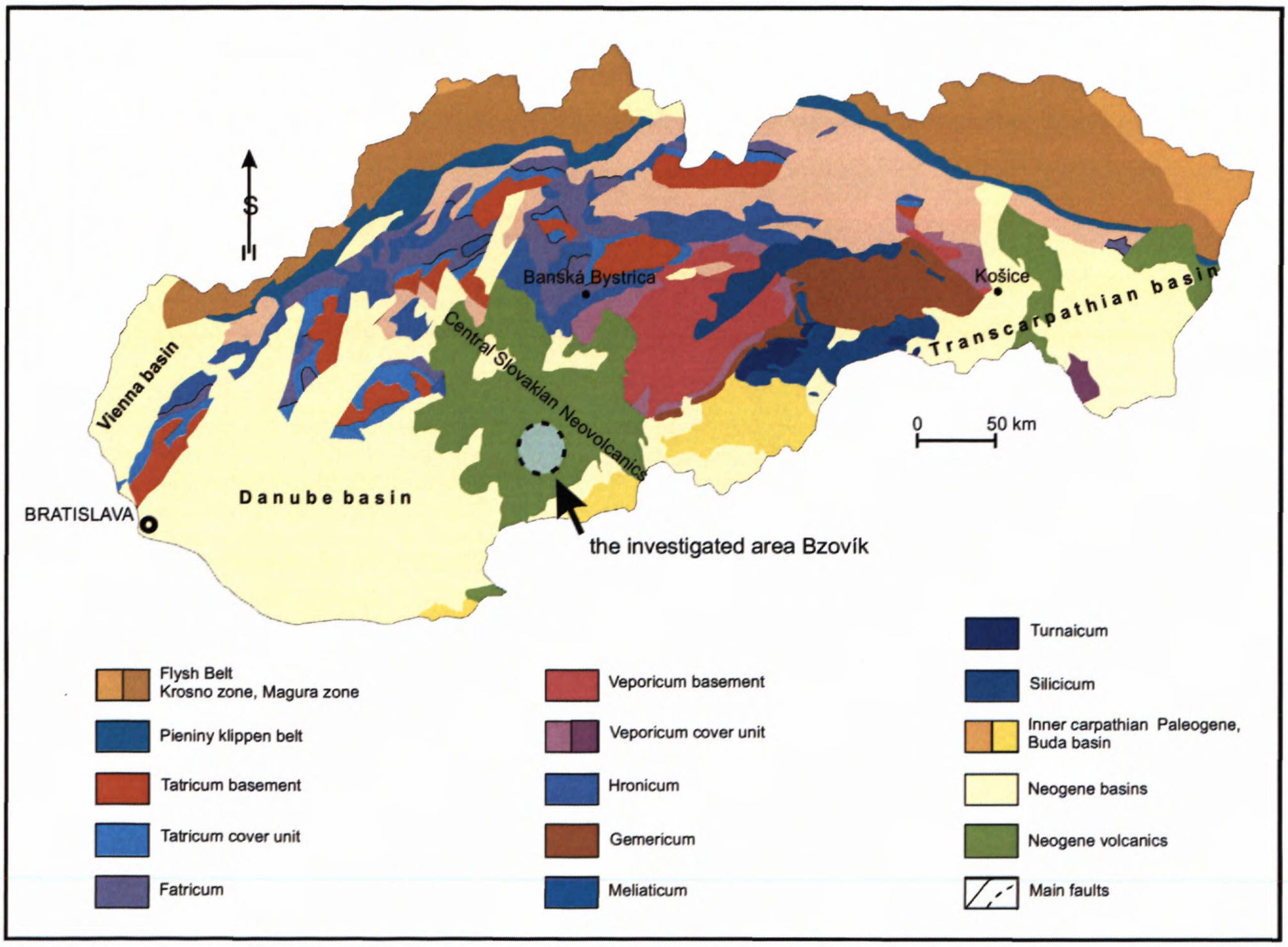

Fig. 1 Transparent tectonic sketch of Slovak Republic (after Biely, 1995) with investigated area location

Overlying Egerian unit reaches thickness 600 – 700 m. Due to its petrographical filling can be considered as suitable trap, because consists of mostly marly silts, siltstones and clays (schliers). Gravels and conglomerates are presented only in the base of this unit. Tuffits layers are occasionally (Vass, et al 1979).

The **main Molasse stage** took time from Eggenburgian to Badenian when main Molasse volcanism took place. The intensive volcanic activity has been learned in the whole scale of Badenian unit. Volcanism had mostly intermediary character – various types of andesites, which are very strongly brecciated. Brecciation reached subsurficial level. Besides of this, volcanoclastic sediments are very porous and permeable.

Pre-volcanic basement in the area is created by Mesozoic rocks (mostly carbonates – limestones and dolomites), which are underlying by crystalline rocks of the Veporicum unit (hybrid granitoids, crystalline schists, phyllits).

Pre-Tertiary fundament is commonly created by the Mesozoic, Late Paleozoic complexes and crystalline rocks. Main portion of Mesozoic rocks can be considered as a suitable environment for CO_2 storage (carbonates). These belong to Late, or Middle Triassic period. Lower Triassic complex is typically present in the shaly facieses, which is practically impermeable horizon for underground water circulation. Similarly or the same characteristics have been learned in the Permian and Crystalline complexes (Vass, et al 1979).

The intensive geophysical investigation targeted at fundament of neovolcanic complex from the old works (Fusán, et. al. 1969), but also from latest ones (Panáček, et al. 1993) has brought several important results that were utilized for this purpose.

Neovolcanic complex itself is a very variegated package of rocks with equally variegated physical properties. The anomaly in question is known since the first basic investigations in the area of Central Slovakian Neovolcanics (Fig. 2). The variations in the density parameter are quite remarkable, but for interpretation purposes an average volume density of this package is usually estimated on the value of 2, 2 g/cm^3. On the contrary, density of fundament is assign at the value of 2, 67 g/ cm^3. That is a reason why the map of Bouguer´s anomalies with above mentioned density has been chosen for depicting of anomaly. (Grand, in Kubeš, et al. 2001). On this base is clear, that the origin of anomaly is not in the volcanic complex, but related to underlying rocks packages – Pre Tertiary basement. A deep structural borehole (GK 4) was drilled for verification of this noticeable anomaly in the late sixties (Konečný, V., et al. 1970) on its area.

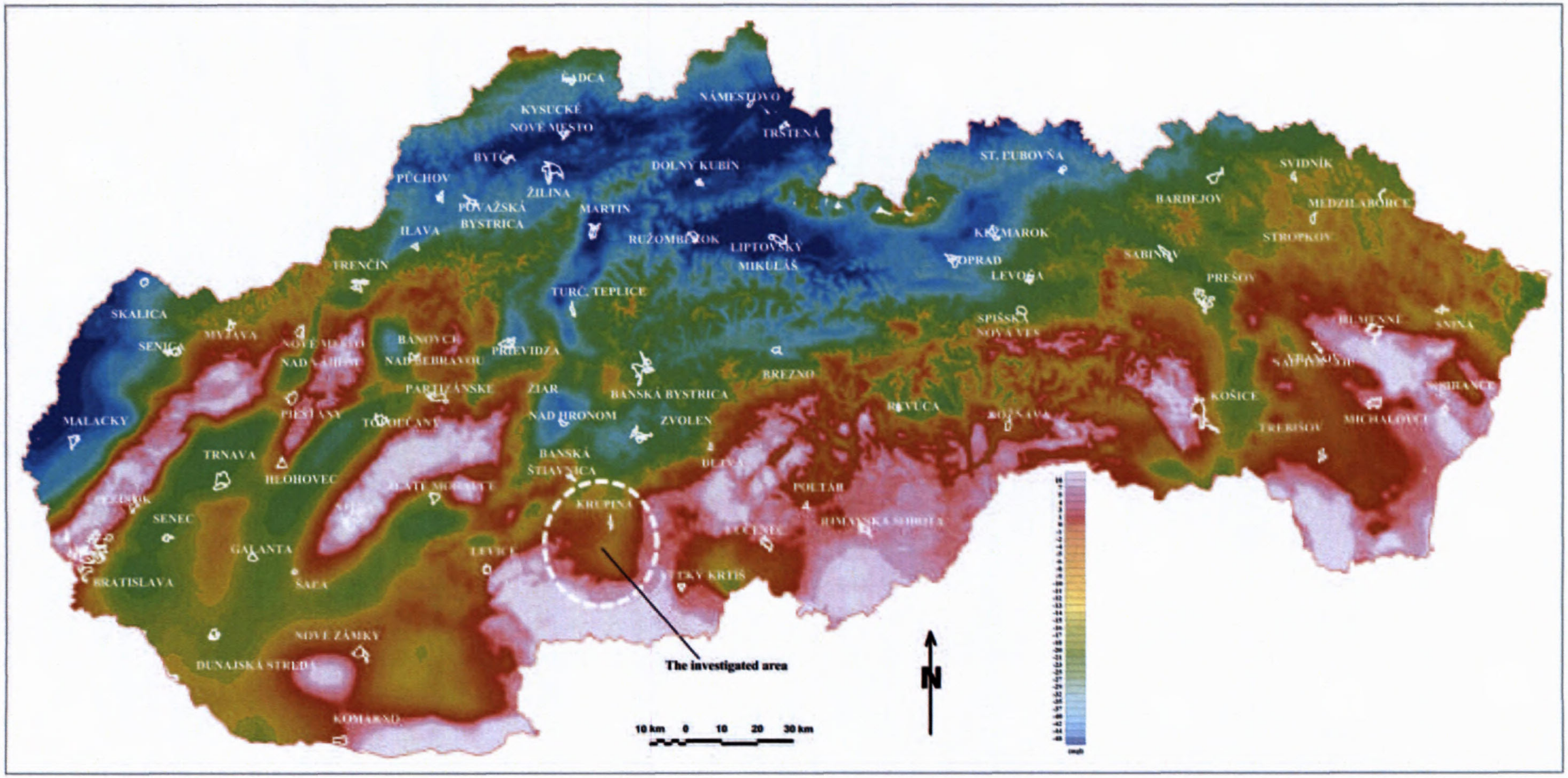

Fig. 2 Gravity map of Slovakia (Bouguer' s anomalies) – reflect of the Bzovík depression (marked area) in the gravity field – vol. dens. 2,2 g/cm3 (processed on the base of Grand, et al. 2001)

3. Results from GK 4 well and their importance for CO_2 storage

The simplified geological profile of the borehole is presented on the Fig. 3.

The uppermost volcano sedimentary unit reaches thickness of almost 1 000 meters. Its typical feature is variability of petrographical filling (tuffs, agglomerates, and tuffits). It is needed to pay attention on its hydrogeological properties, because of its uppermost position in the geological section. This package is defined as a complex possessing mostly intergranular and scarcely joint permeability (in the vicinity of huge faults structures only). Quantity of springs and its yield is not so high. The volcanic complex has a complicated groundwater circuit. It is possible to delineate a shallow subsurface groundwater circuit within the area of Neogene volcanic bound to the cover units as well as to the zone of increased jointing, in which the regimen is distinctly influenced by the climatic conditions. A part of groundwater circulates down to 100–200 m, even deeper, where the discharge regime of the structure reaches equilibrium. The results from extensive drilling in the area of the Krupinská planina Plateau show that the groundwater sources with the greatest yields occur where the tectonic unrest played an important role, i.e. in the lower sections of streams. If the permeability of a rock body is enhanced by tectonic, the yields from wells reach 20 to 30 l/sec at a number of places. The permeability of the volcanic rocks shows some zoning. Due to weathering and to the filling of pores with weathering products the permeability of the upper part of volcanic complex, down to a depth of 30–50 m, is lower. As a result, most wells have the yields below 5.0 l/sec. The Neogene volcanic region is poor in springs. Anyway, results from the deeper part of this complex are not so representative (Malík, et al. 2000).

This package is underlying by lower Paleogene unit, represented by conglomerates, sandstones and less claystones. These rocks possess joint permeability. An intensive brecciation has been observed (Polák, 1978) in this unit. The hanging wall is developed in the form of clays which create the horizon with thickness about 300 m. This layer can be serving as a suitable trap for CO_2.

The lowermost part of the borehole is created by the Mesozoic carbonates complex. The top of this unit is created by package of marl – limestones, marls, shales which is considered as equivalent of Gossau Cretaceous. Subjacent block of carbonates (limestones, dolomites) perhaps belongs to the Middle and Late Triassic. Might be it has suitable environment for CO_2 storage, due to intensive fracturing.

Thickness of the Triassic carbonates is over 300 m. The drilling was stopped in these sequences after reaching of dept 2 108 m. On the base of general geological situation in this locality is presumable that the Permian unit or crystalline rocks should be presented in the footwall of CO_2 reservoir.

The temperature on the bottom of the borehole is 80^0C. The threshold of 31.1 °C for supercritical state achievement is registered in the depth 500 m. The porosity of the carbonates is about 5% (Biela, 1978). Results

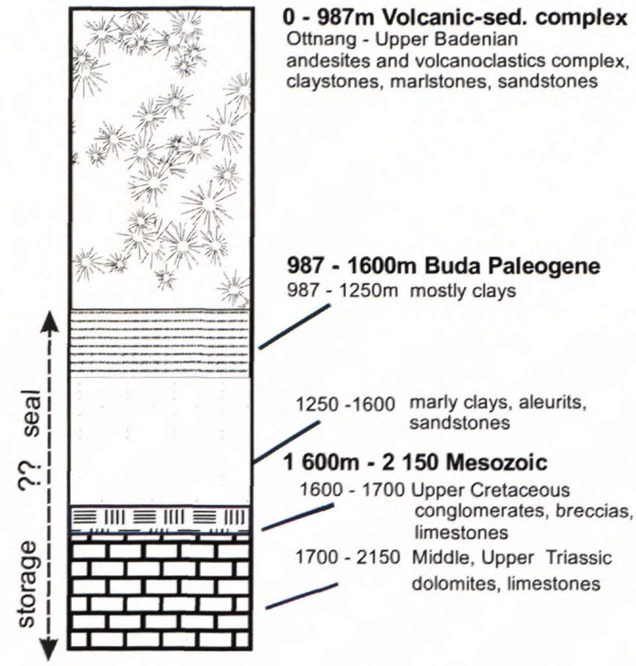

Fig. 3 Simplified geological section of the drilled borehole GK – 4 (after Biela, 1978)

of well logging were not available in that time. According to Polák, (1978) carbonates are sandy and again intensive brecciated. Data regarding permeability are missing. It means that joint permeability should be important positive input for storage purposes.

If we summarize the knowledge, obtained from the borehole, we can considerate, that the deep, although point data have been received, which might be granted potential structure for CO_2 storage. From the borehole section is obvious, that the reservoir part consist of the Mesozoic packet and lower part of Paleogene. Clayey horizon should be serving as an effective seal. This structure can be considered as suitable CO_2 storage site if its potential estimated storage capacity is sufficient for adequate absorption of stored CO_2 in relation to neighboring CO_2 emitters and transport facilities.

4. Consideration for storage site extension

A structural – tectonic map of the studied area is given on the Fig. 4. The shown interpretation resulted from gravity, magnetic and geoelectric measurements, followed up with drilling results. It is obvious that remarkable depression structure in the Pre Tertiary basement has been revealed. The structure is prolonged in the NNE – SSW direction and almost from the all sites is circumscribed by elevation of fundament. Average altitudes of the terrain above see level is about 400 – 450 meters. It means, that isoline (isohyps) of basement with the depth 600 m is sufficient criteria for reservoir extension assessment, regarding super – critical temperature achievement (these areas are depicted on the Fig. 4 by blue color.) The studied object can be considered as a local (?) aquifer.

Krupinská depression is bounded by very expressive faults with directions NNE – SSW. From the genetic

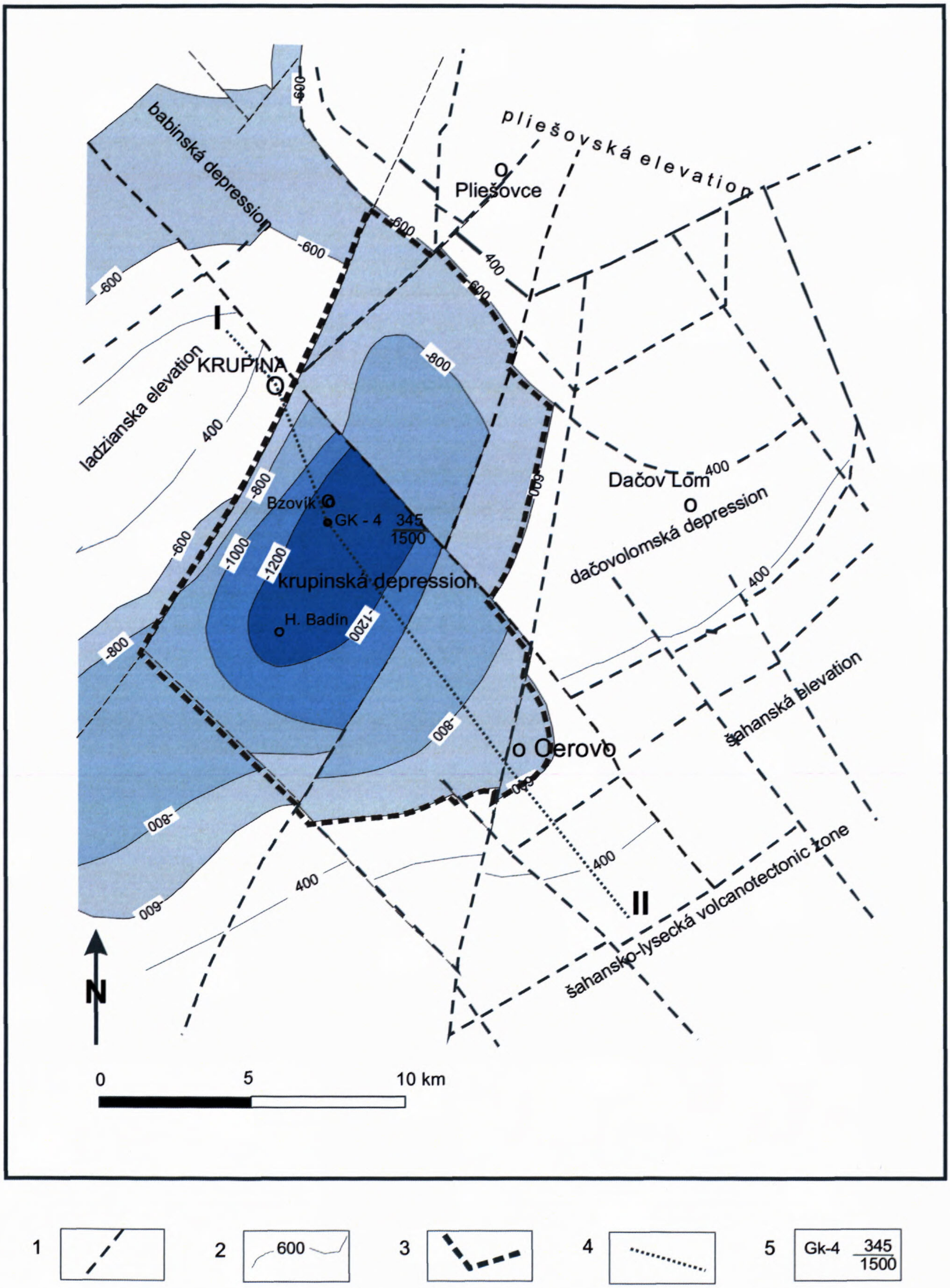

Fig. 4 Structural – tectonic map with depth of pre – Tertiary basement (adapted after Konečný, et al., 1988)
Explanation: 1 – faults, 2 – isohyps of basement bellow sea level, 3 – probable storage site extension (plan), 4 – cross section line, 5 – the borehole altitude/basement depth

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viewpoint it had been created before volcanic event and shaped during volcanic activity. There is a premise (Konečný, et. al. 1998) that faults were active even after finishing volcanic phase. Several faults with direction NW – SE slice the fundament into partial blocks. These geological phenomenons are very important input for CO_2 storage from. The steepest fault boundary is toward Krupina town (the Ladzianska elevation). Equally boundary to the North is expressive (the Ladzianska elevation). Demarcation to the East is not so steep (Šahanská elevation), while the Southern part is practically open. An additional investigation about the packing of these faults is needed, because particular information about wishing colmatage is not available, equally as lithological characteristic neighboring rocks.

Overburden cap rocks should be sufficient for trapping, but in any case is necessary to check tectonic situation, because the fault tectonics was active even after the end of volcanic activity (Konečný, et al. 1998).

Beside of this only physical trapping was assumed, even though is obvious that due to carbonate composition of reservoir rocks a chemical trapping certainly will play substantial role by potential storage of CO_2 in increasing storage site capacity.

An objective geological section is depicted on the Fig. 5. Due to borehole result the Mesozoic carbonate body filled the bottom of depression. The depth of carbonate footwall is unknown and can vary within interval of several hundreds meters. The rocks complex is created mostly by dolomites often brecciated, with marly limestones intercalation. This sedimentary unit has Middle and Upper Triassic age (Polák, 1978). The top of carbonate complex is developed in the form of sandy limestones which age is considered as Jurassic. (this level is not shown on Fig. 5 due to small thickness). The depicted Triassic carbonate complex can be suitable reservoir for CO_2 storage purposes.

In the Paleogene base (the Buda Paleogene) is developed huge complex of detritus carbonates rocks – conglomerates, breccias, sandstones and sandy limestone with total thickness of about 500 m (Vass, et al. 1979). This sedimentary level is another potentially convenient target for CO_2 sequestration. We suppose that the petrographical heterogeneity is very high as well as probable lens development, what are factors that decrease theoretical efficacy of complex in question, originally derive from its immense thickness. The uppermost part of Paleogene is presented by the clay complex with thickness of 300 m in the borehole, which could be served as suitable sealing subject. Its integrity development in the whole area from thickness and petrographical point of view is the imperative condition for existence of CO_2 storage side.

The volcanic – sedimentary complex, which covers the above described sedimentary succession, according to our present-day knowledge, has not substantial meaning for sequestration purposes.

This object is a typical example of structure which can be considered as suitable storage site from the first, initial estimation. Many important data are missing that is a reason, why the calculation volume was accomplished by volumetric approach with the simple formula given by Brook, et al., (2003). In the other words – it is useless to estimate unknown needed parameter, controlled by effort to achieve maximum precise result. There are proves from practice, that real construction, or calculation is facilitated only in these cases, when tangible results from drilling, or other works are available (Wűrdemann, 2008).

5. Discussion

The main goal of this part of contribution is to point at some ambiguity and "weakly or not certain places" that influence at our consideration.

- *Capacity calculation*

The data listed in the Tab. 1 assign that fact, that lesser final result dispersion is achieved by mistakes in geometrical factor assessment, however relative interpretation mistake can reach level far above 100%. Similarly CO_2 density in spite of possible variation does not influence final result in a broad scale. The most significant parameters for final capacity calculation ambiguity are porosity assessment and particularly sweep coefficient. Even in cases, when porosity values are available, often scarcely represent all variations caused by heterogeneity of reservoir horizon. The dominant parameter is though sweep coefficient. Value of this is incorporated to the process of capacity calculation, but without practical knowledge, or at least practical data from similar geological units this value is "so called" specialist's estimation, but sometimes seemed to be from the sphere of fantasy. Presented Tab. 1 is clear evidence of this fact. Differences among calculated capacities regarding this "elective" value can be source of serious incorrect evaluation. In our event is interesting factor, that despite of extremely decreased calculated storage capacity - var. 4 in comparison with initial calculation, this amount is still in the scale, which enables the studied case object in question as potential storage site consider. This last calculation (var. 4) was driven on the base of results achieved by May, et al. (2005), when for regional aquifers the coefficient value between 2% – 8% has been utilized.

In this case scarcely may be effective local storage efficiency (Chadwick, et al. 2008), although it is obvious that the object represents "local" structure, due to experience, that heterogeneity in majority similar geological units of the Western Carpathians is very high.

In term of resource pyramids (McCabe, 1988) our position on this locality is on the bottom part of this pyramid representing "theoretical capacity" only.

- *Faults role*

CO_2 leakage along faults will have three behaviors: upward migration from the storage formation along a fault, lateral movement from the fault into permeable layers, and a continued but attenuated CO_2 flux along the fault above the layers (Chang, et al. 2008).

If typical structural anticline hydrocarbon trap is developed with sufficient thick and impermeable containment, carbon dioxide is gradually concentrated per consequence of its buoyancy within the top of structure (vault dome ore arch), which is natural seal.

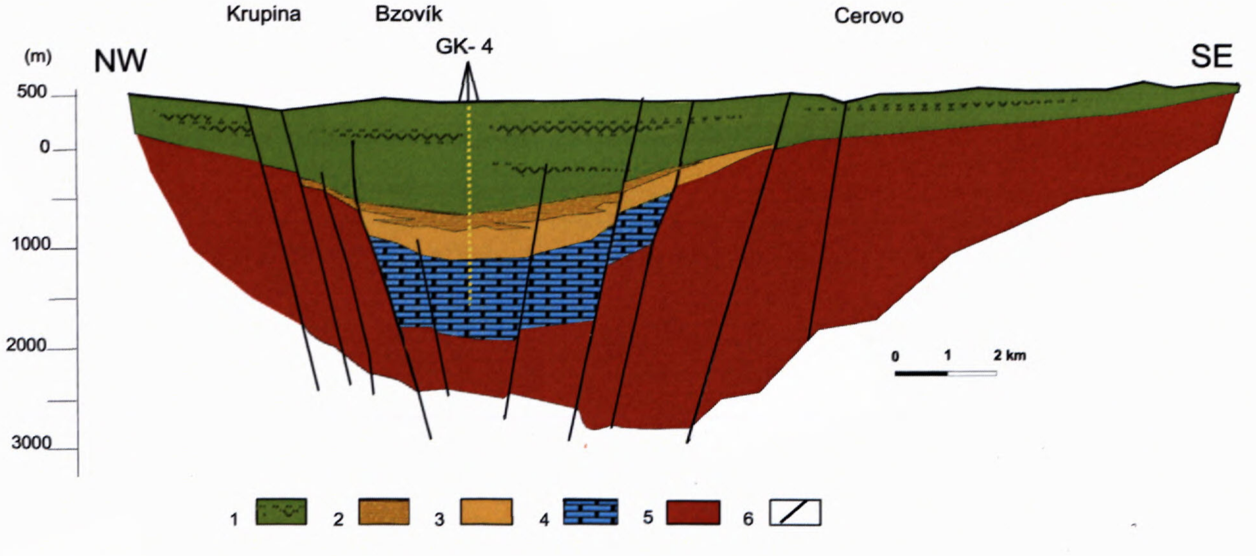

Fig. 5 The objective geological section I – II through the investigated area
Explanation: 1 – volcanic - sedimentary complex (andesites, volcanoclastics, sandstones, claystones, marlstones), 2 – Buda Paleogene – clays mostly, 3 Buda Paleogene - sandstones, limestones, aleurits, 4 – Mesozoic - dolomites mostly, conglomerates, breccias, limestones, 5 – PreMesozoic basement, 6 – Faults

Tab. 1 The capacity calculation – input data for the possible CO_2 storage site Bzovík

Capacity Bzovík	Area extension	Thickness	Porosity	CO_2density	Sweep coef.	Capacity CO_2	Remark
	(m^2)	(m)		(g/cm^3)		(tons)	
the initialt calcul.	146 000 000,00	200	0,15	0,63	0,30	**827 820 000**	
variation1	170 000 000,00	300	0,08	0,63	0,10	**257 040 000**	
variation2	200 000 000,00	300	0,05	0,70	0,08	**168 000 000**	
variation3	150 000 000,00	200	0,04	0,68	0,06	**48 960 000**	
variation4	120 000 000,00	150	0,03	0,63	0,04	**13 608 000**	61x less than the1st

This presented type of depression had been originated by strike slip faults and probably represents pull – apart type of basin, what qualifies to suppose synform development. The dip and character of internal filling of fault structure are dominant factor by consideration about possibility leakages creation, especially in the marginal part of basin, which are located on the high level, than depression center. This scenario is described by Kumar (2004) and Ozah, et al., (2005). They have shown small effectiveness of residual phase trapping using "inject low and let rise" strategy. When CO_2 is injected low in the aquifer buoyancy forces drive the injected CO_2 upward, since CO_2 is less dense than brine the water in the reservoir. As it rises, a residual phase trapped by capillary forces is left behind.

This is no convenient event, because carbon dioxide with its buoyancy is concentrated in these upper parts of storage site and in the course of injection and even after closing storage site, developed pressure can destructive influence marginal faults and thereby contribute to possible leakages paths creation.

This is a question for the future, but from contemporary position seems to be feasible a manner, proposed by Burton and Bryant (2007). An alternative approach is to dissolve the CO_2 into brine at the surface, then inject the saturated brine into deep subsurface formations. The CO_2-laden brine is slightly denser than brine containing without CO_2, so ensuring the complete dissolution of all CO_2 into brine at the surface prior to injection will eliminate the risk of buoyancy-driven leakage.

It is matter of course that other faults (in the inner part of depression) that taken place on this locality should be in detail investigated.

- *Lithological constrains*

An assumption of continual suitable rocks complexes development does not need to by valid in the whole area, especially in the marginal part of locality. Buda Paleogene can be typical example in this locality, because it is representing of the lagunar, hypersaline environment (Vass, et al. 1979), where development rock complex can exhibit inhomogeneities in vertical and horizontal plane. It is very important fact, regarding trapping rocks development, where effect of possible tectonic influence is additional negative feature. In spite of this fact, we suppose, that the uppermost Paleogene rocks complex - clays with proven thickness almost 300 m should be sufficient impervious environment effective seal. Higher lying volcanic - sedimentary complex consists of several aquiclude members (tuffits, lavas stream), but due to its heterogeneous development heterogeneity do not represent reliable trapping subject.

Other important feature consists in this, that aquifer collector beside of hydro dynamical sequestration can contribute to storage by mineral sequestration manner, namely in the cases, when is partly, or completely created by carbonate minerals. This is event of locality in question, because we suppose that carbonate rocks (limestones and dolomites) create main portion of space which should be serve as reservoir horizon.

6. Conclusion

The example of possible CO_2 storage site, hidden beneath volcano sedimentary cover in the Slovak republic, has been presented in this contribution. The depression in the fundament of young volcanic complex exhibits features (structural-tectonic, lithological, hydrogeological, suitable depths and temperatures, sufficient tentative capacity calculation) following that is possible to qualify it as suitable CO_2 storage site. Even in the most pessimistic estimation storage capacity, this object could be sufficient for CO_2 storage aimed at the big source of carbon dioxide emissions (transform gas station Veľké Zlievce. This emitter with annual production 520 kT (NAPL 2006) can supply possible storage site during at least 20 years even by the negative capacity calculation approach, what is in concordance with contemporary relations in this field. At present time does not being any storage site in the world, where annual amount of stored CO_2 remarkably exceeds limit of 1 Mt and planned life time of reservoir does not exceed 30 years. It is obvious, that our initial consideration can be changed, after carrying out of targeted additional investigation.

It is necessary to emphasize, that chemical trapping was not taken into account, and however it is clear that due to carbonate content of reservoir can influence storage capacity in positive direction.

The location of the area regarding population is suitable; on the other hand, big sources of CO_2 are not available in the nearby vicinity of this area. The main branch of transit gas pipeline is about 15 km to the SE of this region. But in the radius about 100 km we can find several big producers from paper, aluminum industry, as well as exchange gas distribution, which overall annual CO_2 production exceeds value 1,5 mil tons.

From this point of view the locality in question can be a good potential target for possible CO_2 storage, on condition, that supplementary tangible geological works will be realized.

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